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A Study of Two Digital Hydrological Networks in South Carolina and an Assessment of Site Reconnaissance Results from the SC Department of Health and Environmental Control Probability Survey for Streams and Rivers

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A STUDY OF TWO DIGITAL HYDROLOGICAL NETWORKS IN SOUTH CAROLINA AND AN ASSESSMENT OF SITE RECONNAISSANCE RESULTS FROM THE SC DEPARTMENT OF HEALTH AND ENVIRONMENTAL CONTROL PROBABILITY SURVEY FOR STREAMS AND RIVERS

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ABSTRACT

The South Carolina Department of Health and Environmental Control (SCDHEC), Surface Water Monitoring Section utilizes a probability survey to assess water quality conditions of streams and rivers in the state. The Generalized Random-Tessellation Stratified survey design prioritizes specific stream order (size) subpopulations and spatial distribution in the generation of potential sample sites, and is intended to survey only perennial stream reaches. Site reconnaissance is conducted to assess site suitability and accessibility. The stream characteristics associated with accepted and rejected sites have been recorded since the late 1990s/early 2000s. Data from 2001-2016 was analyzed to assess apparent trends in both rejected and accepted site characteristics. These trends were evaluated based on frequency of rejection reasons and affected stream orders. Apparent trends in the characteristics of rejected sites were compared against characteristics of sampled sites. A second component to the site rejection assessment determined if there was an association between landcover or land use and site rejection or acceptance. Another focus of the study assessed differences between two digital hydrological networks in South Carolina at the 1:100,000 scale. The EPA Reach File 3.0 network currently used as the survey network was compared with the National Hydrography Dataset Plus (NHDP) network, a combined product between the U.S Environmental Protection Agency and U.S Geological Survey. The two networks were compared for the Pee Dee and Savannah River Basins, and for 4 subwatershed 12-digit Hydrological Code Units (HUCs). The subwatersheds were located in two distinct

ecoregions of South Carolina, the Piedmont and Coastal Plain. The advantages and drawbacks of both networks were assessed based on network definition and site reconnaissance.

The leading reasons for sites to be rejected were intermittency and inaccessibility. Intermittency refers to streams that do not flow year-round, and which do not belong in the sample frame. Intermittency was most often observed in the smallest 1st order streams. Inaccessibility affected all orders to some degree, and refers to sites that did not have an acceptable location from which to sample; the sites are assumed to be target population sites as they cannot be verified via site reconnaissance. Landcover associations assessed at the subwatershed regional scale revealed that site accessibility appeared to be a greater issue in networks located in a rural environment than networks located in urban areas. The two hydrological networks were similar in network linear definition, with differences in stream mileage primarily a result of differences in level of stream connectivity rather than spatial disagreement. Variation in stream density in the NHDP 1:100,000 network prevents SCDHEC from utilizing it for the probability survey. However, if the coverage scales were addressed, the NHDP network has useful attributes, such as identifying streams as perennial or intermittent. The network is not presumed to be exact, but the ability to exclude a significant proportion of non-target streams would be advantageous. Further evaluation and statistical analysis are recommended to determine if SCDHEC would benefit from changing the reference digital hydrological network to the NHDP, as these results suggest.

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LIST OF ABBREVIATIONS

BC .... Brushy Creek-Enoree River

BMP .... Best Management Practice

CWA .... Clean Water Act

DLG .... Digital Line Graph

EPA .... U.S Environmental Protection Agency

GIS .... Geographic Information Systems

GRTS .... Generalized Random-Tesselation Stratified

GS .... Green Swamp

HUC .... Hydrological Code Unit

LLL .... Lower Little Lynches River

MC .... Middle Coneross Creek

NHEERL .... National Health and Environmental Effects Research Lab

NHD .... National Hydrography Dataset

NHDP .... National Hydrography Dataset Plus

NLCD .... National Land Cover Database

NPDES .... National Pollutant Discharge Elimination System

RF3 .... Reach File Version 3.0

SCDHEC .... South Carolina Department of Health and Environmental Control

TMDL .... Total Maximum Daily Load

US .... United States

USGS .... United States Geological Survey

CHAPTER I INTRODUCTION

1.1 BACKGROUND

The Clean Water Act of 1972 (CWA) is the primary federal law governing water quality in the United States (US). The CWA mandates states to regulate pollution sources and to create water quality standards for waters within the state boundaries. Monitoring programs assess the status of waters of interest based on these standards in order to determine if any impairment is inhibiting the designated use of the water. Examples of designated uses can be the support of aquatic life, recreational use, or potable water source. Impairment may be determined through analysis of several parameters; a few examples are dissolved oxygen, pH, macro-invertebrate community, turbidity, and habitat analysis. If the monitoring assessment determines that the water quality is below attainment standards, the source of the impairment is identified and steps are taken to address it. Point-sources are regulated with the National Pollutant Discharge Elimination System (NPDES) which prohibits or limits levels of discharge, while the more diffusive non-point sources may be addressed by Total Maximum Daily Loads (TMDLs) through the use of Best Management Practices (BMPs).

The South Carolina Department of Health and Environmental Control (SCDHEC) is responsible for administering the CWA through the assessment and reporting of the water quality conditions and pollution sources. Summaries provide information on estimates of stream miles that are fully supporting, partially supporting, or not supporting designated use.

Probability surveys are an important tool in assessing water quality and developing these broad state-wide summaries. They provide the ability to make general statements about water quality in the state based on a small subsample of the target population. Hydrological probability surveys sample random locations in order to represent the distribution of target waterbodies throughout the state. Site generation is based on waterbody type; in South Carolina, these include rivers and streams, lakes and reservoirs, and estuaries. SCDHEC utilizes a Generalized Random-Tessellation Stratified (GRTS) survey design for site generation (Stevens & Olsen, 2004). Within the GRTS site generation, different weights are applied based on subpopulations of interest. Specific to the river and stream component, the design incorporates weights prioritizing stream size and location. This ensures that the master sample site list will reflect the proportional presence of specified stream orders and that the sites will be distributed across the state. The Strahler order of a stream reflects its size and position within a channel network. Streams in the 1^{st} order are unbranched tributaries, whereas higher-order streams begin wherever two equal order streams join. The smallest headwater tributaries are 1^{st} order, the largest are 12^{th} order. The 8^{th} river order designation is the largest observed in South Carolina, according to the hydrological network that SCDHEC references. The smallest 1^{St}-3^{rd} stream orders account for approximately 80% of stream length in the world (Mojes & Bhole, 2015). This dominance of the smaller orders is also observed in South Carolina.

The initial selection of prospective probability survey sites is conducted by the SCDHEC Surface Water Monitoring Section using tools developed in cooperation with the U.S. Environmental Protection Agency (EPA), National Health and Environmental Effects Research Laboratory (NHEERL) (SCDHEC, 2014). Each hydrological population of interest, such as the streams and rivers or the estuaries, has its own particular survey design. A computer program is used to generate possible random survey sites, accounting for the state-wide distribution of the resource.

The basic starting hydrographic Geographic Information Systems (GIS) coverage for stream and river site selection in South Carolina is the Reach File Version 3.0 (RF3), a product of EPA NHEERL (Horn et al., 1994). The RF3 is a predecessor to the National Hydrography Dataset (NHD), the NHD being a combined product between the U.S Geological Survey (USGS) Digital Line Graphs (DLGs) and the EPA RF3. DLGs are the digitized form of hydrological lines from USGS quadrant maps that provided cartographic spatial accuracy, such as physical relation to other streams and waterbodies. The RF3 provided attribute characteristics, such as stream order (USGS-1). The first version of NHD was available in 2001 at the medium resolution, or 1:100,000 scale. However, there were some inconsistencies present in the NHD network coverage due to errors in the scanning of quadrant maps for the RF3. For example, a region of the network in upstate South Carolina had sparse stream density in comparison to the rest of the state, a reflection of missing quadrant map data rather than a lack of actual stream density. This under-represented region in the network would have impacted the determination of stream order, resulting in inaccurate estimations of order proportions. A more updated version of the national network in the form of NHDPlus (NHDP), available in 2006, had several improvements; however the 1:100,000 scale network coverage of South Carolina still had the low density in the upstate (Figure 1.1). SCDHEC has utilized the 1:100,000 RF3 network provided by EPA NHEERL since before the release of the first NHD, when the EPA staff filled in the missing region of stream density in the state.[1] EPA does not specifically maintain or update the South Carolina network, however SCDHEC has made modifications to the network over time to improve its utility. Lakes, reservoirs, and estuaries have been removed from the hydrological network to improve the accuracy of the sample frame (Figure 1.2). The NHDP update included several improvements, including the identification of sinks (noncontributing network segments) and the development of the Strahler Order/Strahler Calculator algorithm (USGS-1). This tool significantly improved the accurate drawing of stream order, of particular importance in complex drainage systems.

A feature of interest in the NHD/NHDP is the Fcode, a descriptive code that identifies the stream flow attribute (USGS-2). Stream-flow attributes such as perennial (year-round flow) or intermittent (inconsistent flow) status were based on USGS data. The SCDHEC RF3 (henceforth referred to as Modified) network did not have this particular attribute information, and so all streams in the Modified network are considered perennial for the probability survey and are included in the sample frame.

1.2 MONITORING PROGRAM OF INTEREST

The area of interest is the digital hydrological network for South Carolina's streams and rivers. The survey method being assessed is the GRTS spatially balanced survey design. A master list of sites is generated in order to represent the statewide water quality and provide enough sites to account for several years of monitoring and to adjust

[1] Based on personal communication with Thomas Dewald with USEPA HQ, Tony Olsen with USEPA Corvalis, and SCDHEC staff.

for anticipated cases of site rejection. Every few years the master list is redrawn to refresh the selection options and take into account any updates. There have been four such 'Draws' since the monitoring program began; Draw 1 (2001), Draw 2 (2002-2005), Draw 3 (2006-2010), and the most recent and current Draw 4 (data referenced is from 2011-2016). Of the hundreds of sites generated per Draw, approximately 30 sites are visited monthly for 1 year by SCDHEC staff to represent water quality in the state. The basic goal is to collect monthly samples of each site for the year, though this number may vary. Each year, 30 new sites are chosen in order to represent the statewide spatial spectrum (SCDHEC, 2015). The sites are visited on an individual basis to determine their suitability as a sample point. Sites may be rejected for a variety of reasons; poor or no access, inaccuracies between maps and reality, or a site was identified as not belonging in the target population. Sites are evaluated on a case-by-case basis, with a systematic assessment of each one until 30 have been selected.

The 30 sites are divided into 3 subpopulations from which the site-generation weight is based. The subpopulations for the first 3 Draws were 1^{st} order, 2^{nd} order, and 3^{rd} order or greater. Each subpopulation had target goals of 10 sites. SCDHEC adjusted the subpopulation definitions for the most recent Draw to 1^{st} order, 2^{nd} or 3^{rd} order, and 4^{th} order or greater. The target goals were modified to 8 in the first subpopulation, 10 in the second, and 12 in the third. This adjustment was based on several considerations. There is greater public usage of larger rivers for contact recreation and drinking water, therefore the number of desired sites was increased for this group of stream orders. It was also assumed that combining 2^{nd} and 3^{rd} order streams would provide the same information. While the potential site generation is adjusted for spatial distribution and target goals, how well this is maintained depends on the physical reality corresponding with the generation assumptions. The systematic reconnaissance of the sites means that if a 1st order stream is assessed as unsuitable for inclusion, it is not necessarily replaced with another 1st order site. The design does not select any site more than once within a Draw.

The reconnaissance visits confirm a selected site as being of the target population or determine why it is non-target. In addition, these physical evaluations are used to determine if a site can be sampled at the given coordinates or if an alternate location will offer appropriate accessibility. These alternate locations are only used if they still represent the same stream reach and order, environmental surroundings and condition, and are a permissible distance from the original station coordinates. If any of these conditions cannot be met, an entirely new station will be sampled instead.

1.3 LITERATURE REVIEW

A. Source Data

A study that focuses on a hydrological or aquatic resource usually relies on available maps to determine sample sites, or to pre-determine areas that meet the design parameters of the study. Discrepancies between a mapped network and the physical reality may lead to delays in field data collection. Common issues that come from this type of irregularity include a stream being in a different location than mapped, or not being present at all. The size of the stream may be different, giving it characteristics that do not meet the design parameters of the study. Such discrepancies are common to many studies related to aquatic resources, particularly rivers and streams that undergo constant change and are difficult to precisely represent. The issue of mapping irregularity has been given more attention with articles published that focus entirely on the subject, particularly as it relates to fish conservation efforts (Vance-Boreland et al., 2001). These studies suggest that the hydrographic resolution utilized was likely the source of many of the spatial and geographic irregularities encountered in aquatic-resource work.

The higher resolution 1:24,000 scale of NHD available via USGS shows more detail on a map than the medium resolution 1:100,000 scale, and has been shown to have a greater accuracy at identifying stream lengths in a given area. When comparing the accuracy of hydrographic resolution scales in an Oregon watershed, the 1:24,000 scale was shown to have a 90% accuracy of mapping streams within 12 meters of their actual location while the 1:100,000 was accurate within 50 meters (Vance-Boreland et al., 2001). The same study found that 78% of the streams in its study area were identified as perennial (year-round flow) by the 1:100,000 scale, compared to the 90% perennial classified by the 1:24,000. This indicates that that there may be a larger error of omission for the 1:100,000 scale.

The 1:24,000 scale creates a more thorough image of the stream density in a particular area, picking up stream lengths previously unrepresented on the 1:100,000 scale map. A study located in the Chattooga watershed of South Carolina referred to this variance as the degree to which the resolution can define the stream network (Hansen, 2001). The 1:100,000 can identify 1/7th of a network while the 1:24,000 can identify 1/5th of the network, or 14% vs. 20%. With a goal of assessing a subsample of the full sample frame, greater network identification is always preferable. With a greater stream density representation in the 1:24,000, this indicates that there would be a need to reclassify stream order in a region (Vance-Boreland et al., 2001). However, even with the greater representation in the larger scale resolution, perennial streams were still under-identified in the study. With this in mind, active field reconnaissance and physical assessment will continue to be an integral part of studies seeking to assess stream network density and sizes of stream reaches (Hansen, 2001).

B. Survey Design

A GRTS spatially-balanced survey design, also referred to as random, statistical, or probability, survey is an established and effective tool for characterizing a sample population when a full census is not feasible (Larsen et al., 2007). This is especially true when a spatial component is incorporated into the survey design. A design that has been balanced as such can reliably represent the characteristics of the population being sampled. In the case of a hydrological survey, it can represent the condition of a stream network.

The 2007 Larsen et al. study discusses the purpose, design and implementation of a 'master sample'. Such a sample is larger than necessary for a single survey, allowing for oversampling. When site rejection is expected, an oversample provides a 'buffer' so that the ideal sample number can be preserved. The desired number of samples can be maintained even with rejections, as suitable replacement sites may be drawn from the oversample pool; assuming project protocol permits this action. The Larsen et al. study noted that when utilizing the oversample method, replacement sites must be used as they appear in the master sample. This is emphasized to preserve the spatial balance of the random survey design.

A study conducted in the mid-Atlantic region assessing the quality of wadeable streams found that of their pre-determined target stream population, 20% were not sampled (Herlihy et. al., 2000). The study found that half of that percentage was due to sample site characteristics not meeting the criteria of the target population, such as being intermittent, not being present, or not being wadeable. The other half of rejections were due to a lack of site access, primarily due to landowners denying permission requests. These issues are still prevalent today, and have an impact on the ability of monitoring programs to assess the total population. While it is not expected for a survey to assess every site within a hydrological population**,** it is assumed that every site had equal chance of being included in the subsample utilized to represent the whole population. When this assumption is violated, there is a possibility for representation to be inaccurate.

1.4 PURPOSE AND HYPOTHESES

There were two components to this study. The first assessed the reasons for a site to be rejected from the probability survey on a state-wide analysis, how often those specific rejections occurred, and what stream orders they were occurring in. This component also compared the network definition for two river basins, and four 12-digit Hydrologic Unit Codes (HUCs), referred to as subwatersheds. The networks compared were the Modified network utilized by SCDHEC, and the USGS NHDPlus Version 2 network (NHDP). It was anticipated that most rejections would occur in the 1^{st}-3^{rd} order streams, and that they would also most frequently be rejected for non-target reasons such as intermittency.

The second component assessed the role of landcover and land use in the accessibility of a site. This assessment occurred at a state-wide scale for the sampled and rejected sites of the 16-year dataset, and at the subwatershed scale for the representative network studies. It is anticipated that sites with agricultural or rural profiles will be less accessible and rejected with greater frequency than sites located in developed or urban areas due to the greater availability and frequency of public access points such as bridge crossings or boat launches.

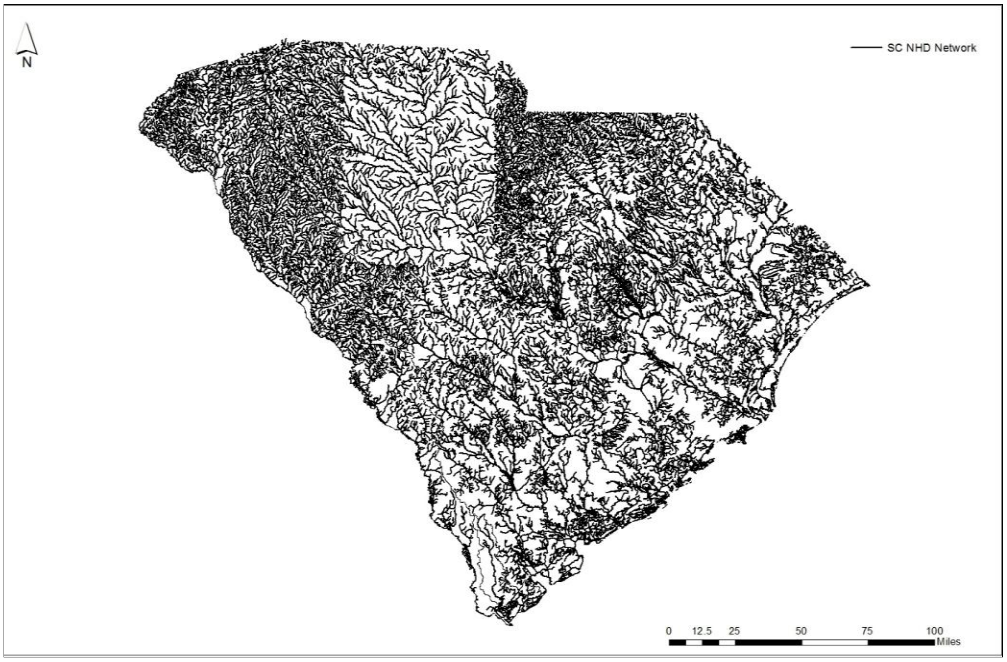


Figure 1.1. The medium resolution NHDP Flowline coverage of South Carolina, with the upstate region of sparse stream density.

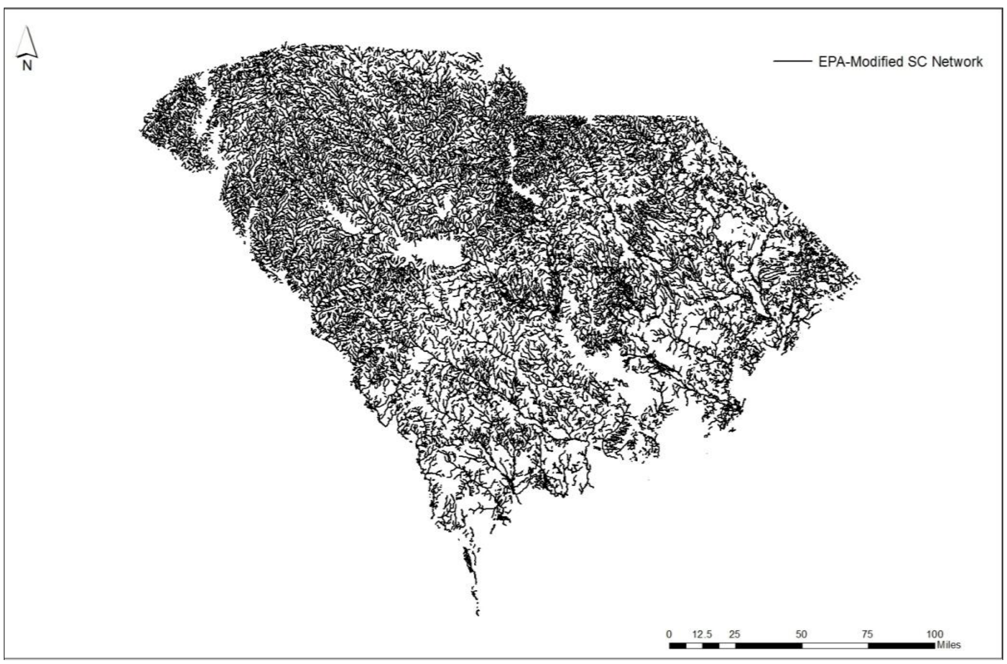


Figure 1.2. The hydrological network utilized by SCDHEC, modified by EPA to fill in the low-density region in the original RF3 network coverage.

CHAPTER II A COMPARISON OF TWO DIGITAL HYDROLOGICAL NETWORKS IN SOUTH CAROLINA

2.1 INTRODUCTION

This chapter will address the similarities and differences between two digital hydrological networks characterizing the stream and river system of South Carolina. These networks are the National Hydrographic Dataset Plus, a USGS product that provides national coverage, and the Modified network, which is specific to South Carolina. The 'Modified' digital hydrological network utilized by SCDHEC is referred to as such for several reasons. The creation of the network was a specific request from SCDHEC, which was actively developing a state-wide random survey for their water quality monitoring program, to the EPA. Staff at EPA added in the missing density from the RF3 data to provide a useable 1:100k scale hydrological network to SCDHEC. The RF3 had the data the state agency was particularly interested in, that of Strahler stream order information. The RF3 was also referenced for the creation of the first NHD, however this special project network was not incorporated into the official RF3 dataset. The NHD, which was still in development, ultimately referenced the original RF3 with the stream density disparity. Thus the NHD displayed the same error. Created as a specific request, the RF3 network is not specifically maintained or updated by EPA. SCDHEC has made improvements to it over time, such as removing coastal streams that were characterized by brackish or salt water. They have also corrected some ordering issues, such as when the algorithm determining stream order misidentified subchannels for new tributaries. Some of these algorithm-based miscalculations remain in the network as artifacts of a pre-NHD network.

The purpose of these comparisons was to assess site rejection and compare network definition of South Carolina at different regional scales. A feature of interest in the NHDP network is the Fcode, which characterizes the type of stream flow. Three Fcode classifications of particular relevance in this study are the perennial, intermittent, and artificial path attributes. Perennial streams have year-round flow, and are what the probability survey in South Carolina is intended to survey; all streams and rivers in the Modified network are assumed to be perennial. Intermittent streams have inconsistent flow, and are not intended to be sampled. Artificial paths are used in the NHDP to maintain network connectivity through waterbodies like lakes, wide streams or double-banked streams, such as a swamp. Because of this range of utility, they can sometimes represent both non-target and target waterbodies.

The analyses discussed in this chapter assessed the influence of these Fcode stream flow attributes in the definition of the NHDP network, and how they compared with the Modified network that is assumed to be perennial. The analyses were done with the intent of assessing the benefits and drawbacks of the Modified and NHDP networks, and to assess if changing to the NHDP network would provide improvements for the monitoring strategy. The comparisons between the networks should be taken in context, as the study involved descriptive assessments rather that tests of statistical significance.

An element also incorporated into the network comparison was the variety of ecoregions present in South Carolina. The Fall Line is a geomorphological boundary between the Piedmont and Coastal Plain that marks where an ancient coastline was once located. The Piedmont is at a higher elevation, with more defined hills and ridges and narrow floodplains. As the Coastal Plain was once covered by ocean, it is a much flatter region (Cooke, 1936). Rivers move slowly through soil of sand and clay, becoming more interconnected as they move towards the coastline. The difference in topography between the two regions reflects the kind of environment that may be more likely to be associated with intermittent streams (Figure 2.1). The remainder of this chapter will address the methods used to assess the trends in site rejections from the probability survey at the state-wide scale and subwatershed scale, and the differences between the two digital hydrological networks at the river basin and subwatershed scale. The results are presented with some discussion, but are revisited with greater attention in Chapter IV.

2.2 METHODOLOGY

A. State-Scale Analysis

This component was a summary analysis of the state-wide stream and river monitoring program, working with the SCDHEC river and stream probability survey database from the past 16 years (2001-2016). The database parameters include characteristics of all sites, sampled and rejected. It includes data on the location and order of the stream, and details of any rejection. This summary analysis determined the frequency of records for different types of rejection, as well as the frequency that each stream order is affected. Stream subpopulation representation in both sampled and rejected populations were assessed. Results were normalized for comparison between Draws; each Draw represents a separate generation of potential sites representing the state-wide population of streams and rivers, generally covering a period of several years of annual monitoring. These summary percentages were calculated primarily via Microsoft Access.

B. River Basin Analysis

The river basin scale of analysis assessed the commonalities and differences between the NHDP network and the Modified network for two river basins; the Savannah river basin and the Pee Dee river basin (Figure 2.2). The river basins selected were outside the low-density region of the NHDP network, to avoid the influence from the stream density disparity. Two GIS layers were created for each river basin; one layer defined the network according to NHDP, the other according to the Modified network. The Modified network attribute data units of measurement for stream lengths are miles; the NHDP corresponding field was thus converted from kilometers to miles for comparison purposes. The proportion of stream orders in the two basins was determined in each network, excluding orders ranked as 0. The proportion of the Fcode stream flow attribute was also determined for the NHDP network (Table 2.1) (USGS-2). The Fcode attribute for the coastline was excluded.

In preparation for the most recent Draw period which started in 2011, SCDHEC removed streams with brackish or saltwater classification from the Modified network sample frame, and additional streams based on individual assessment in GIS. The survey design is intended to represent only freshwater streams, as coastal streams with brackish/saltwater have different characteristics, usage, and are regulated differently. To replicate this stream removal, all stream reaches located in a tidal and open water layer were removed from the NHDP sample frame. This did not remove as much of the sample frame as was removed from the Modified network, resulting in the NHDP covering a slightly larger area than the Modified network for the river basin comparisons. Each table with all relevant network information for the river basins was imported into an Access Database for analysis.

As the Modified network does not differentiate stream-flow attributes, all streams in the layer are assumed to be perennial. Determining rates of NHDP Fcode identification was anticipated to indicate to some degree how the Modified network overestimated the perennial network for the state. Such an assessment would provide an indication rather than an absolute comparison between the networks due to differences in network characterization, such as the mentioned variation in non-target brackish/saltwater stream removal.

Also at the river basin scale, an analysis was conducted to assess the accuracy of the NHDP network Fcode stream-flow attribute. The 2001-2016 historical data of rejected sites after SCDHEC reconnaissance was referenced for the selected river basins. Sites rejected as intermittent were overlaid on the NHDP network in GIS according to each basin. The rejected sites were assigned the Fcode flow attribute of the stream reach they fell on or were nearest to, and then individually verified to have the attribute of the correct stream (the sites having originally been based on the Modified network). Summary percentages were determined in Microsoft Access.

C. Subwatershed Analysis

There are six levels of categorization used by USGS to define hydrological units, the 2-digit scale being the largest and 12-digit the smallest. The levels are referred to as either region, subregion, basin, subbasin, watershed, or subwatershed (USGS-1). They are typically bounded according to drainage basin, but there are exceptions. The 12-digit

HUCs referenced for this analysis are primarily referred to as networks or subwatersheds. If referred to as a subwatershed, it is with the understanding that they may not be fully contained drainage basins.

These units are not bound by state perimeters, and peripheral units in South Carolina are located in up to three states. There are 874 units fully contained in South Carolina, and only these were considered for this assessment. The attribute data for all such units were imported into an Access database. The units were screened for certain requirements; they had to include all three stream subpopulations (according to the most recent Draw), and the ratio of those populations had to be within 9% of the state ratio for that particular subpopulation. The percentage ratio of stream subpopulations had previously been determined for the full state; approximately 62% of the Modified network is 1^{st} order, 27% is defined by $2^{nd}/3^{rd}$ order streams, and 11% is fourth or greater order rivers. Of the 874 HUCs, there were 62 that met these specifications.

This modified list was then imported back into the GIS, where a spatial zoning analysis identified those units with a majority Urban profile; a dominant National Land-Cover Database 2011 (NLCD) categorization of Developed. Landcover is categorized numerically in NLCD, with a classification as 11 associated with open water, 21-24 associated with varying degrees of development, and so on (Table 2.2). There were four subwatersheds from the target list with a majority area classed as having developed/urban landcover, and two were selected that were considered to best represent different ecoregions in the state and that contained relatively complete drainage systems. The units were intentionally chosen to represent an environment in the Piedmont, located above the Fall Line, and one below the Fall Line in the Coastal Plain. As discussed in the introduction of the chapter, the Piedmont and Coastal Plain vary in their geological and topographic characteristics, which may influence stream behavior. By intentionally selecting study sites located in these distinct ecoregions, the study could incorporate this physical variable in assessing the results. A query of the target subwatersheds with a majority landcover of forested or agricultural (collectively considered rural) units yielded a larger selection of 34 forested and 7 agricultural. The two rural units were selected based on their proximity to the majority urban units, with the intent of representing the same geographic and ecoregion characteristics while assessing stream accessibility and network variability.

The rural subwatershed selected above the Fall Line was the Middle Coneross Creek in Oconee County, and the selected urban subwatershed was Brushy Creek-Enoree River in Greenville County. Below the Fall Line, the urban selection was Green Swamp in Sumter County. The rural selection was Lower Little Lynches River in Kershaw County (Figure 2.2).

These subwatersheds were treated as independent sample frames when loaded into the program used by SCDHEC to generate random sites with assigned weights. Only the streams and rivers located in their associated subwatershed were included in that particular sample frame, as the generated sites were intended to represent that specific area. For these individual frames, a target of 12 sampled sites was determined to provide a thorough profile of the subwatershed. An additional 12 sites would be reviewed as oversample options. The review of all 24 sites would provide an in-depth examination of accessibility and stream flow characteristics. The ratio of the first 12 sites in each subpopulation was 3, 4, and 5, which is a close proportion of the true ratio used in the whole state (8, 10, and 12 sites for 1st, 2nd/3rd and 4th+, respectively). The sites 13-24 as oversample followed this ratio approximately, but were not always generated with the same number of sites per subpopulation as the original panel (Table 2.3). The four subwatersheds were visited and assessed using the same site reconnaissance procedure employed by SCDHEC staff for their official visits. All 24 sites for each unit were evaluated for how well they matched the Modified network profile, and if relocation was necessary, how many sites were accessible for sampling and that represented the appropriate reach.

The procedure used to compare the two network definitions of the subwatersheds was the same as used for the river basin comparison in Section B. The two networks (Modified and NHDP) were clipped to the target subwatersheds, with two separate GIS layers for each one. The proportion of stream-order subpopulations in the subwatersheds was assessed according to each major network to determine how they matched or differed in defining the subwatershed stream system. In addition, the proportion of different Fcode stream-flow attributes in the subwatershed were determined according to the NHDP network coverage. As the random water quality survey is intended to assess only perennial streams, the inclusion of intermittent streams is a source of error in the sample frame. This stream-flow status is an attribute available for the NHDP database, and the proportion of Fcode attributes in the subwatershed was queried and calculated in an Access database. Each order was considered individually in order to avoid the potential for overlooking apparent attribute trends specific to only one order that might regularly be grouped with several others.

2.3 RESULTS

A. State-wide Analysis of Rejection Trends

The complete list of rejection reasons identified in the 2001-2016 dataset is described in Table 2.4. While percentages varied across Draws, there were two rejection types that occurred regularly. Intermittent streams and sites with no acceptable access were consistently the leading reasons for rejection. No acceptable access classification represents the most significant number of target population sites that could not be sampled, with a range between 26% and 65% of rejections in the four Draws. There was a range of rejections considered non-target sites which was never less than 25% of rejections in each Draw, and often considerably more (Tables 2.5-2.8).

Intermittent classification was the most frequent assessment for non-target sites, with a range between 12% and 41% of rejections in a Draw. This rejection was often concentrated in the 1st order streams. While the population of interest is perennial streams, the site selection procedure does not distinguish between perennial and intermittent streams from the Modified network. The number of rejected sites due to non-target status, in particular due to intermittent status, is attributed to this characteristic of the sample-frame. It should be noted that sites characterized as having no acceptable access are assumed to be target sites, though this can only be confirmed with reconnaissance. It is likely that a proportion of inaccessible sites are in fact non-target stream reaches, which could potentially alter their overall impact on the sample-frame-particularly those of unconfirmed intermittent status.

There are three major subpopulations that are sampled for the state-wide survey, and thus several stream orders are grouped together when potential sites are generated. If a rejection reason was found to be frequent in a subpopulation but was mainly occurring in only one stream order, this specificity could be overlooked by the order's inclusion in the broader subpopulation. For this reason, the analyses considered each order individually.

The most consistently affected stream orders by site rejection were 1st and 2nd stream orders, cumulatively accounting for 60-80% of rejections across all Draws. While the 1st order streams account for the largest proportion of stream miles in the state, the survey is not proportionally weighed towards them. The current survey draw targets 8 sites in the 1st order subpopulation and 12 sites in the 4th or greater subpopulation. This means that each site for the 1st order subpopulation represents a significantly greater number of miles than a site in the 4th or greater subpopulation. The monitoring strategy focuses on the larger rivers due to their greater usage by the public for recreational activities, as well as commercial and drinking water importance. The smaller tributaries-specifically the 1st order, are the most likely ones to be non-target intermittent streams included in the sample-frame. These headwater tributaries are typically small and slow-moving, and are not the typical waterway utilized for recreational activity. Established access is minimal if existent at all, increasing the chance of accessibility issues in these small streams. While fewer sites are targeted for the largest stream population, this also means that the water quality condition of the sites that are sampled carries greater weight in the final assessment of state-wide water quality conditions.

Public access is important for a site to be considered suitable for sampling, such as a boat-ramp or bridge-crossing. Obtaining permission from private landowners for SCDHEC staff to access a site on their property is impractical on several levels, including the difficulty in arranging specifically scheduled monthly visits and the frequency with which such requests are denied. However, there are situations in which staff on reconnaissance may still consult with the property owner; if they have reason to believe the property owner may allow them to visit and sample on SCDHEC staff's own schedule, or if they determine that the site is particularly desirable as a sample point.

When staff members are out on sampling trips, they are often visiting multiple sites in one day. There are also time-sensitive holding restrictions in place to ensure the viability of the samples. Given the limited timeframe to travel to and from several sites and the lab or office while accounting for these sample-holding restrictions, the necessity for efficiently accessible sites is evident, and for the flexibility to visit them as best fits SCDHEC staff schedule.

Table 2.9a shows how each target subpopulation was represented in each Draw. The first three Draws had an equal target percentage for the subpopulations, an approximate 33% (10 sites in each subpopulation). As mentioned previously, Draw 4 had a change in target percentages; the 1st order subpopulation target was approximately 27% (8 sites), 33% in the 2nd/3rd subpopulation (10 sites), and 40% in the 4th+ population (12 sites). Due to the high percentage of intermittent reaches misidentified as target 1st order streams, reducing the number of target goals for this order was not expected to adversely affect the order representation. Even with the target goal adjustments, the trend of subpopulation inclusion is consistent across Draws. The 1st order subpopulation is consistently under-target while the remaining subpopulations are over-represented.

The target goals are not set quotas, and therefore the actual percentage of order representation does vary. As previously mentioned, the review of suitable sites is systematic and does not necessarily replace sites with others of the same size. Spatial distribution is prioritized over order target goals. The under-representation of 1st order streams is attributed to the frequency that such sites are rejected. These summary analyses show that throughout the dataset, approximately half of site reconnaissance visits consistently resulted in rejected sites across Draws (Table 2.9b). There was some reduction in site rejections for the 2011-2016 Draw, which notably removed the brackish or saltwater streams from the sample frame.

B. River Basin Analysis

1. Pee Dee River Basin

The NHDP network identified 8477 miles in the Pee Dee river basin; the Modified network identified 7972 miles (Table 2.9). The NHDP network will typically show a slightly higher stream mileage due to the artificial paths that maintain connectivity through anastomosing channels and other complex systems (Figure 2.3). Anastomosing refers to the semi-permanent, interlocking channels of a complex river system typical in the Coastal Plain of South Carolina. Often referred to by the more common term 'braided', there are key differences in the terminology. A braided network undergoes much more frequent shifting of channel definition, with unstable banks. An anastomosing network is characterized by greater stability, and is a more accurate representation of the intricate, interconnected subchannels in South Carolina river networks.

Artificial paths are one of the stream-flow types identified by the Fcode attribute. Those that were providing connectivity through lakes and ponds were removed from the NHDP network in order to replicate the proper sample frame (Figure 2.4). The artificial paths that remain after this specification are assumed to be providing connectivity through target streams and river systems. The 1:100k Modified network has had lakes and ponds removed; SCDHEC has also taken steps to remove streams with saltwater-related utility or classification. These streams were removed from the NHDP network based on a tidal stream layer available through SCDHEC, a removal that was not as extensive as the one present in the Modified network; it is expected that some non-target saltwater streams remained in the NHDP sample frame.

According to the NHDP network for the Pee Dee river basin, 52% of 1st order streams and 17% of 2nd order streams are identified as intermittent (Table 2.11). With 1st order streams accounting for 54% of the basin, and 52% of those streams categorized as intermittent, approximately 28% of the basin may be assumed to be non-target intermittent according to NHD based only on the influence of 1st order streams.

The proportion of orders in the basin is comparable between the two networks. Deviations are notable for the higher 6th-8th order rivers; NHDP identified no 8th order rivers and therefore a higher percentage of 7th order river miles, while the Modified network did record 8th order river reaches. When this difference was investigated in GIS, it was found that in the Modified network, a segment of the Great Pee Dee River is categorized as 8th order river, and then becomes a 7th order reach once more after converging with the Little Pee Dee. This is an error likely resulting from the original algorithm that determined stream order for the Modified network. The anastomosing nature of the river system in the Pee Dee basin contains multiple overlapping channels that lose strict definition. At the time this network was digitized in the late 1990s, complex, interweaving subchannels were often read by an algorithm as separate tributaries, and resulted in inaccurate assignment of stream order.

2. Savannah River Basin

The Savannah river basin analysis showed a similar total stream mileage between the two networks after the lake and pond artificial paths were removed (Figure 2.5). The NHDP network assessed 5068 miles for the basin, while the Modified network assessed 4953 miles (Table 2.12). The basin was dominated by 1st order streams, which accounted for approximately 60% of reaches in the network. Of that, 45% were designated as intermittent (Table 2.13). This accounted for an approximate 27% of the basin being intermittent according to NHDP.

As with the Pee Dee basin, the NHDP network for the Savannah basin assessed no 8th order rivers while the Modified network did. The 8th order river miles only contributed 1.05% to the overall Modified network basin, and followed a similar pattern as previously noted by returning to an order of lesser rank. Because the Savannah River serves as the border between South Carolina and Georgia, the river lacks complete connectivity in the Modified network. When connectivity is lost, the river reverts to categorization as a lower order. The NHDP network has better connectivity throughout the river, though it too has some interrupted segments due to the state border.

C. Historical Intermittent Sites

1. Pee Dee Basin

There were 46 sites designated as intermittent in the Pee Dee basin in the 2001-2016 time-frame (Figure 2.6). Of these sites, 78% occurred in 1st order streams according the Modified network, making it the most common source of such rejections (Table 2.14). Of the remaining intermittent rejections, 17% occurred in 2nd order streams and 4% in 3rd order streams.

When the intermittent reaches were assigned the Fcode stream-flow attribute information of the NHDP network, approximately 78% of the total rejections occurred in the 1st order subpopulation (Table 2.15). Of these 1st order sites, 32% were identified as perennial streams and 43% were identified as intermittent. Overall, only 50% of SCDHEC sites categorized as intermittent rejections in the Pee Dee basin were identified as intermittent stream reaches by the NHDP network. Deviations occurred in stream-order assignment in the Modified network that SCDHEC utilizes, notably in regions with anastomosing channels. These networks of crisscrossing streams at times lack specific definition and gradually shift over time, and breaks in the digital network are frequent. Referencing a site located in a 4th order river according to NHDP that was 1st order in the Modified network, the location was likely a subchannel of a 4th order complex river system that was misdrawn as a 1st order tributary. Another element of the difference in stream-order drawing is the fact that some broken or non-contributing segments of network that register in the Modified network have been removed from the NHDP network, forcing it to assign the intermittent site the attributes of the nearest stream, which may be of a different order. This analysis error occurred infrequently; only once in the Pee Dee basin.

2. Savannah Basin

There were 18 historical intermittent sites determined by SCDHEC reconnaissance in the Savannah basin for the 16-year time period (Figure 2.7). According to the Modified network definition of the basin, approximately 61% of the rejections occurred in the 1st

order population, 33% in the 2nd order, and 6% in the 6th order (Table 2.16). The site that was identified as intermittent in the 6th order river was located on the fringes of Strom Thurmond Lake, which the Savannah River passes through. The 6th order site was likely generated on a broken segment of the Savannah River where the algorithm attempted to maintain network connectivity, but where the reconnaissance found it to be inaccurate in reality. The NHDP network had no reaches in this area, and assigned the site the order of the closest 1st order stream (the only instance this occurred in the Savannah basin analysis).

According to the NHDP network, 28% of the intermittent rejections in the Savannah basin were identified as intermittent stream reaches, and all of these were 1st order streams (Table 2.17). In total, 67% of intermittent rejections occurred in 1st order streams, and 33% in 2nd order streams. All of the rejections in 2nd order were identified by the NHDP network as perennial reaches.

D. Four Subwatersheds Above and Below the Fall Line

1. Middle Coneross: Rural Subwatershed Above Fall Line

The hydrological networks were similar in definition between the Modified and NHDP for the Middle Coneross subwatershed (Figure 2.8). There were small differences in stream order proportions; in the NHDP network, there was a 6% increase in the proportion of 2nd order streams in the NHDP, a 3% decrease in the proportion of 3rd order streams and a 3% decrease in 4th order rivers (Table 2.18).

According to the stream status described by the Fcode flow attribute in the NHDP database, 49% of 1st order streams were classified as intermittent (Figure 2.9 and Table 2.19). NHDP identified approximately 63% of the unit network as being in the 1st order subpopulation (Table 2.18). As the random stream survey seeks to sample strictly those streams and rivers that have year-round flow, if this ratio were to occur in the Modified network, it would hypothetically indicate that approximately 31% of the network would not belong in the sample frame.

2. Brushy Creek: Urban Subwatershed Above Fall Line

The network definitions were similar between the NHDP and Modified for the Brushy Creek subwatershed (Figure 2.10, Table 2.20). It is acknowledged that the NHDP may record greater network mileage in all units to some degree due to the artificial paths that maintain connectivity through complex drainages and water bodies such as swamps. There were no intermittent streams identified for Brushy Creek according to the NHDP, with the majority of the network designated as perennial waters (Figure 2.11, Table 2.21). The only other stream attribute present in the network was the designation of artificial path.

3. Lower Little Lynches: Rural Subwatershed Below Fall Line

The results for the Lower Little Lynches network comparison were of particular interest given the apparent differences between the network definitions (Figure 2.12). While the overall mileage was similar, the Modified network identified 62% of the streams as being in the 1st order, while the NHDP identified only 49% as such (Table 2.22). The Modified Network categorized 6% of the Lower Little Lynches hydrological system as being in the 4th order, while the NHDP identified 32% of the system as 4th order. The NHDP omitted a segment of the network that exists according to the Modified network, and also had a significant difference in the stream ordering. When the GIS assessment of the network was considered with site reconnaissance, it was determined that the NHDP was the more accurate definition of the region. The variation in network definition was caused by a connectivity issue which had resulted in a break in a 4th order stretch of river, and altered the assignment of order (Figure 2.13). As previously mentioned, an artifact present in the Modified network is the occasional miss-ordering of broken or anastomosing network segments.

In addition, the removal of the NHDP segment was determined to be an accurate removal after reconnaissance visits on these stream reaches identified the sites as long-term dry beds; referred to as 'no stream' rejections. Even with the removal of the dry streams, the NHDP still identified approximately 33% of the unit as being intermittent, based on the 68% of 1st order streams categorized as intermittent (Table 2.23), and which account for 49% of the unit network. The NHDP network also displayed a stream reach not present in the Modified network. This segment, identified as an artificial path, follows the bank of a stream reach, in effect duplicating the stream mileage for this section. The presence of the artificial path in this scenario appears to be providing connection between a side-channel system and the main stem of the Lower Little Lynches network.

4. Green Swamp: Urban Subwatershed Below Fall Line

The Modified and NHDP networks for the Green Swamp subwatershed were similar, with differences in the order proportion of stream-order lengths attributed to a variation in stream connectivity (Figure 2.14, Table 2.24). The NHDP appears to have better stream system coverage where the Modified network is shown to be absent, but NHDP also maintains connectivity through waterbodies that are accurately removed from the Modified network (Figure 2.15). A notable 91% of 1st order streams in Green Swamp were identified as intermittent according to NHDP (Table 2.25). As 1st order streams account for 54% of the unit network, this would indicate that approximately 49% of the sample frame was non-target intermittent.

2.4 CONCLUSIONS

The analysis of site reconnaissance records from 2001-2016 showed that sites were most frequently rejected due to a lack of an accessible location to sample, or the site was identified as being on a non-target, intermittent stream. In addition, 1^{st} order streams were the most frequently impacted by these reasons for site rejection, though inaccessibility occurred across all stream-orders. Due to the prevalence of sites rejected from 1^{st} order streams, and that they are not necessarily replaced with sites of the same order, the 1^{st} order subpopulation was consistently under-represented across Draws during the 16-year timeframe assessed.

The two digital hydrological networks both reference EPA reach files, so their spatial description of the stream and river systems in South Carolina is extremely similar (with the exception of the region of sparse density in the upstate). A difference in spatial definition that does exist is the connectivity of the network; gaps are present in the Modified network, as demonstrated by the subwatershed comparisons, which remain connected in the NHDP network. The networks also differ in the proportional presence of each stream order in the study areas. The Modified network typically had a greater proportion of 1^{st} order streams in the river basins than the NHDP. The Modified network also described 8^{th} order rivers in both river basins, while the NHDP identified 7^{th} order rivers as the largest. While the 1^{st} order streams are the largest proportion of streams in the state, the Modified network may overestimate the actual stream-mileage; this is due in part to the algorithm error artifact that occurs in areas of increasingly interconnected channels, where interruption in the digital network connectivity results in the order assignment starting as if from the beginning. The Lower Little Lynches River network at the subwatershed regional scale is an example of this issue. The proportional presence of the stream orders varies considerably between the Modified and NHDP network definitions, particularly between the 1st order stream and 4th order river. One factor contributing to this difference was a break in the digital network coverage of a fourth order river, which then reverted to categorization as lower order streams.

The assessment of sites that had been historically rejected by SCDHEC reconnaissance visits as intermittent showed that the NHDP network did not necessarily characterize the rejected streams in a similar way. Only 50% of rejected sites in the Pee Dee river basin were characterized as intermittent by the NHDP, and approximately 30% of rejected sites in the Savannah river basin. So while the NHDP has the potential to remove a proportion of the sample-frame that is non-target due to the stream-flow attribute that identifies intermittent streams, it is not assumed to remove all non-target streams. Site reconnaissance is a critical tool in a monitoring strategy that can confirm if reality matches mapped expectations, as many factors can influence this correspondence.

The results suggest that there could be potential benefits from referencing a NHDP network for the probability survey (after the disparity in stream density coverage has been addressed). Because of the prevalence of intermittent rejections influencing the rejection of sites on 1st order streams, it is expected that the ability to exclude streams with the Fcode identifier for intermittency would be particularly useful. Even with the knowledge that not all non-target streams may be removed due to some inaccuracies between maps and reality, it would still have the potential to remove a notable segment of non-target streams from the sample frame.

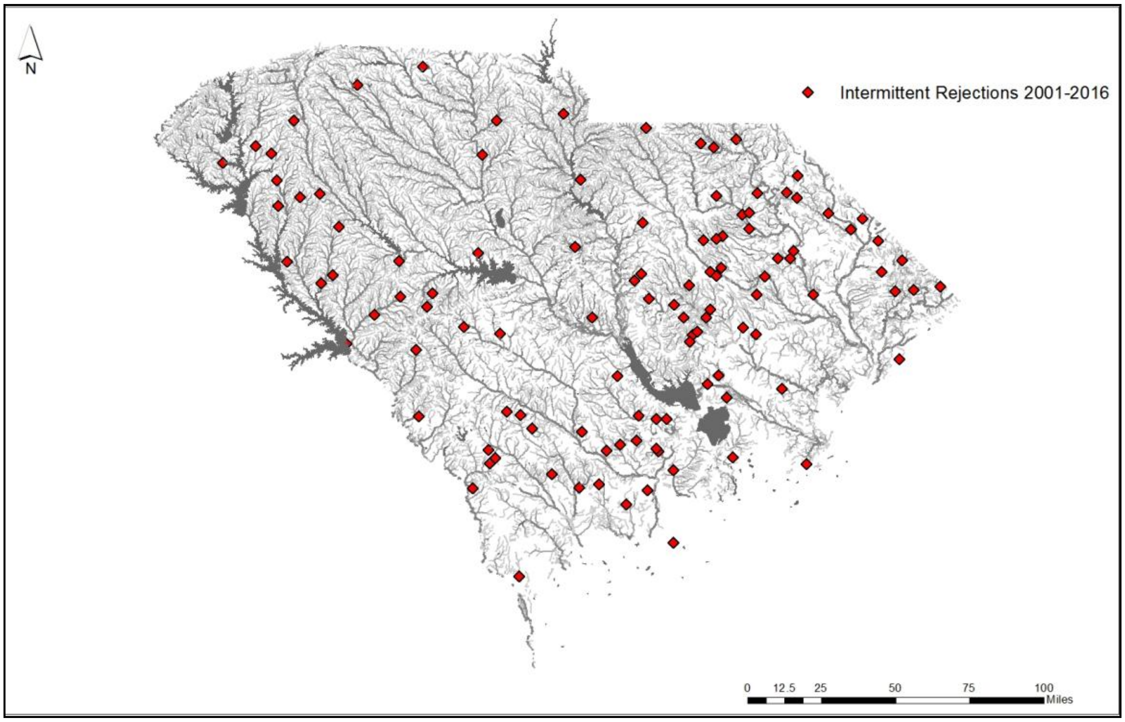


Figure 2.1 All sites identified as intermittent from 2001-2016 draws.

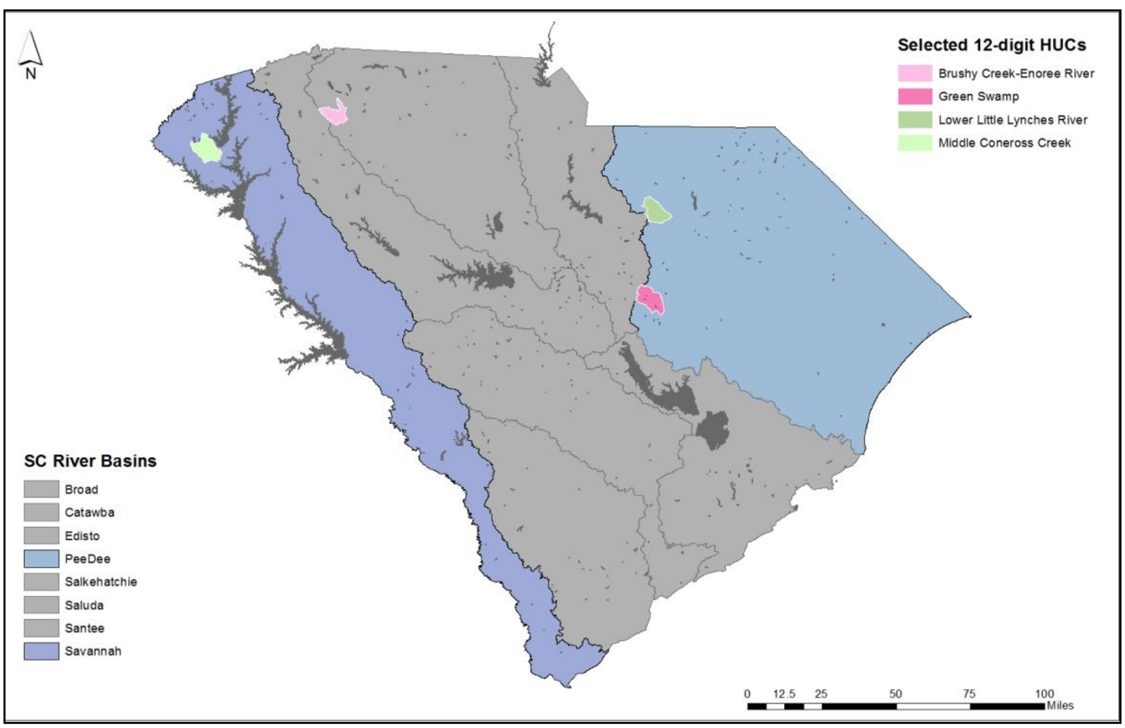


Figure 2.2. The two selected river basins, Pee Dee and Savannah, and four subwatersheds for the network comparisons; Middle Coneross, Brushy Creek, Lower Little Lynches, and Green Swamp.

Table 2.1. NHDP Fcode stream flow attribute descriptions according to the USGS.

Fcode	Feature Type	Description
56600	Coastline	A line of contact between the open sea and the land, including imaginary lines separating inland water bodies from the open sea.
55800	Artificial Path	An abstraction to facilitate hydrologic modeling through open water bodies to act as a surrogate for lakes and other water bodies.
46006	Perennial	Contains water throughout the year, except for infrequent periods of severe drought.
46003	Intermittent	Contains water for only part of the year, but more than just after rainstorms and at snowmelt.
33600	Canal/Ditch	An artificial open waterway constructed to transport water, to irrigate or drain land, to connect two or more bodies of water, or to serve as a waterway for watercraft.
33400	Connector	A known, but nonspecific, connection between two nonadjacent network segments.

Table 2.2 The landcover classification as described by the National Land Cover Database (NLCD). The summary analyses referenced the 2011 version of the NLCD.

NLCD Value	Label
0	No Data
11	Open Water
21	Developed, Open Space
22	Developed, Low Intensity
23	Developed, Medium Intensity
24	Developed, High Intensity
31	Barren Land
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
52	Scrub/Shrub
71	Grasslands/Herbaceous
81	Pasture/Hay
82	Cultivated Crops
90	Woody Wetlands
95	Emergent Herbaceous Wetland

Table 2.3. Number of sites in each stream subpopulation in the Middle Coneross (MC), Brushy Creek (BC), Lower Little Lynches (LLL), and Green Swamp (GS) subwatersheds as generated by an algorithm utilized by the state in their annual statistical survey.

MC	Panel	Oversample
First	3	4
Second/Third	3	2
Fourth+	6	6
BC	Panel	Oversample
First	4	1
Second/Third	4	7
Fourth+	4	4
LLL	Panel	Oversample
First	3	5
Second/Third	4	3
Fourth+	5	4
GS	Panel	Oversample
First	3	3
Second/Third	5	5
Fourth+	4	4

Table 2.4. Rejection reason with description. Descriptors are not all inclusive, but intended to provide general idea of examples of associated rejection. *Rejected sites that were part of the target population are starred; all other exclusions are non-target.*

Rejection	Description
No Acceptable Access* (AA)	No public access where water quality site located
Impoundment (IM)	Site is now within an impoundment that is not designated by sample frame
Impoundment Outflow (OF)	Site is just beyond impoundment; outflow from impoundment would not reflect normal stream concentration behavior
Intermittent (NP)	Stream is not perennial; intermittent or wet weather ditch
No Stream (NS)	Map irregularity; no stream is present where indicated
Saltwater (SW)	Located in saltwater
Physical Barrier* (PB)	Too dangerous to access
Dry due to Drought* (DD)	Stream that has consistent annual flow but is dry due to drought
Unsampled Site* (OT)	Site was selected for sampling, but was not sampled

Tables 2.5. Contribution of rejection type according to stream order in assessment of overall site exclusion for Draw 2001. (RT is row total, total percent by order. CT is column total, total percent by rejection type.)

2001	*AA %	*PB %	*OT %	*DD %	NP %	NS %	IM %	OF %	SW %	*RT*
First	8.82	--	--	--	35.29	--	2.94	--	8.82	*55.88*
Second	2.94	--	--	--	5.88	--	2.94	--	8.82	*20.59*
Third	5.88	--	--	--	--	--	--	--	--	*5.88*
Fourth	2.94	--	2.94	--	--	--	--	--	2.94	*8.82*
Fifth	--	--	--	--	--	--	2.94	--	--	*2.94*
Sixth	2.94	--	--	--	--	--	--	--	--	*2.94*
Seventh	2.94	--	--	--	--	--	--	--	--	*2.94*
Eighth	--	--	--	--	--	--	--	--	--	*0.00*
CT	*26.47*	*0.00*	*2.94*	*0.00*	*41.18*	*0.00*	*8.82*	*0.00*	*20.59*	***100***

Tables 2.6. Contribution of rejection type according to stream order in assessment of overall site exclusion for Draw 2002-2005. (RT is row total, total percent by order. CT is column total, total percent by rejection type.)

2002-2005	*AA %	*PB %	*OT %	*DD %	NP %	NS %	IM %	OF %	SW %	*RT*
First	13.10	2.07	--	--	20.69	4.83	--	1.38	5.52	*47.59*
Second	9.66	1.38	--	--	4.83	2.76	--	2.07	7.59	*28.28*
Third	4.14	3.45	--	--	0.69	0.69	--	--	4.14	*13.10*
Fourth	2.76	0.69	--	--	--	--	--	--	0.69	*4.14*
Fifth	3.45	--	--	--	--	--	--	--	--	*3.45*
Sixth	0.69	--	--	--	0.69	--	--	--	--	*1.38*
Seventh	0.69	--	--	--	--	--	--	--	0.69	*1.38*
Eighth	0.69	--	--	--	--	--	--	--	--	*0.69*
CT	*35.17*	*7.59*	*0.00*	*0.00*	*26.90*	*8.28*	*0.00*	*3.45*	*18.62*	***100***

Table 2.7. Contribution of rejection type according to stream order in assessment of overall site exclusion for Draw 2006-2010. (RT is row total, total percent by order. CT is column total, total percent by rejection type.)

2006-2010	*AA %	*PB %	*OT %	*DD %	NP %	NS %	IM %	OF %	SW %	*RT*
First	24.42	--	0.58	--	9.88	1.16	0.58	1.74	6.40	*44.77*
Second	19.77	0.58	--	1.16	2.33	0.58	1.16	--	6.40	*31.98*
Third	6.40	--	--	--	--	--	0.58	--	1.16	*8.14*
Fourth	6.40	--	--	--	--	--	0.58	--	1.74	*8.72*
Fifth	3.49	--	--	--	--	--	0.58	--	--	*4.07*
Sixth	--	--	--	--	--	--	0.58	--	--	*0.58*
Seventh	1.74	--	--	--	--	--	0.58	--	0.58	*2.91*
Eighth	--	--	--	--	--	--	--	--	--	*0.00*
CT	*62.21*	*0.58*	*0.58*	*1.16*	*12.21*	*1.74*	*4.65*	*1.74*	*16.28*	***100***

Table 2.8. Contribution of rejection type according to stream order in assessment of overall site exclusion for Draw 2011-2016. (RT is row total, total percent by order. CT is column total, total percent by rejection type.)

2011-2016	*AA %	*PB %	*OT %	*DD %	NP %	NS %	IM %	OF %	SW %	*RT*
First	18.47	--	--	--	17.20	1.91	1.27	1.27	--	*40.13*
Second	14.01	--	--	--	3.82	1.27	--	3.18	--	*22.29*
Third	6.37	0.64	--	--	1.91	--	--	0.64	--	*9.55*
Fourth	10.19	1.27	--	--	--	--	--	--	--	*11.46*
Fifth	5.10	--	--	--	--	--	--	--	0.64	*5.73*
Sixth	2.55	--	--	--	--	--	--	--	--	*2.55*
Seventh	6.37	--	--	--	--	--	--	--	--	*6.37*
Eighth	1.91	--	--	--	--	--	--	--	--	*1.91*
CT	*64.97*	*1.91*	*0.00*	*0.00*	*22.93*	*3.18*	*1.27*	*5.10*	*0.64*	***100***

Table 2.9a. Percentage of stream order subpopulation representation in the overall state survey according to Draw. Italicizes indicate the change in subpopulation definition that occurred in the fourth site generation; Draw 2011-2016.

Stream Order Population	% Representation in Draw 2001	% Representation in Draw 2002-2005	% Representation in Draw 2006-2010	% Representation in Draw 2011-2016
First	13.79	19.17	19.33	13.89
Second (*Second/Third*)	44.83	44.17	42.67	*41.66*
Third+ (*Fourth+*)	41.38	36.67	38	*43.88*

Table 2.9b. Number of sites rejected and sampled according to Draw, and the overall percentage of site reconnaissance visits resulting in rejected categorization.

	Draw 2001	Draw 2002-2005	Draw 2006-2010	Draw 2011-2016
Site Reconnaissance Rejected Site #	34	145	172	159
Site Reconnaissance Sampled Site #	29	120	150	180
Rejection % of Reconnaissance Visits	53.97%	54.72%	53.42%	46.9%

Table 2.10. Stream order proportion in the Pee Dee river basin according to the NHDP (left) and Modified (right) networks.

PD NHDP StreamOrder	NHDP Miles	% of PD Basin	PD DHEC StreamOrder	DHEC Miles	% of PD Basin
First	4630.29	54.33	First	4878.34	61.19
Second	1594.37	25.11	Second	1372.42	17.22
Third	849.46	15.8	Third	700.35	8.79
Fourth	460.74	8.48	Fourth	347.98	4.37
Fifth	436.51	9.07	Fifth	370.48	4.65
Sixth	296.39	5.04	Sixth	148.8	1.87
Seventh	209.58	2.68	Seventh	123.85	1.55
Eighth	--	--	Eighth	29.78	0.37
Total	*8477.34*		*Total*	*7972*	

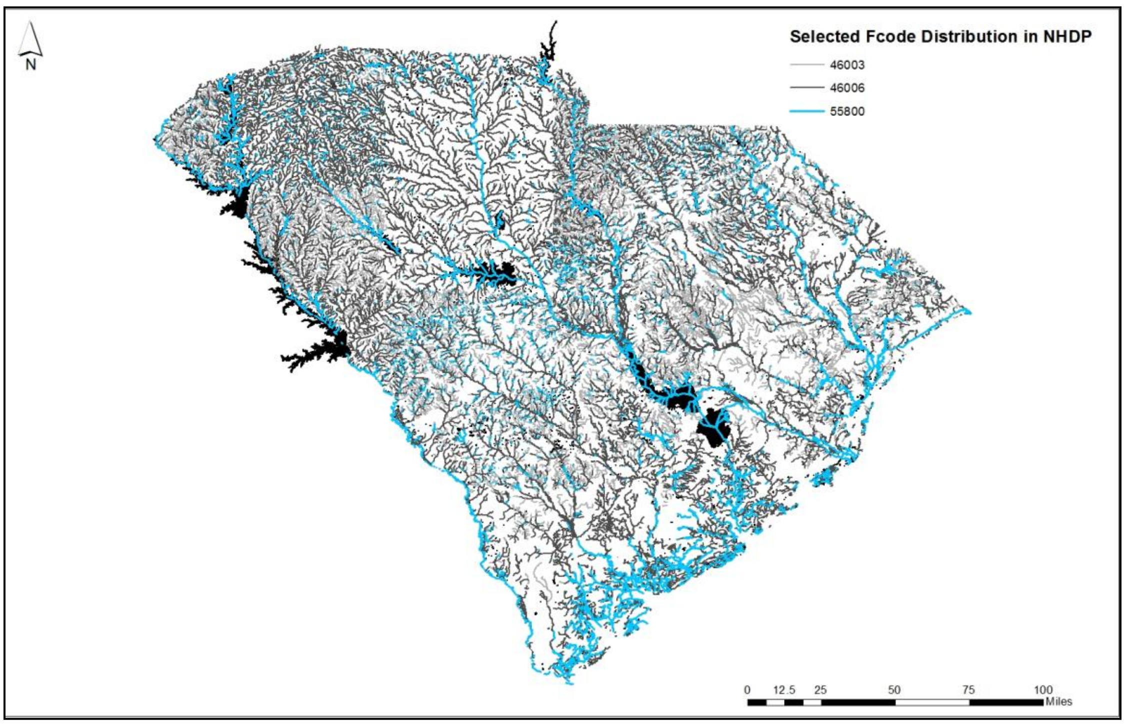


Figure 2.3. Selected Fcode attributes from NHDP network coverage of South Carolina; intermittent (46003; light grey), perennial (46006; dark grey) and artificial path (55800; blue).

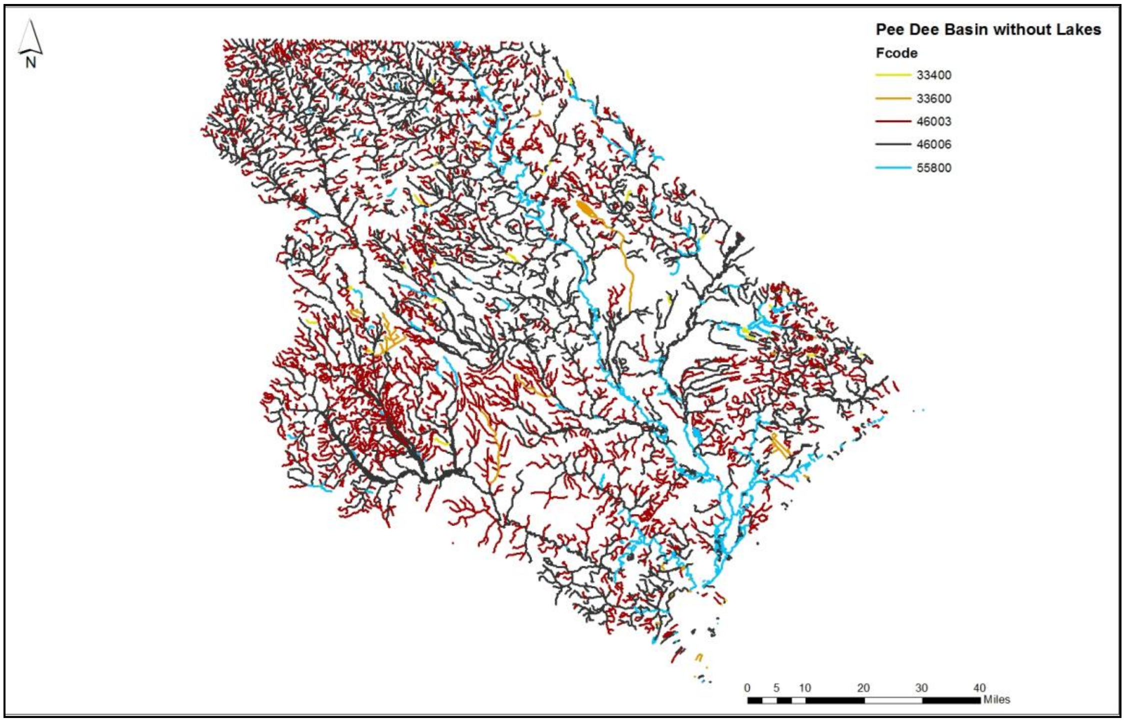


Figure 2.4. Pee Dee River Basin with NHDP network displayed by Fcode attribute; connector (33400, yellow), canal/ditch (33600, orange), intermittent (46003, red), perennial (46006, black), and artificial paths (55800, blue).

Table 2.11. NHDP stream order and attribute proportions represented in Pee Dee river basin. Each stream order is considered independently, with the attribute analyzed for proportion within each order and total stream-miles recorded.

	Connector		*Canal/Ditch*		*Artificial Path*		*Intermittent*		*Perennial*	
PeeDee NHDP	% of Order	Miles in Order	% of Order	Miles in Order	% of Order	Miles in Order	% of Order	Miles in Order	% of Order	Miles in Order
First	1.02	47.23	1.28	59.27	4.44	205.58	51.78	2397.56	41.48	1920.64
Second	1.22	19.45	2.11	33.64	5.3	84.5	17.49	278.85	73.89	1178.08
Third	0.97	8.24	1.94	16.48	6.11	51.9	5.14	43.66	85.84	729.18
Fourth	0.42	1.94	--	--	6.11	28.15	6.53	30.09	86.94	400.56
Fifth	0.52	2.27	--	--	2.34	10.21	9.48	41.38	87.66	382.64
Sixth	--	--	--	--	25.47	75.49	0.7	2.07	73.83	218.83
Seventh	--	--	1.32	2.77	77.19	161.78	--	--	21.49	45.04

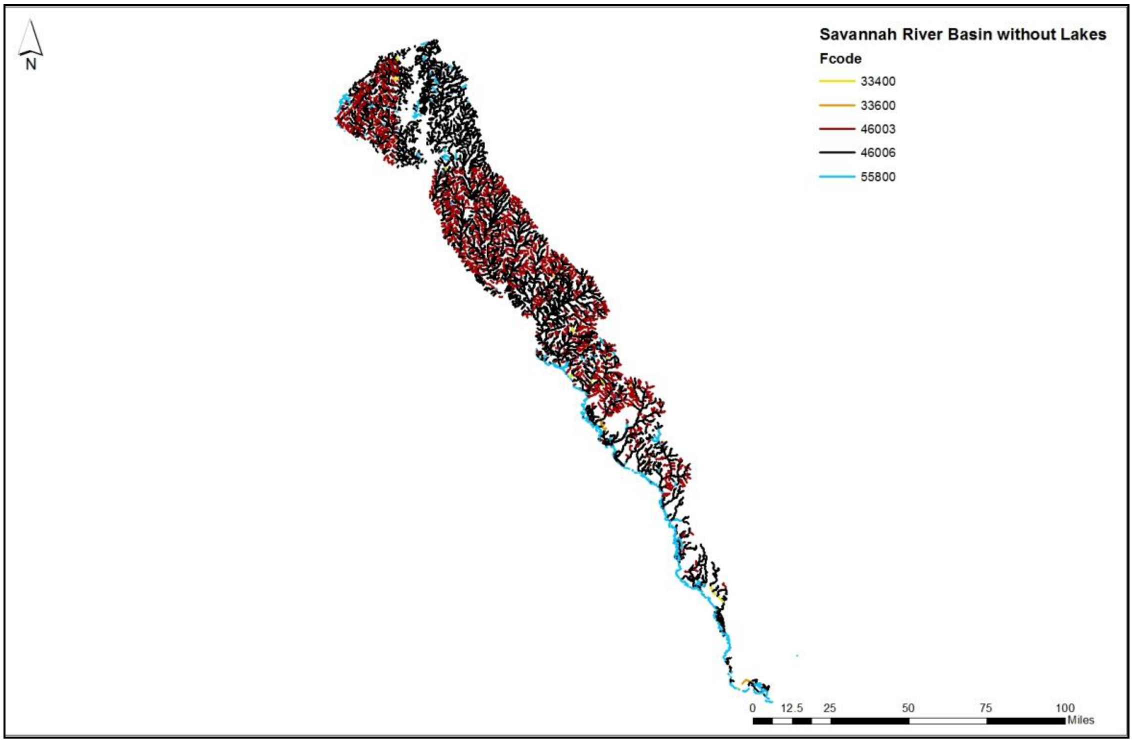


Figure 2.5. Savannah river basin NHDP network displayed by Fcode attribute; connector (33400, yellow), canal/ditch (33600, orange), intermittent (46003, red), perennial (46006, black), and artificial paths (55800, blue).

Table 2.12. NHDP stream order and attribute proportions represented in Savannah river basin. Each stream order is considered independently, with the attribute analyzed for proportion within each order and total stream-miles recorded.

Sav NHDP StreamOrder	NHDP Miles in Basin	% of Basin	Sav DHEC StreamOrder	DHEC Miles in Basin	% of Basin
First	3044.8	60.06	First	3136.93	63.33
Second	1008.78	19.9	Second	919.44	18.56
Third	529.26	10.44	Third	495.63	10.01
Fourth	267.87	5.28	Fourth	266.94	5.39
Fifth	53.56	1.06	Fifth	76.71	1.55
Sixth	8.3	0.16	Sixth	0.9	0.02
Seventh	155.68	3.07	Seventh	4.96	0.1
Eighth	--	--	Eighth	52	1.05
Total	*5068.25*		*Total*	*4953.51*	

Table 2.13. NHDP stream order and attribute proportions represented in Savannah river basin. Each stream order is considered independently, with the attribute analyzed for proportion within each order and total stream-miles recorded.

	Connector		*Canal/ Ditch*		*Artificial Path*		*Intermittent*		*Perennial*	
Sav	% of Order	Miles in Order	% of Order	Miles in Order	% of Order	Miles in Order	% of Order	Miles in Order	% of Order	Miles in Order
First	0.3	9.13	0.19	5.79	4.85	147.67	45.26	1378.08	49.41	1504.44
Second	2.47	24.92	0.26	2.62	5.72	57.7	4.52	45.6	87.03	877.94
Third	1.46	7.73	--	--	5.3	28.05	--	--	93.24	493.48
Fourth	1.29	3.46	--	--	6.75	18.08	--	--	91.96	246.33
Fifth	--	--	--	--	17.57	9.41	--	--	82.43	44.15
Sixth	--	--	--	--	80	6.64	--	--	20	1.66
Seventh	0.34	0.53	--	--	78.31	121.91	--	--	21.36	33.25

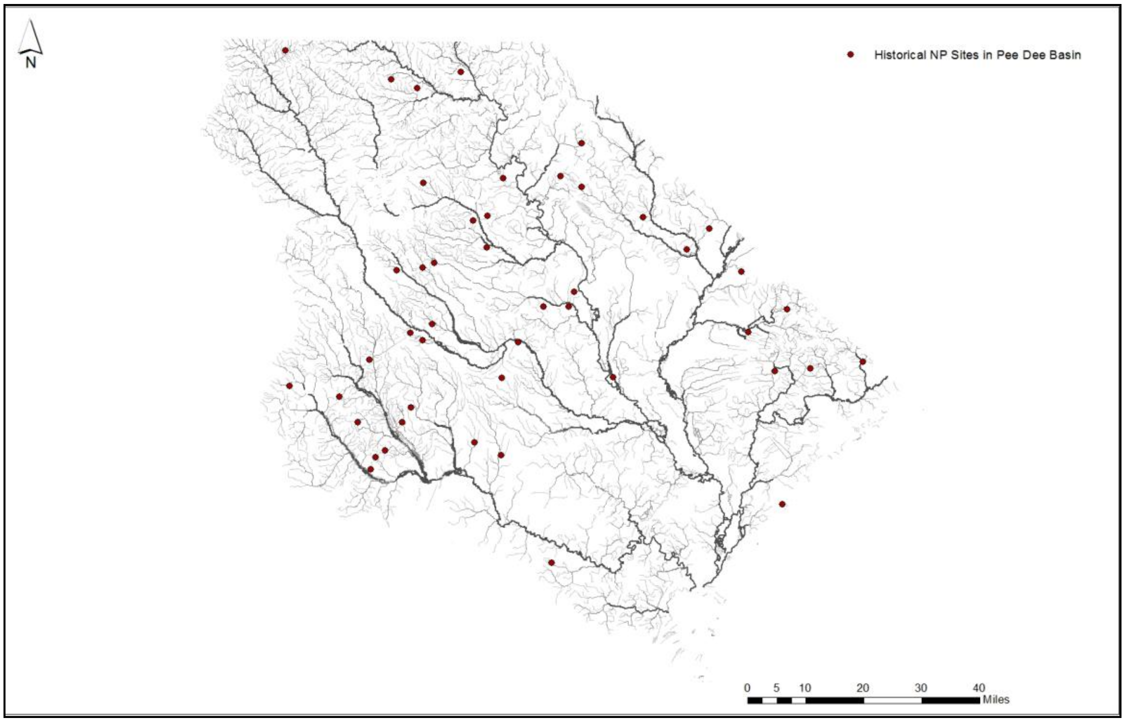


Figure 2.6. Pee Dee river basin with 46 historical intermittent-designated sites in red.

Table 2.14. Percentage of intermittent site classifications occurring in each stream order within Pee Dee river basin, according to the Modified network.

DHEC Stream Order	Intermittent Site Rejections Occurring in Stream Order (%)
First	78.26
Second	17.39
Third	4.35

Table 2.15. Stream order and Fcode flow attribute characteristics of historical intermittent rejections in Pee Dee basin, when assessed with NHDP network. (RT is row total, percentage total according to stream order. CT is column total, percentage total according to stream Fcode flow attribute.)

PD NHDP	% Intermittent	% Perennial	% Connector	*RT*
First	43.48	32.61	2.17	*78.26*
Second	4.35	6.52	2.17	*13.04*
Third	2.17	4.35	--	*6.52*
Fourth	--	2.17	--	*2.17*
CT	*50*	*45.65*	*4.34*	

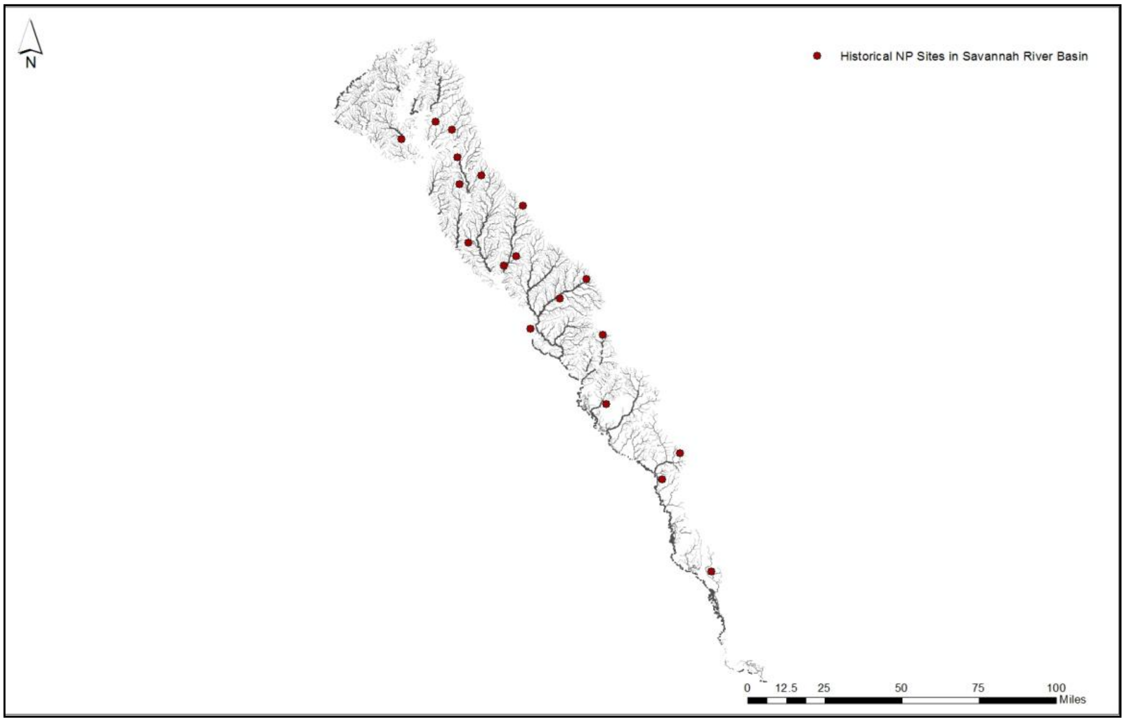


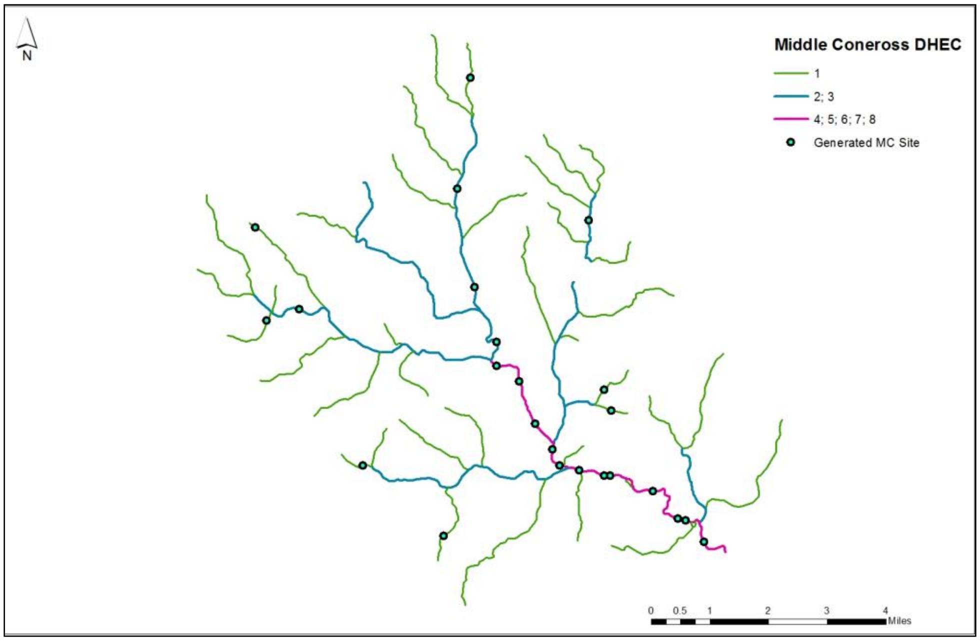
Figure 2.7. Savannah river basin with 18 historical intermittent-designated sites in red.

Table 2.16. Percentage of intermittent site classifications occurring in each stream order within Savannah river basin, according to the Modified network.

DHEC Stream Order	Intermittent Site Rejections Occurring in Order (%)
First	61.11
Second	33.33
Sixth	5.56

Table 2.17. Stream order and Fcode stream flow attribute characteristics of historical intermittent rejections in Savannah river basin, when assessed with NHDP network. (RT is row total, percentage sum by stream order. CT is column total, percentage sum by Fcode flow attribute.)

Sav NHDP	% Intermittent	% Perennial	*RT*
First	27.78	38.89	*66.67*
Second	--	33.33	*33.33*
CT	*27.78*	*72.22*	



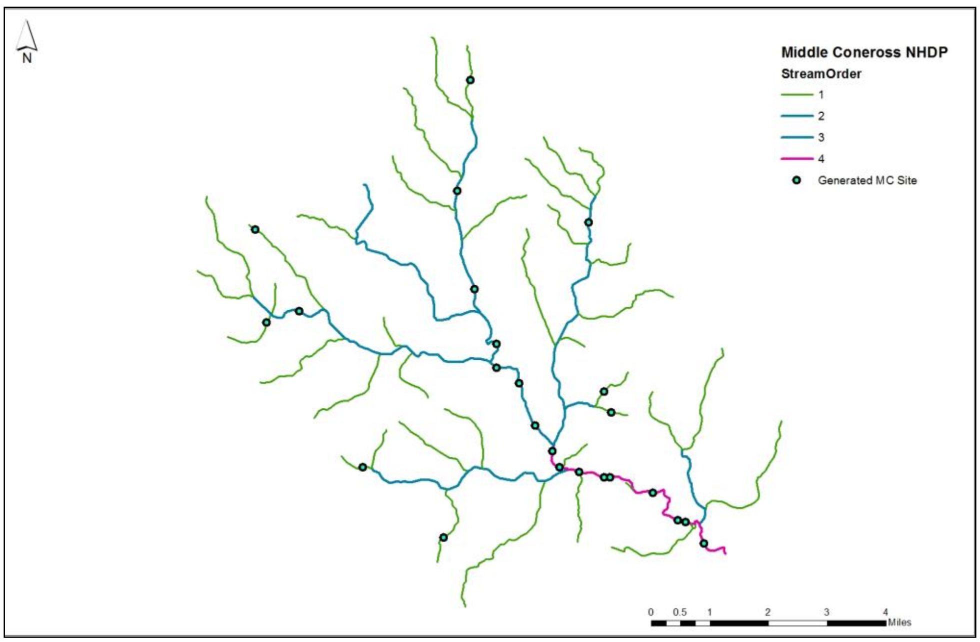


Figure 2.8. Middle Coneross hydrological unit network according to the Modified network utilized by SCDHEC (top) and NHDP network (bottom), showing location of generated sample sites. Color-coded by stream order; 1st order (green), 2nd/3rd order (blue), and 4th order (pink).

Table 2.18. Comparison of order proportion in Middle Coneross subwatershed by NHDP (left) and Modified (right) network.

NHDP Stream Order	% of network	NHDP Miles	DHEC Order	% of network	DHEC miles
First	62.68	52.16	First	62.74	51.55
Second	22.17	18.45	Second	16.47	13.53
Third	9.67	8.05	Third	12.77	10.49
Fourth	5.48	4.56	Fourth	8.03	6.6
	total	*83.22*		*total*	*82.17*

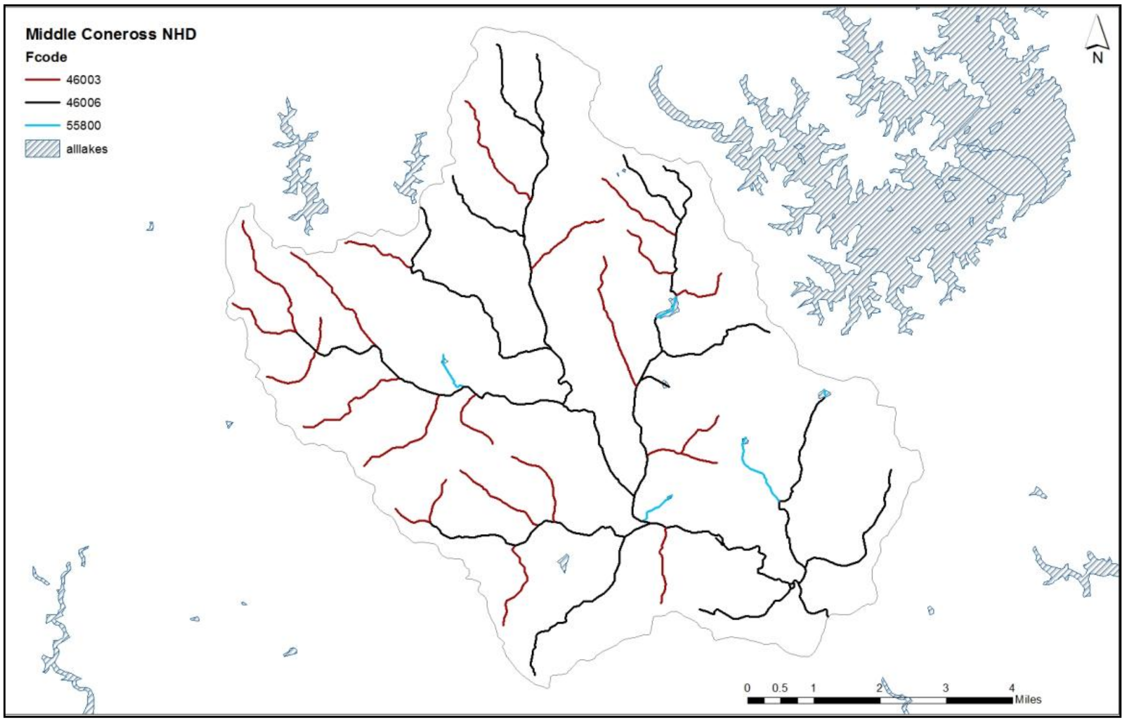


Figure 2.9. Middle Coneross NHDP network with Fcode stream-flow attributes color-coded; intermittent (46003) red, perennial (46006) black, artificial path (55800) blue. Lakes and ponds are striated, generally overlaid with the artificial path.

Table 2.19. NHDP Fcode stream-flow attribute proportional presence of stream length in each order of the Middle Coneross subwatershed.

MC NHDP	% Intermittent	% Perennial	% Artificial Path
First	49.18	39.34	11.48
Second	3.7	92.59	3.7
Third	--	100	--
Fourth	--	100	--

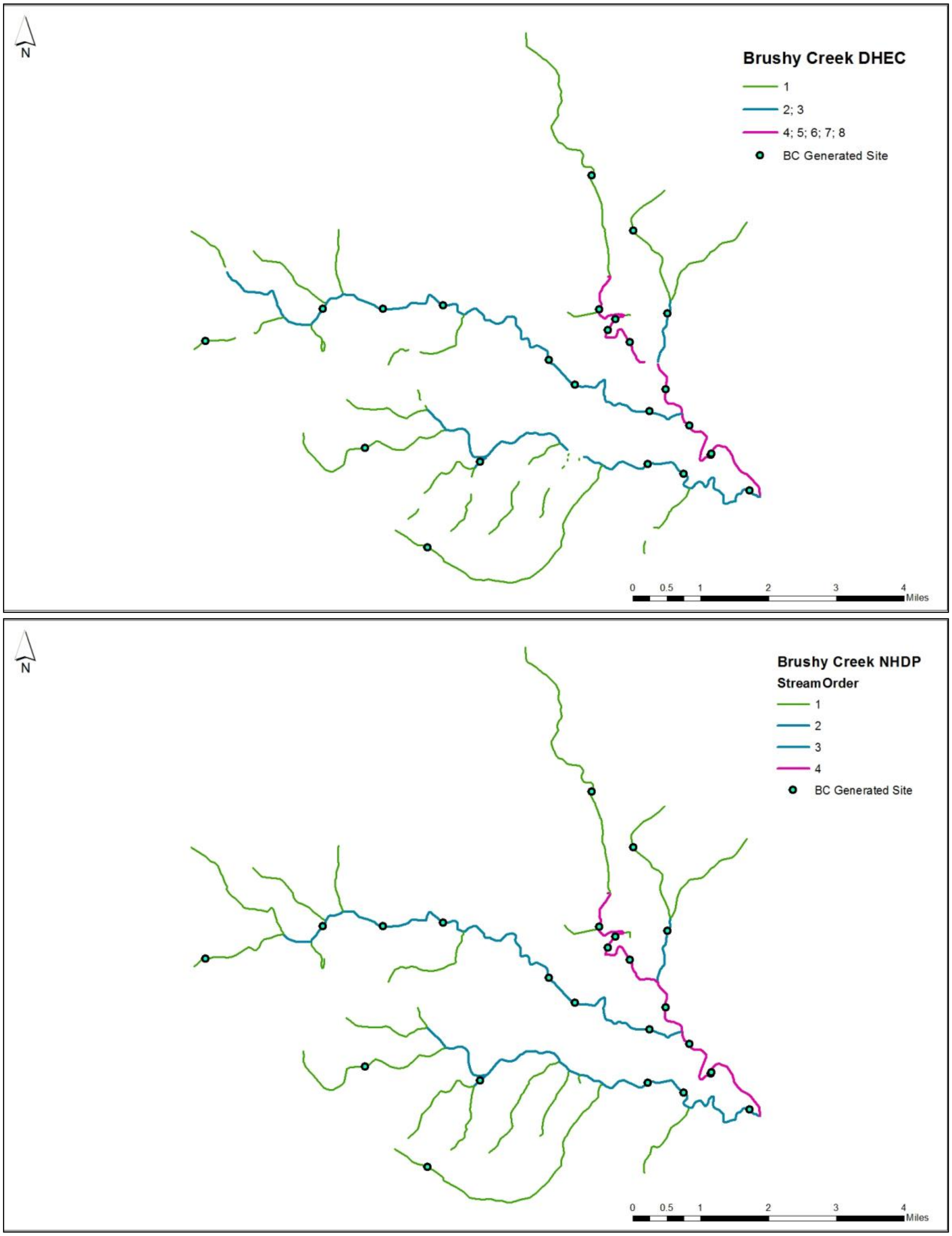


Figure 2.10. Brushy Creek hydrological network according to the Modified network (top) and NHDP network (bottom), showing location of generated sample sites. Color-coded by stream order; 1st order (green), 2nd/3rd order (blue), and 4th order (pink).

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Table 2.20. Comparison of order proportion in Brushy Creek subwatershed by NHDP (left) and Modified (right) network.

NHDP Stream Order	% of network	NHD miles	DHEC Stream Order	% of network	DHEC miles
First	60.13	32.87	First	56.38	29.05
Second	19.04	10.41	Second	22.53	11.61
Third	9.88	5.4	Third	9.92	5.11
Fourth	10.92	5.97	Fourth	11.16	5.75
	total	*54.65*		*total*	*51.52*

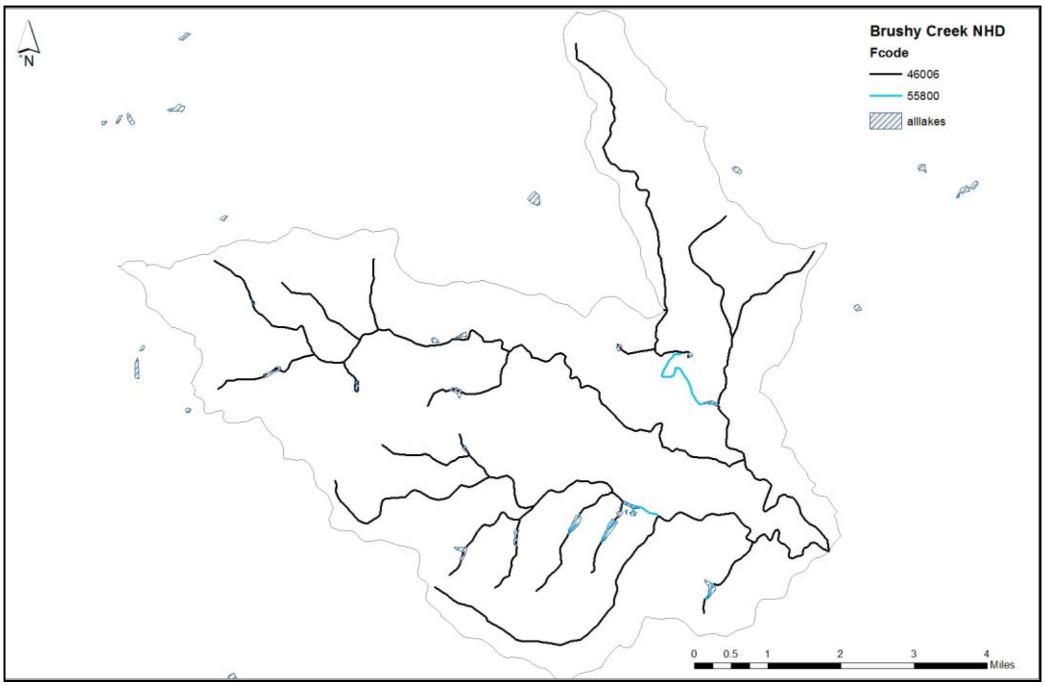

Figure 2.11. Brushy Creek NHDP network with Fcode stream-flow attributes color-coded; perennial (46006) black, artificial path (55800) blue.

Table 2.21. NHD Fcode stream-flow attribute proportional presence of stream length in each order of the Brushy Creek subwatershed.

BC NHDP	Intermittent %	Perennial %	Artificial Path %
First	--	88.89	11.11
Second	--	100	--
Third	--	62.5	37.5
Fourth	--	70	30

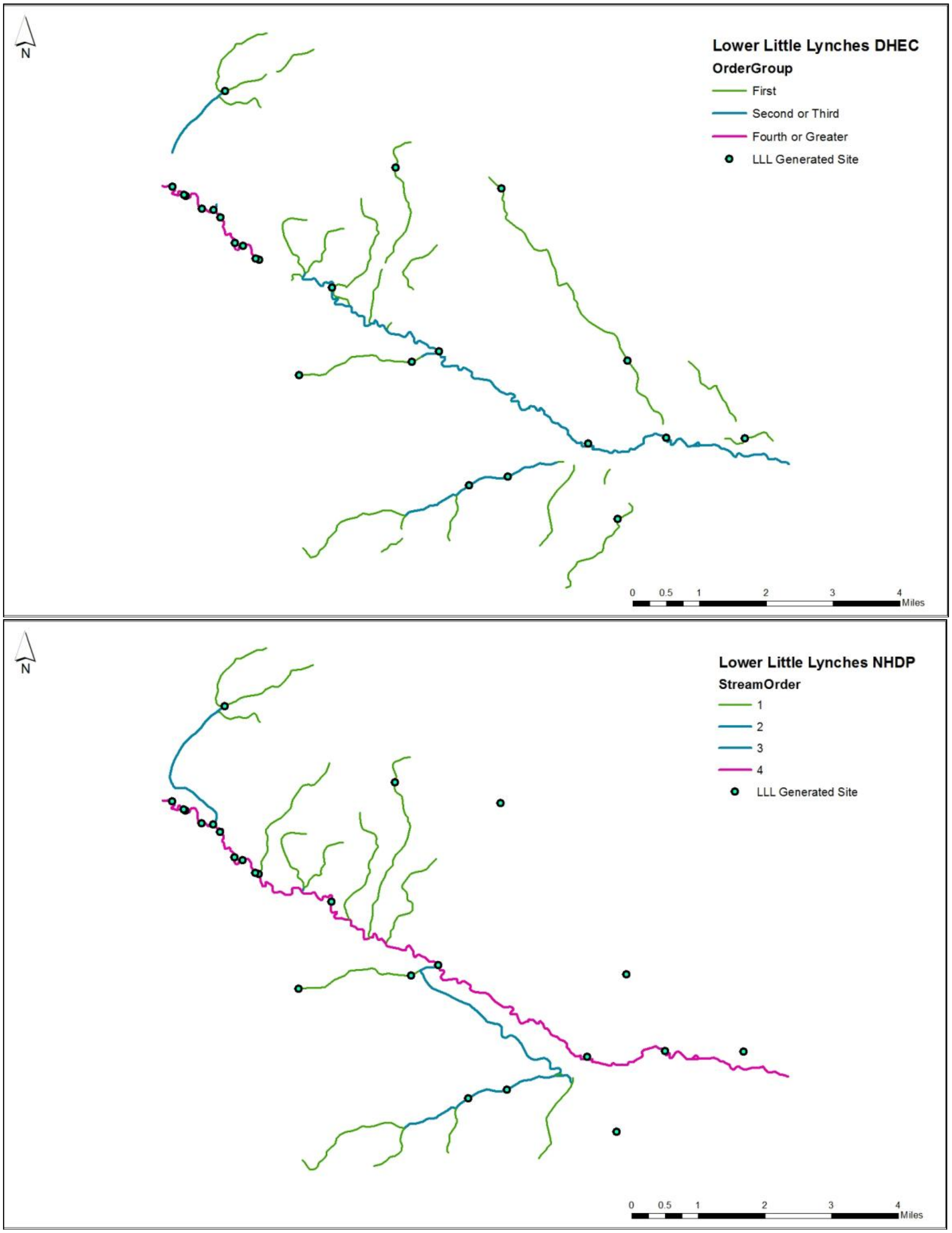

Figure 2.12. Lower Little Lynches subwatershed according to the Modified network utilized by SCDHEC (top) and NHDP network (bottom), showing location of generated sample sites. Color-coded by stream order; 1st order (green), 2nd/3rd order (blue), and 4th order (pink).

Table 2.22. Comparison of order proportion in Lower Little Lynches subwatershed by modified NHDP (left) and Modified (right) network.

NHDP Stream Order	% in network	NHDP miles	DHEC Stream Order	% in network	DHEC miles
First	49.13	22.18	First	62.16	28.63
Second	11.92	5.38	Second	15.57	7.17
Third	7.33	3.31	Third	16.18	7.45
Fourth	31.72	14.32	Fourth	6.04	2.78
	total	*45.19*		*total*	*46.03*

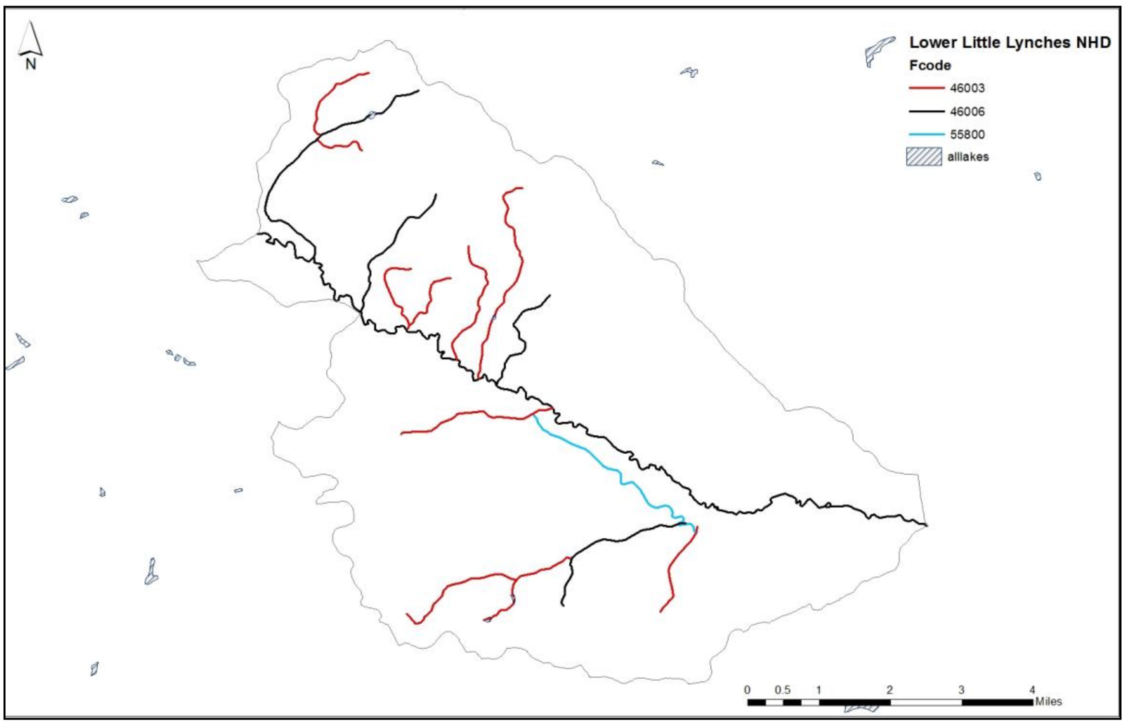

Figure 2.13. Lower Little Lynches NHDP network with Fcode stream-flow attributes color-coded; intermittent (46003) red, perennial (46006) black, artificial path (55800) blue.

Table 2.23. NHDP Fcode stream-flow attribute proportional presence of stream length in each order of the Lower Little Lynches subwatershed.

LLL NHDP	Intermittent %	Perennial %	Artificial Path %
First	67.86	32.14	--
Second	28.57	57.14	14.29
Third	25	--	75
Fourth	--	100	--

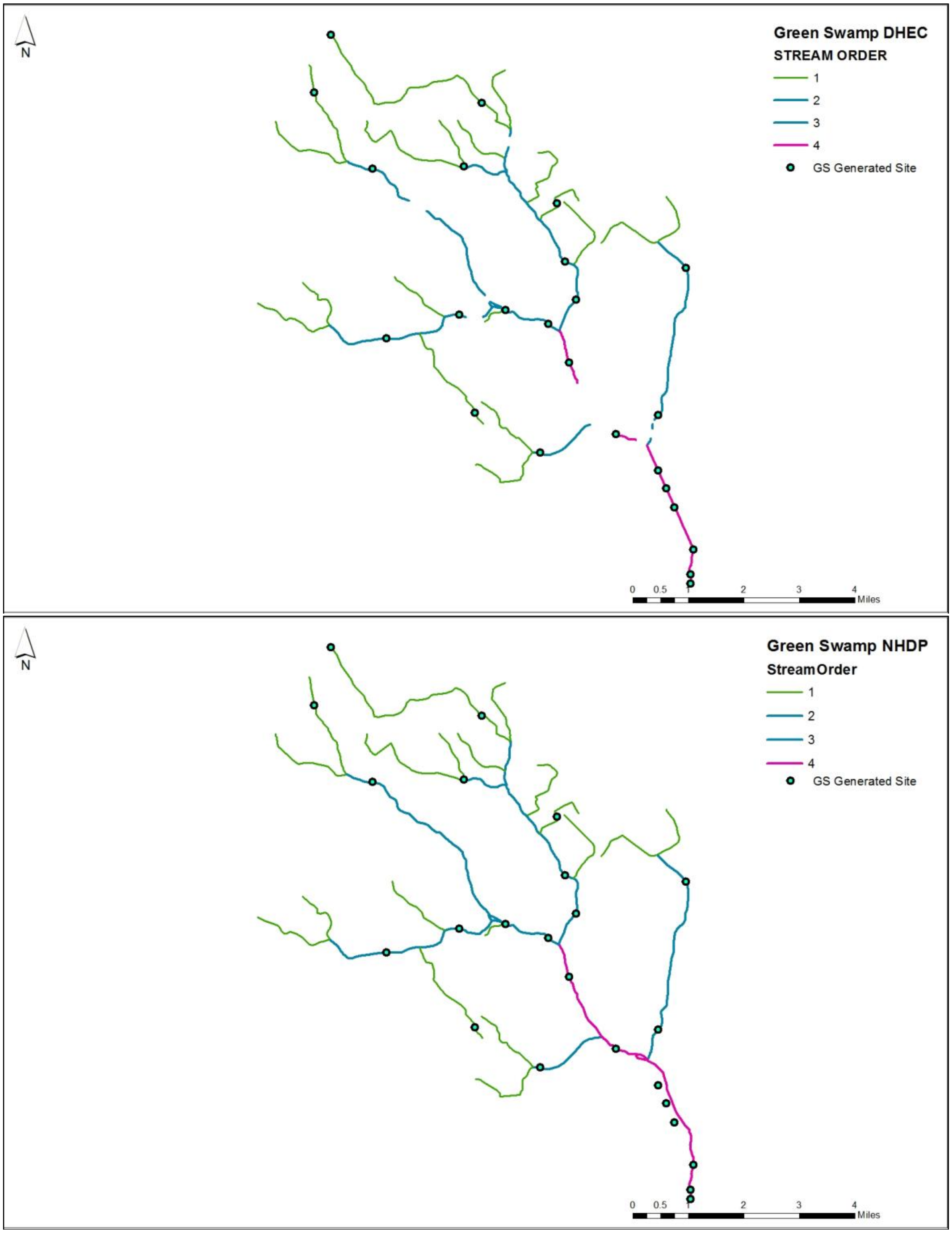

Figure 2.14. Green Swamp subwatershed according to Modified network (top) and NHDP network (bottom), showing location of generated sample sites. Color-coded by stream order; 1st order (green), 2nd/3rd order (blue), and 4th order (pink).

Table 2.24. Comparison of order proportion in Green Swamp subwatershed by NHDP (left) and Modified (right) networks.

NHDP Stream Order	% in network	NHDP miles	DHEC Stream Order	% in network	DHEC miles
First	53.98	30.08	First	57.44	30.08
Second	27.01	15.05	Second	25.19	13.19
Third	8.35	4.65	Third	9.32	4.88
Fourth	10.59	5.9	Fourth	7.94	4.16
	Total	*55.68*		*Total*	*52.31*

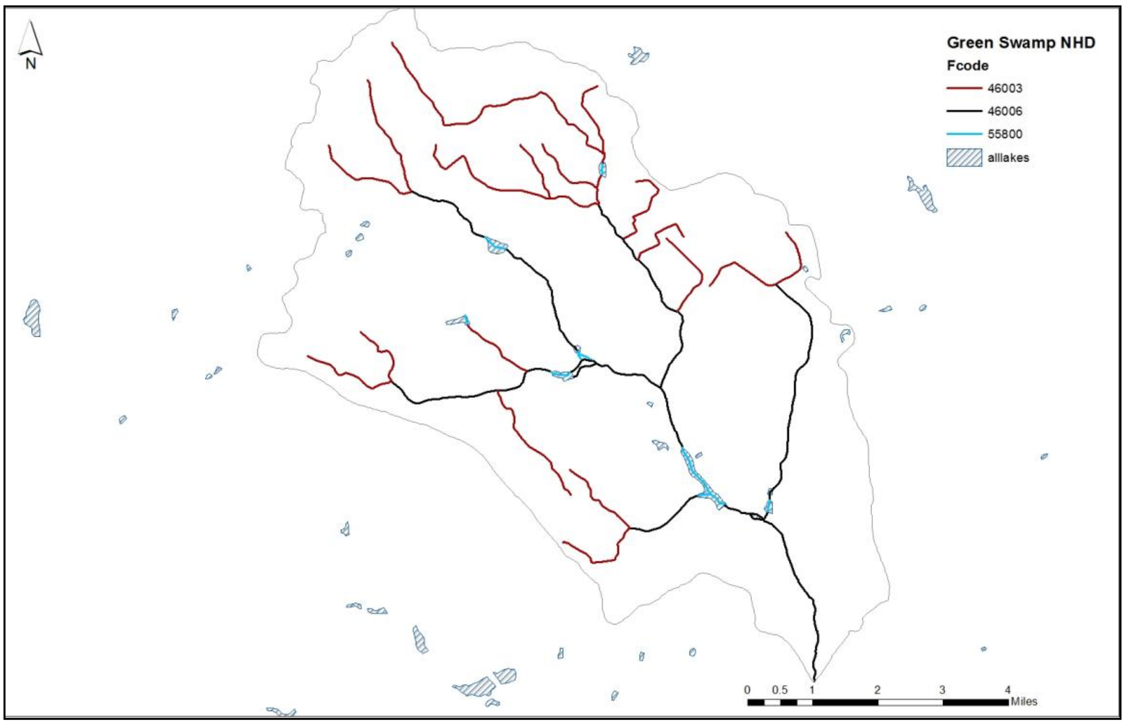

Figure 2.15. Green Swamp NHDP network with Fcode stream-flow attributes color-coded; intermittent (red, 46003), perennial (black, 46006), and artificial path (blue, 55800).

Table 2.25. NHDP Fcode stream-flow attribute proportional presence of stream length in each order of the Green Swamp subwatershed.

GS NHDP	% Intermittent	% Perennial	% Artificial Path
First	91.3	4.35	4.35
Second	13.79	55.17	31.03
Third	--	100	--
Fourth	--	71.43	28.57

CHAPTER III ASSESSING THE RELATIONSHIP BETWEEN LANDCOVER/LAND USE WITH SITE ACCESSIBILITY

3.1 INTRODUCTION

There is significant research into how land use and differences in landscape profile can influence water quality. What may receive less direct acknowledgement is how these same variables can affect the ability to access and sample a stream or river. A survey design such as the one utilized by South Carolina for state-wide water quality prioritizes stream order size and spatial distribution. Generated sample sites will therefore not always be located near convenient access points, and may not be anywhere near road systems. SCDHEC staff is responsible for many projects in addition to the random water quality survey. Because of sample holding constraints (restricted period between time when a sample is collected and when it must be delivered to the SCDHEC lab), the time, energy, and resources state staff are able to put into each of the survey sites is limited. To be efficient with time and resources, it is not always feasible to include particularly inaccessible sites in the survey.

The master sample associated with the survey design generates enough sites distributed across the state that unavoidable exclusion of sites should not significantly influence the accuracy of the sites that are used for representation. The analyses discussed in this section were done to determine if differences in land use or landscape profile had any apparent association with site rejections, such as inaccessibility.

3.2 METHODOLOGY

A. State-Scale Landcover Differences

The second focus of the study was the geospatial and landscape characteristics of probability survey sites. Patterns in location of stream-order rejection or type of rejection were assessed for the available 2001-2016 data. When a site cannot be sampled at the given coordinates but moving the site by some distance is expected to represent the same stream reach water quality, protocol permits the nearby location to serve as the sample site. SCDHEC does not have a maximum cut-off distance for such substitutions, but strives to keep them as close to the original site as possible. These relocations must occur before any other major change to the water profile occurs. For smaller headwater streams, if another tributary joins the stream before the relocated site, the move is more likely to be invalidated. Larger orders may allow tributary joins, as rivers will not be as easily impacted as a headwater stream. An example of an invalidated move on a larger order would be if there was an upstream proximity to an NPDES discharge.

The assessment intended to determine if an apparent relationship existed between site rejection or acceptance and the surrounding landscape characteristics. The majority, or dominant, 2011 NLCD profile was assessed for a 2-mile buffer (approximately 13 square mile area) around all sampled and rejected sites via a GIS spatial zoning analysis. Sampled and rejected sites were considered separately, and according to Draw. The dominant NLCD results were compared with the reasons for rejection to determine if any notable influence or apparent relationship was present. Results per rejection category were independently inclusive for comparative purposes both within Draws and between Draws. An assessment of the dominant NLCD category associated with stream-order subpopulations was done for sampled sites.

B. Subwatershed Scale: Land Use Difference

To provide a more detailed analysis of landscape influence on site accessibility, an assessment of land use conditions was done for the subwatersheds, the same four referenced for the network comparison component of the study in Chapter II. Land use data were referenced with the intent of addressing weaknesses apparent in the NLCD analyses, commented on in Chapter IV.

Parcel zoning data was downloaded for each of the four counties that contained the subwatersheds (Oconee, Greenville, Sumter, and Kershaw). A 200-meter buffer was applied to the generated coordinates of the 24 potential sample sites, and the range of zoning status within that area evaluated. A distance of 200 meters was determined to provide a reasonable snapshot of the immediate area where staff would be parking and sampling. A 200-meter buffer was also applied to the site where it was determined a sample could be taken, if relocation was necessary. This was done to assess if a difference in zoning indicated a land use type where stream reaches were more accessible. Sites are not preferentially moved upstream or downstream, if there is no reason to avoid movement in a specific location (such as a NPDES discharge downstream of a generated site).

The area occupied by each zoning classification within the buffered area of a site was calculated, and the proportional presence determined; each buffered site was considered individually. If a site required relocation to an accessible location, the same analysis was done for the access site to compare differences in land use. This was done to determine if a relationship existed between accessibility issues and land use. The parcel data available for Greenville County was tax-based zoning, a more particular zoning definition than was necessary for this assessment; in addition, the specificity of such data would have prevented productive comparison with other counties. The various tax-based zoning fields were manually reorganized into broader categories that preserved the general character of the land use while enhancing the ability to compare the data with other subwatersheds (Greenville County, 2016). Another variable assessed in the subwatersheds was duplicate site access, meaning that some stream reaches had several generated sample sites, but limited accessibility. For the purposes of this study, there was not a maximum number of sites that could have the same access location.

3.3 RESULTS

A. Landcover Associations

In the assessment of the dominant landcover in the 2 miles surrounding sampled and rejected sites during the years 2001-2016, landcover classifications of forested and wetland dominate all analyses, generally followed by the cultivated (referred to as agricultural) category. A forested profile ranged from 23% to 38% of intermittent rejections and 47% to 56% of inaccessible rejections, the two leading causes of site rejection (Table 3.1). When the dominant landcover was assessed for sampled sites, 41% to 52% of landcover in the 2-mile circumference was identified as forested (Table 3.2). The prevalence of a wetland profile in the results was due to the structure of the NLCD dataset, in which units are 30 meters by 30 meters. For sites located in stream reaches, the wetland category includes the surface area of the stream itself. This results in the analysis including the 'wetland' profile of the stream itself rather than the surrounding terrestrial profile.

The developed/urban classification, which had been anticipated to have a notable presence in the sampled site characteristics, ultimately had a small presence. The analysis results included only 3% to 5% of dominant landcover classified as developed. While sites do have a presumed association with urban features such as roads and bridges, these features are precise and more condensed within the NLCD than other landcover classification may be, limiting the ability to assess a true indication of a relationship.

B. Land Use Difference between Generated and Accessible Sample Sites in Four Subwatersheds

1. Middle Coneross: Rural SubWatershed Above Fall Line

The Middle Coneross subwatershed is located in Oconee County, with a dominant rural landcover profile. Out of 24 sites, 13 were categorized as having potential to be sampled, 10 were inaccessible, and 1 was non-target for 'no stream present' (Table 3.7b). There were 7 sites categorized as 1st order streams, 5 sites as 2nd/3rd order streams, and 12 sites as 4th+ order rivers. Of the 13 successful sample sites, there were four zoning classifications that occurred in the 200 meter area surrounding the generated and/or accessible location. The generated sites were predominantly zoned as Control Free (Table 3.3). Areas zoned as such are not regulated under specific zoning classifications until local residents submit rezoning requests (Oconee County Planning Department, 2011). A designation for a general Municipality was the second most frequent land use zoning. The access location zoning followed the profile of the generated location very closely. The zoning categories remained the same, with mostly small changes in percentages. Of the 13 sample sites, there were 5 cases of duplicate accessible location (one location for 3 sites, one location for 2 sites).

2. Brushy Creek: Urban Subwatershed Above Fall Line

The Brushy Creek-Enoree River unit, referred to as Brushy Creek, was the urban selection above the Fall Line, located in Greenville County. There were 5 sites located in

1^{st} order streams, 11 sites in $2^{nd}/3^{rd}$ order streams, and 8 sites in 4^{th}+ order rivers (Table 3.7b). Of the 24 sites, 1 was inaccessible due to a physical barrier, 3 were inaccessible due to no road crossings near the relevant stream reach, and 20 were determined to be successful, target sample sites. When the land use was assessed for the areas around the generated location of successful sample sites, approximately half of them were dominated by residential use, and half by agricultural use. When these results were compared with the access location of the sites, there was an increase in observed industrial use. Typically the same zoning was seen in the access location as the generated location. Differences in proportional presence did not appear to follow a particular trend. For example, site BC04 had 86% agricultural land use in its generated buffer, and was accessible at a site with 56% industrial land use; while site BC10, which also had a generated location in a dominant agricultural land use (70%), moved to a location with an even greater dominance of 90% agricultural land use (Table 3.4). Of the 20 sample sites, there were 5 sites with duplicate locations (one location for 3 sites, and one location for 2 sites).

3. Lower Little Lynches: Rural Subwatershed Below Fall Line

The rural selection below the Fall Line was the Lower Little Lynches subwatershed in Kershaw County. There were 8 sites in the 1^{st} stream order subpopulation, 7 sites in the $2^{nd}/3^{rd}$ stream order subpopulation, and 9 sites in the 4^{th}+ stream order subpopulation (Table 3.7b). Out of 24 sites, 10 were identified as having potential to be sampled, 10 were inaccessible, and 4 were non-target for no stream present. The region was dominated by a Rural Resource District land use classification which occupied 100% of the area around both generated site location and accessible location (Table 3.5). It also had the highest rate of the subwatersheds of duplicate access points. Of the 10 sites, two locations were identified as the best access point for 7 sites (one location for 4 sites, one location for 2 sites).

4. Green Swamp: Urban Subwatershed Below Fall Line

The Green Swamp subwatershed located in Sumter County was the urban 12-digit HUC selected below the Fall Line. There were 6 sites in the 1st order subpopulation, 10 sites in the 2nd/3rd order subpopulation, and 8 sites in the 4th+ order rivers (Table 3.7b). Out of 24 sites, 15 were identified as having potential to be sampled, 6 were inaccessible, and 3 were non-target for no stream present. There were four land uses in the proximity of the generated sample sites, though they were typically dominated by a Conservation zoning. For most sites, the proportional presence of land use appeared to stay relatively the same at the access locations (Table 3.6). One site that had been entirely in a Military Protection zoned land use was accessible in a 76% Rural Development zoning, and two sites had small additions, 5% or less, of Priority Commercial and Mixed Use zoning.

3.4 CONCLUSIONS

Sample sites that required relocation from their generated coordinates for access typically did not show a trend in land use difference. The area of coverage might alter, but the zoning categories overall remained similar with small changes in proportion. In addition, some zoning classifications were more specific than strictly required for this analysis, such as the Downtown Planning and Commercial/ Mixed Use zoning classifications in Sumter, SC (location of Green Swamp network). Both represent an urban environment, and the analysis was intended to assess a general difference in site accessibility between rural and urban land use profiles.

Another variable in assessing differences in land use between the subwatersheds is the county-based nature of zoning regulations. Counties differ in their long-term development plans and zoning specifications. A land use zone classification may have the same or similar name in different counties, but be defined differently.

However, when the overall percentage of successful sample sites and number of sites rejected due to inaccessibility are assessed strictly between networks in an urban environment versus those in the more rural ones, a more general relationship is apparent. Accessibility to sites appears to be a greater challenge in rural networks than those networks in a more urban environment, a correlation that is expected to be associated with the greater frequency of potential access points that can be considered in a urban setting. The results indicate that more rural segments of the state network could be at risk of under-representation in the survey due to these access issues. As only four subwatersheds were referenced for this particular assessment, further investigation is necessary to determine the accuracy of this potential relationship.

Table 3.1. Dominant NLCD profile within 2 miles of sites rejected from the state-wide survey. Each rejection type is independently inclusive in each Draw to determine specific influence of landcover. Rejection reasons that include target population streams are starred.

2001	AA*	DD*	OT*	PB*	OF	IM	NP	NS	SW
% Open Water	--	--	--	--	--	--	--	--	--
% Urban	--	--	--	--	--	--	14.28	--	--
% Forest	55.55	--	100	--	--	33.33	28.57	--	14.29
% Shrub	--	--	--	--	--	--	--	--	--
% Grassland	--	--	--	--	--	--	7.14	--	--
%Agriculture	--	--	--	--	--	--	21.43	--	--
% Wetland	44.44	--	--	--	--	66.66	28.57	--	85.72
2002-2005	AA*	DD*	OT*	PB*	OF	IM	NP	NS	SW
% Open Water	--	--	--	--	--	--	2.56	--	11.11
% Urban	1.96	--	--	9.09	--	--	--	--	--
% Forest	52.94	--	--	45.45	40	--	23.08	25	14.81
% Shrub	--	--	--	9.09	40	--	2.56	--	3.7
% Grassland	1.96	--	--	--	--	--	2.56	--	--
%Agriculture	5.88	--	--	18.18	--	--	25.64	8.33	--
% Wetland	37.25	--	--	18.18	20	--	43.59	66.66	70.37
2006-2010	AA*	DD*	OT*	PB*	OF	IM	NP	NS	SW
% Open Water	--	--	--	--	--	12.5	--	--	3.57
% Urban	1.9	--	--	100	33.33	--	--	--	--
% Forest	56.19	100	100	--	66.66	50	38.09	33.33	14.29
% Shrub	1.9	--	--	--	--	12.5	--	--	--
% Grassland	0.95	--	--	--	--	--	--	--	--
%Agriculture	4.76	--	--	--	--	25	23.81	66.67	--
% Wetland	34.28	--	--	--	--	--	38.1	--	82.14
2011-2016	AA*	DD*	OT*	PB*	OF	IM	NP	NS	SW
% Open Water	--	--	--	--	--	--	--	--	--
% Urban	1.94	--	--	--	--	--	2.78	--	--
% Forest	46.6	--	--	66.67	50	100	30.55	20	--
% Shrub	3.88	--	--	--	--	--	2.78	--	--
% Grassland	0.97	--	--	--	12.5	--	--	20	--
%Agriculture	5.82	--	--	--	12.5	--	22.22	--	--
% Wetland	40.78	--	--	33.33	25	--	41.67	60	100

Table 3.2. Dominant NLCD profile within 2 miles of sites sampled for the state-wide random survey. Each Draw is 100% inclusive across stream subpopulations. (RT is row total, total percent by NLCD category. CT is column total, total percent by stream order.)

2001	1st	2nd	3rd+	*RT*
% Urban	3.45	--	--	*3.45*
% Forest	3.45	20.68	17.25	*41.38*
% Shrub	--	3.45	6.9	*10.35*
% Grassland	--	--	--	*0*
% Agriculture	3.45	10.34	6.9	*20.69*
% Wetland	3.45	10.34	10.35	*24.14*
CT	*13.8*	*44.81*	*41.4*	***100***
2002-2005	1st	2nd	3rd+	*RT*
% Urban	--	2.5	2.5	*5*
% Forest	5.83	23.34	11.67	*40.84*
% Shrub	--	--	0.83	*0.83*
% Grassland	0.83	--	--	*0.83*
% Agriculture	5	8.34	5.83	*19.17*
% Wetland	7.5	10	15.83	*33.33*
CT	*19.16*	*44.18*	*36.66*	***100***
2006-2010	1st	2nd	3rd+	*RT*
% Urban	1.34	2	1.33	*4.67*
% Forest	5.33	24.67	17.34	*47.34*
% Shrub	0.67	0.67	--	*1.34*
% Grassland	--	1.33	0.67	*2*
% Agriculture	5.33	6	2	*13.33*
% Wetland	6.67	8	16	*30.67*
CT	*19.34*	*42.67*	*37.34*	***100***
2011-2016	1st	2nd/3rd	4th+	*RT*
% Urban	--	1.67	2.23	*3.9*
% Forest	8.34	25	18.35	*51.69*
% Shrub	--	--	--	*0*
% Grassland	--	--	0.56	*0.56*
% Agriculture	2.78	7.22	1.12	*11.12*
% Wetland	2.78	7.77	21.66	*32.21*
CT	*13.9*	*41.66*	*43.92*	***100***

Table 3.3. Proportional dominance of land use zoning in 200m buffer of Middle Coneross (MC) sample sites. Results from generated coordinates (top), compared with actual reconnaissance sites (bottom). Each order is individually inclusive. Sites MC10 and MC14 shared an access location, as did MC12, MC16, and MC22.

GEN Site ID	Control Free	Municipal.	Trad. Rural	Public Rec. Lands
MC01	76.51	23.49	--	--
MC03	100	--	--	--
MC04	--	57.52	42.48	--
MC05	100	--	--	--
MC07	100	--	--	--
MC10*	100	--	--	--
MC11	--	100	--	--
MC12**	100	--	--	--
MC13	100	--	--	--
MC14*	100	--	--	--
MC16**	100	--	--	--
MC21	100	--	--	--
MC22*	99.17	--	--	0.83
RECON Site ID	Control Free	Municipal.	Trad. Rural	Public Rec. Lands
MC01	33.11	66.89	--	--
MC03	100	--	--	--
MC04	--	63.19	36.81	--
MC05	100	--	--	--
MC07	100	--	--	--
MC10 *	99.17	--	--	0.83
MC11	--	100	--	--
MC12 **	100	--	--	--
MC13	100	--	--	--
MC14 *	99.17	--	--	0.83
MC16 **	100	--	--	--
MC21	100	--	--	--
MC22 *	99.17	--	--	0.83

Table 3.4. Proportional dominance of land use zoning in 200m buffer of Brushy Creek (BC) sampling sites. Results from generated coordinates (top), compared with actual reconnaissance sites (next page). Each order is individually inclusive. Sites BC04, BC15 and BC23 shared an access location, as did BC12 and BC19.

GEN Site ID	Res	Commerc/ Mix	Agr	Warehouse/ Industry	Muni/ Govt	Rec	Rec Golf
BC01	60.14	15.88	23.98	--	--	--	--
BC03	--	28.43	26.93	--	44.64	--	--
BC04*	13.16	--	86.84	--	--	--	--
BC05	74.96	25.04	--	--	--	--	--
BC06	100	--	--	--	--	--	--
BC07	3.17	32.74	--	64.09	--	--	--
BC08	99.85	--	--	--	0.15	--	--
BC09	100	--	--	--	--	--	--
BC10	8.54	20.93	70.53	--	--	--	--
BC12**	100	--	--	--	--	--	--
BC13	11.49	13.41	--	--	--	--	75.11
BC14	67.04	--	32.96	--	--	--	--
BC15*	23.04	--	76.97	--	--	--	--
BC16	100	--	--	--	--	--	--
BC17	7.59	--	5.06	--	--	--	87.35
BC18	64.67	2.81	--	--	--	32.52	--
BC19**	11.77	24.23	19.1	3.04	41.85	--	--
BC21	100	--	--	--	--	--	--
BC22	22.47	--	77.53	--	--	--	--
BC23*	6.54	--	78.07	15.39	--	--	--

RECON Site ID	Res.	Commerc/ Mixed	Agr.	Warehouse/ Industrial	Muni/ Govt	Rec.	Rec. Golf
BC01	60.27	15.83	23.91	--	--	--	--
BC03	8.93	7.47	66.4	17.2	--	--	--
BC04*	43.29	--	--	56.71	--	--	--
BC05	23.59	76.42	--	--	--	--	--
BC06	100	--	--	--	--	--	--
BC07	--	77.59	--	22.41	--	--	--
BC08	97.79	--	2.09	--	0.12	--	--
BC09	100	--	--	--	--	--	--
BC10	2.69	7.05	90.27	--	--	--	--
BC12**	35.02	--	30.94	--	34.03	--	--
BC13	1.27	--	--	--	--	--	98.73
BC14	67.94	32.05	--	--	--	--	--
BC15*	--	43.29	--	56.71	--	--	--
BC16	35.02	--	30.94	--	34.03	--	--
BC17	1.27	--	--	--	--	--	98.73
BC18	83.89	16.11	--	--	--	--	--
BC19**	35.02	--	30.94	--	34.03	--	--
BC21	100	--	--	--	--	--	--
BC22	28.89	--	71.11	--	--	--	--
BC23*	--	43.29	--	56.71	--	--	--

Table 3.5. Proportional dominance of land use zoning in 200m buffer of Lower Little Lynches (LLL) River sample sites. Results from generated coordinates (top), compared with actual reconnaissance sites (bottom). Each order is individually inclusive. Sites LLL03, LLL07, LLL11, LLL15, and LLL19 shared the same access location, as did LLL06 with LLL22.

Site ID	GENERATED LOCATION % Rural Resource District	ACCESS LOCATION % Rural Resource District
LLL02	100	100
LLL03*	100	100
LLL06**	100	100
LLL07 *	100	100
LLL09	100	100
LLL10	100	100
LLL11 *	100	100
LLL15*	100	100
LLL19 *	100	100
LLL22**	100	100

.

Table 3.6. Proportional dominance of land use zoning in 200m buffer of Green Swamp (GS) sample sites. Results from generated coordinates (top), compared with actual reconnaissance sites (bottom, next page). Each order is individually inclusive. Sites GS07 and GS11 had the same accessible location, as did GS10 with GS14 and GS23.

GEN Site D	% Military Protec.	% Conserv	% Sub. Develop.	% Downtown Plan.	% Priority Commerc/ Mixed	% Rural Develop.
GS01	100	--	--	--	--	--
GS04	--	75.02	23.82	1.17	--	--
GS07*	--	75.9	24.1	--	--	--
GS09	22.58	58.76	18.66	--	--	--
GS10**	--	100	--	--	--	--
GS11*	--	75.9	24.1	--	--	--
GS13	27.76	72.24	--	--	--	--
GS14**	--	100	--	--	--	--
GS16	--	75.9	24.1	--	--	--
GS17	100	--	--	--	--	--
GS18	--	75.9	24.1	--	--	--
GS19	--	75.9	24.1	--	--	--
GS20	--	75.9	24.1	--	--	--
GS22	--	75.9	24.1	--	--	--
GS23**	--	75.9	24.1	--	--	--

RECON Site ID	% Military Protec.	Conserv.	% Sub. Develop.	% Downtown Plan.	% Priority Commerc/ Mixed	% Rural Develop.
GS01	23.68	--	--	--	--	76.32
GS04	--	75.02	23.82	1.17	--	--
GS07*	--	75.9	24.1	--	--	--
GS09	22.58	58.76	18.66	--	--	--
GS10 **	--	100	--	--	--	--
GS11 *	--	75.9	24.1	--	--	--
GS13	27.76	72.24	--	--	--	--
GS14 **	--	100	--	--	--	--
GS16	--	74.92	23.78	--	1.3	--
GS17	100	--	--	--	--	--
GS18	--	--	94.82	--	5.18	--
GS19	--	75.9	24.1	--	--	--
GS20	--	75.9	24.1	--	--	--
GS22	--	100	--	--	--	--
GS23**	--	75.9	24.1	--	--	--

Table 3.7a. Site status based on reconnaissance of four subwatersheds. Middle Coneross and Brushy Creek were the rural and urban selections above the Fall Line, respectively. Lower Little Lynches River and Green Swamp were the rural and urban selections below the Fall Line, respectively. Rejection percentages from target population are starred. (RT is row total, percent by order. CT is column total, percent by rejection type.)

MC HUC (Rural, above Fall Line)	*AA%	NS%	TS%	*RT*
First	12.5	--	16.67	*29.17*
Second/Third	4.17	4.17	12.5	*20.84*
Fourth+	25	--	25	*50*
CT	*41.67*	*4.17*	*54.17*	

BC HUC (Urban, above Fall Line)	*AA%	*PB%	TS%	*RT*
First	--	16.67	--	*16.67*
Second/Third	8.33	--	37.5	*45.83*
Fourth+	4.17	--	29.17	*33.34*
CT	*12.5*	*16.67*	*66.67*	

LLL HUC (Rural, below Fall Line)	*AA%	NS%	TS%	*RT*
First	8.33	16.67	8.33	*33.33*
Second/Third	16.67	--	12.5	*29.17*
Fourth+	16.67	--	20.83	*37.5*
CT	*41.67*	*16.67*	*41.66*	

GS HUC (Urban, below Fall Line)	*AA%	NS%	TS%	*RT*
First	12.5	4.17	8.33	*25*
Second/Third	--	4.17	33.33	*37.5*
Fourth+	4.17	8.33	20.83	*33.33*
CT	*16.67*	*16.67*	*62.49*	

Table 3.7b. Number of sites in the rejected and sampled population of the four subwatersheds. Rejected sites were from target population are starred. (RT is row total, total number of sites by order. CT is column total, total number of sites by rejection type.)

MC # Sites	*AA	NS	TS	*RT*
First	3	--	4	*7*
Second/Third	1	1	3	*5*
Fourth+	6	--	6	*12*
CT	*10*	*1*	*13*	

BC # Sites	*AA	*PB	TS	*RT*
First	--	1	4	*5*
Second/Third	2	--	9	*11*
Fourth+	1	--	7	*8*
CT	*3*	*1*	*20*	

LLL # Sites	*AA	NS	TS	*RT*
First	2	4	2	*8*
Second/Third	4	--	3	*7*
Fourth+	4	--	5	*9*
CT	*10*	*4*	*10*	

GS # Sites	AA	NS	TS	*RT*
First	3	1	2	*6*
Second/Third	1	1	8	*10*
Fourth+	1	2	5	*8*
CT	*5*	*4*	*15*	

CHAPTER IV DISCUSSION AND CONCLUSION

Opportunities for Improvement

As this study is attempting to cover a broad range of subjects to assess possible sources of influence on the probability survey for water quality, a few conditional perspectives with such an approach must be taken into consideration. Several assessments determine apparent relationships based on landcover. Landcover is constantly changing, with the 2011 NLCD data already outdated to an extent by the time it was publicly available. This is of particular importance in South Carolina, which is experiencing rapid growth in certain areas. By using one snapshot of landcover characteristics to describe a fifteen-year period, the results must be taken in context.

The Modified network utilized for the survey is the 1:100,000 scale, and so all analyses are based at this scale. South Carolina has not updated its network to the NHDP medium resolution or high resolution 1:24,000 scale, as they are not fully accurate for the purposes of the probability survey. The medium resolution is available, but contains the low-density region with incorrect stream density. The high resolution is available with better stream density coverage in all areas, but lacks the attributes relevant for the survey, such as stream order. The high resolution as it is available is appropriate for certain small-scale projects, but for the state-wide monitoring project, it is not yet feasible.
The intention of utilizing the subwatersheds was to recreate the state sample frame at a more detailed, larger cartographic scale, with the same approximate weights applied to the major order subpopulations. This ultimately was somewhat of a flawed ideal. By

reducing the size of the network to a few square miles but requiring the same stream weights as observed in the entire state, it placed limits on the subpopulation of 4^{th}+ streams. Due to the maintenance of the smaller stream order proportions in a small area, none of the subwatersheds have rivers larger than 4^{th} order.

Observations of Site Rejection

In the state-scale analysis of site survey data, there were consistencies across Draws in stream-orders involved in site rejection and in the common reasons for rejection. The 1^{st} and 2^{nd} order streams were the most consistently rejected, with 1^{st} order streams contributing 45% or more to all rejections for the first three Draws. The lowest contribution of 1^{st} order streams to rejections was 40%, which occurred in the most recent Draw; a reduction in part due to the removal of brackish or saltwater reaches from the sample frame.

The random site generation focuses more heavily on the smaller streams, with currently 18 of the 30 annual sites targeting the two subpopulations containing 1^{st} and $2^{nd}/3^{rd}$ order streams, due to their prevalence in the state. A higher probability of rejection may be expected since they represent a larger proportion of the sample frame; however the prevalence of intermittency in the 1^{st} order streams also contributes to their rejection rates. Non-accessible sites are a notable issue across Draws, as well as across orders. They have contributed anywhere between around 25% to almost 65% of rejections in a Draw. When assessed at the level of the subwatershed, sites rejected due to inaccessibility were an issue across orders though their overall influence ranged, accounting for 13% to 42% of rejections across all site classifications.

Differences between Digital Hydrological Networks

If the medium-resolution NHDP network became fully available for South Carolina and SCDHEC determined it appropriate to change the referenced network for the probability survey, it would require a significant adjustment regarding the same frame definition and the weights assigned to the stream subpopulations. As previously noted, the NHDP network has artificial paths providing connectivity through waterbodies such as lakes and ponds, creating additional stream-mileage that is non-target for the surface water quality probability survey. These streams are identified as artificial paths, as are stream reaches that are identified as perennial or intermittent. The artificial paths that are contained within known lakes and ponds can be removed from the NHDP sample frame, while the remaining artificial paths may be assumed to correctly belong in the sample frame. Both networks contain flowlines addressing the multiple channels in an anastomosing network. In some areas they differ in stream ordering, with the NHDP generally providing the more accurate order assessment. As mentioned previously, the algorithm that determined stream orders for the RF3 network experienced some error when it encountered a complex network with subchannels, reverting to classification as lower stream orders (Figure 4.1). The NHDP network displays improvements in maintaining connectivity and stream order in these areas (Figure 4.2). These differences in network stream order assignment is one contributing factor to the differences in order contribution to a river basin. A related factor is the observation that the NHDP network contains some double-banking, particularly in swamps. This is likely a feature that improves connectivity in a system with less precise definition than a standard stream, but also adds duplicate mileage of a reach.

The Modified network has had adjustments over the years. In addition to the original filling in of the low-density region, some stream mileage errors have been corrected, such as the removal of brackish streams. As demonstrated by the analyses in this study, similar selective actions could be taken with a utilizable NHDP layer for the state. Streams with the Fcode identifier 46003 (intermittent) could be excluded from the sample frame. Streams with the Fcode identifier 55800 (artificial path) that are within the bounds of known lakes and ponds can also be selectively excluded. The ability to identify intermittent streams would remove a significant portion of non-target mileage that the current Modified network is not able to automatically exclude.

The two subwatersheds located above the Fall Line, Middle Coneross and Brushy Creek, are in the Piedmont ecoregion. The subwatersheds located below the Fall Line, Lower Little Lynches and Green Swamp, are in the Coastal Plain. The Piedmont is characterized by rolling hills, narrow floodplains, and sandy permeable soils, traits that limit the sprawling stream networks characteristic in the flat Coastal Plain. Thus, it follows expectations that the Lower Little Lynches and Green Swamp subwatersheds were notable for having a greater proportion of their streams identified as intermittent, particularly the 1st order streams. No intermittent streams were identified for the urbanized Brushy Creek, though almost 50% of 1st order streams in rural Middle Coneross were identified as intermittent. This is less than what was observed for both the lower subwatersheds, but higher than what might be expected in the Piedmont. However, the subwatersheds were headwater networks with a large proportion of 1st order streams. While the main intent of this was to replicate the state-wide stream-order subpopulation proportions, this also in some ways targeted areas of a network that would be most likely to experience intermittency due to the dominance of 1st order streams.

Referring to the review of historical reconnaissance sites in Chapter II that were determined to be intermittent by SCDHEC staff, such streams were not always identified as such by the NHDP network. This indicates that the NHDP network does not represent and identify all stream reaches with 100% accuracy, for a variety of reasons. In some situations, the physical reality of channels and flows can change more quickly than map updates can keep up with them. Of particular relevance in South Carolina is the impact of drought. A year or a succession of years with drought conditions can significantly change the behavior of streams, making normally perennial streams intermittent, or drying out streambeds completely. Evaluation during site reconnaissance may indicate the site is a target population rejection due to drought conditions. Conversely, if the conditions have changed enough to remove the perennial stream indicators, site evaluation may determine the site is a non-target intermittent rejection. The intermittency may be true only for that drought period, or the effects may be severe enough to permanently change the flow characteristics of that stream reach. Network maps and site reconnaissance are considered together in these scenarios, though the determination of the site reconnaissance should take precedence in such a conditional situation.

Removing artificial paths in known ponds and lakes, and streams identified as intermittent, would remove a significant portion of sites with the chance of being rejected as non-target. It cannot be assumed that all of the non-target stream reaches would be removed, nor can it be assumed that no target stream reaches would be removed, due to misclassification by NHDP or changes in physical reality. However, the benefits of these exclusions would outweigh the potential of losing a few stream reaches from the sample frame. The number of sites rejected due to intermittency would likely be significantly reduced by such a strategy.

For the assessment of land use zoning and site accessibility at the watershed scale, there was variability in how similar resources were zoned between networks, as zoning is managed by county and can range in restrictiveness and detail. Site relocation was generally over short distances, limiting the difference in land use observed. As the networks covered only a few square miles and often had several sites on the same stretch of stream, the range of movement was further curtailed.

While specific relationships between land use and accessibility weren't as evident, there was an apparent relationship between sites that could be sampled and their landcover profile (Table 3.7a). There was a notable difference in identification of suitable sample sites between the urban subwatersheds and rural subwatersheds. Reconnaissance for Middle Coneross and Lower Little Lynches, the rural networks, identified 54% and 42% of their sites as being suitable sample points; the urban networks, Brushy Creek and Green Swamp, identified 67% and 62% of their sites as suitable sample points. In the same vein, site accessibility was a greater issue in the rural networks. Both Middle Coneross and Lower Little Lynches identified approximately 42% of their sites as inaccessible, with different rates in the subpopulations. In contrast, the urban Brushy Creek identified only 13% of sites as inaccessible, and Green Swamp also identified a low 17% of sites as inaccessible. This means that both rural networks experienced a higher rate of inaccessible sites than their urban counterparts. These rates are general comparisons, as there are likely additional relevant variables that were not considered in the analysis, and sample sizes were small.

While this study did not directly assess the responsible variable, it is presumed to be the proximity of public roads and bridge crossings. Road networks are presumably denser in urban environments, providing a greater number of possible sites to access a stream. Roads in a rural setting may be fewer in number, and may not be anywhere near a selected random stream location. Extensive tracts of land may be under private ownership, where accessing the available dirt roads is not possible without landowner permission.

An interesting observation was made regarding the points of accessibility for the subwatershed sites. The SCDHEC monitoring strategy aims for 30 sites over the full state to meet its survey design. The subwatersheds covered a few square miles but had 24 sites to be assessed, with a target of identifying 12 suitable sites. For some subwatersheds, this resulted in a pronounced example of limited site accessibility. If a 4^{th} order river had 5 sites located on it but only one bridge crossing, all 5 sites could potentially have been moved to that one accessible bridge if there were no indications that the water quality would be different. The point of the assessment was to determine accessibility, which is why all 5 sites could be recorded as successful reconnaissance even though the accessible location was a duplicate. If the analysis had been to choose actual sites to survey, only 1 of the 5 sites would have been acceptable. This example of duplicate accessibility is an extreme exaggeration of what can occur for the state-wide survey. A bridge might be the only accessible point of a site one year, and then is the only option for a different site on the same river 3 years later. If there is no reason to suspect water quality is different between the generated site location and the bridge, it is preferred to sample from the same bridge rather than have to reject the stream reach entirely.

The assessments conducted for this study indicate that there would be advantages to basing the probability survey on the NHDP network for South Carolina, if the stream density issues previously discussed were addressed. The network would require adjustments to make it suitable for the purposes of the probability survey, but the ability to utilize the stream attribute characteristics of perennial versus intermittent could remove a significant proportion of inappropriate sites from the sample frame. This could potentially improve the efficiency of SCDHEC time and resource management. At the subwatershed scale, there were apparent correlations between general landcover profile and site accessibility. The subwatershed networks located in areas of increased development had more sites identified as suitable sample points than rural-located subwatershed networks, which in turn had a corresponding greater rate of inaccessible sites. The state-scale survey has a large enough distribution of sites that this potential for environmental profile bias was not observed in any of the analyses, due to the constantly changing location of sites and the distance between them.

It would be advantageous to remove non-target streams from the sample frame via the NHDP network, though site inaccessibility is an issue that would occur in all hydrological networks. This represents a proportion of stream reaches that are assumed to be target population, but may in fact contain a mixed representation of target and non-target streams. Without physical reconnaissance, it is difficult to confirm and it is the cautious and preferred approach to assume all inaccessible sites are target reaches.

Issues with the Modified network are known, such as the algorithm errors in some anastomosing networks and the lack of specific stream flow attributes. Changing the referenced network to NHDP has the potential to improve the efficiency of reconnaissance visits, as the ability to remove a significant proportion of non-target sites would be advantageous. It could also potentially help improve the representation of 1st order streams, which are typically under-represented because of their rates of rejection. However, 1st order streams, and all stream orders, are impacted by inaccessibility, an issue that will remain no matter what hydrological network is referenced.

Changing the network used for the probability survey in South Carolina would be a significant undertaking, as it would require efforts of SCDHEC staff, EPA, and USGS to correct the stream density disparity still present in the medium-resolution NHDP. The high-resolution NHDP has the correct stream density, but would need stream order assigned. In addition, the high-resolution network would alter the proportion of subpopulations, as it would pick up many more streams not recognized in the medium-resolution scale. Many of these new streams would likely be 1st order streams, so the 1:24,000 high resolution has the potential to actually increase the amount of non-target streams that would need to be excluded (due to the prevalence of intermittency in 1st order streams). Assessing the advantages of the NHDP network would require more thorough experimentation, but it has the potential to be a beneficial tool in SCDHECs water-quality monitoring strategy.

Preliminary Conclusions

This thesis evaluated several variables that related to or had potential to influence the random survey utilized by SCDHEC to monitor state-wide water quality. One component of this was the assessment of issues that caused a site to be rejected from the annual survey for the 16-year period from 2001-2016. These rejection reasons were evaluated based on frequency and most affected stream orders. Other variables potentially influencing site rejection were considered as well, including landcover characteristics. A second component of this study compared the definition of the streams and rivers in South Carolina according to two digital hydrological networks; the Modified network, which is utilized by SCDHEC for the random survey, and the NHDP network, a USGS product with national coverage. The NHDP has additional stream attributes that are not present in the Modified network, attributes that identify the type of stream-flow that should be expected in a stream, such as perennial or intermittent. Intermittency was found to be one of the leading reasons for a site to be rejected from the random survey in the first component of the study, particularly impacting the smallest 1st order streams.

The random survey is intended to evaluate only perennial streams, so the intermittent rejections presents a significant source of non-target waters included in the potential sample population. They also result in an overestimation of the 1st order streams relevant for the survey. Because so many 1st orders streams are found to be inappropriate sample points, and the random survey strategy does not necessitate the replacement of a rejected site with one of the same order, the 1st order stream subpopulation is consistently under-represented in the survey. If the NHDP network could be adopted and the intermittent streams excluded from the potential site generation, it is anticipated that these intermittent rejections would reduce in number and the representation of 1st order subpopulation might improve; more research and experimentation would be required to support this suggestion. Inaccessibility was another frequent reason for sites to be rejected from the survey, which influenced all orders to some degree. Sites rejected due to inaccessibility are automatically assumed to be part of the target population, due to the inability to confirm the site condition. Based on assessment of sites at the subwatershed scale with reconnaissance, inaccessibility had a greater influence on site rejection in rural locations than urban ones. This apparent relationship is thought to be related to the greater number of public access points in an urban setting, such as bridge crossings.

The comparison between the digital hydrological networks revealed that while they are highly similar in the spatial definition of stream reaches, there are some notable differences in stream order assignment, particularly for complex anastomosing networks. An artifact of the algorithm that assigned stream order in the older Modified network is that broken networks or anastomosing channels were sometimes incorrectly identified as separate tributaries of the same order, which caused the main stem of a stream or river to be categorized as a larger order than was accurate. In addition, when presented with a broken network (with incomplete connectivity), the algorithm sometimes 'restarted' the order assignment. For example, if a 4th order river lost connectivity in the digital flowline, the next reach would be assigned as a 1st order stream before returning to the appropriate order value. This was an issue present in many early hydrological networks, including the original NHD. Later algorithm developments have improved this particular issue in the NHDP.

Further investigation would be required to fully assess the influence of variables on site reconnaissance and to support the preliminary results of this thesis study, such as urbanization improving site accessibility. The benefits that could be gained from utilizing the NHDP as the reference network for the random survey also require further assessment. The issues that have prevented SCDHEC from adopting the NHDP have been discussed, and include issues with the scale of stream density coverage. SCDHEC staff has discussed the issue with EPA and USGS, and the potential of updating the official NHDP medium-resolution 1:100,000 scale network with the accuracy improvements that are present in the Modified network. If these points could be addressed, further experimentation would be possible to assess if NHDP can address two issues present in the Modified network; the inclusion of intermittent streams in the list of potential sample sites, and the incorrect order assignment of channels in anastomosing networks. The analyses discussed here indicate that an opportunity to change the reference network to the NHDP could improve the representation of target stream subpopulations, and the efficiency of effort, time and resource management by SCDHEC necessary to execute the probability survey.

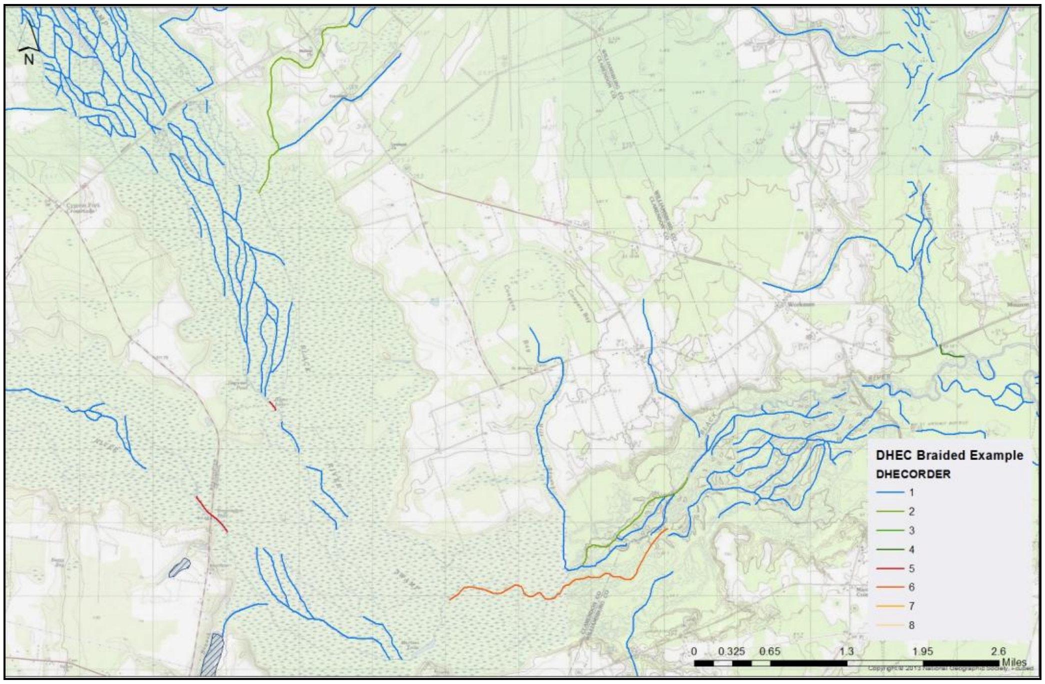

Figure 4.1. Example of the algorithm error assigning incorrect stream order in an anastomosing river network in the Modified network.

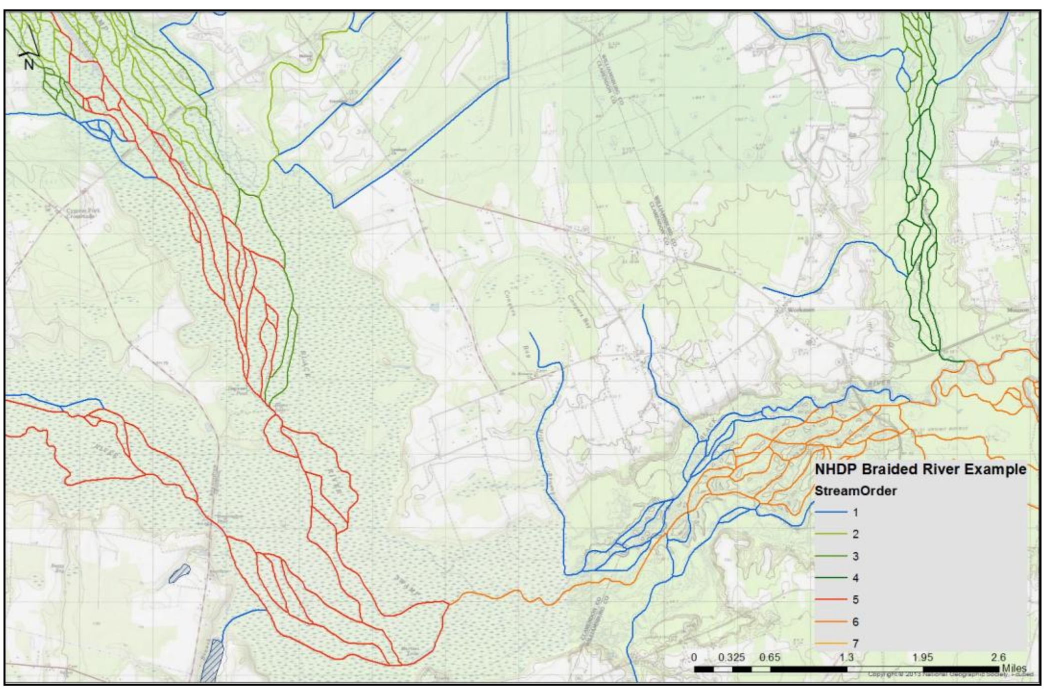

Figure 4.2. Example of drawn stream order in an anastomosing river system, according to the NHDP network.

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