Catawba-Wateree Water Management Group

INTEGRATED WATER RESOURCES PLAN

Final Draft

December 31, 2025

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Contents

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Appendices (not included)

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Acronyms and Abbreviations

Abbreviation	Definition
ATTAINS	Assessment and Total Maximum Daily Load (TMDL) Tracking and Implementation System
BMP	Best Management Practices
CEC	Contaminants of Emerging Concern
CHEOPS	Computer Hydro-Electric Operations and Planning Software™
CMIP6	Coupled Model Intercomparison Project 6
CN	Curve Number
CONUS	Contiguous United States
CRA	Comprehensive Relicensing Agreement
CRE	Critical Reservoir Elevation
CW-DMAG	Catawba-Wateree Drought Management Advisory Group
CWWMG	Catawba-Wateree Water Management Group
DO	Dissolved oxygen
DP	Precipitation changes
DT	Temperature changes
EFDC	Environmental Fluid Dynamics Code
°F	Fahrenheit
FDC	Flow Duration Curve
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
Ft	Feet/foot
FT MSL	Feet above mean sea level
GCM	Global Climate Models
GFDL	Geophysical Fluid Dynamics Laboratory
GIS	Geographical information systems
HABs	Harmful Algae Blooms
HDR	HDR Engineering, Inc.
HDR	HDR Engineering, Inc. of the Carolinas
HFPO-PA	Hexafluoropropylene Oxide Dimer Acid
IBT	Interbasin Transfer
ICLUS	Integrated Climate and Land Use Scenarios
IPCC	Intergovernmental Panel on Climate Change
IWRP	Integrated Water Resources Plan

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Abbreviation	Definition
LIP	Low Inflow Protocol
LOCA	Localized Constructed Analogs
LOCARB	Lower Catawba River Basin
LSPC	Loading Simulation Program in C++
MCL	maximum contaminant levels
MGD	Million gallons per day
MGY	million gallons per year
NCDEQ	North Carolina Department of Environmental Quality
NCDWR	North Carolina Division of Water Resources
NCWRC	North Carolina Wildlife Resources Commission
NESDIS	NOAA National Environmental Satellite, Data, and Information Service
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NME	Normal Minimum Elevation
NOAA	National Oceanic and Atmospheric Administration
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
N-STEPS	Nutrient Scientific Technical Exchange Partnership & Support
NTU	nephelometric turbidity units
OSBM	Office of State Budget and Management
PCB	Polychlorinated Biphenyl
PFAS	Per- and polyfluoroalkyl substances
PFBS	Perfluorobutanesulfonic acid
PFHxS	Perfluorohexane sulfonic acid
PFNA	Perfluorononanoic Acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic acid
ppt	Part per trillion
PRISM	Parameter-elevation Relationships on Independent Slopes Model
PWS	Public Water System/Supplier
RBAC	Catawba-Wateree Basin Advisory Commission
RCP	Representative Concentration Pathway
RFA	South Carolina Revenue and Fiscal Affairs Office
RTI	RTI International

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Abbreviation	Definition
RUS	Remaining Usable Storage
SAT	Stakeholder Advisory Team
SAWSC	South Atlantic Water Science Center
SCDES*	South Carolina Department of Environmental Services
SCDHEC*	South Carolina Department of Health and Environmental Control
SCDNR	South Carolina Department of Natural Resources
SCOR	Scientific Committee on Oceanic Research
SI	Storage Index
SSP	Shared Socioeconomic Pathway
SSURGO	Soil Survey Geographic
SWPC	Source Water Protection Committee
TEP	Thermo-Electric Power
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSI	Total Storage Index
TSS	Total Suspended Solids
TUS	Total Usable Storage
UNRBA	Upper Neuse River Basin Association
USDA	United States Department of Agriculture
USDM	United States Drought Monitor
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
WARMF	Watershed Analysis Risk Management Framework
WaterFALL	Watershed Flow and Allocation Model®
WATERS	USEPA WATERS geospatial data
WEFTEC	Water Environment Federation's Technical Exhibition and Conference
WP-O	Water Protection Ordinance Overlay District
WQ	Water Quality
WQS	Water Quality Standards
WRF	Water Research Foundation
WSMP	Water Supply Master Plan
WSS	Water Supply Study

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Abbreviation	Definition
WWTP	Wastewater Treatment Plan

*SCDHEC (South Carolina Dept. of Health & Environmental Control) split into two new agencies on July 1, 2024: the South Carolina Department of Environmental Services (SCDES) (for environmental matters) and the South Carolina Department of Public Health (DPH) (for health matters).

Glossary

The list below is representative of the full Glossary of Terms that will be included in the Final IWRP Document. Where appropriate, definitions used in the C-W LIP (C-W CRA Appendix C, IWRP Appendix E) are quoted for consistency.

Continuously Accessible Water Supply: The maximum volume of water that can be reliably withdrawn; constrained by the lowest-inflow conditions and recognition of current infrastructure limitations for accessibility.

Critical Intake Elevation: The minimum reservoir elevation required to operate an intake at its approved capacity. This may not correspond to the physical elevation of the intake structure.

Critical Reservoir Elevation (CRE): The highest level of water in a reservoir below which any Large Water Intake used for PWS or industrial uses, or any regional power plant intake located on the reservoir will not operate at its Duke Energy-approved capacity.

Decision Point Year: The anticipated year when demands within the reservoir's sub-basin would require alternative operational strategies if the historical drought of record were to reoccur.

Drought of Record: The period from 2006 to 2009 where the Catawba River Basin collectively experienced the lowest inflow conditions on record.

Full Pond Elevation: Also referred to as 'Normal Full Pond Elevation' or simply 'full pond,' this is the level of a reservoir that corresponds to the point at which water would first begin to spill from the reservoir's dam(s) if Duke Energy took no action.

Large Water Intake: Any water intake (e.g., public water supply, industrial, agricultural, power plant) having a maximum instantaneous capacity greater than or equal to one million gallons per day (MGD) that withdraws water from the Catawba-Wateree River Basin.

Low Inflow Protocol (LIP): The Low Inflow Protocol (LIP) establishes procedures for reductions in water use during periods of low inflow to the Catawba-Wateree Project.

Normal Maximum Elevation: The level of a reservoir (measured in feet above MSL or feet relative to the full pond contour with 100.0 ft. corresponding to full pond) that defines the top of the reservoir's Normal Operating Range for a given day of the year.

Normal Minimum Elevation: The level of a reservoir (measured in feet above Mean Sea Level (MSL) or feet relative to the full pond contour with 100.0 ft. corresponding to full pond) that defines the bottom of the reservoir's Normal Operating Range for a given day of the year.

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Normal Target Elevation: The level of a reservoir (measured in feet above MSL or feet relative to the full pond contour with 100.0 ft corresponding to full pond) Duke Energy will endeavor in good faith to achieve, unless operating in this LIP, the Maintenance and Emergency Protocol (MEP), the Spring Reservoir Level Stabilization Program (Lakes James, Norman, Wylie, and Wateree only), a Spring Stable Flow Period (Lake Wateree only), or a Floodplain Inundation Period (Lake Wateree only). Since inflows vary significantly and outflow demands also vary, Duke Energy will not always be able to maintain actual reservoir level at the Normal Target Elevation. The Normal Target Elevation falls within the Normal Operating Range, but it is not always the average of the Normal Minimum and Normal Maximum Elevations.

Remaining Usable Storage (RUS): The sum of the Project's volume of water expressed in acre-feet contained between each reservoir's Critical Reservoir Elevation and the actual reservoir elevation at any given point in time.

Safe Yield: The amount of water theoretically available for use at a given point.

Storage Index (SI): The ratio, expressed in percent, of Remaining Usable Storage (RUS) to Total Usable Storage (TUS) at any given point in time.

Target Storage Index (TSI): The ratio of RUS to TUS based on the Project reservoirs being at their Normal Target Elevations.

Total Reservoir Storage: All storage within a reservoir, agnostic to critical reservoir elevation.

Total Usable Storage (TUS): The sum of the Project's volume of water expressed in acre-feet contained between each reservoir's Critical Reservoir Elevation and the Normal Full Pond Elevation.

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Introduction

Section 1

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1 Introduction

1.1 Project Background & Evolution

The Catawba-Wateree River Basin (Basin) spans 5,680 square miles in North and South Carolina and extends through portions of 26 counties in North and South Carolina. The headwaters of the Basin originate in the Blue Ridge Mountains of western North Carolina as the Catawba River, which becomes the Wateree River within Lake Wateree in South Carolina. The 376-mile course of the Catawba-Wateree River flows through a network of eleven reservoirs linked in series and owned and operated by Duke Energy Carolinas before flowing into the Congaree River in Columbia, South Carolina. The eleven reservoirs were the vision and work of predecessors of Duke Energy Carolinas, making the Catawba-Wateree River the first river in the United States that was comprehensively planned and developed for electricity production. The first reservoir in the Basin was completed near Rock Hill in 1904, and the last, Lake Norman, was completed in 1963. In total the reservoirs have nearly 80,000 surface acres and approximately 1,800 miles of shoreline. The Basin is an invaluable resource for the region, providing essential drinking water for over two million people, enough electricity production to supply over 4 million average homes, recreational opportunities for millions of visitors, and ecological habitat, as well as fostering economic development. Regional collaboration and comprehensive planning are critical for preserving and maintaining the necessary water supply to meet the continually growing demands on the Basin’s water resources. This Integrated Water Resources Plan (IWRP) addresses those needs through extensive collaboration, analysis, and long-term planning for both water quantity and water quality.

1.1.1 About the CWWMG

The Catawba-Wateree Water Management Group (CWWMG) was established following a 3.5-year stakeholder process related to Duke Energy's re-licensing of the Catawba-Wateree Hydro Project (Federal Energy Regulatory Commission [FERC] Project No. 2232). This process concluded in the summer of 2006 with the signing of the Comprehensive Relicensing Agreement (CRA) by 70 parties. The CRA provided a framework for managing the Basin over the next 40 to 50 years. In addition, the CRA called for the establishment of a water management group. The resulting CWWMG was officially incorporated as a 501(c)(3) non-profit corporation on December 6, 2007, and is funded by dues from voluntary members representing Duke Energy and twenty-one public water utilities from North and South Carolina.

The group’s ongoing mission is to collectively identify, fund, and implement strategic initiatives that extend the capacity of the Catawba-Wateree River to effectively serve the community, while protecting and enhancing the ecological health of the Basin. CWWMG members meet regularly to formulate strategies and implement projects to support that mission. Through October 2025, the CWWMG has completed 75 technical projects with a total investment of $9.3 million (72% coming from the CWWMG and 28% from its partners), all of which has been aimed at protecting the shared water supply.

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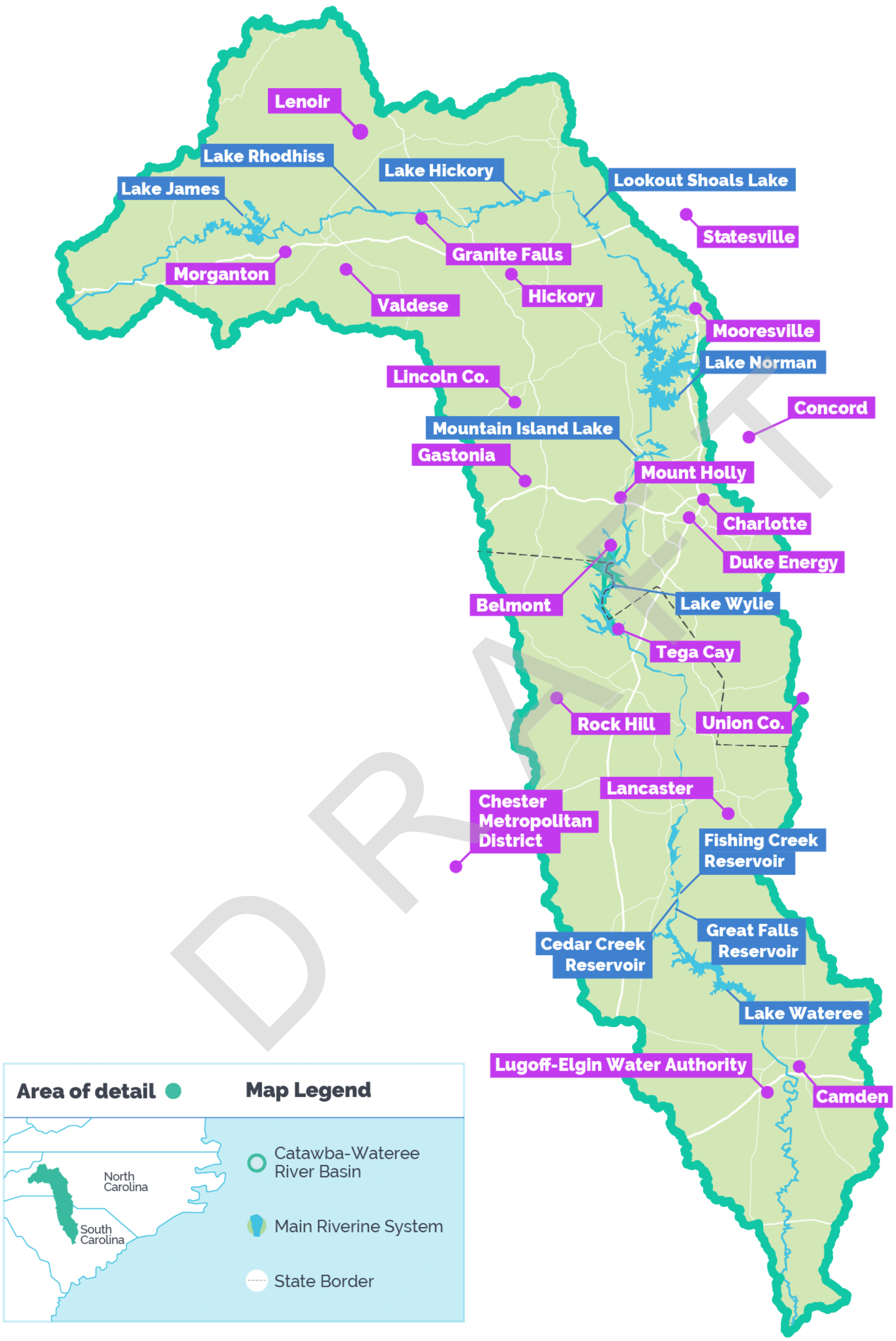

Figure 1-1. Catawba-Wateree River Basin

In 2016, the CWWMG established an Advisory Committee of external stakeholders to represent diverse interests related to the CWWMG's purpose. The individuals of the Advisory Committee review plans and activities of the CWWMG and provide feedback from an external perspective about general direction, governance, strategy, planning, and other aspects supportive of the CWWMG's mission.

In addition, the CWWMG continually seeks collaborative partnerships with other Basin stakeholders to help fund, manage, and oversee projects and initiatives. CWWMG membership currently consists of the following water supply utilities plus Duke Energy.

- Catawba River Water Supply Project*
- Charlotte Water, NC
- Chester Metropolitan District, SC
- City of Belmont, NC
- City of Camden, SC
- City of Concord, NC
- City of Gastonia |Two Rivers Utilities, NC
- City of Hickory, NC
- City of Lenoir, NC
- City of Morganton, NC
- City of Mount Holly, NC
- City of Rock Hill, SC
- City of Statesville, NC
- City of Tega Cay, SC
- Lincoln County, NC
- Lugoff-Elgin Water Authority, SC
- Town of Granite Falls, NC
- Town of Mooresville, NC
- Town of Valdese, NC
- York County, SC

*Lancaster County Water and Sewer District, SC & Union County, NC

1.1.2 Evolution of the Integrated Water Resources Plan

An initial evaluation of water use projections through the year 2058 was completed for relicensing of Duke Energy's Catawba-Wateree Hydroelectric Project and published in the 2006 Water Supply Study (WSS). The study marked a significant milestone as the first comprehensive evaluation of future water needs in the Basin. The WSS's findings were striking, revealing that without changes to water resource management strategies, the Basin's available water supply could face water supply shortages by the 2050's, particularly during drought conditions.

To address this issue, the CWWMG worked with stakeholders for more than four years to design the first basin-wide Water Supply Master Plan (WSMP), published in 2014 and amended in 2015. The WSMP extended water use projections until the year 2065 and dealt primarily with how to extend the water supply of the Catawba River and the 11 reservoirs beyond the year 2100.

In 2021, the CWWMG began the process of updating the WSMP in accordance with the 10-year timeframe stipulated in the Settlement Agreement (see below). The initial effort focused on developing a vision, plan, and scope for the update through a series of workshops with CWWMG member organization representatives and stakeholders. As a result, the update effort was expanded and renamed the Catawba-Wateree IWRP to better represent the CWWMG's comprehensive approach to long-term planning considering water supply, water demand, water quality, source water protection, and ecological and economic impacts. This published IWRP is the result of that five-year analysis and planning effort.

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1.1.3 Project Funding Partners

In 2010, the U.S. Supreme Court issued a Settlement Agreement to resolve a case over water rights within the Basin (SC v NC, Original No. 138). As part of the agreement, the states of North Carolina and South Carolina committed to periodically updating the long-range water supply plan in cooperation with CWWMG. The Settlement Agreement stipulates the states will provide updates supported by regulatory agencies from both North Carolina and South Carolina no less often than every 10 years. The IWRP also provides the River Basin Plan for the South Carolina portion of the river per the basin-wide planning process adopted by the South Carolina Department of Natural Resources (SCDNR) and the South Carolina Department of Environmental Services (SCDES)[1]. Table 1-1 presents the funding support to the IWRP effort from both states and the CWWMG (funding support for CWWMG is estimated).

Table 1-1 IWRP Funding Partners

Regulatory Agency	Funding Support
South Carolina Department of Environmental Services	$500,000
North Carolina Dept of Environmental Quality (NCDEQ)	$500,000
CWWMG	$620,000 (Estimated)
Total	**$1,620,000 (Estimated)**

1.2 Purpose and Layout of the IWRP

1.2.1 Purpose of the IWRP

The IWRP provides an updated, comprehensive water resources planning document for communities and utilities in the Basin to plan for a sustainable and clean water supply and support continued growth and development for current and future generations.

The IWRP includes updated water demand projections to provide a comprehensive summary of water withdrawal and return forecasts for the Basin. These new projections extend to the year 2075, expand the Basin boundary downstream from Wateree Dam to the confluence of the Wateree and Congaree Rivers, and account for a range of potential variations such as droughts and heavy rain that can impact water usage. Based on extensive collaboration with the CWWMG, the IWRP Project Team developed the IWRP to incorporate water supply, water quality, and source water protection measures as well as implications of climate and economic factors. The IWRP consultant Project Team consisted of HDR, RTI, the Catawba Wateree Initiative, the Water Center at the University of Pennsylvania, and William Kreutzberger as an independent water resources consultant.

The IWRP provides every community along the river a data-driven playbook for meeting rising demand without sacrificing water quality and weathering droughts with confidence, aligning land-use decisions with clean-water goals, and stretching every infrastructure dollar for maximum benefit.

[1] Formerly South Carolina Department of Health and Environmental Control. On July 1, 2024, the South Carolina Department of Health and Environmental Control was restructured into two separate entities to cover environmental and public health responsibilities.

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1.2.2 Plan Layout

The IWRP is broken down into specific topic areas, concluding with a concise summary of recommendations.

1. Introduction
2. Current Conditions
3. Future Conditions
4. Surface Water Quantity and Availability
5. Water Quality Evaluations
6. Groundwater Assessment
7. Management Scenarios
8. Recommendations
9. References

1.3 Stakeholder Engagement & Governance

1.3.1 IWRP Steering Committee

In keeping with standard practice by the CWWMG, an internal Steering Committee was established to provide project oversight. The Steering Committee consisted of representatives from the CWWMG Board, CWWMG member organizations, and the CWWMG Advisory Committee. Their role was to specifically represent the CWWMG in providing direction and guidance to the project team of consultants and water resource experts engaged by the CWWMG to develop the IWRP.

1.3.2 IWRP Stakeholder Advisory Team

In addition to CWWMG member involvement, input, and oversight during plan development, the CWWMG assembled an IWRP Stakeholder Advisory Team (SAT) to gather a broad level of input from a diverse group of key organizations having an interest in the future planning efforts for the Basin. The SAT met quarterly to review IWRP development, provide feedback, and foster regional collaboration in support of the IWRP. Organizations participating in the IWRP SAT are listed in Table 1-2.

Table 1-2 Stakeholder Advisory Team

Category	Organization
Agriculture/ Forestry/ Irrigation	(SC) Soil & Water Conservation District
	(NC) Soil & Water Conservation District*
Basin Planning	SCDNR
	SCDES
	NCDEQ
Commercial/ Manufacturing/ Industrial	Dominion Resources
	Gallo
Economic Development	(NC) Western Piedmont Regional Council Of Governments
	(SC) Santee Lynches Council Of Governments
	(SC) Central Midlands Council Of Governments
Environmental/ Environmental Justice Interest Groups	Catawba Riverkeeper
	NC Conservation Fund

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Category	Organization
Local, State, and Federal Agencies	Catawba Nation
	NC Wildlife Resources Commission
	Lake Norman Marine Commission
	Regional Stormwater Partnership of the Carolinas
	Lake Wylie Marine Commission
Recreation	NC Division of Parks and Recreation
	SC Department of Parks, Recreation & Tourism

1.3.3 CWWMG Source Water Protection Committee

Source waters, including rivers, streams, lakes, reservoirs, springs, and groundwater, serve as the primary water supply for both public drinking water systems and private wells. Protecting these resources in the Basin is crucial for providing high-quality drinking water and is an important component of the IWRP plan. In 2018, the CWWMG convened a Source Water Protection Task Force of CWWMG members along with representatives of local land trusts and the Catawba Wateree Initiative to develop a proposed action plan for CWWMG involvement in source water protection in the Basin. The Task Force devised an expanded set of criteria and a scoring method to weight and prioritize land conservation and best practices based on RTI research results from the *Quantifying the Potential Benefit of Land Conservation on Water Supply to Optimize Return on Investments* project sponsored by the CWWMG in conjunction with the Water Research Foundation (WRF Project 4702). The Task Force has since evolved into a standing committee of the CWWMG and meets monthly to review, evaluate, and recommend land conservation projects for CWWMG grant funding. Organizations participating in the Source Water Protection Committee are listed below.

- Catawba-Wateree Initiative
- Catawba Lands Conservancy
- Foothills Conservancy
- The Conservation Fund
- CWWMG
- RTI
- Catawba Riverkeeper
- Katawba Valley Land Trust

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Current Conditions

Section 2

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2 Current Conditions

2.1 Basin Snapshot and Drivers of Change

The Basin includes a highly managed system composed of 11 interconnected reservoirs spanning 12 sub-basins. The reservoirs were constructed and operated by Duke Energy, and each has at least one hydropower station at its main dam that is used to manage flow and lake levels. From the headwaters at Lake James in western North Carolina to Lake Wateree in South Carolina, each reservoir contributes uniquely to flow regulation, storage, and water quality across the Basin (Figure 2-1). As indicated in Section 1.0, these reservoirs are operated as a unified system under the Catawba-Wateree Hydro Project's CRA (2006) and the 2015 FERC Project license, which defines minimum flow requirements, lake level operating ranges, drought protocols, and other operational constraints, as well as state and federally mandated compliance requirements. The CRA ensures coordinated flow releases and water levels to meet municipal, industrial, ecological, and recreational needs.

Today, the Basin faces a dynamic set of conditions that determine how water is managed:

- Climate Variability: Rainfall patterns are shifting, and natural evaporation (which can exceed human consumption) is increasing. These changes affect reservoir levels and the timing of water availability.
- Population Growth and Urban Expansion: The Basin is experiencing significant population growth and is the most populated river basin in North Carolina. New water users and connections to PWS reflects ongoing development and rising demand for water supply and wastewater services.
- Land Use Change: Increasing areas of impervious surface and development pressure alter runoff patterns, reduce ground infiltration, and impact water quality.
- Water Quality Challenges: Several water bodies in the Basin are listed as impaired under the U.S. Environmental Protection Agency (USEPA) Clean Water Act Section 303(d) program due to pollutants such as nutrients, sediment, heavy metals, and other toxic substances. These impairments affect aquatic health and drinking water sources.
- Aging Infrastructure: Many utilities across the Basin have aging systems that pose risks to water reliability due to potential maintenance issues.

These evolving conditions underscore the need for advanced modeling tools that can capture both natural watershed processes and managed reservoir operations. The IWRP uses two complementary models, the Watershed Flow and Allocation® model (WaterFALL) developed by RTI International (RTI) and the Computer Hydroelectric Operations and Planning Software™ (CHEOPS), which was originally developed to support Project relicensing (Duke Energy 2015), to provide this integrated view and an overview of each is provided in this section.

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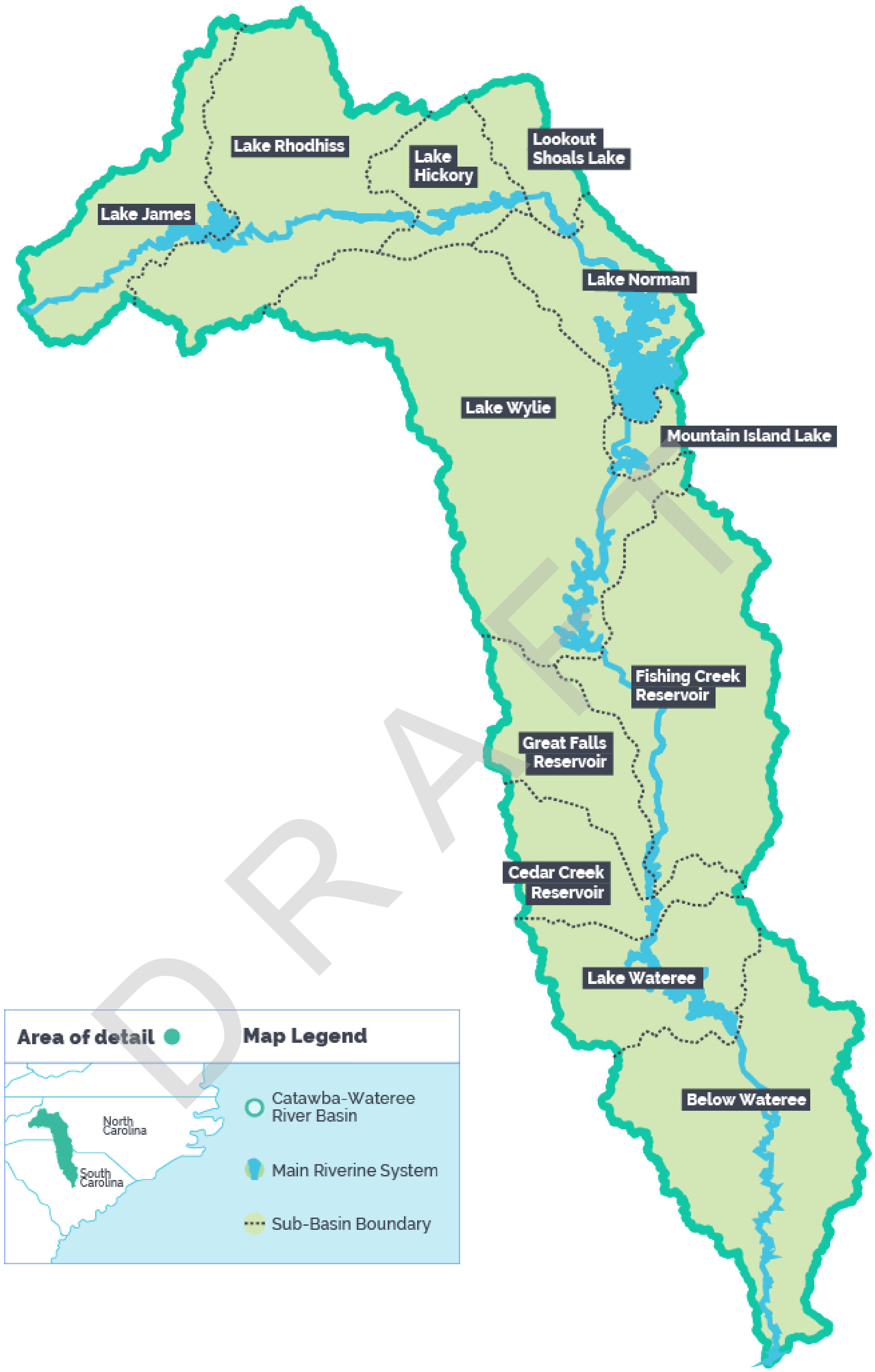

Figure 2-1. Map of the Catawba-Wateree Basin and Subbasins

2.2 Modeling Tools to Understand System Behavior

The IWRP relies on two complementary models to evaluate how water moves through the Basin and how the system responds to changing conditions:

- **WaterFALL** simulates watershed hydrology, including rainfall-runoff processes and inflows to the Basin's reservoirs.
- **CHEOPS** simulates reservoir operations under the Catawba-Wateree Hydro Project's CRA and FERC License, incorporating flow requirements, drought protocols, and operational constraints.

Together, these tools provide a system-wide view of both natural hydrology and managed operations. They enable scenario testing for drought response, water demand forecasting, water quality analysis, and infrastructure planning, which are critical for understanding water availability and system reliability under future conditions. Their combined use allows for scenario testing that reflects both physical watershed processes and the operational rules defined by the CRA and FERC License. Figure 2-2 illustrates the interconnectedness of the WaterFALL and CHEOPS models.

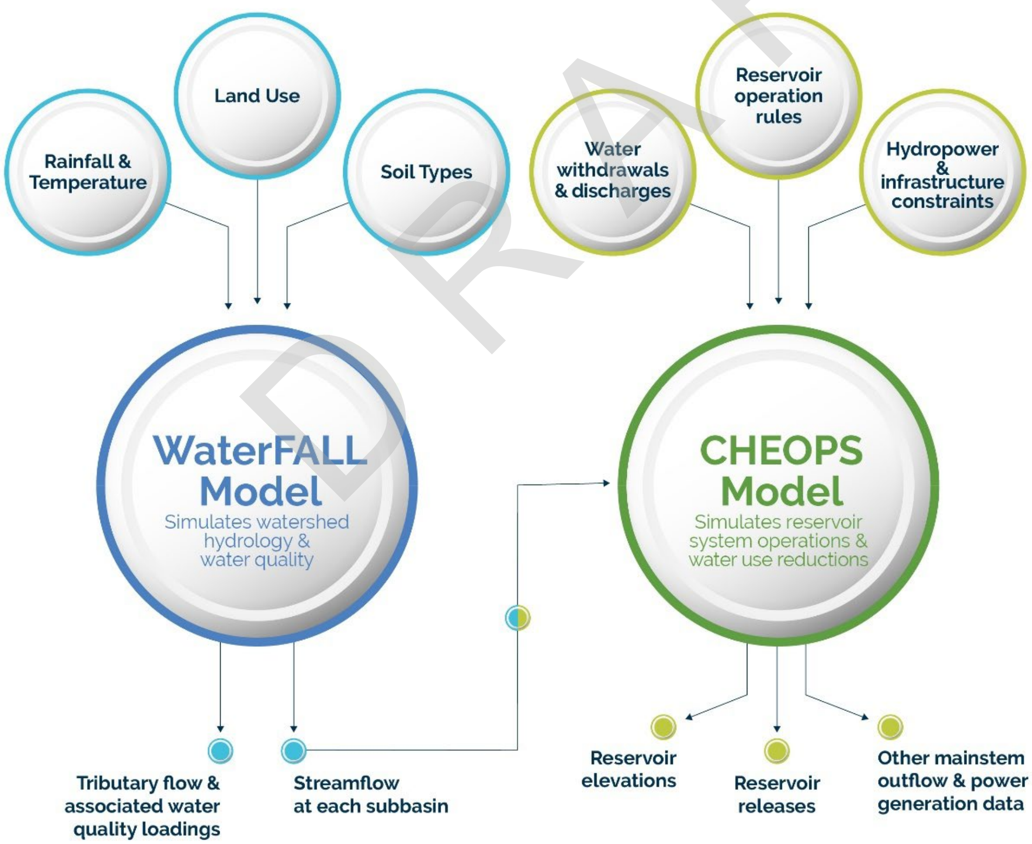

Figure 2-2. Overview of WaterFALL and CHEOPS Modeling Framework

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2.2.1 WaterFALL Model Overview

The WaterFALL model is a rainfall-runoff model that simulates daily streamflow and the associated nutrient and sediment loading from each stream catchment and collectively for watersheds (Figure 2-3; Eddy et al. 2017). It produces water quantity inflows and water quality loads aggregated either as direct reservoir inflow (flow generated in catchments immediately adjacent to the reservoir) or inflows to the main channel upstream of reservoirs.

The WaterFALL model is used to characterize current (and future) water quantity and quality in the watersheds upstream of the 11 main-stem reservoirs in the Basin. The model uses the catchment resolution of the enhanced U.S. Geological Survey (USGS) National Hydrography Database (NHD)-plus data (McKay et al. 2016). WaterFALL simulates two components of surface water flow: (1) runoff and (2) base flow.

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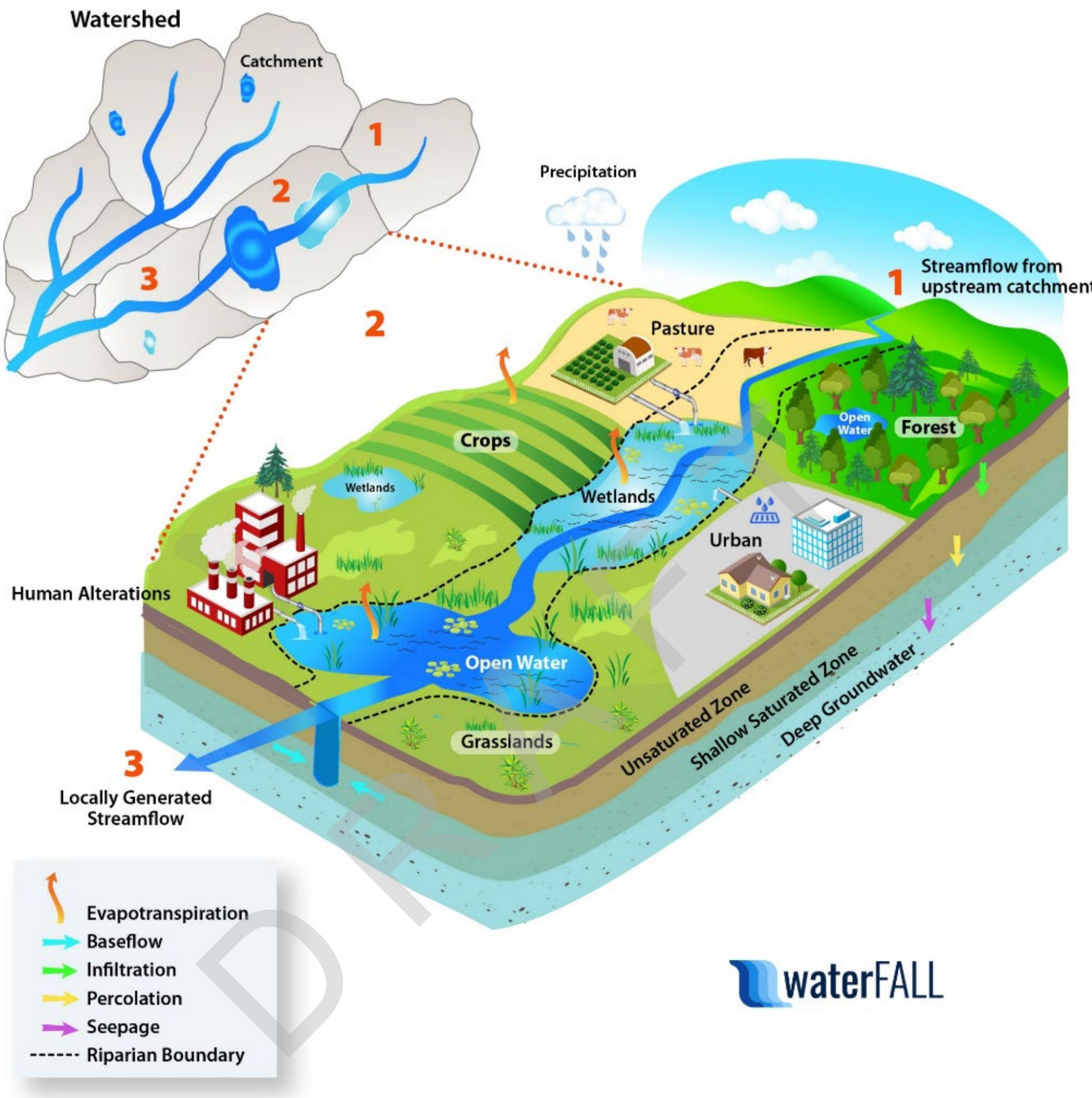

Figure 2-3. WaterFALL Processes and Spatial Framework (RTI International, 2025)

WaterFALL simulates the hydrological cycle for each stream catchment by modeling how water moves through different compartments (i.e., surface, unsaturated zone, shallow saturated zone, and deep groundwater) based on physical parameters and rate constants governed by process-based equations and mass balance. Across the surface, runoff from each type of land use/land cover in upland areas is delivered to riparian areas where surface runoff can infiltrate or continue running off into the stream channel or waterbodies. Rainfall that is not runoff infiltrates into the unsaturated soil layer. The available water capacity of the unsaturated zone controls the rate of percolation downward to the saturated zone. Evapotranspiration, in addition to percolation, depletes water from the unsaturated soil layer with differentiation in rates between the growing (i.e., leaf out) and dormant seasons. The saturated zone is depleted by local groundwater flow to surface water (i.e., shallow base flow).

WaterFALL completes this hydrologic cycle simulation for each catchment within the Basin. Within each catchment, existing land cover/land use, soils, and subsurface hydrologic zones are characterized through both observed physical data and calibrated parameters relating to physical components. Coupling the catchment characteristics with daily estimates of temperature, precipitation, water uses (withdrawals or returns), and reservoir characteristics within the network provides a stream segment-scale daily rainfall-runoff and base flow simulation of streamflow and water quality for the entire Basin.

WaterFALL simulates water quality loading values for total nitrogen (TN), total phosphorus (TP), and total suspended sediment (TSS). Local streamflow and nutrient/sediment loading contributions are routed to estimate downstream cumulative streamflow and loads using a time of travel through each catchment. Loads of these constituents are tracked from their sources, through surface runoff and groundwater pathways, to streams, rivers, and lakes within the model domain. WaterFALL tracks the pathways through the watershed so that the relative contribution of different pollutant sources can be assessed. The model is calibrated to existing local flow gauges and water quality monitoring stations to ensure accurate parameterization of hydrologic and water quality processes, improving confidence in simulated load estimates. WaterFALL can be used to directly assess loadings from individual pervious (rural) land covers with runoff, manure/fertilizer applications, buildup and wash-off on impervious (urban) surfaces, onsite wastewater systems (e.g., septic systems), and subsurface load accumulation and transport to the stream with baseflow as well as point sources contributions and streambank erosion within the stream network.

A detailed explanation of the WaterFALL Model is available in Appendix A – WaterFall Calibration Report.

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2.2.2 CHEOPS Model

The CHEOPS model is the cornerstone of system operations analysis for the Basin. It simulates how water moves through the interconnected reservoirs based on system constraints defined by both physical infrastructure and the operating rules determined in the CRA and FERC License. These constraints include minimum flow requirements, lake level operating ranges, and the drought management protocol (Low Inflow Protocol or LIP) with associated water use reductions, structural components including dams, hydropower units, water intake and effluent discharge structures that control how water is stored, released, withdrawn and returned.

CHEOPS has been used in previous planning efforts, including the 2006 Water Supply Study and the 2014 WSMP, and continues to serve as a critical tool for evaluating water availability, system reliability, and hydropower interactions. For the IWRP, the CHEOPS model was updated to reflect, as of 2022, the infrastructure, climate conditions, and operational priorities of the system ~~as of 2022~~. A full description of the IWRP updates is included in the Model Operations Revision Report (Appendix B – CHEOPS Model Operations Revision Report).

Key following enhancements were incorporated as part of the 2014 WSMP:

- **Expanded Functionality:** Addition of tributary nodes for withdrawal and return points, improving spatial accuracy of water use representation.
- **Operational Flexibility:** A universal on/off switch for water shortage response plans, enabling rapid scenario testing under drought conditions.
- **Performance Improvements:** Faster processing times to support iterative modeling and stakeholder review.
- **Updated Operating Logic:** Incorporation of revised LIP trigger metrics and updated Critical Reservoir Elevations to align with current CRA and FERC License requirements.
- **Scenario Integration:** Ability to model water accessibility enhancement strategies such as intake modifications, reservoir operating level adjustments, and effluent flow recycling.

Further enhancements were incorporated in 2022 and 2023 as part of the current IWRP:

- Updated Infrastructure Conditions:
  - Updated reservoir storage volume curves for most developments using available GIS, bathymetry, and Light Detection and Ranging (i.e., LiDAR) data.
  - Revised leakage rates based on Duke Energy's hydro unit assessment.
  - New spillway discharge curves for Rhodhiss and Wateree developments to reflect increased capacity and Obermeyer gate additions.
  - Updated turbine-generator unit configurations for Rhodhiss, Great Falls-Dearborn, and Rocky Creek-Cedar Creek to reflect current operations.
- **Operational Flexibility:**
  - Modified LIP logic to allow reservoirs to temporarily exceed target elevations during drought while remaining below full pond.
- **Performance Improvements:**
  - Verified and aligned energy generation load shape developed with the 2015 CHEOPS model with data provided from Duke Energy in April 2023.
- **Updated Operating Logic:**
  - Adjusted summer target elevations (+0.5 feet) for Lake James, Lake Norman, and Lake Wylie per FERC license requirements effective 2026.
  - Revised Great Falls-Dearborn (Great Falls Reservoir) target elevations to reduce minimum flow requirements.
  - Updated recreational flow release schedules for multiple developments based on 2023 flow requirements.
  - Integrated changes to support compliance with CRA and WSMP recommendations for improved drought and high flow management.

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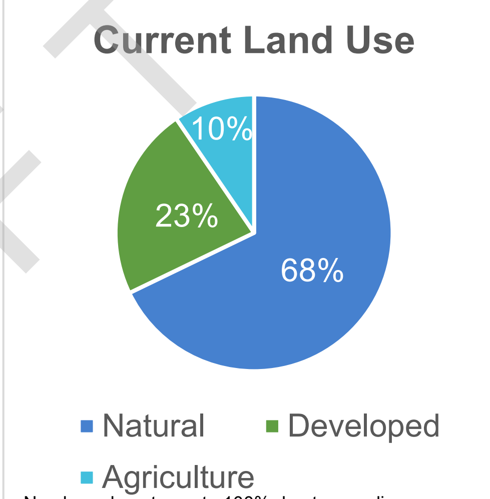
These revisions were developed through a stakeholder-driven process led by the Modeling Technical Team to ensure compliance with NC Session Law 2010-143[2], which directs the state department of environment and natural resources (NCDEQ) to develop basinwide hydrologic models, and alignment with regulatory expectations. The updated CHEOPS framework supports integrated scenario planning, enabling the IWRP to evaluate how the Basin performs under a range of future conditions, including extended droughts, increased demand, and climate variability.

Together with WaterFALL, CHEOPS forms the analytical backbone of the IWRP, enabling scenario testing for drought response, water demand forecasting, and infrastructure planning.

2.3 Land Use and Climate Overview

2.3.1 Land Use

Current land cover and land use in the Basin is dominated by natural land cover (68%) based on a combination of the following land use classification datasets, and results were used in the models described in Sections 2.2.1 and 2.2.2:



Numbers do not sum to 100% due to rounding

- The 2019 National Land Cover Database (NLCD), developed by the USGS, provides the land cover classifications representing the material or vegetation type present on land surface. The 2019 NLCD dataset was the most current version available when the modeling effort for the Integrated Water Resources Plan began in 2021.
- The Integrated Climate and Land Use Scenarios (ICLUS) land use layers are produced by the USEPA (2016) and represent human land use of the specified region. This dataset is necessary because it represents both recent (2020) and projected land use (2070), based on the Intergovernmental Panel on Climate Change's scenarios and pathways.

ICLUS data were incorporated into the analysis because the dataset has the capability to integrate future projections, where NLCD provides current / historic conditions. Due to higher resolution of the NLCD data, the choice was made to use a combination of these two land classification datasets to generate a hybrid baseline land use for the Basin (Table 2-1). However, because NLCD and ICLUS describe slightly different aspects of the land – land cover (NLCD) versus human land use (ICLUS) – specific rules were set based on the different land classification approaches. More information about this approach is described in Appendix A – WaterFALL Calibration Report.

[2] General Assembly of North Carolina Session 2009 Session Law 2010-143. House Bill 1743. Available from: S.L. 2010-143.

The most common land use in the Basin is forest with over one third (38%) of the watershed composed of a mixture of deciduous and evergreen forest. Forested land cover is especially concentrated in the mountainous headwaters, where deciduous forests dominate in the lower elevation areas. Other forested areas include those that are at risk (14%) for potential losses or degradation and infringed forests (1%) which are fragmented lands surrounded by developed and agricultural land uses. Other natural land uses in the watershed include open water (3%) and wetlands (4%) along rivers and reservoirs, areas of grassland (2.3%) and shrub (2.6%) undergoing ecological succession after land clearance, and open space (4.3%) (see Figure 2-4 and Table 2-1).

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Table 2-1. Baseline (2020) Land Use Classifications

	NLCD Description – ICLUS Group	2020 Area (mi^2)	2020 Percent of Total Area
Natural	Water	139	2.5%
	Wetlands	194	3.5%
	Forest	2,099	37.7%
	Forests at Risk	764	13.7%
	Forests Infringed	67	1.2%
	Open Space and Altered Crops	239	4.3%
	Shrub/Scrub	147	2.6%
	Grasslands/Herbaceous	131	2.3%
Developed	Developed, Exurban	446	8.0%
	Developed, Suburban	181	3.2%
	Developed, Medium Urban	186	3.3%
	Developed, High Urban	147	2.6%
	Developed, Open Space (Rural)	9.3	0.2%
	Mixed Use with Developing Population	271	4.9%
	Crops and Wetlands Infringed	8.7	0.2%
	Barren Land	10	0.2%
Agriculture	Pasture/Hay	473	8.5%
	Cultivated Crops	60	1.1%
	Total	**5,571**	**100%**

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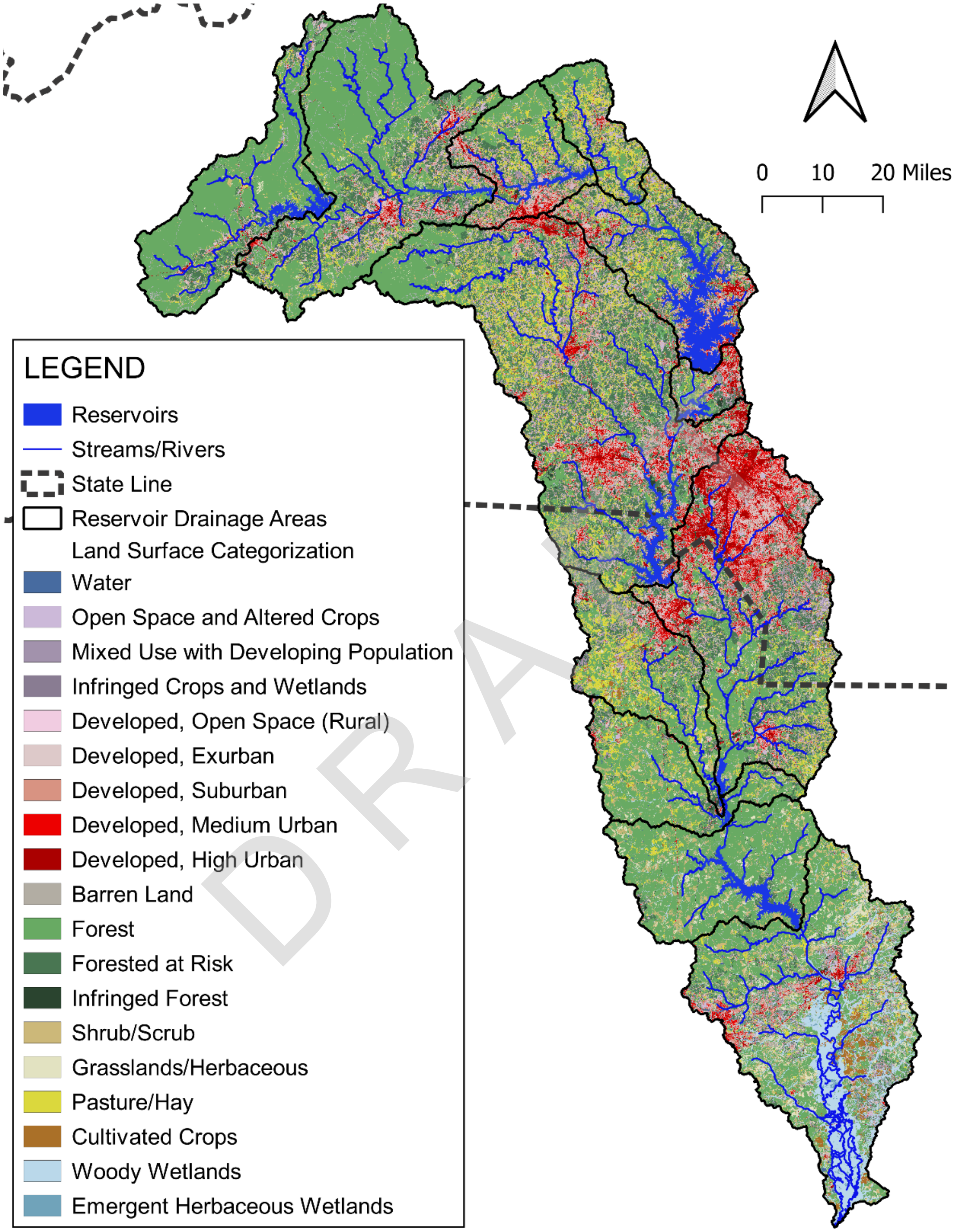

Figure 2-4. Baseline 2020 Land Use

Approximately one-fourth of the Basin is classified as developed land (approximately 23%). The most common developed land in the basin is classified as exurban (8%). This land use represents residential areas that are influenced by nearby urban areas and are potentially vulnerable to development but are composed of parcels generally considered too small for agricultural use (Table 2-2). Higher-population developed land uses in the watershed are concentrated around historic urban centers, surrounded by lower population densities and suburban areas typically located along existing transportation corridors and major highways.

The municipalities and dense urban cores of the Charlotte metropolitan area dominate the land use around the NC/SC State line. In the northern section of the Basin, the municipalities of Morganton and Hickory parallel the river and Interstate 40. South of Lake Wateree, towns in the northeastern Columbia, SC metropolitan area along Interstate 20 are the main sources of development (Figure 2-4).

Table 2-2. Definition of Urban Lands based on Dwelling Units per Acre (USEPA 2016)

ICLUS Population Density Category	Dwelling units per acre
Undeveloped	0
Exurban Low	0.02 - 0.1
Exurban High	0.1 - 0.4
Suburban	0.4
Urban Low	1.6
Urban High	>10

Agricultural land uses, comprised of cultivated crops and pasture/hay for livestock, compose nearly 10% of total land area in the Basin. Agriculture is distributed throughout the Basin but is most abundant in the mid-elevation Piedmont region of North and South Carolina (Figure 2-4). Major crops cultivated in the Basin include hay, corn, soybeans, and winter wheat as defined by the USDA Cropscape dataset. Cropland rarely forms large contiguous reaches across the landscape; the average field size in the Basin is 0.45 acres as defined by USDA Cropland datasets. Pasture and hay cultivation are the most common agricultural land uses. Pastures tend to be larger than crop fields, with an average pasture area of 112 acres in the Basin.

2.3.2 Climate

Most of the Basin has a humid subtropical climate, with some headwater regions in Pisgah National Forest classified as oceanic climate. Annual precipitation is highest in the northwestern, high-elevation headwaters of the Basin, particularly along the Linville River. In general, annual precipitation decreases as the Basin progresses south. Mean daily temperature exhibits the opposite trend – with the highest daily temperatures in the southeastern, low-elevation wetlands near the confluence with the Congaree River and low temperatures in the high-elevation northwestern headwaters.

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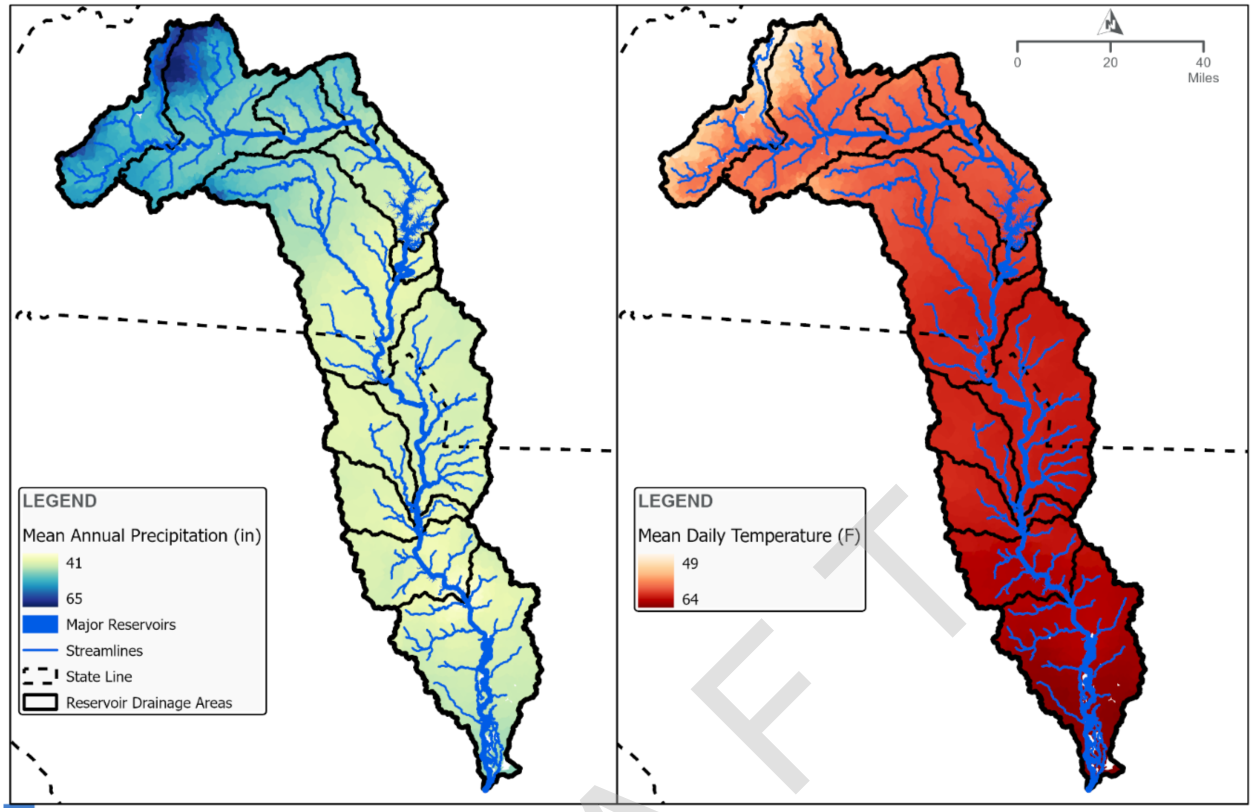

Figure 2-5. Mean Annual Precipitation (left) and Mean Daily Temperature (right) for the Basin based on PRISM Climate Group from 1981 through 2020

Precipitation is distributed relatively evenly throughout the year with an average annual rainfall of 44.5 inches, with fall and winter being slightly drier than spring and summer Table 2-3). As shown in Figure 2-5, the upper Basin is wetter (50.4 inches per year) than the middle and lower parts of the Basin, which experience 6 to 7 inches less rainfall on average over the long-term record. Across the Basin, average temperatures during the 1981-2020 model period range from about 38°F in January to 77°F in July.

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Table 2-3. Average monthly precipitation (inches) and temperature (PRISM Climate Group 2022).

Month	Precipitation (inches)			Basin-wide Precipitation (inches)	Average Temperature (F)
	Upper Basin	Mid Basin	Lower Basin		
January	4.0	3.7	3.7	11.4	38.3
February	3.9	3.5	3.4	10.8	41.8
March	4.2	4.0	3.7	11.9	48.9
April	4.2	3.5	2.9	10.6	57.8
May	4.3	3.6	3.1	11	65.9
June	4.5	4.1	4.0	12.6	73.7
July	4.8	3.7	4.2	12.7	77.2
August	4.6	4.1	5.0	13.7	75.8
September	4.3	3.6	3.6	11.5	69.3
October	3.8	3.5	3.2	10.5	58.9
November	3.7	3.3	3.1	10.1	48.7
December	4.3	3.9	3.7	11.9	41.2
Total Precipitation and Average Temperature	**50.4**	**44.5**	**43.5**	**138.4**	**58.1**

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Time series plots (Figure 2-6 through Figure 2-8) showing U.S. Drought Monitor (USDM) conditions from 2000 to 2025 are provided for three counties in the Basin to illustrate the dramatic and widespread impacts of major drought events. The most severe drought period is highlighted by the dark vertical bars spanning late 2007 into 2008, where the three counties that were most affected—McDowell (NC), Mecklenburg (NC), and Kershaw (SC)—spent several continuous months with significant portions of their land area in the most intense categories, D3 (Extreme) and D4 (Exceptional Drought). This event led to critical, sustained water shortages and major agricultural losses.

The charts also show notable drought periods in the early 2000s, specifically in 2001 and 2002, when all three counties experienced D3 and D4 conditions. Looking at the more recent past (from 2018 onward), the region has generally experienced fewer sustained periods of severe drought compared to the decade 2000-2010, with drought conditions mostly limited to D0 (Abnormally Dry) or D1 (Moderate Drought) events.

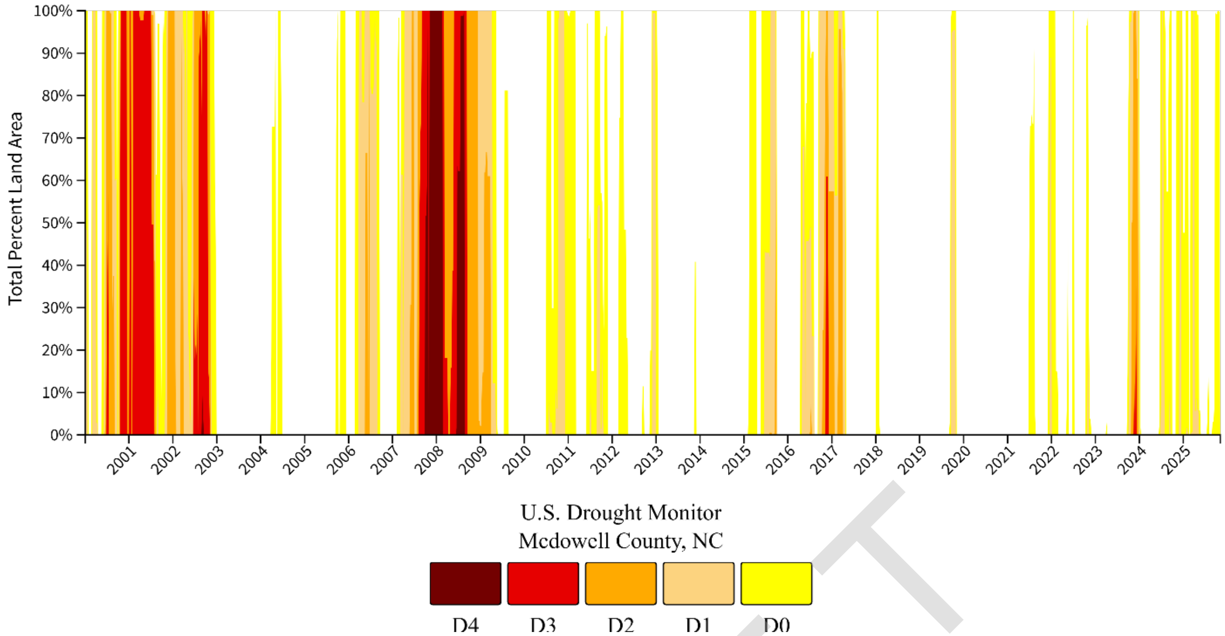

Figure 2-6. U.S. Drought Monitor (USDM) Time Series for McDowell County, NC (2000–2025)

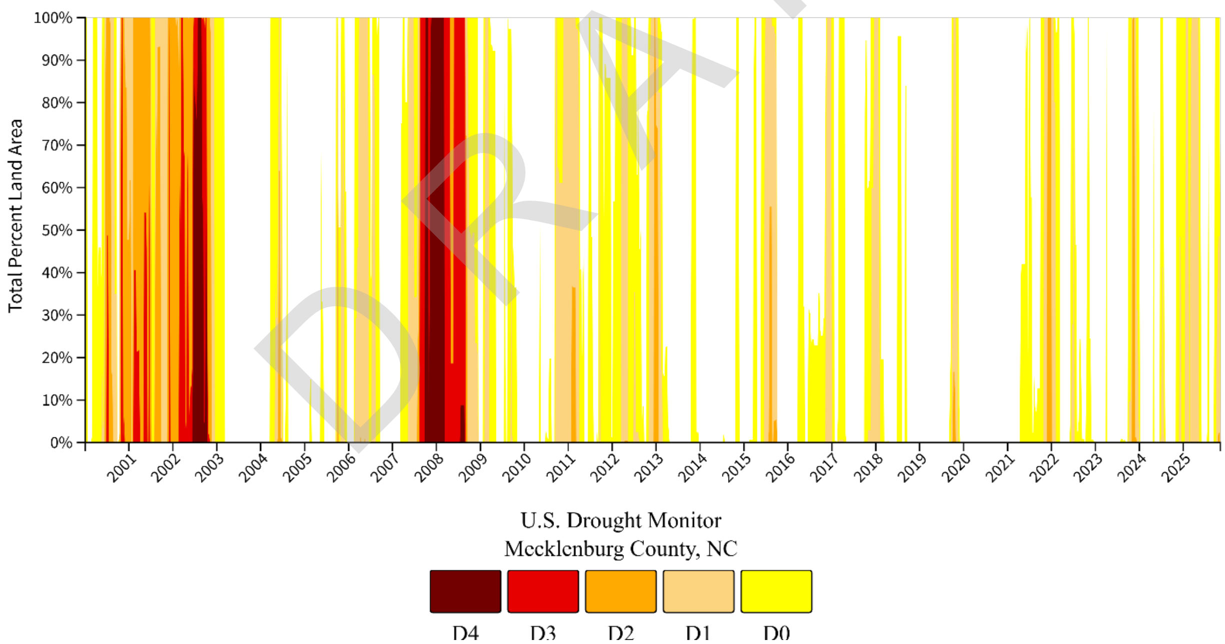

Figure 2-7. U.S. Drought Monitor (USDM) Time Series for Mecklenburg County, NC (2000–2025)

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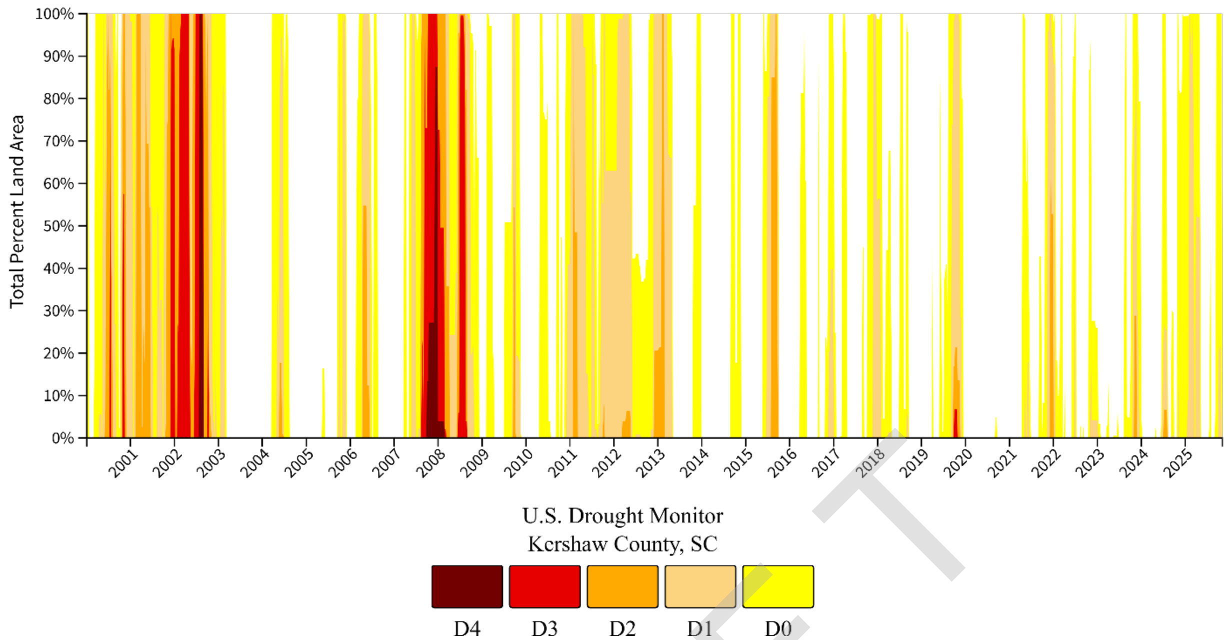

Figure 2-8. U.S. Drought Monitor (USDM) Time Series for Kershaw County, SC (2000-2025)

2.4 Water Quality

Water quality concerns within the watershed are focused mainly on the impacts of nutrients and sediment on aquatic health and reservoir operation. Both of these parameters have contributed to degradation of water quality in reservoirs. In addition to reduction in reservoir storage, sediment entering a reservoir from upstream or runoff flows can transport adsorbed nutrients, chemicals, and toxins. High nutrient concentrations in reservoirs can result in eutrophication and algal blooms, leading to ecological impairment.

The USEPA Assessment and Total Maximum Daily Load Tracking and Implementation System (ATTAINS) geospatial data (WATERS Geospatial Data Downloads | USEPA) was reviewed to compile an inventory impaired streams and lakes in the Basin. Figure 2-9Figure 2-10 presents assessment units (catchments) on the 303(d) list for North Carolina and South Carolina for different impairment parameters. The most common listing in both states is due to impaired benthic macroinvertebrate communities, followed by bacteria (NC: Fecal Coliform; SC: Escherichia Coli [E. Coli]). Impairment due to TP, TN, and Dissolved Oxygen (DO) is mainly seen in South Carolina, whereas impairment by turbidity is mainly observed on tributaries around Lake Norman in North Carolina.

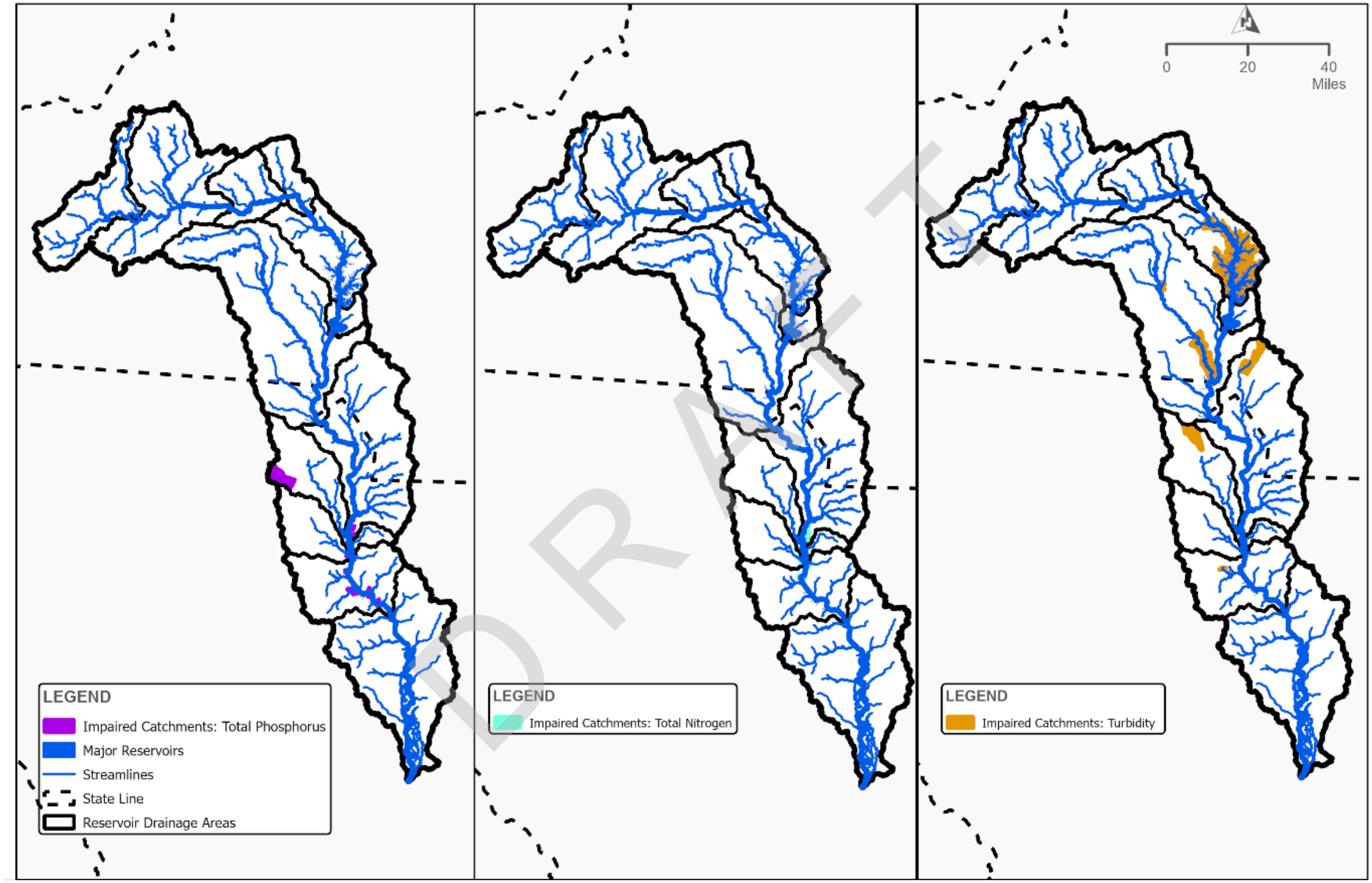

Figure 2-9. 303(d) List Impairments for Nutrients and Turbidity Mapped by Catchment in the Catawba-Wateree Basin based on USEPA ATTAINS database

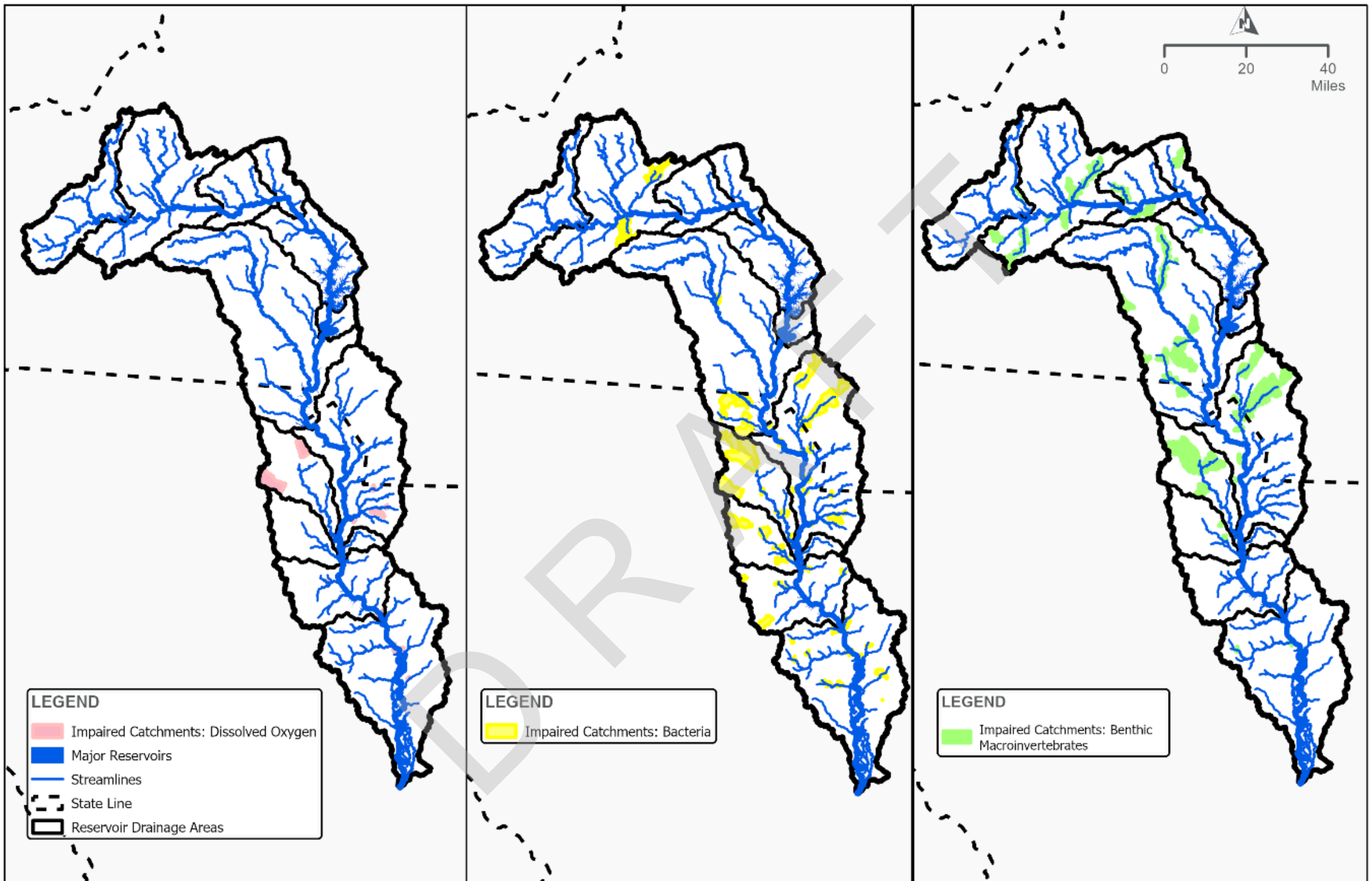

Figure 2-10. 303(d) List Impairments for Dissolved Oxygen, Bacteria, and Benthic Macroinvertebrates Mapped by Catchment in the Catawba-Wateree Basin based on USEPA ATTAINS database

2.5 Setting the Stage for IWRP Development

The Basin's current conditions, including climate, land use, impaired waters, and infrastructure challenges form the foundation for the IWRP. These factors inform and shape the questions the IWRP must answer and the strategies it must evaluate.

By quantifying how water moves through the Basin and how it is affected by both natural and human-driven effects, the modeling tools and data presented here enable the IWRP to simulate future scenarios with greater accuracy, as discussed in the next section. This effort includes evaluating water availability under drought conditions, assessing the impact of land development on runoff and water quality, and identifying infrastructure vulnerabilities and sets the stage for evaluations of water availability, water quality, groundwater, and mitigation strategies. It ensures the Plan is rooted in a clear understanding of the Basin as it exists today, and that future recommendations are responsive to the currently observed conditions.

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Future Basin Conditions

Section 3

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3 Future Conditions

3.1 Introduction

Planning for future conditions is a fundamental component of water resource management. While today's systems and forecasting capabilities are reliable, recent events are a reminder that conditions can change quickly, and drought conditions are not the only threat to the basin. Hurricane Helene brought record-breaking rainfall and flooding to the southeastern U.S. in September 2024, overwhelming existing infrastructure and natural systems. A summary on Hurricane Helene, provided in Appendix C, illustrates how extreme events can disrupt operations and underscores the need for strategies that anticipate both gradual trends and extreme events.

The IWRP looks ahead to mid-21st century conditions and beyond, evaluating how changes in land use, climate, and water use may shape the Basin's future. These scenarios incorporate projected urban growth, shifts in temperature and precipitation, and evolving water demands, including potential changes in withdrawals and point-source discharges. By considering a range of possibilities, the IWRP provides a framework for understanding vulnerabilities and identifying opportunities to strengthen resilience.

This approach is not about predicting a single future. It is about preparing for many. By combining robust data with adaptive strategies, the IWRP positions the Basin to manage uncertainty, protect water resources, and ensure reliable service for generations.

3.2 Projected Future Land Use/Land Cover

Future land use patterns will play a major role in determining water quality and availability across the Basin. Projections indicate continued urban growth and development/redevelopment, paired with a steady decline in natural and agricultural lands, replaced by impervious surfaces. These changes influence how water moves through the landscape, affecting runoff, infiltration, and water quality.

To develop these projections, the IWRP uses nationally recognized datasets that combine current land cover with modeled growth scenarios. The analysis applies USEPA's ICLUS dataset, which provides land use layers at 10-year intervals through 2100 (UEPA 2016). For the IWRP, the 2070 projection, under a moderate growth pathway, was selected. The selection was based on the Shared Socioeconomic Pathway 2 (SSP2) and Representative Concentration Pathway 4.5 (RCP4.5). SSP2 reflects population and developmental trends, while RCP4.5 represents the environmental drivers. Details on how ICLUS integrates dynamic climate variables to enable scenario-based simulations are provided in USEPA (2016).

By 2070, the Basin is expected to experience a clear shift towards higher-density development. Results show mixed-use areas expand by more than 150 mi^2, while High Urban and Medium Urban classes, where High and Medium refer to the level of density, also grow significantly. In total, by 2070 the Basin is projected to grow its developed areas by approximately 184 mi^2. In contrast, natural and agricultural lands are reduced in area with natural areas decreasing by

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66 mi^2 and pasture lands decreasing by nearly 100 mi^2. These changes are summarized in Table 3-1 and are shown on Figure 3-1 and Figure 3-2.

Table 3-1. Projected future (2070) land use area and relative change from 2020.

	Land Surface Categorization	2070 Area (mi^2)	Change in Area from 2020 to 2070 mi^2	%	2070 Change Percent of Total Area (%)
Natural	Water	139	0	0	0
	Wetlands	187	-6.0	-5.6	-0.1
	Forest	1899	-200	-9.5	-3.6
	Forests at Risk	919	155	20.3	2.8
	Forests Infringed	111	44.5	66.7	0.8
	Open Space and Altered Crops	205	-33.7	-14.1	-0.6
	Shrub/Scrub	133	-13.9	-9.4	-0.2
	Grasslands/Herbaceous	119	-12.1	-9.2	-0.2
Developed	Mixed Use with Developing Population	427	156	57.6	2.8
	Crops and Wetlands Infringed	10.0	1.3	15.3	0.0
	Developed, Open Space (Rural)	9.1	-0.2	-2.5	0.0
	Developed, Exurban	462	16.2	3.6	0.3
	Developed, Suburban	149	-31.8	-17.6	-0.6
	Developed, Medium Urban	213	26.4	14.2	0.5
	Developed, High Urban	163	16.1	10.9	0.3
	Barren Land	10.0	0.0	0	0.0
Agriculture	Pasture/Hay	373	-99.9	-21.1	-1.8
	Cultivated Crops	41.3	-18.7	-31.2	-0.3
	Total	**5,571**			

Note: Through GIS processing of the hydrologic catchments and cumulative drainage areas along the mainstream flow paths, the Basin area is approximately 5,570 mi^2. This discrepancy in area compared to the published area of the Basin is attributed to not counting areas draining to braided stream reaches that are not included in the hydrologic navigation.

The total increases in developed areas and net losses in natural areas do not represent overall changes. Land categorizations reveal how human influence extends into areas still considered natural.

- Pristine Forest land that provides optimal water quantity and quality protection is reduced by 200 mi^2, a 4% decrease in Basin area by 2070.
- Forests transition to developed classes, including Mixed Use, Exurban, or Suburban classes, as well as conversions to Forests at Risk and Forests Infringed. These changes diminish ecological function and increase impervious areas. Forests at Risk grow by 155 mi^2, and Forests Infringed by 45 mi^2.

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- Agricultural lands decline significantly, losing approximately 119 mi^2 of productive agricultural land, primarily Pasture rather than Cultivated Crops. These losses are seen mostly in the central Basin.

To understand the geographic distribution of land use changes, Figure 3-3 illustrates shifts in three broad land use categories: Altered (developed classes), Vegetated (natural land classes impacted by humans), and Pristine (natural classes unaffected by humans) by reservoir subbasin. The upper subbasins include Lake James, Lake Rhodhiss, Lake Hickory, and Lookout Shoals Lake. The central subbasins include Lake Norman, Mountain Island Lake, and Lake Wylie. The lower subbasins include Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir, Lake Wateree, and then Below Wateree.

The watersheds in the middle of the Basin are approximately 50% Altered, while Lake James and Lake Wateree subbasins retain the greatest percentage of Pristine land. In the upper Basin, Lake James areas correspond to Pisgah National Forest, while the lands around Lake Wateree in the lower Basin benefit from larger tracts of protected lands, including the 3,452-acre Liberty Hill property along the eastern shoreline of the lake, protected through purchase by The Conservation Fund and SCDNR, and a connected plot of 1,500 acres to the north owned by SCDNR.

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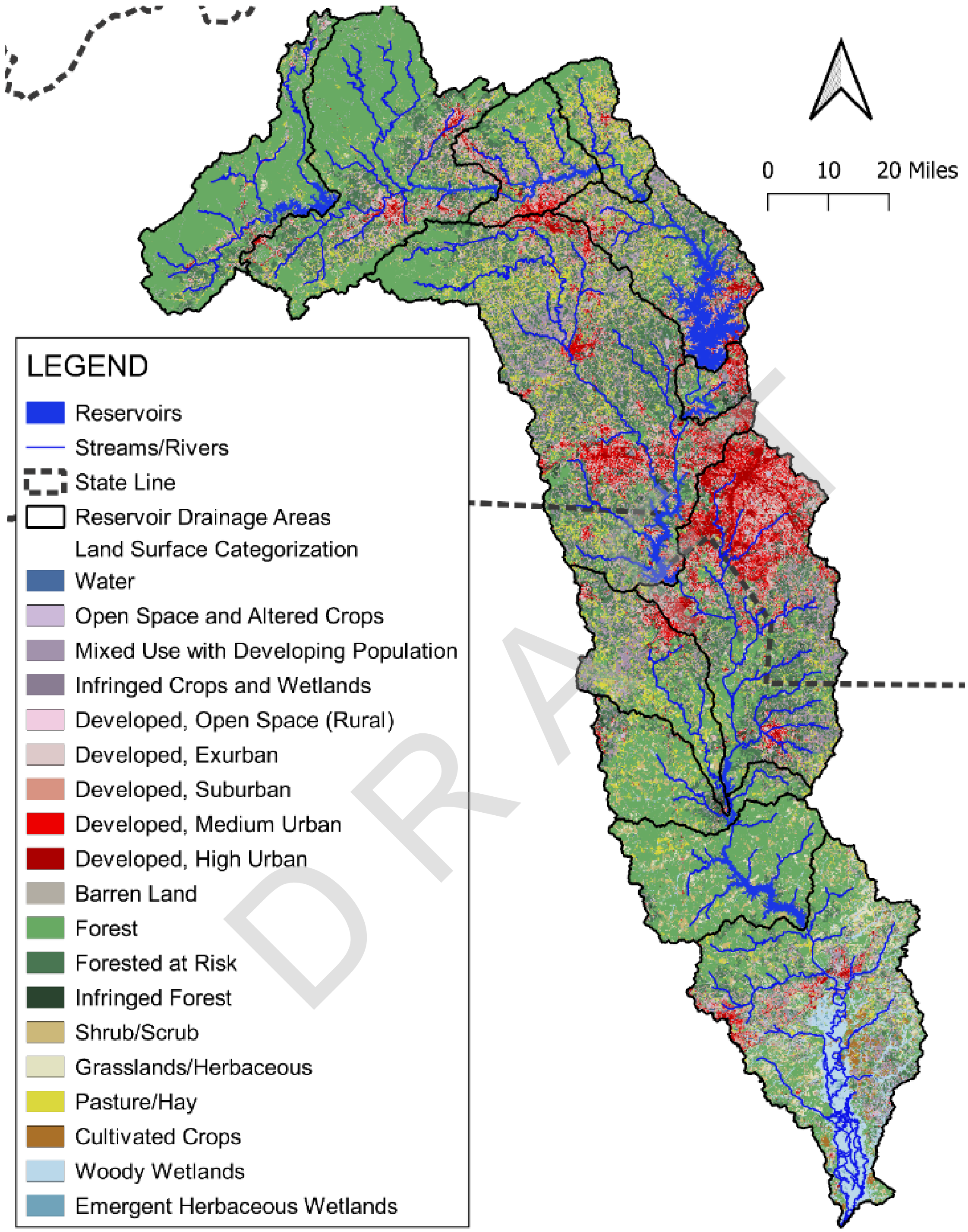

Figure 3-1. Projected 2070 land cover

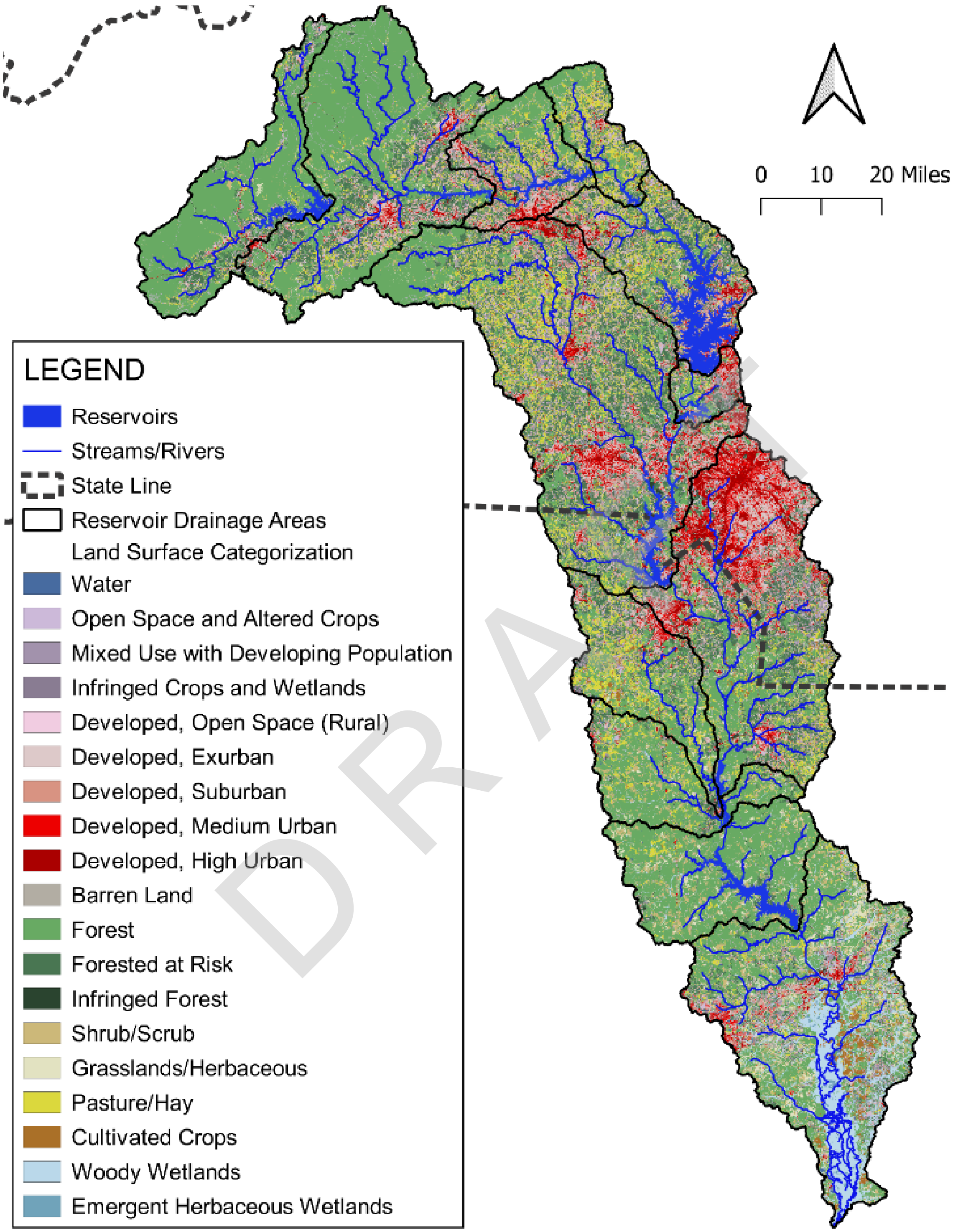

Figure 3-2. Baseline 2020 Land Use

The loss of Pristine lands to developed and human impacted natural lands is evident in the increasing shares of the Vegetated (light green) and Altered (red) areas within each subbasin on Figure 3-3. This shift is most prominent in the central Basin subbasins from Mountain Island Lake through to Great Falls/Cedar Creek.

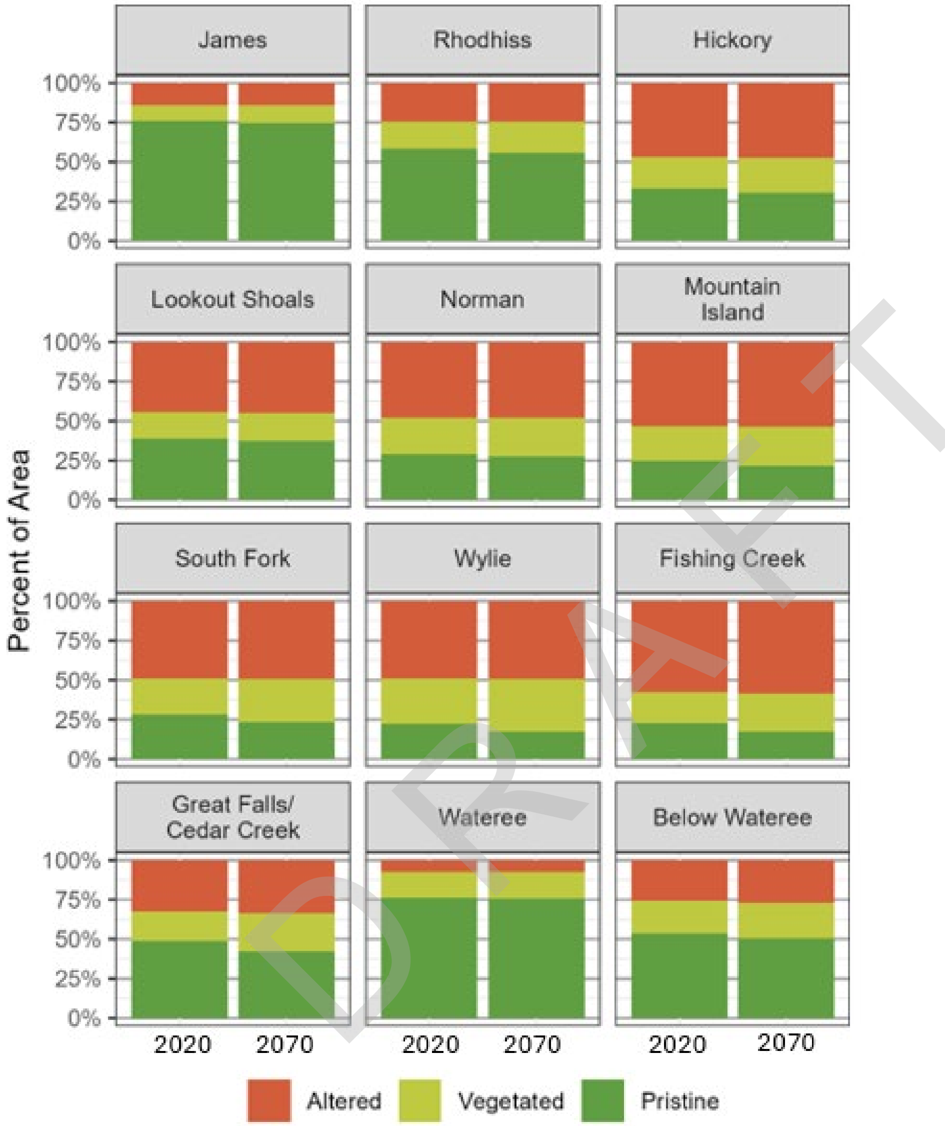

Figure 3-3. Breakdown in Natural Lands under Current (2020) and Projected Future (2070) Conditions by Subbasins

While Figure 3-3 shows the relative land use differences, Table 3-2 provides the actual changes in area (in mi^2) by land use category for each subbasin. Small relative changes within a large subbasin can translate into substantial changes in total area, while what appears to be large relative changes in a small subbasin can represent only modest area changes. For example, Mountain Island Lake and Below Wateree subbasins show similar relative changes across land-use categories despite having different starting proportions. However, Mountain Island Lake loses just over 2.0 mi^2 of Pristine Forest, whereas Below Wateree loses 26.5 mi^2—more than 10 times as much. Likewise, Lake Rhodhiss does not show large relative losses of Pristine lands yet the subbasin still loses nearly 20 mi^2 of these high-functioning areas. Overall, future projections indicate a loss of 136 mi^2 of Pristine lands from the headwaters of the South Fork subbasin to the outlet of Cedar Creek Reservoir, with an additional loss of over 26 mi^2 below Lake Wateree. These losses correspond to an increase of 28.5 mi^2 of Altered land. These trends underscore the importance of incorporating land use change into water resource modeling to anticipate impacts on both water quantity and quality.

Table 3-2. Projected Change in Category Area by Subbasin in the Future

	Area Change 2020 to 2070 (mi^2)		
Subbasin	**Altered**	**Vegetated**	**Pristine**
James	0.24	4.69	-4.91
Rhodhiss	1.29	18.42	-19.71
Hickory	0.4	6.03	-6.41
Lookout Shoals	0.19	2.07	-2.25
Norman	0.74	5.19	-5.9
Mountain Island	0.41	1.8	-2.18
South Fork	3.16	26.78	-29.94
Wylie	2.75	24.54	-27.28
Fishing Creek	5.86	37.04	-42.89
Great Falls/ Cedar Creek	5.93	29.76	-35.68
Wateree	0.36	1.54	-1.91
Below Wateree	10.77	15.75	-26.5

3.3 Projected Future Climate Conditions

Future climate conditions will influence water resources in the Basin. Projections for North Carolina and South Carolina indicate unprecedented warming, with mid-century temperatures projected to rise by 2 to 5 degrees Fahrenheit (°F) under a higher emissions pathway as shown on Figure 3-4 (NOAA 2022).

While temperature increases of statistical measure are expected in both North and South Carolina, precipitation changes are not as consistent between the two states. North Carolina is projected to experience between a 5% to 10% increase in annual rainfall by year 2100 (Note: Hatching represents areas where most climate models indicate a statistically significant change.

Figure 3-5), and this increase is expected to be statistically significant based on available data (Frankson, et al., 2022; Runkle, et al., 2022). In contrast, South Carolina's precipitation has varied on yearly and decadal timescales with few statistically significant trends in annual or seasonal totals over time. The number of fall precipitation days has increased, but overall, few other statistically significant changes are evident in seasonal or annual precipitation (SCOR 2023). In keeping with this trend, a statistically significant statewide increase in South Carolina

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is not anticipated (SCDNR 2022)., however increased precipitation in North Carolina and temperature increases in both states projected over the next century are critical factors to consider in Basin water planning and management.

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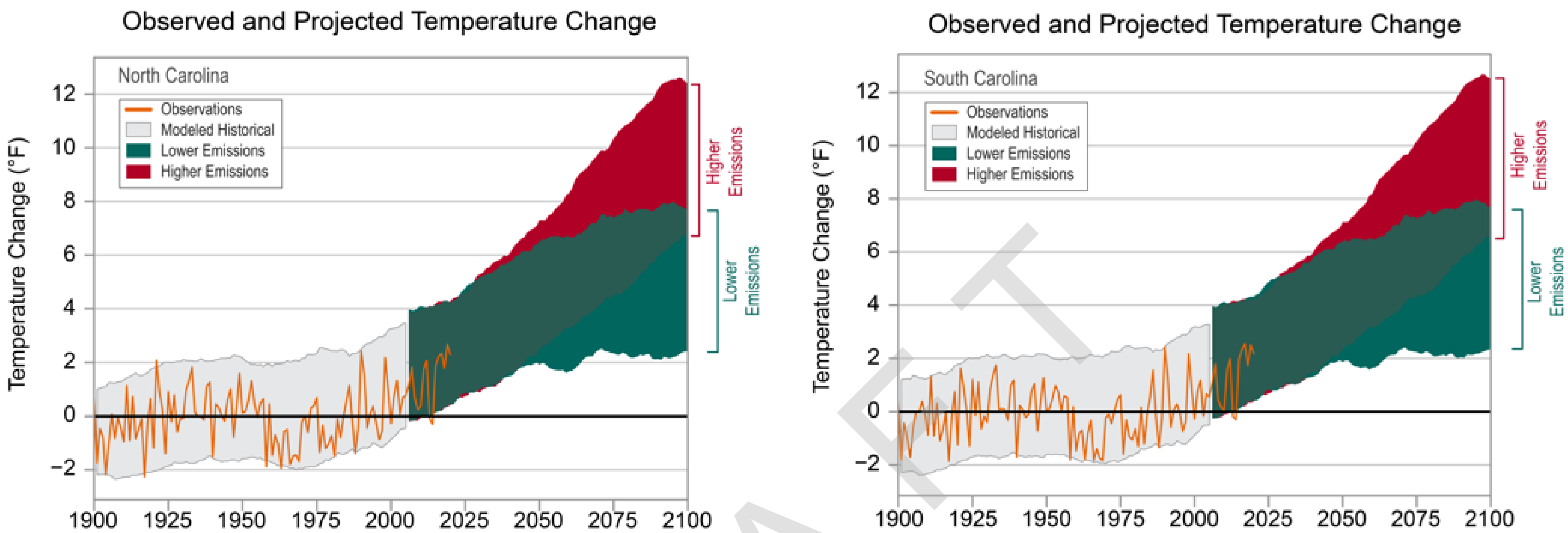

Figure 3-4. North Carolina and South Carolina average temperature historic trends and projections.
Source: **(NOAA NESDIS 2022)**

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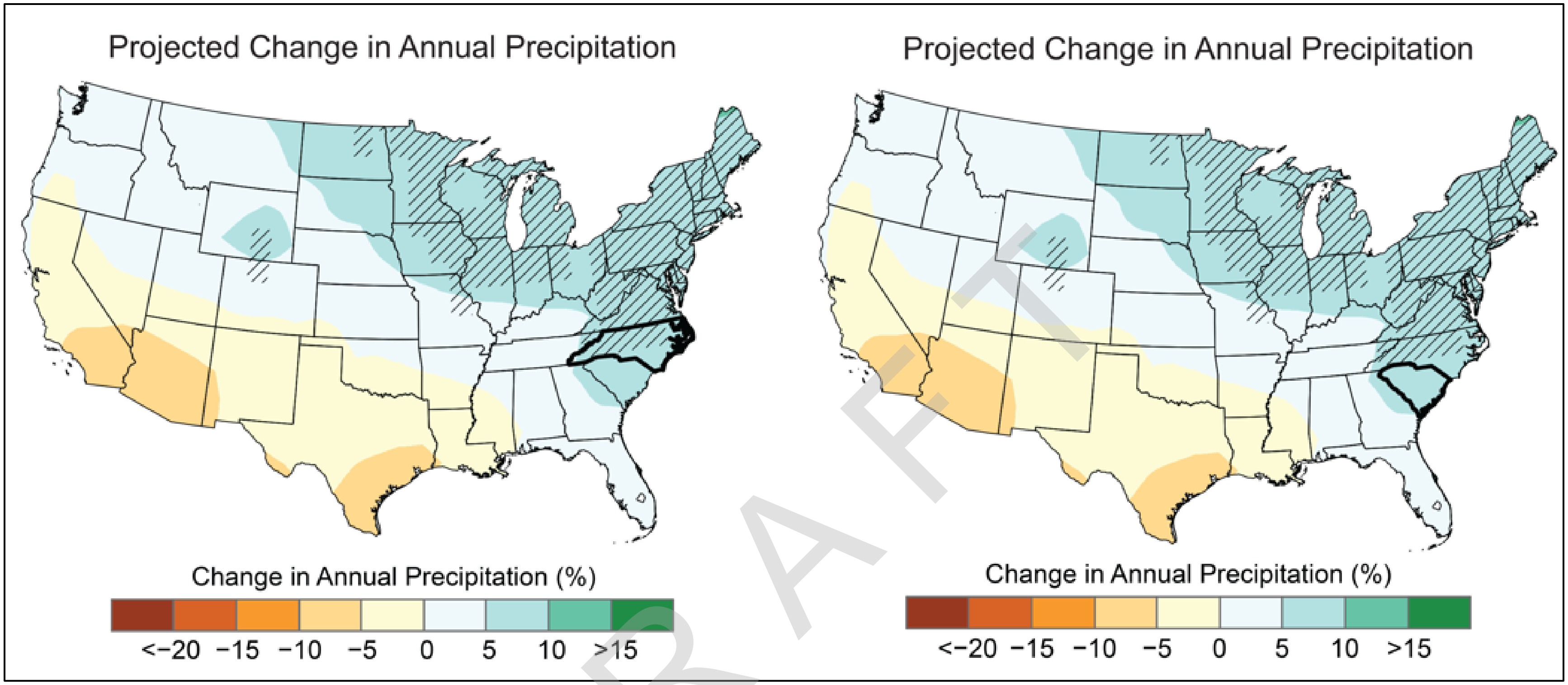

Note: Hatching represents areas where most climate models indicate a statistically significant change.

Figure 3-5. Projected changes (hatch marks) in total annual precipitation for mid-21st century compared to late 20th century.
Source: **(NOAA NESDIS, 2022)**

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Projections of future climate conditions carry a large degree of uncertainty. Global Climate Models (GCMs) used to generate these projections are highly complex and rely on many assumptions about the global economy and carbon emissions. To capture this range of uncertainty, the IWRP uses abounding box approach, combining temperature (ΔT) and precipitation (ΔP) changes in four unique scenarios:

- Dry/Hot: Much hotter and much drier
- Wet/Hot: Much hotter and much wetter
- Dry/Warm: Warmer and much drier
- Wet/Warm: Warmer and much wetter

These scenarios represent the extremes of potential conditions and allow planners to test system sensitivity to both drought and high flow risks (Figure 3-6).

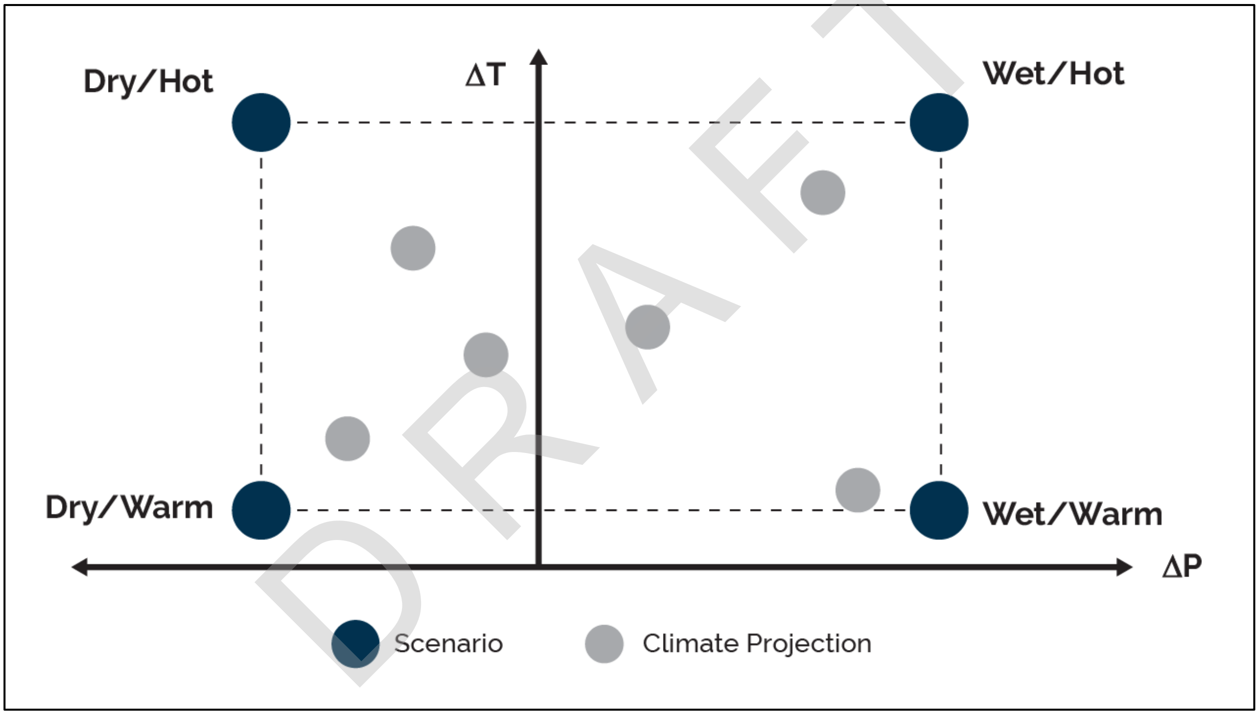

Figure 3-6. Climate scenarios that encompass potential projected future conditions representing temperature changes (ΔT) and precipitation changes (ΔP)

These projected changes form the foundation for evaluating future watershed conditions. North Carolina's potential increase in precipitation and South Carolina's minimal long-term change support the creation of the Wet and Dry scenarios. The consistent expectation of warming across both states also drives the development of Warm and Hot temperature scenarios.Combined, these four scenarios capture a reasonable range of possible future conditions and allow evaluation of how sensitive the system may be to changes in precipitation and temperature.

3.3.1 Global Climate Model and Downscaling Approach

Future climate conditions were developed using the Localized Constructed Analogs (LOCA)-downscaled dataset from the CMIP6 archive. The underlying projections were generated by the GFDL-CM4 GCM, which was selected for its relatively high degree of accuracy over the modeling area (Ashfaq, 2022). The SSP245 moderate emissions pathway was chosen to align with projected water use for the 2045–2075 period.

> CMIP6, or the Coupled Model Intercomparison Project Phase 6, is a compilation of global climate projections from several climate models. The models produce simulations of future climate conditions (2015-2100). The CMIP6 supported the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6; IPCC 2021) and the Fifth U.S. National Climate Assessment (NCA5; USGCRP 2023a).

Since the raw GCM output is typically too coarse for local water-resource applications, the data was processed using the LOCA statistical downscaling method. This approach produces a high-resolution, bias-corrected time series of daily projected precipitation and temperature across the basin for the 2045–2075 period. These downscaled projections formed the basis for calculating the climate adjustment factors used in the scenario analysis.

3.3.2 Future Climate Adjustment Factors

The climate scenarios were constructed by applying specific adjustment factors derived from downscaled CMIP6 projections to the historic daily precipitation and temperature time series for the 1981–2020 baseline period. The precipitation factors are expressed as monthly multipliers, while the temperature factors represent additional degrees Fahrenheit added to the baseline values. These monthly factors are summarized in Table 3-3.

Table 3-3. Monthly Adjustment Factors for Future Climate Scenarios.

		Precipitation Multiplier		Temperature Adjustment (°F)	
Month	**Season**	**Wet**	**Dry**	**Warm**	**Hot**
January	Winter	1.11	0.92	3.0	4.4
February	Winter	1.10	0.93	3.2	4.5
March	Spring	1.10	0.94	2.8	4.2
April	Spring	1.09	0.93	3.6	4.8
May	Spring	1.09	0.93	3.1	4.1
June	Summer	1.08	0.93	3.0	3.7
July	Summer	1.07	0.94	3.1	3.6
August	Summer	1.10	0.92	3.5	4.1
September	Fall	1.16	0.90	3.7	4.6
October	Fall	1.18	0.92	3.2	4.4

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		Precipitation Multiplier		Temperature Adjustment (°F)	
November	Fall	1.12	0.92	3.1	4.3
December	Winter	1.10	0.95	3.1	4.6
Annual Average:		**1.11**	**0.93**	**3.2**	**4.3**

Note: Monthly precipitation multipliers (Wet and Dry) and temperature adjustments (Warm and Hot), in °F, derived from LOCA-Downscaled GFDL-CM4 (SSP245) projections and applied to the historic daily time series.

3.3.2.1 PRECIPITATION ADJUSTMENT METHODOLOGY

Historic climate records were used to classify months as Wet or Dry based on cumulative rainfall. A month was classified as Wet if its historic cumulative rainfall was greater than the monthly average plus 30% of the standard deviation of historic monthly rainfall, and Dry if it was less than or equal to the monthly average minus the same factor. This classification system was applied to both the historic data and the future rainfall projections.

Precipitation adjustment factors were then calculated for each month and wetness type. This factor is the ratio of the mean future projected rainfall to the mean historic rainfall for that specific wetness category. This approach ensures Wet and Dry scenarios reflect future shifts in the frequency and intensity of rainfall based on the time of year and the underlying historic conditions (Figure 3-7). For example, the Wet Scenario applies a multiplier of 1.11 to all daily precipitation values in January months, effectively increasing that day's precipitation by 11%. Annual averages indicate an 11% increase for Wet conditions and a 7% decrease for dry conditions.

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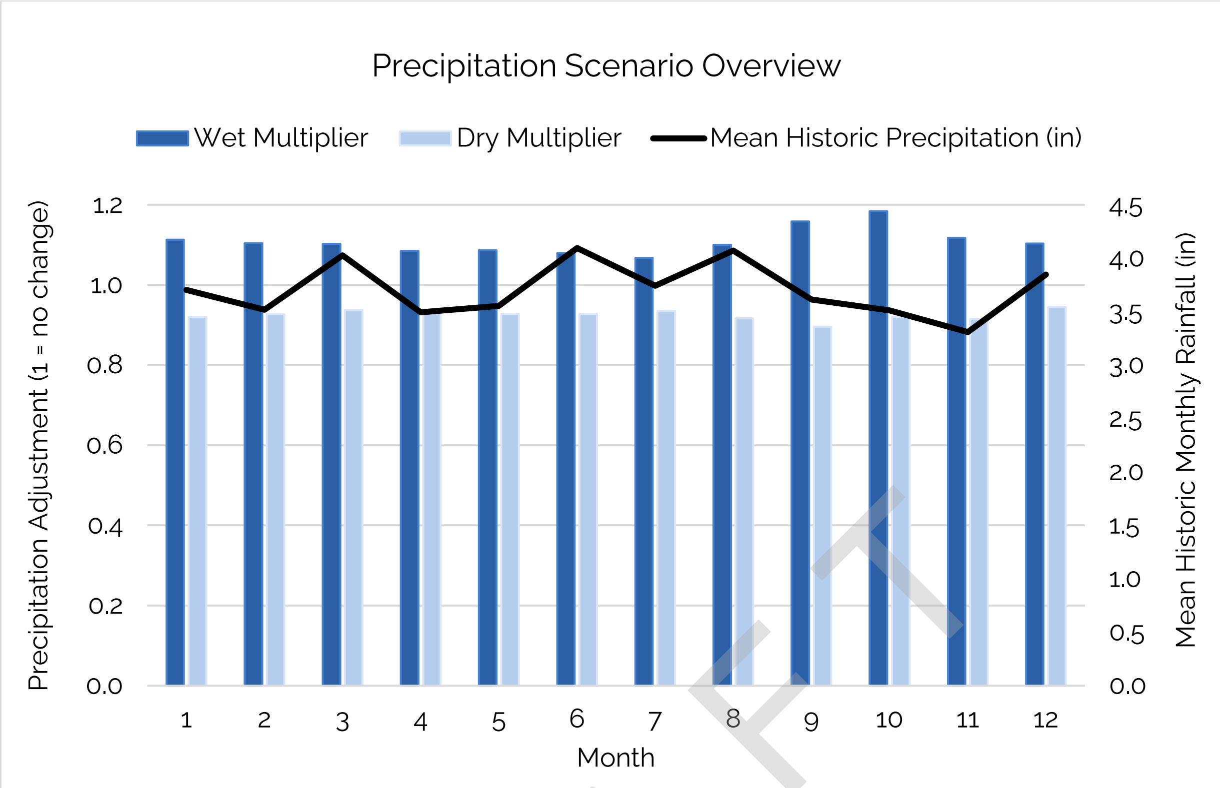

Figure 3-7. Precipitation Scenario Overview: Monthly Basin-wide Multipliers Applied to Historic Precipitation

3.3.2.2 TEMPERATURE ADJUSTMENT METHODOLOGY

Projections show a universal increase in mean temperatures across the Basin, leading to the development of Warm and Hot temperature scenarios. Temperature adjustments were derived based on the monthly difference in mean temperatures between the future projections (CMIP6, SSP245) and the historic baseline. The Warm Scenario adjustment factor was based on the simple difference between the future mean projected temperature and the historic mean. The Hot Scenario includes the same baseline difference plus an additional 30% of the future standard deviation, resulting in a larger increase in projected monthly temperature.

These adjustments range from 2.8°F to 3.7°F for the Warm Scenario and 3.6°F to 4.8°F for the Hot Scenario (Table 3-3). They are applied to the historic daily temperature time series to create the temperature inputs for the future model runs (Figure 3-8).

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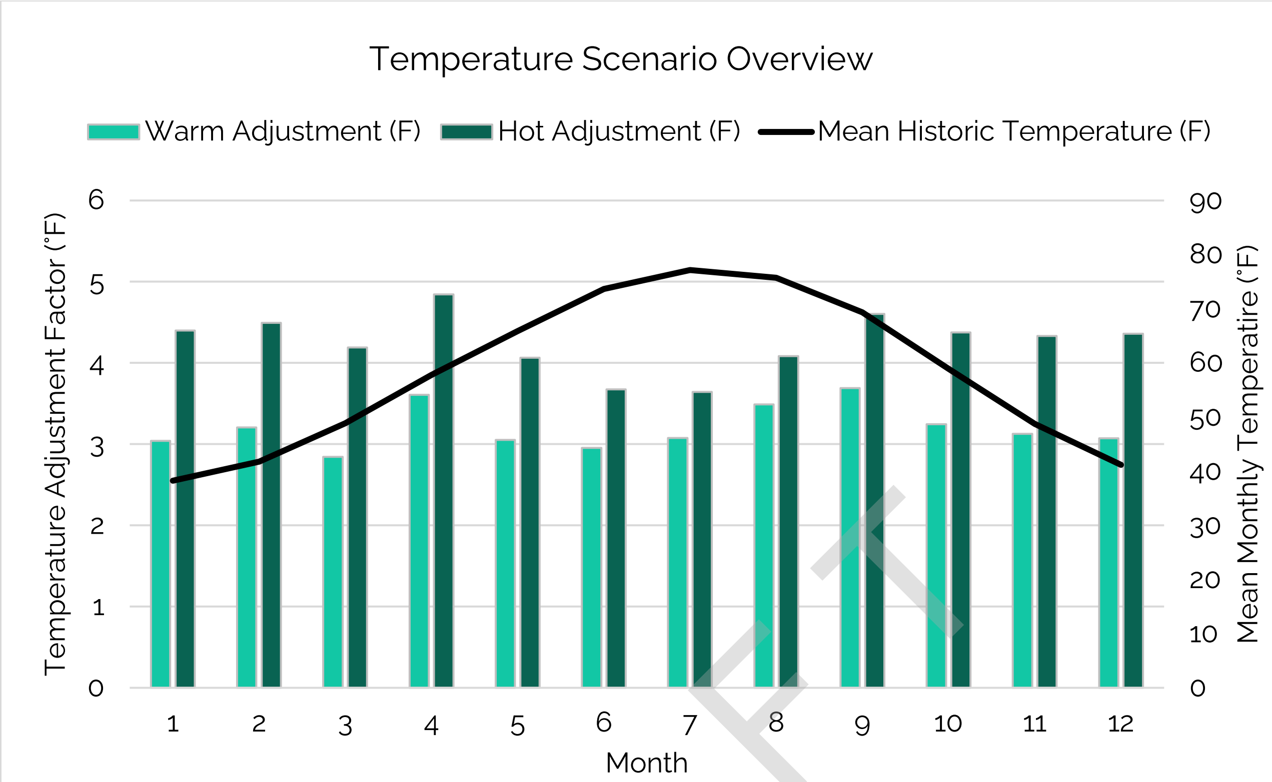

Figure 3-8. Temperature Scenario Overview: Monthly Basin-wide Adjustments Applied to Historic Temperature.

3.4 Basin-wide Water Withdrawal and Discharge Projections

3.4.1 Purpose and Role of Forecasting

Forecasting future net water withdrawals is a core component of IWRP, providing a data-driven foundation for evaluating long-term water needs across the Basin. The forecast builds on nearly two decades of regional water supply planning in the Basin. The need for robust forecasting was first recognized during Duke Energy's hydro project relicensing process in the early 2000s, which led to the 2006 Water Supply Study and the introduction of **safe yield**[3] as a long-term water availability planning benchmark. This work was expanded in the 2014 WSMP, which extended projections to 2065 and focused on strategies to sustain reservoir capacity through the end of the century.

The IWRP continues this legacy, with the first phase centered on updating the long-range water demand forecast to reflect current conditions, expanded Basin boundaries, and improved modeling techniques. The updated forecast incorporates several key enhancements:

[3] Safe yield is the amount of water that can safely be withdrawn from a surface waterbody. This value is used to characterize a water resource's ability to serve as a long-term supply. The use of safe yield and water quantity availability for the purposes of this Plan is described further in Section 4.

- **Expanded Basin Boundary**: The forecast now includes approximately 76 additional river miles downstream of Lake Wateree, extending to the confluence with the Congaree River.
- **Updated Data Sources**: Historical water use data from 2006 to 2020 was compiled from state and federal sources, including Local Water Supply Plans, EPA Discharge Monitoring Reports, and direct input from CWWMG member utilities.
- **Refined Methodology**: The forecast uses both deterministic and probabilistic approaches to account for uncertainty and variability in future conditions.
- **User-Level Detail**: Projections were developed for individual facilities and aggregated by watershed and user category, allowing for more precise planning.
- **Extended Planning Horizon**: Forecasts now extend through 2075, providing a longer-term view of water demand.

By integrating historical trends, stakeholder input, and advanced modeling techniques, the IWRP forecast provides a comprehensive and flexible framework for evaluating future water needs. This updated forecast serves as the foundation for all subsequent planning activities, including infrastructure evaluation, scenario development, and regional coordination.

3.4.2 Forecasting Approach

The IWRP forecast estimates future **net water withdrawals** through the year 2075. Net water withdrawals are defined as total surface water withdrawals minus surface water return flows. The IWRP forecast was developed using a comprehensive, multi-step approach that integrates historical data, stakeholder input, and advanced modeling techniques. This approach builds on prior planning efforts and reflects the expanded geographic scope and evolving water use dynamics of the Basin. Full details are provided in Appendix D.

3.4.2.1 STEP 1: DATA COLLECTION AND FACILITY LEVEL ANALYSIS

A central component of the forecasting effort included developing updated historical water use profiles for hundreds of individual water withdrawers and dischargers. Water users (i.e., facilities) were grouped into four major categories for forecasting purposes:

- **Agricultural & Irrigation:** Includes crop irrigation, livestock watering, golf course irrigation, and lakeside residential irrigation. These uses are considered fully consumptive, with no return flows to surface water.
- **Thermal-Electric Power:** Covers water used for cooling and other processes at energy generation facilities, primarily Duke Energy’s nuclear and coal-fired plants. Future projections reflect planned retirements and new power plants, including the introduction of new nuclear power technologies.
- **Public Water Supply & Wastewater Utilities:** Encompasses municipal and regional systems that withdraw and return water for residential, commercial, and industrial use. Forecasts incorporate Local Water Supply Plans data, discharge monitoring reports, and direct utility input.

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- **Direct Industrial Users:** Includes facilities with direct surface water withdrawals and returns for manufacturing and processing. Many of these users now rely on public systems, and their water use is increasingly captured under the Public Water Supply & Wastewater Utilities category.

For each facility, historical data were compiled and validated using:

- **Monthly withdrawal and return data** from Local Water Supply Plans for North Carolina systems (2002 and 2007–2020).
- **Discharge Monitoring Reports** for wastewater facilities (2002–2020), obtained from both North Carolina and South Carolina agencies.
- **Catawba-Wateree Drought Management Advisory Group submissions** from CWWMG members (2011–2020), which provided monthly facility-level data.
- **Direct outreach to utilities and industries**, including individual meetings with CWWMG members to validate historical data, confirm service area growth trends, and refine future projections.

This granular, user-level approach allowed the forecast to reflect actual water use patterns rather than relying solely on generalized assumptions. Each facility's historical data was reviewed, and projections were developed based on observed trends and regional growth expectations.

3.4.2.2 STEP 2: ESTABLISHING A REPRESENTATIVE BASE YEAR

To establish a stable foundation for long-range projections, the IWRP defined a representative base year using average water use data from 2006 to 2020, where available. This method accounts for climatological variability and socio-economic disruptions, such as the COVID-19 pandemic, which affected water use patterns in recent years. By averaging across a 15-year period, the base year captures typical conditions and smooths out anomalies that could skew future projections.

3.4.2.3 STEP 3: DEVELOPING THE DETERMINISTIC FORECAST

Following validation and organization of historical data by facility and subbasin, deterministic forecasts were developed for each individual water withdrawer and discharger. These forecasts represent single-point estimates of future water use, based on observed trends, projected growth rates, and planning assumptions specific to each facility. Forecasts were then aggregated to produce subbasin-level and basin-wide projections. The deterministic forecast provides the baseline scenario for future water demand and discharges, forming the foundation for subsequent uncertainty analysis. Additionally, seasonal demand coefficients, derived from historical monthly patterns, were developed.

3.4.2.4 STEP 4: INCORPORATING UNCERTAINTY

A Monte Carlo simulation was used to incorporate uncertainty into the deterministic, basin-wide forecast. This method evaluates interannual variation in water use and generates a range of possible outcomes, represented by percentile forecasts (5th, 25th, 50th, 75th, and 95th). This probabilistic modeling was applied to over 200 facility-level data points, with drift rates derived from historical fluctuations to develop the basin-wide forecast.

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3.4.3 Key Forecast Insights

The IWRP forecast provides a detailed picture of how water demand across the Basin may evolve through 2075. It highlights both expected growth and areas of decline, offering valuable insights into infrastructure planning and policy development.

3.4.3.1 BASIN-WIDE TRENDS

Under the 50th percentile (median) scenario, net water withdrawals are projected to increase from approximately 194 MGD in the base year to 354 MGD by 2075. The probabilistic forecast range spans from 287 MGD (25th percentile) to 432 MGD (75th percentile) in 2075, reflecting the variability in future conditions due to climate, economic shifts, and technological change.

The forecast also shows increasing divergence between percentile scenarios over time, underscoring the importance of flexible, adaptive planning. For example, the difference between the 25th and 75th percentile projections grow from approximately 51 MGD in 2045 to approximately 145 MGD by 2075.

Table 3-4. Projected Annual Average Withdrawal, Return, and Net Withdrawals by Watershed, in MGD.

Watershed	Base Year	2025	2035	2045	2055	2065	2075
Withdrawals, MGD							
Lake James	7	8	8	9	9	9	10
Lake Rhodhiss	30	32	34	37	38	40	42
Lake Hickory	15	17	22	23	25	27	28
Lookout Shoals Lake	4	4	5	5	6	6	7
Lake Norman	58	62	76	87	103	117	124
Mountain Island Lake	115	118	134	154	177	203	234
Lake Wylie	72	71	77	84	91	100	103
Fishing Creek Res.	56	61	69	77	87	99	113
Great Falls Res.	<1	<1	<1	<1	<1	<1	<1
Cedar Creek Res.	<1	<1	<1	<1	<1	<1	<1
Lake Wateree	5	7	16	31	39	40	43
Below Wateree	44	45	47	49	51	53	55
Subtotal	**406**	**426**	**489**	**556**	**626**	**695**	**760**
Returns, MGD							
Lake James	2	2	2	2	2	3	3
Lake Rhodhiss	13	12	13	14	15	16	17
Lake Hickory	5	5	6	7	7	8	9
Lookout Shoals Lake	1	1	1	1	1	1	1
Lake Norman	1	1	1	1	1	1	1
Mountain Island Lake	5	6	6	7	8	8	9

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Watershed	Base Year	2025	2035	2045	2055	2065	2075
Lake Wylie	24	30	33	38	43	47	52
Fishing Creek Res.	116	121	145	171	196	223	252
Great Falls Res.	1	1	1	2	2	2	2
Cedar Creek Res.	1	1	1	1	1	1	1
Lake Wateree	<1	<1	<1	<1	<1	<1	<1
Below Wateree	45	47	49	51	54	56	59
Subtotal	**212**	**226**	**259**	**294**	**329**	**366**	**405**
Net Withdrawals, MGD							
Lake James	5	5	6	7	7	7	7
Lake Rhodhiss	17	20	21	23	24	24	25
Lake Hickory	10	12	15	16	17	19	20
Lookout Shoals Lake	4	4	4	4	5	5	6
Lake Norman	57	61	76	86	102	116	123
Mountain Island Lake	110	112	128	147	169	195	225
Lake Wylie	49	41	44	46	49	53	51
Fishing Creek Res.	-60	-59	-76	-93	-109	-124	-138
Great Falls-Dearborn Res.	-1	-1	-1	-1	-2	-2	-2
Cedar Creek Res.	-1	-1	-1	-1	-1	-1	-1
Lake Wateree	5	7	16	31	39	40	43
Below Wateree	-1	-1	-2	-2	-3	-3	-3
Subtotal	**194**	**200**	**230**	**262**	**298**	**330**	**354**

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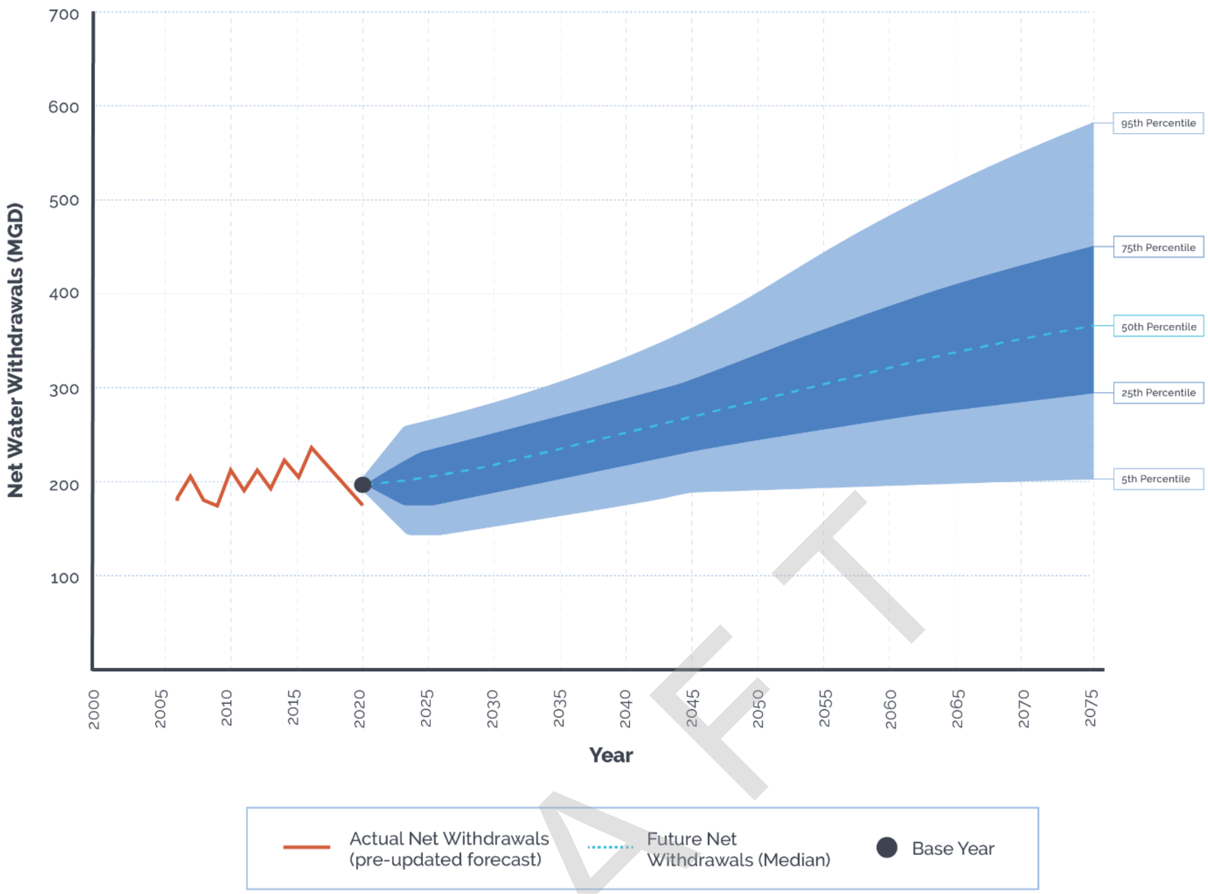

Figure 3-9. Catawba-Wateree Basin Probabilistic Net Withdrawals Forecast, 2006-2075

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3.4.3.2 CATEGORY HIGHLIGHTS

- **Agricultural & Irrigation:**
  - Net withdrawals are projected to increase by 15.5 MGD by 2075, driven by expanded Basin boundaries (i.e., addition of area below Lake Wateree).
  - Crop and livestock water use projections rely on conservative estimates from USGS data, with no assumed technological improvements.
  - Golf course irrigation forecasts are based on historical usage and projected growth in the number of courses, using county-level AGRs from the U.S. Economic Census.
- **Thermal-Electric Power:**
  - Net withdrawals are expected to increase over time; however, declined significantly as compared to previous forecasts due to the planned retirement of coal-fired units, construction of gas-fired generation and the transition to modular nuclear reactors.
  - Duke Energy's updated projections reflect a net withdrawal reduction of approximately 65 MGD compared to previous forecasts.

  - The shift in energy generation technology also redistributes water demand across sub-basins, with new facilities projected for Lake Norman and Lake Wateree.
- **Public Water Supply & Wastewater Utilities:**
  - Net withdrawals increase by 112 MGD by 2050, reflecting strong growth in residential and industrial sectors (where the industries are served by public water suppliers).
  - Forecasts incorporate service area expansion, population density analysis, and disaggregation of customer types.
  - Negative net withdrawals in some watersheds (e.g., Fishing Creek) reflect return flows exceeding withdrawals due to regional wastewater treatment discharge patterns.
- **Direct Industrial Users:**
  - Net withdrawals are projected to decrease slightly, as many industries now receive water through public systems and return flows often exceed withdrawals.
  - Forecasts are informed by Gross State Product trends for each industry sector, with adjustments to avoid unrealistic declines.
  - The expanded Basin boundary adds several large industrial users, but overall demand remains stable due to efficiency improvements and economic shifts.

3.4.4 Planning Implications

The following bullets summarize key findings from the forecasting effort and highlight how the results will inform future planning:

- **Expanded Basin Coverage and Updated Energy Forecasts:** Including the additional watershed below Lake Wateree and revised Duke Energy projections significantly impacted net withdrawal estimates, adding new industrial and Agriculture and Industrial users while reducing TEP •Thermal-Electric Power demand by nearly 65 MGD compared to prior forecasts.
- **Recognizing Uncertainty in Future Conditions:** Historical fluctuations in water use highlight the need to account for variability. Probabilistic modeling provides a range of outcomes and supports more resilient planning.
- **Supporting Scenario Planning and System Updates:** While the 50th percentile forecast is recommended for long-range planning, the full forecast range is used to support scenario development, water supply model updates, and water quality evaluations.

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3.5 Assessment of Future Natural and Landscape Conditions on Basin Water Resources

Future water quantity and quality in the Basin will be driven by land use changes and daily climate variability. Land use refers to changes in the land surface, including both the cover and use characteristics, with impacts seen from new urban development replacing existing forests or agricultural lands. Climate change introduces shifts in daily temperature and precipitation.

The IWRP uses a modeling approach (introduced in Section 2.2 and detailed in Appendix A) that simulates these changes dynamically. Rather than applying fixed assumptions (such as a set rate in inflow reduction or evaporation increase per decade, as was done in the 2014 WSMP), the model responds to daily changes in temperature and precipitation with further variation in that response due to the variations in land use surrounding each reach of the river. This allows the model to capture how combined changes in land use affect inflows, evaporation, and surface loads of sediment and nutrients delivered to the streams and reservoirs. A key objective of this approach is to determine which combination of land use and/or climate factors causes the largest changes to the Basin by simulating different scenarios using the model.

3.5.1 IWRP Scenarios

The modeling effort creates a complete set of scenarios by combining various future land use and climate conditions. This strategic approach gives watershed managers a clear view of potential water quantity and quality challenges across a wide spectrum of futures.

3.5.1.1 FUTURE LAND USE

Future land use shows how urban development will change the landscape. These changes impact the water cycle by increasing the speed of stormwater runoff, reducing the amount of water that soaks into the ground, and increasing the likelihood of pollution (like sediment and nutrients) entering streams and reservoirs. This scenario is essential for helping planners anticipate and manage future issues related to water quality and flooding.

3.5.1.2 CLIMATE SCENARIOS

Four climate scenarios represent the extremes of projected air temperature and precipitation changes (See Section 3.3):

- **Hot/Dry Scenario:** Significantly higher air temperatures and significantly less rainfall creates the most severe water stress. The higher temperatures lead to greater evapotranspiration, while low rainfall creates the greatest challenge for water supply reliability and maintaining streamflow.
- **Hot/Wet Scenario**: Significantly higher air temperatures with more rainfall increases risk of infrastructure impacts and flooding as well as large pollutant loads entering streams and reservoirs through runoff and streambank erosion. Intense storms and high reservoir inflows demand planning for flash flooding, even as evapotranspiration remains elevated.

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- **Warm/Dry Scenario:** Warmer temperatures and reduced rainfall still pose major water stress. Increased evapotranspiration and lower streamflows reduce available water, though impacts may vary seasonally.
- **Warm/Wet Scenario:** Warmer temperatures with more rainfall mirror Hot/Wet risks on a smaller scale. Intense storms and elevated runoff challenge infrastructure, while evapotranspiration losses persist. Water quality concerns remain elevated during storm events.

3.5.1.3 COMBINATIONS OF LAND USE AND CLIMATE

The most realistic and complex implications for the Basin emerge when the changes in land use and climate happen together. By combining the expected land development growth with the extreme climate possibilities, the model generates the worst case scenario for future planning.

- **Future Land Use + Hot/Dry:** Combines severe water supply stress (high evapotranspiration and low rainfall) with the water quality implications caused by urban development and loss of regulating forest areas. The results inform long-term decisions about water storage and land management/conservation efforts.
- **Future Land Use + Warm/Wet:** Pairs increased pollutant load generation from developed lands with the wetter climate conditions that raise overall water volumes that in turn transport the increased loads through runoff, baseflow, and streamflow. The results inform long-term decisions on pollution control and managing peak flows.

3.5.2 Representation of Potential Future Critical Conditions

Recent extreme events provide a tangible reference point for understanding future climate scenarios. Table 3-5 compares two historic events, the 2007–2008 drought of record and the November 2020 storm event, to how they would appear under each bounding climate scenario. The example uses a representative point in the center of the Basin, located between Gastonia and Charlotte along the mainstem of the Catawba River, just upstream from Lake Wylie.

As shown in Table 3-5, the four future scenarios significantly reshape the historic 2007-2008 drought event, both in terms of the total precipitation as well as the maximum temperature reached during that event. In the Wet scenarios, the total precipitation increases by 8.0 inches, easing drought conditions. In contrast, the Dry scenarios exacerbate the drought conditions, reducing rainfall by an additional 5.4 inches. Figure 3-10 illustrates these daily trends across scenarios. Across the future scenarios, maximum temperature saw a clear increase relative to the Baseline of 90.5°F, rising by approximately 6.3°F in the Warm scenarios (Max Temp = 96.8°F) and by approximately 7.3°F in the more intense Hot scenarios (Max Temp = 97.8°F). This temperature change is independent of the precipitation scenario, reflecting the high confidence in regional warming.

For the November 2020 storm event, which brought 10 inches of rainfall to the central portions of the Basin, future scenarios alter rainfall totals by approximately an inch in each direction: 9.2 inches under Dry scenarios and 11.2 inches under Wet scenarios. Given the extended duration of this storm event, runoff impacts depend not only on surface conditions but also on subsurface saturation, which likely exceeded capacity after prolonged rainfall.

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Table 3-5. Comparison of Recent Past Critical Periods with Future Projected Representations

			Climate Scenarios			
	Metric	**Baseline**	**Hot/ Dry**	**Hot/ Wet**	**Warm/ Dry**	**Warm/Wet**
2007 – 2008 Drought[1]	Total Precipitation (cm)	75.6	70.2	83. 6	70.2	83.6
	Peak temperature (°F)	90.5	97.8	97.8	96.8	96.8
Nov 10-17, 2020 Storm Event	Total Precipitation (cm)	10.0	9.2	11.2	9.2	11.2

[1]May 2007 through April 2008

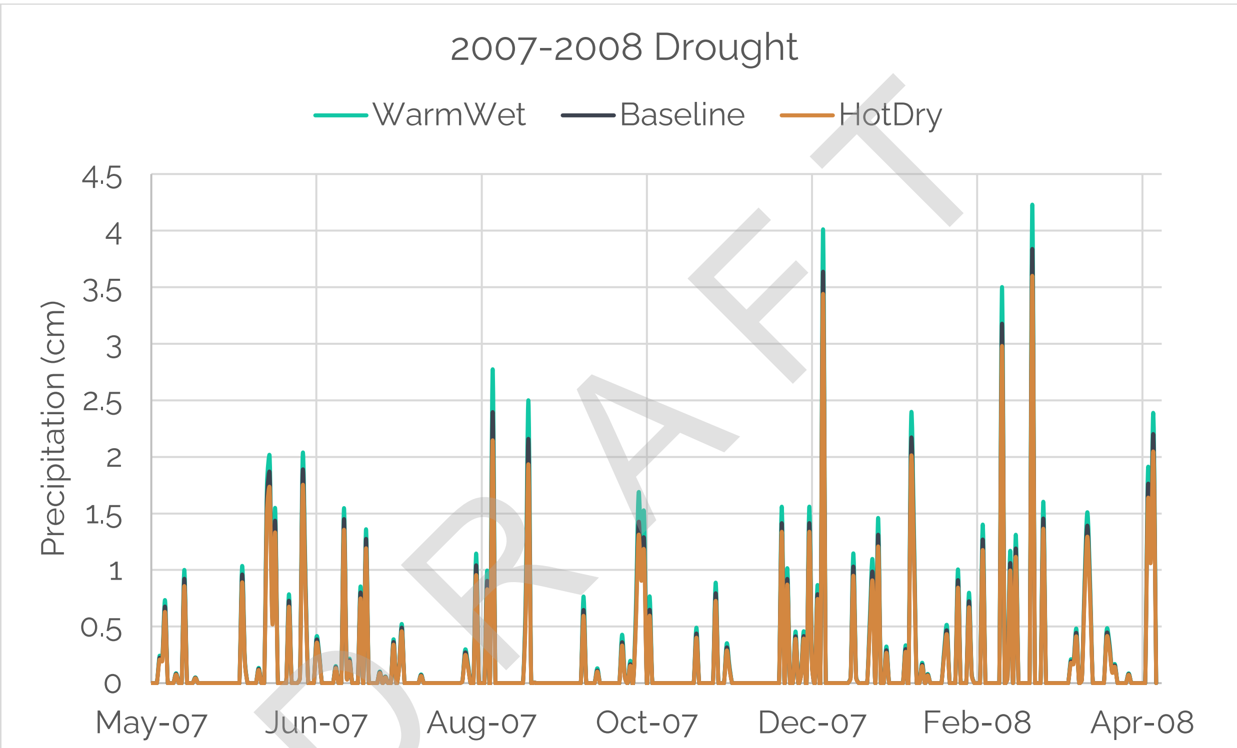

Figure 3-10. Daily Precipitation During the May 2007 through April 2008 Drought Period by Scenario

These events illustrate only one dimension of the forces shaping water quantity and quality throughout the Basin. By highlighting the changes during these specific periods, the IWRP analysis assesses major climate-driven vulnerabilities, factors beyond direct control, and allows for the evaluation of strategies to reduce such impacts. This includes exploring land management approaches such as targeted conservation measures and adaptive working-land practices to strengthen resilience.

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Surface Water Quantity & Availability

Section 4

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4 Surface Water Quantity & Availability

4.1 Introduction

Managing surface water quantity and availability is central to ensuring long-term water supply reliability. This section evaluates how streamflow, runoff, and reservoir inflows respond to changes in land use, climate, and water demands using the WaterFALL and CHEOPS models introduced in Section 2. The analysis compares current conditions with future scenarios to understand where risks may emerge and what issues should be addressed to help maintain resilience within the Basin.

Rather than focusing solely on technical outputs, this section highlights what the results mean for planning: where flooding risks may increase, where low-flow conditions could challenge supply, and how reservoir performance may change under different scenarios. These insights inform decisions about infrastructure, drought management, and regional coordination, and are critical for adapting to a changing future.

In addition to tributary analysis, the evaluation includes reservoir water yield modeling to assess system performance under varying conditions and interbasin transfer (IBT) review to understand how water movement across basins influences availability. Together, these components provide a comprehensive view of surface water quantity and its implications for long-term planning.

4.2 Tributary Water Quantity Analysis

Surface water quantity varies widely across the Basin, influenced by land use, climate, and physical characteristics. To understand these dynamics, daily hydrologic processes were simulated for more than 7,000 catchments over a 38-year period (1982–2020) using the WaterFALL model. Using long-term records, this model provides a robust baseline for comparing current conditions with future scenarios that incorporate land use change and climate variability.

For assessment of current versus future conditions, the analysis focused on the most recent 20 year period (2001–2020) as input for current land use/land cover. The model dynamically simulates changes in the hydrologic cycle for each day of the selected assessment period, capturing how future drivers (land use and climate) affect streamflow and runoff patterns. A detailed explanation of the WaterFALL model and calibration approach is provided in Appendix A.

Figure 4-1 illustrates the subbasin-level depiction used in this analysis under current and projected future conditions.

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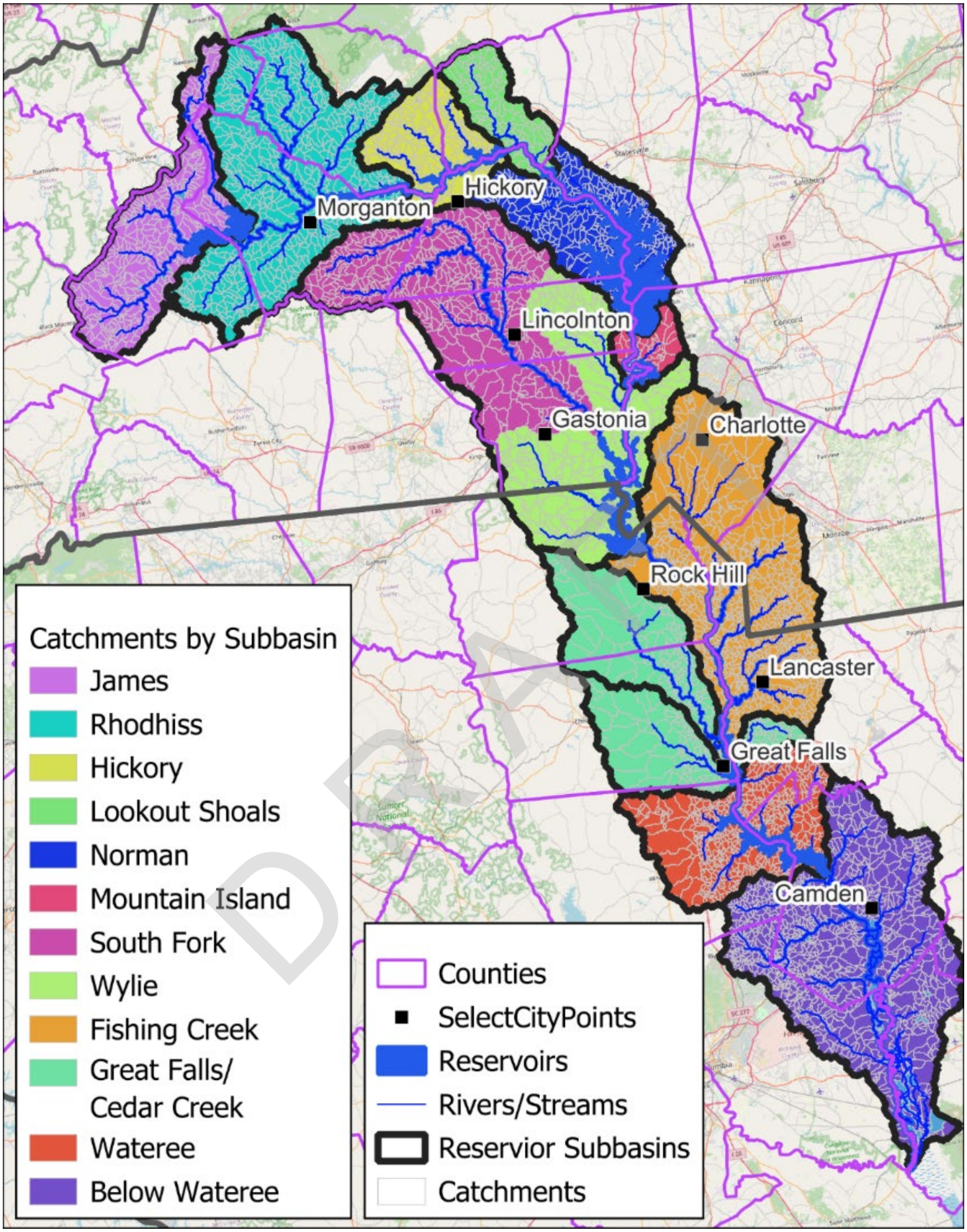

Figure 4-1. Catchment level depiction of the Catawba-Wateree Basin

Hydrologic metrics were calculated from streamflow time series following established methods (Olden and Poff 2003; Henriksen et al. 2006). These metrics summarize the hydrologic regime across five key components: magnitude, frequency, duration, timing, and rate of change. They distill complex time series into values that can be compared across scenarios and scales, making them useful for planning, regulatory compliance, and ecological assessments.

Table 4-1 lists the metrics applied to describe flow regimes for individual catchments, tributaries, and reservoir inflows under baseline and projected conditions. These include mean annual runoff, peak daily runoff, low-flow duration, flooding potential, reservoir inflows, and LIP triggers. Examining these metrics across scenarios highlights critical concerns such as localized flooding, extended drought periods, and reservoir performance, and informs strategies to mitigate potential climate-driven water quantity challenges.

To support interpretation of these hydrologic metrics, several terms are defined:

- **Tributaries:** Streams that flow into the mainstem of the Basin between reservoirs or directly into reservoirs.
- **High flows:** Days when streamflow exceeds the 75th percentile of the long-term daily record.
- **Peak flows:** Days when streamflow exceeds the 90th percentile of the long-term daily record.
- **Low-flow events:** Consecutive days when streamflow falls below the 25th percentile of the long-term daily record.

Table 4-1. Hydrologic metrics selected to describe the flow regime across the Basin and scenarios

Metric	Definition	Units	Scale	Metric Interpretation
Mean annual total runoff	Annual runoff divided by the catchment area	in/acre	Catchment	Higher runoff signifies increasing risk of localized pluvial flooding beyond current infrastructure abilities.
Peak daily runoff	90th percentile of daily long-term runoff	in/acre	Catchment	Quantifies runoff from major storms which may be manageable through nature-based measures.
Average duration of low flow	Average number of consecutive days of streamflow below 25th percentile of long-term daily flow each year	weeks/year	Catchment	Longer low flow periods increase risk of water shortages and ecological stress.
Flooding Potential	Count of days above 75th and 90th percentile thresholds across the assessment period	days/year	Tributary	More high and/or peak flows increase risk of riverine (i.e., fluvial) flooding.

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Metric	Definition	Units	Scale	Metric Interpretation
Reservoir Inflows	The total inflow to each reservoir including upstream tributaries to the Catawba River	Million gallons/year	Reservoir	Reductions in inflows affect the ability to meet water demands and lead to potential water quality concerns.
Low Inflow Protocol Trigger	Days when 6-month rolling streamflow average is <85% of long-term gaged streamflow.	days/year	Gage locations	More days below threshold suggests higher likelihood of triggering LIP Stage 0.

The following sections step through each metric, describing current conditions and expected changes due to land use and climate scenarios, as well as combined effects.

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4.2.1 Runoff Patterns and Scenario Impacts

Mean annual runoff represents the total runoff reaching the local stream reaches over daily storm events within a year. To allow direct comparisons across the catchments, the total annual runoff (in inches) for each catchment is divided by its area to calculate a unit rate of runoff. This normalization enables comparison between catchments, even though runoff contributions within a catchment vary based on land cover (e.g., impervious versus pervious surface).

Current conditions show wide variability in runoff rates across the Basin. Concentrated areas of high runoff occur in the mountainous headwaters (Figure 4-2, left), where steep slopes and poorly draining soil conditions drive higher runoff despite predominantly natural land cover. Other areas of high runoff rates are located within the central Basin, where highly urbanized lands with predominately impervious surfaces dominate. These localized areas of existing high runoff can be targeted for immediate management action through restoration or green infrastructure to improve land cover and drainage.

Under the **Future Land Use scenario,** runoff is expected to increase due to expanded impervious surfaces in metropolitan areas of the central Basin (Figure 4-2, right). Increased density of urbanization will exacerbate localized runoff issues, with multiple *hot spots* evident. Development along the I-40 corridor in the upper Basin and along US-1 corridor in the lower Basin provides opportunities for land use management within specific catchments.

RUNOFF HIGHLIGHTS

Surface runoff varies, with high rates in mountainous headwaters and urbanized areas. The Future Land Use scenario increases localized *hot spots,* while Wet climate scenarios amplify runoff volumes and Dry climate scenarios reduce runoff overall.

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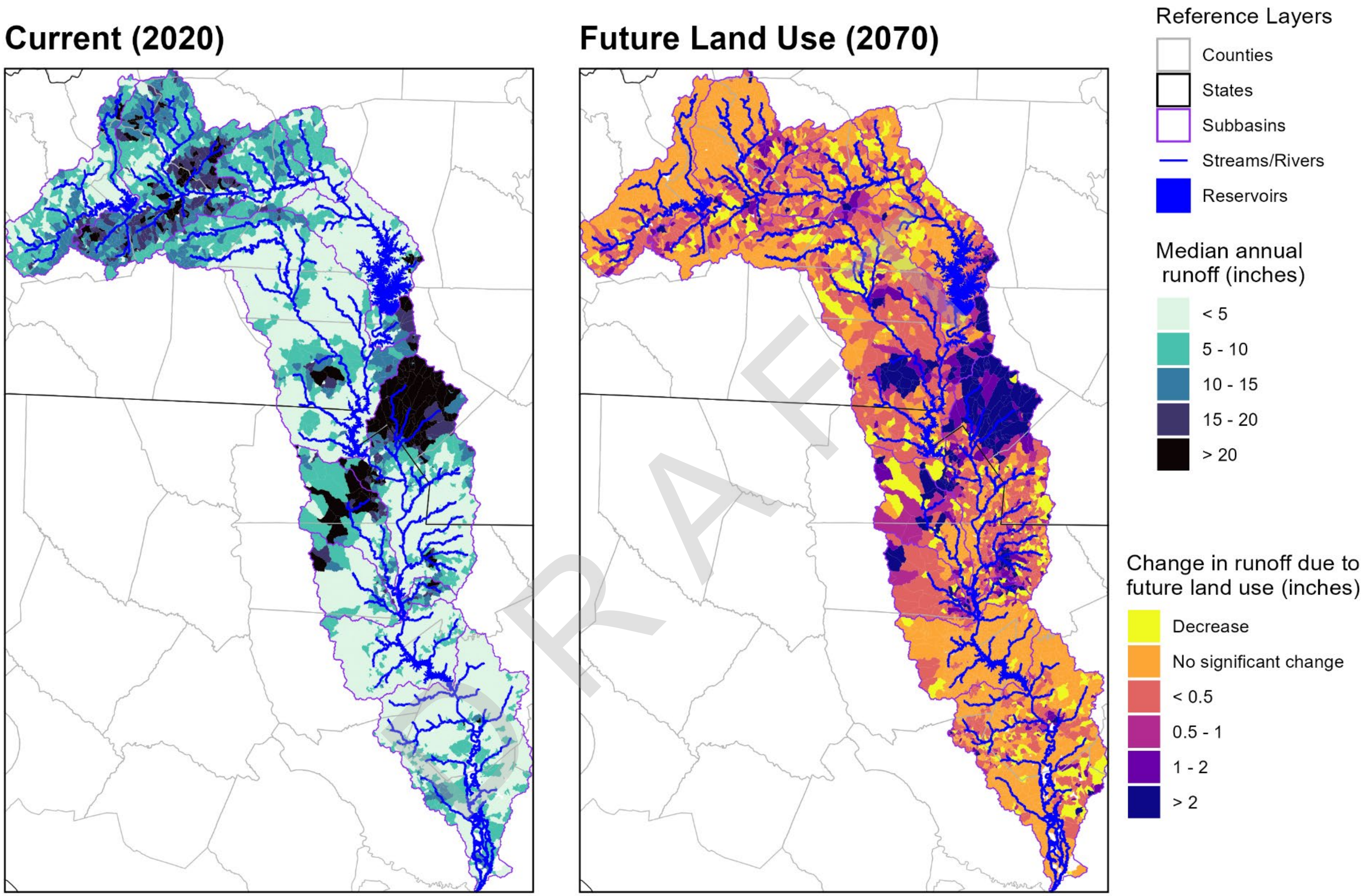

Figure 4-2. Median annual runoff by catchment for current (left) and future (right) land use.

Comparing across subbasins, Fishing Creek (791 square miles) contributes the greatest volume of runoff (in million gallons per year or MGY) on average to the flowing waters of the Basin, as detailed in Table 4-2. This is driven by both its size and altered land use. Rhodhiss (704 square miles) and Great Falls/Cedar Creek subbasins (543 square miles) contribute the second and third most runoff, respectively, although both subbasins supply less runoff per square mile than Fishing Creek.

Future conditions indicate minimal increases in mean annual total runoff under the Future Land Use scenario,, substantial increases under Wet climate scenarios, and notable decreases under Dry climate scenarios. The largest increases associated with Future Land Use occur in the southern subbasins (Wylie, Fishing Creek, and Great Falls/Cedar Creek). When combined with Wet climate conditions, these subbasins experience significant increases in runoff volume compared to either factor alone, while northern and central subbasins show only slight increases.

Table 4-2. Median Annual Runoff (MGY) per Subbasin by Scenario

Subbasin	Current Scenario	Future Land Use	Hot/ Dry	Hot/ Wet	Warm/ Dry	Warm/ Wet	Future Land Use & Hot/Dry	Future Land Use & Warm/ Wet
James	43,991	44,390	33,947	64,962	33,875	64,831	34,275	65,335
Rhodhiss	146,327	148,460	117,032	205,111	117,002	205,012	118,863	207,738
Hickory	25,069	25,650	21,272	37,959	21,270	37,958	21,805	38,806
Lookout Shoals	13,109	13,198	10,713	19,360	10,713	19,359	10,788	19,499
Norman	18,419	19,342	15,108	28,021	15,104	28,007	15,894	29,123
Mountain Island	11,317	12,445	9,756	15,814	9,754	15,812	10,751	17,183
South Fork	62,174	64,554	50,294	93,147	50,263	93,077	52,371	96,299
Wylie	51,129	58,131	41,555	71,989	41,545	71,977	47,681	80,694
Fishing Creek	179,841	199,801	150,241	232,384	150,205	232,277	167,905	256,323
Great Falls/ Cedar Creek	85,742	91,455	68,512	115,947	68,464	115,897	73,366	123,171
Wateree	16,792	16,833	12,002	25,306	12,002	25,307	12,028	25,363
Below Wateree	51,108	52,202	38,019	74,284	38,019	74,285	38,881	75,777

To further evaluate localized flooding concerns, maximum daily runoff within each catchment was considered across each subbasin (Appendix E, Table E-1). This metric normalizes runoff depth by area, allowing direct comparisons of runoff during peak storm events across subbasins. The most pronounced changes in daily maximum runoff due to Future Land Use occur in the South Fork subbasin. Wet scenarios, regardless of temperature shift or inclusion of Future Land Use, produce the largest increases in daily maximum runoff. While these unit rates

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enable comparison across subbasins and scenarios for the most extreme storm events, they do not fully capture the volumetric impacts because the subbasins vary in size.

4.2.2 Low Flow Conditions and Event Durations

Low flow stream conditions can affect aquatic organisms and habitat and can potentially limit water availability for uses such as recreation, water supply, and power generation. Current conditions indicate that tributaries in Fishing Creek (southern portion of the subbasin), Great Falls / Cedar Creek, and Wateree are especially vulnerable to extended low-flow periods (Figure 4-3, left). Isolated tributaries in the Wylie subbasin outside the South Fork tributary also show elevated risk. These patterns reflect a combination of physical and human factors including land use, soils, and topography, rather than a single, dominant driver.

In the Future Land Use scenario, the duration of low flow events is projected to increase in many areas over the next 20 years. Figure 4-3 (right) highlights the catchments where these changes occur. Duration changes were categorized as

- **Minor increases:** less than two additional days per event
- **Increases:** at least two but less than three additional days per event
- **Significant increases:** three or more additional days per event

While no area is expected to experience a significant increase, both northern and southern sections of the Basin are expected to experience consistent minor extensions of low-flow periods. The South Fork subbasin shows the greatest geographic likelihood of extended low-flow durations, while southern portions of Fishing Creek subbasin also exhibit notable increases.

LOW FLOW CONDITIONS HIGHLIGHTS

Extended low-flow periods occur in several subbasins and are projected to lengthen under Dry climate scenarios.

Future Land Use changes also contribute to longer durations in some subbasins.

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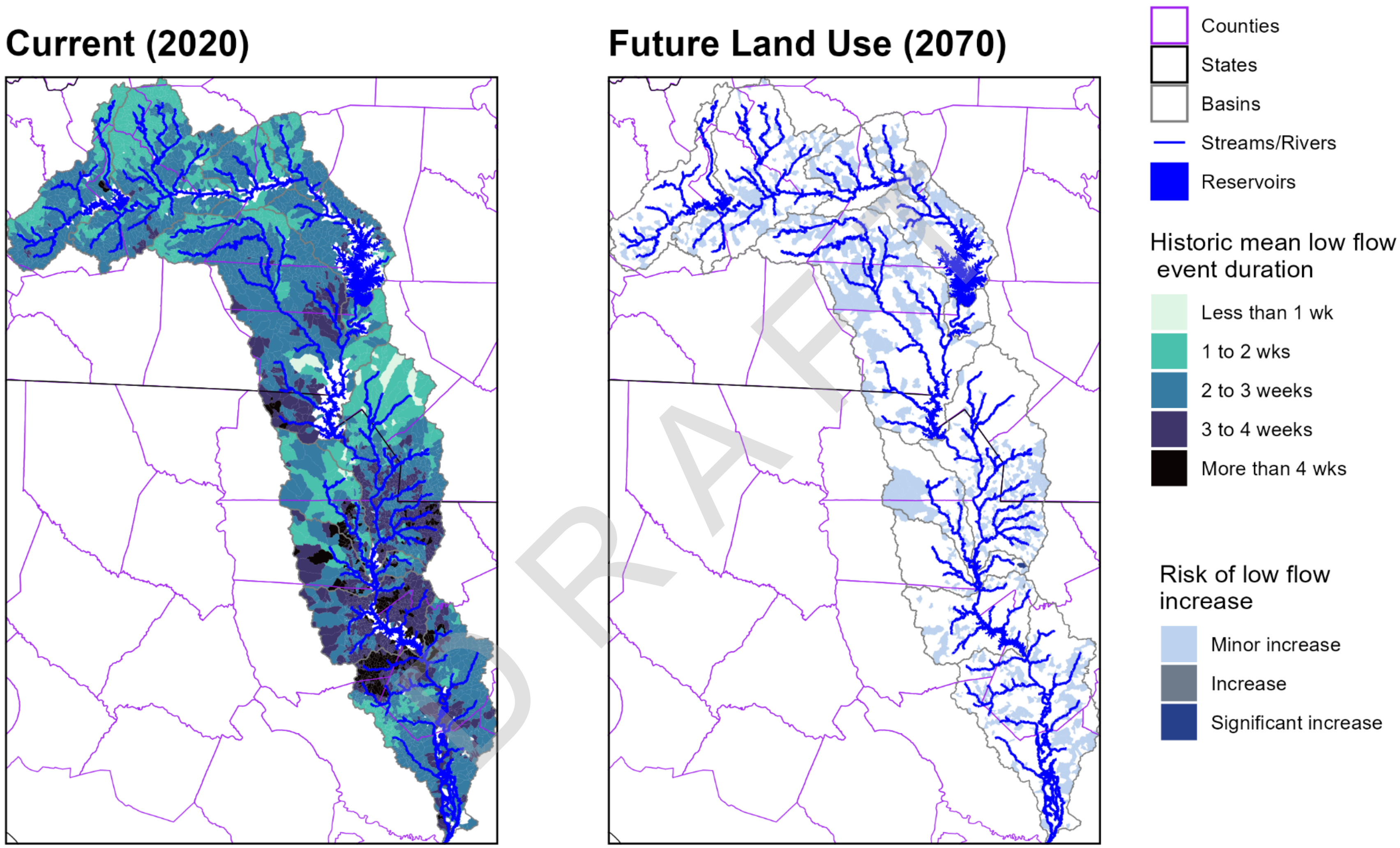

Figure 4-3. Average duration of low flow events by subbasin for current (left) and future (right) land use.

Analysis of future scenarios indicates that the length of streams experiencing increased low-flow durations varies across subbasins, with changes driven by land use and climate conditions. Detailed subbasin-level results, including stream length changes under each scenario, are provided in Appendix E (Table E-2). Highlights from the analysis include:

- **Future Land Use Scenario:** Increases low-flow durations across all subbasins, but only the lower subbasins (Great Falls/Cedar Creek through Below Wateree) show low-flow duration increases of two or more days.
- **Dry Climate Scenarios (Hot/Dry, Warm/Dry):** Produces the greatest increases in both severity and affected stream length throughout the Basin. Differences between Hot/Dry and Warm/Dry scenarios are modest, but the hotter temperatures generally lead to greater impacts with more stream reaches experiencing increases in low-flow duration of more than three days.
- **Wet Climate Scenarios (Hot/Wet, Warm/Wet):** Even with overall higher rainfall, Wet scenarios still lengthen low-flow durations. Most impacts are minor, with moderate increases mainly in northern subbasins such as James and Rhodhiss. These changes likely reflect higher evapotranspiration rates during dry periods in areas with natural vegetative cover, even under wetter climates. Warm/Wet generally shows slightly less impact than Hot/Wet in terms of both length of reaches impacts and severity of low-flow duration increase.
- **Combined Scenarios (Future Land Use + Hot/Dry or Warm/Wet):** Adding Future Land Use to the Hot/Dry scenario generally reduces the severity of the duration increases and, in over half the subbasins, decreases the overall length of stream impacted. Adding Future Land Use to Warm/Wet makes only minor differences compared to Warm/Wet alone, with slight increases in length of streams impacted for Lookout Shoals, Great Falls/Cedar Creek, and Wateree. In the remaining subbasins, combined scenarios reduce overall stream lengths with increased low-flow durations compared to climate-only scenarios, likely because altered land uses allow small storms to generate runoff and break low-flow periods.

4.2.3 Flooding Potential Under Future Conditions

The potential for flooding is assessed by counting the increase in the number of high-flow and peak-flow days within Basin tributaries. These metrics characterize the potential riverine (fluvial) flood conditions for stream reaches flowing through tributary outlets to the mainstem and reservoirs. High and peak flows are evaluated separately (a single day can only be classified as one or the other) and peak flows represent the more extreme condition. Any tributary with increased peak flows also shows increased high flows. Therefore, the two metrics should be considered together, as shown on Figure 4-4 for the Future Land Use scenario. Tributaries with no increase in high flows but an increase in peak flows indicate that flood potential is driven by changes in peak levels.

Under the Future Land Use scenario, the likelihood of riverine flooding (peak flow days) increases sporadically in the larger tributaries of the northern Basin, some tributaries of the South Fork and Lake Norman, and most tributaries Below Wateree. In the central Basin

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(Mountain Island, South Fork, Fishing Creek, and Great Falls/Cedar Creek) the peak flow risk increases even more. Similarly, high flow events become more frequent throughout the central and southern Basin, with limited tributary increases in the northern Basin. While some high flows do not reach peak levels, their timing can still create significant impacts if they occur consecutively or over extended periods.

FLOODING POTENTIAL HIGHLIGHTS

Future Land Use and Wet climate scenarios increase the frequency of high-flow and peak-flow events, particularly in central and southern subbasins, raising flood risk.

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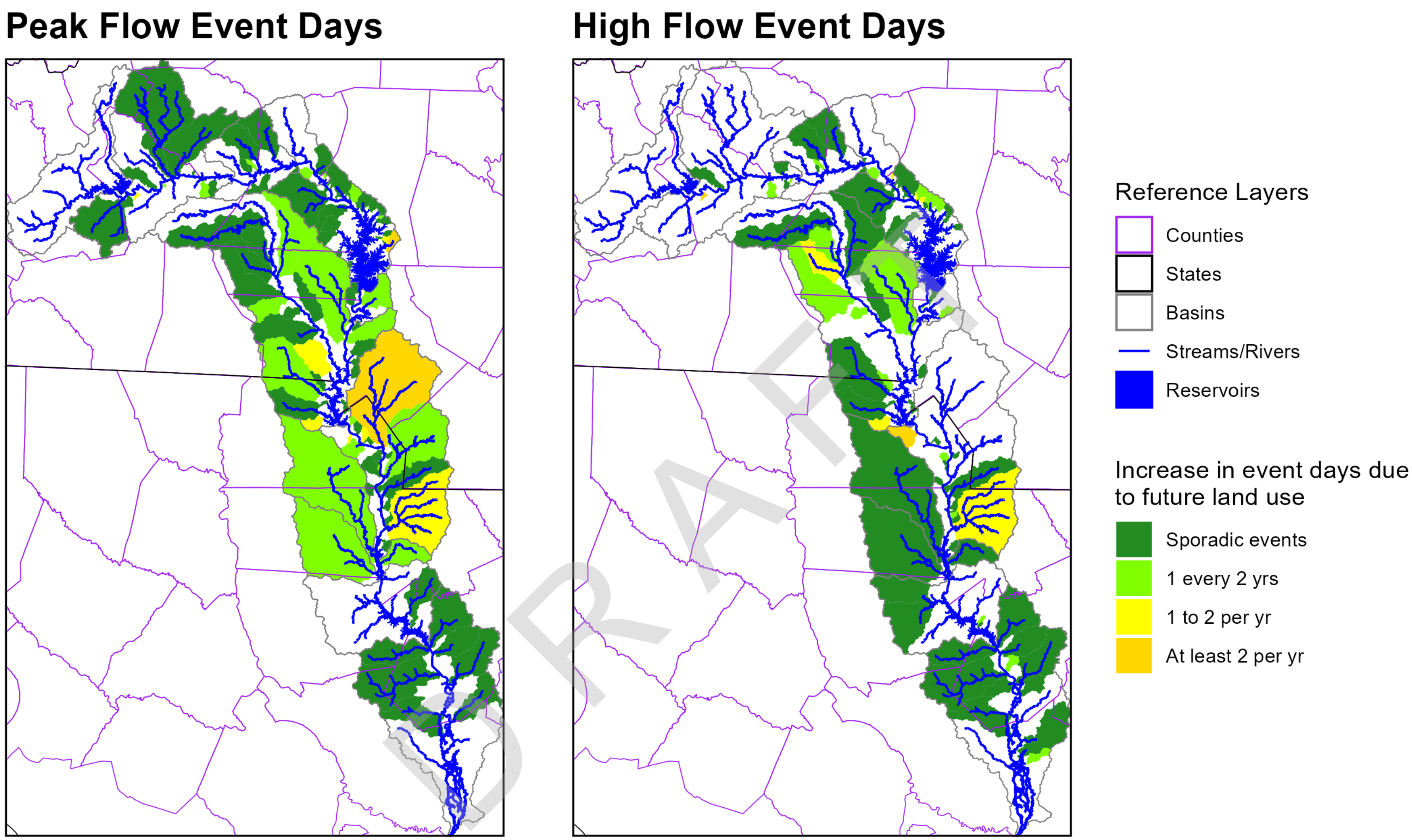

Figure 4-4. Increase in flooding potential under the future land use (2070) for peak flow (left) and high flow (right).

Climate projections reinforce these findings. Dry scenarios show no increase in peak flows, even when combined with Future Land Use. In contrast, Wet scenarios produce widespread increases in peak flows across the largest tributaries (drainage area greater than 15 square miles), as summarized in Table 4-3. Under Wet projected climates, nearly all the major tributaries experience the highest risk category, with more than two additional peak flow events per year on average. Only in the southern Basin under the Hot/Wet climate are the impacts somewhat reduced for selected tributaries within Great Falls/Cedar Creek, Wateree, and Below Wateree subbasins.

Table 4-3. Increase in Days with Flood Risks by Major Tributary within a Subbasin by Scenario

Subbasin	Tributary	Future Land Use	Warm/Wet	Hot/Wet	Future Land Use & Warm/Wet
James	Catawba River	None	> 2/yr	> 2/yr	> 2/yr
	North Fork Catawba River				
	Linville River				
Rhodhiss	Johns River	Sporadic	> 2/yr	> 2/yr	> 2/yr
	Muddy Creek				
	Lower Creek				
	Warrior Fork	None	> 2/yr	> 2/yr	> 2/yr
	Silver Creek				
	Hunting Creek				
	Canoe Creek	Sporadic	> 2/yr	> 2/yr	> 2/yr
Hickory	Middle Little River	Sporadic	> 2/yr	> 2/yr	> 2/yr
	Upper Little River				
	Gunpowder Creek	None	> 2/yr	> 2/yr	> 2/yr
	Drowning Creek				
Lookout Shoals	Lower Little River	None	> 2/yr	> 2/yr	> 2/yr
	Elk Shoals Creek	Sporadic	> 2/yr	> 2/yr	> 2/yr
Norman	Lyle Creek	Sporadic	> 2/yr	> 2/yr	> 2/yr
	Buffalo Shoals Creek				
	Balls Creek				
Mountain Island	McDowell Creek	1 every 2 yrs	> 2/yr	> 2/yr	> 2/yr
South Fork	Henry Fork	None	> 2/yr	> 2/yr	> 2/yr
	Jacob Fork	Sporadic	> 2/yr	> 2/yr	> 2/yr
	Clark Creek	1 every 2 yrs	> 2/yr	> 2/yr	> 2/yr

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Subbasin	Tributary	Future Land Use	Warm/Wet	Hot/Wet	Future Land Use & Warm/Wet
	Indian Creek	Sporadic	> 2/yr	> 2/yr	> 2/yr
	Little Long Creek				
	Howards Creek				
	Hoyle Creek				
	Pott Creek				
	Beaverdam Creek	1 every 2 yrs	> 2/yr	> 2/yr	> 2/yr
Wylie	Dutchmans Creek	1 every 2 yrs	> 2/yr	> 2/yr	> 2/yr
	Crowders Creek				
	Allison Creek	Sporadic	> 2/yr	> 2/yr	> 2/yr
	Long Creek	1 every 2 yrs	> 2/yr	> 2/yr	> 2/yr
	Catawba Creek	1 - 2/yr	> 2/yr	> 2/yr	> 2/yr
Fishing Creek	Sugar Creek	> 2/yr	> 2/yr	> 2/yr	> 2/yr
	Cane Creek	1 - 2/yr	> 2/yr	> 2/yr	> 2/yr
	Twelvemile Creek	1 every 2 yrs	> 2/yr	> 2/yr	> 2/yr
	Waxhaw Creek	Sporadic	> 2/yr	> 2/yr	> 2/yr
	Big Dutchman Creek	None	> 2/yr	> 2/yr	> 2/yr
Great Falls/Cedar Creek	Fishing Creek	1 every 2 yrs	> 2/yr	> 2/yr	> 2/yr
	Rocky Creek				
	Camp Creek	1 every 2 yrs	> 2/yr	1 every 2 yrs	> 2/yr
Wateree	Little Wateree Creek	None	> 2/yr	1 - 2/yr	> 2/yr
	Big Wateree Creek	None	> 2/yr	> 2/yr	> 2/yr
	Beaver Creek	Sporadic	> 2/yr	1/2 yrs	> 2/yr
	Dutchmans Creek	None	> 2/yr	1/2 yrs	> 2/yr
	Cedar Creek	None	> 2/yr	> 2/yr	> 2/yr
	Singleton Creek				
	White Oak Creek	None	> 2/yr	1 - 2/yr	> 2/yr
Below Wateree	Twentyfive Mile Creek	Sporadic	> 2/yr	> 2/yr	> 2/yr
	Grannies Quarter Creek				
	Colonels Creek	None	> 2/yr	1 - 2/yr	> 2/yr
	Big Pine Tree Creek	Sporadic	> 2/yr	> 2/yr	> 2/yr

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Subbasin	Tributary	Future Land Use	Warm/Wet	Hot/Wet	Future Land Use & Warm/Wet
	Spears Creek				
	Sawneys Creek				
	Rafting Creek	None	> 2/yr	1 every 2 yrs	> 2/yr
	Swift Creek	Sporadic	> 2/yr	Sporadic	> 2/yr
	Sanders Creek	Sporadic	> 2/yr	> 2/yr	> 2/yr
	Gum Swamp Branch	None	> 2/yr	None	> 2/yr
	Gillies Creek	None	> 2/yr	> 2/yr	> 2/yr
	Town Creek	None	> 2/yr	None	1 - 2/yr

Note: Tributaries are listed in descending order by drainage area for each subbasin

4.2.4 Reservoir Inflows Variability

Reservoir inflows were compiled from the WaterFALL model scenarios. These modeled daily flows provide inputs for the CHEOPS operations model that include hydrologic variability across the system. WaterFALL simulates rainfall-runoff processes and routes the flows through the upstream network, creating continuous inflow records that consider variations in precipitation and watershed characteristics impacting each reservoir.

Total inflow is represented by four components:

- **Tributary streamflow** routed through National Hydrography Dataset (NHD) catchments and entering either the mainstem of the river upstream of the reservoir or directly to the reservoir itself.
- **Direct reservoir precipitation** from rainfall that occurs over the reservoir surfaces.
- **Direct runoff** from the land area surrounding either the mainstem of the river upstream of the reservoir or the reservoir pool itself.
- **Mainstem inflows** (i.e., the volume released from the upstream reservoir) are not included in the compiled WaterFALL inputs, rather this volume is taken from the upstream CHEOPS operations model and added to the daily compiled tributary streamflow and runoff volumes from WaterFALL.

Figure 4-5 illustrates how these elements combine to represent the full watershed contributions to each reservoir. Together, they capture both basin-scale inputs and localized storm-driven responses.

RESERVOIR INFLOWS HIGHLIGHTS

Reservoir inflows are highly sensitive to future climate and land use conditions. Warm/Wet scenarios produce the highest inflow volumes, while the Hot/Dry scenarios yield the lowest. Larger upstream reservoirs show the greatest variability between scenarios, underscoring the need to plan for both wetter and drier futures relative to current conditions.

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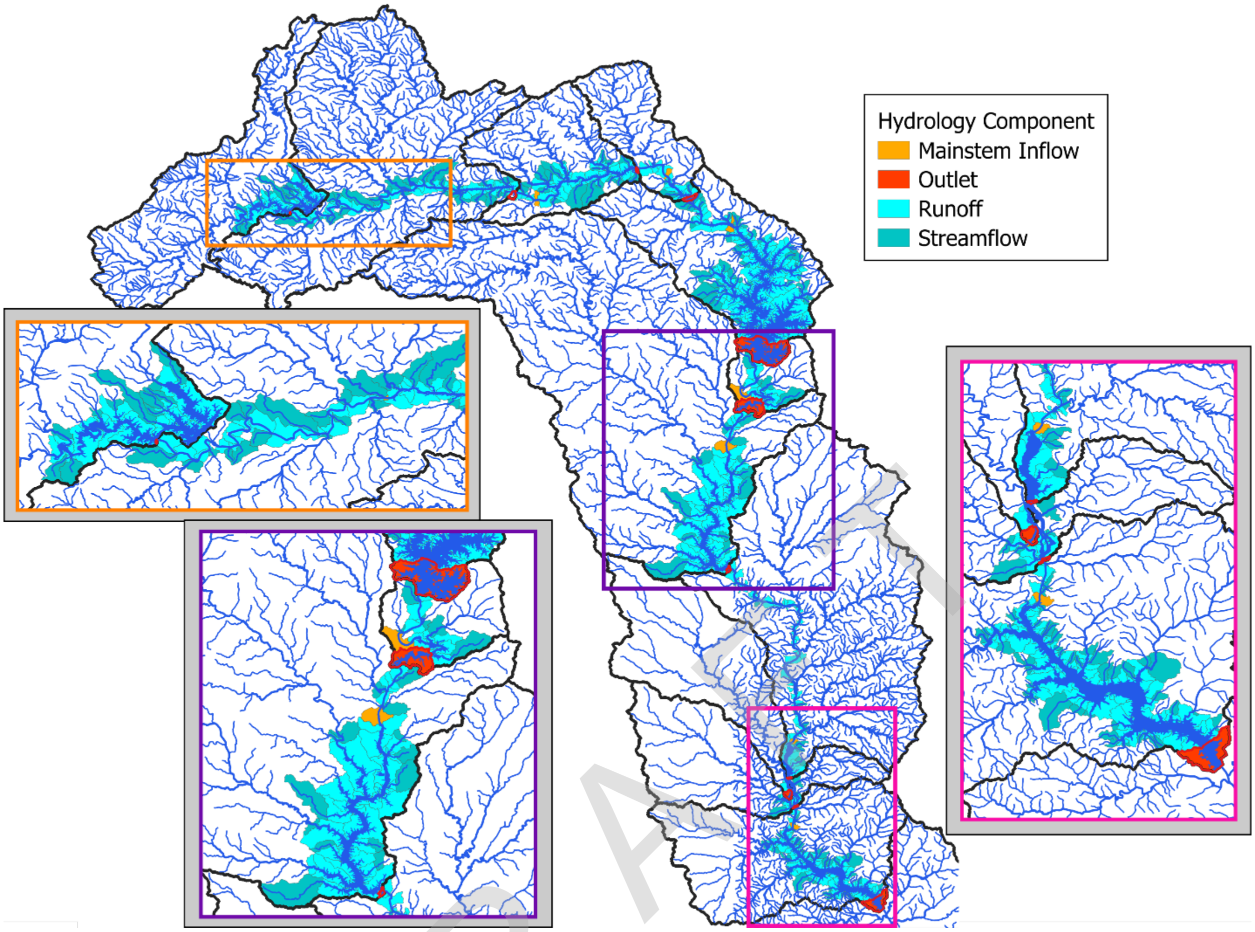

Figure 4-5. Modeled hydrologic components contributing inflow to Catawba Basin reservoirs, including mainstem inflow, tributary inflow (streamflow), and adjacent runoff, as simulated by the WaterFALL model.

Bar charts display the annual inflow volume (in MGY) for each reservoir in the Basin across the simulation period, illustrating the hydrologic variability under three distinct scenarios: Current, Future Land Use with Warm/Wet Climate, and Future Land Use with Hot/Dry Climate. These grouped bar charts illustrate how projected inflows vary by scenario and year as shown for Lake Wylie on Figure 4-6 and presented in Appendix E (Figures E-1 through E-10) for all reservoirs. Each bar for a given year represents the total inflow, with the scenarios layered to show their respective magnitudes.

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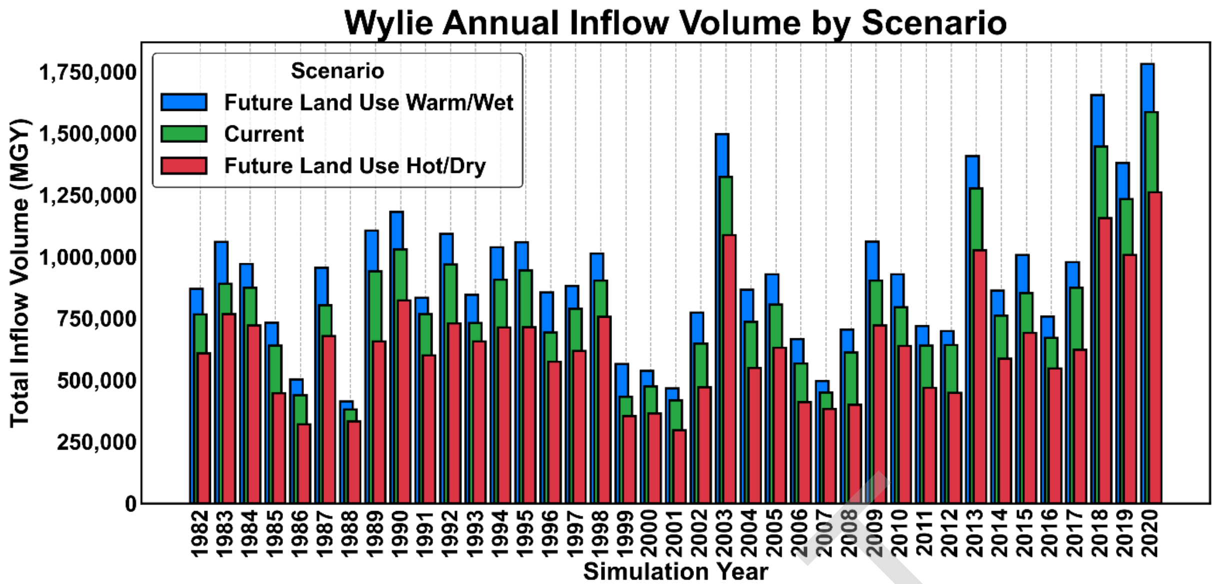

Figure 4-6. Lake Wylie Annual Inflow Volume.

Across nearly all reservoirs, a consistent scenario-driven pattern emerges. The Future Land Use Warm/Wet scenario generally produces the highest annual inflow volumes, exceeding both the Current and Hot/Dry projections. This suggests that a warmer but wetter future could lead to substantially greater water availability. Conversely, the Future Land Use Hot/Dry scenario typically yields the lowest annual inflows, indicating reduced water availability and greater susceptibility to low-flow conditions relative to the Current scenario. The magnitude of these differences varies by reservoir scale and location. Larger upstream reservoirs such as Rhodhiss and Hickory show the greatest spread, with inflows in wet years under Warm/Wet conditions nearly 50 percent higher than Hot/Dry projections. Smaller downstream reservoirs exhibit similar patterns but with proportionally smaller differences.

Overall, the analysis confirms a high degree of uncertainty in future water availability driven by climate variability. Planning must account for both significantly wetter and substantially drier annual conditions than the Current baseline.

4.2.5 LIP Streamflow Trigger Analysis

The LIP for the Catawba-Wateree River Basin uses three trigger points to define drought conditions, ranging from Stage 0 (drought watch) to Stage 4 (extreme drought). One of these trigger points is based on monitored USGS streamflow gages, which serve as indicators of the water flowing into the reservoir system (Table 4-4).

The streamflow trigger relies on measurements from four key USGS streamflow gages:

- #02145000: South Fork Catawba River at Lowell, NC
- #02137727: Catawba River near Pleasant Gardens, NC
- #02140991: Johns River at Arney's Store, NC

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- #02147500: Rocky Creek at Great Falls, SC

To assess the streamflow trigger, a rolling six-month average streamflow is calculated for each day of the period of record (baseline) for the catchment corresponding to each USGS gage. This establishes the long-term (LT) average for a specific day of the year. The analysis uses the last 20 years of daily records simulated by the model. For any given simulation day under a scenario, the actual flow is compared against a predetermined percentage of this baseline average. For example:

- **Stage 0 (drought watch):** streamflow ≤ 85% of LT six-month average
- **Stage 4 (extreme drought):** streamflow ≤ 40% of LT six-month average

The complete set of streamflow thresholds for all LIP stages is detailed in Table 4-4. The number of days when streamflow falls below the threshold (e.g., 0.85 x LT six-month average for the baseline average) is counted for each scenario.

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Table 4-4. Summary of LIP Trigger Points

Stage	Storage Index[1]		Drought Monitor[2] (3-month average)		Monitored USGS[3] Streamflow Gages
0[4]	90% < SI ≤ 100% TSI	—	3mo Avg DM = 0	—	AVG ≤ 85% LT 6mo Avg
1	75% TSI < SI ≤ 90% TSI	and	3mo Avg DM ≥ 1	or	AVG ≤ 78% LT 6mo Avg
2	57% TSI < SI ≤ 75% TSI	and	3mo Avg DM ≥ 2	or	AVG ≤ 65% LT 6mo Avg
3	42% TSI < SI ≤ 57% TSI	and	3mo Avg DM ≥ 3	or	AVG ≤ 55% LT 6mo Avg
4	SI ≤ 42% TSI	and	3mo Avg DM = 4	or	AVG ≤ 40% LT 6mo Avg

[1] The Storage Index is the ratio of Remaining Usable Storage (RUS) to Total Usable Storage (TUS) at a given point in time. The TSI is the Storage Index when all project reservoirs are at Target elevation.
[2] DM = The three-month numeric average of the published U.S. Drought Monitor.
[3] The sum of the rolling six-month average for the Monitored USGS Streamflow Gages as a percentage of the period of record (i.e., long-term [LT]) rolling average for the same six-month period for the Monitored USGS Streamflow Gages.
[4] Stage 0 is triggered when any two of the three trigger points are reached.

Even under wet climate conditions, years with severe low-flow events remain possible, indicating continued vulnerability to drought.

Figure 4-7 illustrates the average daily magnitude (with standard deviation) of the streamflow thresholds for Stage 0 (i.e., 85 x LT six-month average for the Current scenario) by month at these four monitoring locations. Seasonal flow patterns emerge across stream gages. For example, the USGS South Fork Catawba River at Lowell stream gage shows the highest magnitude of flow and a distinct peak during late spring (April-June), while the flows at the Catawba River near Pleasant Gardens gage remain relatively lower and more stable throughout the year. These monthly averages and standard deviations form the basis for calculating LT baseline used in LIP triggers.

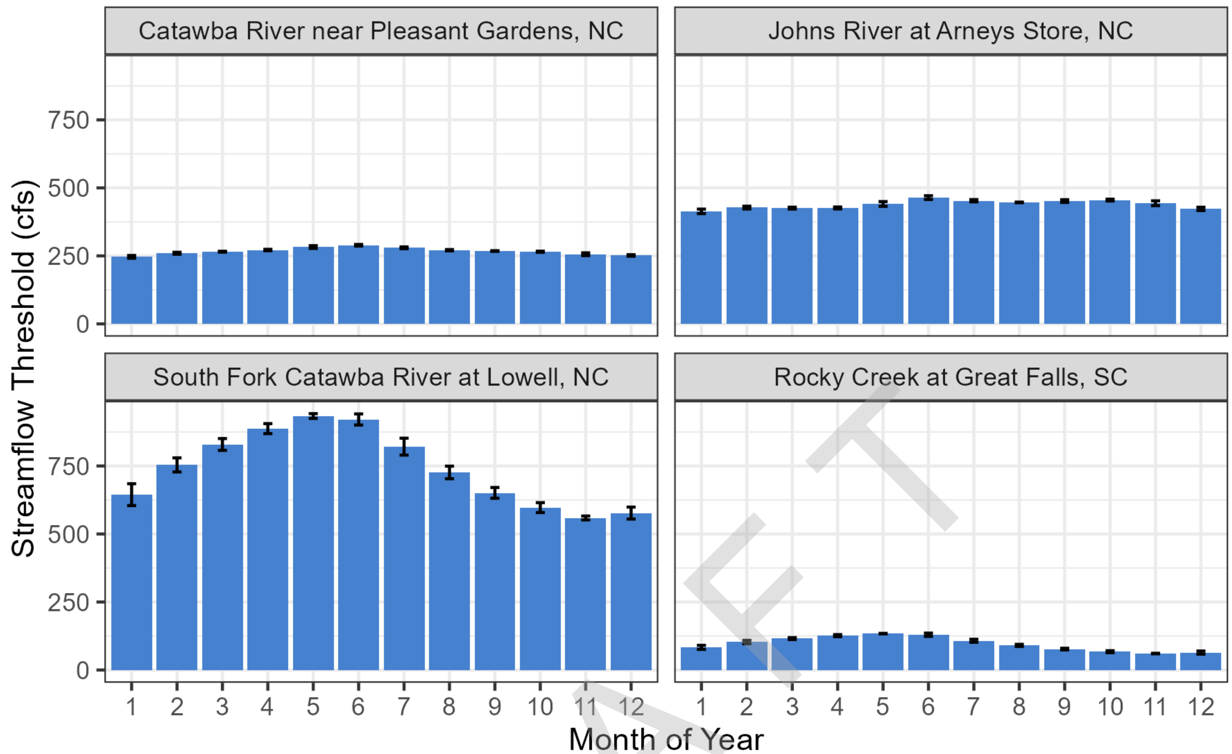

Figure 4-7. Monthly Average of Daily Streamflow Thresholds for the Stage 0 LIP Trigger

Model results focus on the Annual Days Below Gage Threshold for the Stage 0 LIP trigger, counting the number of days per year where streamflow falls below the critical threshold. Results depicted on Figure 4-8 demonstrate significant variability, ranging from zero (a completely wet year) up to 365 days (a year where flows are below the threshold almost entirely). Even under Wet climate scenarios (Hot/Wet and Warm/Wet), years with extreme low-flow events remain possible.

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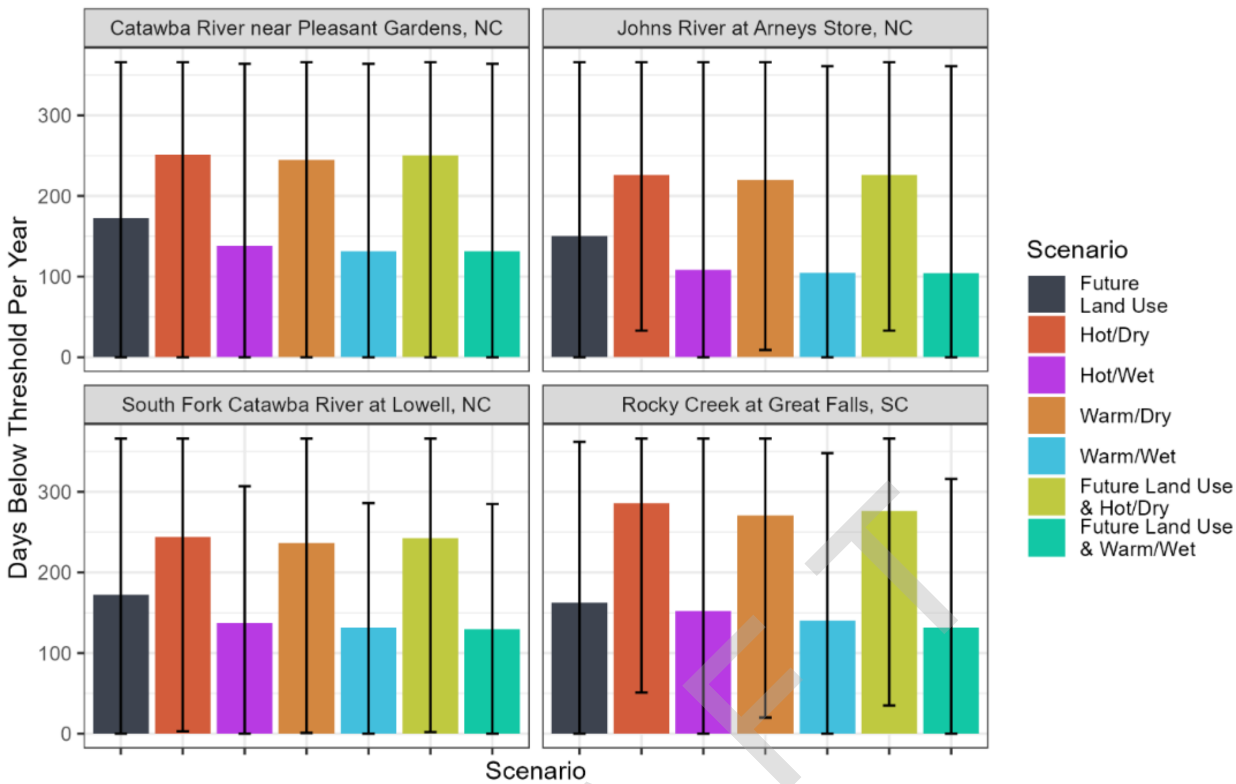

Figure 4-8. Annual Days Below Gage Threshold with Annual Minimum and Maximum

4.2.6 Summary of Tributary Water Quantity Findings

Analyses of Basin tributary conditions under current and future scenarios highlight several important trends:

- **Runoff**: Current runoff within the Basin varies widely, with high rates in mountainous headwaters and urbanized areas. The Future Land Use scenario increases localized *hot spots* for runoff, while Wet climate scenarios amplify runoff and Dry scenarios reduce overall volumes of runoff.
- **Low-Flow Durations**: Extended low-flow periods currently occur in several tributaries and are projected to lengthen under Dry climate scenarios. Future Land Use changes alone only slightly increase the extent and severity of low flow durations, although when combined with a dry climate, Future Land Use changes contribute to longer durations of low-flow conditions in some subbasins.
- **Flooding Potential**: Future Land Use and Wet climate scenarios increase the frequency of high-flow and peak-flow events, particularly in central and southern subbasins, raising flood risks.
- **Reservoir Inflows**: Reservoir inflows are highly sensitive to future climate and land use conditions. When combined with Future Land Use, Warm/Wet scenarios produce the highest inflow volumes, while the Hot/Dry scenario yields the lowest. Larger upstream reservoirs show the greatest variability between scenarios, underscoring the need to plan for both wetter and drier futures relative to current conditions and for long-term

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planning on water allocations between the reservoirs with potentially less supply or excess in the headwater reservoirs.

- **LIP Triggers**: Even under Wet climate conditions, years with extreme low-flow events remain possible, indicating continued vulnerability to entering into LIP stages.

These findings underscore the variability of hydrologic responses across scenarios and the importance of planning for both extremes, flooding and drought, when evaluating future water supply reliability and infrastructure performance.

4.3 Reservoir Water Yield Modeling

4.3.1 Purpose of Water Supply Quantity Evaluation

A reliable water supply is essential for meeting public water supply, power generation, industrial use, agriculture, recreation and environmental needs across the Basin. This evaluation considers hydrologic and operational conditions to understand how future demands and reservoir performance may affect water availability. It also identifies potential shortages or situations where water users may need to implement atypical operations or contingency measures to meet water supply needs. By identifying these conditions, this IWRP helps prioritize strategies to extend water availability and promote a long-term investment in sustainable water supply. These strategies are detailed in Section 7.

4.3.2 Reservoir Storage and Intake Characteristics

Reservoir storage and intake elevations are critical factors in determining water supply reliability. For each large water intake[4] owner, the **critical intake elevation** reflects the minimum reservoir elevation required to operate an intake at its approved capacity and may not correspond to the physical elevation of the intake structure. Many users have multi-level intakes that provide flexibility to withdraw water at various depths to adapt to lake levels, turbidity, or short-term water quality conditions. For these multi-level intake users, the critical intake elevation reflects the deepest operable intake opening.

All CWWMG members and large water intake owners were contacted for updates to their critical intake elevations, and responses are documented in Appendix F. Twelve critical intakes were updated or removed due to facility retirement.

Within each reservoir, the highest elevation (shallowest) critical intake elevation, used for public water supply, industrial water supply, or regional power plant supply, is that reservoir's **critical reservoir elevation (CRE)**, shown on Figure 4-9. Based on the critical intake elevation updates, five CREs were modified as compared to the WSMP primary yield evaluation (four lowered and one raised).

[4] Per the Catawba-Wateree Hydroelectric Project's Low Inflow Protocol (Appendix G) a Large Water Intake refers to any water intake (e.g., public water supply, industrial, agricultural, power plant) having a maximum instantaneous capacity greater than or equal to one million gallons per day (MGD) that withdraws water from the Catawba-Wateree River Basin.

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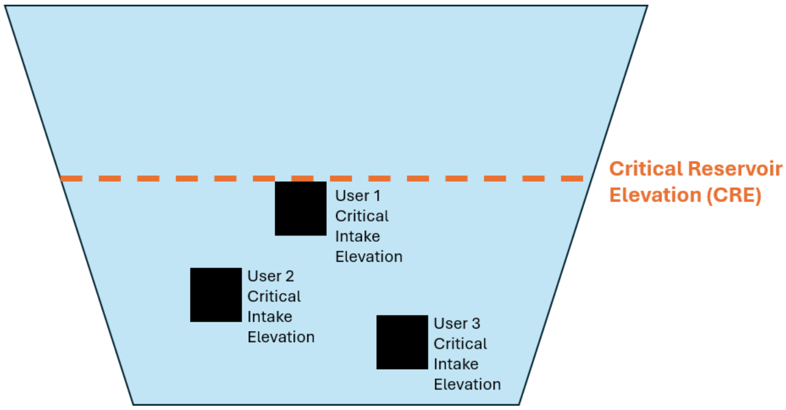

Figure 4-9. Schematic of Critical Intake and Critical Reservoir Elevations

Table 4-5 summarizes each reservoir's CRE as compiled for the IWRP, approximate remaining storage capacity below the CRE, and intake defining the CRE. Due to this updated information for planning purposes, these CRE are not identical to the most recent LIP revision (2022) and may be considered in a future LIP update. This information supports water supply planning and operational decision-making by identifying physical limits that influence water availability.

Table 4-5.Summary Table of Estimated Remaining Reservoir Storage and Critical Intakes

Reservoir Name	CRE (ft below full pond)	CRE Defining User	Approximate Remaining Reservoir Volume below CRE (million gallons)	Estimated Number of Operational Large Water Intakes below the CRE
Lake James	50	Duke Energy hydropower operational limitation	22,500	0
Lake Rhodhiss	8.6	Town of Valdese raw water intake	10,300	2
Lake Hickory	9	City of Hickory raw water intake	31,100	1
Lookout Shoals Lake	25.1	City of Statesville raw water intake	2,700	0
Lake Norman	10	Duke Energy McGuire Nuclear Station cooling water intake operational limitation	248,300	4
Mountain Island Lake	9.5	City of Mount Holly raw water intake	7,100	2
Lake Wylie[1]	7.4	City of Belmont, Clariant Corporation, and confidential industry raw water intakes	52,400	3
Fishing Creek Reservoir	10.2	Chester Metropolitan District raw water intake	4,900	0
Great Falls Reservoir	12.8	Duke Energy hydropower operational limitation	450	0
Cedar Creek Reservoir	19.7	Duke Energy hydropower operational limitation	2,000	0

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Reservoir Name	CRE (ft below full pond)	CRE Defining User	Approximate Remaining Reservoir Volume below CRE (million gallons)	Estimated Number of Operational Large Water Intakes below the CRE
Lake Wateree	7.5	City of Camden raw water intake	57,600	1

[1]As of the time of this writing (2025), the City of Belmont is experiencing a short-term intake restriction that temporarily raises its operational intake elevation due to reservoir sedimentation; however, for the purposes of long-term water availability planning, the IWRP assumes the intake will be returned to its original critical intake elevation., which defines the Lake Wylie CRE.

4.3.3 Water Supply Quantity Evaluation and Continuously Accessible Water Supply Determination

Previous Basin assessments used the term **safe yield** to describe the amount of water theoretically available for use at a given location. While useful, this metric's definition often varied, based on assumptions about reliability, constraints, and hydrologic conditions.

The IWRP refers to this safe yield concept as the **continuously accessible water supply**. This definition is intended to inform the question: "How much water can be leveraged 100% of the time by all large water intake owners?" This maximum volume of water that can be reliably withdrawn is constrained by the lowest-inflow conditions and recognition of current infrastructure limitations for accessibility. For each of the Catawba-Wateree Hydro Project reservoirs, the respective CRE defines this infrastructure limitation. This evaluation also takes into account the movement of water between reservoirs and the role that wastewater discharges provide in supporting downstream supply to reduce the overall net withdrawal.

Consistent with the previously developed WSMP and WSS, this quantification of continuously accessible supply provides a more conservative measure of water supply availability by drawing only from above the CRE, accounting for physical intake limitations rather than the total reservoir storage (shown in Figure 4-10). The **remaining usable storage** is the water supply available between the critical reservoir elevation and the reservoir's water surface elevation at any point in time, which varies based on time of year and operational conditions. This remaining usable storage is the accessible water supply for all large water intake owners.

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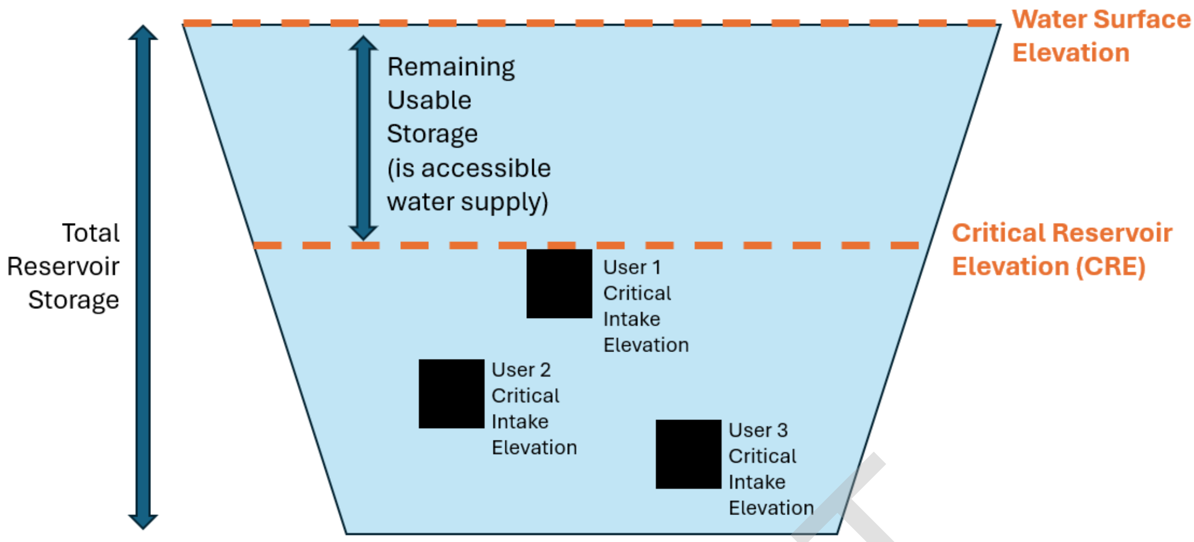

Figure 4-10. Schematic of Critical Reservoir Elevation and accessible water supply in a Reservoir

The IWRP determines the continuously accessible water supply by modeling reservoir operations under critical low-inflow periods. The model incorporates inflows, operating rules, intake elevations, and projected water demands and discharges (returns), simulating conditions to identify the highest water demand that does not cause reservoir elevations to drop below the CRE while meeting downstream flow requirements.

The total reservoir storage is a useful reference because while the CRE is defined by limitations for the most-shallow intake, a larger portion of the total reservoir storage is applicable to other (deeper) large water intakes in the reservoir that would still be able to access water. When the water surface elevation is below the CRE, owners of shallow intakes are required to implement alternative operational measures, such as temporary pumping or interconnections, to maintain access to the water supply. In contrast, all deeper intakes within the reservoir may continue to provide reliable water supply access for some period of time. The continuously accessible water supply defines the practical volume usable for planning, management, and is an indicator of when operational contingencies are required for a particular user in a reservoir.

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Alignment with the South Carolina Water Planning Framework

The IWRP's definition of Continuously Accessible Water Supply is similar in function to the SC Water Planning Framework (SCDNR, 2019, pg. 52), which defines **Surface Water Supply** as the "maximum amount of water available for withdrawal 100% of the time at a location on a surface water body without violating any applied Surface Water Conditions on the surface water source and considering upstream demands", where a **Surface Water Condition** is "… intended to physically limit the amount of water that can be withdrawn from a surface water source, and are independent of water demand". The IWRP's Surface Water Conditions would include the critical intake elevations, dam outlet structures, and meeting FERC License requirements for minimum water releases from hydro project dams and minimum reservoir elevations.

4.3.4 Low Inflow Protocol (LIP) impact on reservoir operations and storage

The LIP establishes procedures for operating the Catawba-Wateree Hydroelectric Project and managing water withdrawals during periods of low inflow, such as droughts. Duke Energy operates the reservoirs following the LIP, allowing them to coordinate water use reductions among hydroelectric operations and other water users. This protocol also facilitates the preservation of reservoir storage and possibly delaying water supply shortages. The LIP is a hallmark management strategy for extending available water supply during drought conditions.

The LIP defines three primary triggers that determine the drought stage and corresponding water use restrictions:

1. **Storage Index Trigger**: Compares actual Storage Index for the eleven reservoirs to the Target Storage Index (i.e., Storage Index if all eleven reservoirs were at their respective Normal Target Elevations).
2. **Streamflow Trigger**: Uses rolling averages of streamflow measurements at four key USGS gages.
3. **Drought Monitor Trigger**: Incorporates area-weighted USDM data reflecting regional drought severity.

A Groundwater Trigger is also incorporated for reference when recovering from LIP Stages, but it is not currently leveraged to determine an LIP stage. At a future date, enough groundwater data will be available to utilize the comparative data.

Duke Energy declares LIP stages from Stage 0 (Low Inflow Watch) through Stage 4 (Regional Emergency), with each stage imposing progressively greater reductions in hydroelectric water releases and water withdrawals by other users. These reductions help maintain reservoir levels above critical intake elevations and protect water supply reliability until rainfall improves. Water users, including public water suppliers, implement water use reductions consistent with the LIP stage. The protocol specifies response times and reduction goals to ensure timely and effective conservation actions as detailed in Table 4-6.

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Table 4-6. LIP Stage Water Use Reductions for Public Water Suppliers

Owners of public and large water supply intakes	Owner Timeline for Implementing Actions (days)	LIP Language for Water Use Reductions
Stage 0 (Drought Watch)	Not Applicable	Not Applicable
Stage 1	14	"Request… voluntary" 3-5%
Stage 2	14	"Require… mandatory" 5-10%
Stage 3	14	"Require… increased mandatory" 10-20
Stage 4 (Regional Emergency)	14	"Notify… emergency" 20-30%

The Normal Minimum Elevation (NME) represents the lower limit of the reservoir's Normal Operating Range for a specific day of the year. This elevation is adjusted during each LIP stage, with the extent of drawdown varying by reservoir. When a LIP stage is triggered, the NME is reduced to establish a lower operating range under diminished inflow conditions.

The LIP remains the most critical tool for protecting and preserving water supply during drought conditions in the Basin. The Catawba-Wateree Drought Management Advisory Group (CW-DMAG) oversees the LIP, regularly reviewing and updating it to incorporate lessons learned and to improve responsiveness, including findings from the previous WSMP. The Stage declarations are indicative of past drought conditions, shown on Figure 4-11. While only sustained increased rainfall can end a drought, by working together to share water use reductions via the LIP, Duke Energy and the Large Water Intake owners are effectively creating time for the necessary rainfall to return. In fact, this cooperative approach through the LIP is the only thing that kept some Large Water Intakes from being uncovered in the Drought of Record. The Catawba-Wateree Project Low Inflow Protocol documentation is provided in Appendix G.

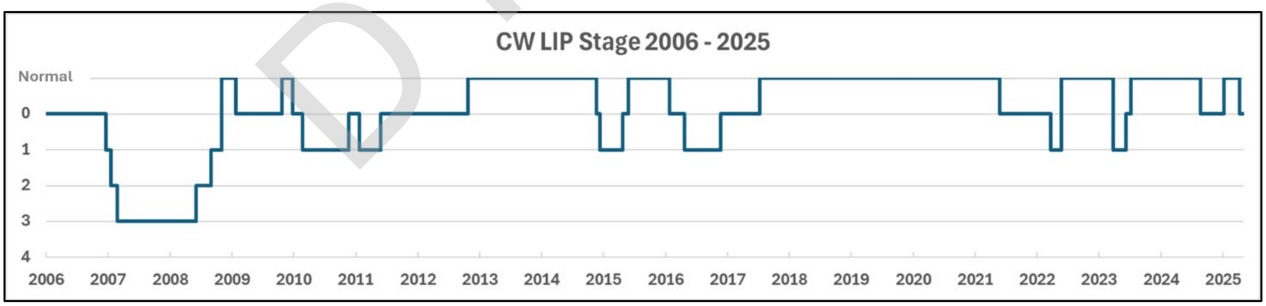

Figure 4-11. Historical Low Inflow Protocol Stage Determination (mid 2006-2025)

4.3.5 Process of Determining Continuously Accessible Water Supply with Thresholds

Determining the continuously accessible water supply for each reservoir in the Basin requires a detailed hydrologic modeling approach that reflects how the system operates under normal and drought conditions. The Basin functions as an interconnected system, generally operated by a single entity, i.e., Duke Energy. In practice, increasing demands on a downstream reservoir often result in water being released from upstream reservoirs in order to maintain balance across the system.

Due to the variability in supply and demand across the Basin, in particular, the storage volume and the operational differences for all eleven reservoirs, estimating water quantities at any one time is complex. Operational constraints vary, and the point at which one reservoir reaches its limit does not necessarily define availability for the entire system. Additional water may remain accessible upstream even after a downstream reservoir reaches the CRE. To capture these dynamics, the model simulates conditions where demands are not uniformly adjusted across the Basin, allowing incremental determination of water availability.

This process involves the following key steps and assumptions:

1. **Model Setup and Baseline Conditions**
   The CHEOPS hydrologic model simulates reservoir operations over the critical low inflow period. These reduced inflows represent the historically lowest water supply conditions and are based on the Drought of Record which occurred from 2006 to 2009. These representative inflows were developed using the WaterFALL model, described in Section 3. Baseline conditions include water withdrawal and discharges (returns) projections, reservoir operating rules, and physical constraints such as critical intake elevations.
2. **Critical Reservoir Elevations as Thresholds**
   Each reservoir has a defined CRE. This elevation represents the lowest water surface elevation at which a large water intake remains operable for the most shallow user. These elevations serve as thresholds for evaluating reservoir performance under increasing water demand.
3. **Incremental Demand Increase and Exceedance Identification**
   Beginning with the defined baseline demand (Table 3-1), the model incrementally increases water withdrawals in 10-year projection steps (2035, 2045, 2055, etc.) described in Section 3. After each increment, the model simulates reservoir water surface elevations throughout the drought period. An **exceedance** occurs when any reservoir's water surface elevation drops **at least 1.0 ft below its CRE for three or more consecutive days**[5].
4. **Locking Reservoir Demand Upon Exceedance**
   Once a reservoir reaches an exceedance at a given demand level, the demand is locked, for all subsequent simulations, at the last non-exceedance level. Other reservoirs that have not reached the exceedance requirement continue to increase demand incrementally. This approach reflects the operational reality: **a reservoir cannot supply more water once it reaches its physical or regulatory limit.**

[5] The finalized exceedance metric was determined by the CWWMG in 2025 following workshop discussion on October 1, 2025. The exceedance threshold leveraged in the 2006 WSS was one day at 1.0 ft below CRE and in the 2014/15 WSMP it was three days at one-tenth of a foot below CRE for all scenario suites. In the IWRP, using a three-day threshold reflects the ability for the majority of users to utilize strategies or off-stream storage (e.g. PWS reservoirs or distribution system storage tanks) to support demands for a period when an intake may be unavailable. Leveraging 1.0 ft below the CRE recognizes the range of expected precision from inflow data (e.g. calibrating WaterFALL flows to USGS gages with Fair/Poor ratings) and critical intake elevations.

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The **Decision Point Year** represents the anticipated year when demands within the reservoir's sub-basin would require alternative operational strategies if the historical drought of record were to reoccur.

5. **Determining the Continuously Accessible Water Supply Range**
   For each reservoir, the model defines the range between the highest demand level that did not cause exceedance and the level at which the exceedance first occurred. This is the **Decision Point Year**, the forecasted demand year at which a reservoir's accessible storage is projected to be exceeded under drought of record conditions and be beyond the continuously accessible water supply. Combining these values across all reservoirs provides a Basin-wide range of near-term water supply.
6. **Use of Results for Planning**
   The results guide water resource planning by identifying which reservoirs may experience accessibility limitations and in what general planning timeline, should the drought of record occur again. Modeling then evaluates, in Section 7, the effectiveness of various management and infrastructure strategies to extend water availability and accessibility.

4.3.6 Reservoir Water Accessibility Modeling Results

Modeling results for the baseline and future condition scenarios, based on the **2006–2009 critical low-inflow period,** demonstrate how water accessibility varies across the Basin. The accessibility options include variations in the influence of **land use change, climate conditions** (discussed in Section 3), and operational or demand considerations.

While the IWRP modeling results cannot predict the exact conditions that will exist decades from now, the analysis highlights the sensitivity of water availability to these factors, providing critical insight for planning. Understanding this sensitivity helps to identify supply limitations and informs strategies to maintain reliability.

The future condition scenarios evaluated are summarized in Table 4-7.

Table 4-7. Individual Future Condition Scenarios

Future Condition Category	Scenario Name Code	Description
Baseline	Base[a]	IWRP Baseline: Current operational conditions, 50th percentile water demand forecast, inflow reflective of historical climate and land use.
Land Use	LU-01	Future Land Use: Baseline Scenario plus projected land use in 2070.
Climate	CC-04	Dry-Hot Climate: Modified inflow dataset reflective of the Dry-Hot climate scenario.
	CC-05	Dry-Warm Climate: Modified inflow dataset reflective of the Dry-Warm climate scenario.
	CC-06	Wet-Hot Climate: Modified inflow dataset reflective of the Wet-Hot climate scenario.

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Future Condition Category	Scenario Name Code	Description
	CC-07	Wet-Warm Climate: Modified inflow dataset reflective of the Wet-Warm climate scenario.
Water Demands	PG-04	Effect of lower demand projection: 25th Percentile probabilistic water demand representative of slower population growth, per capita demand, or industrial use than the primary demand forecast.
	PG-05[a]	Effect of higher demand projection: 95th Percentile probabilistic water demand representative of faster population growth, per capita demand, or industrial use than the primary demand forecast.

[a] Scenario output was provided to the SC Santee River Basin Council for their use as a boundary condition in their water supply modeling.

Table 4-8 and Table 4-9 present a summary of modeled scenarios and the results for each simulation. Figure 4-12 and Figure 4-13 demonstrate the range of decision year impacts for the two most impactful future condition categories; climate and water use demand, respectively. More detailed results output for individual scenarios, including minimum and average reservoir releases, are found in Appendix H.

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Table 4-8 Baseline Scenario (Base) Summary

BASELINE SCENARIO												
Definition	The Baseline Scenario is based on conditions outlined in the CRA established under the current FERC License for the Catawba-Wateree Hydro Project, including the LIP, and the 50th percentile *most likely* water demand forecast. Results are intended to be used for comparison with individual scenarios and strategies to be evaluated.											
Results	Simulated elevations dip below the CRE within the Basin (Rhodhiss through Wylie) under baseline conditions; with exceedances (defined as 1.0 ft below CRE for three or more consecutive days) by 2085 in Mountain Island Lake and 2035 in Lake Wylie.											
Reservoir	**2025**	**2035**	**2045**	**2055**	**2065**	**2075**	**2085**	**2095**	**2105**	**2115**	**2125**	**Decision Point Year**
Lake James	○	○	○	○	○	○	○	○	○	○	○	Beyond 2125
Lake Rhodhiss	~	~	~	~	~	~	~	~	~	~	~	Beyond 2125
Lake Hickory	○	~	~	~	~	~	~	~	~	~	~	Beyond 2125
Lookout Shoals Lake	○	○	○	~	~	~	~	~	~	~	~	Beyond 2125
Lake Norman	○	~	~	~	~	~	~	~	~	~	~	Beyond 2125
Mtn. Island Lake	~	~	~	~	~	~	△	△	△	△	△	2075-2085
Lake Wylie	~	△	△	△	△	△	△	△	△	△	△	2025-2035
Fishing Creek Reservoir	○	○	○	○	○	○	○	○	○	○	○	Beyond 2125
Great Falls Reservoir	○	○	○	○	○	○	○	○	○	○	○	Beyond 2125
Cedar Creek Reservoir	○	○	○	○	○	○	○	○	○	○	○	Beyond 2125
Lake Wateree	○	○	○	○	○	○	○	○	○	○	○	Beyond 2125

○ = 0 days below CRE | ~ = Some day/s below CRE | △ = 3+ consecutive days 1+ ft below CRE

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Table 4-9 Summary of Alternative Future Conditions Impact on Water Supply Availability Decision Point Year

Reservoir	Decision Point Year by Scenario						
	Base Baseline	LU-01 Future Land Use	CC-06 Wet/Hot Climate	CC-07 Wet/Warm Climate	CC-04 Dry/Hot Climate	PG-04 Low Demand	PG-05 High Demand
Lake James	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125
Lake Rhodhiss	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125
Lake Hickory	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125
Lookout Shoals Lake	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125
Lake Norman	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	2055-2065*	Beyond 2125	Beyond 2125
Mtn. Island Lake	2075-2085	2075-2085	2075-2085	2075-2085	2055-2065*	2075-2085	2045-2055*
Lake Wylie	2025-2035	2025-2035	2025-2035	2035-2045^	2025*	2095-2105^	2025*
Fishing Creek Reservoir	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125
Great Falls Reservoir	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	2055-2065*	Beyond 2125	Beyond 2125
Cedar Creek Reservoir	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125
Lake Wateree	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125	Beyond 2125
*Earlier Decision Point Year than Baseline				^Later Decision Point Year than Baseline			

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As seen in Table 4-9, the Future Land Use resulted in no change to the decision point year from the Baseline year. This outcome indicates, for the Future Land Use Scenario, that forecasted land use changes through 2070, including increased watershed densification and build out, alone, is not a primary driver to affect water availability during drought conditions. Higher density within the watershed generally increases runoff and flow that reaches the mainstem river and associated reservoirs; however, this effect is negligible under the low-flow conditions simulated for this evaluation.

As described in Section 3, the IWRP incorporates four climate change scenarios in order to establish a bounding range of potential future conditions, reflecting combinations of drier versus wetter and warmer versus hotter climates based on established models. Shown on Figure 4-12, this range of future climate conditions generally decreases water accessibility. The reduction in water accessibility triggers an earlier decision point year for Lake Norman, Mountain Island Lake, and Great Falls Reservoir. For Lake Wylie, which has the earliest baseline decision point year (2025–2035) within the Basin, climate change impacts vary by scenario: wetter conditions extend the decision point year range by approximately a decade, while drier conditions accelerate the decision point year by a similar margin.

Reservoir	Decision Point Year Range by Climate Change Impact										
	2025	2035	2045	2055	2065	2075	2085	2095	2105	2115	2125
Lake James											Baseline
Lake Rhodhiss											Baseline
Lake Hickory											Baseline
Lookout Shoals Lake											Baseline
Lake Norman					Climate Impact						Baseline
Mtn. Island Lake					Climate Impact		Baseline				
Lake Wylie	Climate Impact	Baseline	Climate Impact								
Fishing Creek Reservoir											Baseline
Great Falls Reservoir					Climate Impact						Baseline
Cedar Creek Reservoir											Baseline
Lake Wateree											Baseline

Those reservoirs without an indicated Climate Impact Range had the same Decision Point Year as the Baseline Scenario.

Figure 4-12. Decision Point Year Range for the Range of Climate Change Scenarios

Future water demand represents a key determinant of water accessibility and availability within the Basin. The Baseline scenario applies the 50th percentile forecast, thus reflecting the most probable demand conditions based on current data. To evaluate the sensitivity of water availability to demand variability, the IWRP modeled low and high demand scenarios. These scenarios correspond to the 5th and 95th percentile forecasts, respectively (see Section 3.1 for details on the probabilistic demand methodology). As shown on Figure 4-13, under the high demand scenario, decision point years for Lake Norman, Mountain Island Lake, and Lake Wylie advance by one to three decades. Conversely, under the low demand scenario, Mountain Island Lake's decision point year is extended by approximately four decades and Lake Wylie's decision point year is extended by seven decades.

Two key observations emerge: (1) The high demand scenario does not accelerate decision point years for the reservoirs located between Lake James and Lookout Shoals Lake or between Fishing Creek Reservoir and Lake Wateree. This scenario indicates relative resilience to demand variability; however, increased demand withdrawals also correspond to increased wastewater discharges. These discharges provide supplemental inflows to downstream reservoirs. (2) Even under the low demand scenario, a decision point year occurs by 2095–2105, demonstrating that reductions in water usage alone are insufficient to extend accessibility beyond the next century.

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Reservoir	Decision Point Year Range by Water Demand Scenario										
	2025	2035	2045	2055	2065	2075	2085	2095	2105	2115	2125
Lake James											Baseline
Lake Rhodhiss											Baseline
Lake Hickory											Baseline
Lookout Shoals Lake											Baseline
Lake Norman									High Demand		Baseline
Mtn. Island Lake				High Demand			Baseline				Low Demand
Lake Wylie	High Demand	Baseline							Low Demand		
Fishing Creek Reservoir											Baseline
Great Falls Reservoir											Baseline
Cedar Creek Reservoir											Baseline
Lake Wateree											Baseline

Those reservoirs without an indicated Demand Impact had the same Decision Point Year as the Baseline Scenario.

Figure 4-13. Decision Point Year for the Range of Water Demand Scenarios

Future water accessibility within the Basin varies significantly across the range of future condition scenarios that were evaluated. The IWRP modeling analysis indicates that climate variability and water demand, including both withdrawals and return flows, are the primary factors influencing reservoir decision point years. Across these scenarios, the reservoirs experiencing the most variability in water accessibility, listed in order from most affected to least affected, are Lake Wylie, Mountain Island Lake, Lake Norman, and Great Falls Reservoir. The remaining Project reservoirs did not experience variability in Decision Point Year under the explored future conditions.

These reservoirs are also first, fifth, and sixth most shallow critical reservoir elevations, respectively, of the 11-reservoir system. The decision point year represents the anticipated year when demands within a reservoir's subbasin would require alternative operational strategies if the historical drought of record were to recur. This analysis focuses on water accessibility under current operational constraints. Other large water intake owners within the reservoir maintain access to supply at each decision point year. The large water intake owners with the shallowest intakes in a reservoir would be required to transition to contingency measures such as interconnections or temporary pumping solutions.

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4.3.7 Water Supply Management Scenarios

The next phase of the water quantity evaluation assesses management strategies that may extend water accessibility and consequently defer the Decision Point Year. A variety of potential management scenarios were modeled and evaluated to inform the efficacy of strategies on increasing water supply accessibility within the Basin during extreme low-flow conditions. As identified above, baseline and alternative future conditions indicate that the Decision Point Year for Lake Wylie may occur between 2025-2035 should the drought of record reoccur. Potential management scenarios were therefore focused on identifying opportunities to enhance supply accessibility for Lake Wylie, and therefore the system as a whole, beyond 2075.

Reservoir supply accessibility strategies can be focused on reducing water demand, increasing supply, and enhanced operational management of the current supply available. The full suite of potential strategies and their resulting impact on Decision Point Year, LIP determinations, and downstream flows are included in Appendix H. The following highlights the key findings of reservoir management scenario evaluations that are focused on operations and management of the Project reservoirs and Large Water Intakes. One primary strategy is to modify the CRE, which may be through a physical intake or user operations modification that allow an increased depth of use. The other strategy is to modify the LIP NME to change the lower operating range of a reservoir under diminished inflow conditions. This NME change effectively allows more water to be released from one reservoir's storage to support downstream reservoirs during low flow conditions to balance the supply but does not prescribe that a reservoir must be lowered to that elevation.

The IWRP evaluation iterated across more than a dozen combinations of scenarios that varied the CRE and LIP NME of four Project reservoirs, as illustrated in Figure 4-14. These reservoirs and modifications were selected for evaluation based on relatively high Total Reservoir Storage and/or earlier baseline Decision Point Years.

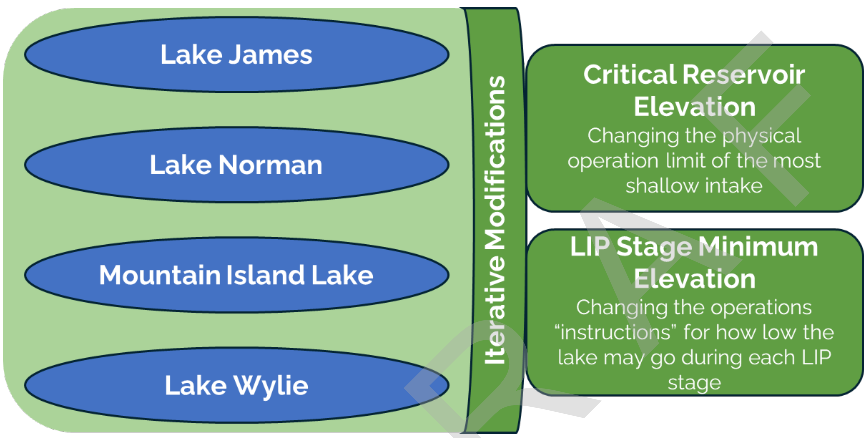

Figure 4-14. Schematic of alternative operations scenarios developed

These iterative modifications have varied impact on individual reservoirs. Four key illustrative alternatives and the resulting Decision Point Year are summarized in Table 4-10 and described below.

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Table 4-10. Key Alternatives Scenarios and resulting Decision Point Year

Future Condition Category	Scenario Name Code	Alternative	Detail Description	Decision Point Year [a]	Decision Point Year Extension Compared to Baseline
Baseline	**Base**	-	Baseline Scenario for comparison	Mtn. Island Lake 2075-2085 Lake Wylie 2025-2035	n/a
Potential Operational Changes	**CI-06**	Lake Norman CRE modification.	Lake Norman CRE lowered to 746 ft msl. based on potential thermal limitation modifications for McGuire Nuclear Station.	Mtn. Island Lake 2075-2085 Lake Wylie 2025-2035	none
	CI-06B	Lake Norman CRE and LIP NME modification.	Lake Norman CRE lowered to 746 ft msl and an additional 2 ft reduction in LIP Stage 1 NME and 4 ft reduction in LIP Stage 2 & 3 NME.	Mtn. Island Lake 2085-2095 Lake Wylie 2055-2065	+ 3 decades
Iterative Modifications	**CI-07B**	Lake Norman CRE and LIP NME modification. Mtn. Island Lake and Lake Wylie CRE modification.	Lake Norman CRE lowered to 746 ft msl. Additional 2 ft reduction in LIP Stage 1 NME and 4 ft reduction in LIP Stage 2 & 3 NME. Modified CRE in Mtn. Island Lake (637.5 ft msl) and Lake Wylie (559.4 ft msl)	Mtn. Island Lake 2085-2095 Lake Wylie 2065-2075	+ 4 decades
	CI-PL (CI-06B_ PL-07B)	Lake Norman CRE and LIP NME modification. Lake James NME modification.	Lake Norman CRE lowered to 746 ft msl. Additional 2 ft reduction in LIP Stage 1 NME and 4 ft reduction in LIP Stage 2 & 3 NME. Lake James LIP NME reduction of 18, 27, and 30 ft for Stages 1, 2, and 3 respectively.	Lake Wylie 2095-2105	+ 7 decades

[a] Unlisted reservoirs had simulated Decision Point Years beyond 2125

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The potential operational change scenario where only the Lake Norman CRE was modified (CI-06) did not result in a change to the decision point year as compared to Baseline. This lack of impact is primarily due to the baseline decision point year for Lake Norman being simulated to occur beyond 2125 and the lowering of the CRE by 4.0 ft only further extending that timeframe. While this modification decreases the number of days the simulated reservoir elevation is near the critical reservoir elevation (see Appendix H for details), the additional accessible storage in Lake Norman alone is insufficient to influence the Decision Point Year for Mountain Island Lake or Lake Wylie. It is important to note that lowering a CRE not only increases accessible storage within the individual reservoir, but also affects the calculation of total usable storage (sum of the Project's volume of water between each reservoir's CRE and the Normal Full Pond Elevation for that time of year) across the Catawba-Wateree Hydroelectric Project, which in turn influences LIP declarations.

When the CRE and LIP NME of an upstream reservoir are both modified, as seen for example in CI-06B for Lake Norman, the downstream reservoirs of Mountain Island Lake and Lake Wylie have an extension in Decision Point Year due to the increase in allowable water supply released during LIP stages controlled by the NME. This scenario highlights the role of CRE and LIP NME modifications working in conjunction to support downstream reservoirs during critically low flows.

Through the iterations of the tested operational changes, the CI-PL scenario demonstrates that operational management and intake modifications may extend Lake Wylie's Decision Point Year to 2095-2105, and all other reservoirs extend beyond 2125 (Illustrated in Figure 4-15). The modifications include changes to Lake Norman's CRE and NME and Lake James's NME, which enable Lake James, as the first reservoir in the Catawba-Wateree chain, to release upstream storage that supports all downstream reservoirs. This suite of management alternatives effectively increases available and accessible water supply at the needed reservoirs during low inflows through the current century (+7 decade improvement, which could conceptually be applied to the other future climate and demand conditions modeling scenarios.) In addition to the water supply benefits, this suite introduces additional recreational, ecological, and financial impacts that require detailed consideration by the CWWMG and its partners. Future recommendations must also balance intake modifications and LIP adjustments with demand management strategies to support sustainable use. The next section explores interbasin transfers as a management factor in this context.

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Reservoir	Decision Point Year Range by Alternative Operations Impacts										
	2025	2035	2045	2055	2065	2075	2085	2095	2105	2115	2125
Lake James											Baseline
Lake Rhodhiss											Baseline
Lake Hickory											Baseline
Lookout Shoals Lake											Baseline
Lake Norman											Baseline
Mtn. Island Lake							Baseline	→	→	→	Alts. Impact Range
Lake Wylie		Baseline	→	→	→	→	→	→	Alts. Impact Range		
Fishing Creek Reservoir											Baseline
Great Falls Reservoir											Baseline
Cedar Creek Reservoir											Baseline
Lake Wateree											Baseline

Those reservoirs w ithout an indicated Management Range had the same Decision Point Year as the Baseline Scenario.

Figure 4-15. Decision Point Year for the Range of Alternative Operations Scenarios

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4.4 Interbasin Transfer Review

IBTs are a component of surface water management and overall water balance. An IBT occurs when surface water is moved from one river basin to another. The transfer amount is the water withdrawn and not returned to its source basin. These transfers can support regional growth, improve receiving system reliability, and help utilities meet demand across jurisdictional and geographic boundaries. However, they also require careful evaluation to ensure that water availability, ecological health, and users in the source basin are not adversely impacted.

IBTs are regulated by state agencies in both North Carolina and South Carolina, and each state defines and manages IBTs differently. North Carolina uses a set of 35 designated IBT basins (after recent changes to the General Statutes), defined in NC General Statute § 143-215.22G (1b), and regulates transfers of 2.0 MGD or more under s §143-215.22L. These transfers require certification from the Environmental Management Commission, including technical review, environmental documentation, and public engagement. South Carolina defines IBTs based on the state's eight major river basins and regulates them through the Surface Water Withdrawal, Permitting, Use, and Reporting program, under S.C. Code §49-4-90 and S.C. Code Regs. §61-119. In South Carolina, IBTs are evaluated as part of the surface water withdrawal permitting process administered by SCDES, which also includes public notice and environmental review. The 2010 US Supreme Court case settlement agreement between South and North Carolina (SC v. NC, Original Case No. 138) also imposes some requirements for administration of IBTs on the two states and these are described further in Section 4.5.

For the purposes of the IWRP, the project team conducted a basin-level IBT review focused on three primary objectives:

1. **Existing Transfers**: Identify and document all legacy, permitted, and certified IBTs greater than 1.0 MGD involving the Basin. This effort included coordination with both NCDEQ and SCDES to develop a comprehensive database of known transfers.
2. **Characterize Transfer Volumes**: Summarize IBT volumes using consistent units and definitions.

3. **Estimate Future IBT Volumes**: Using the IWRP net water withdrawal forecast as the foundation, estimate the volume of water that will potentially be transferred out of the Basin in the Base Year (historical average), 2055, and 2075. These estimates reflect both consumptive use and wastewater discharges associated with the Basin and/or receiving basins.

4.4.1 Existing IBT Transfers and Volumes

The IWRP project team compiled information provided by both North Carolina DEQ and South Carolina DES to develop a comprehensive list of known transfers, including permitted, legacy, and certified IBTs. While dozens of utilities move water within the Basin (i.e., intrabasin transfers) to meet their service area needs, only a limited number currently operate transfers greater than 1.0 MGD outside the Basin, as shown in Figure 4-16.

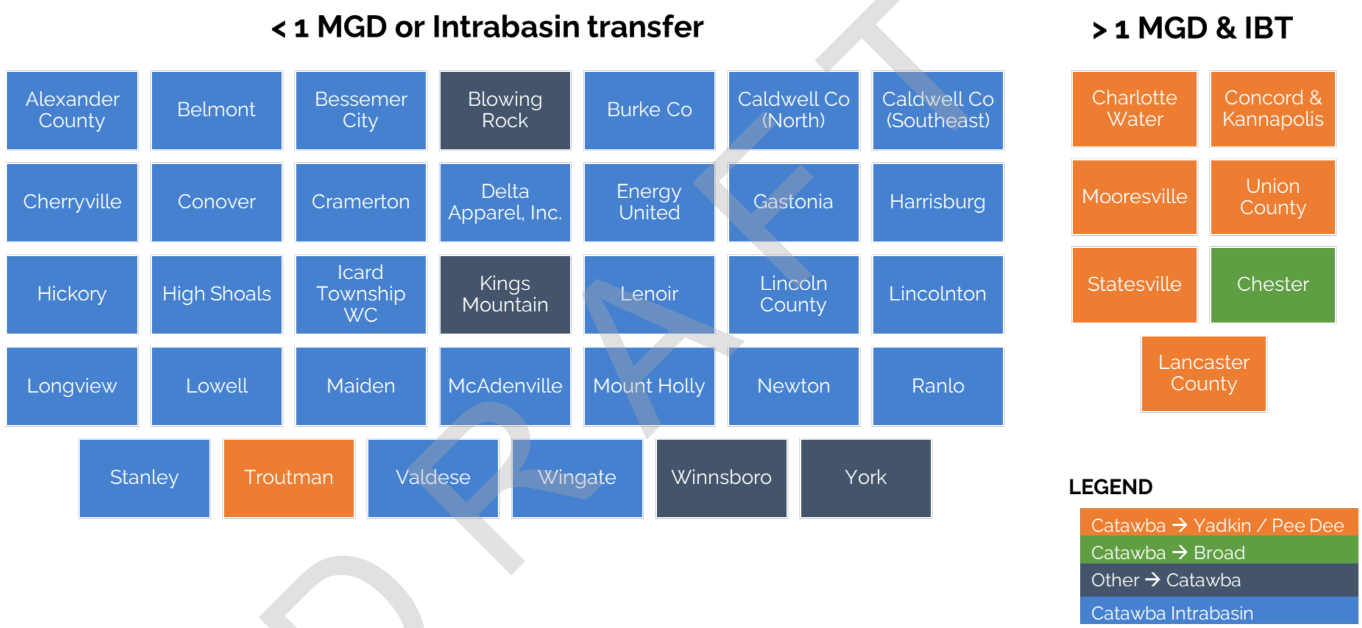

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Figure 4-16. North and South Carolina Interbasin and Intrabasin Transfers

For the IWRP, the focus is on transfers from the Catawba-Wateree to the Yadkin-Pee Dee or Broad River basins that are greater than 1.0 MGD as illustrated on Figure 4-17. The agency, certificate limit and basis for the limit, are provided in Table 4-11.

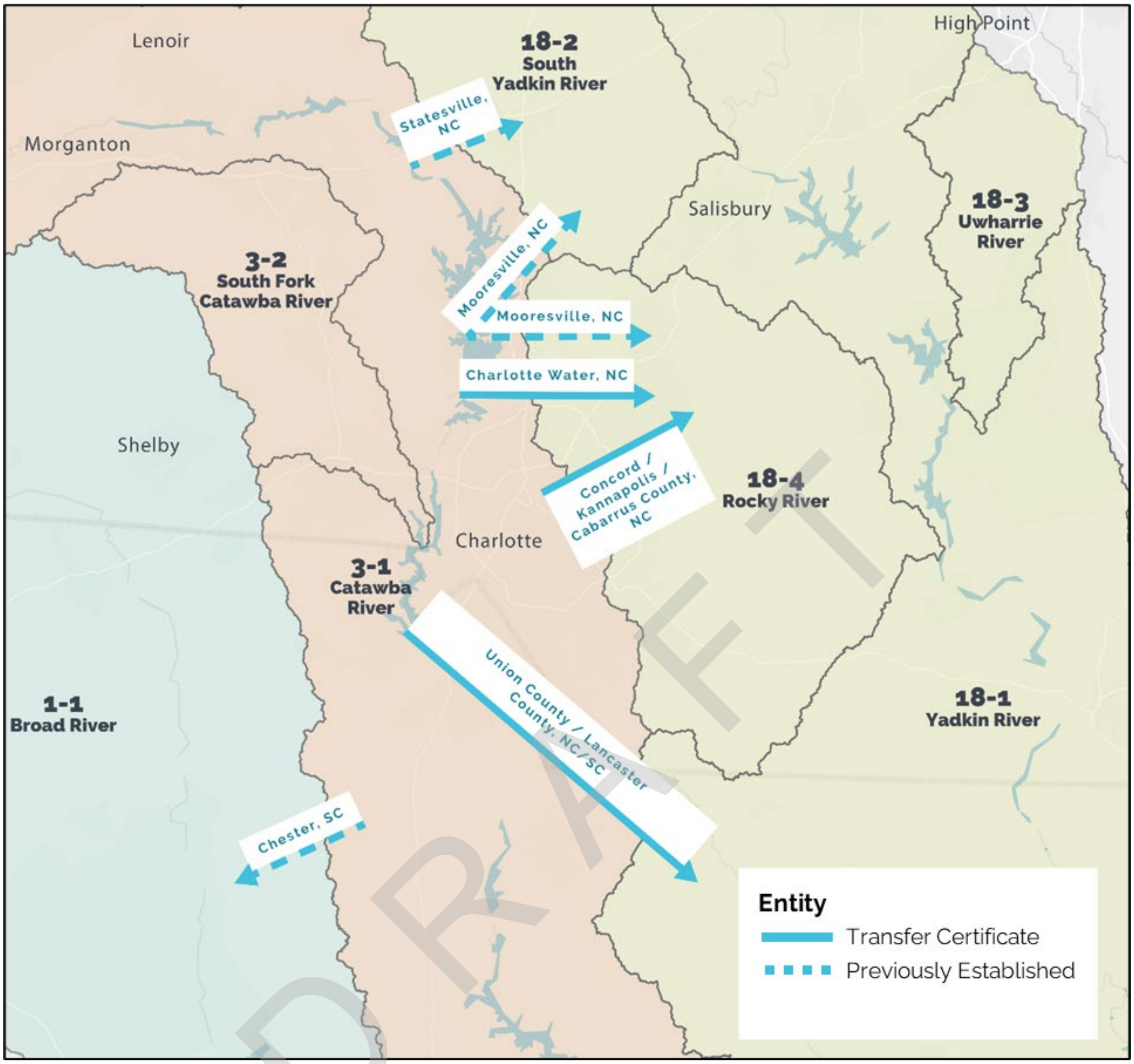

Figure 4-17. Interbasin Transfers Greater than 1 MGD

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Table 4-11. Interbasin Transfers Summary Greater than One MGD

Agency	Certificate Transfer Limit (MGD) and Basis	Comment
City of Statesville	15 max-day (legacy)	Intake in Lookout Shoals Lake, discharge to the Yadkin River Basin.
Charlotte Water	33 max-day	Intakes in Mt. Island Lake and Lake Norman, discharges to the Yadkin River Basin.
Town of Mooresville	9.54 max-day (legacy)	Intake in Lake Norman, discharge to the Yadkin River Basin.
Concord/ Kannapolis/ Cabarrus County	10 max-day	IBT from the Catawba River (e.g., Lake Norman) to discharge to the Yadkin River Basin.
Union County/ Lancaster County	Union County: 5 max-day (legacy) Lancaster & Union County: 20 max month average day equivalent	Estimated IBT from Catawba River Water Treatment Plant into Lancaster and Union Counties discharged to the Yadkin/Pee Dee River Basin.
Chester Metropolitan District	9.2 max-day equivalent	Withdrawals from the Catawba River with discharge to the Broad River Basin.

4.4.2 Estimating Future Transfers

The IWRP net water withdrawal forecast provides detailed projections of surface water withdrawals and discharges for each utility and facility within the Basin. These data allow the calculation of projected net withdrawals from the Basin as the volume of water withdrawn from the Basin minus the volume returned to it.

Some portion of the net withdrawal from the source Basin is attributed to consumptive use within the Basin, such as irrigation, cooling towers, or industrial processes. The remaining volume represents water that is either discharged or used consumptively outside the Basin and is therefore considered an IBT.

To estimate future transfer volumes, the IWRP team applied a high-level mass balance approach using forecast data for the Base Year, 2055, and 2075. This analysis was refined through coordination with utilities to confirm service area boundaries and verify assumptions regarding:

- **Discharges to receiving basins:** Wastewater that is treated and discharged outside the Catawba-Wateree Basin.
- **Consumptive use outside the Basin:** Water used in service areas outside the Catawba-Wateree Basin and not returned to surface water.

Together, these components define the total estimated volume of water transferred out of the Basin. Table 4-12 presents the estimated cumulative IBT, for utilities with IBTs greater than 1.0 MGD, on an average day basis for each milestone year.

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Table 4-12. Estimated Average Day IBT Base Year, 2055, and 2075, for Utilities with Current IBT Greater than 1 MGD

Average Day Estimates, MGD	Base Year (Historical Avg)	2055	2075
Estimated Discharge outside the Catawba-Wateree Basin	21.3	48.0	52.3
Consumptive Loss outside the Catawba-Wateree Basin	6.9	9.5	16.8
Estimated Total IBT, Avg. Day	**28.2**	**57.5**	**69.1**

These values reflect the estimated cumulative IBTs for utilities with IBTs greater than 1.0 MGD. While the estimates are suitable for the IWRP's basin-level planning, individual utilities may refine their projections for future IBT certification or permitting processes.

4.4.3 Scenario Evaluation: Returning Wastewater to the Catawba-Wateree Basin

To better understand the potential influence of IBT on Basin conditions, the IWRP team evaluated a hypothetical scenario in which all forecasted wastewater discharges outside the Basin were returned, as depicted in Figure 4-18. This scenario was not intended to reflect the practical feasibility of the scenario, nor does it account for regulatory, infrastructure, or operational constraints. Instead, the scenario is intended to provide a conceptual understanding of the overall potential effect of water transfer volumes (existing and future) on reservoir performance.

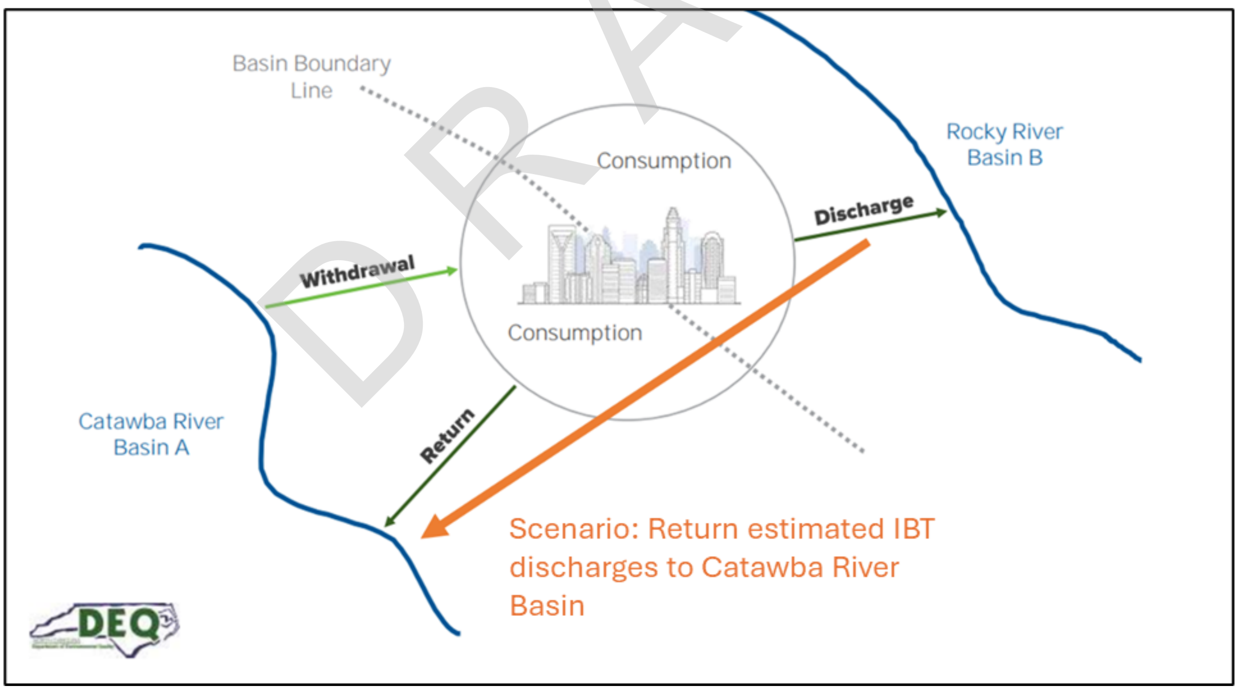

Figure 4-18. IBT Wastewater Return Scenario Infographic

Using the CHEOPS model, the estimated out-of-Basin wastewater discharge volumes through 2075 were returned to subbasins within the Basin. The return locations were based on existing discharge locations for a utility's treatment plant or a logical alternate location. The scenario was modeled against the drought of record (2006-2009) to evaluate potential effects on water supply availability at the Basinwide and subbasin level. Key performance measures were used to access changes in system behavior, including:

- Days spent in LIP stages
- Reservoir elevation trends
- Number of days with reservoir levels more than one foot below the applicable Critical Reservoir Elevation

At the Basin-wide level, the LIP represents three criteria that cover the drought conditions at any given time for the entire Basin, where Stage 4 is extreme drought and Stage 0 is a drought watch, as described in Sections 4.2.5 and 4.3. IBTs impact reservoir storage, which is one of the three LIP criteria. Under the IBT return scenario, the model results showed a 34-day shift in duration of Stage 2 (severe drought) to Stage 1 (moderate drought), indicating an overall potential improvement in reservoir performance during drought conditions across the Basin.

The modeled scenario also indicated effects at the localized, subbasin level. This was specifically applicable for Lake Wylie, which had impacted accessibility within the IBT discharge scenario planning window, i.e. through 2075,and is shown in Table 4-13.

- The number of days with the reservoir elevation more than 0.5 foot below the critical reservoir elevation threshold decreased from 42 to 4 days, resulting in 38 additional days of accessible water during a part of the drought of record duration (2006 to 2009).
- The lowest elevation improved by several feet under the discharge scenario, providing a potential increased buffer during drought conditions.
- The Decision Point Year, or year when water accessibility would be impacted as qualified by 3 or more consecutive days below the defined threshold, for Lake Wylie remained unchanged (2025-2035) when using the 0.5 ft below CRE threshold. The Decision Point Year is extended beyond 2035 but is exceeded before the next demand milestone year when using the 1.0 ft below CRE threshold (2055 includes 144 days 1.0 or more feet below the CRE).

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Table 4-13. IBT Discharge Return Scenario Days below CRE Thresholds

IBT DISCHARGE RETURN SCENARIO				
Definition	The IBT Discharge Return Scenario is based on conditions outlined in the CRA established under the current FERC License for the Catawba-Wateree Hydro Project, including the LIP, and a modified 50th percentile *most likely* water demand forecast for 2035 and 2055 whereby all estimated WWTP Discharges detailed in Table 4-12 are returned to C-W Basin. Results are to support a conceptual understanding of the overall potential effect of water transfer volumes (existing and future) on reservoir performance.			
Reservoir	**# Days during Drought of Record Years (2006-2009) Below Defined Threshold**			
	0.5 ft Below CRE Threshold		**1.0 ft Below CRE Threshold**	
	2035	**2055**	**2035**	**2055**
Lake James	0	0	0	0
Lake Rhodhiss	0	0	0	0
Lake Hickory	0	0	0	0
Lookout ShoalsLake	0	0	0	0
Lake Norman	0	0	0	0
Mtn. Island Lake	0	0	0	0
Lake Wylie	4	147	0	144
Fishing Creek Reservoir	0	0	0	0
Great Falls Reservoir	0	0	0	0
Cedar Creek Reservoir	0	0	0	0
Lake Wateree	0	0	0	0

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While the scenario demonstrates that returning discharge flows to the Basin could improve system performance, particularly at the subbasin level, the scenario also reinforces that the removal of IBTs are not a standalone solution to support water accessibility in the Basin. The benefits are localized and do not eliminate the need for broader water supply planning, demand management, infrastructure investment, or coordinated drought response.

4.4.4 Governance and Planning Considerations for IBTs

Long-term water sustainability requires not only technical planning but also thoughtful governance. As utilities and regional partnerships work to meet future demand, the regulatory frameworks that shape water movement across basins play a critical role in determining what solutions are feasible.

National guidance, such as the American Water Works Association's 2050 initiative, emphasizes watershed-based thinking and regional coordination as foundational elements of sustainable water management. These concepts encourage planning that reflects hydrologic systems rather than political boundaries and offer a useful lens for evaluating IBT policy.

In North Carolina, the regulation of IBTs at the sub-basin level presents challenges for regional coordination. Recent legislative changes have begun to address this issue. For example, sub-basin designations were removed for the Haw River and Deep River within the Cape Fear River Basin, and for Contentnea Creek within the Neuse River Basin, eliminating the requirement for IBT certification for transfers between these sub-basins. These changes offer greater flexibility for managing water transfers within major basins and reflect a broader shift toward watershed-based governance with a recognition of the need for greater regulatory and policy-based enhancements to allow flexibility in regional coordination and cooperation.

As regional planning continues to evolve, regulatory agencies and utilities each have a role to play in advancing sustainable approaches to IBTs. Regulatory frameworks that enable watershed-based planning can help ensure that viable, sustainable solutions remain accessible to regional partnerships. At the same time, utilities with existing or potential future IBTs should actively evaluate alternatives that reflect their specific system context. This evaluation includes assessing infrastructure feasibility, cost-benefit tradeoffs, and potential impacts on basin conditions. Such analysis is essential to informing future decisions and supporting broader regional coordination.

While perspectives vary on the appropriate scope of IBT regulation, ongoing dialogue around watershed-based governance may help identify opportunities to balance sustainability, reliability, and regional collaboration.

4.4.5 2010 Settlement Agreement Alignment

The 2010 US Supreme Court case settlement agreement between South and North Carolina regarding equitable apportionment of the Catawba River requires the CWWMG to serve as an active participant in future planning efforts within the Basin. In accordance with this obligation, the CWWMG affirms the requirements summarized in the agreement, which includes providing notice of IBT applications to all water users in both States, preparing environmental impact statements for proposed IBTs, developing written findings of fact regarding necessity and reasonableness, and assessing potential effects during drought conditions. Additional provisions include the applicant’s responsibility to justify proposed IBTs and the states’ preparation of annual reports detailing average daily transfer amounts for each entity holding an IBT certificate. See Appendix I for the full settlement agreement language.

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Water Quality Evaluations

Section 5

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5 Water Quality Evaluations

5.1 Introduction to Water Quality

5.1.1 Why Does Water Quality Matter for Water Supply Management?

Management of water supply includes both the amount of available water (i.e., water quantity) and the condition or quality of the water resources (i.e., water quality). Water quality affects the safety and suitability of water for various uses such as drinking water supply, irrigation, commercial processes, recreation, and power generation. Clean water is necessary for public and ecosystem health. Impaired water quality can lead to increased treatment costs and limitation of use for its intended purposes (e.g., irrigation, swimming, fishing). Therefore, comprehensive management of both water quantity and quality is evaluated in the 2025 IWRP.

5.1.2 What is Water Quality?

Water quality is generally defined as the physical, chemical, and biological characteristics of water. It is a comprehensive measure encompassing everything from presence of pathogens, sediment and other pollutants to the water's temperature, dissolved oxygen concentration, and pH.

Characteristic	Example Parameter
Physical	Turbidity Total Solids Temperature Color Specific Conductance
Chemical	pH Dissolved Oxygen Nutrients Heavy Metals PFOA/PFAS Pharmaceuticals Polychlorinated Biphenyls Pesticides
Biological	Bacteria (Fecal Coliform) Algae Viruses

Monitoring data from streams, rivers, and lakes within the Basin are used to assess water quality. When there are numeric water quality standards (WQS), data are compared against these standards to determine the water quality condition and/or the degree of impairment. When numeric standards or published descriptive criteria are not available, a qualitative or visual assessment is conducted to determine the water quality condition relative to a reference condition or as determined by professional judgement.

5.1.3 What Factors Affect Water Quality?

Water quality in lakes, streams, and rivers is influenced by a variety of natural, human, and environmental factors through the water cycle. The cycle begins with precipitation falling on the land surface. Precipitation either runs off the land surface via overland processes or infiltrates into the soil. Infiltrated water can then either travel laterally through the soil layers to the stream network or seep into the deeper groundwater aquifer. Nonpoint source (NPS) pollution is water contamination from diffuse sources. Surface and shallow subsurface runoff can pick up pollutants from various sources, e. g., farms, cities, construction sites, and lawns. These sources allow the transportation of these pollutants into local waterways.

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Examples of NPS pollution include:

- **Agricultural runoff:** Fertilizer, pesticides, and animal waste washed off farm fields by rainwater into nearby streams and rivers.
- **Urban runoff:** Stormwater carrying pollutants like oil, grease, heavy metals, fertilizers, sediment, and bacteria from streets, parking lots, lawns, and construction sites.
- **Atmospheric deposition:** Pollutants transported through the air and deposited onto land and water surfaces through rain, snow, or dry deposition.
- **Forestry practices:** Sediment and nutrient runoff from logging operations and forest roads.

Nonpoint sources of pollution exist across the Basin and vary from forested sources in the headwaters of the upper Basin, to a mixture of forested, agriculture, and suburban sources in the Piedmont, to mainly urban runoff in the Charlotte metropolitan area and other growing cities of the lower Basin. Pollution from atmospheric deposition is variable and dependent upon short-range (e.g., ammonia from high density agricultural operations) and long-range (emissions from industry hundreds of miles away) upwind sources and local topography which influences precipitation volume.

While NPS pollution occurs from an indirect source, point sources of pollution originate from a single location, typically a discharge pipe. Point sources of pollution often require a permit (i.e., National Pollutant Discharge Elimination System) issued by the relevant state agency for volume and mass and/or concentration to discharge effluent to receiving waters. Point sources include, but are not limited to, industrial wastewater, municipal wastewater or sewage treatment facilities, and animal feeding operations. In the Basin, there are over 350 permitted discharges of pollution. Permits help protect water quality by specifying an acceptable level of a pollutant (e.g., bacteria, nutrient, sediment) that can be present in the discharge. State agencies administer the permits and have the responsibility of enforcing the limits established in the permit. Major dischargers report flow and effluent mass and/or concentrations to national monitoring systems at specified intervals. These data have been obtained to quantify the influence of point sources on Basin water quality.

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5.1.4 What are Ways to Protect or Restore Water Quality?

The primary goal of the Clean Water Act (*Title 33 U.S. Code, Chapter 26*) is to restore and maintain the chemical, physical, and biological integrity of the nation's waters by regulating point source discharges of pollutants, setting WQS for surface waters, and reporting on quality of the nation's waters. When monitoring and assessment data indicate that a surface water does not meet applicable WQS or designated use, the waterbody is referred to as an *impaired water* and placed on the U.S. Environmental Protection Agency (USEPA) Section 303(d) list (Refer to Section 5.2.1 for more information on impaired waters in the Basin). For these impaired waters, a total maximum daily load (TMDL) must be established for all pollutants preventing the attainment of the WQS. A TMDL is the maximum amount of a pollutant that a waterbody can receive and still meet WQS. The TMDL plan allocates the amount of pollution to point and nonpoint sources and plans for achieving pollutant reductions and for measuring the effects of the plan. Point sources are managed by permit limits while nonpoint sources are managed by state and local programs.

The Clean Water Act also manages nonpoint sources of pollution through state and tribal watershed management programs. These programs focus on human sources of impairment to either prevent or reduce the creation at the source or treat the degraded water through best management practices before pollutants enter rivers, lakes and streams. These programs assist state and local governments and non-governmental organizations implement water quality projects.

5.1.5 How do State Governments Protect and Restore Water Quality?

North Carolina (NCDEQ) and South Carolina (SCDES) have assigned state WQS commensurate with a designated use of a waterbody and both states have similar categories of designated use. Variations of sub-sets of general classifications between the two states exist; however, both states have recognized and distinguished between general use to maintain and support aquatic life and general contact recreation, trout habitats, and high value resource areas. Both agencies establish appropriate water uses and protection classifications, as well as, general rules and specific water quality criteria to protect existing water uses, establish anti-degradation rules, protect public welfare, and maintain and enhance water quality.

5.1.6 What are Ways to Assess Water Quality?

Water quality can be assessed directly through the collection of monitoring data or by applying values provided in published literature, which can be used to estimate pollutant loading entering a waterbody when details or observations on the contributing sources do not exist or are unavailable. Empirical or statistical relationships are another way to estimate pollutant loads. Models provide another approach for estimating pollutant loads by using a set of equations to describe watershed processes. Compared to using current monitoring or historical data, models can provide more detail on watershed processes (e.g., runoff, infiltration), adapt to local conditions such as soil and slope, and represent changes in land use and management practices.

This IWRP relies on a combination of methods to assess water quality in the Basin including summarization of monitoring data, modeling of sediment and nutrients (specifically total nitrogen [TN] and total phosphorus [TP] with WaterFALL), and published literature and previous assessments of other critical water quality concerns.

5.2 Water Quality Issues in the Basin

Many water quality concerns within the Basin stem from the impacts of nutrients and sediment on aquatic health and reservoir operations. Both parameters have significantly contributed to water quality degradation throughout the Basin.

Sediment loads can reduce the available storage capacity in reservoirs and transport adsorbed nutrients and other contaminants of concern, such as metals. High nutrient concentrations (such as TN and TP) can lead to eutrophication and algal blooms in reservoirs, resulting in ecological impairment and the potential production of waterborne toxins.

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5.2.1 Reported Impairments and Concerns

An inventory of impaired streams and lakes in the Basin was compiled using the USEPA Assessment and TMDL Tracking and Implementation System (ATTAINS) geospatial data. Data from the most recent approved §303(d) lists were used: the 2024 list for South Carolina and the 2022 list for North Carolina.

Based on Table 5-1, which displays the count of impaired catchments (streams or lakes) by subbasin and impairment type, the most prevalent water quality issues in the Basin are polychlorinated biphenyls (PCB) and turbidity impairments. Pathogen impairments are also a major concern, affecting many catchments across several subbasins, notably Lake Rhodhiss, Fishing Creek Reservoir, and Below Wateree. Spatially, turbidity impairments are most pronounced around Lake Norman, consistent with observations in tributaries in that region of North Carolina. Conversely, nutrient impairments and oxygen depletion impairments are more concentrated in the lower basin, primarily in the Fishing Creek, Cedar Creek, Great Falls, Wateree, and Below Wateree subbasins in South Carolina.

Table 5-1. Count of Impaired Catchments in the Catawba-Wateree River Basin by Subbasin and Impairment Parameter

Subbasin	Nutrients	Oxygen Depletion	Turbidity	Algal Growth	Pathogen	PCBs	Total
James	0	0	0	0	0	0	0
Rhodhiss	0	0	0	0	34	0	34
Hickory	0	0	0	0	0	0	0
Lookout Shoals	0	0	0	0	0	0	0
Norman	0	0	127	0	0	127	254
Mountain Island	0	0	3	0	0	13	16
Wylie	0	0	15	0	10	46	71
Fishing Creek	4	6	9	0	30	3	52
Cedar Creek	5	1	5	0	6	2	19
Great Falls	7	1	6	0	6	0	20
Wateree	5	2	1	1	3	2	14
Below Wateree	1	6	13	0	20	13	53
Grand Total	**22**	**16**	**179**	**1**	**109**	**206**	**533**

The spatial distribution of water quality impairments across the Basin is illustrated by Figure 5-1 and Figure 5-2. These figures reveal that turbidity and nutrient impairments, while geographically distinct, are generally prevalent across the middle and lower parts of the Basin. Dissolved oxygen depletion is primarily observed in the lower subbasins. Notably, within the four most upstream subbasins, pathogen impairments in Rhodhiss are the only listed impairment, indicating the headwaters are relatively less affected overall. Figure 5-2 spatially depicts the widespread presence of PCB impairments found throughout the central and lower Basin.

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Pathogen impairments are also a pervasive issue, particularly visible in the central portion of the watershed. Currently, algal growth impairments affect a minimal number of catchments.

From a subbasin standpoint, Norman has by far the most impairments, with 254, accounting for nearly half of the Basin's total of 533. The next highest subbasins are Wylie with 71 and Below Wateree with 53. Interestingly, Norman's impairments are limited to just two parameters—turbidity and PCBs—whereas Below Wateree's impairments are distributed across almost all parameters, including nutrients, oxygen depletion, turbidity, pathogens, and PCBs. This contrast highlights both the intensity of impairments in Norman and the diversity of water quality challenges in Below Wateree.

Overall, the Basin's water quality challenges are driven by a combination of widespread turbidity, PCB, and pathogen impairments that vary by subbasin and reflect both local land-use pressures and downstream accumulation effects. While the upper headwaters remain far less impacted, the middle and lower Basin exhibit a diverse mix of impairments that require targeted management strategies. These spatial patterns underscore the need for area-specific restoration and monitoring efforts to address water quality concerns in each subbasin and support long-term improvements in watershed health.

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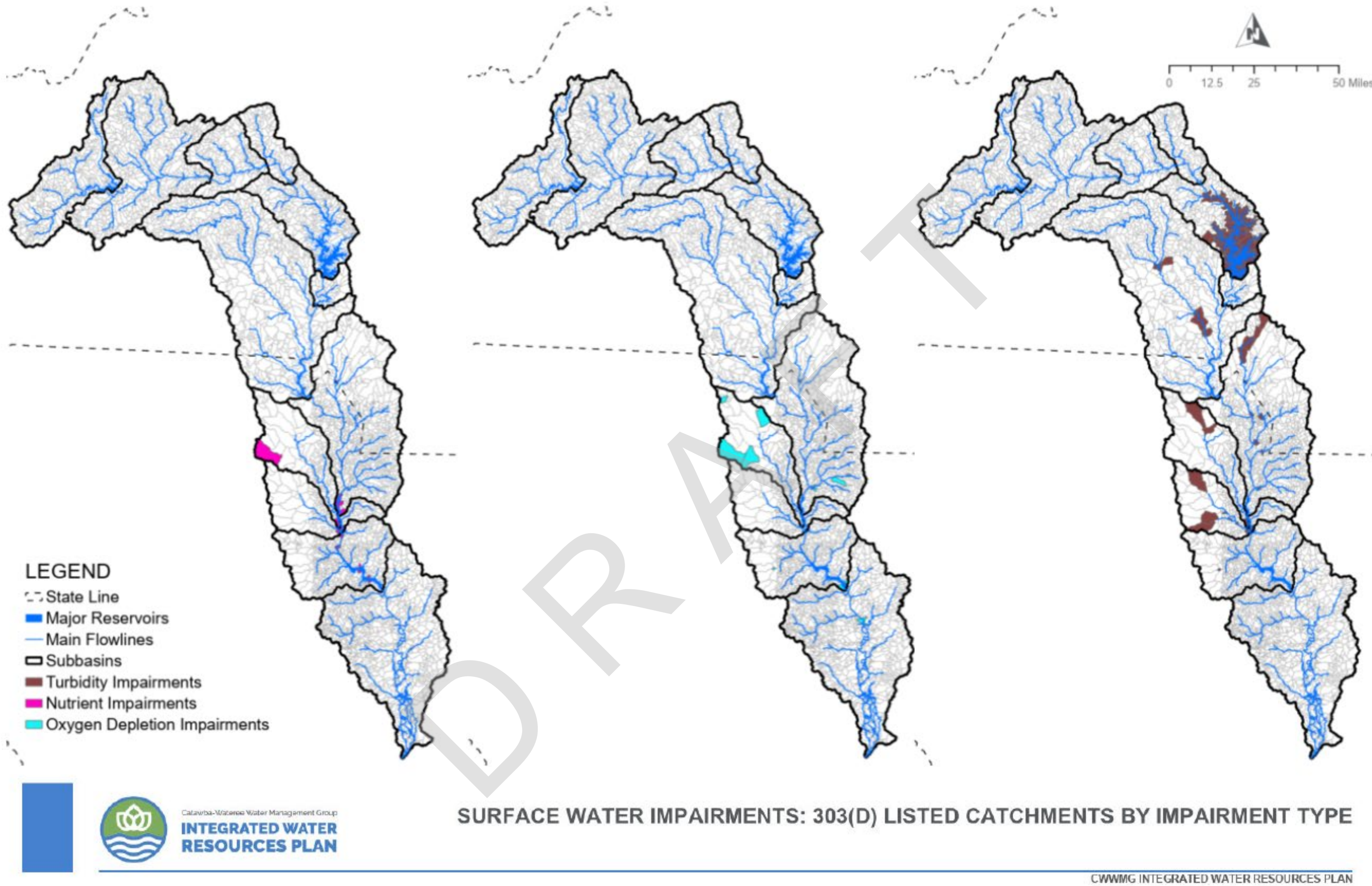

Figure 5-1. 303(d) Listed Impairments for Turbidity, Nutrients, and Dissolved Oxygen Depletion in the Basin from USEPA ATTAINS

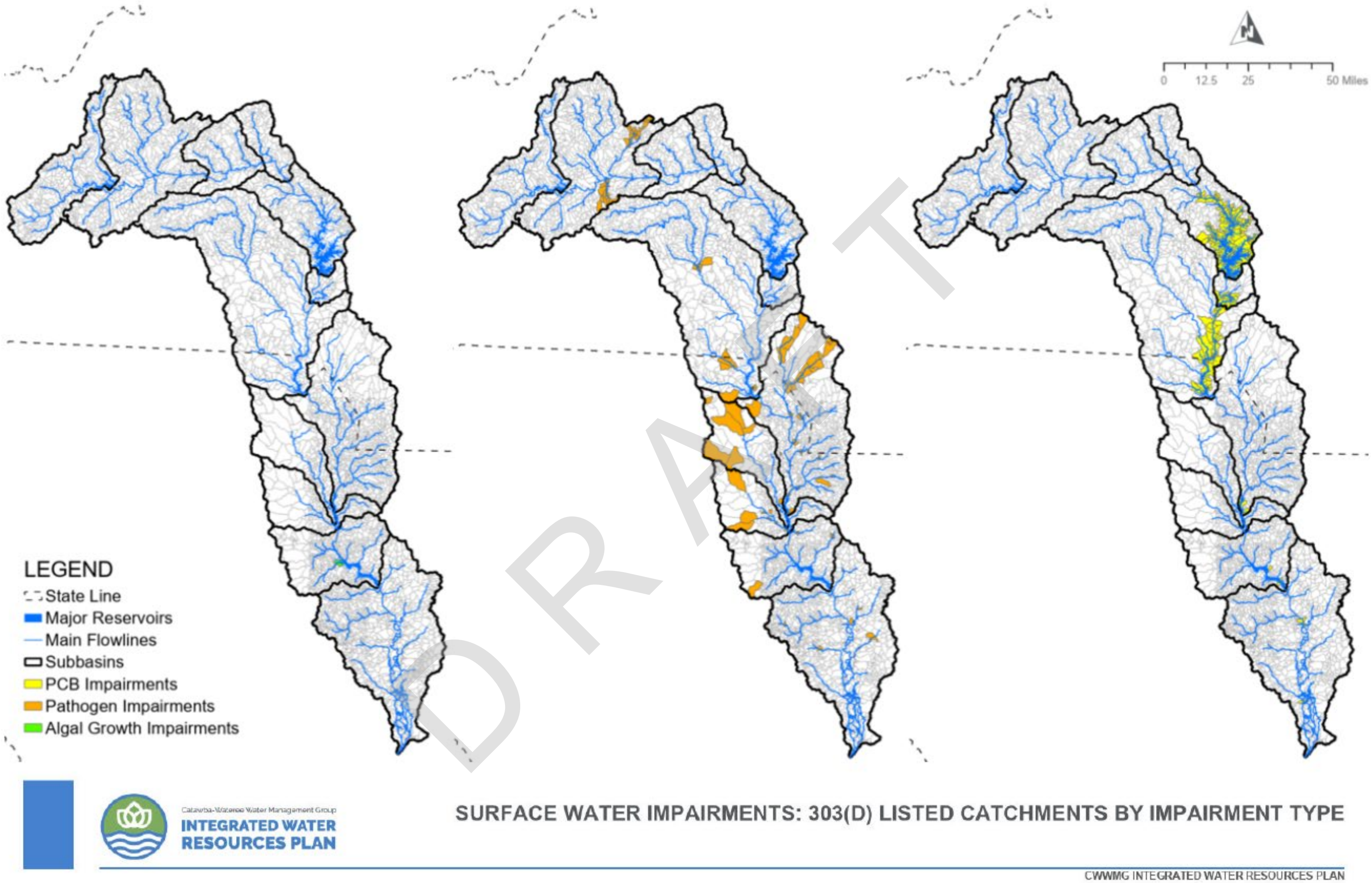

Figure 5-2. 303(d) Listed Impairments for PCBs, Pathogens, and Algal Growth in the Basin from USEPA ATTAINS

5.2.2 Lower Catawba River Basin (LOWCARB)

The Lower Catawba River Basin (LOWCARB) Dischargers Group was formed in 2017 to address impaired waters on the §303(d) list and is actively engaged in comprehensive initiatives to manage water quality in the LOWCARB. The area of focus is from the discharge of Lake Wylie to the dam at Lake Wateree. These efforts are driven by the need to address existing nutrient levels causing or contributing to water quality problems and harmful algal blooms (HABs) and to set new, site-specific WQS that the existing ecoregion-based numeric nutrient criteria may not adequately address.

LOWCARB Dischargers Group
- Charlotte Water
- Charlotte-Mecklenburg Stormwater Services
- Chester County
- City of Lancaster
- Fort Mill, SC
- Lancaster County
- New-Indy Catawba, LLC
- Rock Hill, SC
- Union County (NC)
- York County

The LOWCARB has faced long-standing water quality issues related to nutrients and chlorophyll-a requiring the development of TMDLs. In 2016, SCDES proposed aggregate phosphorus and nitrogen reductions for both point sources and nonpoint sources, prompting LOWCARB to request additional study. These efforts involved extensive field data collection and analysis to improve the understanding, beyond routine ambient monitoring, of the system's physical conditions and ecology.

5.2.2.1 MONITORING IN THE LOWER CATAWBA RIVER BASIN

LOWCARB arranged for intensive data collection in 2017-2018, and SCDES and USEPA conducted additional intensive data collection in 2019-2021, which included continuous data collection using buoys, wet weather sampling, benthic sampling, algal growth potential and group composition, and discharge measurements at Fishing Creek Reservoir and Lake Wateree (USEPA 2019; Bell et al. 2025). The full database, including information from the last 25 years, has been shared with modeling groups. Data are being evaluated against national models of biological response to nutrient loading.

5.2.2.2 ASSESSMENT OF MONITORING DATA AND CRITERIA DEVELOPMENT

The LOWCARB Dischargers Group sponsored science-based analyses of existing monitoring data and current water quality assessment methods to develop an innovative approach for developing chlorophyll-a criteria. Based on the analysis, the LOWCARB Group proposed different targets for each reservoir based on the designated uses of the waterbody (i.e., primary/secondary recreation, drinking water supply, aquatic life, and industrial/agriculture use). Attainment of these targets should be based on seasonal (April–October) geometric mean of chlorophyll in the photic zone (the uppermost layer of the reservoir where sunlight can penetrate, allowing for photosynthesis), with an allowable frequency of exceedance not to exceed one in three years (Bell et al. 2025). Methods proposed include evaluating the criterion at one site in the lake or spatially averaging values for different areas within the reservoir. LOWCARB's recommendation of chlorophyll-a criterion for Lake Wateree is 25 micrograms per liter (ug/L), which translates to a 20–30% reduction from current condition. SCDES is currently reviewing these recommendations and will undergo broader review through the state's triennial review of WQS.

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In parallel, SCDES partnered with the USEPA's Nutrient Scientific Technical Exchange Partnership & Support (N-STEPS) program to perform similar modeling. Both groups used the same data and tools, with a goal of direct comparison and reconciliation of their proposed criteria.

5.2.2.3 MODELING

SCDES contracted with Tetra Tech to develop, in four reservoirs in the Basin, sophisticated LSPC (Loading Simulation Program in C++) watershed and EFDC (Environmental Fluid Dynamics Code) hydrodynamic and water quality models for the Basin. The models are in their late stages of development with the current focus on refining predictions for lake stratification and phosphorus calibration.

5.2.2.4 FUTURE DIRECTION AND TMDLS

SCDES will evaluate the results from both approaches to propose criteria. The goal of the models is to propose a draft TMDL using the new, site-specific criteria, with endpoints for nitrogen, phosphorus, and chlorophyll-a. If possible, a target for microsystin (a type of toxin produced by certain species of cyanobacteria, also known as blue-green algae) may be added to the existing criteria.

5.3 Basin-Wide Water Quality Assessments

The WaterFALL model was used to simulate daily streamflow and the associated nutrient (TN and TP) and total suspended solids (TSS) loading from each subbasin and collectively for all watersheds in the Basin. The WaterFALL model results characterize current and future water quality and the effect of different mitigation strategies. Sediment and nutrient loads are tracked from their sources through the watershed so that the relative contribution (and location) of different pollutant sources can be assessed.

WaterFALL considers the following sources to characterize water quality effects in the Basin:

- **Land use and soils condition-based surface generation and transport via runoff** – each land use type was characterized by soil erosivity parameters (e.g., erosivity factor, slope, slope length, cover management factor) that determine how much sediment is loosened and transported across the land surface based on the amount of precipitation on any day. For nutrients, each land use type was characterized by the average concentration of dissolved TN and TP within runoff and the particulate TN and TP concentrations attached to the soils associated with that type of land use. Nutrient loads were transported on days with runoff where dissolved and particulate loads are summed into a total load.
- **Transport with baseflow** – infiltrated water from the surface (i.e., precipitation that does not run off the land) brings TN, TP, and sediment to the saturated subsurface. As water leaves this subsurface compartment, it brings with it loads from the completely mixed subsurface between background concentrations and infiltrated loads.
- **Streambank erosion** – bank erosion was evaluated by classifying each river segment as having either high or low erosion potential based on physical and land use characteristics known to influence channel stability. In the absence of Basin-wide field data, a streamlined

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vulnerability index—adapted from methods used in prior North Carolina models—was applied to each catchment using criteria such as channel slope, impervious and agricultural land cover, soil erodibility, riparian vegetation condition, headwater status, and channel sinuosity. These characteristics and their associated thresholds were selected from published literature and previous modeling efforts to differentiate where substantial sediment loads are most likely to be mobilized during high-flow events. Catchments meeting multiple high-risk criteria were assigned a high erosion classification, with additional weight given to developed riparian areas due to their strong influence on bank instability. This approach provides a consistent, data-driven method for identifying reaches most vulnerable to erosion across the Basin.

- **Point sources** – information on permitted discharges, including location and discharged flow and loads over time, were obtained from USEPA reporting systems. Monthly time series of flow and loads were included as inputs to the corresponding river segment where the discharge occurs.
- **Septic systems** – the number of septic systems in areas of the Basin not covered by sewer systems was estimated based on a population dataset where an assumption of 2.3 people/septic system was used. A load of nitrogen from each septic system was incorporated into the subsurface loading that may be transported into the river network through baseflow.
- **External application of manure and/or fertilizer to cultivated croplands** – estimates of the mass of TN and TP added over cropland during a set period of each year. This mass was incorporated into the surface stores which can be eroded during runoff events.

A detailed explanation of the WaterFALL Model is available in Appendix A, WaterFALL Calibration Report.

As with water quantity described in Chapter 4, the IWRP considers the current water quality conditions and scenarios of future projected water quality due to land use and climate changes. Table 5-2 presents the metrics chosen to quantify the current water quality conditions and the projected changes that can potentially be managed in the future.

Table 5-2. Water Quality Metrics Selected to Describe Conditions Across the Basin and Scenarios

Metric	Definition	Units	Scale	Metric Interpretation
Concentration	Daily concentration (mass per volume) in each stream segment	mg/L	Catchment & tributary	Catchments used to identify current areas of concern and variations across Basin; tributaries used to identify focus areas for future hot spots.
Surface Load	Mass of constituent generated per catchment area	lbs/acre	Catchment	Quantifies the impacts of the land surface in contributing NPS loads. Using the load per area allows direct comparisons across different catchments.

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Metric	Definition	Units	Scale	Metric Interpretation
Load to Reservoir	The cumulative load entering a reservoir from the river network or lakeshore during the specified time interval	tons/year	Reservoir & tributary	Annual load and range in annual loads to reservoirs inform potential water quality concerns. Annual loads by tributary identify portions of the Basin with the greatest contributions of constituent loads.
Sediment Accumulation	Volume of sediment expected to settle in each reservoir	acre-feet	Reservoir & tributary	Based on assumed density, estimates the storage volume lost due to sedimentation each year.

mg/L=milligrams per liter; lbs=pounds

5.3.1 Concentrations in Rivers and Streams

While South Carolina has WQS for TSS, TN, or TP in lakes and reservoirs (of a certain size), neither state has WQS for these parameters in rivers and streams. Therefore, current and future conditions are evaluated using regionally applicable values for nitrogen and phosphorus, and a statistical relationship between TSS and turbidity (criteria for turbidity are available) developed using data collected in the Basin. Median constituent instream concentrations are calculated for each subbasin from WaterFALL simulation output. The median value was selected for use in this evaluation because its robustness against extreme values (outliers), like a sudden pollution event, provides better confidence in typical/normal conditions. These values are compared to available criteria and across scenario results to illustrate current conditions relative to a healthy ecological condition and to show how water quality conditions are predicted to change under future land use and climate scenarios.

5.3.1.1 TOTAL SUSPENDED SOLIDS CONCENTRATIONS

Both North and South Carolina have WQS for turbidity in rivers and streams, which is a measure of clarity (i.e., cloudiness) in a fluid determined by the amount of light scattered by suspended particles in the fluid. Turbidity is usually measured in nephelometric turbidity units (NTU) and can be used to estimate TSS by developing a mathematical relationship (i.e., correlation) between the two parameters using observed data. To determine this relationship, 23 years of data (1994–2017) from 135 sites within Mecklenburg County were used. Turbidity (measured in NTU) and TSS (measured in mg/L) were determined to have a statistically

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significant (R^2 = 0.83) linear relationship across the dataset (

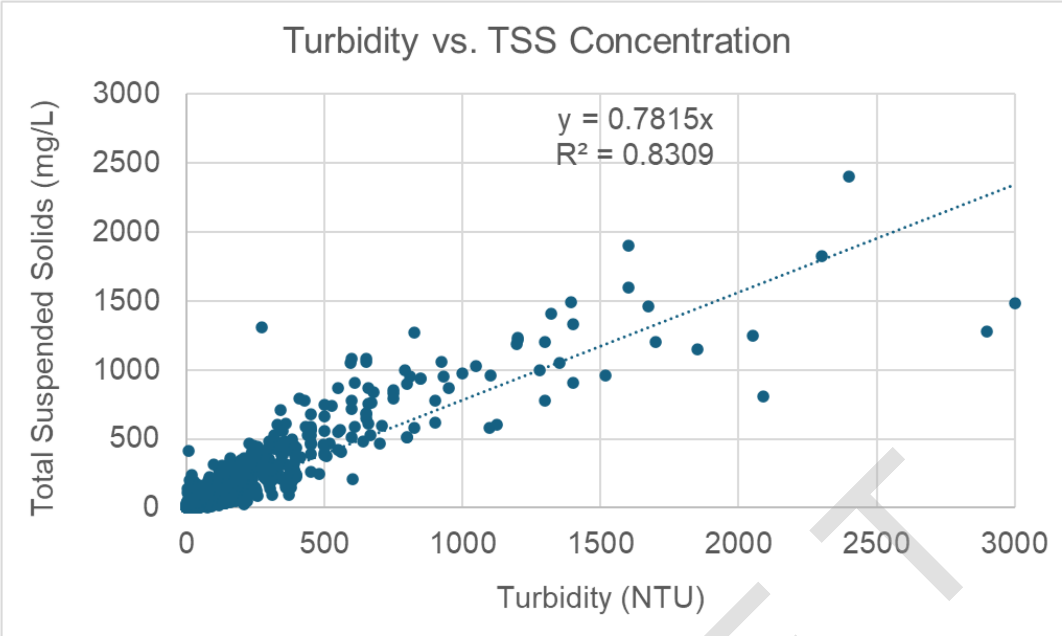

Figure 5-3).

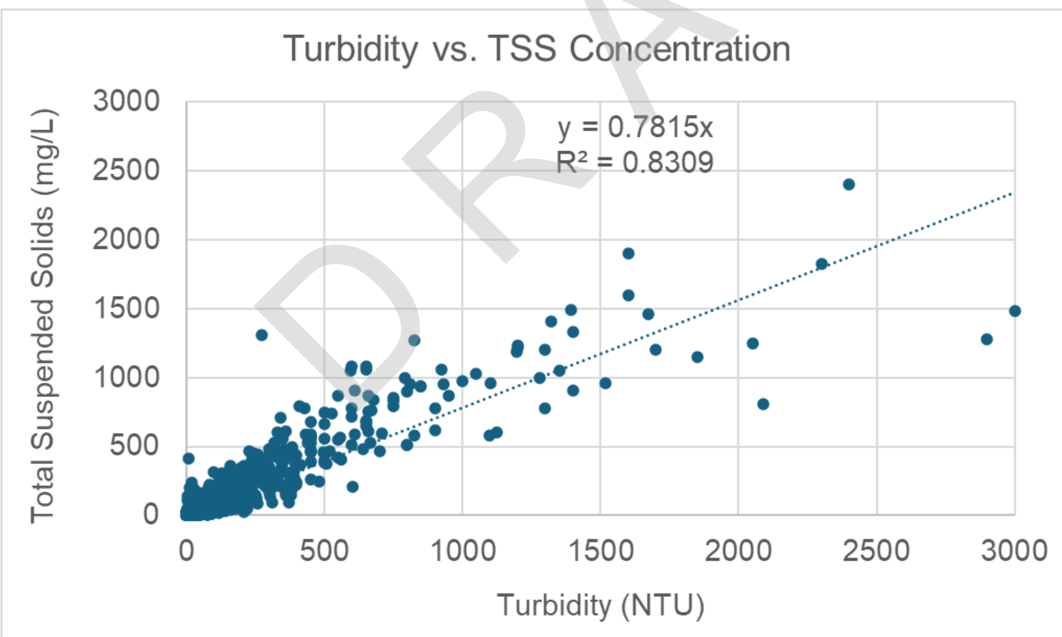

Figure 5-3. Relationship Between Turbidity and Total Suspended Solids Concentrations Determined from Observed Data (1994-2017).

The relationship was used to translate turbidity WQS into TSS criterion to evaluate water quality modeling results for the IWRP (Table 5-3). In North Carolina, turbidity standards are provided for trout and non-trout waters. Trout waters are limited to the headwater tributary areas of the

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James, Rhodhiss, Hickory, and South Fork subbasins, as well as one mainstem stretch of the Catawba River just downstream of Lake James (Figure 5-4), all located in North Carolina. South Carolina has similar turbidity WQS for trout waters vs. non-trout waters; however, it also includes a lake-only turbidity threshold. For the IWRP, the TSS criteria of 8 mg/L and 39 mg/L were used for trout and non-trout waters, respectively.

Table 5-3. Compilation of Numeric Criteria and Thresholds Identified for Sediment-Related Parameters

Source	Applicability	Qualifier	Turbidity Criteria (NTU)	Calculated TSS Concentration (mg/L)
NC WQS	Streams not designated as trout waters; Class C waters	Not to exceed	50	39
	Streams, lakes, or reservoirs designated as trout waters; Class C waters	Not to exceed	10	8
SC WQS	Freshwaters. Except for lakes.	Not to exceed provided existing uses are maintained	50	39
	Trout waters	Not to exceed	10 NTU or 10% above natural conditions, provided uses are maintained	8

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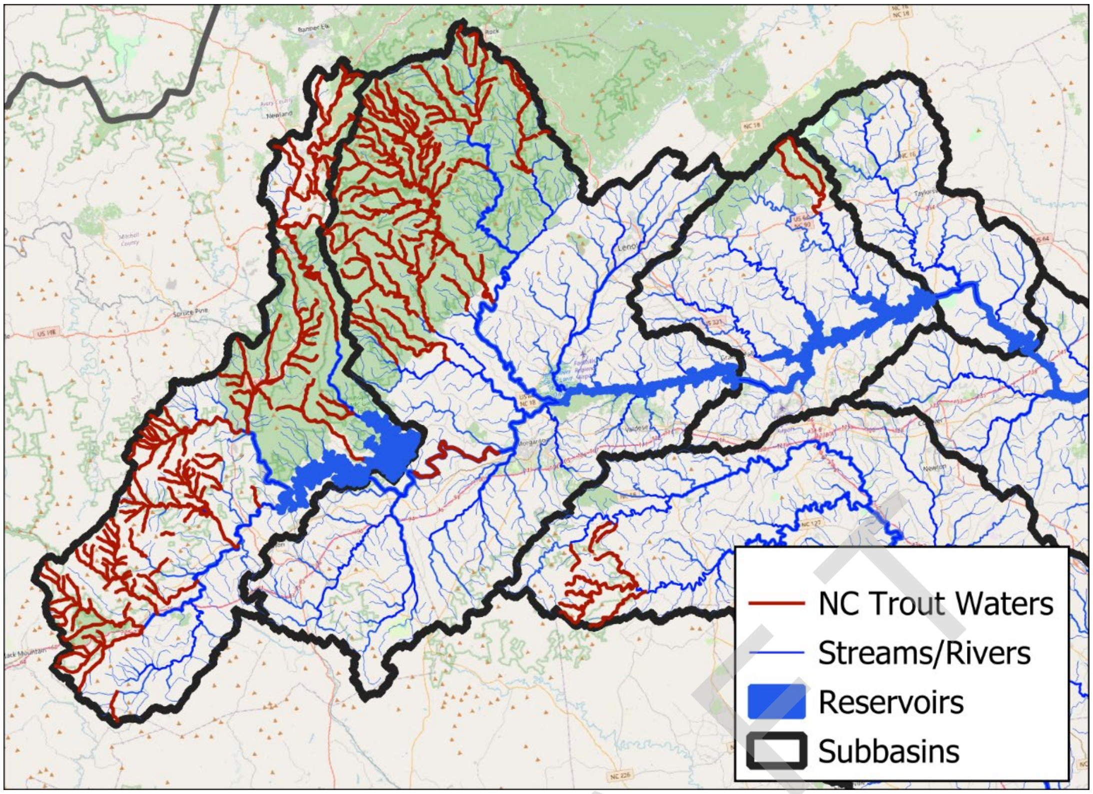

Figure 5-4. Designated Trout Waters within North Carolina

The current turbidity condition simulation indicates that, in trout waters, the median value is less than the water quality criteria. Episodic exceedances of the criteria occur during high discharge events when surface runoff mobilizes overland erosion and sediment transport, and perhaps during temporary periods of land disturbance.

Results indicate the current condition median simulated TSS values exceed the WQS for non-trout waters in isolated catchments in the central and southern portions of the Basin (Rhodhiss, Norman, Mountain Island, South Fork, Fishing Creek, and Below Wateree subbasins). This indicates these isolated locations are generating high sediment loads relative to other portions of the watershed, and the established water quality criteria are exceeded on most days. Potential causes of exceedances of the 50 NTU/39mg/L threshold include degraded riparian area integrity, nearby agricultural operations, and land disturbance.

Maps B, C, and D on Figure 5-5 illustrate the simulated percent change in median daily TSS values from current condition (Map A) under Future Land Use, Future Land Use & Hot/Dry climate, and Future Land Use & Warm/Wet climate scenarios, respectively. The results indicate that:

- Median in-stream TSS concentration is expected to either stay the same or increase in most subbasins (there are a few isolated locations where concentration is expected to decrease).

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- The transition to future land use will have some impact on in-stream TSS concentrations, and that impact is focused on the portion of the watershed between Lake Norman and Lake Wylie.
- The Future Land Use & Hot/Dry climate scenario will have the greatest impact on in-stream TSS concentrations, resulting in significant increases in concentrations in the central portion of the watershed.
- Concentrations predicted in the Future Land Use & Warm/Wet climate scenario are lower than the Future Land Use & Hot/Dry climate scenario. The dominant driver of this relationship is the increase in streamflow generated by the wetter climate forcing data.

It is important to note that high TSS concentrations do not necessarily translate to high loads. The load of sediment exported from a watershed and delivered to downstream waterbodies may actually decrease if increased concentration is offset by decreased water volume. Sediment loading is discussed in detail in the following section.

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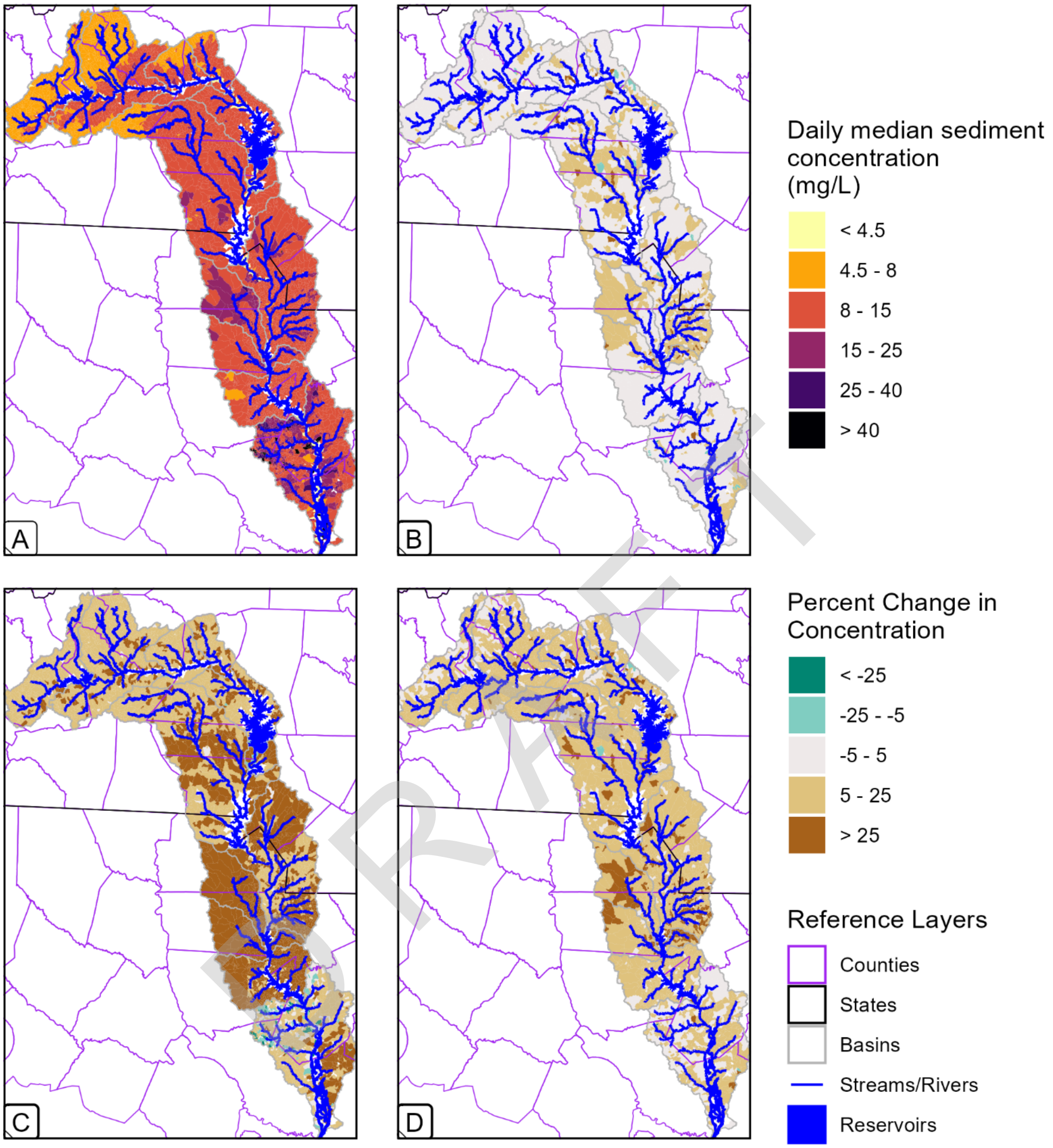

Figure 5-5. Assessment of Sediment Concentrations (mg/L) for all River and Stream Reaches Under Current Conditions (A) and Percent Change under the Scenarios of Future Land Use (B), Future Land Use & Hot/Dry Climate (C), and Future Land Use & Warm/Wet Climate (D)

Assessment of future changes to in-stream TSS concentrations use median (i.e., 50^{th}percentile) value across every stream segment within the subbasin with the minimum and maximum concentrations found displayed in parentheses (Table 5-4). Values in bold indicate an exceedance of the non-trout WQS. The Future Land Use scenario has greatest impacts in the Fishing Creek and Great Falls/Cedar Creek subbasins with significant increases to both the median and maximum concentrations. The climate change (with Future Land Use) scenarios

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impact in-stream TSS concentrations across all subbasins, with increases in both median and maximum concentrations across both scenarios beyond the Future Land Use changes alone. The increase in TSS concentration is greater for the Hot/Dry scenario than for the Warm/Wet scenario. This is expected because reduced water volumes under Hot/Dry conditions lead to less dilution, resulting in higher concentrations.

Table 5-4. Median (50th percentile) Daily TSS Concentrations in mg/L (with Minimum and Maximum) across River/Stream Segments within Each Subbasin

Subbasin	Current	Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
James	6.5 (0.1 - 10.4)	6.5 (0.1 - 10.5)	7.4 (0.1 - 12.3)	6.9 (0.1 - 12.4)
Rhodhiss	8.2 (0.1 - 16.3)	8.3 (0.1 - 16.3)	9.5 (0.1 - 21.5)	9.1 (0.1 - 19.2)
Hickory	9.4 (0 - 17.6)	9.6 (0 - 18.6)	11.1 (0 - 20.8)	10.4 (0.1 - 20.3)
Lookout Shoals	8.8 (0 - 12.8)	8.9 (0 - 13)	10.6 (0 - 15.8)	9.5 (0.1 - 14.5)
Norman	11.1 (0.1 - 21.4)	11.5 (0.1 - 21.9)	13.6 (0.1 - 31.6)	12.5 (0.1 - 26.9)
Mountain Island	10.6 (2.4 - 15.3)	11 (2.5 - 16)	14.1 (2.2 - 23.1)	11.9 (3.1 - 17.3)
South Fork	10.2 (5.3 - 18)	10.6 (5.3 - 18.7)	12.3 (5.9 - 31.2)	11.5 (5.8 - 19.2)
Wylie	11.3 (1.9 - 29.3)	11.8 (2.1 - 29.2)	14 (1.8 - 31.7)	12.6 (2.7 - 30.5)
Fishing Creek	11.8 (1.5 - 75)	12.5 (1.5 - 100)	15.1 (1.5 - 149)	13.7 (1.5 - 124.5)
Great Falls/Cedar Creek	12.8 (1.2 - 26)	13.9 (1.3 - 31)	21.4 (1.1 - 66)	15.9 (1.5 - 41)
Wateree	9.3 (1.2 - 14)	9.3 (1.3 - 14)	12.3 (1.1 - 20)	10.1 (1.5 - 15)
Below Wateree	**65.6** (1.4 - 1000)	**65.8** (1.5 - 1000)	**67.6** (1.2 - 1000)	**66.6** (1.5 - 1000)

Note: Bold values indicate exceedances of the 50 NTU (39 mg/L) WQS for freshwaters in both states.

5.3.1.2 TOTAL NITROGEN AND PHOSPHORUS CONCENTRATIONS

North Carolina has not established any nutrient standards for waters in the Basin. South Carolina has established WQS only for larger lakes (greater than 40 acres). Given the lack of specific WQS for most of the waters within the Basin, other sources of water quality thresholds were considered.

The USEPA published recommended nutrient criteria for ecoregions across the U.S. based on observed data from reference stream locations. Most of the Basin is in Nutrient Ecoregion IX, Level III Ecoregion 45 (Southeastern Temperate Forested Plains and Hills); therefore, the results described in the Rivers and Streams Nutrient Criteria Technical Guidance Manual (USEPA 2000) are used. In another study, McDowell et al. (2020) examined water quality challenges associated with eutrophication resulting in a set of global thresholds for TN and TP loading. These thresholds, based on acceptable levels of algal growth, are proposed for use in corporate water stewardship accounting by the Science Based Targets Network when there is

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an absence of local data (Science Based Targets Network 2023). The criteria are used as guides to evaluate the future scenarios (Table 5-5).

Table 5-5. Compilation of Numeric Criteria and Thresholds Identified for Total Nitrogen and Total Phosphorus

Source	Applicability	Qualifier	TN (mg/L)	TP (mg/L)
USEPA (2000)	Nutrient Ecoregion IX, Level III Ecoregion 45	25th Percentile	0.41 (calculated)	0.04
			0.62 (reported)	
	Nutrient Ecoregion IX Aggregate	25th Percentile	0.69	0.03
SC WQS	Lakes of forty (40) acres or more in Piedmont and Southeastern Plains ecoregions	Not to exceed provided existing uses are maintained	1.5	0.06
McDowell et al. (2020)	Global threshold concentration	Median concentration	0.8	0.05

The spatial distribution of median nitrogen concentration, and the percent change from current condition for the future land use and climate scenarios are presented in Figure 5-6. Simulated minimum, median, and maximum nitrogen concentrations are presented for the four selected model scenarios in Table 5-6.

The simulation of current conditions indicates that, with the exception of the James, Rhodhiss, Mountain Island, and Wateree subbasins, median nitrogen values exceed the USEPA and Science Based Targets Network criteria of 0.8 mg/L for TN (Table 5-6 and panel A of Figure 5-6). The results further indicate that excess nitrogen is available to fuel algae growth across the majority of the Basin. Common sources of nitrogen include atmospheric deposition, agricultural runoff, failing and/or inefficient point source and septic system treatment, excess fertilizer application in residential areas, and natural sources (e.g., litter fall in deciduous forests). The maximum simulated concentration exceeds the global criteria suggested by McDowell et al. (2020) and ecoregional criteria in all subbasins indicating that, even in relatively pristine environments, high nitrogen concentrations may exist for limited stream reaches with specific conditions. Instream concentrations are typically highest under low flow conditions.

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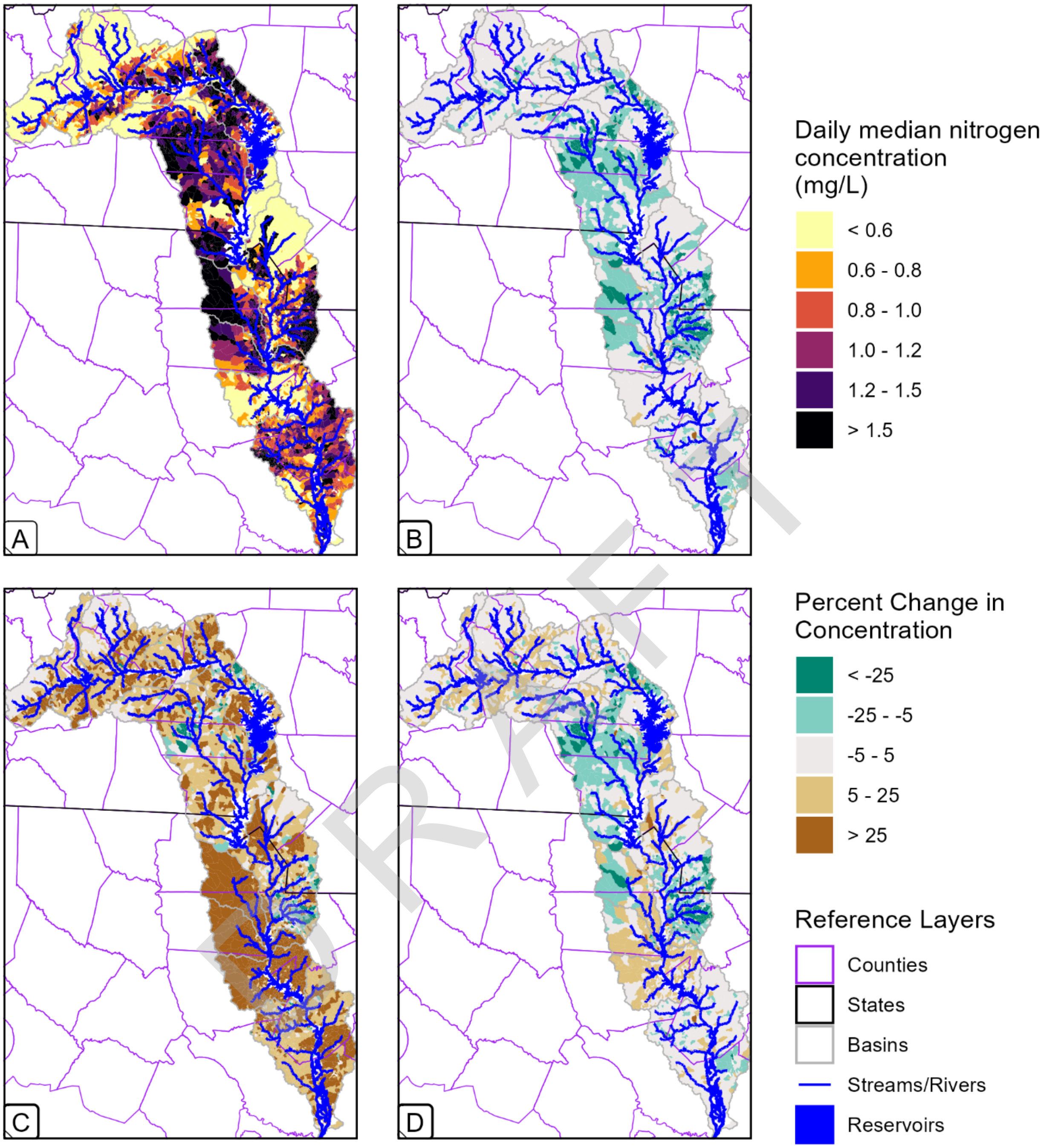

Figure 5-6. Assessment of Total Nitrogen Concentrations for All River and Stream Reaches Under Current Conditions (A) and Percent Change under the Scenarios of Future Land Use (B), Future Land Use & Hot/Dry Climate (C), and Future Land Use & Warm/Wet Climate (D)

Panels B, C, and D of Figure 5-6 illustrate the expected changes in nitrogen concentrations that result from land use and climate change, while Panel A displays the current nitrogen concentrations. Panel B indicates that Future Land Use is likely to create a decrease in river and lake nitrogen concentrations, particularly in the central portion of the watershed. Conversion of land from agricultural uses to residential uses is the dominant driver of this result. When future climate is considered along with the Future Land Use, results indicate that the Hot/Dry scenario will result in increasing nitrogen concentrations in surface waters, and that increase is distributed evenly across the Basin. Results are mixed under a Warm/Wet future climate. Increases in nitrogen concentrations are projected for the northern and southern portions of the Basin, while decreases in nitrogen concentrations are projected for the central portion. This decrease is driven by a combination of conversion of agricultural land to uses that receive less anthropogenic loading (e.g., agricultural to residential) and increased streamflows, while increases can result from additional loading resulting from increased streamflow, from development of forested lands, or a combination of these mechanisms.

Table 5-6. Median Daily Nitrogen Concentrations (with Minimum and Maximum) across River/Stream Segments within Each Subbasin

Subbasin	Current	Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
James	0.4 (0.1 - **1.2**)	0.4 (0.1 - **1.2**)	0.4 (0.1 - **1.4**)	0.4 (0.2 - **1.3**)
Rhodhiss	0.6 (<0.1 - **7**)	0.6 (<0.1 - **7**)	0.7 (<0.1 - **7**)	0.6 (<0.1 - **7**)
Hickory	**0.9** (0.2 - **8.8**)	**0.9** (0.2 - **8.8**)	**1.1** (0.2 - **8.8**)	**1** (0.2 - **8.8**)
Lookout Shoals	**1.2** (0.2 - **2.6**)	**1.1** (0.2 - **2.4**)	**1.4** (0.2 - **2.9**)	**1.2** (0.2 - **2.5**)
Norman	**1.2** (<0.1 - **3**)	**1** (<0.1 - **3**)	**1.3** (<0.1 - **4.2**)	**1.1** (<0.1 - **2.9**)
Mountain Island	0.7 (0.2 - **1.9**)	0.6 (0.2 - **1.9**)	0.8 (0.2 - **2.5**)	0.6 (0.2 - **2**)
South Fork	**1.1** (0.2 - **4**)	**1** (0.2 - **3.9**)	**1.2** (0.2 - **4.6**)	**1** (0.2 - **3.9**)
Wylie	**1.2** (<0.1 - **14.2**)	**1.1** (<0.1 - **14.4**)	**1.4** (<0.1 - **16.4**)	**1.1** (<0.1 - **14.1**)
Fishing Creek	**1.2** (<0.1 - **20**)	**1.1** (<0.1 - **19.9**)	**1.3** (<0.1 - **20.9**)	**1.1** (<0.1 - **19.6**)
Great Falls/Cedar Creek	**1.6** (0.2 - **5.6**)	**1.4** (0.2 - **6.2**)	**2.4** (0.2 - **11.3**)	**1.6** (0.2 - **6.8**)
Wateree	0.5 (0.2 - **2.7**)	0.5 (0.2 - **2.7**)	0.7 (0.2 - **3.9**)	0.6 (0.2 - **2.8**)
Below Wateree	**2.3** (0.2 - **150.7**)	**2.3** (0.2 - **150.7**)	**2.6** (0.2 - **160.1**)	**2.3** (0.2 - **151**)

Note: Bold values indicate exceedances of the 0.8 mg/L WQS for freshwaters in both states.

The spatial distribution of median phosphorus concentration, and the percent change from current condition for the future land use and climate scenarios are presented in Figure 5-7. Simulated minimum, median, and maximum phosphorus concentrations within the stream reaches of the subbasin are presented for the four selected model scenarios in Table 5-7. The current condition simulation indicates that median phosphorus concentration exceeds the suggested standard (0.05 mg/L) in the majority of subbasins, exceptions being the Basin headwaters in James and Rhodhiss and in the Lake Wateree region. In these subbasins, maximum values exceed the criteria indicating that even in these relatively pristine areas, conditions arise that prompt limited stream reaches to experience negative impacts to water quality.

Panels B, C, and D of Figure 5-7 illustrate the expected changes in phosphorus concentrations from current conditions (Panel A) that result from land use and climate change scenarios. Results are similar in spatial pattern to nitrogen at the catchment level, meaning that catchments with high or low percent changes in nitrogen generally experience similar changes in phosphorus. Panel B indicates that Future Land Use within the Basin is likely to result in a decrease in river and lake phosphorus concentrations, particularly in the central portion of the Basin. Conversion of land from agricultural uses to residential uses is the dominant driver of this result. When future climate is considered along with the Future Land Use, results indicate that the Hot/Dry scenario will result in increasing phosphorus concentrations in surface waters, and that increase is distributed fairly evenly across the Basin. Results for isolated catchments in the South Fork, tributaries on the east side of the Catawba River mainstem between Wylie and Fishing Creek, and Below Wateree indicate that phosphorus concentrations may decrease under Future Land Use and Hot/Dry climate conditions. Headwater catchments in the James and Hickory subbasins remain unchanged due to the expanse of protected lands in these subbasins. Results are mixed under a Warm/Wet future climate. Moderate increases in phosphorus concentrations are projected for portions of the northern and southern regions of the watershed, while decreases are projected for a large fraction of the central portion. Decreases are likely driven by conversion of agricultural land to uses that receive less anthropogenic loading (e.g., agricultural to residential) combined with higher streamflows, while increases can result from additional loading resulting from increased streamflow, development of forested/natural lands, or a combination of these mechanisms.

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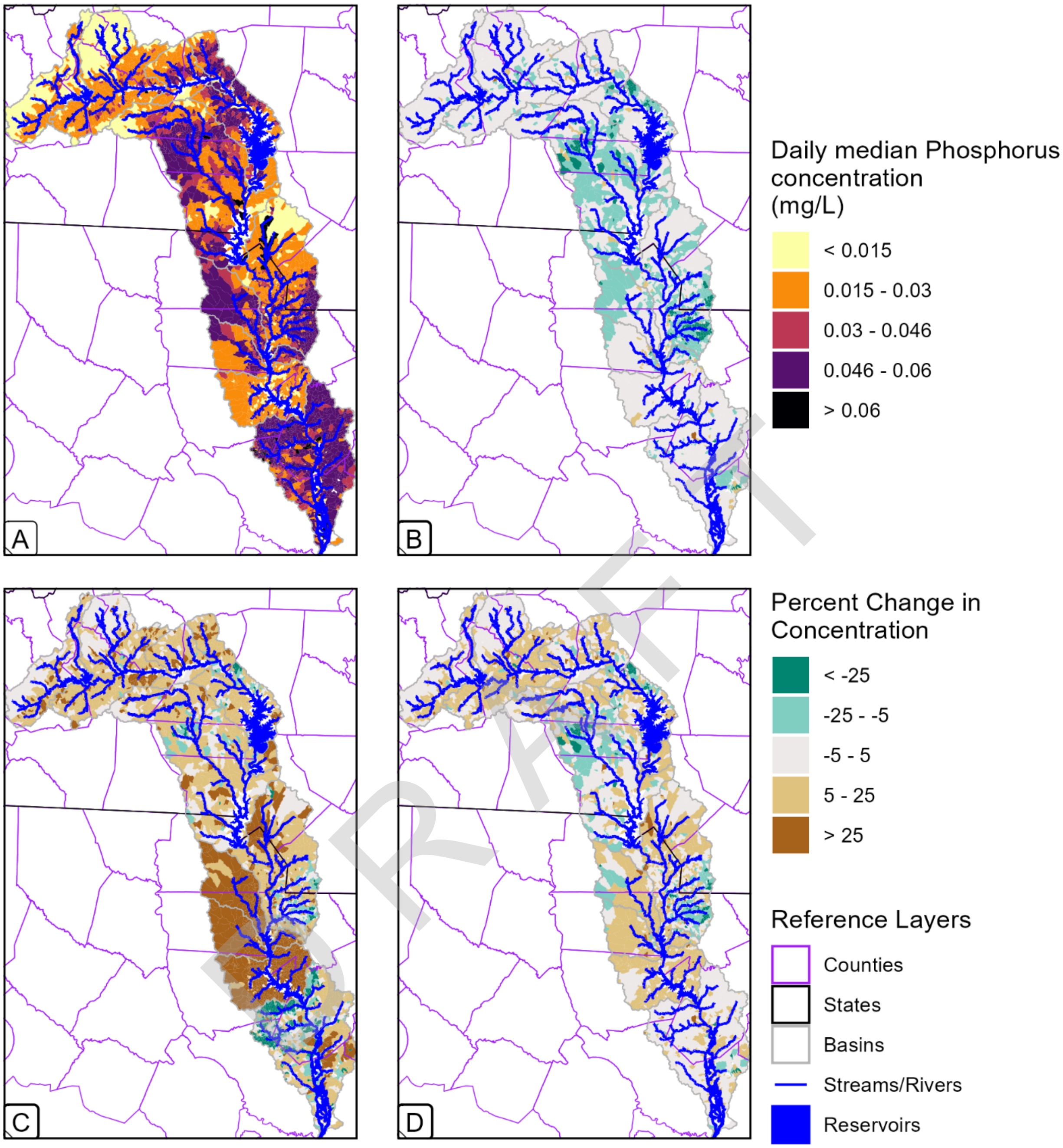

Figure 5-7. Assessment of Total Phosphorus Concentrations for All River and Stream Reaches Under Current Conditions (A) and Percent Change under the Scenarios of Future Land Use (B), Future Land Use & Hot/Dry Climate (C), and Future Land Use & Warm/Wet Climate (D)

Table 5-7. Median Daily Phosphorus Concentrations (with Minimum and Maximum) across River/Stream Segments within Each Subbasin

Subbasin	Current	Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
James	0.019 (0.008 - **0.16**)	0.019 (0.008 - **0.16**)	0.021 (0.007 - **0.19**)	0.02 (0.0099 **- 0.16**)
Rhodhiss	0.03 (0 - **2.0**)	0.029 (0 - **2.0**)	0.034 (0 - **2.0**)	0.032 (0 - **2.0**)
Hickory	**0.052** (0.008 - **1.43**)	**0.052** (0.008 - **1.43**)	**0.059** (0.007 - **1.43**)	**0.054** (0.009 - **1.43**)
Lookout Shoals	**0.053** (0.008 - **0.16**)	**0.052** (0.008 - **0.16**)	**0.063** (0.007 - **0.21**)	**0.055** (0.009 - **0.16**)
Norman	**0.06** (0 - **0.23**)	**0.056** (0 - **0.23**)	**0.065** (0 - **0.26**)	**0.06** **(0 - 0.23)**
Mountain Island	**0.035** (0.008 - **0.095**)	**0.033** (0.008 - **0.093**)	**0.041** (0.007 - **0.109**)	**0.036** (0.010 - **0.098**)
South Fork	**0.058** (0.01 - **1.94**)	**0.055** (0.01 - **1.94**)	**0.065** (0.012 - **2.26**)	**0.057** (0.011 - **1.9**)
Wylie	**0.082** (0 - **4.3**)	**0.079** (0 - **4.3**)	**0.087** (0 - **4.3**)	**0.082** (0 - **4.3**)
Fishing Creek	**0.066** (0.003 - **0.84**)	**0.061** (0.002 - **0.87**)	**0.074** (0.002 - **1.0**)	**0.066** (0.002 - **0.88**)
Great Falls/ Cedar Creek	**0.07** (0.012 - **0.28**)	**0.066** (0.012 - **0.25**)	**0.10** (0.012 - **0.61**)	**0.076** (0.012 - **0.28**)
Wateree	0.03 (0.012 - **0.12**)	0.03 (0.012 - **0.12**)	0.04 (0.012 - **0.16**)	0.032 (0.012 - **0.13**)
Below Wateree	**0.413** (0.012 - **36**)	**0.413** (0.012 - **36**)	**0.395** (0.012 - **38**)	**0.418** (0.012 - **36**)

Note: Bold values indicate exceedances of the 0.05 mg/L WQS for freshwaters in both states.

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5.3.2 Surface Loadings of Nutrients and Sediment

Daily sediment loadings generated from the land surface (i.e., erosion) can vary dramatically, sometimes by three to four orders of magnitude. These differences are driven by variations in storm intensity and by the physical characteristics of the landscape, such as steep slopes or soils that erode easily. Because sediment loads can transport constituents attached to individual sediment particles, high sediment loads trigger increases in loads of other parameters such as nutrients. This high level of variability becomes clear when examining the modeled sediment and nutrient loadings across the Basin.

5.3.2.1 SURFACE LOADINGS OF SEDIMENT

The assessment of sediment surface loads (i.e., the amount of sediment eroded from an area of land and contributed to the stream network) integrates the spatial distribution across catchments with the quantitative median loads per subbasin (Figure 5-8). Under Current Conditions, Figure 5-8A highlights several areas of high sediment loading where daily loads exceed 1.0 lb/acre. These higher-loading areas are mainly located in the upper, headwater regions. Table 5-8 supports this interpretation, showing that the James subbasin has the highest median daily sediment load at 2.3 lbs/acre, followed by the Rhodhiss subbasin at 1.5 lbs/acre. In comparison, the lower portions of the Basin show very low sediment generation rates, which is consistent with the low median values in the Norman and Wylie subbasins (approximately 0.1 lbs/acre). Although the table focuses on median values, the maximum loads provide important context. For example, Rhodhiss has a maximum loading rate of 33.7 lbs/acre, indicating that even in subbasins with high median loads, some individual catchments can experience very high erosion under certain conditions.

The future scenarios demonstrate the strong influence of climate on sediment generation. When only Future Land Use is applied, land development and modification within the central Basin (particularly South Fork and Fishing Creek subbasins) leads to increases of more than 25% in sediment loading rates (Figure 5-8B). The climate-based scenarios show more substantial changes. Under the Hot/Dry Climate scenario, sediment loads generally decrease across most catchments. This trend is shown in Figure 5-8C by green and light blue shading and is supported by the values in Table 5-8. For example, the median load in the James subbasin decreases from 2.3 to 2.0 lbs/acre. These reductions are likely due to fewer intense rainfall events that would otherwise generate runoff and erosion.

The Warm/Wet climate scenario shows a very different outcome. Under this scenario, sediment loads increase throughout the Basin, and many areas experience increases greater than 25%. This widespread increase is visible in the dark brown shading in Figure 5-8D. Table 5-8 confirms this pattern. Median loads rise in several subbasins, including an increase from 1.5 to 1.7 lbs/acre in Rhodhiss and increases from 0.3 and 0.4 lbs/acre in the Great Falls and Cedar Creek subbasins. The increases shown in both the map and the table indicate that more frequent and intense rainfall events in a Warm/Wet future are likely to drive greater erosion across the Basin.

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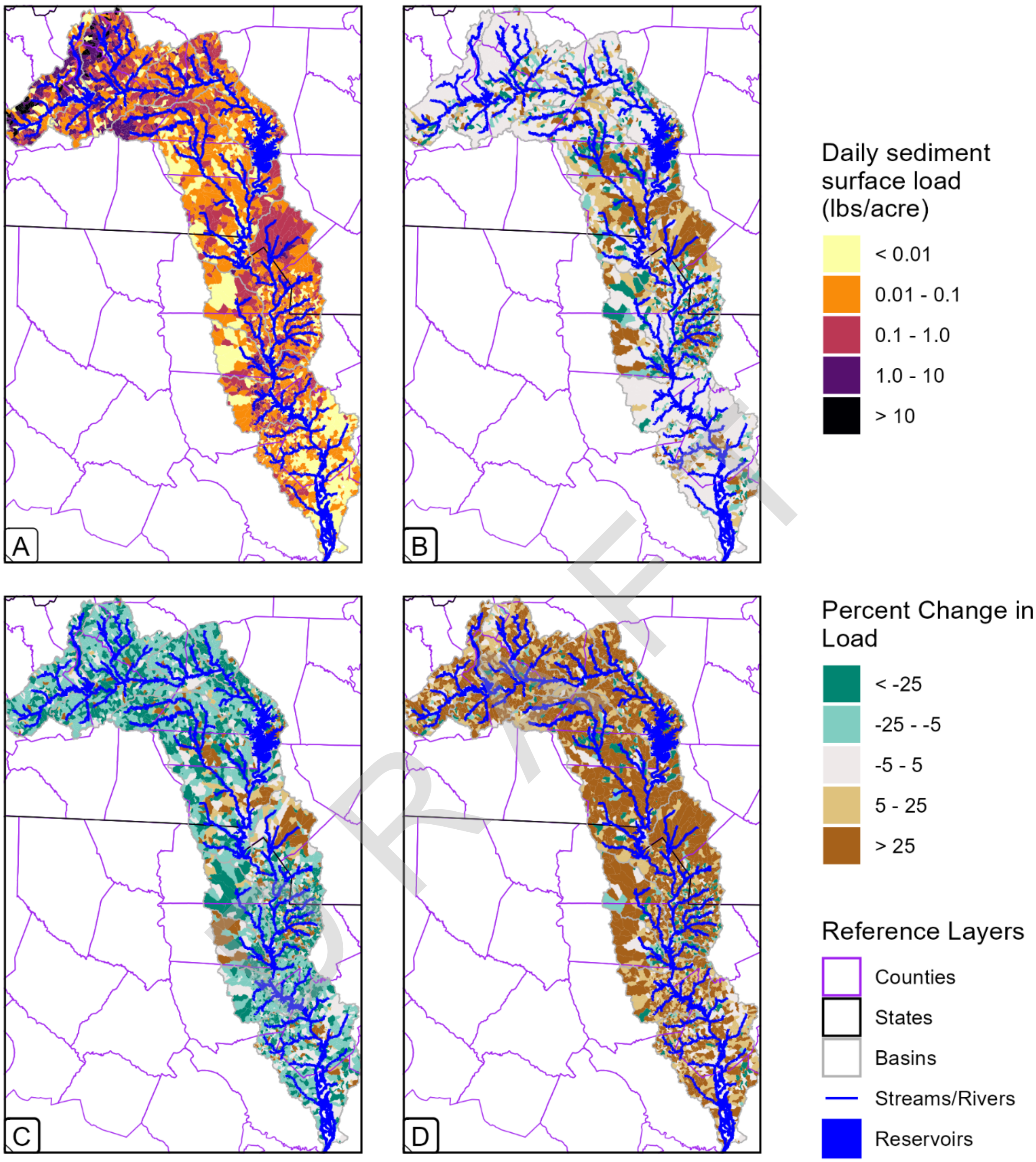

Figure 5-8. Assessment of Surface Generated Load of Sediment for All Catchments Under Current Conditions (A) and Percent Change Under the Scenarios of Future Land Use (B), Future Land Use & Hot/Dry Climate (C), and Future Land Use & Warm/Wet Climate (D)

Table 5-8. Median Daily Surface Generated Sediment Load (with Minimum and Maximum) within Each Subbasin (lbs/acre)

Subbasin	Current	Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
James	2.3 (0 - 25.4)	2.3 (0 - 25.4)	2 (0 - 23.2)	2.8 (0 - 26.1)
Rhodhiss	1.5 (0 - 33.7)	1.5 (0 - 33.7)	1.3 (0 - 31.3)	1.7 (0 - 36.6)
Hickory	0.4 (0 - 7.2)	0.4 (0 - 7.2)	0.3 (0 - 6.8)	0.5 (0 - 8)
Lookout Shoals	0.5 (0 - 9.6)	0.5 (0 - 7.3)	0.4 (0 - 6.8)	0.6 (0 - 8.4)
Norman	0.1 (0 - 2.0)	0.1 (0 - 2.0)	0.1 (0 - 1.7)	0.2 (0 - 2.5)
Mountain Island	0.1 (0 - 0.8)	0.1 (0 - 1.0)	0.1 (0 - 0.9)	0.1 (0 - 1.1)
South Fork	0.5 (0 - 7.4)	0.5 (0 - 7.4)	0.4 (0 - 6.4)	0.6 (0 - 7.7)
Wylie	0.1 (0 - 1.3)	0.1 (0 - 1.4)	0.1 (0 - 1.2)	0.1 (0 - 1.7)
Fishing Creek	0.2 (0 - 6.1)	0.2 (0 - 6.1)	0.2 (0 - 5.5)	0.2 (0 - 7)
Great Falls/ Cedar Creek	0.3 (0 - 7.4)	0.3 (0 - 7.4)	0.3 (0 - 6.5)	0.4 (0 - 8.6)
Wateree	0.3 (0 - 22.4)	0.3 (0 - 22.4)	0.3 (0 - 21.3)	0.4 (0 - 24.1)
Below Wateree	0.1 (0 - 2.1)	0.1 (0 - 2.1)	0.1 (0 - 2.1)	0.1 (0 - 2.1)

5.3.2.2 SURFACE LOADINGS OF NITROGEN

The assessment of nitrogen surface loads combines both the spatial distribution of loading across catchments (Figure 5-9) and the summary of median daily loads for each subbasin (Table 5-9). Under Current Conditions, the spatial map (Figure 5-9A) shows that most of the Basin experiences very low nitrogen surface loads, generally below 0.01 lbs/acre. Areas with higher nitrogen loading, represented by darker shading for values greater than 0.01 lbs/acre, occur primarily in the upstream, mountainous headwater regions of the Basin. Table 5-9 supports this pattern by identifying the James subbasin (0.01 lbs/acre) and the Rhodhiss subbasin (0.007 lbs/acre) as having the highest median current loads. In contrast, the downstream, lower relief portions of the Basin show very low nitrogen levels on the map, which is consistent with their low median values. Many subbasins in these downstream areas, including Mountain Island, Wylie, and Below Wateree, have median loads of 0.01 lbs/acre or less. Although the table highlights median values, the maximum loads provide important additional context. For example, selected catchments within the Rhodhiss subbasin experience a maximum loading rate of 0.23 lbs/acre, which shows that localized catchments within otherwise lower generating subbasins can experience much higher nitrogen runoff due to specific land uses or conditions.

The modeled scenarios for future conditions show that nitrogen loading responds to changes in both land use and climate. When only Future Land Use is applied, the spatial pattern of nitrogen loads remains nearly the same as under current conditions. The close similarity between

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Figure 5-9A and 5-9B suggests that projected land-use changes alone do not substantially alter nitrogen loading across the Basin except for highly densifying urban areas in the central Basin. The climate scenarios; however, demonstrate stronger effects. Under the Hot/Dry climate scenario, nitrogen loads decrease across much of the Basin, particularly in the northern regions. This decrease is shown Figure 5-9C by widespread green and light blue shading, representing reductions greater than 5% and greater than 25%. Table 5-9 confirms these reductions, including a decrease in the median load for the James subbasin from 0.01 to 0.009 lbs/acre. The Warm/Wet climate scenario results in the opposite pattern. Nitrogen loads increase across a large portion of the Basin, with many areas showing increases greater than 25%, shown in dark brown in Figure 5-9D. Table 5-9 supports this trend, with increases in median load from 0.01 to 0.012 lbs/acre in the James subbasin and from 0.007 to 0.008 lbs/acre in the Rhodhiss subbasin. Taken together, the map and table indicate that more frequent and intense rainfall events in a Warm/Wet future are likely to increase nitrogen loads to streams and rivers across the Basin by enhancing the ability of runoff to transport nitrogen from the land surface.

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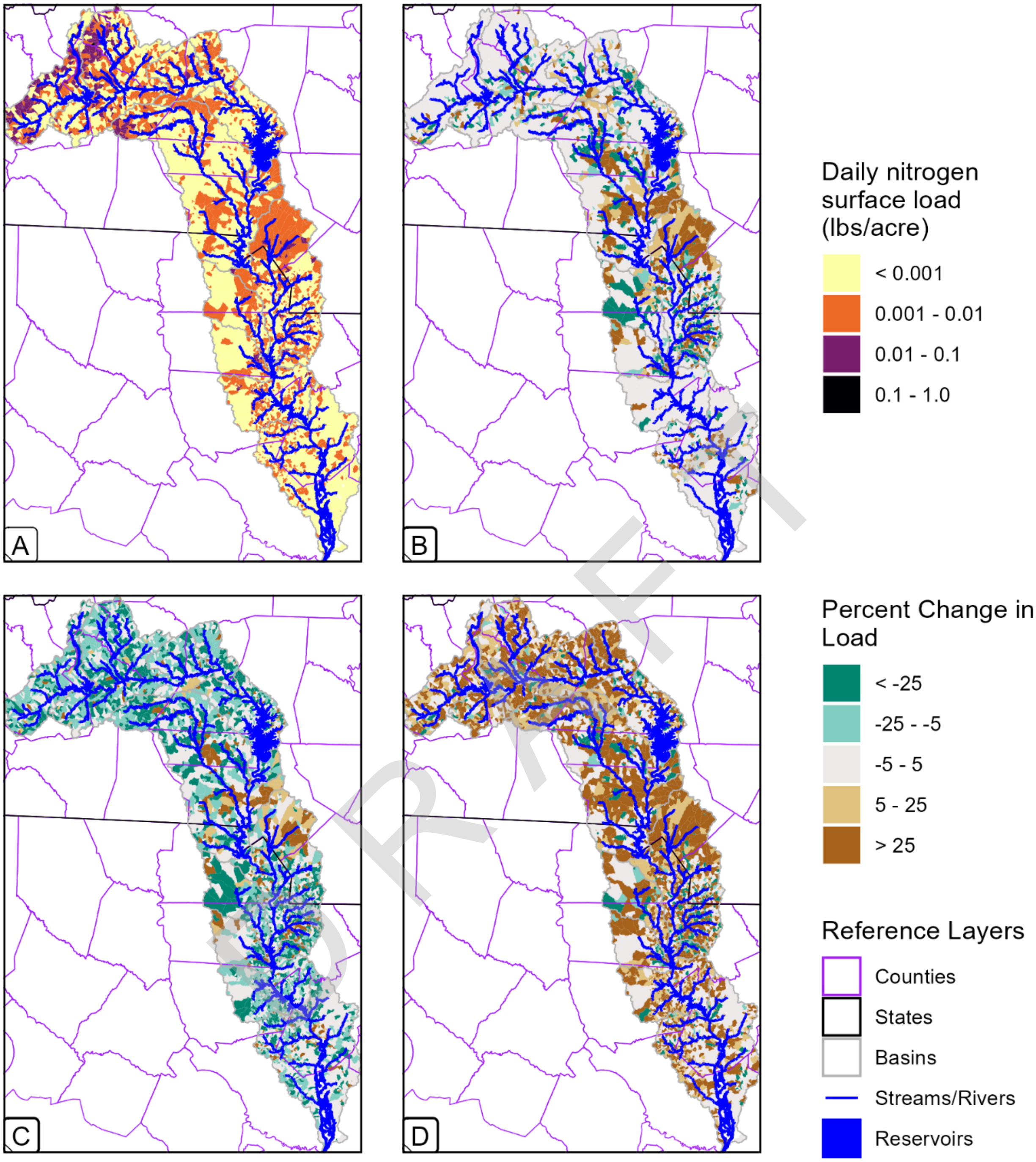

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Figure 5-9. Assessment of Surface Generated Load of Nitrogen for All Catchments Under Current Conditions (A) and Percent Change Under the Scenarios of Future Land Use (B), Future Land Use & Hot/Dry Climate (C), and Future Land Use & Warm/Wet Climate (D)

Table 5-9. Median Daily Surface Generated Nitrogen Load (with Minimum and Maximum) within Each Subbasin (lbs/acre)

Subbasin	Current	Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
James	0.01 (0 - 0.08)	0.01 (0 - 0.08)	0.009 (0 - 0.08)	0.012 (0 - 0.09)
Rhodhiss	0.007 (0 - 0.23)	0.007 (0 - 0.23)	0.006 (0 - 0.21)	0.008 (0 - 0.25)
Hickory	0.003 (0 - 0.04)	0.003 (0 - 0.04)	0.002 (0 - 0.03)	0.003 (0 - 0.05)
Lookout Shoals	0.005 (0 - 0.08)	0.005 (0 - 0.11)	0.004 (0 - 0.1)	0.006 (0 - 0.12)
Norman	0.002 (0 - 0.04)	0.002 (0 - 0.04)	0.002 (0 - 0.03)	0.002 (0 - 0.05)
Mountain Island	0.001 (0 - 0.01)	0.001 (0 - 0.01)	0.001 (0 - 0.01)	0.002 (0 - 0.01)
South Fork	0.003 (0 - 0.04)	0.003 (0 - 0.04)	0.002 (0 - 0.04)	0.004 (0 - 0.05)
Wylie	0.001 (0 - 0.01)	0.002 (0 - 0.01)	0.001 (0 - 0.01)	0.002 (0 - 0.01)
Fishing Creek	0.002 (0 - 0.05)	0.002 (0 - 0.03)	0.002 (0 - 0.03)	0.003 (0 - 0.03)
Great Falls/ Cedar Creek	0.004 (0 - 0.05)	0.003 (0 - 0.03)	0.003 (0 - 0.03)	0.004 (0 - 0.03)
Wateree	0.002 (0 - 0.13)	0.002 (0 - 0.13)	0.002 (0 - 0.12)	0.003 (0 - 0.14)
Below Wateree	0.001 (0 - 0.03)	0.001 (0 - 0.03)	0.001 (0 - 0.03)	0.001 (0 - 0.03)

5.3.2.3 SURFACE LOADING OF PHOSPHOROUS

The assessment of phosphorus surface loads utilizes the same approach applied to sediment and nitrogen, i.e., combining the spatial distribution of loading across catchments (Figure 5-10) with the summary of median daily loads for each subbasin (Table 5-10). Under Current Conditions, Figure 5-10A demonstrates that phosphorus surface loads are generally low throughout the Basin. Most catchments fall within the range of less than 0.0001 to 0.001 lbs/acre, represented by yellow and orange shading. Areas with higher phosphorus loading, designated in purple and black for values greater than 0.001 lbs/acre, are concentrated in the upper portion of the Basin. Thispattern is similar to the patterns observed for sediment and nitrogen and attributable to the mountainous headwater region more readily eroding during precipitation events. Table 5-10 supports these observations by identifying the James subbasin (0.001 lbs/acre) and the Rhodhiss subbasin (0.0007 lbs/acre) as again having the highest median current loads. In contrast, the lower parts of the Basin reflect very low phosphorus levels on the map, consistent with the lowest median values in the table, such as the phosphorus loading rate of 0.0001 lbs/acre estimated for Below Wateree. Although the median values are low across the Basin, maximum loads help illustrate where localized phosphorus runoff can be much higher. For example, Rhodhiss reaches a maximum of 0.0237 lbs/acre, indicating that certain catchments within this subbasin experience much greater phosphorus runoff due to specific land characteristics or sources.

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The future scenarios show that phosphorus loading responds strongly to climate conditions. When only Future Land Use is applied, the overall spatial distribution, again, reflects increases in the central Basin. The distribution varies slightly from nitrogen with greater increases seen more widespread along the South Fork Catawba River due to the availability of legacy phosphorus in the soils. While land use change provokes limited and localized variations to phosphorus loads generated from the land surface, climate changes produce widespread fluctuations in the Basin. Under the Hot/Dry climate scenario, phosphorus loads decrease across much of the Basin. Figure 5-10C demonstrates this pattern through widespread green and light blue shading, representing reductions greater than 5% and greater than 25%. Table 5-10 confirms these reductions, including a slight decrease in the median load for the James subbasin from 0.001 to 0.0009 lbs/acre. The Warm/Wet climate scenario displays the opposite trend. Under this scenario, phosphorus loads increase across large portions of the Basin, with many catchments experiencing increases greater than 25%. This trend is visible in Figure 5-10D through dark brown shading. Table 5-10 supports these findings with increases in median subbasin loads, including an increase from 0.001 to 0.0012 lbs/acre in the James subbasin and from 0.0007 to 0.0008 lbs/acre in the Rhodhiss subbasin. Together, the spatial and tabular results reflect that more frequent and intense rainfall events in a Warm/Wet future are likely to increase phosphorus runoff across the Basin by increasing erosion and the transport of particulate phosphorus.

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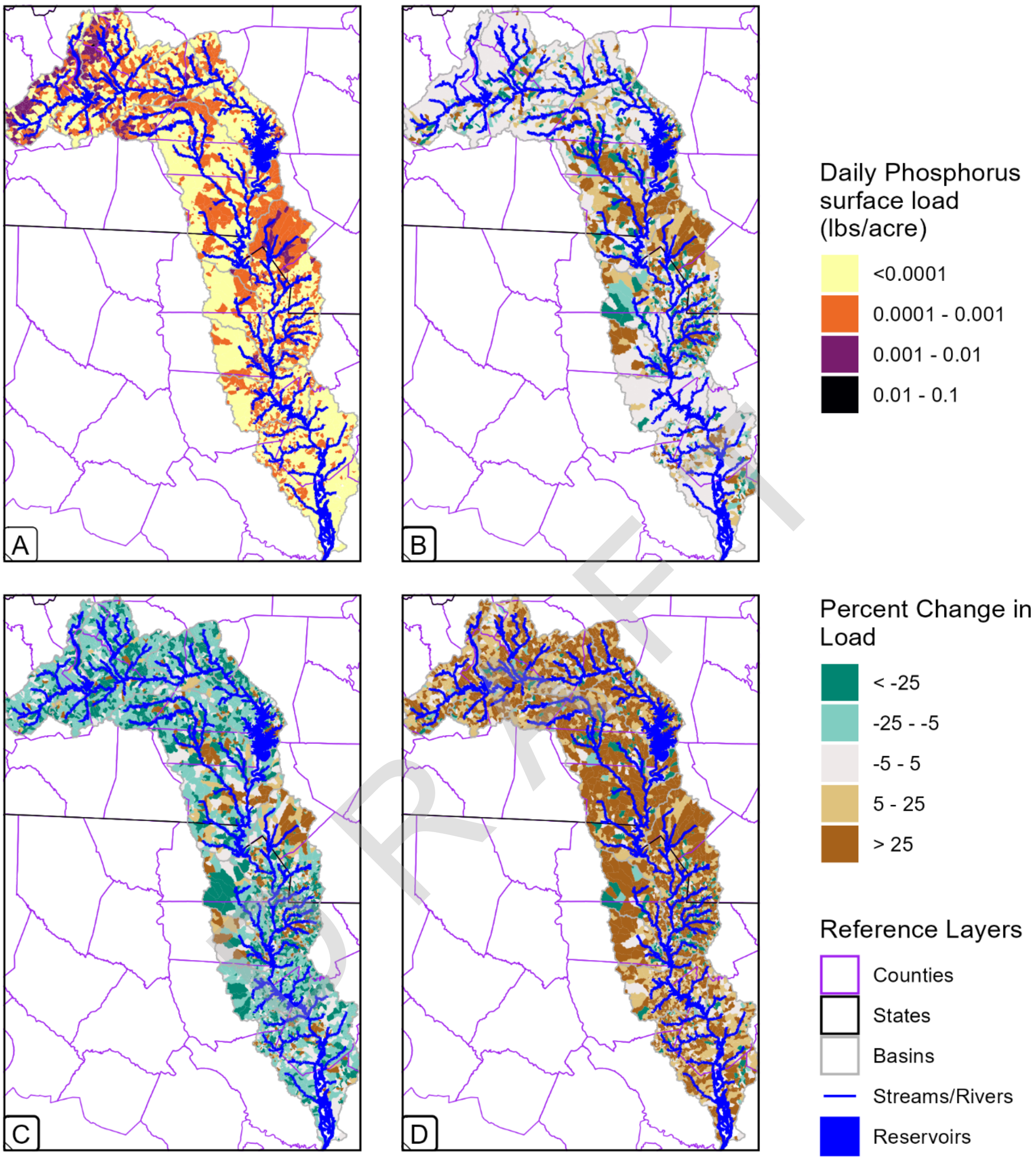

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Figure 5-10. Assessment of Surface Generated Load of Phosphorus for All Catchments Under Current Conditions (A) and Percent Change Under the Scenarios of Future Land Use (B), Future Land Use & Hot/Dry Climate (C), and Future Land Use & Warm/Wet Climate (D)

Table 5-10. Median Daily Surface Generated Phosphorus Load (with Minimum and Maximum) within Each Subbasin (lbs/acre)

Subbasin	Current	Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
James	0.001 (0 - 0.0099)	0.001 (0 - 0.0099)	0.0009 (0 - 0.0089)	0.0012 (0 - 0.0101)
Rhodhiss	0.0007 (0 - 0.0237)	0.0007 (0 - 0.0237)	0.0006 (0 - 0.0222)	0.0008 (0 - 0.0255)
Hickory	0.0003 (0 - 0.004)	0.0003 (0 - 0.004)	0.0003 (0 - 0.0039)	0.0004 (0 - 0.0045)
Lookout Shoals	0.0004 (0 - 0.0069)	0.0004 (0 - 0.0082)	0.0004 (0 - 0.0073)	0.0005 (0 - 0.0092)
Norman	0.0002 (0 - 0.0032)	0.0002 (0 - 0.0032)	0.0002 (0 - 0.0031)	0.0002 (0 - 0.0033)
Mountain Island	0.0002 (0 - 0.0012)	0.0002 (0 - 0.0015)	0.0002 (0 - 0.0014)	0.0002 (0 - 0.0016)
South Fork	0.0003 (0 - 0.0047)	0.0003 (0 - 0.0047)	0.0002 (0 - 0.0035)	0.0003 (0 - 0.0055)
Wylie	0.0002 (0 - 0.0018)	0.0002 (0 - 0.0019)	0.0002 (0 - 0.0017)	0.0002 (0 - 0.0022)
Fishing Creek	0.0003 (0 - 0.0049)	0.0003 (0 - 0.0049)	0.0002 (0 - 0.0043)	0.0003 (0 - 0.0051)
Great Falls/ Cedar Creek	0.0003 (0 - 0.0038)	0.0003 (0 - 0.0029)	0.0002 (0 - 0.0028)	0.0003 (0 - 0.0031)
Wateree	0.0002 (0 - 0.0144)	0.0002 (0 - 0.0144)	0.0002 (0 - 0.0135)	0.0003 (0 - 0.0156)
Below Wateree	0.0001 (0 - 0.0042)	0.0001 (0 - 0.0042)	0.0001 (0 - 0.004)	0.0001 (0 - 0.0043)

5.3.3 Loads to Reservoirs

The cumulative load entering a reservoir from the river network or lakeshore is expressed in terms of total tons per year of sediment, nitrogen, and phosphorus. This annual load, a combination of parameter concentration (e.g., mg/L) and annual flow, characterizes the amount of the parameter delivered to the reservoir by the various tributaries within each subbasin and from direct runoff and baseflow of the surrounding shoreline. Additionally, this metric is useful in evaluating watershed targets; such as those used for TMDLs and for measuring impact of land management practices on a large scale. The annual median results are presented in tabular form while box plots are utilized to identify the range of loadings, (25^{th} and 75^{th}) percentiles, the extreme annual loads (line and dots) for each reservoir, and the four selected model scenarios.

5.3.3.1 ANNUAL SEDIMENT LOAD

Currently, annual sediment loading is greatest in Rhodhiss and Fishing Creek subbasins and is lowest in Mountain Island and Wateree subbasins (Table 5-11 and Figure 5-11). Annual sediment loading increases under the Future Land Use scenario for all subbasins except Lookout Shoals which is expected to see a decrease of 579 tons (-2%). This decrease is associated with a land use change. The community is transitioning some pasture lands into mixed used lands. The greatest volume of sediment increase due to Future Land Use is in the Fishing Creek subbasin. The subbasin is expected to have a 21% increase from current conditions through the addition of 25,316 tons of produced sediment. Fishing Creek contains a

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large portion of the Charlotte Metropolitan area. Increased densification of urban areas contributes to the higher loadings.

In the Future Land Use & Hot/Dry scenario, annual sediment loadings are lower than current conditions due to lower annual runoff and associated flow in the subbasins. In this scenario, the Rhodhiss subbasin will see decreased sediment by (-18%), or 49,080 tons, the greatest reduction in the Basin. Fishing Creek subbasin is projected to have the smallest decrease under this scenario (-1,247 tons; -1%) illustrating the Future Land Use changes produce higher sediment loads.

In the Future Land Use & Warm/Wet scenario, annual sediment loads increase compared with current conditions, ranging from 64,284 tons (a 54% increase) in Fishing Creek to 3,199 tons (a 19% increase) in Below Wateree. These changes reflect a combination of increased sedimentation from land use changes and higher flows causing more runoff and erosion due to a wetter climate. The greatest gross load increase is projected for the Rhodhiss subbasin (96,726 tons),a 35% increase from current conditions. This scenario has the greatest variability in the potential results as shown in the box and whisker plot (Figure 5-11). Lake Rhodhiss could experience an annual load greater than 750,000 tons under extreme conditions.

Table 5-11. Comparison of Current and Future Median Annual Loading of Sediment (tons) to each Reservoir

Subbasin	Current (tons)	Change in Annual Sediment Load by Scenario (tons)		
		Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
James	82,309	298	-15,888	31,044
		0%	-19%	38%
Rhodhiss	272,974	1,221	-49,080	96,726
		0%	-18%	35%
Hickory	35,578	365	-6,635	12,829
		1%	-19%	36%
Lookout Shoals	35,827	-579	-7,718	12,282
		-2%	-22%	34%
Norman	21,793	100	-4,407	7,508
		0%	-20%	34%
Mountain Island	12,191	564	-2,619	5,223
		5%	-21%	43%
Wylie	74,556	7,016	-8,894	33,898
		9%	-12%	45%
Fishing Creek	118,739	25,316	-1,247	64,284
		21%	-1%	54%

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Subbasin	Current (tons)	Change in Annual Sediment Load by Scenario (tons)		
		Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
Great Falls/Cedar Creek	42,135	3,895	-4,911	16,333
		9%	-12%	39%
Wateree	29,075	2,353	-4,446	11,453
		8%	-15%	39%
Below Wateree	16,692	334	-3,284	3,199
		2%	-20%	19%

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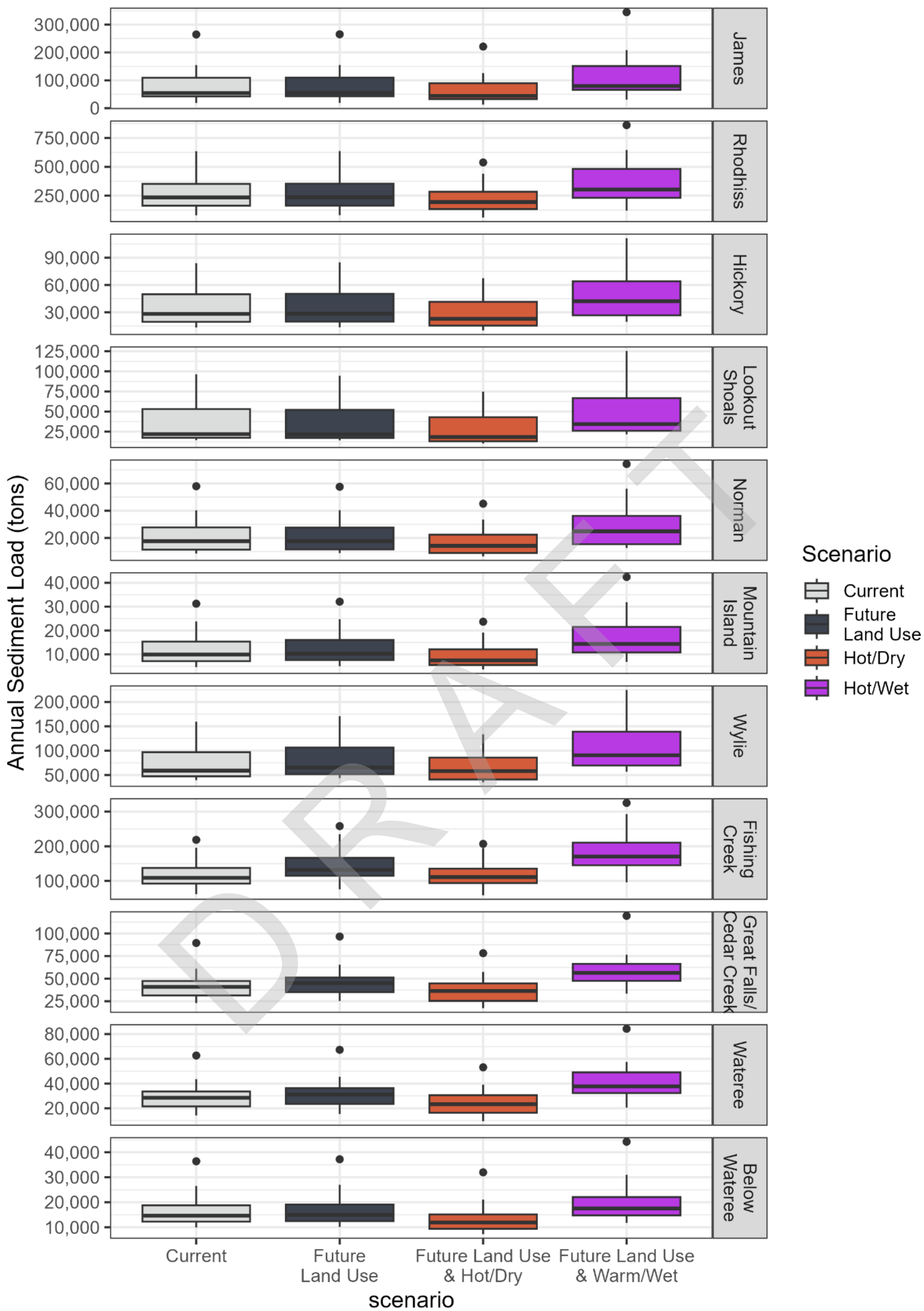

Figure 5-11. Annual Sediment Load by Reservoir subbasin Under Current Conditions, Future Land Use, Future Land Use & Hot/Dry Climate, and Future Land Use & Warm/Wet Climate Scenarios

Box shows 25th percentile, median, and 75th percentile

5.3.3.2 ANNUAL NITROGEN LOAD

Currently, annual nitrogen loading is greatest in Fishing Creek (6,679 tons) followed by loadings to Great Falls/Cedar Creek (4,080 tons) and Wateree (4,007 tons) (Table 5-12 and Figure 5-12). The lowest annual nitrogen load is found in Lake James (593 tons) and Below Wateree (698 tons). Annual nitrogen loading increases under the Future Land Use scenario for all subbasins except for the James subbasin where there is no significant change. The largest decrease in nitrogen is projected in the Great Falls/Cedar Creek subbasin with a decrease of 157 tons (4%), in the annual nitrogen load. Nitrogen loadings decrease due to land use transitions from worked lands to mixed used and developed lands where surface stores of nitrogen are lower and less build up over impervious lands is expected as compared to natural and worked lands.

In the Future Land Use & Hot/Dry scenario, annual nitrogen loading is lower than both the Current conditions and Future Land Use scenario due to lower annual runoff and associated flow in the subbasins. In this scenario, Great Falls/Cedar Creek subbasin had the greatest decrease of 790 tons of sediment (-19%). Lake James subbasin is projected to have the least decrease (-89 tons; -15%).

In the Future Land Use & Warm/Wet scenario, annual nitrogen load increases range from 25% (259 tons in Mountain Island) to 7% (52 tons in Below Wateree) over Current conditions. These changes reflect a combination of decreased nitrogen load from land use changes and higher flows causing more runoff from a wetter climate. The highest load increase is projected from the Fishing Creek subbasin (549 tons) and from the Wateree subbasin (475 tons), 8% and 12%, respectively, from Current conditions.

Table 5-12. Comparison Current and Future Median Annual Loading of Nitrogen (tons) to each Reservoir

Subbasin	Current (tons)	Change in Annual Nitrogen Load by Scenario (tons)		
		Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
James	593	0.1	-89	140
		0%	-15%	24%
Rhodhiss	2,374	-23	-380	523
		-1%	-16%	22%
Hickory	1,514	-16	-276	336
		-1%	-18%	22%
Lookout Shoals	1,773	-24	-338	390
		-1%	-19%	22%
Norman	1,913	-55	-385	364
		-3%	-20%	19%
Mountain Island	1,054	-26	-278	259
		-2%	-26%	25%

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Subbasin	Current (tons)	Change in Annual Nitrogen Load by Scenario (tons)		
		Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
Wylie	2,953	-146	-547	345
		-5%	-19%	12%
Fishing Creek	6,679	-130	-754	549
		-2%	-11%	8%
Great Falls/Cedar Creek	4,080	-157	-790	461
		-4%	-19%	11%
Wateree	4,007	-127	-759	475
		-3%	-19%	12%
Below Wateree	698	-13	-112	52
		-2%	-16%	7%

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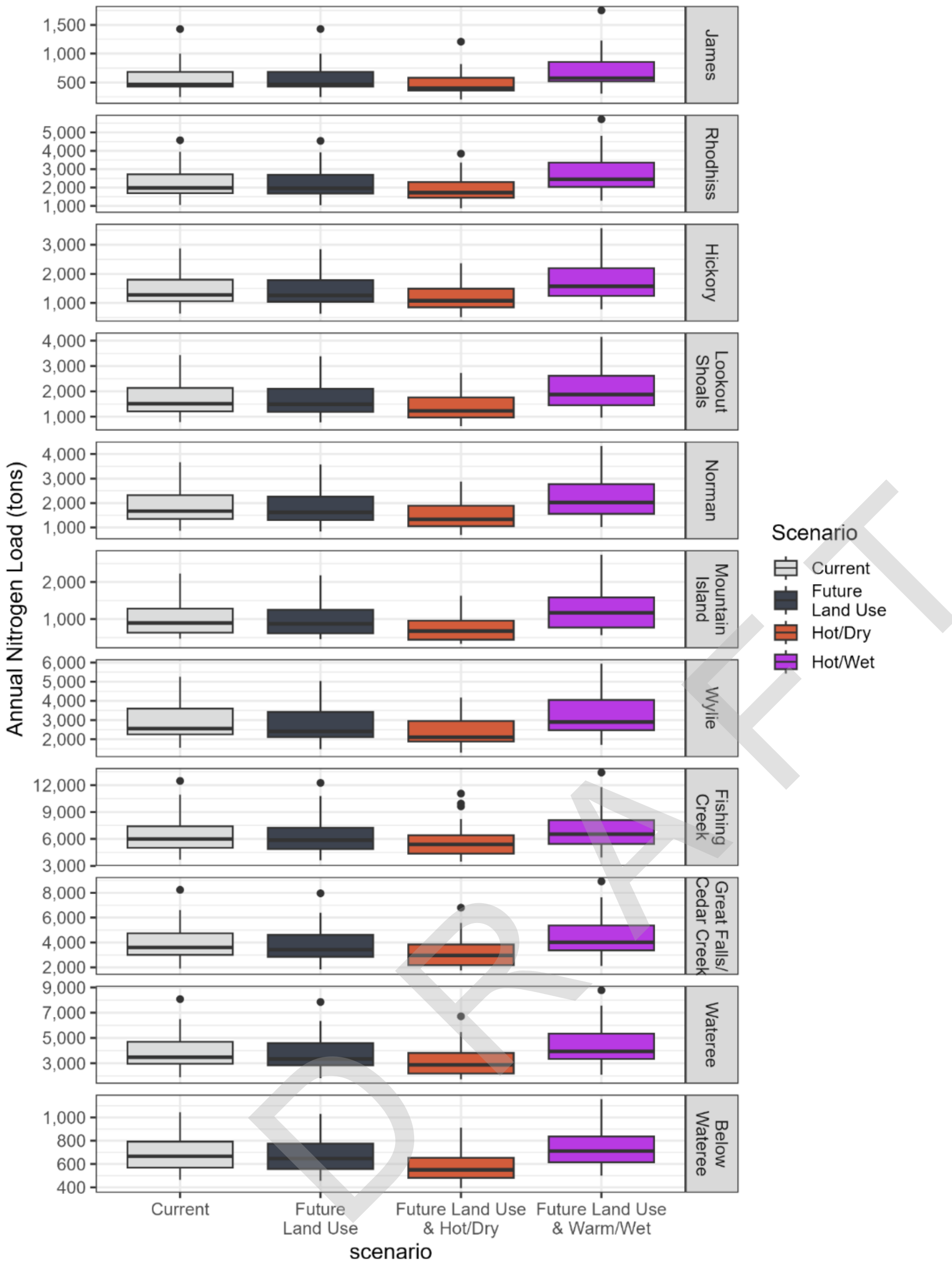

Figure 5-12. Annual Nitrogen Load by Reservoir Subbasin Under Current Conditions, Future Land Use, Future Land Use & Hot/Dry Climate, and Future Land Use & Warm/Wet Climate Scenarios
Box shows 25th percentile, median, and 75th percentile

5.3.3.3 ANNUAL PHOSPHORUS LOAD

Annual phosphorus loads to the reservoirs, based on Current Conditions, range from 627 tons in the Fishing Creek subbasin to 39 tons in the Mountain Island subbasin (Table 5-13 and Figure 5-13). In the Future Land Use scenario, annual phosphorus loading increases slightly or is projected to have minor decreases (-0.01 tons in Rhodhiss and -0.3 tons in Lookout Shoals). The greatest mass of phosphorus increase is projected for the Fishing Creek subbasin with 22 tons of phosphorus, which is a 3% increase.

In the Future Land Use & Hot/Dry scenario, annual phosphorus loading decreases in all subbasins due to lower annual runoff and associated flow in the subbasins. In this scenario, Fishing Creek subbasin had the largest decrease of 60 tons of sediment (-10%) while the James subbasin is projected to have the smallest decrease (-9 tons; -15%).

In the Future Land Use & Warm/Wet scenario, annual phosphorus load increases range from 100 tons in Fishing Creek to 10 tons in Below Wateree over Current conditions. These changes reflect a combination of increased phosphorus load from land use changes and higher flows causing more runoff from a wetter climate. The highest percent load increase is projected for Mountain Island subbasin (33%) compared to current conditions.

Table 5-13. Comparison Current and Future Median Annual Loading of Phosphorus (tons) to Each Reservoir

Subbasin	Current (tons)	Change in Annual Phosphorus Load by Scenario (tons)		
		Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
James	59	0.2	-9	14
		0%	-15%	24%
Rhodhiss	233	0	-35	53
		0%	-15%	23%
Hickory	114	0.3	-22	28
		0%	-19%	25%
Lookout Shoals	81	-0.3	-17	22
		0%	-21%	27%
Norman	100	2.6	-19	27
		3%	-19%	27%
Mountain Island	39	1	-10	13
		3%	-26%	33%
Wylie	190	5	-25	39
		3%	-13%	21%
Fishing Creek	627	22	-60	100
		3%	-10%	16%
Great Falls/Cedar Creek	268	8	-40	47
		3%	-15%	18%
Wateree	218	6	-37	39
		3%	-17%	18%
Below Wateree	87	0.2	-21	10
		0%	-24%	11%

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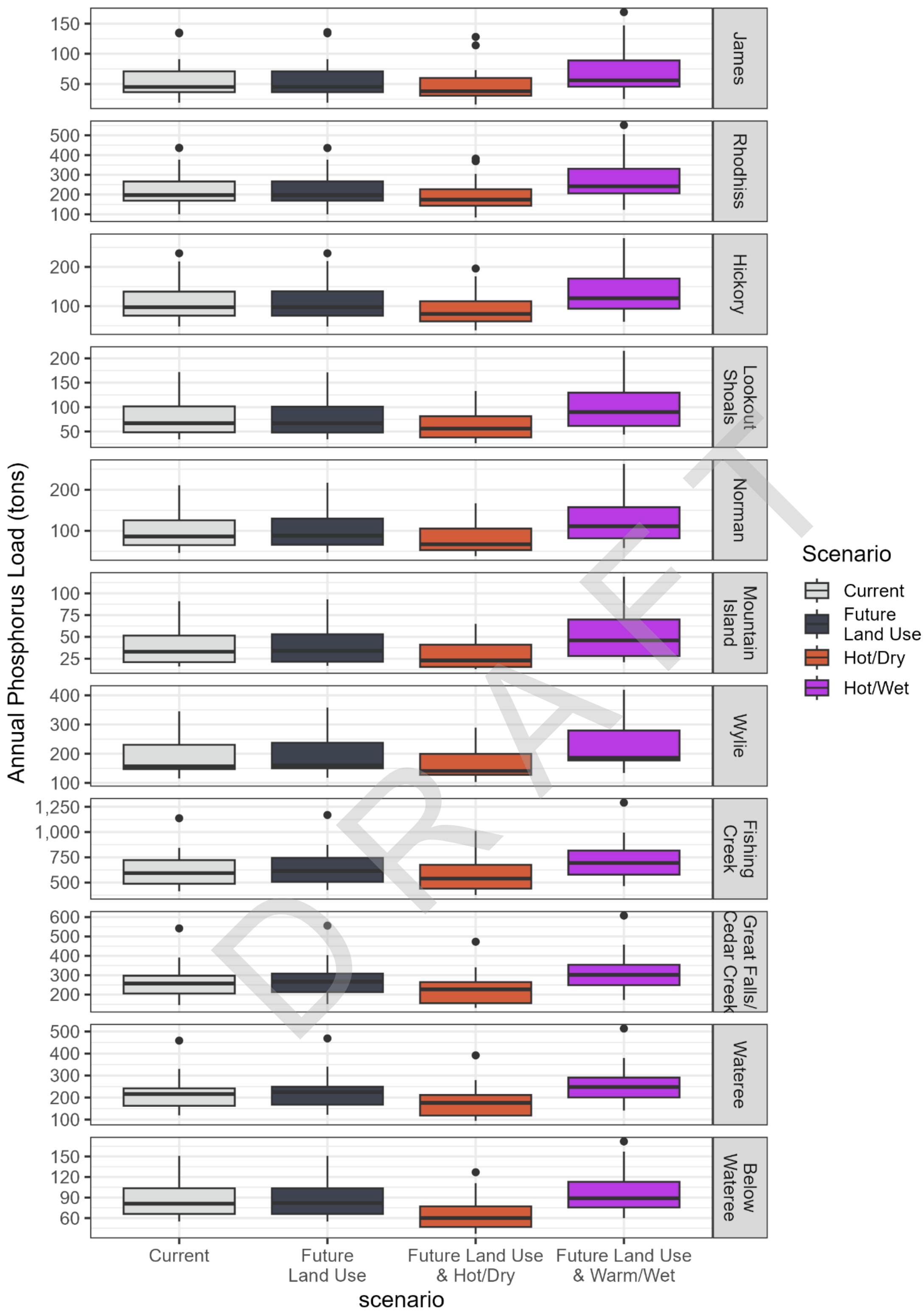

Figure 5-13. Annual Phosphorus Load by Reservoir subbasin Under Current Conditions, Future Land Use, Future Land Use & Hot/Dry Climate, and Future Land Use & Warm/Wet Climate Scenarios

Box shows 25th percentile, median, and 75th percentile

5.3.3.4 HIGHEST LOAD CARRYING TRIBUTARIES

To assist with the implementation of management recommendations and other interventions, it is helpful to consider which tributaries of each reservoir contribute the highest amount annual loads of sediment and nutrients. Table 5-14 lists, for each parameter and subbasin, the four (or in cases with close magnitudes, five) tributaries that contribute the greatest loading to each reservoir. Along with the tributary name, the average percentage of the total tributary load across the four selected scenarios is presented. The scenarios do not include loadings transported through the mainstem of the Catawba River nor in the identified Current, Future Land Use, Future Land Use & Hot/Dry, and Future Land Use & Warm/Wet scenarios. The variation in percent load contribution by tributary across the scenarios was minor; therefore, allowing for the listing of the top four tributaries. Only in a limited number of cases did the ranking of the tributary loads change from one scenario to the next. However, the ranking of the tributaries does change by parameter. This is visible at Lake James. Paddy Creek contributes the fourth most sediment loading; however, for nutrients, the loads derived from the shoreline are the fourth most contributing source.

Lake James provides an example to further explain the information in Table 5-14. The headwaters of the Catawba River contribute the highest proportions of sediment (55%), nitrogen (52%) and phosphorus (44%) to Lake James. Linville River ranks second in tributary load (22%) for sediment, but third for nitrogen (21%) and phosphorus (20%). Conversely, the North Catawba River tributary ranks third for sediment (19%), but second for nitrogen (21%) and phosphorus (32%). For sediment, Paddy Creek tributary contributes 1% of the annual sediment load and the shoreline of Lake James contributes 2% nitrogen and 1% phosphorus annual loads.

For all reservoirs, except Lake Wateree and the contributions to the Wateree River below Lake Wateree, there is one dominant source of loading to the reservoir by parameter. Knowing this breakdown, as well as the relative contributions and geographic extents of the source tributaries (Figure 5-14), provides vital information for moving towards the management of water quality throughout the Basin.

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Table 5-14. Top Four Tributaries for Annual Load Contributions by Parameter for Each Reservoir (With Percentage of Total Load from Tributaries)

Subbasin	Sediment		Nitrogen		Phosphorus	
James	Catawba River	55	Catawba River	52	Catawba River	44
	Linville River	22	North Fork Catawba River	21	North Fork Catawba River	32
	North Fork Catawba River	19	Linville River	21	Linville River	20
	Paddy Creek	1	Shoreline	2	Shoreline	1
Rhodhiss	Johns River	41	Johns River	27	Johns River	26
	Lower Creek	13	Lower Creek	18	Lower Creek	21
	Warrior Fork	13	Muddy Creek	17	Muddy Creek	17
	Muddy Creek	13	Warrior Fork	11	Warrior Fork	10
Hickory	Middle Little River	38	Middle Little River	27	Gunpowder Creek	26
	Upper Little River	16	Gunpowder Creek	19	Middle Little River	26
	Gunpowder Creek	13	Upper Little River	16	Upper Little River	15
	Drowning Creek	7	Drowning Creek	7	Drowning Creek	7
			Shoreline	7		
Lookout Shoals	Lower Little River	89	Lower Little River	77	Lower Little River	83
	Elk Shoals Creek	6	Elk Shoals Creek	12	Elk Shoals Creek	9
	Elk Shoal Creek	1	Elk Shoal Creek	3	Elk Shoal Creek	2
	Island Creek	1	Shoreline	4	Shoreline	2
Norman	Lyle Creek	36	Lyle Creek	35	Lyle Creek	46
	Buffalo Shoals Creek	11	Shoreline	16	Buffalo Shoals Creek	8
	Shoreline	10	Buffalo Shoals Creek	9	Shoreline	7
	Balls Creek	5	Balls Creek	8	Reeds Creek	6

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Subbasin	Sediment		Nitrogen		Phosphorus	
Mountain Island	McDowell Creek	66	McDowell Creek	73	McDowell Creek	75
	Gar Creek	11	Shoreline	9	Shoreline	7
	Shoreline	9	Johnson Creek	8	Johnson Creek	6
	Johnson Creek	7	Unnamed tributary below Cowans Ford Dam	3	Gar Creek	4
Wylie	South Fork Catawba River	69	South Fork Catawba River	67	South Fork Catawba River	62
	Dutchmans Creek	7	Dutchmans Creek	8	Dutchmans Creek	11
	Crowders Creek	6	Crowders Creek	7	Fites Creek	6
	Long Creek	4	Fites Creek	6	Crowders Creek	7
Fishing Creek	Sugar Creek	63	Sugar Creek	64	Sugar Creek	69
	Cane Creek	12	Manchester Creek	13	Cane Creek	11
	Twelvemile Creek	11	Twelvemile Creek	9	Twelvemile Creek	10
	Big Dutchman Creek	3	Cane Creek	8	Waxhaw Creek	2
Great Falls/ Cedar Creek	Fishing Creek	58	Fishing Creek	64	Fishing Creek	62
	Rocky Creek	29	Rocky Creek	27	Rocky Creek	23
	Camp Creek	11	Camp Creek	8	Camp Creek	14
	Debutary Creek	1	Debutary Creek	0.4	Debutary Creek	0.4
	Shoreline	1	Shoreline	0.3		
Wateree	Big Wateree Creek	26	Big Wateree Creek	29	Big Wateree Creek	22
	Beaver Creek	18	Beaver Creek	16	Beaver Creek	19
	Dutchmans Creek	15	Dutchmans Creek	13	Dutchmans Creek	17
	Cedar Creek	12	Cedar Creek	10	Cedar Creek	13

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Subbasin	Sediment		Nitrogen		Phosphorus	
Below Wateree	Twentyfive Mile Creek	23	Twentyfive Mile Creek	23	Twentyfive Mile Creek	25
	Colonels Creek	16	Spears Creek	14	Spears Creek	17
	Spears Creek	14	Big Pine Tree Creek	9	Sawneys Creek	9
	Sawneys Creek	9	Swift Creek	8	Grannies Quarter Creek	7
					Big Pine Tree Creek	7

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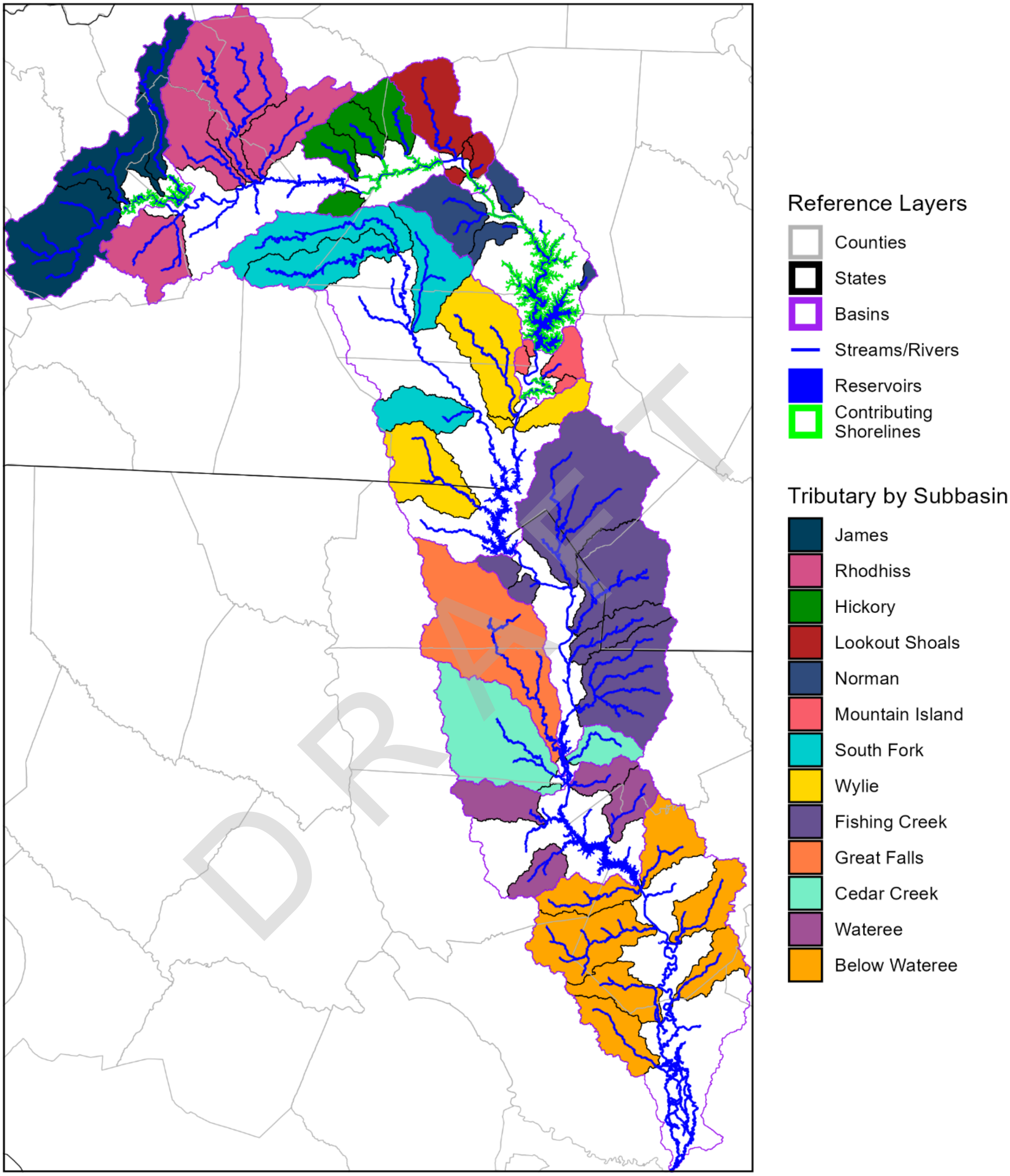

Figure 5-14. Tributaries Identified as Providing Highest Loadings of Sediment and Nutrients within Each Subbasin

5.3.4 Sediment Accumulation within Reservoirs

In addition to the water quality concentrations and loadings that signal potential water quality and ecological concerns throughout the streams, rivers, and reservoirs within the Basin, the volume of sediment moving through the waterways and settling in the reservoirs also has the potential to impact water supplies. As concentrations of sediment increase within the water column, and as water velocities slow in the streams/rivers and reservoirs, sediment particles settle to the bottom of the waterbody. In streams and rivers, sedimentation can impair biologic communities by covering natural, rocky streambeds. In reservoirs, bottom sediment can cause reoccurring water quality conditions; such as, being resuspended or supplying absorbed nutrients and/or other water quality parameters. Additionally, in reservoirs, sediment accumulation may affect navigation and water intake structures.

To understand the sedimentation impacts on reservoirs, the analysis from the previous section, which highlights the four (or five) largest tributary loading sources to each reservoir, is expanded. This expansion allows for estimates of the sediment volume that may settle within the reservoir based on the tributary load delivered. Rough estimates of the median sediment volume settling are made under the following assumptions (Table 5-15):

- Settled sediment has a density of approximately 1,630 tons/acre-foot (i.e., 75 lbs/ft^3) as referenced from studies conducted throughout the Carolina piedmont region.
- Settling rates vary by reservoir and approximate rates were determined during the WaterFALL model simulations of each reservoir using a calibration process to match simulated concentrations in the reservoirs to observed concentration data.

Using these assumptions and the tributary loads simulated for the four selected scenarios, the volume of each reservoir that will be lost to sedimentation is estimated in acre-feet and compared against the volume of each reservoir at its Critical Reservoir Elevation as listed in Table 5-15. Despite the relatively high estimated settling rate for several of the reservoirs (e.g., 80% for Lake Rhodhiss), the volume of settled sediment does not appear to be of concern to any reservoir when examining the total volume available before a water supply impact was felt. However, these volumes were estimated by tributary, given that sediment is more likely to be deposited within the coves and bays through which the tributary flows are delivered, rather than to the main volumes of the reservoir. It is in these coves and bays where the greatest impacts are likely to be felt. Therefore, management may need to be targeted to improve water quality conditions and prevent extreme events from exacerbating isolated water quality concerns.

Table 5-15. Estimated Annual Volume of Sedimentation Due to Tributary Loadings (acre-feet)

Subbasin[1]	Tributary	Acre-ft			
		Current	Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
James (67,432 ac-ft; 30%)	Catawba River	2.78	2.8	2.23	3.83
	Linville River	1.09	1.09	0.91	1.49
	North Fork Catawba River	0.95	0.95	0.76	1.32

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Subbasin[1]	Tributary	Current	Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
		Acre-ft			
	Paddy Creek	0.04	0.04	0.03	0.06
	Shoreline	0.04	0.04	0.03	0.05
Rhodhiss (28,517 ac-ft; 80%)	Johns River	3.73	3.74	3.05	5.07
	Lower Creek	1.24	1.24	1.02	1.66
	Warrior Fork	1.22	1.22	1	1.66
	Muddy Creek	1.17	1.19	0.97	1.57
	Shoreline	0.1	0.1	0.08	0.13
Hickory (103,767 ac-ft; 50%)	Middle Little River	0.6	0.6	0.49	0.8
	Upper Little River	0.25	0.25	0.2	0.35
	Gunpowder Creek	0.2	0.21	0.17	0.28
	Drowning Creek	0.1	0.1	0.08	0.14
	Shoreline	0.05	0.05	0.04	0.07
Lookout Shoals (8,274 ac-ft; 50%)	Lower Little River	0.92	0.91	0.73	1.23
	Elk Shoals Creek	0.06	0.06	0.05	0.08
	Elk Shoal Creek	0.02	0.01	0.01	0.02
	Island Creek	0.01	0.01	0.01	0.02
	Shoreline	0.01	0.01	0.01	0.01
Norman (769,254 ac-ft; 0.5%)	Lyle Creek	0.25	0.24	0.19	0.32
	Buffalo Shoals Creek	0.08	0.07	0.05	0.09
	Shoreline	0.07	0.07	0.06	0.09
	Balls Creek	0.03	0.03	0.03	0.04
Mountain Island (36,065 ac-ft; 3%)	McDowell Creek	0.11	0.13	0.11	0.16
	Gar Creek	0.02	0.02	0.02	0.03
	Shoreline	0.02	0.02	0.01	0.02
	Johnson Creek	0.01	0.01	0.01	0.02
Wylie (160,707 ac-ft; 10%)	South Fork Catawba River	2.56	2.64	2.14	3.55
	Dutchmans Creek	0.26	0.28	0.23	0.37
	Crowders Creek	0.22	0.25	0.21	0.33
	Long Creek	0.12	0.17	0.15	0.22

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Subbasin[1]	Tributary	Current	Future Land Use	Future Land Use & Hot/Dry	Future Land Use & Warm/Wet
		Acre-ft			
	Shoreline	0.09	0.09	0.08	0.11
Fishing Creek (25,633 ac-ft; 30%)	Sugar Creek	1.72	2.28	1.96	2.79
	Cane Creek	0.36	0.41	0.32	0.53
	Twelvemile Creek	0.36	0.38	0.31	0.49
	Big Dutchman Creek	0.1	0.12	0.1	0.15
	Shoreline	0.01	0.01	0.01	0.01
Great Falls/Cedar Creek (7,577 ac-ft combined; 20%)	Fishing Creek	0.63	0.65	0.53	0.83
	Rocky Creek	0.32	0.32	0.26	0.43
	Camp Creek	0.13	0.12	0.1	0.16
	Debutary Creek	0.01	0.01	0	0.01
	Shoreline	0.01	0.01	0.01	0.01
Wateree (173,981 ac-ft; 5%)	Big Wateree Creek	0.12	0.12	0.09	0.16
	Beaver Creek	0.08	0.08	0.06	0.11
	Dutchmans Creek	0.07	0.07	0.05	0.09
	Cedar Creek	0.05	0.05	0.04	0.07
	Shoreline	0.02	0.02	0.02	0.02
Below Wateree (Riverine loading only)	Twentyfive Mile Creek	0.23	0.24	0.19	0.28
	Colonels Creek	0.16	0.17	0.14	0.21
	Spears Creek	0.15	0.15	0.11	0.17
	Sawneys Creek	0.09	0.09	0.07	0.11
	Shoreline	0.01	0.01	0.01	0.02

[1]Included for each reservoir are the volume at the Critical Reservoir Elevation and the WaterFALL calibration sedimentation rate applied to mass of sediment held within the reservoir storage volume each day in a completely mixed assumption.

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5.4 Qualitative Water Quality Evaluations

5.4.1 Harmful Algal Blooms

5.4.1.1 OVERVIEW OF HABS

Harmful algal blooms or HABs are the proliferation of a toxic or nuisance algae or cyanobacteria that negatively affects humans or the natural environment. These blooms are a national concern in freshwater and marine ecosystems because of their negative impacts on the environment and human health, as well as driving economic losses to aquaculture, fisheries and tourism operations. HABs have been previously defined as events where a noticeable visual discoloration of the water occurs due to a rapidly growing cyanobacteria population accumulation often at the water surface but sometimes deeper in the water column (Rousso, Bertone, Stewart, & Hamilton, 2020).

The mechanics of bloom formation are conceptually simple; algae colonies thrive in the presence of nutrients, heat, and sunlight. Many studies have aimed to better understand the specific mechanics of HAB formation. Findings include that environmental determinants most likely to be associated with cyanobacteria bloom occurrence include external waterbody stressors such as nutrient loadings, precipitation, wind speed, and discharge and internal waterbody stressors, such as chlorophyll-a, water temperature, and transparency (Myer, Urquhart, Schaeffer, & Johnston, 2020; Bertani, et al., 2017). Some studies have found that reducing nutrients does not guarantee the decline of blooms (Rao, et al., 2021) and that other factors play important roles interacting with nutrients in regulating HAB formation, such as, meteorology (Yang, et al., 2016) and hydrology (Liu, et al., 2019). The complexity of these interactions limits potential forecasting or prediction of HABs.

A better understanding of drivers of HAB formation has evolved in recent years, as more water managers are dealing with the issue. Algal blooms occur naturally, but human activities that disturb ecosystems seem to contribute to more frequent occurrence and intensity. Human-induced changes to the environment, such as, increased nutrient loadings, food web alterations, introduced species, water flow modifications, and climate change all play a role in causing blooms to occur more often and in locations not previously affected. Scientists are still trying to understand what causes toxins to be generated in algal blooms; therefore, management activities are focused on reduction of bloom biomass.

5.4.1.2 RESOURCES

In recent years, a number of resources and online platforms for reporting, monitoring, and understanding HABs have proliferated. North Carolina Division of Water Resources (NCDWR) has developed a Fish Kill and Algal Bloom Report Dashboard[6] (Figure 5-15). The dashboard provides a map and monthly timeline of positive reports across the state, including agency monitoring and citizen observations.

SCDES has developed an interface for Algal Bloom Monitoring[7] (Figure 5-16), the information submitted in the interface forms a monitoring network across the state and indicates if bloom formation is expected in the near future.

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[6] Fish Kill and Algal Bloom Report Dashboard
[7] Algal Bloom Monitoring

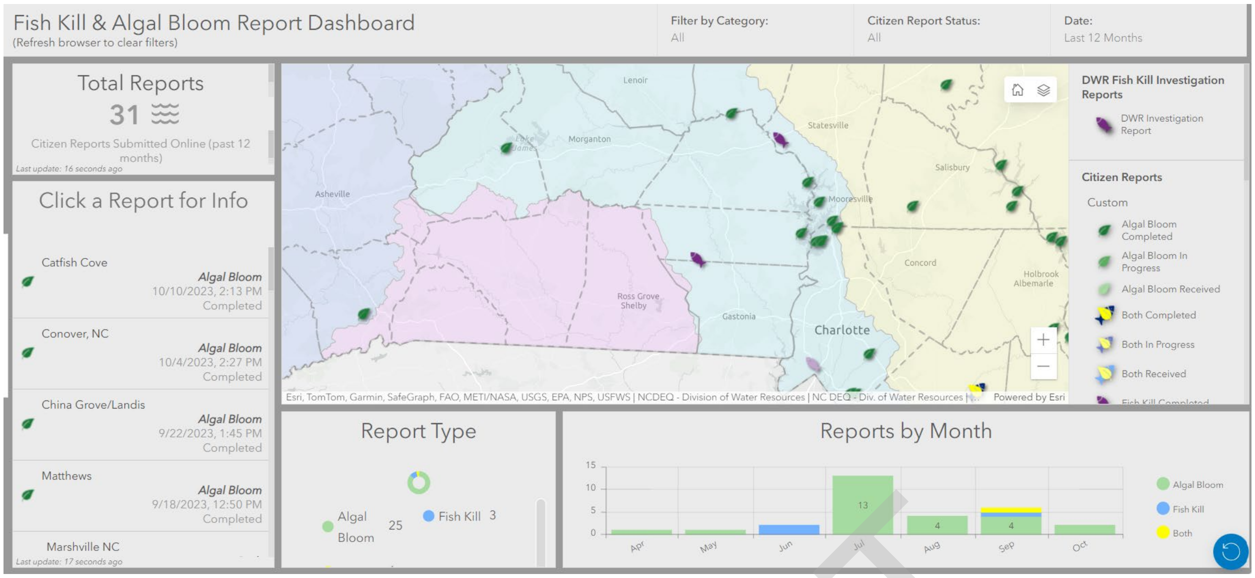

Figure 5-15. North Carolina DWR Fish Kill and Algal Bloom Report Dashboard

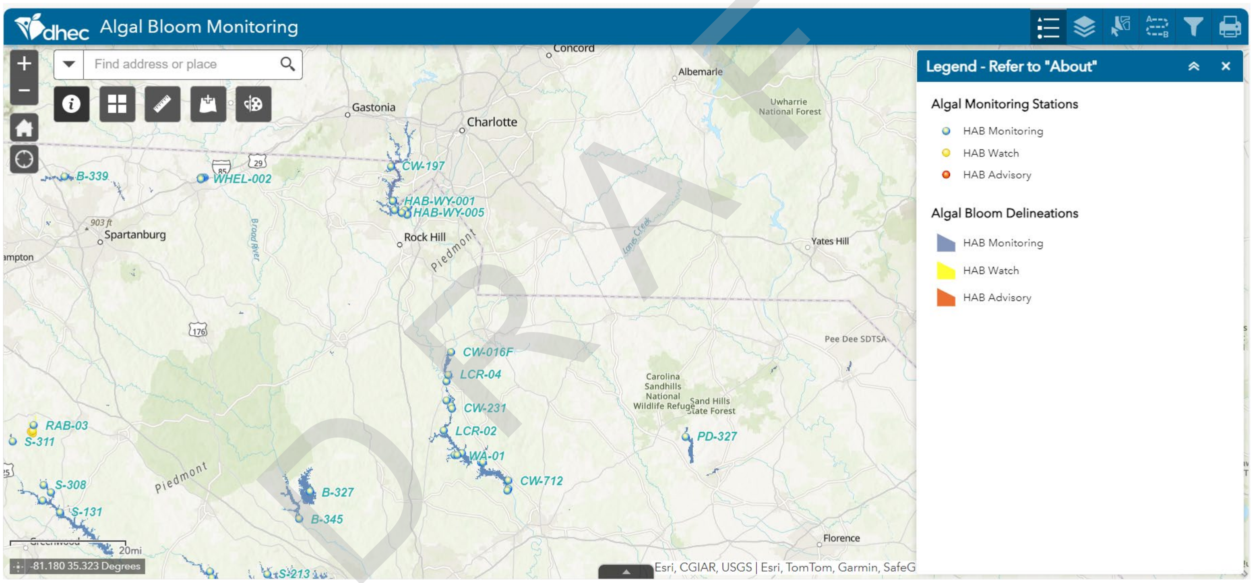

Figure 5-16. South Carolina DHEC Algal Bloom Monitoring Dashboard

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SCDES focuses on testing lake samples for cyanotoxins during the warmer months (May through October). Samples are collected from routine stations and in response to public notification. Health advisories are issued for recreational contact based on concentration of microcystins (8 µg/L) and cylindrospermopsin (15 ug/L). A HAB Watch warning is issued when there is a potential bloom that has been identified but is not producing toxins greater than the standards. A HAB Advisory is issued when a bloom is present and is producing toxins above the standard. People and pets should avoid contact with waters potentially containing HABs.

In North Carolina, in addition to state agencies, Charlotte-Mecklenburg Storm Water Services monitors Lake Norman, Mountain Island Lake, and Lake Wylie within Mecklenburg County.

Another available resource is the Cyanobacteria Assessment Network (CyAN)[8], a multi-agency project among USEPA, National Aeronautics and Space Administration, National Oceanic and Atmospheric Agency, U.S. Geological Survey, and the U.S. Army Corps of Engineers. The network is used to develop an early warning indicator system to detect algal blooms in U.S. freshwater systems utilizing satellite data. Historic imagery to show distribution within reservoirs is housed within the database. Satellite-derived cyanobacteria abundance data are available in the form of rasters of Cyanobacteria Index (CI) values. This product is available daily at a 300-meter resolution, with imagery coverage for each day published within 24 hours. The CI value in each pixel represents the maximum CI value for both the daily and seven day composite periods. Extensive pre-processing is conducted prior to publishing to account for cloud coverage and is actively being improved. An example of this data is presented in Figure 5-17, which illustrates the maximum cyanobacteria abundance for July 14, 2018, at Lake Wateree and upstream reservoirs from the previous seven days. Given the coarse spatial resolution of this dataset, is limited for most reservoirs in the Basin—especially smaller or narrow waterbodies—and is most useful for larger lakes where blooms cover broader areas. CyAN is being transitioned toward use of higher-resolution platforms, such as Sentinel-2 derived products, to enable improved spatial detail in the future.

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[8] Cyanobacteria Assessment Network (CyAN)

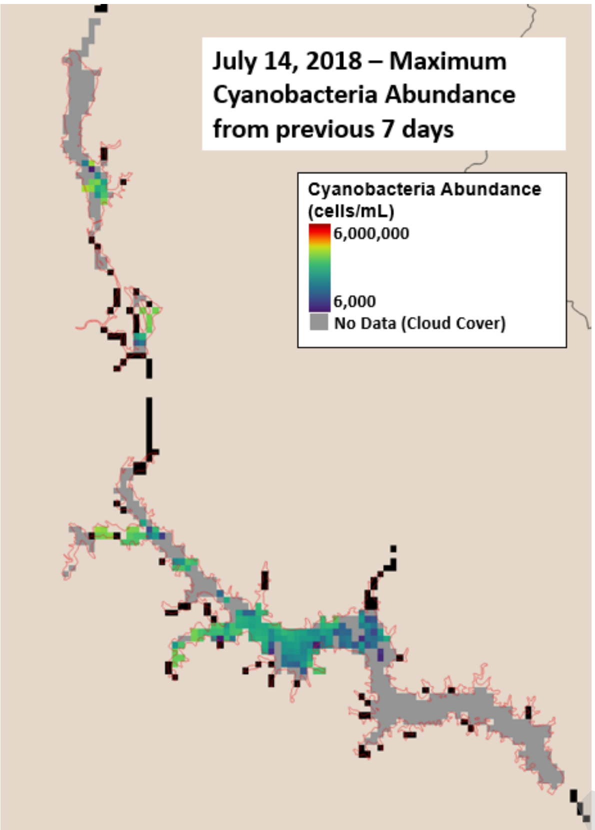

Figure 5-17. Example of the maximum cyanobacteria abundance at Lake Wateree and upstream reservoirs

Based on the CyAN data, USEPA has developed an HAB forecast model[9] that issues a weekly prediction of the chance of a HAB formation in large lakes and reservoirs across the U.S. Three lakes within the Basin are included in these predictions including Lake James, Lake Norman and Lake Wylie. The value of the forecast is a probability from 0% to 100% that the lake may experience a cyanobacteria-dominated bloom in the next seven days. A bloom is defined as a lake-wide median surface chlorophyll-a concentration greater than 12 ug/L. In the summer of 2025, probabilities ranged from 0.1% in April to 3.3% in late August (Figure 5-18). Forecast models can be used for managers to plan monitoring and sampling activities and to issue public health warnings.

[9] Available from HAB Forecasts | USEPA

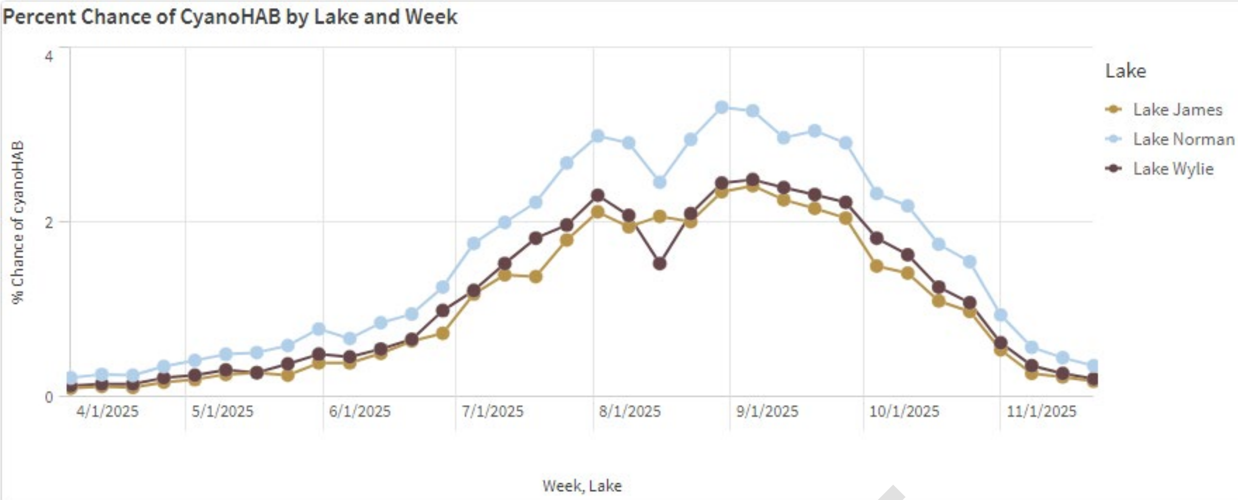

Figure 5-18. Forecast of the likelihood of HAB formation in Lake James, Lake Norman, and Lake Wylie

5.4.1.3 RECOMMENDATIONS FOR THE BASIN (HABS)

Under the Future Land Use Scenario for the Basin, there is projected to be an intensification and expansion of developed areas with a corresponding loss in forest and agricultural lands. Population growth will increase the amounts of nutrients from wastewater treatment plants and urban/suburban stormwater runoff. When combined with the projected climate of higher temperatures, it is expected that HAB formation will be intensified in magnitude, frequency, and duration within reservoirs. These potential future changes would impact the nutrient availability, water temperature, and hydrology in the reservoir's drainage areas. The risk for bloom formation is greatest in late summer (August – September) coinciding when rainfall is often driven by highly variable weather; i.e., tropical storms. In the Dry climate scenario, increased periods of drought are favorable for increased bloom formation. In the Wet climate scenario, higher amounts of precipitation would flush the nutrients from the system leading to a decrease in bloom formation. However, intermediate rainfall could increase nutrients to reservoirs and bloom formation could increase after these episodic events or even transport blooms further downstream. As an example, after the passage of Hurricane Helene in late September 2024, Lake Norman experienced a localized algal bloom of the cyanobacteria (Ferguson 2025). The bloom lasted for nearly two months and was presumably caused by a temporary influx of nutrients in the lake which is normally nutrient limited.

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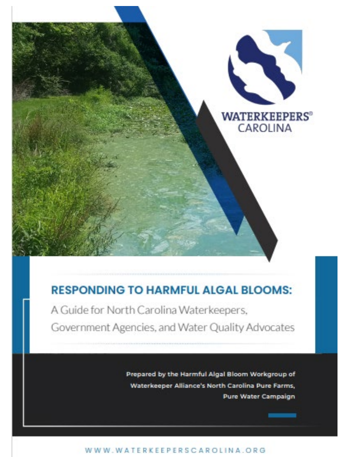

Responding-to-Harmful-Algal-Blooms.pdf: A guide for North Carolina waterkeepers, government agencies, and water quality Advocates.

Although monitoring HABs is time- and resource-intensive, it is critical for managing risk to public health. Basin water managers may choose to take a risk management approach toward monitoring priority reservoirs based on past occurrences of HABs, current environmental conditions (including the levels of nitrogen and phosphorus, temperature), and waterbody use (i.e., type of recreation and the number of users). The biggest risk, particularly financially, is to drinking water supplies which could increase treatment costs. Another risk is hypoxia or low oxygen levels that occur as blooms die off. Lower lake oxygen levels lead to stress or even death of aquatic organisms, such as fish, in the lakes. Studies indicate that most reservoirs in the Southeastern US experience hypoxia during the summer months (Burkholder et al. 2023).

5.4.2 Invasive Species

5.4.2.1 OVERVIEW OF INVASIVE SPECIES

Across the Southeastern U.S., invasive aquatic species in freshwater ecosystems pose significant threats to waterbody management and native biodiversity. These non-native species can outcompete and displace native flora and fauna, leading to detrimental impacts on the region's aquatic ecosystems. The introduction of non-native species often occurs through human activities such as aquarium releases, ballast water discharge from ships, and accidental escapes from aquaculture facilities. As a result, effective management and prevention strategies are crucial to mitigate the impacts of invasive species on the freshwater ecosystems of the Southeastern U.S.

The primary invasive organisms of concern in the Basin are aquatic plants and mollusks. Invasive plants have been identified in all 11 of the reservoirs managed by Duke Energy, including hydrilla, alligator weed, and parrot feather (Table 5-16). These plants can form dense mats on or below the water surface, impeding water flow, blocking sunlight, depleting oxygen levels, interfering with recreation, and potentially blocking water intakes. Such changes negatively affect native aquatic plants, fish, and other organisms dependent on these ecosystems. Invasive mollusk species, such as mystery snails and corbicula, have been identified in the Basin and surrounding basins. These species can block water intakes and outcompete native mollusks, which play a critical role in maintaining water quality.

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Table 5-16. Invasive Species of Concern in the Basin

Name	Description	Treatment
Hydrilla	Nonnative aquatic plant that grows submersed, often forming a thick mat on the surface of the water later in the growing season.	Sterile grass carp that will eat the hydrilla; requires multiple years for control.
Lyngbya	Blue-green algae that can form dense mats within water bodies.	Few proven treatment methods exist; chelated copper-based algaecides are being used for spot treatments.
Alligator Weed	Nonnative plant that grows in mats rooted along the water's edge.	Herbicide application is most effective; although biological controls (e.g., flea beetle) have also been used.
Parrot Feather	Nonnative aquatic plant that grows both submersed and near shore of lakes, ponds, or wetlands.	Herbicides most often used for treatment.
Mystery snails	Smooth, coiled shell, olive green or brown in color ranging from 1 to 2.5 inches found in soft bottoms of lakes.	Physical removal by use of containment screens, mechanical hydro-rake, and traps.
Asian Clam (*Corbicula* spp.)	Relatively small (1-2 inch) bivalve; yellow to blackish-brown in color; triangular shape with heavy, distinct growth rings	None.

Efforts to address aquatic invasive species involve a combination of early detection, monitoring, and control measures. Collaborative initiatives between government agencies, research institutions, and water managers can help bridge knowledge and resource gaps.

5.4.2.2 RESOURCES (INVASIVE SPECIES)

Water managers in the Basin have a history of proactively monitoring and addressing invasive species. Duke Energy began surveying its reservoirs for invasive species in 1983, laying the groundwork for continued monitoring and management. This is continued today, with Duke Energy conducting surveys of aquatic plants along the shoreline of each of the Basin's 11 reservoirs on a regular basis. This monitoring and management has evolved into a collaborative cost-share partnership between Duke Energy, CWWMG, local governments, and regulators in North and South Carolina. This program has funded several successful interventions and removal of invasive species over its lifetime, such as the management of nearly 640 acres of hydrilla from Lake Norman in 2018.

In 2022, the Southeast Regional Invasive Species and Climate Change Management Network[10] was formed to connect scientists, natural resource managers, policymakers, and stakeholders by sharing knowledge, building stronger partnerships, and synthesizing the latest research. The network strives to reduce the joint effects of climate change and invasive species.

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[10] Southeast Regional Invasive Species and Climate Change Management Network

5.4.2.3 RECOMMENDATIONS FOR THE BASIN (INVASIVE SPECIES)

As noted in Duke Energy's 2021 Aquatic Plant Survey of the Basin, "the most effective means of controlling invasive aquatic plants is prevention and early detection/rapid response to new invasions." To support this effort, Duke Energy also provides a citizen reporting tool for the public to report sightings of invasive aquatic plants (Aquatic Plant Report - Duke Energy).

The focus of invasive species management should be shifting towards surveillance and monitoring activities that can lead to early detection followed by prompt implementation of control measures. Mehta, Haight, Homans, Polasky, & Venette (2007) illustrates that for species with high damage, it is often optimal to assign significant resources to detection efforts even if the species is difficult to detect. Increased monitoring and more interagency and interstate coordination is also necessary for invasive-species management.

In general, climate change may put native species at a disadvantage because they will no longer experience the ranges of environmental variables to which they are best adapted. However, there are few good predictions of which invasive species will have greater effects under climate change. Given that climate change will interact with other existing stressors to affect the distribution, spread, abundance, and impact of invasive species, it will take more research to understand how specific invasive species may behave under an altered climate and which new species will emerge as invasive.

In recent years, CWWMG has helped to coordinate treatment actions and funding for lyngbya among members, local stakeholders, and government agencies that are the source of funding. These efforts have resulted in efficient treatment programs and should be continued.

5.4.3 Contaminants of Emerging Concern

Contaminants of Concern are a constantly evolving group of water quality concerns that fall outside of those conventionally managed with wastewater treatment. In the Basin, these consist of Per- and polyfluoroalkyl substances (PFAS), polychlorinated biphenyls (PCB), pharmaceuticals, and microplastics. These are synthetic compounds that are usually present at extremely low concentrations relative to other water quality parameters, presenting challenges to monitoring and management.

5.4.3.1 PFAS

PFAS has been gaining more attention from regulators and water managers in recent years. PFAS and related compounds are synthetic chemicals known for their water- and grease-resistant properties, making them common in a variety of industrial, commercial, and consumer products. These substances have been used in firefighting foams, non-stick cookware, waterproof clothing, and more. However, their resistant nature has led to their accumulation in the environment, including soil, water, and air.

The health concerns associated with PFAS exposure have garnered increasing attention. Studies have linked PFAS to adverse health effects, including potential connections to cancer, reproductive issues, and immune system disruption. Given their mobility and resistance to degradation, PFAS have been detected in the ambient environment and drinking water supplies

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across the country. This has prompted regulatory actions at both the federal and state levels to monitor and control PFAS contamination.

On April 10, 2024, USEPA announced National Primary Drinking Water Regulations[11] for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) (Table 5-17) and gave public water utilities until 2029 to comply with the maximum contaminant levels (MCLs). In May 2025, USEPA announced that they will keep the April 2024 MCLs, but extended the compliance date until 2031. USEPA plans to issue a final rule in Spring 2026. On November 1, 2025, North Carolina 2L standards for PFAS went into effect for three PFAS compounds.

Table 5-17. Maximum contaminant levels (MCL) for PFAS based on the National Primary Drinking Water Regulation (USEPA 2024)

Compound	Final MCL parts per trillion (ppt)
PFOA	4.0 ppt
PFOS	4.0 ppt
PFHxS	10.0 ppt
PFNA	10.0 ppt
GenX (HFPO-DA)	10.0 ppt
Mixtures containing two or more of: PFHxS, PFNA, Genx, and PFBS	Hazard Index of 1 (unitless)

High PFAS concentrations in the environment are associated with areas that have experienced intensive emissions in the past. In the Basin, these tend to be locations with repeated firefighting, such as Charlotte-Douglas Airport where multiple PFAS compounds were detected in 2019. Outside of these acute emissions, atmospheric deposition and degradation of everyday consumer products have led to a widespread, low concentrations of PFAS. In the Basin, over 10 drinking water providers have detected PFAS in their water system (Source).

During 2022 and 2023, SCDES sampled more than 100 streams, rivers, and lakes sites. PFAS was detected in nearly all surveyed water sites. PFOA and PFOA were found in 20% and 12% of total PFAS, respectively, across the state (SCDHEC, 2023). PFAS was also detected in freshwater fish samples across the state. SCDHEC has had positive detections of PFAS at all their monitoring stations along the mainstem of the Catawba-Wateree.

As PFAS has grown in prominence and concern for water managers, a number of resources have emerged for centralizing reporting and testing. The North Carolina PFAS Testing Network[12] is a collaborative statewide study among scientists to serve as a common destination for sharing testing data and the latest research. Testing data includes samples from drinking water systems in the Basin and measurements of atmospheric deposition rates in Charlotte. NCDEQ conducted PFAS sampling at 533 small water systems in 2023 and 228 in 2024 that

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[11] National Primary Drinking Water Regulations
[12] North Carolina PFAS Testing Network

opted into a one-time sampling. Results from this sampling effort are included in the maps shown on Figure 5-19.[13]

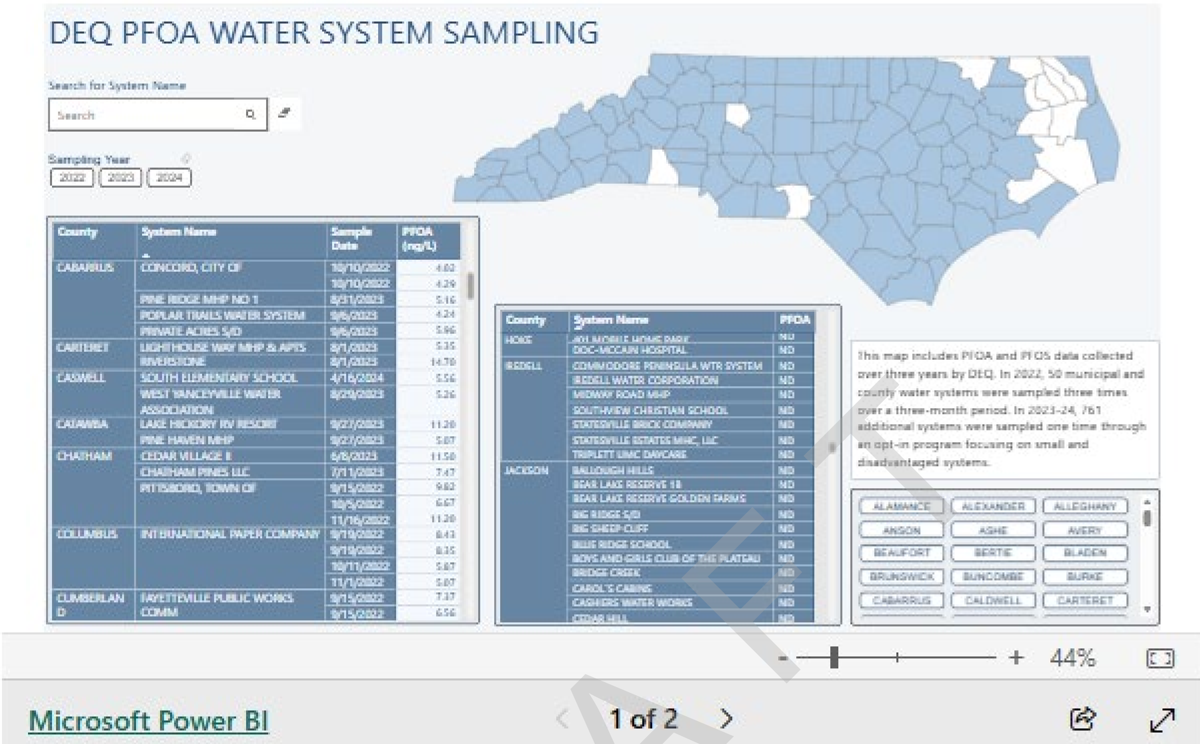

Figure 5-19. NCDEQ PFOA Water Sampling Results Dashboard

In South Carolina, SCDES runs the Ambient Surface Water PFAS project, which shares locations where surface water samples and fish tissue samples were collected and tested for PFAS and precursor compounds. This dataset includes 12 surface water sampling sites and two fish tissue sampling sites within the Catawba watershed (Figure 5-20).

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[13] DEQ PFAS Sampling of Public Water Systems | NCDEQ

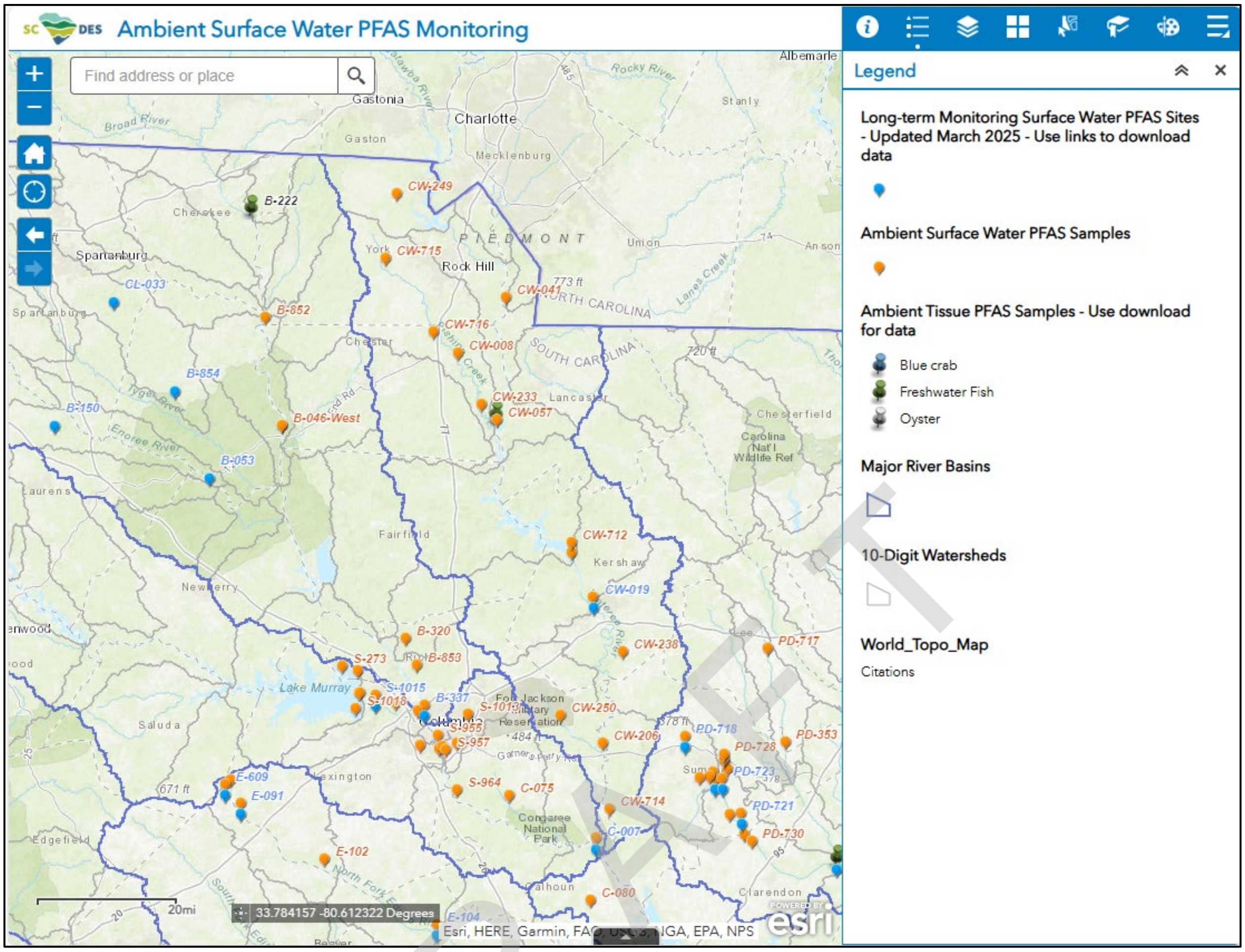

Figure 5-20. Ambient Surface Water PFAS project sampling sites

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In addition to regulators, the Environmental Working Group[14] has developed an interactive map combining data across states and actors. The PFAS Contamination in the US map (Figure 5-21) was released in November 2023 and shows drinking water systems and groundwater wells that have tested positive for PFAS throughout the Basin.

[14] Environmental Working Group

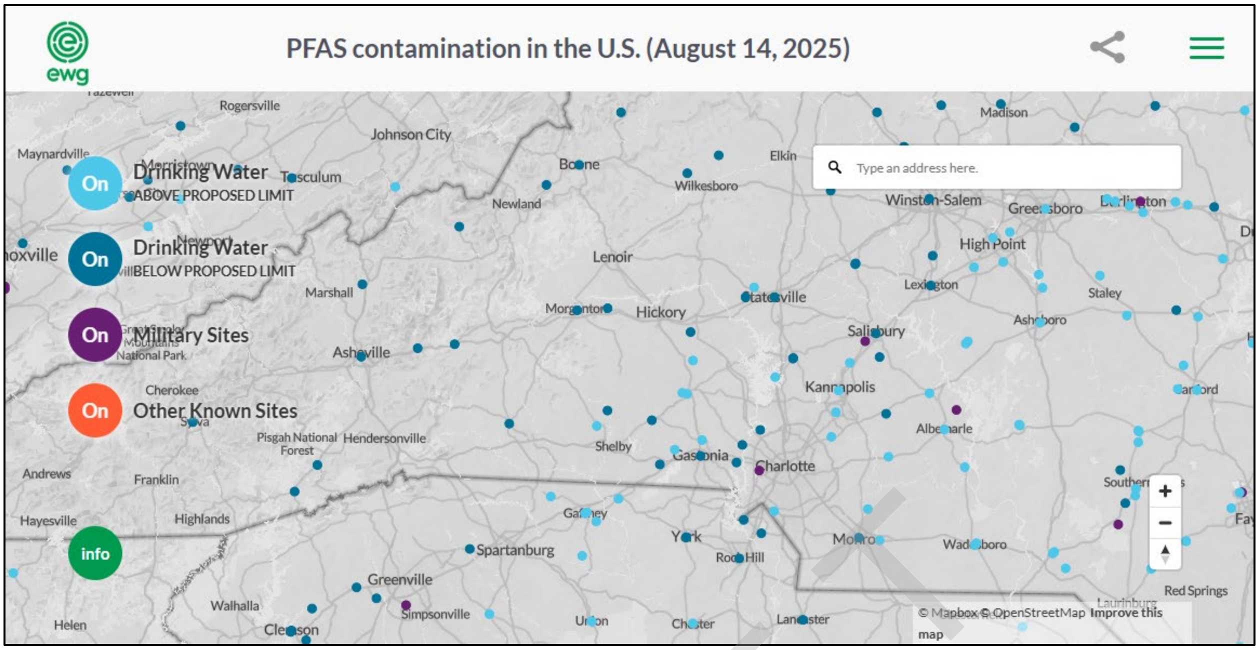

Figure 5-21. PFAS contamination in the U.S. as of August 14, 2025 (from the Environmental Working Group)

5.4.3.2 POLYCHLORINATED BIPHENYLS

PCBs are man-made chemicals that were produced from 1929 until manufacturing was banned in 1979 by the Toxic Control Substance Act. PCBs are still found in electrical and heating equipment, hydraulic oils, thermal insulation, paints, and plastics. PCBs are still a concern today because they persist in the environment for long periods of time and are still found in elevated levels in soil, sediment, and in the tissue of fish and other animals. PCBs also accumulate in plants and animals causing a risk for higher trophic levels. The adverse health effects of PCBs has been widely studied and have been shown to cause cancer in animals as well as serious effects on the immune system, reproductive system, nervous system, and endocrine system (Learn about Polychlorinated Biphenyls | USEPA).

Fish, from several lakes and reservoirs in the Basin, have been found to contain high levels of PCBs. These high levels cause regulatory agencies in North Carolina and South Carolina to issue consumption advisories (Table 5-18). Concentrations were generally higher in South Carolina with Cedar Creek Reservoir and Fishing Creek Reservoir having the highest levels of PCBs and Lake Norman, Mountain Island Lake, and Lake Wylie having the lowest (Glover and Gundersen, 2021).

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Table 5-18. Applicable Fish Consumption Advisories for PCBs

Reservoir	State	Fish Consumption Advisory for PCBs
Lake Norman	NC	STP, HYS
Mountain Island Lake	NC	BLC, CHC
Lake Wylie	NC/SC	LMB, CHC, BKS
Fishing Creek Reservoir	SC	LMB, BLC, CHC, WHB, BKS
Cedar Creek Reservoir	SC	LMB, BLC, CHC, WHB, BKS
Lake Wateree	SC	LMB, BLC, CHC, WHB, STB, BKS

Note. LMB = largemouth bass, HYS = hybrid striped bass, BLC = blue catfish, CHC = channel catfish, BKS = black crappie, WHB = white catfish, STP = striped bass. Source: Glover and Gundersen, 2021.

PCBs are regulated by the Toxic Substances Control Act and details are available in Title 40 of the Code of Federal Regulations. In South Carolina, PCB regulations are governed by the South Carolina Code of Regulations, Part A, Section 61-9.504.C. These regulations require the sampling and monitoring of sludges for PCBs, particularly for land application. If levels exceed certain thresholds, additional sampling and reporting are required. The regulations also include provisions for the disposal of industrial sludge and the application of sludges to land, ensuring that PCB levels are controlled to prevent contamination.

5.4.3.3 PHARMACEUTICALS

Pharmaceuticals antibiotics, prescription and nonprescription drugs, animal and plant steroids, reproductive hormones, and personal-care products, are widely used by humans and farm animals to prevent and treat health concerns. Once ingested, residual compounds are excreted, reaching water supplies through wastewater effluent and surface runoff. Other sources of pharmaceuticals include industrial manufacturing processes and household disposal of medication. As a result, pharmaceuticals are found in wastewater, surface waterbodies, and even groundwater supplies (Ortuzar et al. 2022; Loper et al. 2007).

Pharmaceutical compounds are found at relatively low concentrations in natural waters, but the environmental impacts are largely unknown. Fish and other wildlife may be at risk from chronic exposure and bioaccumulation causing development and reproductive issues and resistance to antibiotics. Since many of these compounds are not removed by conventional drinking water treatment processes, they may be present in drinking water supplies. Furthermore, communities relying on groundwater sources of drinking water have higher risk of exposure.

5.4.3.4 MICROPLASTICS

Microplastics is a term that was first used in 1990 to describe plastic pollution (Ryan and Moloney 1990). Microplastics are described by their size and are defined as plastics smaller than five millimeters (mm) but larger than one micrometer (μm). Microplastics have been found everywhere—from the highest mountain peaks to the deep ocean waters. Because of their small size and widespread distribution, they are an emerging area of concern.

There are two main types of microplastics. Primary microplastics are intentionally manufactured as pellets or microbeads for use in products such as cosmetics or toothpaste. Secondary

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microplastics come from larger pieces of plastic such as beverage bottles, bags, and toys. Microplastics are so small that that aquatic organisms can mistake them for food, and they accumulate in the food chain to large organisms. Research is being conducted to understand the long-term effect on human health and aquatic life.

Efforts to reduce primary sources of microplastics are focused on the reduction of use in consumer products. Trash traps are being used to target secondary sources of microplastics—large plastic debris and other trash the enter streams and rivers. Waterkeepers Carolina have installed 25 trash traps with several located in the Basin. Their Dashboard reports the quantity and type of debris removed.

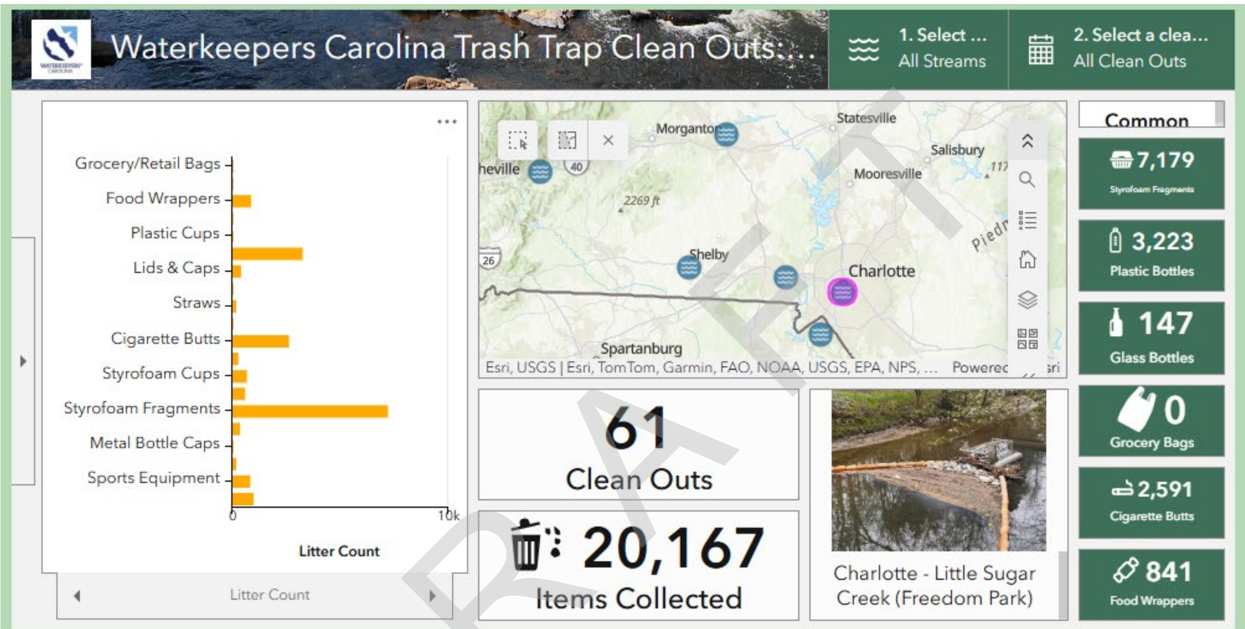

Figure 5-22. Catawba Riverkeeper Dashboard

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5.4.4 Recommendations for the Basin

Except for some of the PFAS compounds, Contaminants of Emerging Concern are considered unregulated contaminants. In other words, neither the USEPA nor state governments have established MCLs. Some compounds may have a health advisory standard, which is a suggested limit but is not a regulated limit under the Safe Drinking Water Act. The Safe Drinking Water Act requires USEPA to issue a list of unregulated contaminants to be monitored by public water suppliers such as Charlotte Water every five years. The results from the testing is publicly available in Charlotte Water Consumer Confidence reports.

PFAS: SC Recommendations:

- Establish statewide long-term surface water monitoring program for PFAS. Multiple years of evidence (seasonal) as a series of locations will resolve interannual variability attributed to changes in hydrology and PFAS inputs from possible pathways.
- Continue to gather PFAS data in freshwater fish to help develop species-specific consumption advisories.

- Develop an understanding of sources that release PFAS to the environment.
- Find approaches to limit or reduce PFAS release to the environment.

PFAS: NC Recommendations

- Refer to Action Strategy for PFAS (NC DEQ, 2022)
- Protecting Communities
  - Prioritize testing of public drinking water systems and private drinking water wells.
  - Reporting of PFAS emissions or discharges to air, surface water and groundwater from priority locations like industrial sites, wastewater treatment plants, and landfills.
- Protecting Drinking Water
  - Enact regulatory standards for groundwater, surface water and drinking water.
  - Implement standards by modifying existing permits with enforceable limits of PFAS discharges and use approved standards to ensure that drinking water is treated to the level that is protective of human health.
  - Support initiatives that focus on pollution prevention and minimize future PFAS releases.
- Cleaning up Existing Contamination
  - Focus on remediation to address known sites for PFAS contamination and work to hold polluters accountable for the clean-up.
- Pharmaceuticals
  - Monitoring of drinking water supplies and wastewater by state and local agencies.
  - Application of advanced treatment technologies in both centralized and decentralized approaches to ensure comprehensive mitigation. Centralized treatment options include advanced oxidation processes like ozonation, membrane technologies, adsorption, and electrochemical methods.
  - Preventing release of pharmaceuticals can be achieved by educating individuals on proper disposal practices and effluent treatment from industrial and medical facilities.

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Groundwater Assessment

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6 Groundwater Assessments

6.1 Groundwater Conditions and Trends

6.1.1 Groundwater Sites

Water resource conditions in the Catawba-Wateree Basin gained heightened attention following the multi-year drought from 1998 to 2002, which highlighted the importance of improved monitoring and planning for low-inflow periods. In response, USGS partnered with Duke Energy and the CWWMG to develop a Basin-wide streamflow and groundwater monitoring network, with Duke Energy funding the streamflow gages used in the LIP and the CWWMG funding the groundwater gages, to provide the long-term data needed to establish critical trigger levels for the Basin's Low Inflow Protocol (LIP). The network includes twenty-one groundwater monitoring stations organized into ten clusters, each strategically located on higher ground, away from floodplains and outside the immediate influence of surface water reservoirs to ensure measurements reflect natural, long-term groundwater conditions. Each cluster contains at least two wells installed close together but at different depths to monitor the hydrogeologic zones characteristic of the Piedmont and Mountain regions: the regolith, which responds rapidly to precipitation and short-term recharge; the transition zone, which exhibits mixed properties; and the bedrock, where water levels change more slowly and reflect long-term storage that supports baseflow. The twenty-one monitoring wells used in this study are listed in Table 6-1, grouped by their respective clusters and identified by their target hydrogeologic zone and USGS site number. Water-level observations from all wells are available at an hourly timestep through USGS web portals, and Figure 6-1 shows the locations of these monitoring stations.

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Table 6-1. Monitoring Well Inventory

USGS Site Number	Cluster Location	Well ID	Hydrogeologic Zone
USGS-354133082042201	Pleasant Gardens RS	MC-107	Regolith
USGS-354133082042203		MC-109	Bedrock
USGS-344333080503600	Lancaster County Airport	Lan- 497	Regolith
USGS-344333080503601		Lan- 498	Bedrock
USGS-342440080443900	Kershaw County NR Liberty Hill	Ker- 433	Regolith
USGS-342440080443901		Ker- 435	Bedrock
USGS-353135080524201	Langtree RS	IR-130	Regolith
USGS-353135080524202		IR-131	Transition Zone
USGS-353135080524203		IR-132	Quartz Diorite
USGS-354302081433201	Glen Alpine RS	BK-126	Bedrock
USGS-354302081433202		BK-127	Regolith
USGS-355031081243202	Granite Falls RS	CD-101	Transition Zone
USGS-355031081243303		CD-102	Bedrock
USGS-354616081085101	Oxford RS	CW-350	Transition Zone
USGS-354616081085102		CW-351	Bedrock
USGS-352012081154301	Pasour Mtn RS	GS-289	Regolith
USGS-352012081154302		GS-290	Transition Zone
USGS-345609080415102	Mineral Springs RS	UN-147	Transition Zone
USGS-345609080415103		UN-148	Bedrock
USGS-345830081033100	York County Airport	YRK-3295	Bedrock
USGS-345830081033101		YRK-3296	Regolith

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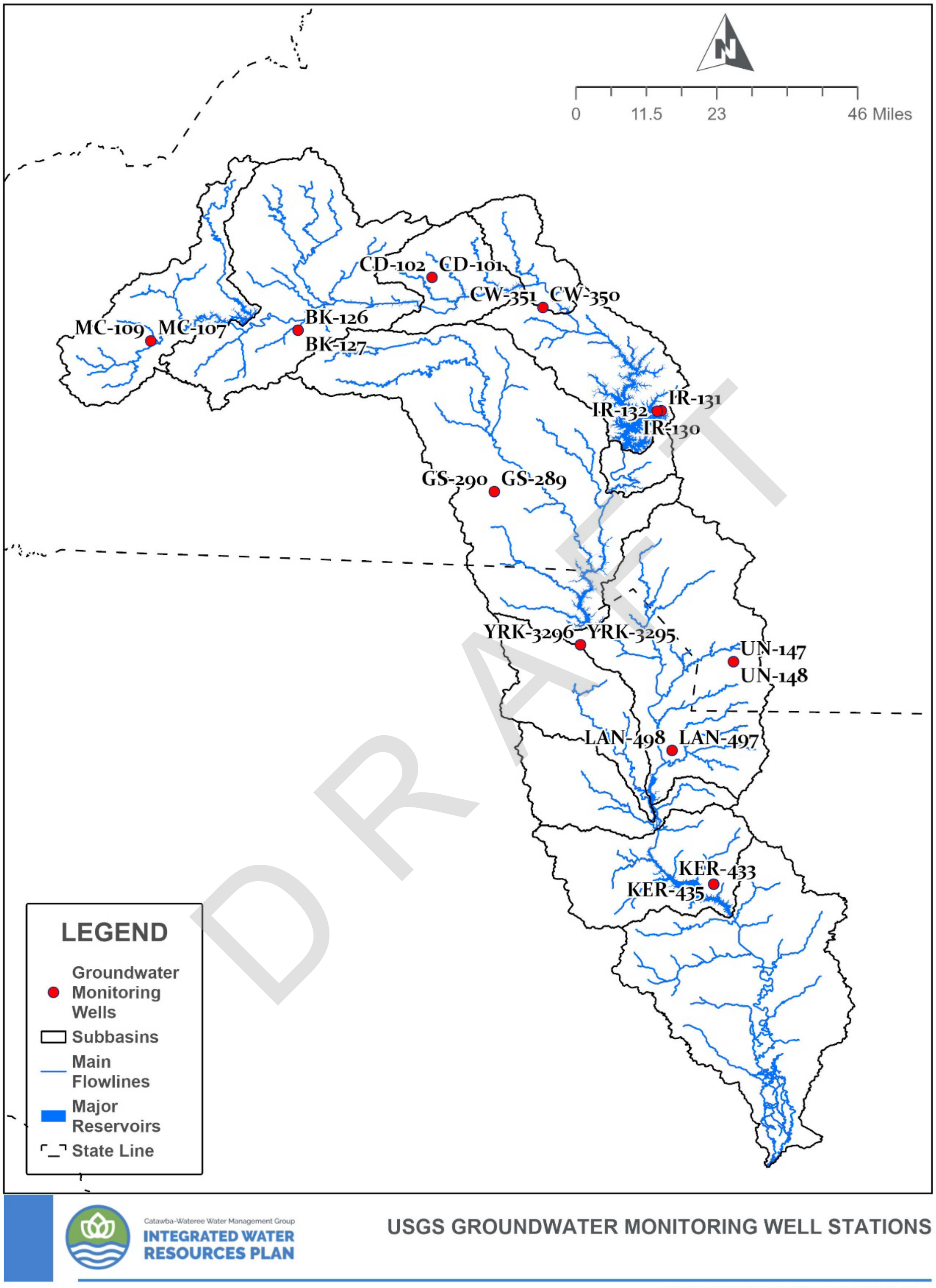

Figure 6-1. Groundwater Monitoring Well Stations in the Catawba-Wateree Basin.

6.1.2 Annual and Seasonal Variability

Groundwater levels in the bedrock monitoring network demonstrate stable long-term conditions, with multi-year trends dominated by predictable seasonal fluctuations. As shown in Figure 6-2, there is no evidence of widespread or sustained long-term decline across the network over the past two decades. Instead, groundwater levels in the bedrock aquifer system have remained generally consistent, with annual patterns of recharge and drawdown exerting the strongest influence.

Water levels across all monitored bedrock sites rise and fall in a highly synchronized pattern, regardless of their absolute depth below ground. This synchronized behavior reflects regional climate-driven recharge patterns, which ultimately drive the surface flow and deep seepage processes that directly regulate groundwater levels in the fractured bedrock system.

The time series plot also highlights clear differences in water-level stability and seasonal amplitude among the wells. Sites such as BK-126, one of the shallowest wells, and CW-351, one of the deepest, exhibit stable long-term behavior with minimal interannual variability, suggesting consistent local hydrogeologic conditions that buffer them from pronounced fluctuations. In contrast, wells such as IR-132 and CD-102, which are geographically between BK-126 and CW-351 in the upper Basin, show larger seasonal amplitudes and more noticeable interannual variability, indicating local hydrogeologic settings that are more sensitive to variations in recharge or seasonal water loss.

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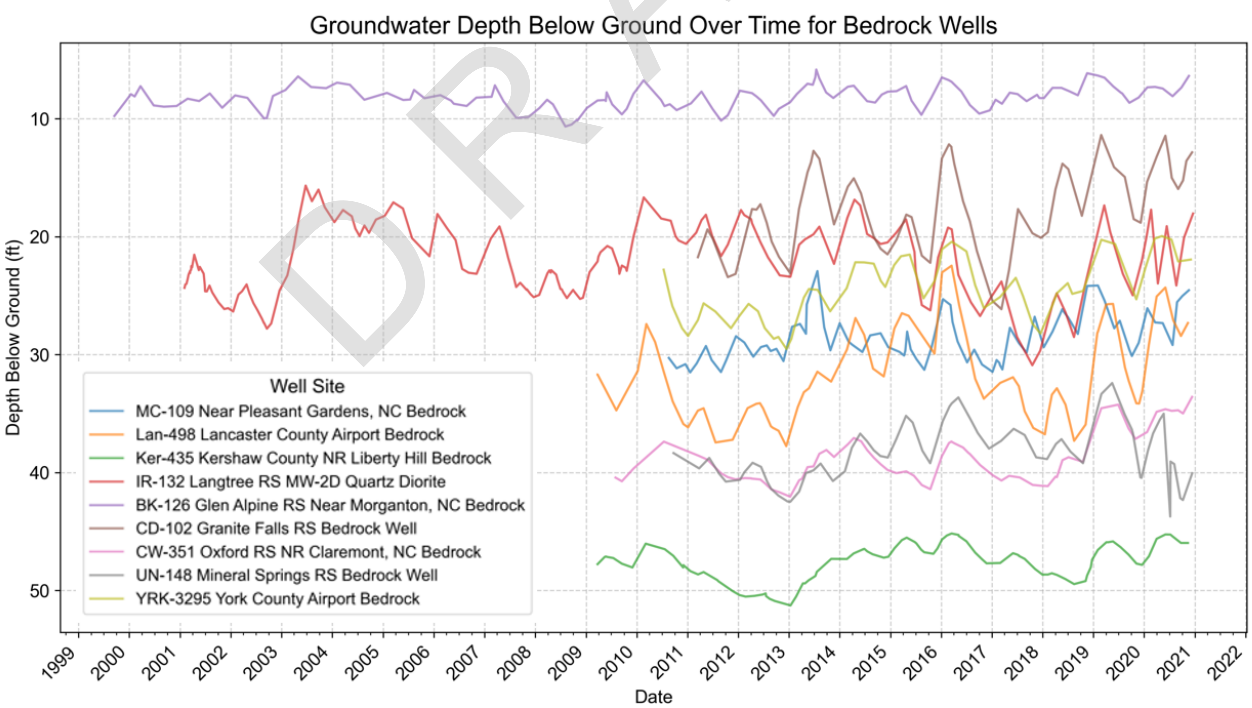

Figure 6-2. Long-Term Groundwater Level

Despite these site-specific differences, all wells display a consistent seasonal cycle that defines groundwater dynamics in the Basin. Figure 6-3 shows that groundwater levels typically peak in the spring (March-May), representing the primary recharge period when precipitation is high and evapotranspiration is low. Water levels then decline through summer (June-August) and into fall (September-November) as evapotranspiration intensifies and seasonal water demand increases. The magnitude of this cycle varies by site. Wells such as Ker-435 and Lan-498 show moderate seasonal changes, while wells like UN-148 and IR-132 exhibit more pronounced summer drawdowns, reflecting their greater sensitivity to seasonal climatic stresses.

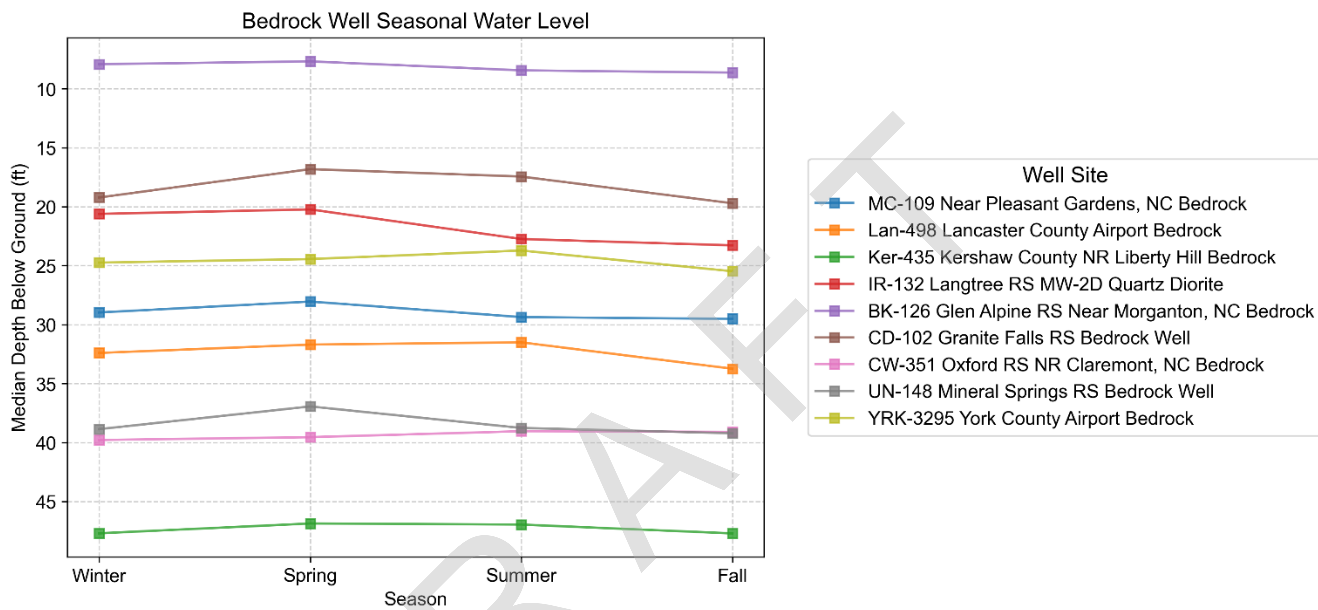

Figure 6-3. Seasonal Groundwater Level

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6.2 Groundwater-Surface Water Interactions

The comprehensive groundwater monitoring network provides critical insight into how groundwater levels respond to Basin-wide hydrologic conditions. This analysis focuses on understanding how measured groundwater levels correspond to modeled streamflow and seepage dynamics, which represent the movement of water into the groundwater system.

To evaluate these relationships, a comparative analysis was conducted for each monitoring well. The primary goal was to quantify the strength and consistency of the correlation between observed groundwater depths over time and the modeled flow and seepage, allowing for a clearer understanding of how groundwater levels reflect broader hydrologic inputs.

6.2.1 Analytical Approach

Groundwater levels were compared directly with the WaterFALL simulated streamflow for the tributary within the same catchment as the well. This comparison provides insight into the immediate, local connection between the water table and the adjacent stream channel. To assess broader hydrologic influences on groundwater storage, well water levels were compared against the WaterFALL simulated deep seepage rate (i.e., rate of water moving down into the deeper groundwater aquifer) for the corresponding catchment. Because deep seepage in the model represents water lost to deeper groundwater, this comparison helps characterize how subsurface water storage (after infiltration from the surface) and seepage from this subsurface storage are associated with observed groundwater-level variability.

To reduce the influence of high-frequency variability in the daily hydrology and focus on trends relevant to drought management, simulated flow and seepage rates were analyzed over multiple averaging intervals: daily, three-month, and six-month. The three-month averages are particularly useful for identifying sustained low flow or low recharge periods and for relating those sustained conditions to multi-month changes in groundwater depth.

6.2.2 Findings

Analysis across all monitored wells consistently revealed a strong, direct correlation between groundwater depth below ground and the modeled streamflow and seepage time series. This consistent pattern confirms that the primary driver of groundwater level fluctuations is variations in surface flow and deep seepage, which are, in turn, driven by climate patterns and events. Overall, the results indicate that changes in groundwater levels closely follow broader hydrologic trends, reflecting the integrated response of the aquifer system to regional and local water inputs.

Focusing on a representative example at Glen Alpine RS near Morganton, the BK-126 bedrock well and BK-127 regolith well both exhibit a similar total fluctuation range of approximately 4 feet between their maximum and minimum recorded depths. This indicates the aquifer system has relatively limited storage capacity and is highly sensitive to variations in flow and recharge. Both wells respond strongly to changes in hydrologic conditions, and periods of unusually low flow or seepage can rapidly drive water levels to annual minima, overriding longer-term trends. These observations highlight the sensitivity of the groundwater system to short-term hydrologic stresses and underscore the importance of continuous monitoring to understand groundwater level response to both seasonal and acute water deficits. Under a Hot/Dry future climate scenario, the frequency and duration of low flow periods are expected to increase, which could exacerbate water level declines and place additional stress on the aquifer system. Additional wells are included in Appendix J.

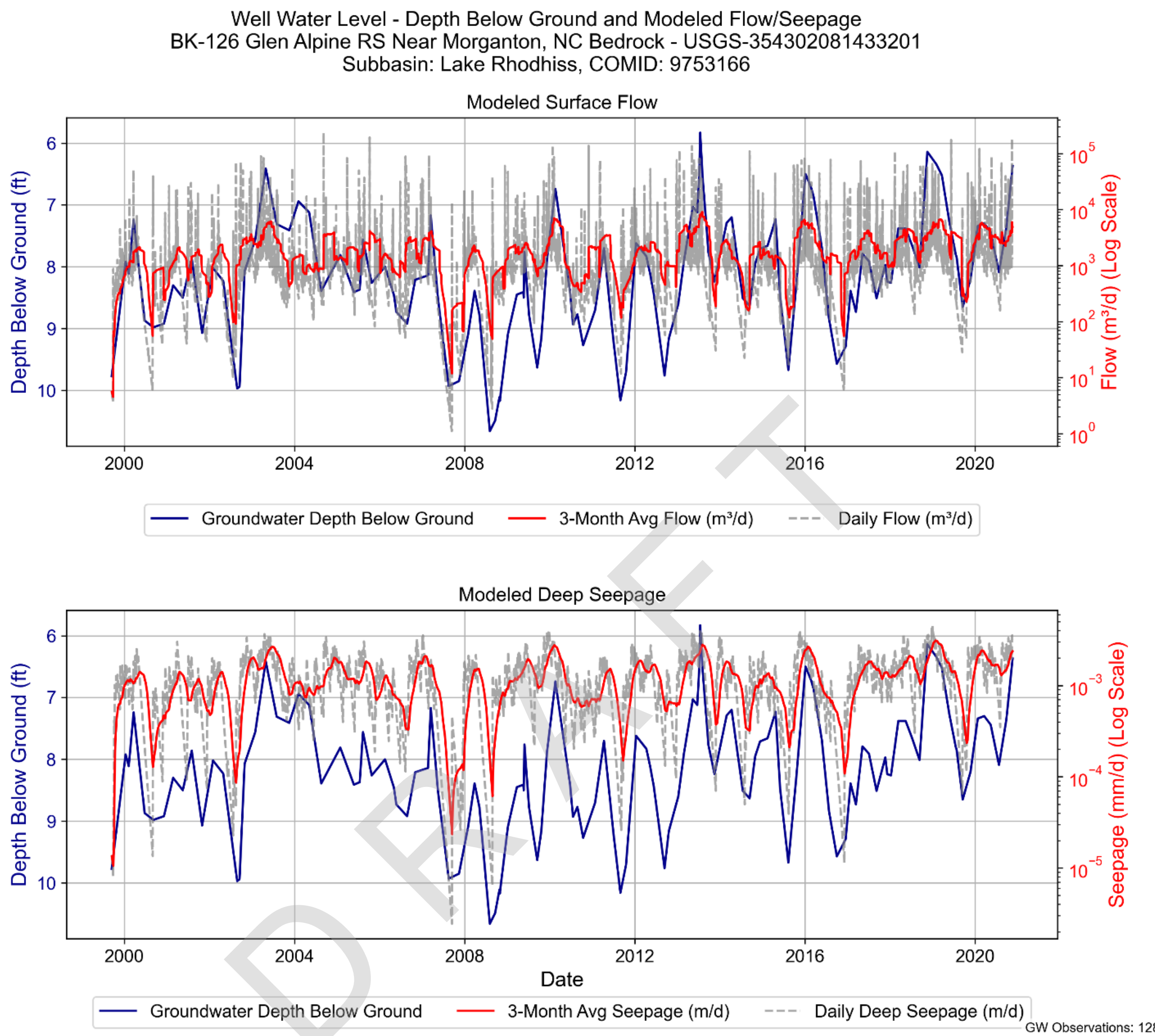

Figure 6-4. Groundwater Elevations Streamflow (top) and Compared to Groundwater Recharge Rates (bottom) for Well BK-126

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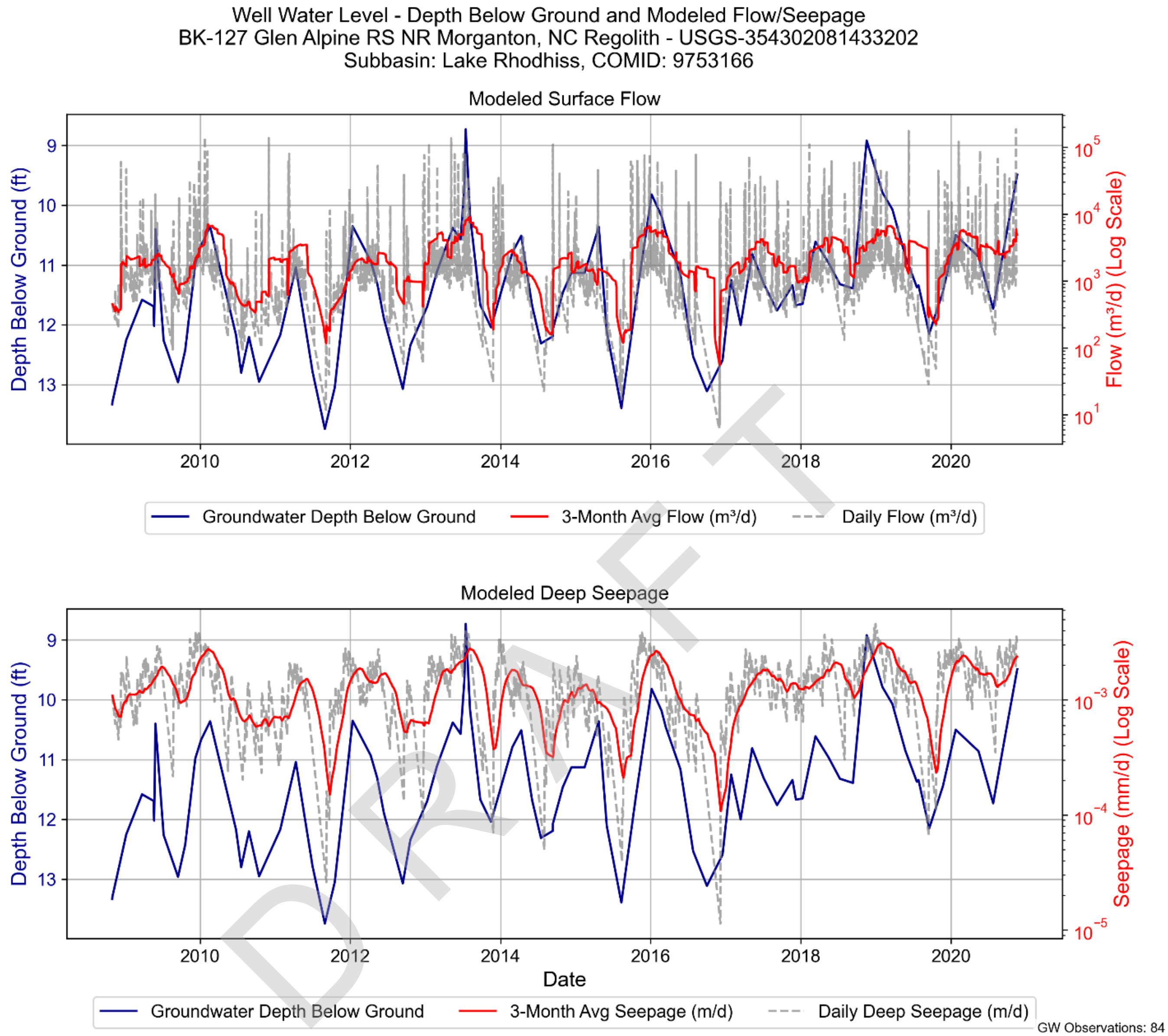

Figure 6-5. Groundwater Elevations Compared to Streamflow (top) and Groundwater Recharge Rates (bottom) for Well BK-127

6.3 Recommendations for Groundwater Management

Analysis of monitored wells consistently shows a strong correlation between groundwater levels and modeled streamflow and seepage. This relationship confirms that variations in surface flow and subsurface recharge are the primary drivers of water table fluctuations and demonstrates the value of incorporating groundwater observations into proactive water resource management strategies. This analysis shows promise for considering the three-month average groundwater levels as a potential trigger point for drought management protocols or early warning systems, as it effectively captures sustained hydrologic stress while filtering out short-term variability.

Additionally, as the current LIP has recovery requirements stating that "groundwater levels must show improvement to designate less restrictive LIP stages" (See Appendix G) with the monthly average of the daily mean water levels used as the indicator for this recovery metric. However, calculations based on groundwater levels are still for informational purposes only until approved USGS data reflecting the full range of historical hydrologic conditions in the Catawba-Wateree River Basin are available. Therefore, while groundwater observations provide valuable insight, the data are not yet sufficient to be used as a formal LIP recovery trigger. We recommend continuing to collect groundwater data to further develop the context needed for potential future use in LIP decision-making.

Using groundwater levels in this way could help guide decisions on water use restrictions, conservation measures, or public advisories. Wells that respond quickly to changes in deep seepage may serve as leading indicators, while wells reflecting deeper or slower-responding parts of the system can provide context on longer-term trends. Given projected impacts from Hot/Dry future climate scenario, including more frequent and prolonged low flow conditions, monitoring groundwater levels can help identify the most vulnerable systems and support targeted management actions. Further study of aquifer response under low flow conditions can inform sustainable allocation and long-term planning.

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Management Scenarios

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7 Management Scenarios

Future climate change impacts are largely beyond local control, including shifts in temperature, precipitation, and extreme events. In contrast, land use changes can be actively managed, offering a practical way to reduce future risks to hydrology and water quality. Because land management is one of the few controllable factors, a set of scenarios was developed to evaluate how different interventions could influence watershed conditions.

Three watershed scale management scenarios were examined. In each, WaterFALL parameters were adjusted in all applicable catchments to simulate the impact of basin-wide management actions. The Natural Land Conservation scenario prevents any current natural lands from being developed in the future. The Riparian Buffer Conservation scenario protects natural land within riparian areas from future development. The Agricultural Conservation scenario applies a range of Best Management Practices to existing agricultural lands. These watershed scale scenarios are designed to identify local priority areas where conservation or improved agricultural management could provide the greatest benefits to hydrology and water quality.

In addition to the watershed scale management scenarios, four case studies focus on specific parcels or groups of parcels where local land conservancies and regional planning agencies have considered investments for specific conservation efforts. These case studies quantify the hydrology and water quality benefits of land conservation, land and stream restoration, or Best Management Practices (BMP) implementation, evaluating both local catchment effects and downstream impacts. Together, the scenarios and case studies provide a practical framework for understanding where targeted land management actions can most effectively support watershed resilience.

7.1 Natural Land & Riparian Buffer Conservation

7.1.1 Natural Land Conservation

The Natural Land Conservation scenario evaluates the effect of preventing currently natural lands from converting to developed uses in the future (2070). Under this scenario, all natural land uses present in 2020 (such as forests, grasslands, and wetlands) are held constant while the remaining portions of the watershed continue to develop or increase in development intensity (Figure 7-1). Agricultural lands are still allowed to convert to developed uses, and existing developed areas may intensify, but natural areas are maintained in their 2020 condition.

This scenario is not intended to represent a realistic future land use projection or to impose restrictions on development. Instead, it provides a way to identify priority conservation areas by highlighting locations where retaining natural land cover would produce the greatest hydrologic and water quality benefits, particularly in relation to identified hot spot catchments.

Under the Future Land Use scenario, approximately 20,381 acres of natural land across the Basin are projected to be converted to developed uses by 2070 (Table 7-1). The spatial distribution of these projected losses, which identifies potential priority areas for conservation under this scenario, is presented in Figure 7-1. This spatial distribution highlights the

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catchments with the greatest anticipated loss of natural lands to development. According to Table 7-1, the Below Wateree subbasin accounts for the largest share of projected loss (6,875 acres), followed by Great Falls/Cedar Creek (3,782 acres) and Fishing Creek (3,704 acres), together comprising the majority of Basin-wide natural land conversion. Because this analysis takes into consideration the lands already protected by some form of land ownership (i.e., local, state, or federal) or conservation easement, the Upper Basin, which includes Pisgah National Forest as well as other regional and local lands, has significantly less land available to conserve. Similarly, the lands around Lake Wateree are already held by state and private conservation interests, thus leaving smaller areas of land projected to be developed and available for conservation.

Table 7-1. Natural Land Area Projected to Develop by 2070 (acres)

Basin	All Natural Lands
James	143
Rhodhiss	805
Hickory	240
Lookout Shoals	121
Norman	458
Mountain Island	244
South Fork	2,015
Wylie	1,758
Fishing Creek	3,704
Great Falls/Cedar Creek	3,782
Wateree	236
Below Wateree	6,875
Total	**20,381**

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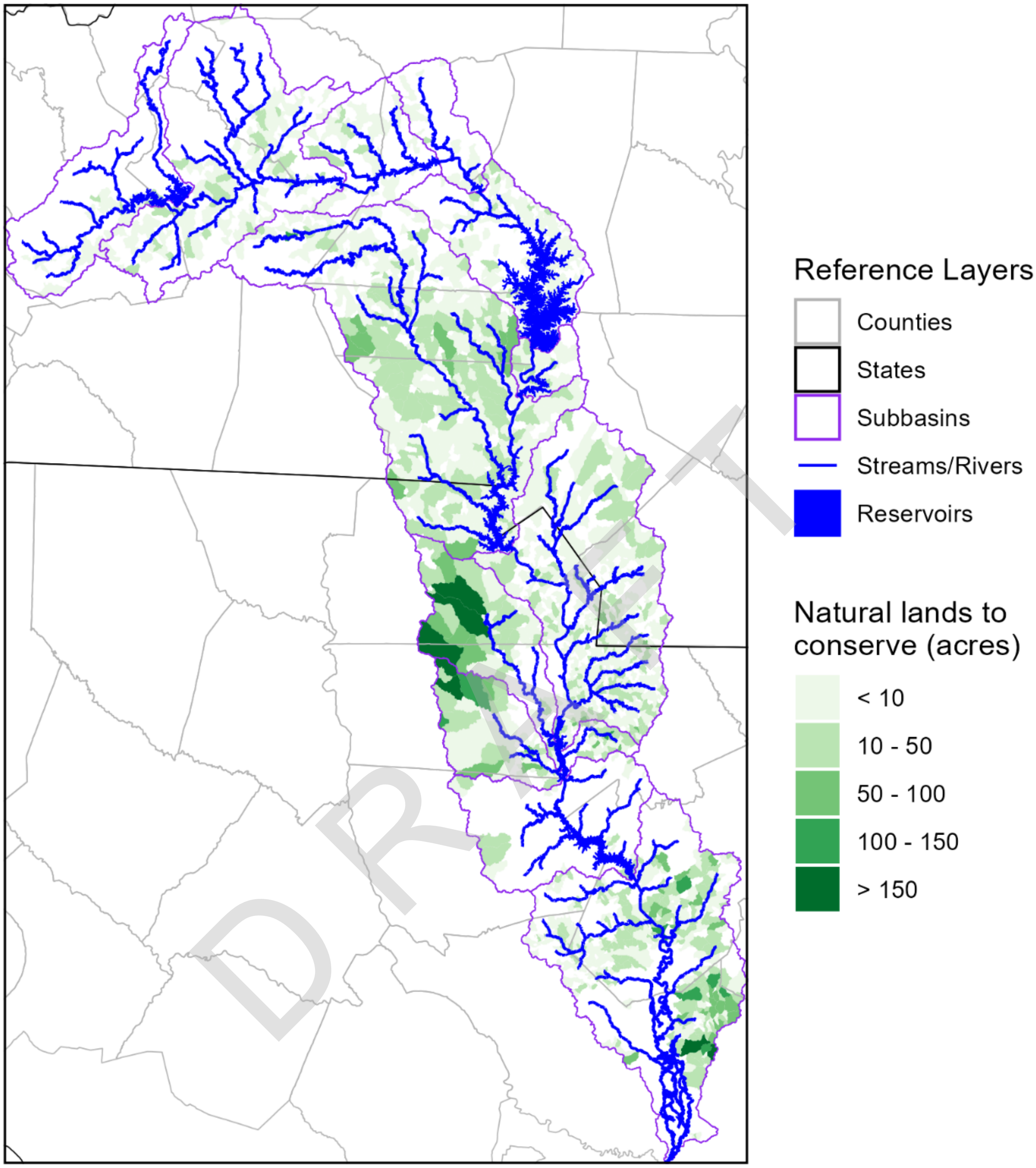
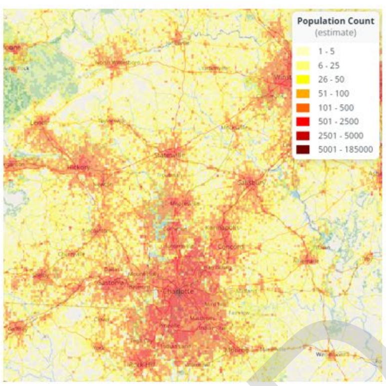


Figure 7-1. Area of Natural Lands that are Projected to Develop

Since conserving natural land reduces the amount of area available for future development, adjustments were made to account for displaced growth. A gridded population dataset (Weber et al., 2022) was used to estimate the 2020 population in each catchment, and county-level projections (NC-OSBM, 2023; SC-RFA, 2021) were used to estimate the 2070 population (Figure 7-2). Residential land use classes were mapped to ICLUS categories (exurban low density, exurban high density, suburban, urban low density, and urban high density), and nonresidential classes were designated as either natural or agricultural. Very rural residential areas (.i.e., one house per 50 acres) were included in population calculations as exurban low density but were ultimately treated as natural land for the purposes of conservation.

Population density (people per acre) was calculated for each catchment under both the Future Land Use scenario and the Natural Lands Conservation scenario. When population density per catchment in the conservation scenario exceeded the assigned threshold, developed land classes in the catchment were intensified to accommodate the required population. Increased development intensity triggers higher runoff rates and greater water quality accumulation rates.

LandScan 2020 Gridded Population × State Estimations of Future Population by County = 2070 Population by Catchment



	County	Growth from 2020 to 2070
South Carolina	Fairfield	-29.1%
	Kershaw	58.7%
	Lancaster	332.9%
	Lee	-47.5%
	Richland	60.2%
	Sumter	-13.6%
	York	280.7%
North Carolina	Alexander	0.9%
	Avery	0.3%
	Buncombe	57.6%
	Burke	-0.5%
	Caldwell	0.8%
	Catawba	34.3%
	Cleveland	9.4%
	Gaston	47.6%
	Iredell	136.0%
	Lincoln	82.6%
	McDowell	0.4%
	Mecklenburg	98.3%
	Mitchell	-11.5%
	Rutherford	12.2%
	Union	151.5%
	Watauga	34.4%
	Wilkes	-1.3%
	Yancey	-4.3%

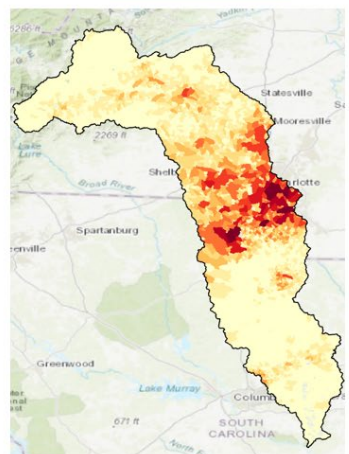


Figure 7-2. Future population estimation methodology

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Figure 7-3 provides an example from a catchment in Mecklenburg County. The 2020 population for this catchment was 7,640 people, and the county is projected to grow by 98.3% by 2070, resulting in an estimated future population of 15,150 people. In the Future Land Use scenario, a large portion of the catchment's natural land transitions to exurban high density to accommodate this growth (Figure 7-3a and Figure 7-3b). In the Natural Land Conservation scenario (Figure 7-3c), this natural land is retained, and the additional population is absorbed entirely within existing developed areas. This increases both population density and development intensity in the already developed portions of the catchment.

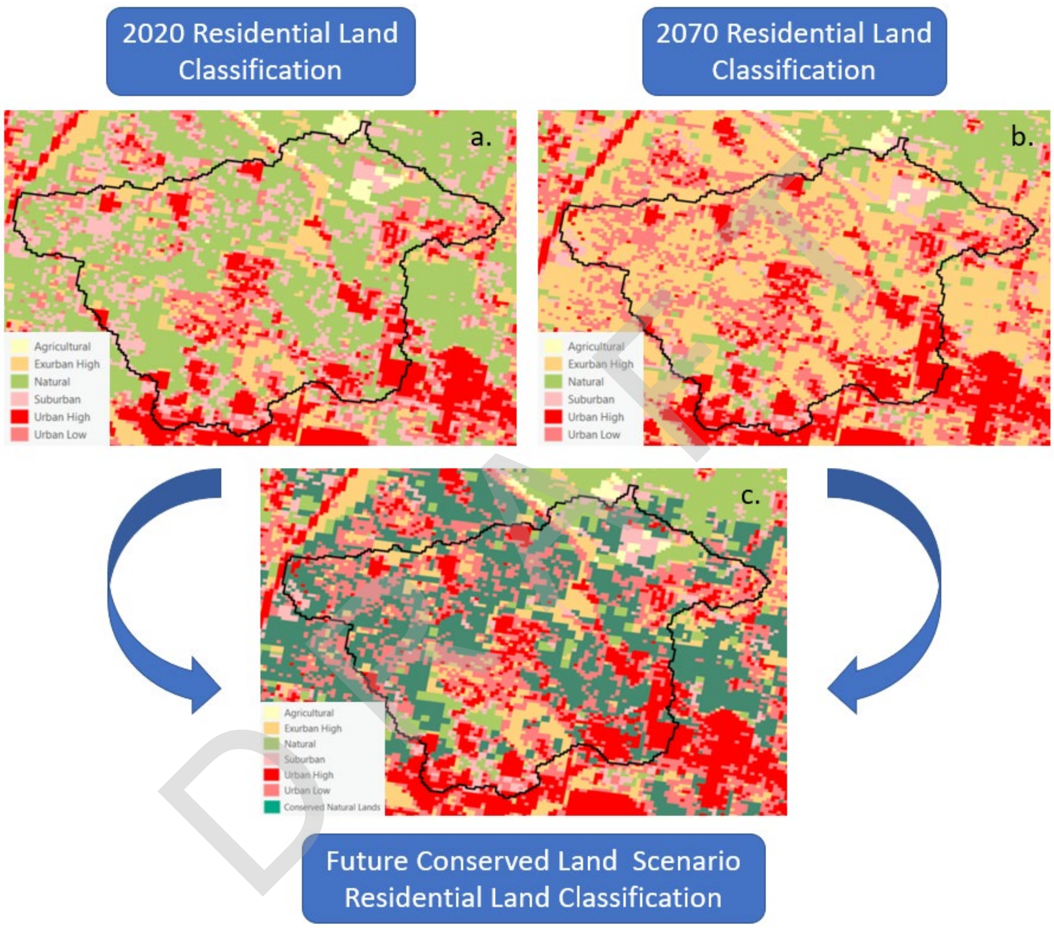

Figure 7-3. Example of Natural Land Conservation and Development Intensification

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7.1.2 Riparian Buffer Conservation

A riparian buffer is a vegetated area, typically forested, that borders a stream, river, lake, or other waterbody. The root systems within these buffers help stabilize streambanks and reduce erosion, while the vegetation allows greater infiltration and filters nutrients, sediment, and other pollutants before they reach the waterbody. Preserving riparian buffers is widely recognized as an important strategy for maintaining water quality and protecting aquatic ecosystems.

Despite their known ecological importance, the protection of riparian areas across the Basin is characterized by a lack of uniform or consistently applied mandatory buffer ordinances, resulting in a complex patchwork of local rules across both North Carolina and South Carolina. North Carolina jurisdictions frequently employ tiered and complex rules based on water quality and stream size: for instance, Charlotte and Mecklenburg County require buffers ranging from 30 to over 100 feet for both perennial and intermittent streams, with widths often varying by contributing drainage area and management divided into multiple use zones. In contrast, the approach within South Carolina varies widely: while Kershaw County mandates a wide, ecologically-focused minimum of 100 feet along perennial streams, most other South Carolina counties enforce a baseline 50-foot setback that is often tied to flood prevention and protecting streams without a delineated floodway, reflecting a focus on property and structural elevation rather than comprehensive, ecologically-tiered water quality rules. This significant disparity across jurisdictions demonstrates there is no single, uniform regulatory approach across the Basin to ensure the preservation of these critical natural corridors. The full list of the various buffer ordinances is provided in Table 7-2.

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Table 7-2. Riparian Buffer Ordinances by Jurisdiction

Jurisdiction	Entity Type	State	Riparian Buffer Required	Perennial Stream Buffer Width (ft)	Intermittent Stream Buffer Width (ft)	Ordinance Notes
Lenoir	City	NC	Yes	30 ft (with 20 ft vegetated setback)	30 ft	30-ft buffer required; perennial streams include a 20-ft vegetated setback.
Morganton	City	NC	Yes	30 ft	30 ft	Minimum 30-ft buffer landward of all perennial and intermittent surface waters.
Hickory	City	NC	Yes	10–100 ft	Not specified	Perennial waters only. Agricultural activities require a minimum 10-ft vegetated buffer or equivalent control. New development requires 30 ft (low-density) or 100 ft (high-density) vegetative buffer within the WP-O district. Conservation subdivisions require ≥50-ft upland buffers along wetlands, lakes, and perennial streams.
Statesville	City	NC	Yes	50 ft	Not specified	Undisturbed natural buffer required along perennial streams only; 50-ft total width measured as 25 ft on each side from the stream centerline (USGS Blue Line).
Gastonia	City	NC	Yes	30 ft	30 ft	Minimum 30-ft buffer landward of all perennial and intermittent surface waters; applies to applicable development.
Mt. Holly	City	NC	Yes	≥40 ft or 5× stream width (whichever is greater)	≥40 ft or 5× stream width (whichever is greater)	No encroachments permitted within 20 ft on each side of the stream top of bank, or five times the stream width, whichever is greater, unless certified by a registered professional engineer demonstrating no increase in base flood levels.
Charlotte	City	NC	Yes	30–100+ ft	30–100+ ft	Applies to both perennial and intermittent streams. Buffer width varies by contributing drainage area: 30 ft for streams <50 acres (includes 10-ft streamside zone); 35 ft for 50–<300 acres; 50 ft for 300–<640 acres; 100 ft for ≥640 acres, plus 50% of the flood fringe beyond 100 ft. Buffers include multiple zones; disturbance allowed but must be revegetated, with bank stabilization required within the 10-ft streamside zone.

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Jurisdiction	Entity Type	State	Riparian Buffer Required	Perennial Stream Buffer Width (ft)	Intermittent Stream Buffer Width (ft)	Ordinance Notes
Belmont	City	NC	Yes	20 ft or 5× stream width (whichever is greater)	20 ft or 5× stream width (whichever is greater)	No encroachments—including fill, new construction, substantial improvements, or new development—are allowed within the buffer unless a registered professional engineer certifies that flood levels will not increase during the base flood.
Iredell	County	NC	Yes	30 ft	25-30ft	Land-disturbing activity is prohibited near lakes or natural watercourses unless a buffer is provided. Minimum buffer is 30 ft inside the water supply watershed and 25 ft outside. Subdivisions adjacent to perennial streams must provide a 30-ft undisturbed buffer along perennial waters.
Union	County	NC	Yes	30–100 ft	30–100 ft	Applies to both perennial and intermittent streams. Buffer width varies by site or local requirements, ranging from 30 to 100 ft.
Mecklenburg	County	NC	Yes	30–100+ ft	30–100+ ft	Applies to both perennial and intermittent streams. Buffer width varies by stream size and watershed sensitivity: 30 ft minimum for smaller streams, up to 100 ft plus a portion of the FEMA Flood Fringe for larger streams or those in critical watersheds. Buffer is divided into three zones—Stream Side, Managed Use, and Upland—with activity restrictions varying by zone.
Gaston	County	NC	Yes	30–100 ft	Not specified	Buffer width along perennial waters depends on development density: 30 ft minimum for low-density development and 100 ft for high-density development.
Lincoln	County	NC	Yes	50 ft or full width of 100-year floodplain, whichever is greater	50 ft or full width of 100-year floodplain, whichever is greater	Minimum 50-ft vegetative buffer is required, with a 30-ft undisturbed inner zone and a 20-ft vegetated outer zone. Applies to both perennial and intermittent streams. Full width of the 100-year floodplain can be used if greater. Buffer protects water quality and controls erosion from land-disturbing activities

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Jurisdiction	Entity Type	State	Riparian Buffer Required	Perennial Stream Buffer Width (ft)	Intermittent Stream Buffer Width (ft)	Ordinance Notes
McDowell	County	NC	Yes	50 ft	50 ft	Applies to rivers and streams without an established regulatory floodway. All new development or substantial improvement must maintain an undisturbed 50-ft vegetated buffer measured from the top of bank on both sides.
Catawba	County	NC	Yes	25–50 ft	25–50 ft	Applies to lakes and watercourses throughout Catawba County. Minimum 25-ft undisturbed vegetative buffer is required generally, with a 50-ft buffer specifically within the Sherrills Ford Sewershed to provide additional water quality protection.
Burke	County	NC	Yes	100 ft or width of regulatory floodway (whichever is greater)	100 ft or width of regulatory floodway (whichever is greater)	Applies to flood-prone areas along streams. No land-disturbing activity is allowed within 100 ft of the stream channel or within the regulatory floodway, whichever is greater, to prevent increased flood heights and erosion.
Caldwell	County	NC	Yes	50 ft	Undisturbed buffer (width not specified)	Requires a 50-ft vegetative buffer for new development along perennial streams or impounded water bodies. Undisturbed buffers are also enforced for both perennial and intermittent streams to comply with stormwater regulations.
Alexander	County	NC	Yes	30 ft	30 ft	All development along streams or rivers without a delineated regulatory floodway must maintain a 30-ft minimum natural or vegetated buffer measured from the top of bank on both sides. Buffer protects against flood risk and erosion.
Avery	County	NC	Yes	30 ft	30 ft	All new development along streams or water bodies without a delineated floodway must maintain a 30-ft minimum undisturbed natural or vegetated buffer measured from the top of bank on both sides.
Valdese	Town	NC	Yes	30–100 ft	30–100 ft	Buffer width varies by drainage area and watershed classification. Minimum 30-ft streamside zone with highly restricted uses, with total buffer width potentially extending to 100 ft depending on stream size and watershed.

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Jurisdiction	Entity Type	State	Riparian Buffer Required	Perennial Stream Buffer Width (ft)	Intermittent Stream Buffer Width (ft)	Ordinance Notes
Granite Falls	Town	NC	Yes	30 ft	30 ft	All development within the Special Flood Hazard Area along rivers or streams without a delineated floodway must maintain a 30-ft minimum natural or vegetated buffer measured from the top of bank on both sides.
Mooresville	Town	NC	Yes	30–100 ft	30–100 ft	Buffer width is tiered based on the area of land disturbance: 30 ft for 1–10 acres, 50 ft for 10–50 acres, and 100 ft for disturbances over 50 acres. No built-upon areas are allowed within the full buffer width.
Long View	Town	NC	Not specified	Not specified	Not specified	No specific local buffer ordinance exists. Development is subject to state rules, which require a 25-ft undisturbed vegetative buffer only along designated trout streams.
Rock Hill	City	SC	Yes	50–100+ ft	50–100+ ft	Minimum 50-ft riparian buffer along the river, including a 30-ft undisturbed zone and a 20-ft managed zone. Wider buffers up to 100 ft or more may be required based on larger jurisdictional requirements.
Lancaster	City	SC	Yes	200 ft	100 ft	Buffer widths are set at 200 ft for perennial streams and 100 ft for intermittent streams.
Chester	City	SC	Yes	50–100+ ft	50 ft (minimum)	Mandatory minimum buffer is 50 ft along streams without a delineated floodway. Best practice and regional recommendations often advocate for 100 ft or greater, sometimes split into two zones (35-ft inner and 65-ft outer) to better protect water quality.
Camden	County	SC	Yes	50 ft	50 ft	All development along streams without an established regulatory floodway must maintain a 50-ft undisturbed natural or vegetated buffer measured from the top of bank. Additionally, the city’s Zoning Ordinance requires buffers for all new development or major expansions to help transition between different land uses and to protect water bodies, though non-stream buffer widths vary based on adjoining land use.

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Jurisdiction	Entity Type	State	Riparian Buffer Required	Perennial Stream Buffer Width (ft)	Intermittent Stream Buffer Width (ft)	Ordinance Notes
Fairfield	County	SC	Yes	50 ft	50 ft	Minimum 50-ft riparian buffer is required along streams without a delineated floodway and on all undeveloped lots fronting Lake Wateree and the Reservoir. Buffers must remain undisturbed, with strict limits on disturbance, tree removal, and structures.
Chester	County	SC	Yes	50–100+ ft	50 ft (minimum)	Minimum buffer is 50 ft along perennial streams, with larger buffers (100+ ft) potentially required in Zoning Overlay or natural resource conservation areas. Intermittent streams generally have a minimum 50-ft buffer.
York	County	SC	Yes	50–500 ft	50 ft	A 50-ft undisturbed natural vegetative buffer is required along streams lacking a delineated floodway. Perennial streams and the Catawba River/Lake Wylie require a separate 50-ft Riparian Buffer, with Scenic Overlay Buffers extending up to 500 ft in certain areas to protect visual integrity.
Richland	County	SC	Yes	50 ft or floodway width (whichever is greater)	50 ft or floodway width (whichever is greater)	Requires a separate, undisturbed 50-ft water quality buffer along all jurisdictional perennial and intermittent streams and wetlands. Buffer width must be the greater of 50 ft or the delineated floodway width where applicable.
Lee	County	SC	Yes	50 ft	Not specified	New development adjacent to perennial waters must maintain a 50-ft vegetated riparian buffer to filter runoff and protect water quality in the Deep River and Rocky River Watersheds. Exceptions may require a water quality impact assessment.
Lancaster	County	SC	Yes	50–200 ft	50 ft	Streams without delineated floodways in flood-prone areas require a minimum 50-ft undisturbed vegetative buffer. Perennial streams in the Carolina Heelsplitter Overlay District require a 200-ft undisturbed native forested buffer. A 25-ft Corridor Frontage Buffer applies along certain major highways.

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Jurisdiction	Entity Type	State	Riparian Buffer Required	Perennial Stream Buffer Width (ft)	Intermittent Stream Buffer Width (ft)	Ordinance Notes
Kershaw	County	SC	Yes	100 ft or width of floodway (whichever is greater)	50 ft or width of floodway (whichever is greater)	Requires a 100-ft natural buffer along perennial streams and a 50-ft buffer along intermittent streams. A 50-ft buffer is also required perpendicular to the shoreline at the 100-year high water elevation. If the floodway is wider than the standard buffer, the buffer must match the floodway width.

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Due to inconsistencies and the lack of uniformity in mandatory local buffer ordinances, establishing a single regulatory standard for modeling is not possible. For this analysis, the national NHDPlus-scale riparian zone dataset developed by the U.S. Forest Service was used to define riparian areas, which delineates riparian extent based on modeled 50-year flood depths. Natural lands located within this mapped buffer were treated as protected areas. This dataset was used for consistency in assessments across the Basin; however, given the riparian area is derived from elevation changes, the width of the riparian area for each segment of stream or river varies. Therefore, this analysis cannot currently determine the ideal width of riparian buffers, but it can quantify the benefit of retaining natural lands within the riparian area as delineated by modeled 50-year flood depth.

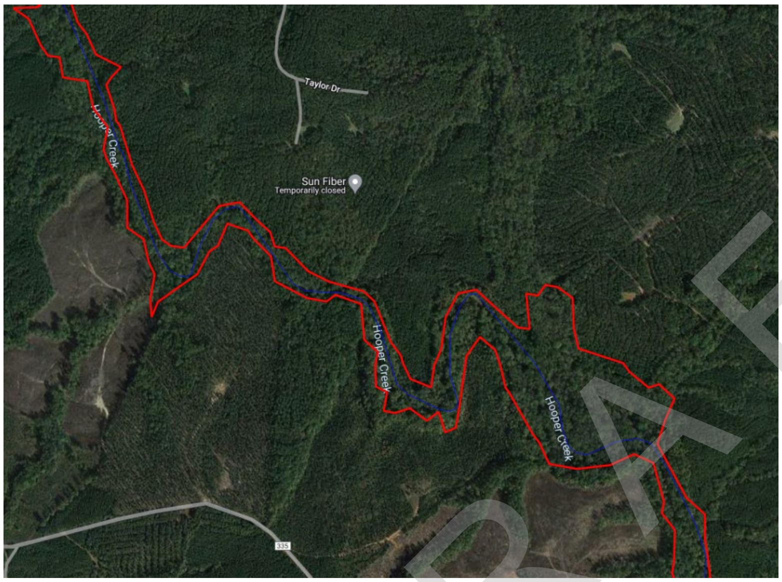

Figure 7-4. Example Riparian Buffer Area

The Riparian Buffer Conservation scenario follows a similar approach to the Natural Land Conservation scenario, with one key difference. Rather than conserving all natural land within a catchment, only natural lands located inside the riparian buffer area were prevented from transitioning to developed land uses (Figure 7-5). Natural lands located outside the buffer were allowed to develop according to the projected Future Land Use scenario. Areas within the buffer that were developed prior to 2020 were retained as developed.

This scenario isolates the potential hydrologic and water quality benefits of protecting riparian corridors while allowing development to proceed elsewhere within the watershed. By comparing results across catchments, the scenario highlights priority locations where riparian conservation may provide the greatest improvements to future watershed conditions. This scenario also helps highlight the extent of conservation needed within a catchment by comparing the benefits achieved during full natural land conservation versus natural land conservation only within the riparian buffer. If the reductions in hydrologic and water quality issues are similar, then focusing conservation within the riparian area is justified over more extensive land conservation options. The intent of these analyses is to lower the barriers to achieving conservation goals, provide more feasible targets, and focus conservation efforts.

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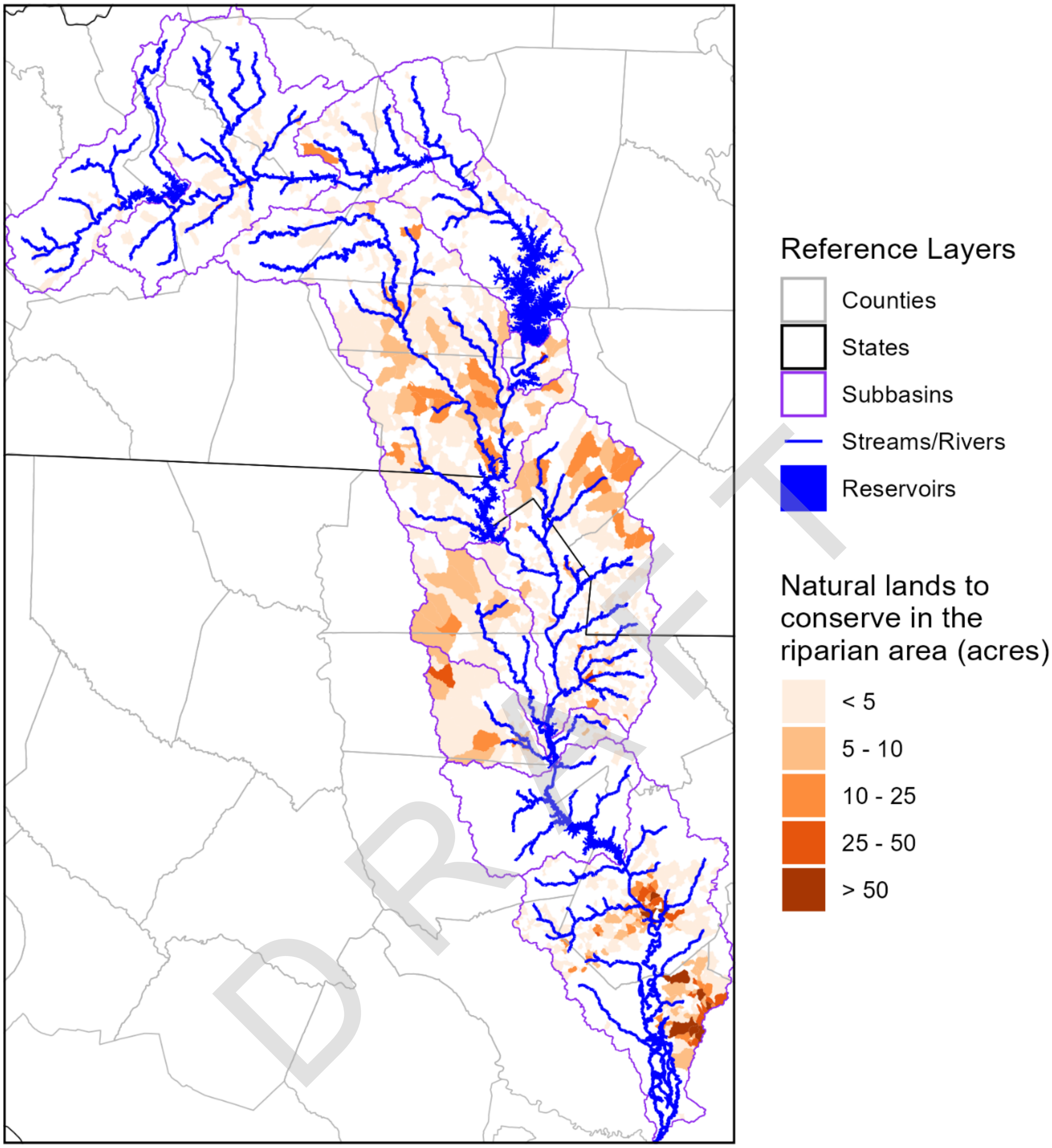

Figure 7-5. Area of Natural Lands within the Riparian Buffer Area that are Projected to Develop

Based on the Future Land Use scenario, an estimated 4,399 acres of natural land within riparian buffer areas are projected to be converted to developed uses by 2070 (Table 7-3). The spatial distribution of this projected loss, representing the highest-priority areas for riparian conservation, is illustrated in Figure 7-5. As shown in both the table and figure, the majority of riparian area development is concentrated in the southern portion of the watershed, with the Below Wateree subbasin accounting for 2,501 acres of projected loss, followed by Fishing Creek (648 acres) and South Fork (377 acres). Like the Natural Land Conservation scenario, there is less projected development to the riparian areas in the Upper Basin and the Wateree subbasin. However, there is a distinction with the riparian area development where there are obvious increases in potential development in the regions corresponding to urban growth, such as in the Gastonia, Belmont, and Charlotte area in the Central Basin and in the Lugoff, Camden, and surrounding Sumter region in the Below Wateree subbasin. These areas at risk point to the need for smart urban growth, including rules around conserving natural riparian lands and potentially other lower impact development or green infrastructure options.

Table 7-3. Natural Lands in the Riparian Buffer Area Projected to Develop by 2070 (acres)

Basin	Natural Lands in the Riparian Buffer Area
James	14
Rhodhiss	103
Hickory	36
Lookout Shoals	0.8
Norman	37
Mountain Island	62
South Fork	377
Wylie	306
Fishing Creek	648
Great Falls/Cedar Creek	311
Wateree	3.5
Below Wateree	2,501
Total	**4,399**

7.2 Agricultural Conservation Practices

This management scenario evaluates the implementation of widely adopted agricultural BMPs across agricultural lands. Input from discussions with representatives from the North Carolina Farm Bureau, along with a review of land use datasets focused on crop type, provided context on current agricultural practices and regional trends. The Natural Resources Conservation Service (NRCS) was consulted to identify the most frequently funded and implemented BMPs over the past 5 years (Table 7-4). Since each BMP influences water quantity and water quality differently, their effects were represented individually within the modeling framework. The intent of this scenario is to provide supporting data to programs that incentivize agricultural preservation, such as the recently enacted Mecklenburg County Agricultural Preservation Plan.

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Table 7-4. Top Agricultural Conservation Practices within North and South Carolina with Their Impacts

Category	NRCS Agricultural Practices	Impact on Water Quantity	Impact on Water Quality
Livestock Access Control	Fencing and watering facilities	✓	✓
Nutrient Management	Nutrient management, improving nutrient uptake efficiency, and reducing risk of nutrient losses		✓
Soil Stabilization	Cover crop		✓
	Pasture/Hay planting	✓	✓
	Tree/Shrub establishment	✓	✓
Riparian vegetation restoration	Critical area planting	✓	✓

To identify catchments with meaningful agricultural activity, the USDA CropScape dataset (Boryan, Yang, Mueller, & Craig, 2011) was used to summarize total cropland area and average field size for each catchment. The average catchment contained 30.5 acres of cropland with an average field size of 0.45 acres (based on a GIS-based analysis of the USDA's Cropscape Cropland Data Layer). Catchments meeting or exceeding both thresholds were considered eligible for crop-related BMPs. Pasture lands were evaluated using the land use/land cover raster, summarizing total pasture area and average pasture size by catchment. The average catchment pasture area was 112 acres, with an average pasture size of 2.3 acres. Catchments meeting both criteria were considered eligible for pasture-related BMPs.

A hierarchical set of rules was established to assign a single BMP to each eligible agricultural catchment based on existing land use conditions and current BMP implementation trends. The hierarchy was applied as follows:

1. **Livestock Access Control:** Implemented in catchments that were eligible for pasture BMPs and contained pastureland within riparian buffer areas.
2. **Cover Crops:** Implemented in catchments that were eligible for crop BMPs, had not received a higher-priority BMP, and were dominated by corn or soybean production. The dominant crop type for each catchment was determined using the CropScape dataset.
3. **Tree/Shrub Establishment:** Implemented in catchments eligible for either crop or pasture BMPs that had not received a higher-priority BMP and contained fallow or idle cropland of notable size. Fallow land was identified using CropScape summaries of total fallow area and average field size. Catchments with at least 2.4 acres of fallow land and an average field size of 0.2 acres were considered to meet this criterion.
4. **Critical Area Planting:** Implemented in catchments eligible for crop BMPs that had not received a higher-priority BMP and contained cropland within riparian buffer areas.
5. **Nutrient Management:** Implemented in remaining catchments eligible for crop BMPs that had not received any higher-priority BMP.
6. **Pasture/Hay Planting:** Implemented in remaining catchments eligible for pasture BMPs that had not received any higher-priority BMP.

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Applying this hierarchy resulted in a single prioritized BMP being assigned to each eligible agricultural catchment.

The available agricultural area and the prioritized BMP assigned to each catchment are visualized in Figure 7-6. The left panel of Figure 7-6 shows the total agricultural area eligible for conservation practices while the right panel displays the BMP assigned to each catchment based on the established hierarchy, illustrating the spatial distribution of practices across the Basin. This visualization confirms that agricultural conservation opportunities are widely distributed across the whole Basin, although in most catchments the application area was 50 acres or less.

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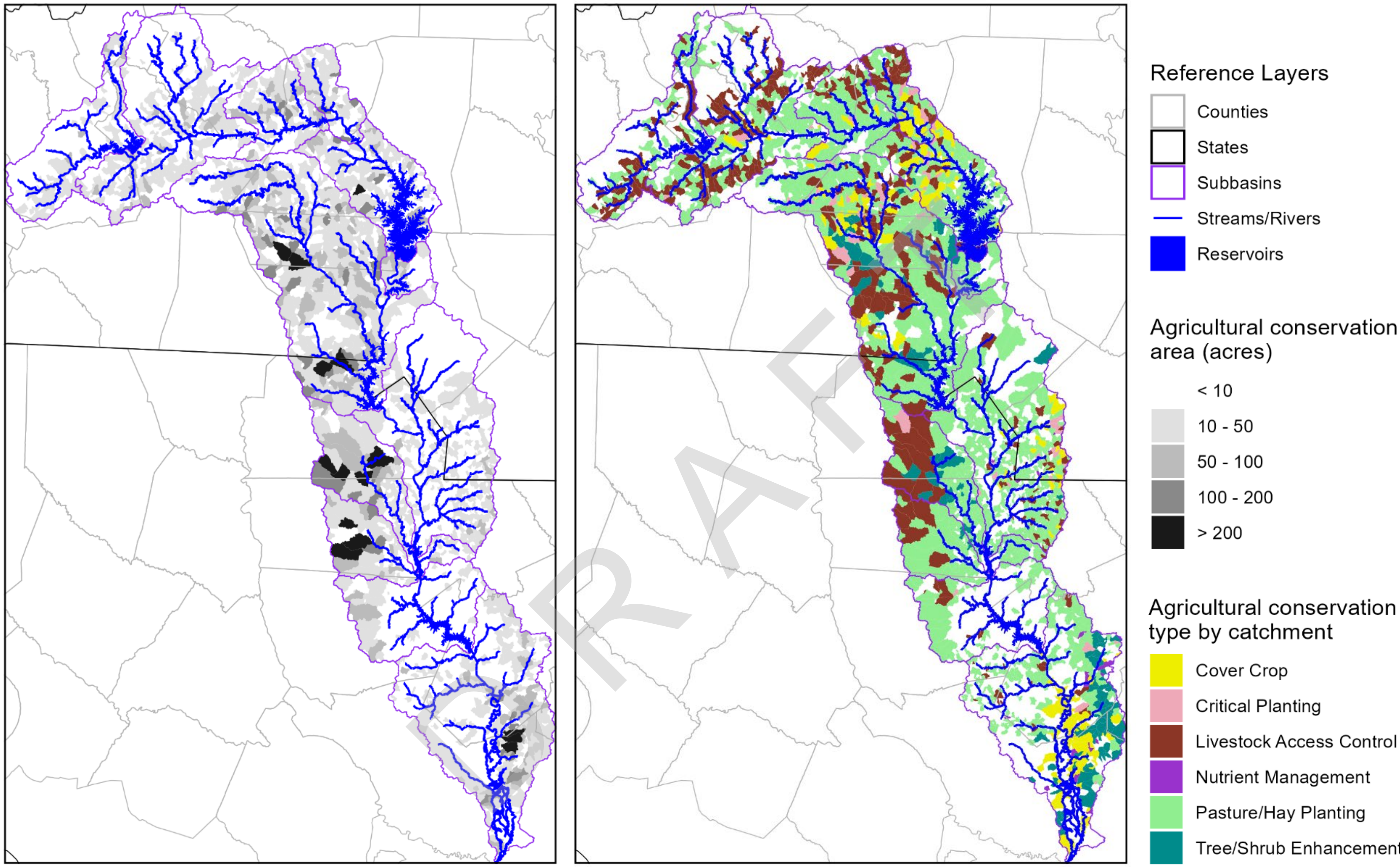

Figure 7-6. Available Area and Prioritized Type of Agricultural Conservation Practices by Catchment

Each catchment's assigned BMP was implemented on a portion of its agricultural land area. The estimated percentage of land currently adopting each practice was calculated using NRCS cost-share data and extrapolated to represent anticipated implementation levels under the improved agricultural management scenario.

7.3 Basin-Wide Benefit Summaries

The following benefits maps identify the areas that benefit from the implementation of natural land conservation, riparian buffer conservation, and/or agricultural conservation practices. Depending on the hydrologic or water quality issues examined, the maps identify either the local catchment or the tributary in which the management option provides a benefit. By mapping the results for each metric, the analysis helps to identify areas for action by issue. Taken together, these maps identify hot spots for where the greatest changes are expected or are occurring but can be managed through land use-based strategies.

7.3.1 Mean Annual Runoff

7.3.1.1 NATURAL LAND & RIPARIAN BUFFER CONSERVATION

Mean annual runoff is highly dependent on the land use composition and with widespread future land use changes, mean annual runoff was expected to increase throughout much of the Basin. In Figure 7-7 the extent of the mitigation through natural land conservation (left panel) or riparian area conservation (right panel) is presented on a gradient. The darkest green shaded catchments (value of > 100%) indicate that by conserving natural lands, the entire increase in mean annual runoff can be managed and eliminated. In these catchments, land conservation, in combination with some of the future development that converts cropland into low density housing, improves the runoff conditions beyond what the future increase was projected to be. In the middle, lighter green categories land conservation can mitigate 50% to 100% of the expected increases in mean annual runoff, even when the population expected in those areas is shifted to other developed areas within the same catchment.

Under the Natural Land Conservation scenario every subbasin has catchments that benefit from land conservation and, by doing so, they can mitigate the impacts of development on runoff. In the Upper Basin, outside of the already protected areas, land conservation benefits are present in the majority of catchments expected to experience land development into the future. In the Central Basin, there are pockets of conservation benefit areas within the South Fork Catawba subbasin and in the greater Wylie subbasin as well as in the Great Falls and Cedar Creek subbasins. The Fishing Creek subbasin is divided in the impacts seen from conservation. In the upper portions of Fishing Creek, natural land conservation is less beneficial than it is within the Charlotte area; however, in the lower portions of the Fishing Creek subbasin, there is a high density of catchments in which natural land conservation is highly beneficial. In the Lower Basin, due to the Wateree subbasin already containing a high coverage of protected lands, there are only limited beneficial catchments. In the Below Wateree subbasin there are isolated, but significant, benefits to land conservation in the region of Lugoff and Camden, as well as further south on the outskirts of Sumter.

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Significant benefits from conservation of natural lands within only the riparian area are more isolated than when conserving all natural lands in a catchment due to not every catchment having natural land in the riparian area to conserve. Therefore, benefits are confined to those catchments with opportunities for natural land conservation in the riparian area. These catchment locations provide priority areas for action, i.e., in these locations conservation of only the riparian area provides similar benefits to conserving greater areas thereby identifying areas with the most efficient conservation results.

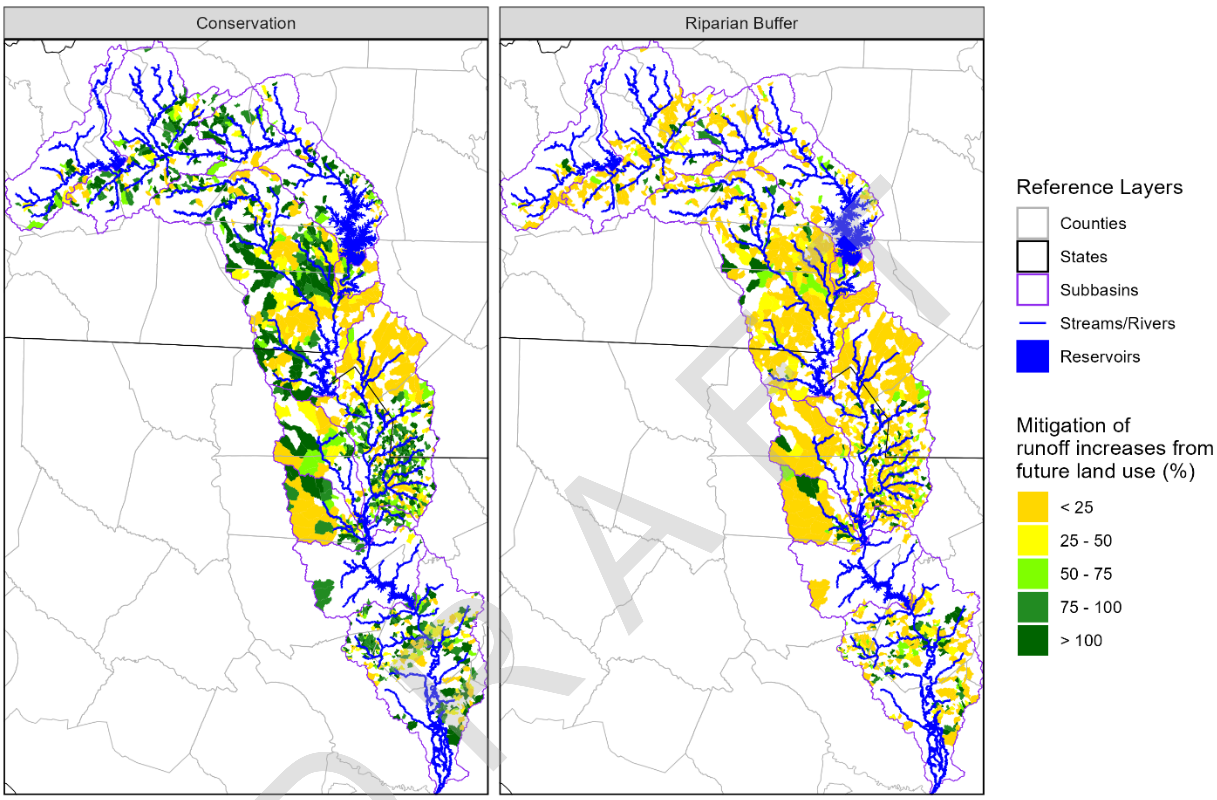

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Figure 7-7. Reduction Benefit to Future Mean Annual Runoff Changes through Conservation

7.3.1.2 AGRICULTURAL CONSERVATION

Given the types and implementation area of the various agricultural conservation practices, there are lower projected benefits to runoff reduction from these management options. Additionally, this scenario examines the reduction in the current rate of runoff due to the practice of implementation rather than examining the reduction benefit in a projected future increase. Therefore, the percentage changes are lower than in the conservation scenarios that are evaluated against the Future Land Use scenario.

Across the majority of the Basin, implementation of agricultural conservation practices is estimated to reduce mean annual runoff by less than 5% (Figure 7-8). There are; however, isolated areas in the James, Rhodhiss, Norman, South Fork portion of Wylie, and lower Fishing Creek subbasins where greater benefits to runoff reduction from the implementation of agricultural conservation practices are expected. These areas mainly correspond to the implementation of Livestock Access Controls. These controls should improve the vegetation quality within the stream/river riparian areas allowing greater infiltration and attenuation of runoff from upland areas in the catchment.

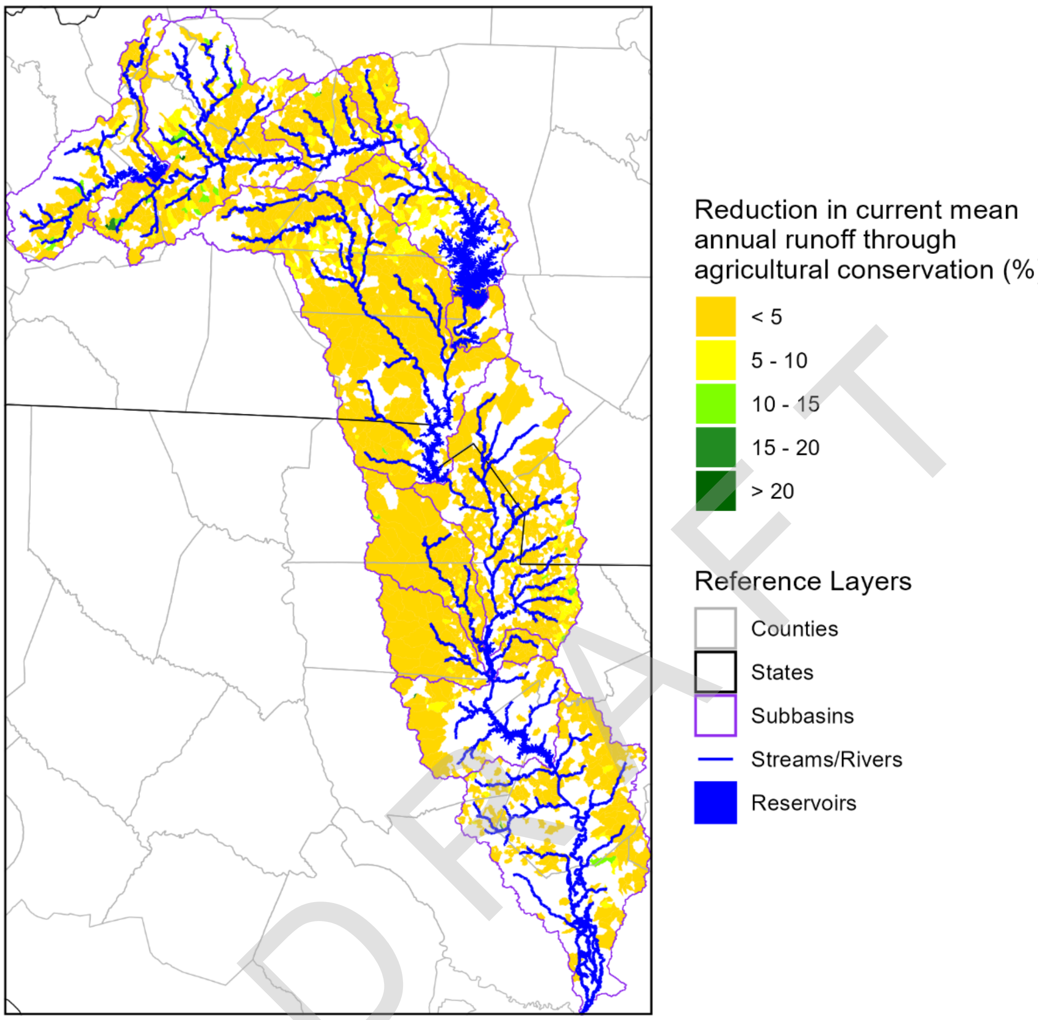

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Figure 7-8. Reduction Benefit to Current Mean Annual Runoff through Agricultural Conservation

7.3.2 Low Flow Conditions and Event Durations

7.3.2.1 NATURAL LAND & RIPARIAN BUFFER CONSERVATION

In most catchments with the conservation of natural lands, low flow durations are improved (i.e., reduced) over the expected future conditions due to land use change (Figure 7-9). As with runoff, being more specific with conservation and focusing solely in the riparian area provides more limited benefits geographically. There are, however, still a significant number of catchments where riparian natural land conservation provides benefits. These benefits provide opportunities for preventing increases to low flow durations in all subbasins with some notable clustering:

- Along the eastern edge of Lake Norman between Statesville and Mooresville and through Troutman, land conservation will prevent increased low flow durations in the small creeks contributing to the lake.
- In the South Fork drainage area of the Wylie subbasin, there are conservation opportunities around Lincolnton for the tributaries to the South Fork Catawba River.
- In the Lower Basin there are conservation opportunities surrounding the growing metropolitan areas.

The riparian buffer opportunities follow the same geographic and subbasin clustering, although to a lesser extent. Surrounding Lake Norman, for example, focus on conservation only within the riparian buffer area limits the benefits to only a couple creeks as opposed to extending to the eastern edge of the subbasin. Similarly, in the other cluster areas, opportunities to reduce the impacts of land use change on low flow durations with riparian buffers are limited to specific stream reaches with larger riparian areas.

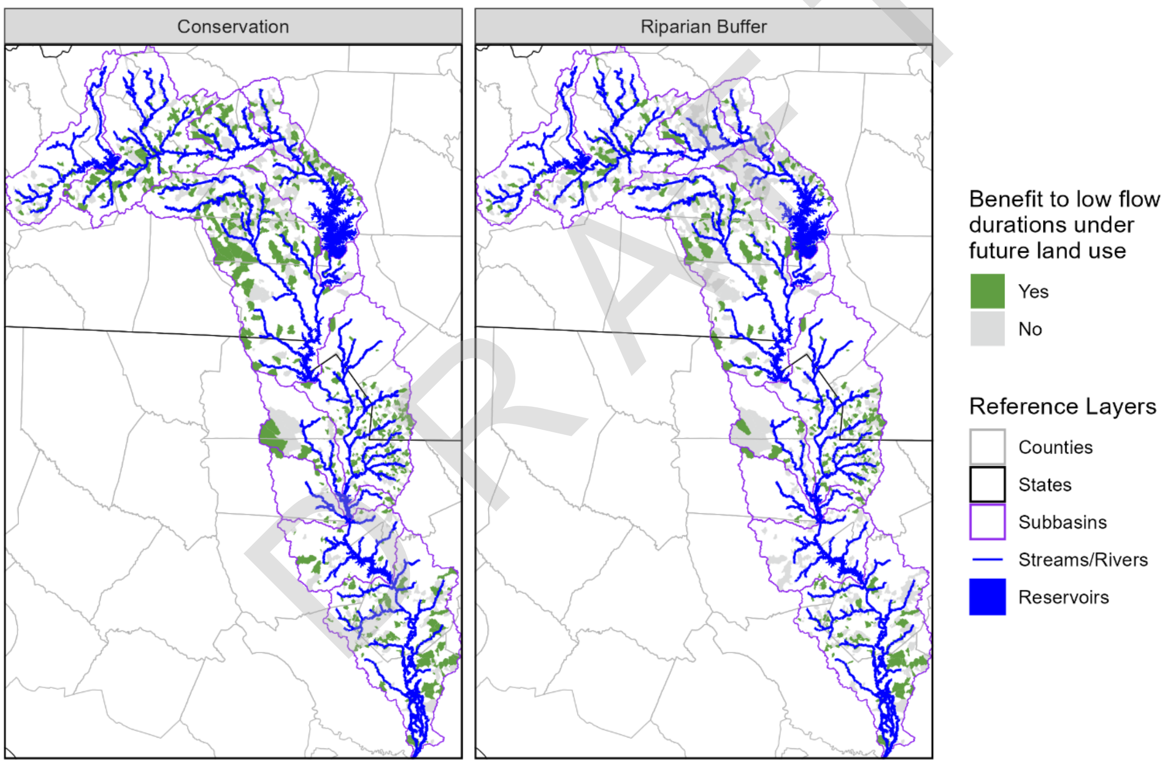

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Figure 7-9. Reduction Benefit to Future Low Flow Durations through Conservation

7.3.2.2 AGRICULTURAL CONSERVATION

For agricultural conservation, the benefits to low flow durations were examined in more detail (Figure 7-10) given that the benefits for this scenario are compared against the current low flow durations and not future conditions. With this analysis, showing *Improvement* for a catchment indicated that average low flow durations are decreased by at least one day over the long-term record. The category of *Minor improvement* is used to show catchments in which agricultural conservation can decrease average low flow durations by less than one day over the long-term. As low flows are a cumulative metric, the benefits of agricultural conservation can extend downstream of the catchments in which the agricultural practices are implemented. Therefore, the analysis of benefits is not limited to only catchments with proposed agricultural conservation practices. Catchments without any color in Figure 7-10 have no estimated benefits to low flow durations with agricultural conservation implementation.

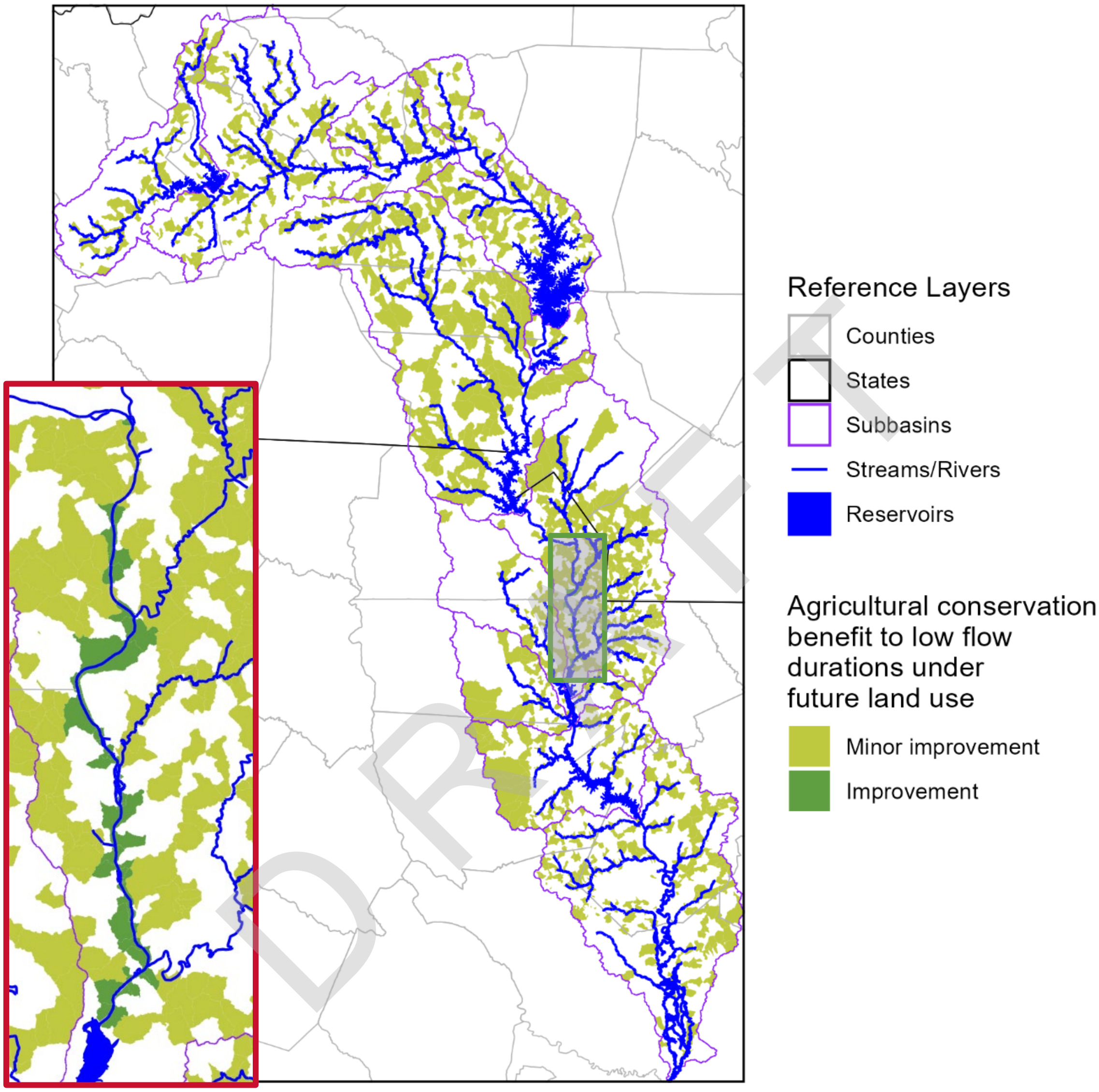

Figure 7-10. Reduction Benefits to Current Low Flow Durations through Agricultural Conservation

There are greater benefits from agricultural conservation (i.e., category of *Improvement*) along the mainstem Catawba River within the Fishing Creek subbasin (inset of Figure 7-10). Downstream of the confluence of Sugar Creek the duration of low flows decreases until the tailwaters of Fishing Creek Reservoir are reached. This is due to the upstream agricultural conservation practices, which are almost exclusively pasture planting. This area, being highly urbanized, has limited existing pasture lands. This analysis demonstrates that by planting out these limited areas with a higher-quality vegetation and by improving soils conditions, the low flow durations within the mainstem Catawba River can be improved even though the dominant land use within the drainage area is urban.

7.3.3 Flooding Potential

7.3.3.1 NATURAL LAND & RIPARIAN BUFFER CONSERVATION

Increases in potential flood-causing streamflows due to future land use changes are expected within the tributaries through much of the Basin. In the analysis of surface water quantities, the assessment of *high* flows (i.e., flows greater than the 75th percentile of long-term daily flow) and *peak* flows (i.e., flows greater than the 90th percentile of long-term daily flow) were found to have increases ranging from sporadic events to increases of at least two additional days per year. In assessing the mitigation potential of conserving natural lands against these streamflow thresholds intended to represent riverine flood risks, a tributary is classified as having a benefit if under conservation the number of days with flows of flood potentials decreases in any number from the projected occurrence under the Future Land Use scenario.

For high flows (Figure 7-11), a selection of tributaries do receive flood resilience benefits due to the land conservation implementation within their drainage areas, both in the case of preserving all natural lands (left panel) and when focusing conservation solely within the riparian area (right panel). Given there was less expected increase in potential flood flows and there is less land still needing conservation protections in the Upper Basin, it is not surprising that there is little benefit of conservation on flood flows in that portion of the Basin. There are; however, potential benefits in the Central and Lower Basin for reducing high flow days.

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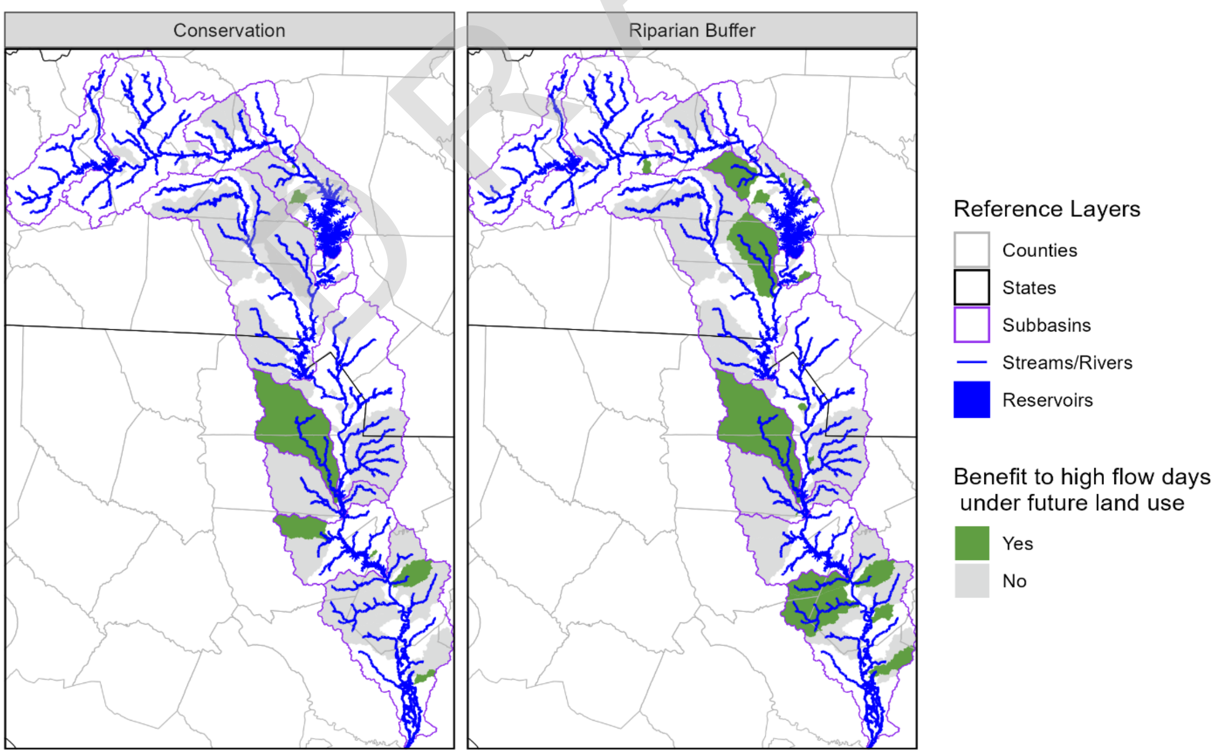

Figure 7-11. Reduction Benefit in Future High Flow Events through Conservation

Both land conservation scenarios can reduce the number of days with flood potential flows within Fishing Creek (Figure 7-11 and Table 7-5); therefore, focusing on conservation within the riparian areas of this tributary could be a lower bar of entry for efforts in this region. The other location at risk of development and where full conservation of natural lands provides the highest benefit is in Duck Cove around Mountain Island Lake. This area should be assessed for protection status as it can be highly influential to the flows and water quality loads reaching the lake and the drinking water intakes for Charlotte Water, Mt. Holly, and Gastonia. With the riparian land focus for conservation, there are several tributaries in the Central and Lower Basin (Table 7-5) that provide the largest reductions to potential future high flows. These tributaries can be assessed for specific parcels and overlying regulations for conservation efforts.

Table 7-5. Tributaries with Greater Benefits to the Reduction of High Flows through Conservation

Natural Land Conservation	Riparian Area Conservation
▪ Duck Cove (Mountain Island) ▪ Fishing Creek (Great Falls)	▪ Unnamed tributary just north of Lancaster Airport (Fishing Creek) ▪ Fishing Creek (Great Falls) ▪ Town Creek (Below Wateree) ▪ Higgins Branch (Fishing Creek) ▪ Gar Creek (Mountain Island)

Peak flow reduction through conservation of natural lands shows a greater likelihood of benefits throughout all areas of the Basin (Figure 7-12). Since this analysis identifies peak flows as those flow magnitudes that occur only about 10% of the time, slight reductions in flow magnitude due to management are enough to provide a benefit as assessed with this method. With this caveat, there are benefits to peak flows in several Upper Basin tributaries as compared to when looking at the lower threshold for high flows. Peak flows are also reduced with both land conservation scenarios within Fishing Creek, Great Falls, and Cedar Creek subbasins.

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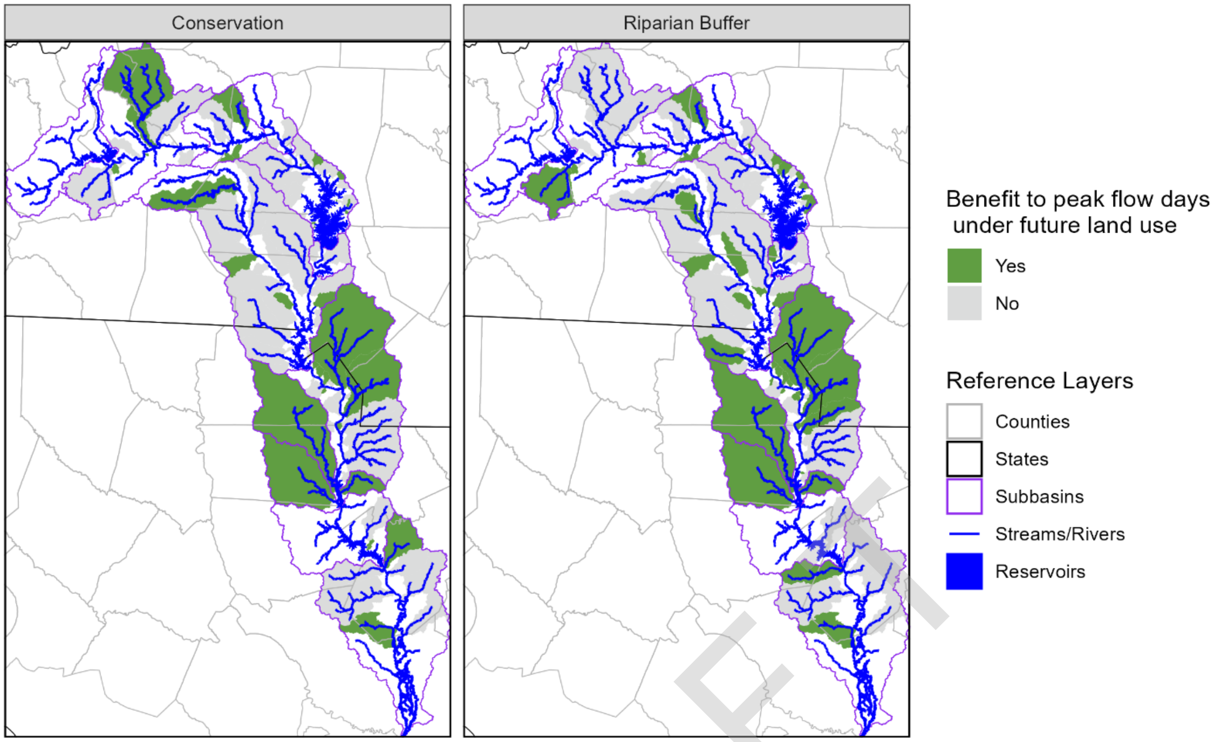

Figure 7-12. Reduction Benefit in Future Peak Flow Events through Conservation

With the greater geographic expanse of conservation benefits to peak flows, there are a greater number of tributaries for both calibration schemes that reduce a more significant number of peak flow days (Table 7-6). There are several tributaries in common between the schemes, which provide the opportunity for addressing either all natural lands or focusing only in the riparian areas. Like with high flows, conserving lands along the eastern edge of Lake Norman provides benefits, along with Duharts Creek in the Wylie subbasin. In the Central Basin other tributaries include Johnnytown Branch, Sugar Creek, Rocky Creek, and Fishing Creek. In addition, conserving riparian areas in Reedy Creek in the Upper Basin provides greater benefits than other areas of the Basin.

Table 7-6. Tributaries with Greater Benefits to the Reduction of Peak Flows through Conservation

Natural Land Conservation	Riparian Area Conservation
▪ Small tributaries leading in Lake Norman ▪ Duharts Creek in Lake Wylie ▪ Rocky Creek in Cedar Creek ▪ Johnnytown Branch in Fishing Creek ▪ Fishing Creek in Great Falls ▪ Sugar Creek in Fishing Creek	▪ Small tributaries leading in Lake Norman ▪ Johnnytown Branch in Fishing Creek ▪ Duharts Creek in Lake Wylie ▪ Sugar Creek in Fishing Creek ▪ Rocky Creek in Cedar Creek ▪ Small tributaries leading into Catawba River in Fishing Creek ▪ Reedy Creek in Lake Rhodhiss

As an example of the land conditions that result in these findings, an aerial view of one of the small creek drainage areas to Lake Norman is shown in Figure 7-13. This area is just north of the Williamson Road exit from I-77 in Mooresville. As apparent in the view, this is an area of

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increasing development, which could benefit from maintaining the natural lands that remain within the area around the upstream end of the tributary flowline.

Figure 7-13. Example of Small Tributary Leading into Lake Norman with Priority to Protect Riparian Buffers and/or Conserve Land to Prevent Peak Flow Increases

Another example of targeted areas for conservation is Duharts Creek in the Wylie subbasin where the creek winds through remaining natural areas in between housing developments and some cleared lands (Figure 7-14). The headwaters of this creek are in a commercial area near Eastridge Mall in Gastonia. While the upstream area is highly developed and likely contributing to the increasing peak flows, the downstream portions pictured with some remaining natural lands become more critical for flow and runoff attenuation.

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Figure 7-14. Duharts Creek in Lake Wylie (drains west side of Gastonia; picture is example of the current land uses where the potential to lose the remaining vegetated lands causes greater impacts)

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As shown in these examples, the identified creeks are often those near the main waterbodies and adjoining at least some areas of dense development highlighting the need for conservation planning and smart growth initiatives that seek to conserve the natural lands in the uplands or in the riparian area as available.

7.3.3.2 AGRICULTURAL CONSERVATION

The potential of widely adopted agricultural BMPs to reduce the frequency of high and peak flow events was evaluated. This analysis focuses on current flow thresholds rather than projected future flows considered in the Natural Land Conservation scenario. Because most agricultural practices primarily target water quality rather than water quantity, their impact on extreme storm-driven flows is limited. As a result, these practices are expected to influence daily average flows more than extreme events, yielding only modest overall reductions. A tributary is considered to benefit from BMP implementation if the number of days exceeding the current flood-potential threshold decreases.

For high flows greater than the 75th percentile of current long-term daily flow, the benefits of agricultural conservation are limited and geographically scattered (Figure 7-15, left panel). The spatial effect is generally minimal, reflecting the limited capacity of these practices to substantially reduce the large runoff volumes associated with sustained high-flow conditions. Nonetheless, a few subbasins in the lower part of the Basin show reductions in high-flow days, indicating that specific combinations of land use and BMPs can positively influence the flow regime.

Peak flow reduction, defined as flows exceeding the 90th percentile of current daily flows, shows broader potential benefits across the Basin (Figure 7-15, right panel). Because peak flows are infrequent, occurring only about 10% of the time, even modest reductions in flow magnitude can yield measurable benefits. These benefits are observed throughout the Upper, Central, and Lower Basin subbasins, with certain tributaries showing greater reductions in peak flows, including:

- Fishing Creek in Great Falls
- Big Dutchmans Creek in the Fishing Creek subbasin
- Balls Creek in Lake Norman

This pattern suggests that agricultural practices that focus on improving soil structure and vegetative cover, including cover crops, pasture and hay planting, critical area planting, tree and shrub establishment, and livestock access control, can play a modest but meaningful role in mitigating the most extreme, though infrequent, flow events across the study area.

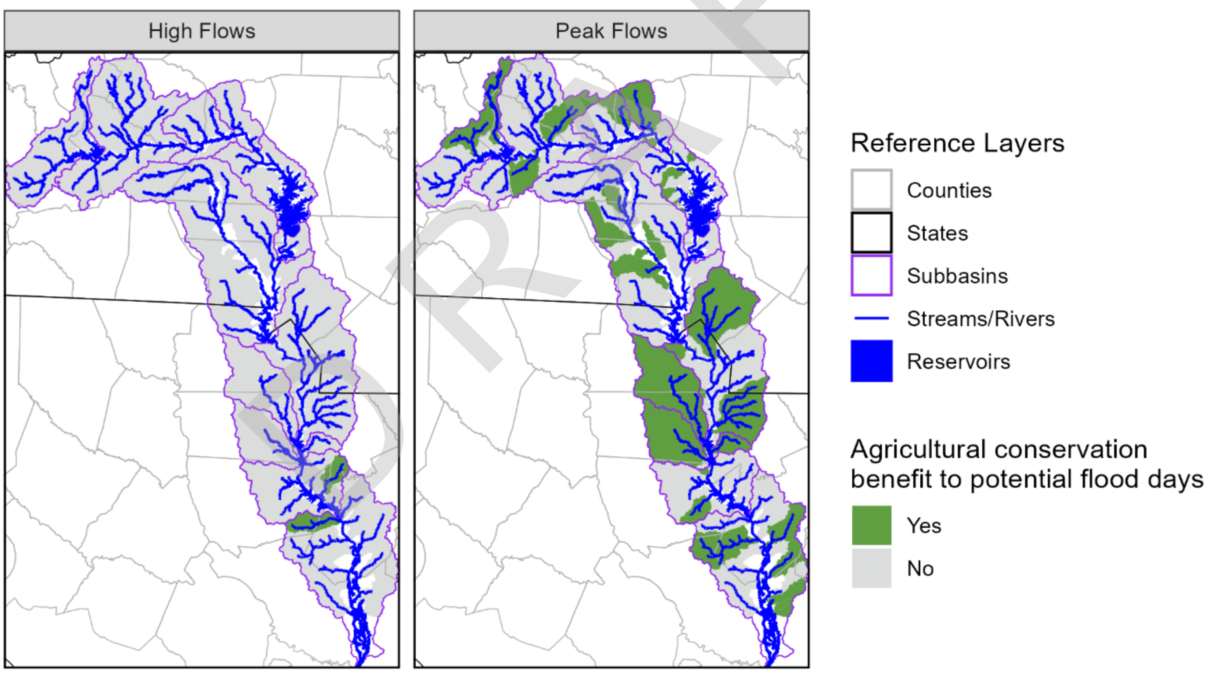

Figure 7-15. Reduction Benefit in Current High and Peak Flow Events through Agricultural Conservation

7.3.4 Concentrations in Rivers and Streams

Both conservation of natural lands and agricultural practices lead to improved instream concentrations of sediment, nitrogen, and phosphorus in almost every stream reach flowing through catchments with implemented management areas. While the improvements vary in magnitude, the consistency in benefits to water quality concentrations supports the extended implementation of both types of management practices. Figure 7-16 and Figure 7-17 display the confirmation of benefits to projected sediment concentrations through conservation and to current phosphorus concentrations through agricultural conservation, respectively.

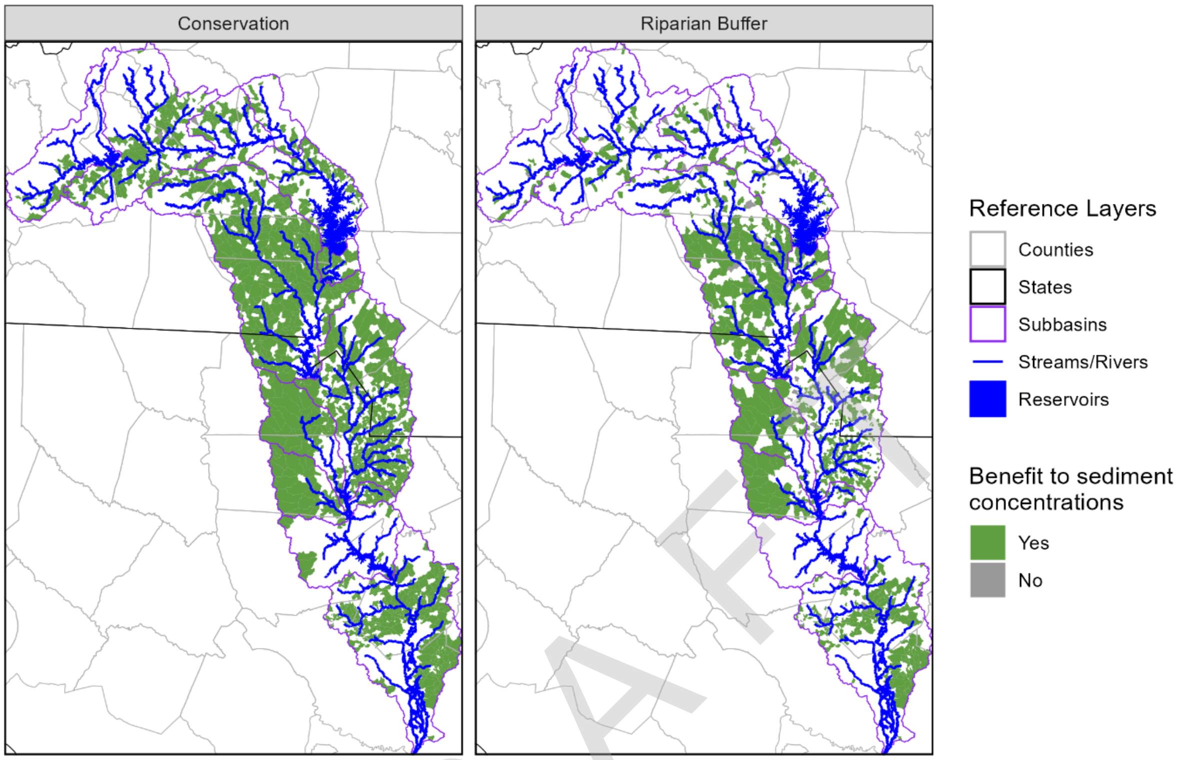

Figure 7-16. Benefit to Future Instream Sediment Concentrations from Conservation

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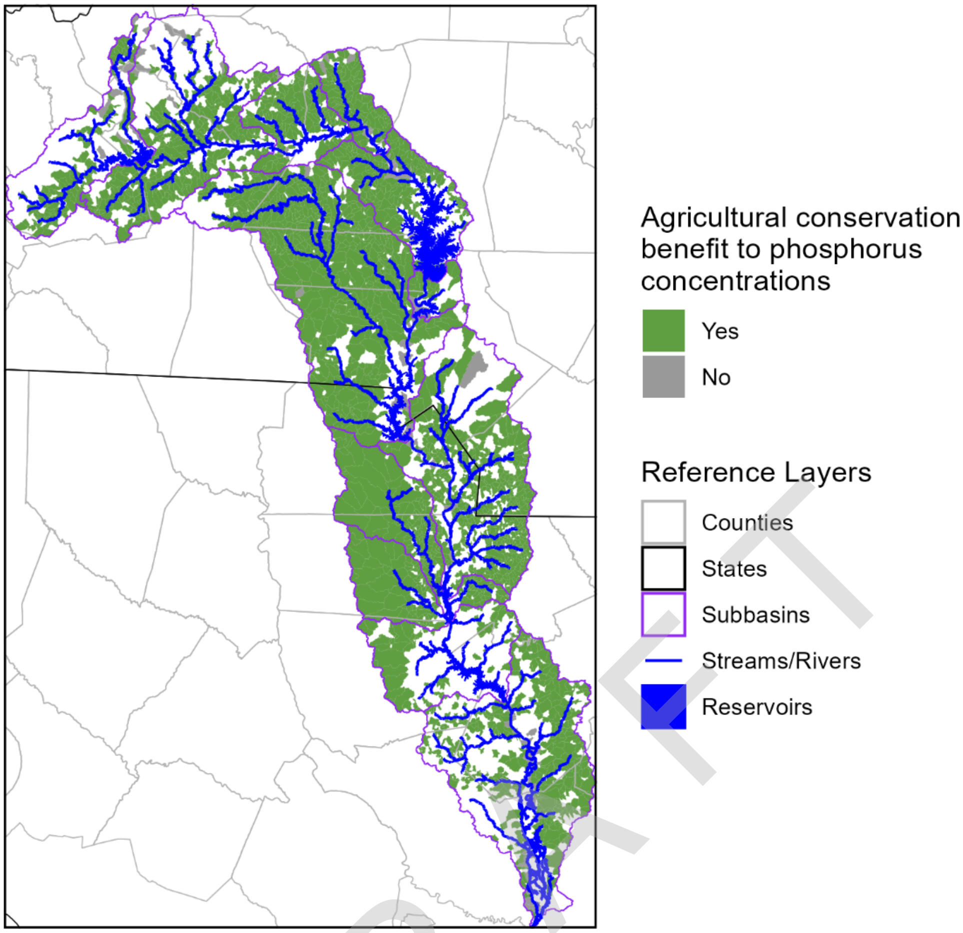

Figure 7-17. Benefit to Current Instream Phosphorus Concentrations from Agricultural Conservation

In a limited number of catchments throughout the Basin, the implementation of either natural land conservation or agricultural conservation can reduce median water quality concentrations below the target values identified to represent healthy flowing systems as discussed in Chapter 5 (0.8 mg/L for nitrogen, 0.05 mg/L for phosphorus, and 39 mg/L for sediment). For conservation, the targets were assessed against the Future Land Use scenario concentrations in the individual stream reaches compared to the concentrations after the implementation of natural lands conservation. Median nitrogen and phosphorus concentrations in a select few locations throughout the Central and Lower Basin that would have exceeded the target value under Future Land Use are brought below the target after land concentration. Median sediment concentrations did not exceed the water quality target under the Future Land Use scenario and therefore was not examined further.

Agricultural conservation is able to bring a larger number, although still limited, of reaches into compliance with the nitrogen and phosphorus water quality targets compared to current conditions. The benefited reaches extend from the Upper to Lower Basin for both parameters. An example of these priority hot spots for agricultural conservation are shown for nitrogen in Figure 7-18.

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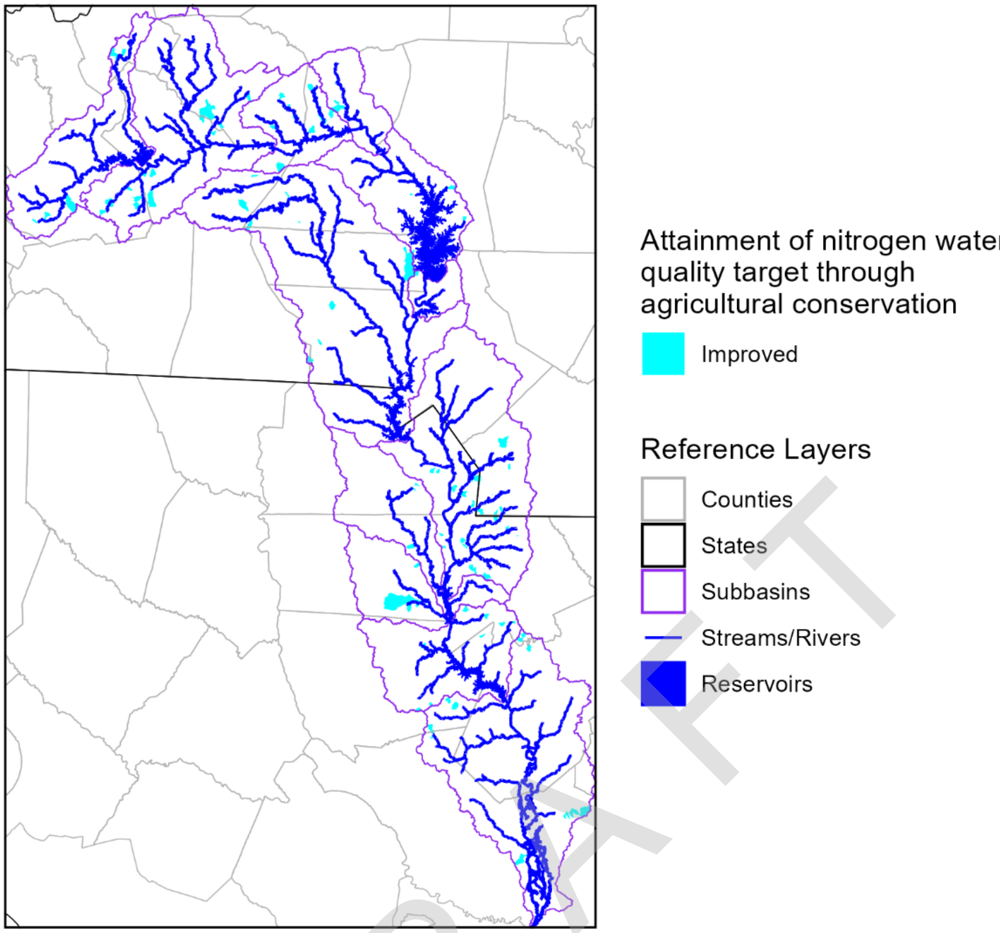

Figure 7-18. Catchments Where Agricultural Conservation Implementation Brings Instream Water Quality Concentrations Below Target Values

7.3.5 Surface Loadings of Nutrients and Sediment

7.3.5.1 NATURAL LAND & RIPARIAN BUFFER CONSERVATION

The results from the Natural Land Conservation and Riparian Buffer Conservation scenarios clearly demonstrate two distinct and effective pathways for mitigating the future increase in surface loadings of nitrogen, phosphorus, and sediment projected under the Future Land Use scenario.

The Natural Land Conservation scenario, shown in the left panels of Figure 7-19 through Figure 7-21, provides a comprehensive, landscape-scale benefit by preventing the conversion of all existing natural lands, including forests, grasslands, and wetlands, to developed uses by 2070. This approach yields widespread and high-value mitigation across the Basin, particularly in high-growth catchments within the Central and Lower Basin. Mitigation rates for the surface loadings across catchments achieve at least 25% reductions in almost every implementation catchment with some catchments achieving reductions of over 100% of the projected Future Land Use scenario load increase, with many areas exhibiting 75–100% reductions in projected future loads.

These substantial reductions occur because retaining natural land cover preserves the landscape's inherent capacity for infiltration and pollutant attenuation, even as future loadings increase from developed lands. By maintaining natural cover upstream, the generation and downstream transport of runoff and associated pollutants are substantially reduced. High mitigation rates occur throughout the Basin but are most pronounced in the Central and Lower Basin subbasins, including areas such as Below Wateree and Fishing Creek, where the greatest future loss of natural land is anticipated. As discussed with mean annual runoff, there are clusters of benefits around Charlotte, Gastonia, and further south in Lugoff, Camden, and outside of Sumter. In contrast, the northern subbasins show more dispersed, although still high, mitigation benefits, largely because a significant portion of natural land is already protected and relatively little future land conversion is projected.

By comparison, the Riparian Buffer Conservation scenario, shown in the right panels of Figure 7-19 through Figure 7-21, applies the more targeted natural land conservation within the riparian area. Although more spatially limited in implementation area, this strategy remains highly effective. For all three pollutants, mitigation rates within implementation catchments are almost all greater than 25% with some areas still achieving mitigation rates of over 100% even with conservation limited to the riparian area. Although there are fewer catchments with benefits due to the fewer number of opportunity areas, the distribution of higher mitigation rates is similar to that observed under the Natural Land Conservation scenario, though the benefits are more localized along the stream network. As with the other metrics, these findings indicate that there are locations where riparian areas can be the focus of conservation while still achieving similar benefits to addressing all conservation lands. In other areas, conservation across both the upland and riparian areas will be required to mitigate the impact of development outside of the natural lands.

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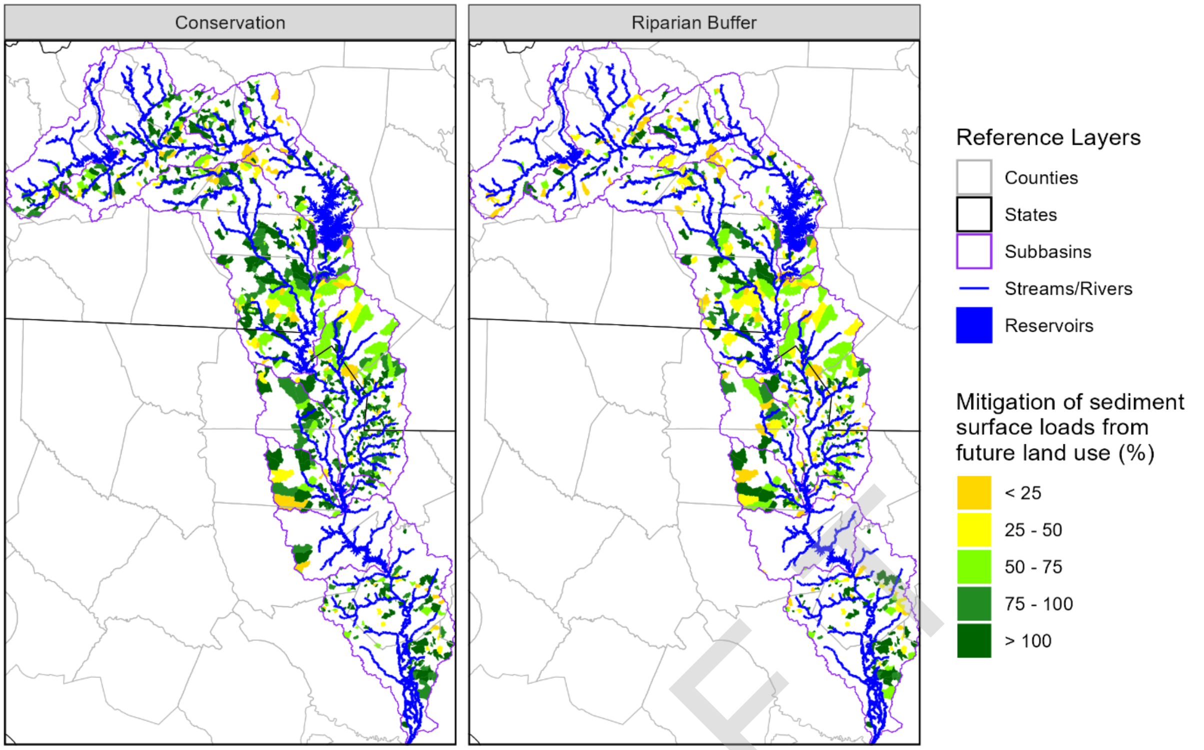

Figure 7-19. Benefit of Conservation on the Increase in Sediment Loads Generated from the Land Surface Under Future Land Use Change

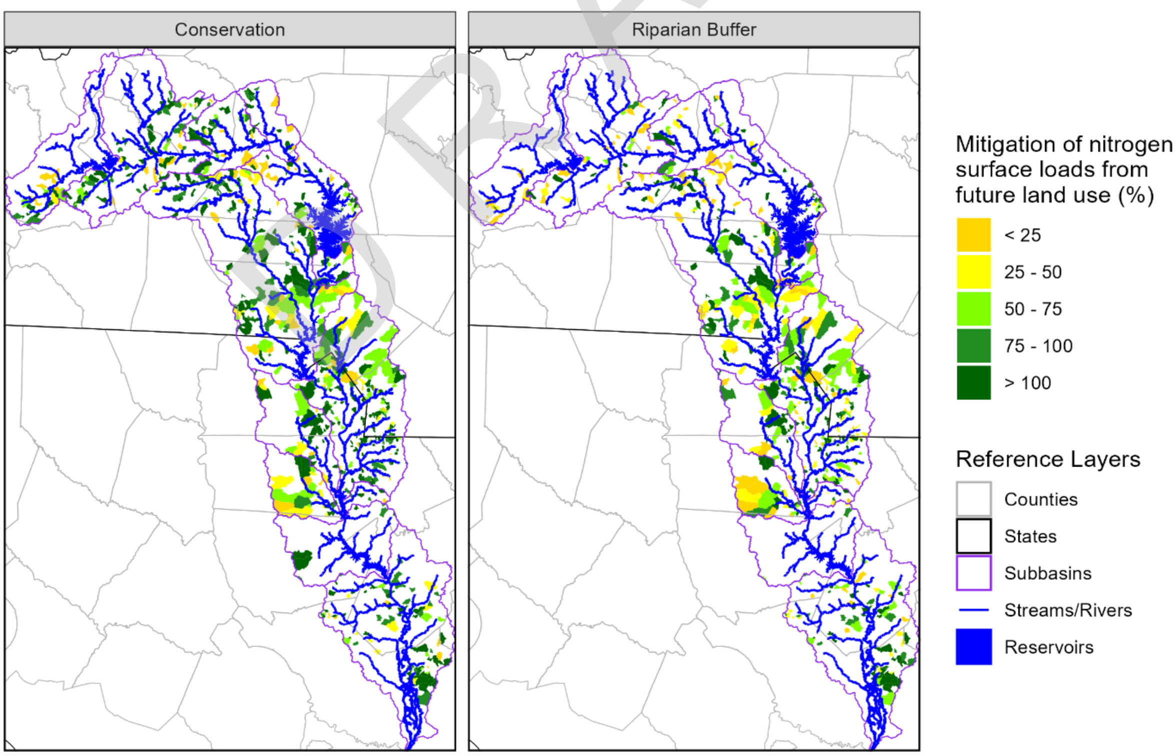

Figure 7-20. Benefit of Conservation on the Increase in Nitrogen Loads Generated from the Land Surface Under Future Land Use Change

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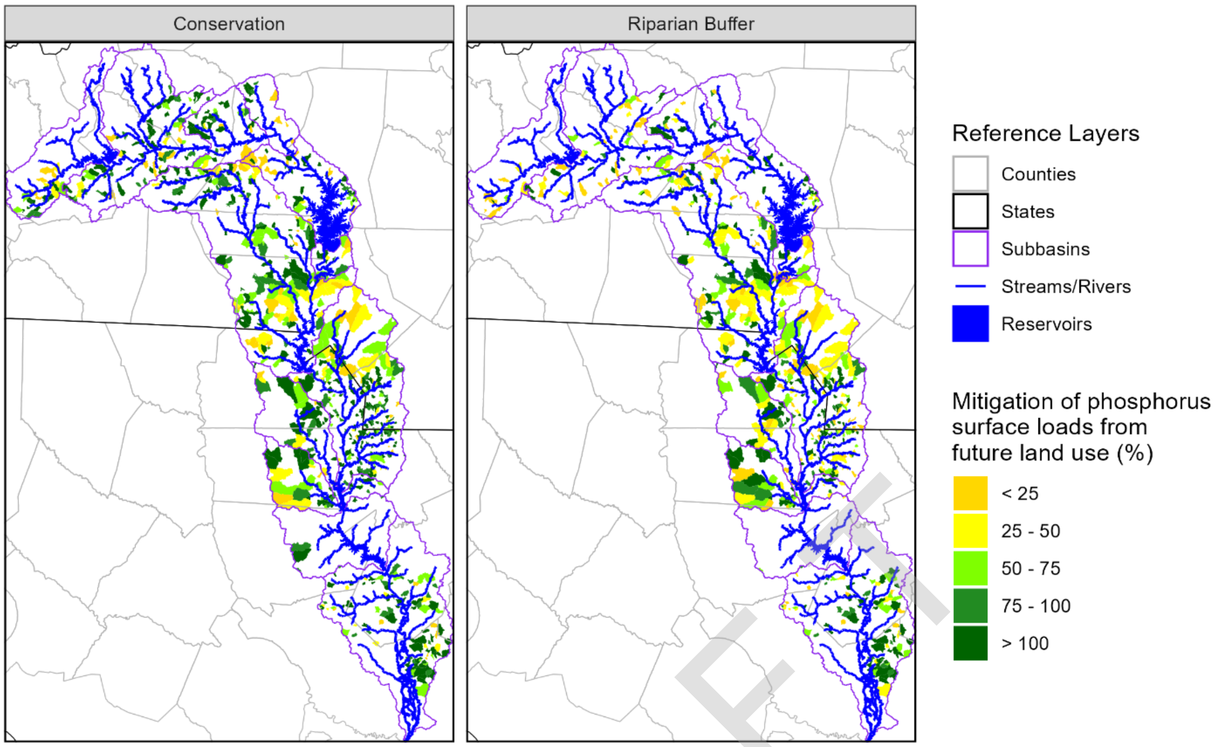

Figure 7-21. Benefit of Conservation on the Increase in Phosphorus Loads Generated from the Land Surface Under Future Land Use Change

Together, these scenarios identify complementary conservation priorities. The Natural Land Conservation scenario highlights areas with the greatest potential for future natural land loss, where broad protection would yield substantial benefits. The Riparian Buffer Conservation scenario, by comparison, identifies stream corridors most vulnerable to development pressures and where the protective filtering function of riparian vegetation is most critical.

7.3.5.2 AGRICULTURAL CONSERVATION

With the Agricultural Conservation scenario, the analysis considers the percent of the current surface load that can be reduced, rather than quantifying the benefit to just the projected increase in load due to land use change as with the conservation scenario. Therefore, the overall percent change calculated for mitigation rates per catchment is lower. In reality, these mitigation percentages can equate to similar mass removals in the conservation scenarios.

Figure 7-22 compares the surface load reductions for sediment, nitrogen, and phosphorus attained through agricultural conservation practice implementation. Overall, nitrogen and phosphorus are projected to have more extensive reductions in loads (as a percent of the current load) than sediment, particularly in the Upper Basin and in the headwaters of the South Fork Catawba River. In this analysis, the Lookout Shoals subbasin stands out for its consistent and elevated surface load mitigation mainly through livestock access control measures.

In general, the greater mitigation impacts for surface loadings of water quality parameters coincide with the livestock access control practices where the projects are assumed to include fencing off the riparian area of the stream channel, allowing high quality vegetation to reestablish thereby reducing sediment erosion and nutrient transport from that area. Because this practice was restricted to the riparian area, its implemented area was set at 80% of the available area, whereas other practices that can impact both the upland and riparian agricultural areas had lower implementation areas (i.e., 34% for cover crops; 28% for pasture/hay planting). Therefore, the implementation area, type of practice, position of practice, and type of changes to the land surface and water quality generation processes all interact to provide a variety of benefits and the application of these practices should not be limited to only the type assigned to each catchment under this scenario.

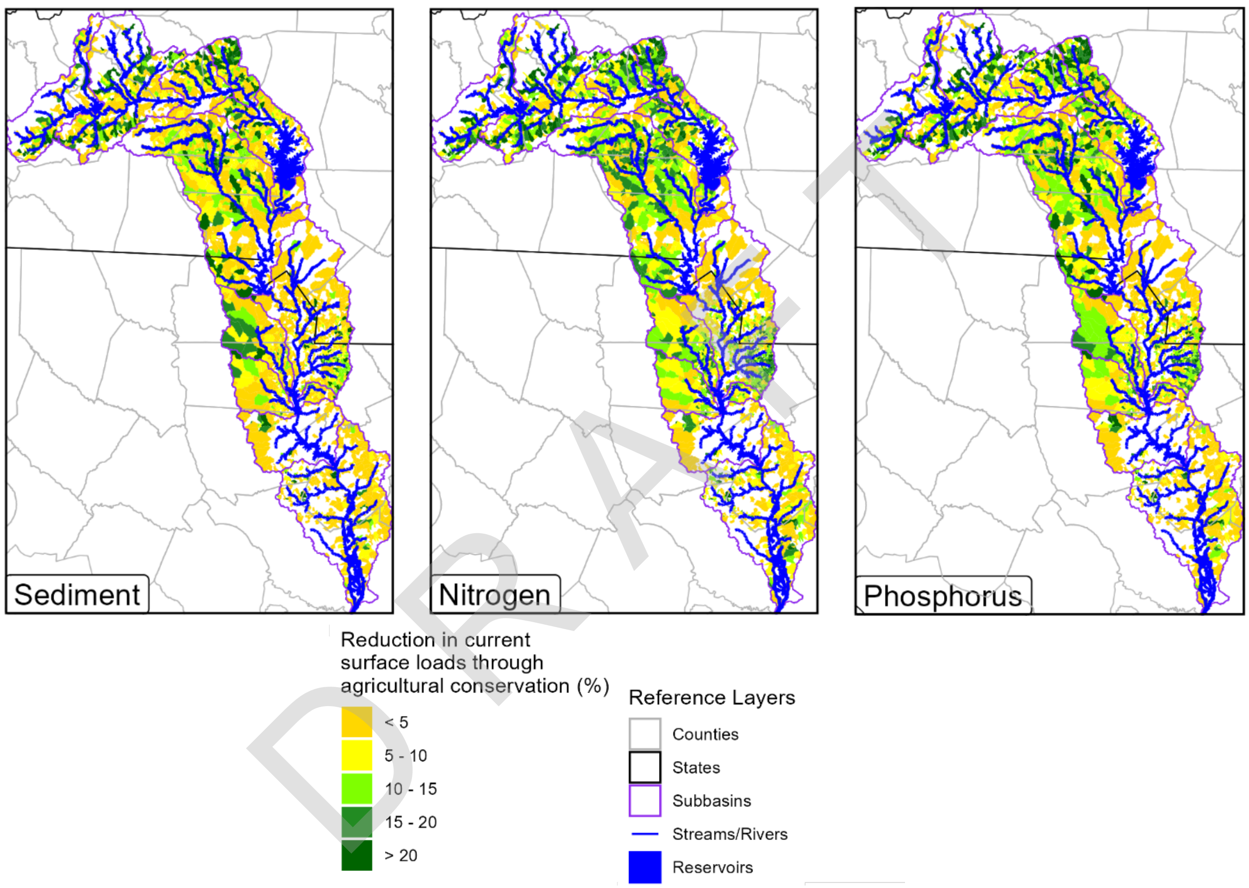

Figure 7-22. Benefits to Current Surface Loads from Agricultural Conservation

7.3.6 Loads to Reservoirs

Because the management scenarios are designed to examine the potential for different land management strategies and are not intended to represent a prescription for comprehensive current or future actions, corresponding load reductions to the reservoirs cannot be calculated in the same way the strategies are assessed across the different catchments and tributaries of the Basin. However, the various findings from examining the benefits of the natural lands conservation and agricultural conservation practices on the selected hydrologic and water quality conditions point to the following conclusions:

- Reductions in runoff from the land surface and in the water reaching the stream channel can be achieved through all three management strategies.
- At the same time, all three management strategies have the potential to protect against increases in low flow periods helping to ensure water continues flowing downstream to the reservoirs.
- Similarly, the strategies are able to protect against increases in potential flood flows through the runoff reductions and the corresponding slowing of water moving through the catchment and accumulating in the stream channels.
- These hydrologic changes bring with them reductions in water quality loadings from the land surface, subsurface, and streambanks.
- With the implementation of the strategies, selected locations have shown that the land conservation practices have the potential to provide benefits beyond reducing just the load increases expected due to land use change.
- Similarly, agricultural conservation practices implemented in the near term have the potential to reduce a significant mass of sediment and nutrients from reaching the streams before even beginning to mitigate future land use changes.

When applied strategically throughout the Basin, these land management strategies have a high potential to provide 1) streamflow resilience against future potential drought and flood conditions and 2) instream water quality improvements that can lead to reduced water quality concerns within the reservoirs themselves.

7.4 Recommendations for Integrated Land-based Management by Subbasin

To translate the Basin-wide benefits discussed in the previous section into actionable strategies and discussion guides, the specific opportunities, benefits, and interacting conditions or characteristics for each subbasin are listed in the following tables. Below is an example for Lake James that identifies the overall guidance for the subbasin, while hot spot maps will provide more site-specific considerations for action. A complete set of summary tables is provided in Appendix L. Within the tables, the issues, projected changes, and opportunity for management are ranked using the following indicators:

■ Significant issue, projected change, or potential mitigation benefit through management
◘ Some issues, moderate projected change, or moderate or inconsistent mitigation benefit
□ Minor/Inconsistent issues, projected change, or mitigation benefit

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Lake James

Location	Headwaters of the Catawba-Wateree Basin within the Blue Ridge ecoregion.						
Notable Characteristics:	• Federal Pisgah National Forest; Linville Gorge State holdings through NCWRC NC DNCR Foothills Conservancy of NC • High relief subbasin • North Carolina designated Trout waters						
Key Information	**Counties** Avery, Burke, McDowell		**Municipalities:** Marion, Old Fort		**Transportation** I-40, US-70, US-221		**Area** 386
Projected Land Use Change (mi²)	**Altered** 0.24		**Vegetated** 4.69		**Pristine** -4.9		
Management Opportunity (acres)	**Conservation** 143		**Buffer** 14		Agriculture 1,850		Livestock Access Control; Pasture/ Hay Planting; Cover Crop
	Mean Annual Runoff	**Peak Daily Runoff**	**Low Flow Duration**	**Flooding Potential**	**Concentrations**		**Surface Loading**
Current Issues	■	■	□	■	S:	□	■
					N:	□	■
					P:	□	■
Future Project Changes[1]	□/■	□/◘	□/◘	□/■	S:	□/□	□/□
					N:	□/□	□/□
					P:	□/□	□/□
Response to Management Strategies	◘	◘	◘	□	S:	◘	◘
					N:	◘	◘
					P:	◘	◘
Notes	High relief areas lead to specific event concerns for both hydrology and WQ which will increase with a wet climate. Moderate ranking of management is due to lower implementation opportunity due to large area of existing protections.						
Tributary Focus	• Catawba River (S, N, P) • Linville River (S, N, P) • North Fork Catawba River (S, N, P)				• Paddy Creek (S) • Shoreline (N, P)		
Recommendations	• Targeted management through land preservation to maintain existing natural infrastructure in areas not yet protected. • Consider smart growth initiatives within Marion. • Support restoration efforts for natural channels, high quality vegetation, and reservoir sedimentation from Hurricane Helene.						
Legend	□ Minor/Inconsistent issues, projected change, or mitigation benefit			◘ Some issues, moderate projected change, or moderate or inconsistent mitigation benefit		■ Significant issue, projected change, or potential mitigation benefit through management	
	S = sediment			N = nitrogen		P = phosphorus	

[1]Future conditions are rated for projected land use change alone (first rating) and for climate impacts (second rating)

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Recommendations

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8 Recommendations

8.1 Summary

The IWRP evaluates water supply and quality across Basin rivers, streams, and 11 reservoirs using more than 40 years of daily simulations of hydrology, water quality processes, and reservoir performance. Analyses were conducted at the catchment level, the land area surrounding each river reach, and aggregated to tributary and reservoir subbasin scales to capture total inflows. These assessments reflect current and projected conditions influenced by land use, climate variability, physical characteristics, and human system modifications.

To anticipate future needs, the IWRP incorporated long-range water demand forecasts that estimate net withdrawals through 2075. These projections, combined with scenario-based modeling of land use and climate change, provide insight into how growth and variability will affect water availability. Reservoir operations were simulated using the CHEOPS model, which applies system constraints and operating rules to evaluate performance under drought, high-flow events, and assumed changing demand patterns. Together, these tools enable a comprehensive view of both natural watershed processes and managed system behavior.

Described in detail in Sections 4- through 6, future scenarios included a 2070 land use projection and four bounding climate conditions*:* Hot/Dry, Hot/Wet, Warm/Dry, and Warm/Wet*,* along with combined scenarios that pair land use change with extreme climate conditions. Management strategies were also tested, including 1) conservation of natural lands, 2) riparian buffer protection, and 3) agricultural best practices. While modeled at the Basin scale, recommended implementation actions focus on "hot spots" where targeted measures show efficiency in mitigating projected changes and reservoir level operations management*.*

Recommendations were developed using this integrated modeling framework, supplemented by data gathering on other Basin challenges and input from the IWRP Stakeholder Advisory Team*,* IWRP Steering Committee, and CWWMG Board and committees.

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8.2 Recommendations

Recommendations developed for the IWRP represent the culmination of years of collaboration, planning, and stakeholder engagement. These actionable strategies are intended to safeguard water quantity and quality while supporting sustainable growth and economic vitality—they reflect a forward-looking approach, balancing immediate needs with long-term resilience.

IWRP recommendations acknowledge the uncertainties of future conditions, including climate variability, land use change, and evolving regulatory landscapes, and provide a framework for adaptive management, and present a portfolio of options to provide flexibility for members to respond to emerging challenges and opportunities. By integrating policy, planning, technical projects, and drought preparedness, these recommendations aim to strengthen regional coordination, optimize resource use, and protect the Basin's water resources for generations to come.

These actions support the CWWMG's mission to "*collectively identify, fund, and implement strategic initiatives that extend the capacity of the Catawba-Wateree River to effectively serve the community, while protecting and enhancing the ecological health of the Basin*[15]".

The IWRP proposes recommendations across four major categories. This list provides the recommendation highlights with additional details in the following sections.

A. Policy, Legislative, and Regulatory

1. Coordinate consistent riparian buffer regulations across jurisdictions
2. Advance watershed-based governance for IBTs
3. Ensure meaningful and timely compliance with the 2010 US Supreme Court Case Settlement Agreement (SC v. NC, Original Case No. 138)

B. Planning Process Recommendations

1. Enhance Source Water Protection Committee (SWPC) Evaluation Framework
2. Coordinate Subbasin Land Conservation and Management
3. Strengthen Conservation Communications

C. Technical and Program Recommendations

1. Monitoring Program Recommendations:
   a. Establish a CWWMG Monitoring Committee
   b. Promote increased water quality and quantity sampling at priority locations
2. Conduct More Detailed Study of Riparian Buffers
3. Water Conservation Enhancement Strategy Recommendations:
   a. Mitigate Water Loss
   b. Optimize Treatment Plant Operations
   c. Reduce Per-Capita Water Use (during normal conditions)
   d. Enhance Water Reuse
4. Monitor Industrial Customer Class Growth Trends
5. Update Reservoir Storage and Bathymetry
6. Implement Subbasin-Specific Management Recommendations

D. Drought Planning and Response Recommendations

1. Low Inflow Protocol Recommendations:
   a. Strengthen LIP water use reduction timelines.
   b. Collaborate with non-PWS large water intake owners for water use reduction goals
   c. Evaluate revising LIP stage minimum reservoir elevation requirements for Lake James and Lake Norman Expand participation in CW-DMAG.

[15] https://www.catawbawatereewmg.org/our-mission

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2. Raw Water Intake Operational Contingency Recommendations:
    a. Enhance outreach to industrial intake owners.
    b. Revise intake contingency plans.
    c. Implement emergency response tabletop exercises.
3. Raw Water Intake Modifications Recommendations:
    a. Assess ability to lower intake elevations for critical facilities.
    b. Use probability-based evaluations to prioritize operational vs. capital solutions.

8.2.1 Policy, Regulatory, and Legislative Recommendations

Policy, Regulatory, and Legislative Recommendations are intended to address policy and funding considerations critical to advancing integrated water resource planning in the Basin. Specifically, this category encompasses potential modifications to existing state and local laws, regulations, and ordinances; the development of new legislative or regulatory frameworks; and strategies for establishing sustainable, recurring funding mechanisms to support ongoing water planning initiatives.

8.2.1.1 COORDINATE CONSISTENT RIPARIAN BUFFER REGULATIONS ACROSS JURISDICTIONS

Conservation of remaining natural lands within the riparian buffer areas provides significant water quality protections for instream water quality and some regulation of potential flood-inducing flow issues as demonstrated by the IWRP modeling analysis. While many local governments have established buffer regulations, they vary in width (i.e., mandated protected area), application, and enforcement policy.

The CWWMG should use its technical study approach to further identify the optimal riparian buffer conservation goals and then coordinate through their membership to bring forward more consistent regulations with enforcement capabilities to the municipalities within priority areas.

8.2.1.2 ADVANCE WATERSHED-BASED GOVERNANCE FOR IBTS

Current IBT regulations differ between states and often focus on subbasin boundaries, creating challenges for regional coordination. While recent legislative changes indicate some flexibility[16], long-term sustainability requires governance that reflects hydrologic systems rather than political boundaries. National guidance emphasizes watershed-based planning and regional collaboration as essential for balancing reliability, environmental health, and growth. Recommendations for the CWWMG are as follows (additional details provided in Section 4.4):

- Support regulatory and policy enhancements that remove subbasin boundary restrictions and advance watershed-based governance, enabling greater flexibility for transfers within major basins and improving regional coordination.

[16] NC SL 2025-77 included provisions to eliminate certain subbasin designations and remove the requirement for an interbasin transfer certificate for water transfers between subbasins within the same major river basin of NC, focused only in the Neuse and Cape Fear major river basins (i.e. not applicable in the Catawba or neighboring basins). The law’s findings include reference to support for regionalization and collaborative management for water and wastewater services.

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- In addition to state statutory requirements, CWWMG should encourage utility evaluation of IBT alternatives that consider infrastructure feasibility, cost-benefit tradeoffs, and basin-level impacts. Through the IWRP and its successors, the C-W Basin has established a modeling framework that should be used to assess potential IBTs involving the Basin in the future to support consistent analysis.

8.2.1.3 ENSURE MEANINGFUL AND TIMELY COMPLIANCE WITH THE 2010 US SUPREME COURT CASE SETTLEMENT AGREEMENT (SC V. NC, ORIGINAL CASE NO. 138)

Request NCDEQ and SCDES each assign a leadership-level staff person to have primary responsibility for ongoing Settlement Agreement compliance, including but not limited to timely and appropriate budgeting for each state's portion of the next update of the IWRP, based on the CWWMG's projected cost for preparing the update and an assumption of splitting the cost equally three ways.

8.2.2 Planning Process Recommendations

The CWWMG operates through monthly meetings with their membership, board, and subcommittees. CWWMG members meet regularly to formulate strategies and projects to help understand and address the Basin's water challenges. Committees, formed from participants from member organizations and external subject matter experts, consider specific topics for review and action concluding with recommendations to the CWWMG board and membership for next steps. Through the Advisory Committee, the CWWMG receives external feedback and perspectives to help inform general direction, governance, strategy, planning and other aspects supportive of the CWWMG's mission. In light of the various methods of operation and participation roles, the following recommendations are made to modify or enhance standing CWWMG processes.

a. **Enhance Source Water Protection Committee (SWPC) Evaluation Framework**
   Expand the Source Water Protection Committee (SWPC) efforts by using the project evaluation framework updated during this IWRP process to consider a larger breadth of projects/actions (e.g., projects that would enhance total storage in the reservoirs, manage invasive species, etc.). The SWPC should also continue to investigate public-private partnerships to enhance and leverage funding opportunities for priority watershed projects.

b. **Coordinate Subbasin Land Conservation and Management**
   Coordinate among members within individual reservoir subbasins, or through divisions of the Basin such as upper, central, and lower, to facilitate communications, planning, and implementation actions using the IWRP set of conservation and management priorities by subbasin as a guide. Determine whether this coordination is formal through committee formation or informal through actions such as email distribution lists and ad-hoc meeting facilitation. Consider the existing Lake Advisory and Technical Committees already in place for the Catawba-Wateree Habitat Enhancement Program as a starting point for forming groups and setting procedures.

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c. **Strengthen Conservation Communications**
Within CWWMG's Communications Strategy, incorporate new data-supported topics for advocacy to: 1) Promote strategic land conservation; 2) Increase education and support for agricultural conservation practices; and 3) Work to identify and promote practical ways to implement conservation areas, nature-based solutions and green infrastructure/stormwater control measures into new development.

8.2.3 Technical and Program Recommendations

Technical and program recommendations in the IWRP address data gaps and information needs and include evaluation of management actions in the face of land use and climate change and includes subbasin specific recommendations. Each of these larger recommendations are described below.

8.2.3.1 MONITORING PROGRAM RECOMMENDATIONS

The IWRP includes an overview of current monitoring programs based on data collection and stakeholder input. This review reveals gaps in the type, frequency, and location of observed data that limit the ability to identify critical conditions and support management decisions. Addressing these gaps will strengthen planning and improve system reliability. Key gaps include:

- Limited monitoring coverage in the southernmost portion of the Basin below Lake Wateree in South Carolina.
- Insufficient long-term (10+ years) monthly nutrient monitoring sites (TSS, nitrogen, and phosphorus) across the Basin.
- Need for more consistent, year-round baseline data to support trend analysis and model calibration for water quality.
- Sparse monitoring near major tributary confluences and areas with known or high-risk nutrient loading. Similarly, sparse monitoring of streamflow in the tributaries of Lake Wateree and Wateree River.
- Limited continuous sensors (e.g., turbidity, dissolved oxygen, temperature) in key locations to capture event-based variability.

Recommendations:

a. **Establish a CWWMG Monitoring Committee**
Establish a Monitoring Committee following the existing Source Water Protection Committee design (i.e., membership, meeting schedule, and project review and recommendation process). Through this committee the CWWMG should: 1) Encourage membership from active monitoring agencies; 2) Provide a budget to support potentially both long-term monitoring programs and specific issue-focused sample collection; 3) Document desired/required sampling program procedures/attributes; and 4) Seek to establish monitoring at the prioritized locations determined from this effort. Consider working through the Monitoring Coalition Program within the North Carolina Division of Water Resources to facilitate the entire process and take advantage of

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existing standards and tracking systems. 5) Create a CWWMG State Agency Monitoring Program Liaison Role who will lead the new committee on monitoring or repurpose and focus the existing Water Quality Committee to serve this role.

b. **Promote increased Water Quality & Quantity Sampling**
Review and promote increased sampling at the locations identified by the IWRP for water quality (as shown in Figure 8-1) and for streamflow within the Lake Wateree and Wateree River subbasins.

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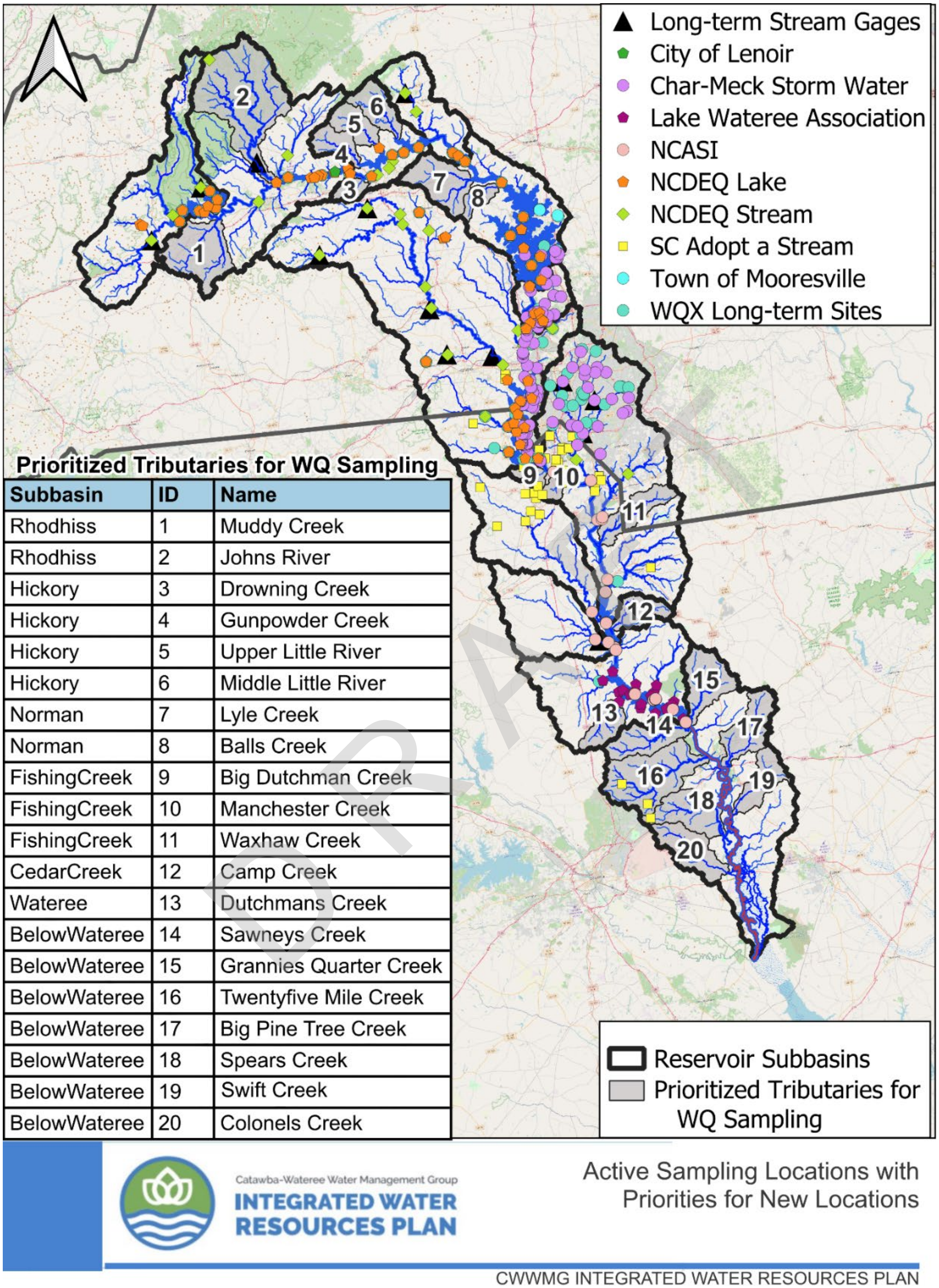

Prioritized Tributaries for WQ Sampling

Subbasin	ID	Name
Rhodhiss	1	Muddy Creek
Rhodhiss	2	Johns River
Hickory	3	Drowning Creek
Hickory	4	Gunpowder Creek
Hickory	5	Upper Little River
Hickory	6	Middle Little River
Norman	7	Lyle Creek
Norman	8	Balls Creek
FishingCreek	9	Big Dutchman Creek
FishingCreek	10	Manchester Creek
FishingCreek	11	Waxhaw Creek
CedarCreek	12	Camp Creek
Wateree	13	Dutchmans Creek
BelowWateree	14	Sawneys Creek
BelowWateree	15	Grannies Quarter Creek
BelowWateree	16	Twentyfive Mile Creek
BelowWateree	17	Big Pine Tree Creek
BelowWateree	18	Spears Creek
BelowWateree	19	Swift Creek
BelowWateree	20	Colonels Creek

Figure 8-1. Active Sampling Locations with Priorities for New Locations

8.2.3.2 CONDUCT MORE DETAILED STUDY OF RIPARIAN BUFFERS

As noted above, conservation of existing natural lands within the Basin's riparian buffer areas shows promise for efficient mitigation of potential future land use and/or climate-induced changes to water quality and, to a lesser extent, water quantity issues. The IWRP analysis is not able to determine specific buffer widths but rather used an elevation and hydrologic based dataset that used a consistent method to identify a riparian area. To inform potential policy recommendations, this analysis must be translated from the riparian area to a riparian buffer width with supporting details (e.g., applicable to which streams; one or more widths based on stream order or location; priority locations; land use limitations within the buffer).

Recommendation: Build on the existing IWRP analysis and conduct a further assessment of riparian buffers through geospatial analysis and modeling to inform specific riparian buffer width and land use recommendations and guide regulatory and policy action.

8.2.3.3 WATER CONSERVATION ENHANCEMENT STRATEGY RECOMMENDATIONS

Water Conservation is a fundamental tool for ensuring sustainable water resources and mitigating the impacts of anticipated population growth, industrial development, and climate variability. By reducing water distribution system losses, optimizing operational efficiency, and promoting responsible water use, conservation measures help preserve supply reliability and utilization of current water supplies while minimizing the need for additional supply identification.

Build upon the CWWMG Water Loss Management Program functions and dedicate action towards the following recommendations:

a. **Mitigate Water Loss**
   Implement targeted leakage reduction measures informed by data from the CWWMG Water Loss Audit Program developed in response to the WSMP. Focus on repairing high-loss areas first and establish a process to monitor progress and report improvements over time.

b. **Optimize Treatment Plant Operations**
   Encourage utilities to review treatment plant operations to identify ways to reduce overall water demand. .

c. **Reduce Per-Capita Water Use**
   Promote sustained reductions in per-capita water use outside of drought periods by supporting public education campaigns that encourage everyday conservation practices and tracking usage trends to measure progress and adjust strategies as needed.

   - The evaluation process should leverage previous WSMP residential reductions goals.
   - Develop standardized residential account billing terms and classifications across the Basin to support future evaluations, (e.g. multi-family residential uses separate from single family residential).
   - Enhance PWS staff focus on water conservation across the organization and consider dedicated staff specialists as applicable to the organization.

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d. **Enhance Water Reuse**
   Assess opportunities for utilities to implement non-potable reuse strategies to offset raw water demand.

8.2.3.4 MONITOR INDUSTRIAL CUSTOMER CLASS GROWTH TRENDS

Industrial and commercial customer water use trends for public water suppliers have evolved over the course of the IWRP's development. Monitor potential industrial buildouts that could significantly increase water demand beyond current forecasts (e.g. Data Centers) by engaging with economic development agencies for early insights and modeling demand impacts to integrate into regional planning. Compare demands to the IWRP forecast to identify shifting trends to provide indicators of changes to the basis of the IWRP. Encourage and emphasize the importance of engaging public water suppliers to local economic development organizations.

8.2.3.5 UPDATE RESERVOIR STORAGE AND BATHYMETRY

Recognizing the apparent sediment infill that occurred during the high flows and debris associated with Hurricane Helene (September 2024) and its potential impact on reservoir storage capacity, it is recommended that updated bathymetric surveys be conducted for all eleven mainstem lakes, with a priority for those further upstream and largest storage (e.g., Lake James through Norman, Wylie). These surveys will provide accurate data on current storage volumes, inform operational planning, and support water supply reliability under changing conditions.

8.2.3.6 IMPLEMENT SUBBASIN-SPECIFIC MANAGEMENT RECOMMENDATIONS

Each subbasin will receive a tailored set of recommended management priorities. These priorities will be based on the subbasin characteristics and identified current and projected future issues. Priorities will include both types of management approaches ranked by highest need and/or least effort for significant impact as well as a list of tributaries with corresponding maps of *hot spot* catchments for action. Each tributary will include a description of current and projected future concerns and areas identified with the potential for land use-based management. If groupings of *hot spots* are identified outside one of the prioritized tributaries within a subbasin, those *hot spots* will be described as a separate set of actions. Attached to this recommendation list is an example for Lake Rhodhiss.

8.2.4 Drought Planning and Response Recommendations

The CWWMG and CW-DMAG members are committed participants in the Catawba-Wateree Low Inflow Protocol, which guides objective determination of drought conditions and corresponding actions to modify lake operation and water user behavior. Modeling highlighted which reservoirs were more vulnerable to drought impacts and the efficacy of the LIP.

Recommendations by subtopic:

1. **Low Inflow Protocol Recommendations:**
   a. Strengthen LIP water use and minimum flowreduction implementation timelines. Develop collaborative communication plans for dry periods in collaboration with the CW-DMAG. Define common messaging, clarify communication platforms, and align

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communication strategies within sub-basins and neighboring jurisdictions for consistency.

b. Collaborate with industrial users to develop water use reduction goals during drought conditions, such as LIP Stages 2-4. This opportunity is applicable to non-PWS large water intake owners as well as industrial customers connected to PWS whose executed agreements have specific clauses exempting the user from water restrictions to see if there are opportunities.

c. Evaluate revising LIP stage minimum reservoir elevation requirements for Lake James and Lake Norman. during LIP Stages 2 and 3 to allow larger volumes of water releases as needed to support downstream reservoirs by accessing available storage.

d. Promote increased participation of PWS in the CW-DMAG to expand the network of informed and coordinated water systems.

2. Raw Water Intake Operational Contingency Recommendations:

a. Enhance outreach to industrial intake owners. Facilitate discussions on intake contingency planning and availability of PWS support during low-flow conditions.

b. CWWMG Members developed intake contingency plans in 2015 as recommended in the WSMP. All members should plan to revise these plans based on updated information from IWRP, new members, and review opportunities for interconnection and enhanced mutual aid during drought periods.

c. Implement emergency response tabletop exercises to support response to drought (and potential contamination events). These may be targeted for each reservoir and practice leveraging interlocal partners for response through the CWWMG.

3. Raw Water Intake Modifications Recommendations:

a. The IWRP conducted drought planning modeling scenarios focused on the most severe conditions, including a re-run of the worst Drought of Record and amplified challenges from climate change. Develop probability-based, user-specific evaluations of IWRP drought-scenario modeling to refine tradeoffs between capital changes and LIP adjustments to mitigate drought impacts based on annual likelihood.

b. The following entities may assess their ability to lower or otherwise enhance the drawdown depth of their intake to maintain water accessibility during the lowest inflow conditions and anticipated future withdrawal demands to the listed modified Critical Reservoir Elevations in

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Table 8-1. Recommended Large Water Intakes for CRE Modification Evaluation

Reservoir	User (s)	CRE (ft msl)
Lake Norman	Duke Energy-McGuire Nuclear Station	746.0
Mountain Island Lake	Mt Holly	637.5
Lake Wylie	Belmont Clariant Confidential Industry	559.4

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References

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