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Tar-Pamlico and Neuse River Basins, North Carolina, Geomorphic Summary Report

Kathleen E. Harris and Christopher P. Haring

June 2022

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Abstract

The Tar-Pamlico and Neuse River Basins are neighboring basins in eastern North Carolina, both originating in the piedmont physiographic region, transitioning to coastal plains, and emptying into Pamlico Sound. The Pittsburgh District is responsible for the continued efforts to assist local sponsors with managing these basins and submitted a Water Operations Technical Support (WOTS) request. The WOTS program, funded by Headquarters, US Army Corps of Engineers, provides funding for the Coastal and Hydraulics Laboratory (CHL) to provide technical assistance to develop innovative solutions to water resource problems. The objectives of this study are to identify flood risk management alternatives to address the accumulation of woody debris in the channel systems. CHL compiled existing conditions information and researched current and potential new methods for managing woody debris to provide a comprehensive list of recommendations. The results and recommendations are provided in this document.

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Preface

This study was conducted for the US Army Corps of Engineers (USACE), Pittsburg District, under Water Operations Technical Support, Funding Account Code U4381330; AMSCO Code 008241. The technical monitor was Dr. Pat Deliman.

The work was performed by the River and Estuarine Engineering Branch of the Flood and Storm Protection Division, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication of this report, Mr. David P. May was branch chief; Dr. Cary A. Talbot was division chief; and Dr. Julie Rosati was the technical director for Flood and Storm Technical Programs. The deputy director of ERDC-CHL was Mr. Keith Flowers, and the director was Dr. Ty V. Wamsley.

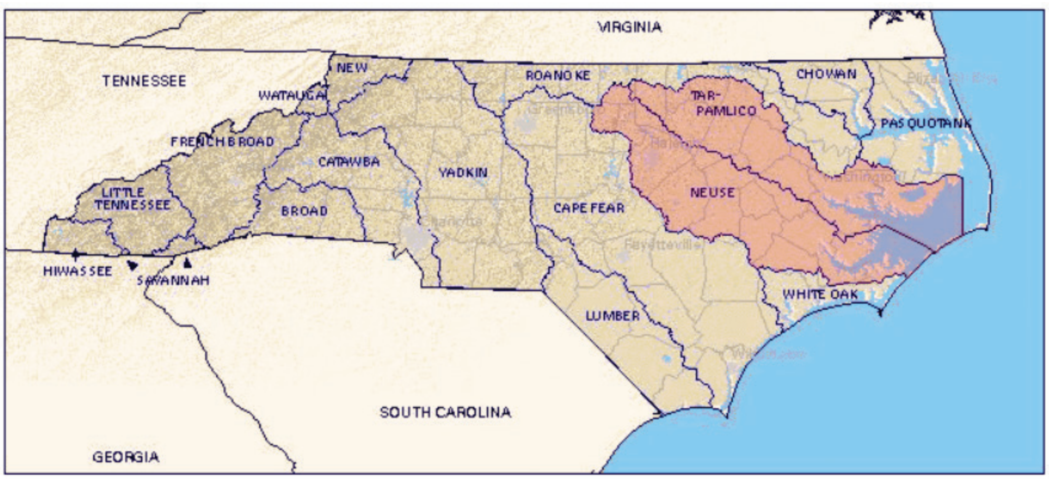
The authors acknowledge the USACE Pittsburg, Huntington, and Wilmington Districts for providing background information and data to ERDC-CHL to assist in the assessment.

The commander of ERDC was COL Teresa A. Schlosser, and the director was Dr. David W. Pittman.

1 Introduction

This study investigates the neighboring basins of the Tar-Pamlico and Neuse in eastern North Carolina (Figure 1). The two basins are similar in size and physiographic regions, and both face flooding issues, particularly in their urban centers. The Tar-Pamlico River Basin is more rural with a few population centers whereas the Neuse River Basin is more populated and includes the city centers of Raleigh and Durham. The study seeks to investigate the flooding problems these two basins are facing, review data and studies conducted in the basins, identify the role large woody debris (LWD) plays in the river systems, provide options available for debris management, and present recommendations to the districts.

Figure 1. Map of North Carolina River basins – the Tar-Pamlico and Neuse River Basins are the basins of interest for this study, highlighted in red (modified from nc.usgs.water.gov).



1.1 Background

As part of the report, summary information was taken from numerous district reports and presentations provided to the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC CHL) (LRP 2020; SAW 2020). The Tar-Pamlico and Neuse River Basins are experiencing flooding that impacts the communities along the rivers and poses a risk to life and property. In several cases, the flooding also impacts critical infrastructure such as hospitals, bridges, and roads. The impacts to infrastructure reduce the ability of emergency personal to travel within and between cities. Another situation occurs in Washington, NC (Tar River), where impacts to a US Army National Guard emergency storage facility impairs access to flood-fighting supplies and recovery efforts. There are additional environmental concerns when flood flows connect rivers to waste water retention ponds at concentrated animal feeding operations. When this occurs, considerable pollution enters the river system. Riverbank erosion processes lead to a substantial amount of debris deposition, specifically woody debris from tree branches and trunks. LWD has been observed in the main stem of the rivers, causing concern that the debris is exacerbating the erosion and flooding problems. This report provides a summary of existing conditions and issues associated with the erosion and flooding problems in the two basins.

1.2 Objective

The objective of this study is to compile existing geomorphic information within the two river basins of interest, the Tar-Pamlico and Neuse, and compile existing research regarding the management of woody debris in rivers to develop recommendations to be provided to the districts that manage the basins. Specifically, the focus of this study is to identify options for debris removal from the river systems.

1.3 Approach

Information about the Tar-Pamlico and Neuse River Basins was collected regarding the physical and geomorphic features of the basins, the problems faced within the basin, and past studies conducted. Research was then compiled regarding the role of LWD in rivers and watersheds, the impact debris has on flooding, and typical and novel methods of managing and removing nuisance debris. Finally, recommendations were formulated for addressing the debris in these river basins.

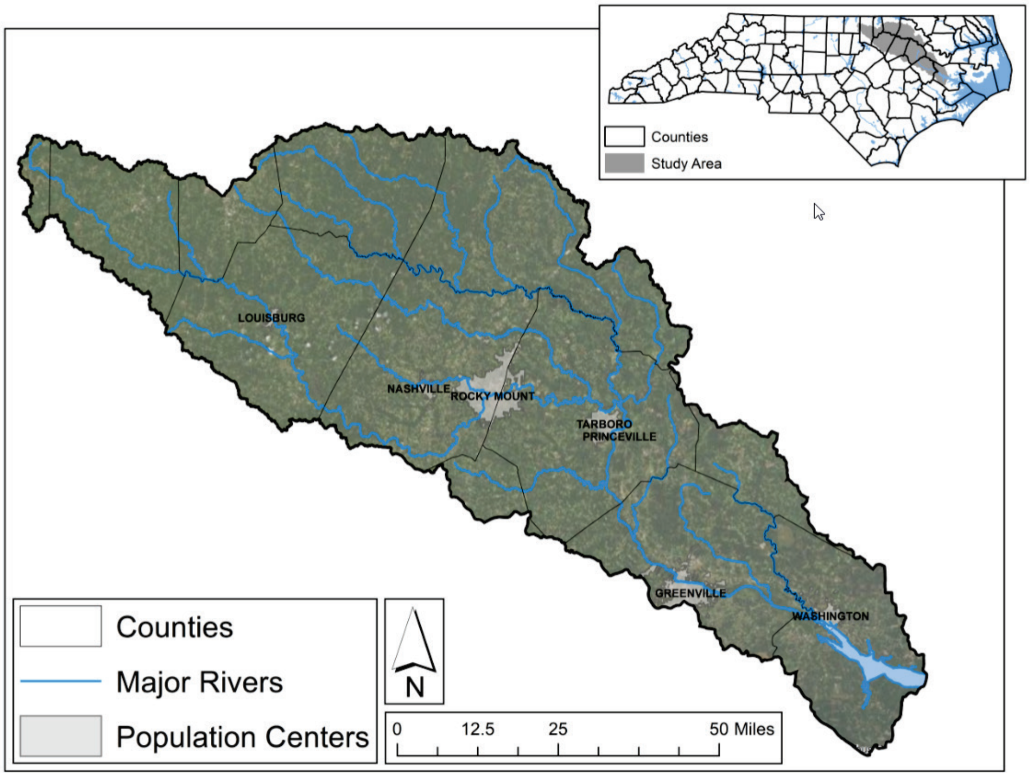
2 Study Contents

2.1 Tar-Pamlico River Basin preliminary assessment

The Tar-Pamlico River Basin is an approximately 6,000 mi^2(*) river basin in northeastern North Carolina, beginning in the eastern Piedmont and transitioning to the Coastal Plains before draining into Pamlico Sound (Figure 2). The river of interest in the basin is the Tar River. The basin is mostly rural but home to approximately 450,000 residents with population centers in the cities of Washington, Greenville, Tarboro, Princeville, Rocky Mount, Nashville, and Louisburg. As of the 2011 National Land Cover Dataset (NLCD), the developed area is approximately 7% with development and population growth centered around Greenville, Rocky Mount, Washington, and some rural areas in commuting distance from Raleigh. Some negative growth in other municipalities is also present. From 2000 to 2011, there was minimal population growth and land development in the basin. A trend analysis was performed on long-term record, dating back to late 1800s/early 1900s to determine if there were statistically significant changes in rainfall or discharge in the basin, and all trends were deemed statistically insignificant except for a slight increase in rainfall at Greenville of an average of 0.6 in./yr and a slight decrease in discharge at Conetoe Creek near Bethel, NC, of an average of 8.05 cfs/yr. Based on these analyses, it was determined that population growth and development did not impact flooding in the basin.

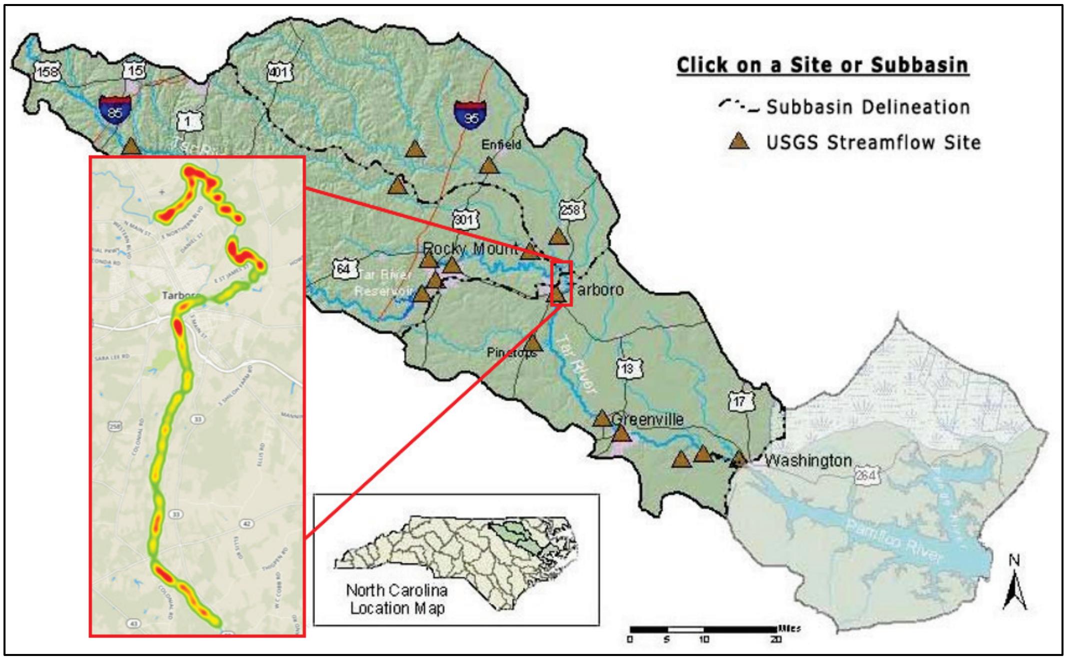
* For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

Figure 2. Tar-Pamlico River Basin (source: US Army Corps of Engineers [USACE], Pittsburg District [LRP 2020]).



The cities within the Tar-Pamlico River Basin have faced recurring flooding due to several hurricanes in the past 2 decades and with reported channel buildup of woody debris within the river, causing concern that the debris is exacerbating flooding problems. The US Army National Guard collected locations and photos of the debris in the Tar River, and at the time of this report, ERDC-CHL received that dataset for around the city of Tarboro (Figure 3) and corresponding photos (in the appendix). This semi-quantitative dataset provides points and locations of debris but is of a qualitative nature in that the severity of the debris at each point location is not quantified. From these data, there appear to be concentrated sites of debris accumulation in the meander bends of the river surrounding the city of Tarboro and at bridge crossings. From the photos, debris appears to consist of dead tree branches and trunks, primarily concentrated along the banks and not extending across the channel. There are several photos (in the appendix) that show what appears to be bank erosion, triggering trees to topple into the river.

Figure 3. Debris data collected on the Tar River near Tarboro (source: US Army National Guard; US Geological Survey [USGS]).

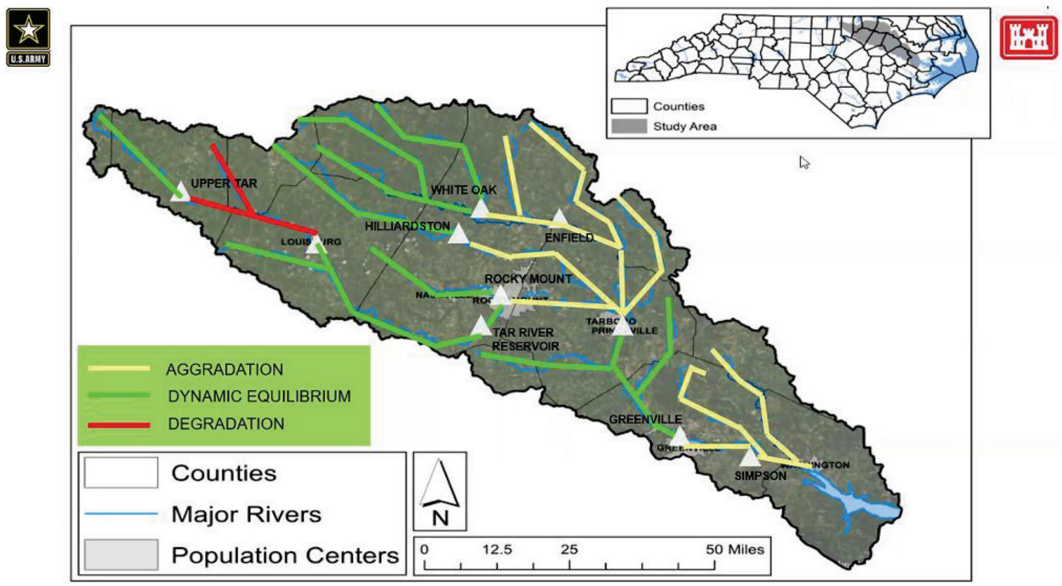


In addition to the debris data collection, other past efforts include

- a geomorphic assessment based on specific gage and rating curve data at US Geological Survey (USGS) gaging stations
- USGS inundation maps for the basin
- an OASIS hydrologic model for water management decisions
- and a US Army Corps of Engineers (USACE) feasibility study of structural, nonstructural, and natural and nature-based features for flood risk management (FRM).

A specific gage analysis of the Tar-Pamlico River Basin was conducted by the Huntington District (LRH). Specific gage and rating curve analyses were conducted for the USGS stream gages within the basin for the full record available at each gage. The specific gage analysis was conducted by plotting regression curves through the rating curve data to then collect the stage values for the specific discharges. Figure 4 shows the various trends in the river basin based on the gage analysis. LRH reported that approximately half of the reaches were deemed in dynamic equilibrium, half aggradational, and only a couple were suspected to be degradational. Of those reaches that were deemed aggradational, the analysis indicated 2–3 ft of aggradation has occurred, and the reaches deemed degradational indicated 2–3 ft of degradation.

Figure 4. Tar-Pamlico River Basin geomorphic assessment based on specific gage and rating curve analyses (source: USACE Huntington District [LRH]).



The *Tar River Basin Flood Analysis and Mitigation Strategies Study* report (NCDOT NCEM 2018a) completed by the North Carolina Division of Emergency Management (NCEM) and the North Carolina Department of Transportation provides in-depth data information on the basin, trends in development, rainfall, and streamflow, engineering analysis utilizing coarse hydrologic and hydraulic models, flood risk analysis, and cost-benefit analyses of proposed mitigation strategies. The study reports there is no statistically significant evidence that development has caused increases in flooding along the main stem of the Tar River. The report also provides estimates on costs, benefits, and other concerns regarding flood mitigation for projects. The projects include retention, dam removal, and flow diversion.

2.2 Neuse River Basin preliminary assessment

The Neuse River Basin is similar in size and physiographic region to its neighboring basin of the Tar-Pamlico, with approximately 6,200 mi^2 crossing from Piedmont to Coastal Plain to drain into Pamlico Sound. The river of interest is the Neuse River, which once originated at the confluence of the Eno and Flat Rivers but now flows from the Falls Lake Reservoir Dam that is used for flood control, drinking water, and recreation. The Neuse River Basin is also much more developed than the Tar-Pamlico River Basin, with a population of approximately 1.6 million as of 2016, which includes the metropolitan areas of Raleigh and Durham in its upper basin (Figure 5). Most population growth in the basin is focused in the upper basin, in Wake and Johnston Counties. As of the 2011 NLCD, 15.6% of the land cover is developed, and the basin has also experienced increases in developed area between the NLCD studies in 2001 and 2011, particularly in the upper basin. A trend analysis at gages with long-term record, dating back to late 1800s/early 1900s, was performed on rainfall and streamflow to determine if the increase in development has statistically impacted flooding. No trends were detected in the majority of the basin, but slight upward trends in rainfall were detected at Greenville with an increase of an average of 0.06 in./yr and at Kinston with an increase of an average of 0.05 in./yr.

Figure 5. Neuse River Basin (source: USACE Wilmington District [SAW]).

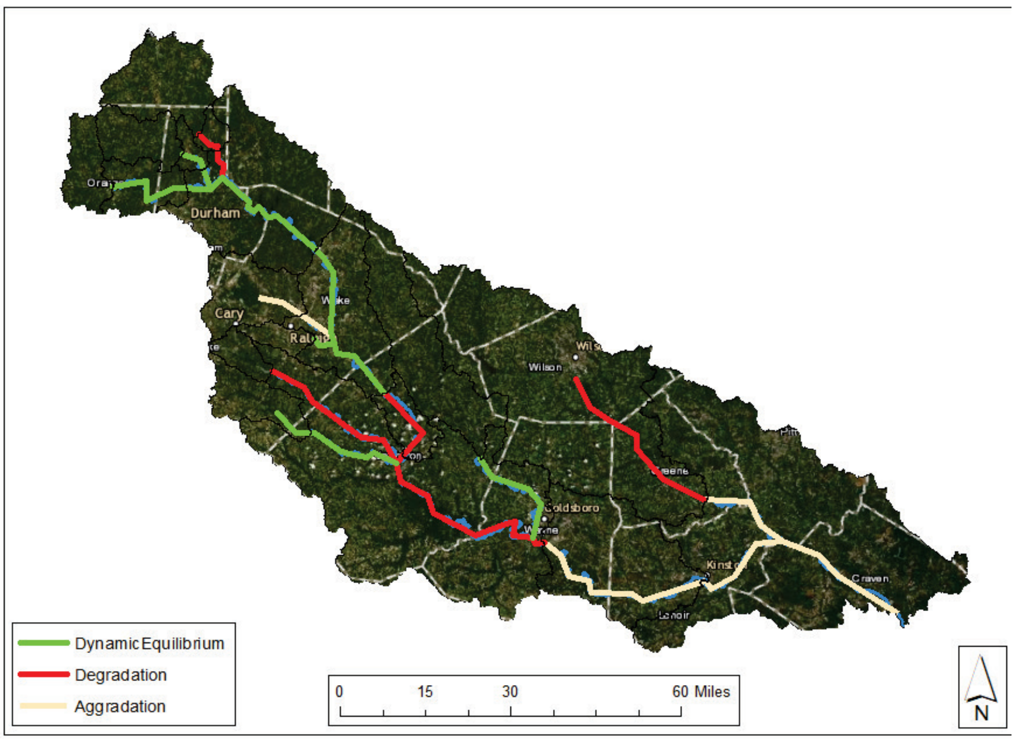
Past water resource projects within the basin include

- an OASIS model used to model water levels for water planning decisions (rather than to monitor and model flooding)
- dam removal projects along the river for ecological restoration of habitat and spawning grounds

- a USACE feasibility study to identify flood risks and restoration features
- previous vulnerable property buyouts by NCEM and the Federal Emergency Management Administration
- NCEM floodplain mapping and emergency preparedness programs within the basin
- a sedimentation study utilizing stage discharge rating curves at USGS gage stations.

Similar to the Tar-Pamlico Basin, a sedimentation study was conducted within the Neuse River Basin based on a rating curve analysis at USGS stream gages conducted by USACE Wilmington District (SAW). The system was determined to be either aggradational, degradational, or in dynamic equilibrium at gage locations throughout the basin (Figure 6). The determined condition of the river at each gage was assumed to continue downstream until the next gage gave a different result.

Figure 6. Neuse River Basin geomorphic assessment based on rating curve analysis (source: USACE SAW).



The *Neuse River Basin Flood Analysis and Mitigation Strategies Study* report (NCDOT NCEM 2018b) completed by NCEM and NCDOT provides in-depth data information of the basin, trends in development, rainfall, and streamflow, engineering analysis utilizing coarse hydrologic and hydraulic models, flood risk analysis, and cost-benefit analyses of proposed mitigation strategies. The study states that there is no statistically significant evidence that development has caused increases in flooding along the main stem of the Neuse River and provides possible costs, benefits, and issues regarding flood mitigation for projects such as channel modification, new levee structures, retention, widening floodplain, and elevation/acquisition/relocation.

2.3 Large woody debris (LWD) in rivers

LWD is a vital component within river systems, serving as valuable aquatic habitat and in some places provides some stabilizing influence on the channels (Cottingham et al. 2003; Treadwell et al. 2007). However, there are potential negative impacts of LWD such as the accumulation of LWD on bridge piers, which can cause blockages and induce local scour that can threaten the structure (Panici and Kripakaran 2021; Wipf et al. 2012). Additionally, excess debris can cause local scour along the banks and channel bed (Manners et al. 2007).

There is also concern that the presence of LWD can cause or worsen flooding, particularly in urban centers. While this may hold true in severe cases, some researchers have concluded that the role of LWD in flooding has been overstated in cases of mild to moderate debris accumulation within the rivers (Treadwell et al. 2007; Rutherfurd et al. 2002). For example, according to Rutherfurd et al. 2002, the cross-sectional area of LWD at a particular cross section in a river must be at least 10% of the entire cross-sectional area before there is a significant impact on water levels upstream. Additionally, LWD may have an insignificant impact on the frequency or duration of larger floods but could increase the duration of smaller, bankfull flood events by a couple hours, depending on the river system and location within the catchment (Rutherfurd et al. 2002). In general, it is presented that small but visible amounts of LWD effect relatively small changes in water surface elevation and subsequent flooding. For example, in a river that is 98.4 ft and 6.6 ft with a flow of 4.9 ft/s, a log that takes up approximately one-third of the cross section 65.6 ft long, 3.3 ft diameter, perpendicular to the flow would cause a 5% increase in the water surface elevation upstream, or approximately 3.9 in. (Rutherfurd et al. 2002). Therefore, a log that would appear to be a major impediment to flow actually causes a small change in stage relative to cross-section area. Removal of large quantities of LWD would not only eliminate valuable aquatic habitat but could introduce instability and induce bank and bed erosion by disturbing the structure of the banks and bed (Treadwell et al. 2007). A more sustainable approach may be to recognize the value of LWD and modify infrastructure to allow LWD to pass downstream while preserving areas of LWD storage to maintain its presence and ecological benefit (Lassattre and Kondolf 2012).

Research regarding management of LWD has largely been focused on structures for diverting LWD away from critical infrastructure (e.g., bridge piers, culvert, hydropower intakes) or for collecting debris for easier removal. Numerous structures have been employed such as foils, fins (Figure 7), or debris sweepers (Figure 8) to encourage the passage of debris around bridge piers rather that the accumulation (Lagasse et al. 2010; Bradley et al. 2005). Additionally, steel or timber racks are used to stop debris from reaching bridge piers (Figure 9) (Bradley et al. 2005; Schmocker and Hager 2013) and trash racks and other proprietary rack structures are used to stop debris from entering hydropower or storm water intakes (Figure 10) (Tyler 2011; Bradley et al. 2005). Structures such as piles (Figure 11) and debris dams (Figure 12) retain LWD in more optimal locations (Wallerstein and Thorne 1997; Bradley 2005) and gate structures capture LWD at the banks for more convenient removal (Figure 13) (Panici and Kripakaran 2021). Many of these options come with the added expense of periodic removal of debris from the structures themselves whether designed to accumulate LWD or not.

Figure 7. Debris fin deflectors diverting debris from bridge piers (Bradley et al. 2005).

Figure 8. Debris sweeper installed on the Cedar Creek in Washington, USA (Bradley et al. 2005).

Figure 9. Post and rail debris rack (Bradley et al. 2005).

Figure 10. Debris deflector protecting a culvert from debris accumulation (Bradley et al. 2005).

Figure 11. Test flume deflector post configurations (Wallerstein et al. 1997).

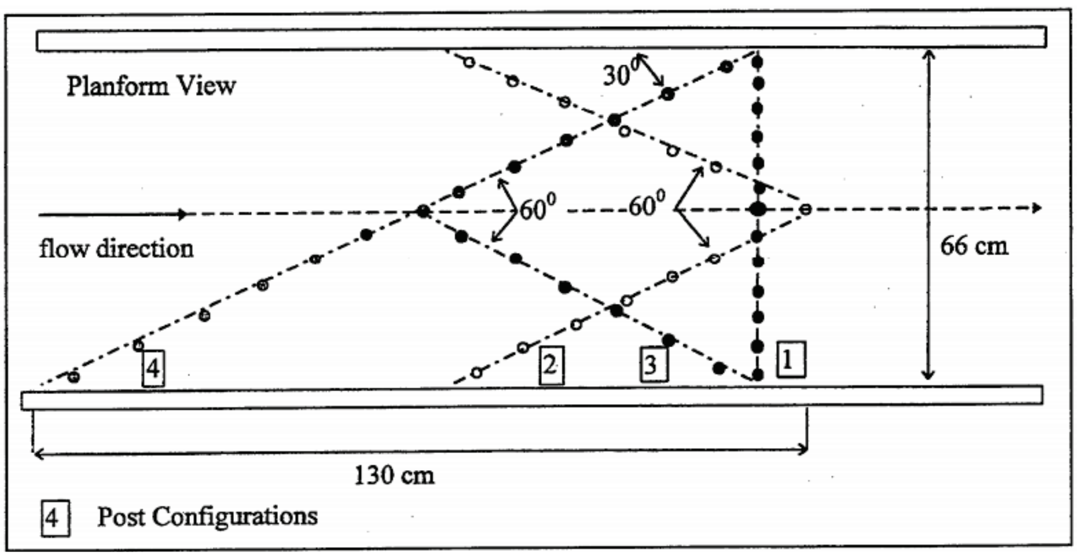
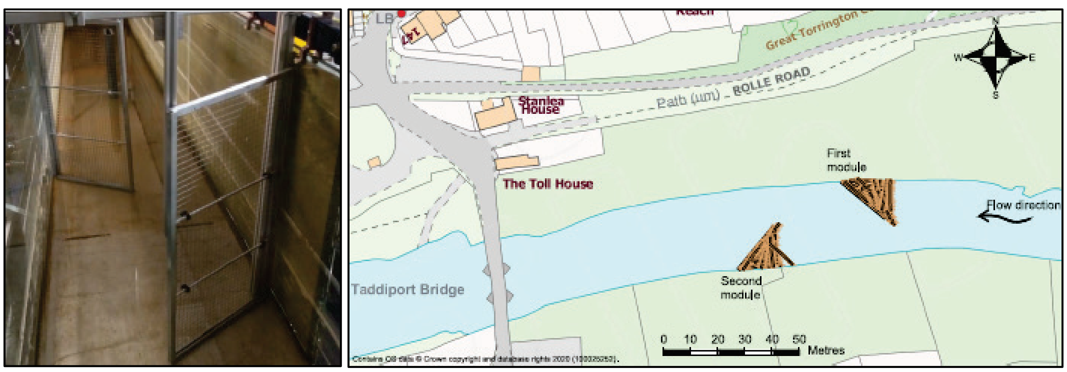


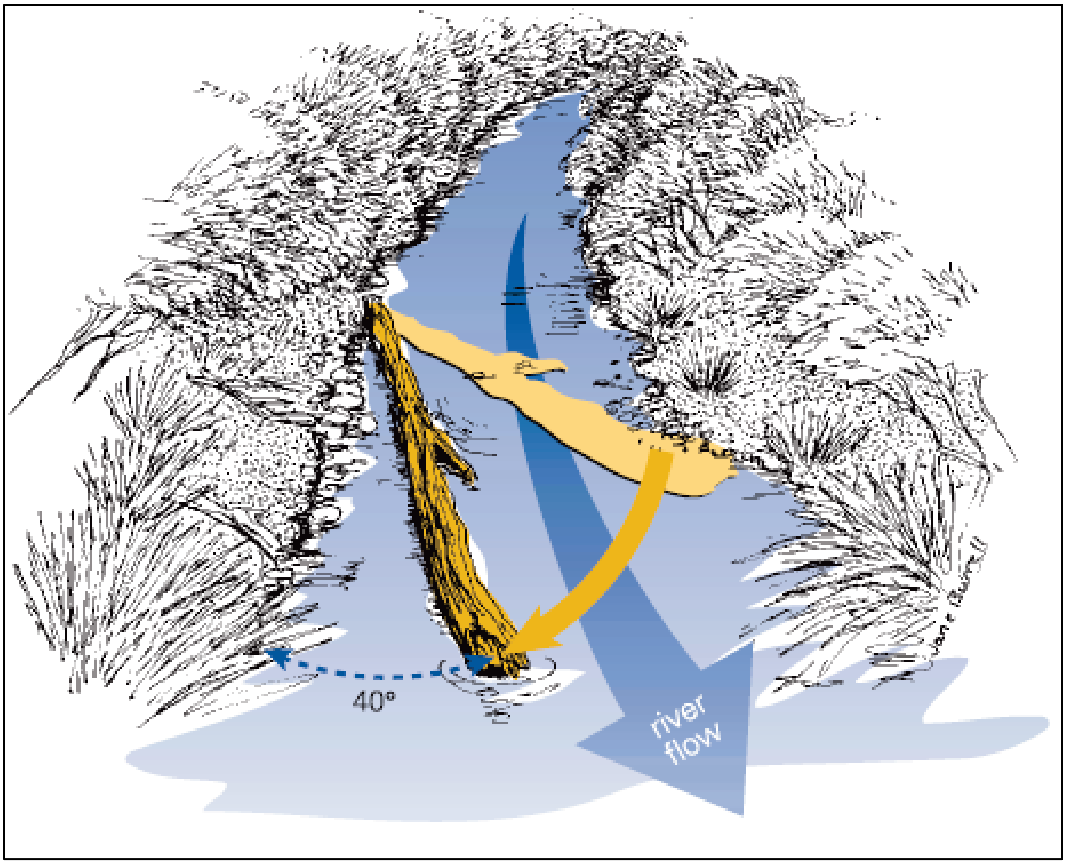
Figure 12. Debris dam made of timber (Bradley et al. 2005).

Figure 13. Model debris gates in a flume (left) and proposed gate placement in study river (right) (Panici and Kripakaran 2021).



There are also recommendations on leaving LWD within rivers in non-extreme cases and repositioning large logs if necessary. For instance, rotating a log from perpendicular to the flow to 20° to 40° from the bank in the downstream direction (Figure 14) lessens the impedance to flow and diverts water away from the bank to reduce local scour (Rutherfurd et al. 2002; Mott 2006). However, these modifications would still pose the issue of time and funding to remove or move the LWD to the desired location.

Figure 14. Orientation of LWD to bank to reduce impedance to flow and bank erosion (Rutherfurd et al. 2002).



A possible solution to managing LWD not proposed in literature is to stabilize the river system to decrease bank erosion and debris supply, therefore reducing the supply of LWD that comes from trees falling in from bank erosion and caving. While LWD within rivers is needed for habitat and can be helpful for stability, ensuring the river system is in dynamic equilibrium and not experiencing excessive bank and bed erosion can lessen the degree to which LWD is entering the system and ideally eliminate the excess of LWD causing problems.

3 Conclusions and Recommendations

There is a wide range of geomorphic, hydrologic, and FRM information developed from various groups on the Tar-Pamlico and Neuse River watersheds. This report is a result of concentrated efforts to review and describe existing conditions as they relate to LWD in the river systems and if there are any existing options or technological advancements for potential management of those materials. Based on evaluation of existing data and review of literature, this section provides a summary of conclusions and recommendations.

3.1 Conclusions

The Tar River around Tarboro, North Carolina, has a considerable amount of LWD, though the size and magnitude of debris has not been quantified and it has not been determined that the presence of this debris is the cause of flooding along the river. Photos collected at the same time as the debris data show areas of bank erosion, which could be contributing to the debris in the system, and therefore addressing system-wide stability could alleviate the issue of debris being added to the system. However, as most reaches in the basin are aggradational or in equilibrium, with only a few upper reaches being degradational, these bank erosion sites generally reflect local instabilities associated with meander migration and obstructions caused by debris and are not symptomatic of system-wide instabilities associated with degradation. This topic warrants further investigation.

The Neuse River Basin, based on rating curve analyses, appears to have more geomorphic instabilities and areas of degradation compared to the Tar-Pamlico. There are currently no data on the extent of debris within the basin. Current debris removal options were described in Section 1.1.1, and in reviewing the information, there does not appear to be any new technology at this time to remove debris from river systems besides manual removal, as has been done in past. The best option would be to determine watershed-wide issues with stability and concentrate efforts to restore the stability in rivers to reduce erosion and limit the supply of debris. The main issue with accumulation of debris is threat to infrastructure, so a program to monitor and remove excess debris at critical infrastructure locations is needed.

Both the Tar and Neuse Rivers have been the subject of several ecological and FRM studies within the past several years. The analyses within existing reports provide options for flood mitigation at varying levels locally and can be used to better inform comprehensive FRM decisions within the basins moving forward.

3.2 Recommendations

Based on existing information summarized in this report, the following list of recommendations was compiled.

- While the existing dataset on LWD in the Tar River is helpful, it is limited in extent and information. It is recommended that further debris data be collected and quantified for a larger extent of the river. This is especially important at locations where critical public infrastructure exists and vicinities around larger urbanized population centers.
- Location of debris sources and identification of geomorphic and erosional processes that are leading to increased supplies of LWD need to be identified. Geomorphic watershed studies are recommended to assess these issues. A potential starting point is to investigate the reach relationships to aggradational, degradational, and equilibrium areas identified in the specific gage analysis.
- In researching removal of LWD options, no new technologies were discovered. A summary of the typical LWD removal options is listed in Section 1.1.1 of this report.
- As LWD is impacting bridges, roadways, and other infrastructure, it is highly recommended that a program be developed to monitor buildup at these critical locations. The program should develop identification, monitoring, and mitigation strategies to provide guidance on removal of LWD in the Tar River system. For example, after large flow events, critical areas identified in a comprehensive monitoring plan should be evaluated for debris accumulation. If the areas have accumulated substantial LWD, as defined in the monitoring plan, then mitigation strategies for LWD removal are set in place and priority removal is completed.
- Further geomorphic assessment in both basins is recommended. The existing reports contain valuable information regarding basin development and information regarding rainfall and runoff trends, but the most recent reports for the basins are from 2016 and 2018 data. Several significant storm events have occurred in the area of interest

since (Hurricane Matthew in 2016 and Hurricane Florence in 2018, for example), development has continued, and more recent land use data has been published such as NLCD data collected in 2019. Therefore, updated values and analyses are recommended to better inform flood risk decisions.

- Given the hydraulic rating curve data that have been collected for the Neuse River Basin, it is recommended that a specific gage analysis be conducted to provide additional information on geomorphic trends within the Neuse River system.
- USACE has recently developed a geomorphic watershed assessment approach with the FluvialGeomorph (FG) toolkit (Haring et at. 2020; Haring and Biedenharn 2021). FG uses existing high-resolution terrain data and other survey data (if available) to assess geomorphic conditions within watersheds. This tool, or others, could be used to identify locations of instability within the rivers such as knick points, over-widening conditions, active floodplain connections, and others so that efforts can be focused to address the sources of instability within the basins. For example, on the Tar River, reaches that are identified as degradational could be further investigated using FG to identify channel stability issues and concentrate stabilization and restoration efforts in order to reduce erosion and LWD supply. On the Neuse River, reaches identified as aggradational can be further investigated to assess the effect of aggradation and resulting decrease in channel capacity. Identification of potential areas of impact to flooding and flood risk management within the basin can then be located.

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Appendix: Selection of Tar River Debris Photos

Figure A-1. Fallen tree in the Tar River near Tarboro, NC.

Figure A-2. A tree at risk of falling into the river as erosion occurs at its roots, seen in the Tar River near Tarboro, NC.

Figure A-3. Smaller amounts of LWD along banks in the Tar River near Tarboro, NC.

Figure A-4. Bank caving and LWD in the Tar River near Tarboro, NC.

Figure A-5. LWD along banks of Tar River near Tarboro, NC.

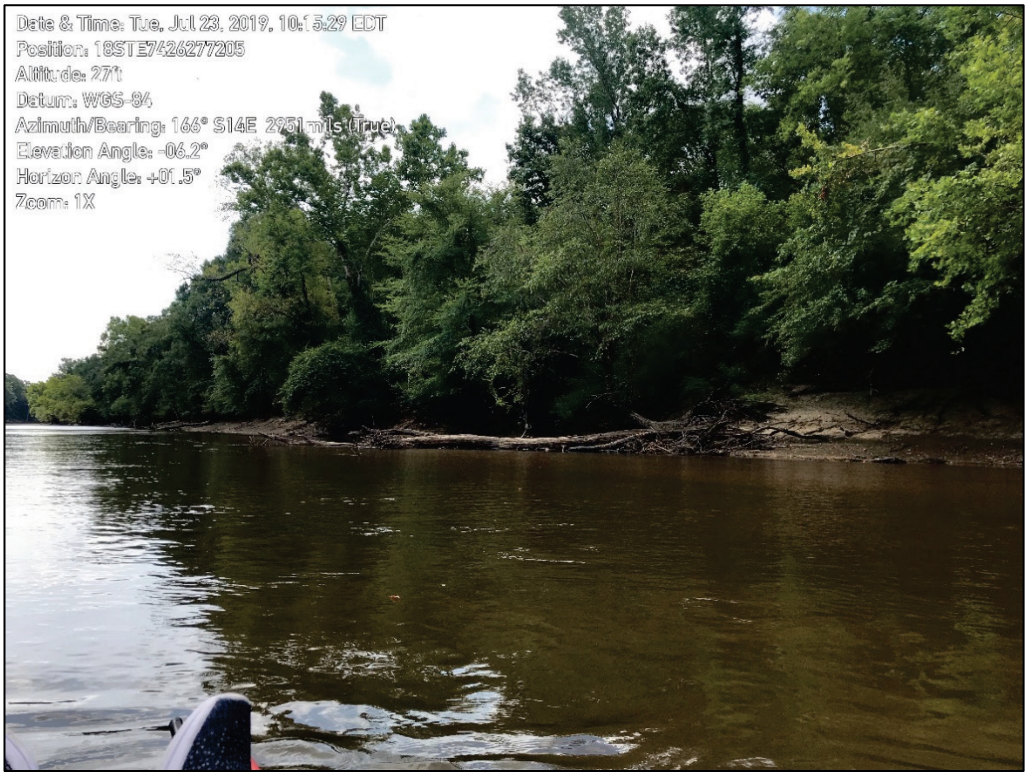

Figure A-6. Large pile of LWD in the Tar River near Tarboro, NC. Person and kayak for size reference.

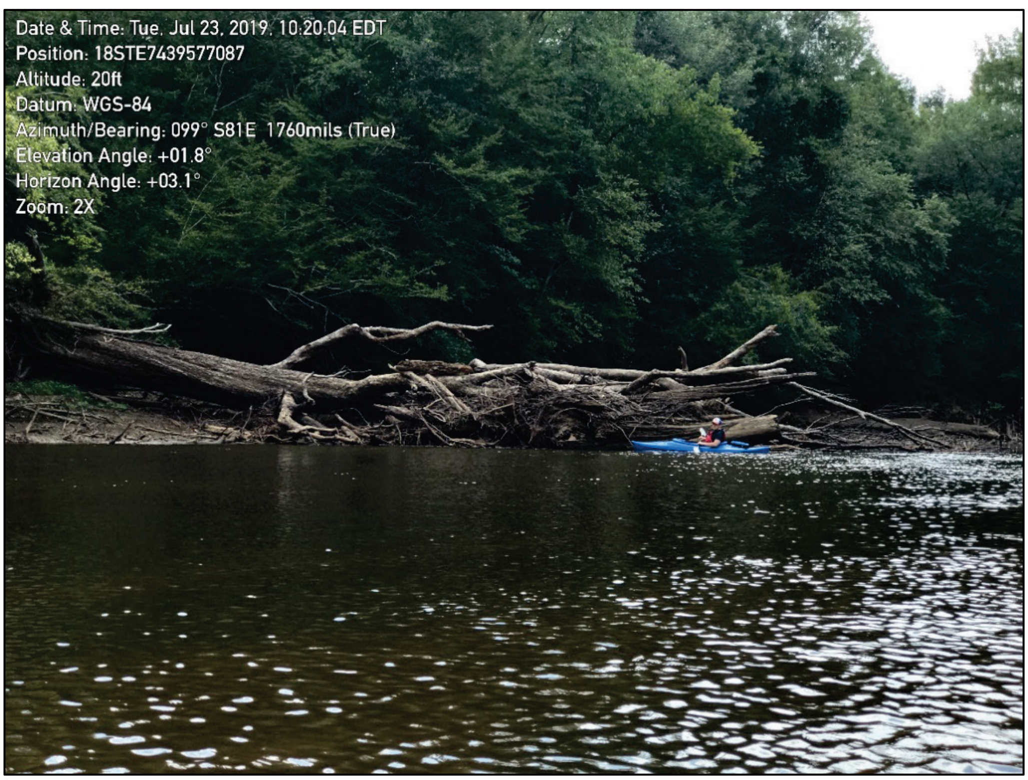

Figure A-7. Small pile of LWD in the Tar River near Tarboro, NC. Person and kayak for size reference.

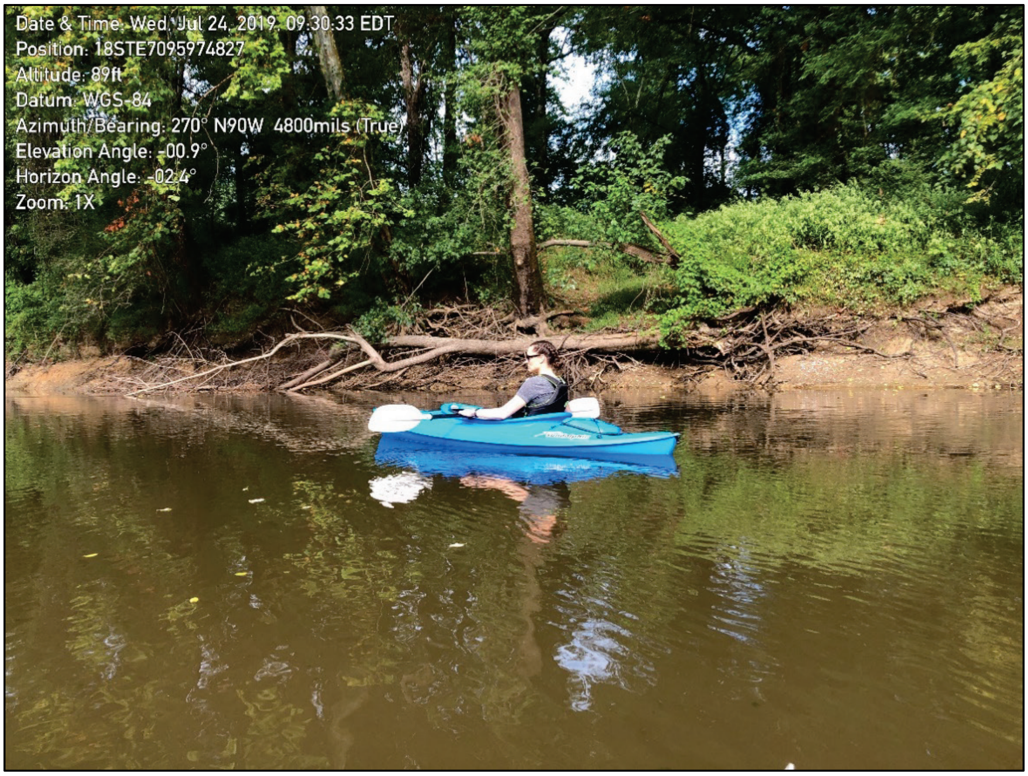

Figure A-8. Possible past stabilization efforts on the Tar River near Tarboro, NC.

Figure A-9. A tree at risk of falling into the river as the soil around the roots erodes, seen on the Tar River near Tarboro, NC.

Figure A-10. Submerged LWD on the Tar River near Tarboro, NC.

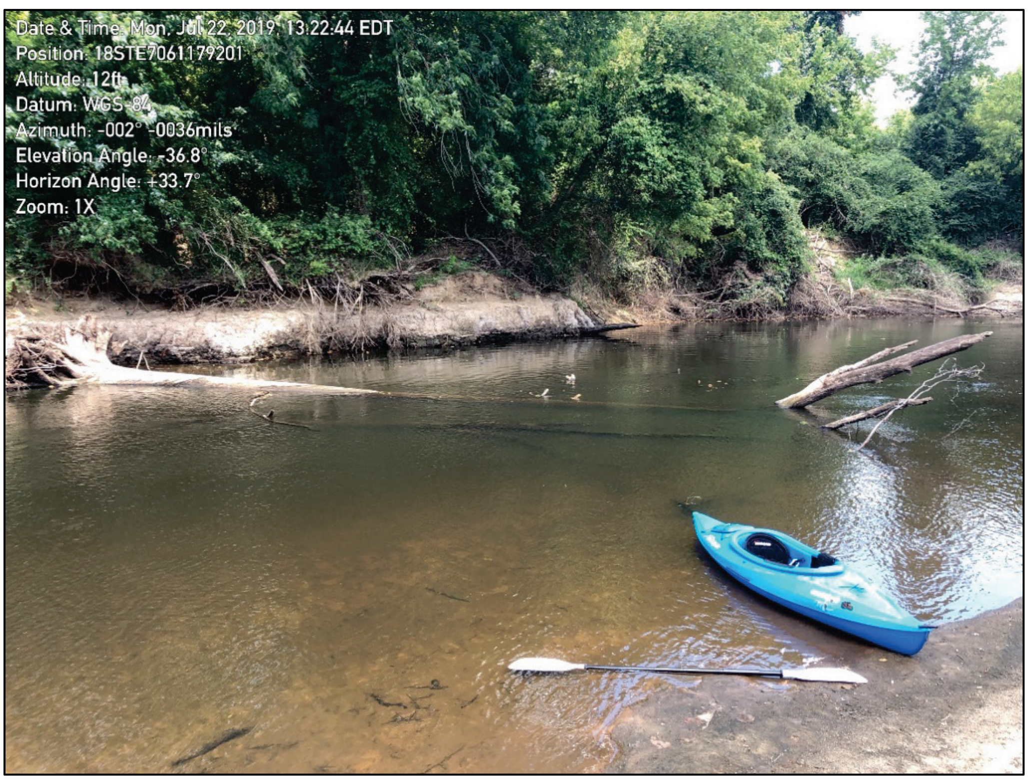

Figure A-11. LWD along the bank of the Tar River near Tarboro, NC.

Figure A-12. Tar River near Tarboro, NC will LWD present, but not across the entirety of the channel.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	0.0254	meters
miles (US statute)	1,609.347	meters
square feet	0.09290304	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

Abbreviations

CHL	Coastal and Hydraulics Laboratory
ERDC	US Army Engineer Research and Development Center
FG	FluvialGeomorph
FRM	Flood risk management
LRH	Huntington District
LWD	Large woody debris
NCDOT	North Carolina Department of Transportation
NCEM	North Carolina Division of Emergency Management
NLCD	National Land Cover Dataset
SAW	Wilmington District
USACE	US Army Corps of Engineers
USGS	US Geological Survey

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14. ABSTRACT
The Tar-Pamlico and Neuse River Basins are neighboring basins in eastern North Carolina, both originating in the piedmont physiographic region, transitioning to coastal plains, and emptying into Pamlico Sound. The Pittsburgh District is responsible for the continued efforts to assist local sponsors with managing these basins and submitted a Water Operations Technical Support (WOTS) request. The WOTS program, funded by Headquarters, US Army Corps of Engineers, provides funding for the Coastal and Hydraulics Laboratory (CHL) to provide technical assistance to develop innovative solutions to water resource problems. The objectives of this study are to identify flood risk management alternatives to address the accumulation of woody debris in the channel systems. CHL compiled existing conditions information and researched current and potential new methods for managing woody debris to provide a comprehensive list of recommendations. The results and recommendations are provided in this document.

15. SUBJECT TERMS
Coarse woody debris, Flood control, Neuse River Watershed (N.C.), Pamlico Sound (N.C.), Tar River Watershed (Person County-Beaufort County, N.C.)

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