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Subtask 2.4: Hydrologic and Hydraulic Modeling Gap Analysis

North Carolina Flood Resiliency Blueprint

Prepared for the North Carolina Department of Environmental Quality by AECOM and ESP Associates

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Definitions

A comprehensive list of definitions applicable to multiple Flood Resiliency Blueprint documents is provided in a separate document.

Acronyms

2D – Two Dimensional

ADCIRC – Advanced Circulation (coastal surge model)

AEP – Annual Exceedance Probability

APS – ADCIRC Prediction System

APSViz – APS visualization application

CERA – Coastal Emergency Risk Assessment

DFIRM - Digital Flood Insurance Rate Map

EAP – Emergency Action Plan

ERDC – United States Corps of Engineers Engineering Research and Development Center

FEMA – Federal Emergency Management Agency

FIS - Flood Insurance Study

FRIS – Flood Risk Information System

HEC-HMS – Hydrologic Engineering Center Hydrologic Modeling System; Open-source model developed by the United States Army Corps of Engineers

HEC-RAS – Hydrologic Engineering Center River Analysis System; Open-source model developed by the United States Army Corps of Engineers

H&H – Hydrology and Hydraulics

HUC – Hydrologic Unit Code

ICM – Integrated Catchment Modeling; Proprietary model developed by InfoWorks

ICPR – Interconnected Channel and Pond Routing; Proprietary model developed by Streamline Technologies

LiDAR - Light Detection and Ranging

MWBM - Monthly Water Balance Model

NA – Not Available

NC – North Carolina

NCDEQ – North Carolina Department of Environmental Quality

NCDOT – North Carolina Department of Transportation

NCEM – North Carolina Emergency Management

NCFMP – North Carolina Floodplain Mapping Program

NHC – National Hurricane Center

NHM – National Hydrologic Model

NOAA – National Oceanic and Atmospheric Administration

NWM – National Water Model

NWS – National Weather Service

OASIS – Options Analysis in Irrigation Systems; Open-Source model developed by Dr. Nicolas Roost

P-Surge – Probabilistic Storm Surge model

PNNL – Pacific Northwest National Laboratory

PRMS - Precipitation-Runoff Modeling System

RENCI – Renaissance Computing Institute

RIFT – Rapid Infrastructure Flood Tool

SACS - South Atlantic Coastal Study

SDP - SLOSH Display Program

SFC – State Floodplain Compliance

SLOSH – Sea Lake and Overland Surges from Hurricanes (coastal surge model)

SLR – Sea Level Rise

SMS – Surface-water Modeling System; Proprietary model developed by Aquaveo

SRH-2D – Sediment and River Hydraulics – Two Dimension; Open-Source model developed by the US Bureau of Reclamation

STWAVE – Steady-state spectral Wave model

SWAN – Simulated Waves Nearshore (coastal wave model)

SWAT – Soil and Water Assessment Tool

UNC – University of North Carolina

US – United States

USACE – United States Army Corps of Engineers

USGS – United States Geological Survey

WRF – Weather Research and Forecasting

XPSWMM – Stormwater Wastewater Management Model; Proprietary model developed by XP Software (additional versions by Innovyze and Aqauveo)

1 Introduction

Purpose: Subtask 2.4 – Report on Hydrology and Hydraulic (H&H) modeling studies: age, scale, level of detail, modeling platform (e.g., open source or proprietary), flood hazards modeled, and considerations for future risk.

The intent of this document is to identify and evaluate H&H modeling within North Carolina that could be available for use in projects performed as part of the North Carolina Flood Resiliency Blueprint (Blueprint). Specifically, this document is intended to provide a Gap Analysis for H&H modeling available within the state, including those developed as part of resiliency assessments . Efforts were made to capture all H&H modeling that could be made available through coordination with Blueprint stakeholders and that either already had associated products that could support evaluation and decision-making regarding proposed projects intended to reduce flood impacts projects or could be used to develop such products . H&H modeling information is a critical component of a successful flood resiliency effort. Results and data from H&H modeling provide valuable flood hazard information that is necessary to perform risk assessments for events with known probability of occurrence. Risk assessments link the flood hazards identified in the H&H modeling to estimated damages enabling the evaluation of the effectiveness of mitigation and resiliency projects. Combined with risk assessments, H&H modeling products, when presented correctly, also provide valuable outreach opportunities to stakeholders for project understanding and buy-in.

For purposes of this document, H&H models can be broken down into the following categories:

- **Hydrologic Models**: Input-output models that simulate the water cycle using the water balance equation. These models can focus on flow (quantity) as well as chemical/physical properties (quality) of water. When used for flood studies, the models calculate runoff that occurs during a precipitation event . Input parameters typically include precipitation (volume and timing distribution) and runoff parameters based on soil and landcover data. The models use a variety of methods to transform the rainfall into runoff and provide flow data (peak, volume, and timing) as an output .
- **Hydraulic Models**: Input-output models that use flow data obtained from hydrologic models to calculate streamflow characteristics including water surface elevation, depth and width of water, and velocity. Hydraulic models rely heavily on accurate topographic data and hydraulic parameters such as the Manning's roughness coefficient, a value that represents a surface's resistance to flow. Hydraulic models can further be broken down into one- and two-dimensional (2D). One-dimensional models assume flow only moves in one general direction (upstream to downstream), whereas 2D models calculate flow in any lateral direction. One-dimensional models are generally simpler and easier to use but limited in extent (most only model a single reach of a stream). Two-dimensional models often cover a large area and can be setup to include all the potential flooding sources within that area. Some 2D models have now integrated hydrologic calculations with the hydraulic model which can reduce the effort of translating hydrologic model output to a hydraulic model input. Two-dimensional models do require more intensive processing and may take several hours to calculate depending on the size and level of detail.

Both hydrologic and hydraulic models may be open source (free to use) or proprietary (pay for license to use). Proprietary models may provide enhanced features or products that some stakeholders find valuable, but their use can be limited if licenses are required . In general, open-source models provide comparable features and products to proprietary models and are widely used/accepted within the flood modeling community .

This document will overview the H&H modeling sources identified in this effort and note gaps that exist within the dataset pertaining to the following criteria: age, scale (spatial extent), level of detail, modeling platform availability, flood hazards modeled, and considerations for future risk.

2 State Agency Datasets

2.1 North Carolina Floodplain Mapping Program Regulatory Riverine Modeling

Beginning in the year 2000, North Carolina became the first Cooperating Technical State with the Federal Emergency Management Agency (FEMA) in the management of the National Flood Insurance Program. This partnership resulted in one of the most well-known and pro-active statewide floodplain mapping programs. The North Carolina Floodplain Mapping Program (NCFMP) has performed flood insurance studies (FISs) to update digital flood insurance rate maps (DFIRMs) across the entire state and is currently in a map maintenance phase.

Studies are performed with varying levels of detail including:

- **Detailed** - Multiple flood events with varying probability of occurrence (also known as flood profiles) analyzed with regulatory floodway (the channel of a stream and the adjacent land area that must be reserved in order to discharge the base flood with cumulatively increasing the water surface elevation more than a designated height) and field survey of hydraulic structures (bridges, culverts, dams, levees) and cross sections incorporated into model geometry. This is the highest level of study performed for regulatory modeling for FEMA.
- **Limited Detail** – A 1-percent-annual-chance profile (also known as the 100-year flood or base flood) only modeled with advisory non-encroachment area (the portion of the floodplain where construction, placement of fill, or similar alteration of topography may be prohibited by a community due to the effects such development would have on the conveyance of discharge) and field or light detection and ranging (LiDAR) based measurements and photos of hydraulic structures (no field survey). This level of study is less accurate than “detailed” but can be performed at reduced effort/cost . The hydraulic structures (e.g., bridges, culverts) may be somewhat crude due to the lack of survey data and the channel dimensions are typically approximated.
- **Approximate** – A 1 percent-annual-chance (100-year or base flood) floodplain delineation with no base flood elevations determined (also called unnumbered Zone A). Often these studies lack a model entirely or depend on a model with no hydraulic structures or field survey incorporated. These studies can be significantly out of date and inaccurate. They have largely been replaced but can still be found in parts of the state. The original floodplain delineations may have been based on soil maps or other information.
- **Redelineation** – Older detailed studies that used older models (typically HEC-2). These studies include multiple flood events with varying probabilities whose model results have been re-mapped on updated topographic data. Although originally based on detailed survey data available at the time of model production, these studies can be significantly out of date and are gradually being replaced with new models.

The NCFMP developed an enterprise database to house the supporting data associated with the flood mapping efforts including field survey, H&H modeling and results, and mapping products necessary for the development of the FISs and DFIRMs. This data is available through the Flood Risk Information System (FRIS) website. Table 1 provides summary information for the NCFMP regulatory modeling dataset.

Table 1: NCFMP Regulatory Modeling Dataset Information

NCFMP Regulatory Riverine Modeling	
Source of Information	North Carolina Emergency Management – Floodplain Mapping Program
Link to Online Data	https://fris.nc.gov/fris/Home.aspx?ST=NC
Data Owner	State of North Carolina
Date Created	2000
Date of Access	February 2023
Frequency of Updates	Annual funding for cyclical updates throughout the state
Update Needed	Yes – Regular updates necessary to maintain reliable products

Table 2 below describes the criteria used to perform the gap analysis. The actual criteria are presented in Table 3.

Table 2: NCFMP Regulatory Modeling Gap Analysis Criteria Description

Criteria Description	
Age	The average age of models available from currently effective studies.
Scale (Spatial Extent)	The dataset is statewide. To better gauge modeling coverage, the total miles of regulatory study within each hydrologic unit code (HUC) 8 is compared to the total estimated miles of streams draining ½ square mile (considered to be a minimum drainage area feasible for a regulatory H&H model) and calculated as a %.
Level of Detail	The % of study performed with each study type; Detailed, Limited Detail, Approximate, and Redelineation.
Modeling Platform Availability	Open source (free to use) or proprietary (pay for license) modeling software.
Flood Hazards Modeled	Flood recurrence interval events analyzed.
Future Conditions	The % of miles with future conditions compared to the total estimated miles of streams draining ½ square mile . For purposes of this dataset, future conditions are based on build-out conditions and do not include any climate change considerations.

The requested gap analysis criteria were analyzed by summarizing the statewide H&H model information available in the NCFMP enterprise database by 8-digit hydrologic unit code (HUC 8).

Figure 1, Figure 2, and Figure 3 below present the regulatory modeling dataset's age, scale (coverage), and level of detail (percent detailed study) summarized by HUC 8. Table 3 summarizes the gap analysis criteria by HUC 8.

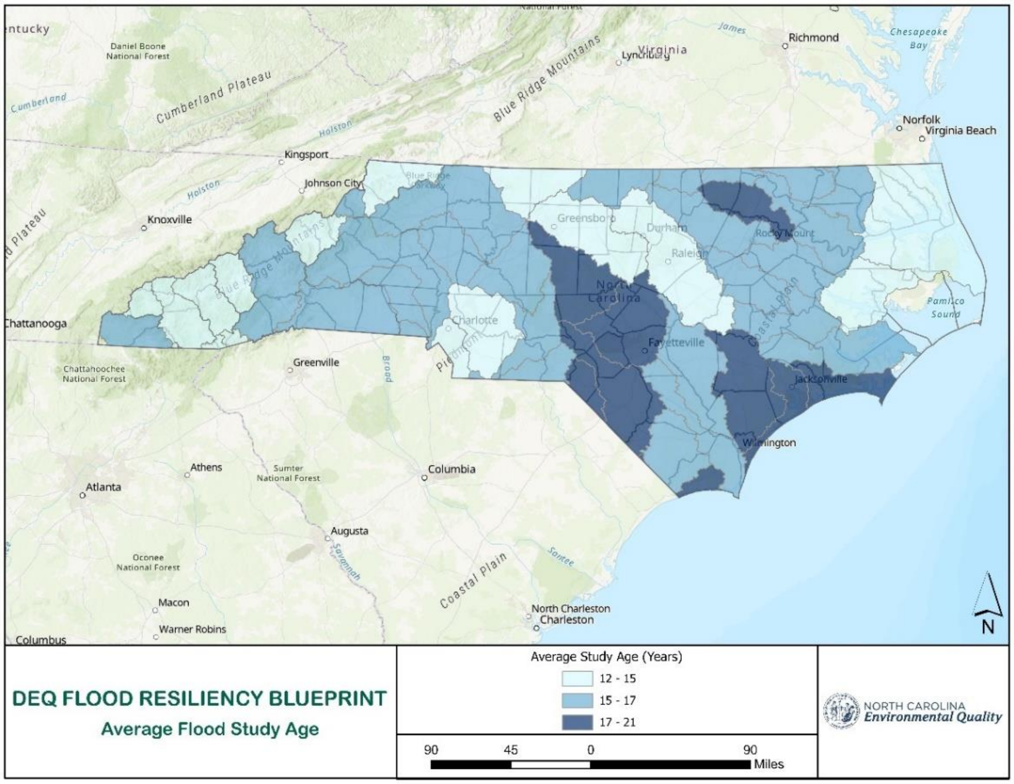

Figure 1: NCFMP Regulatory Modeling Age

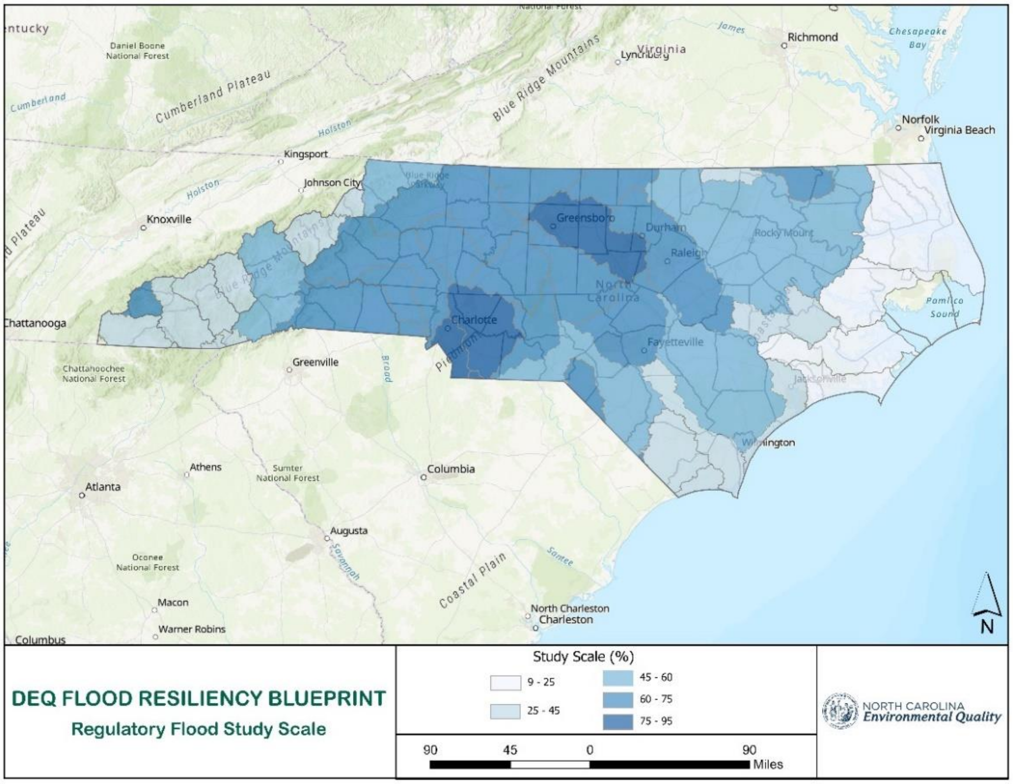

Figure 2: NCFMP Regulatory Modeling Scale (Coverage)

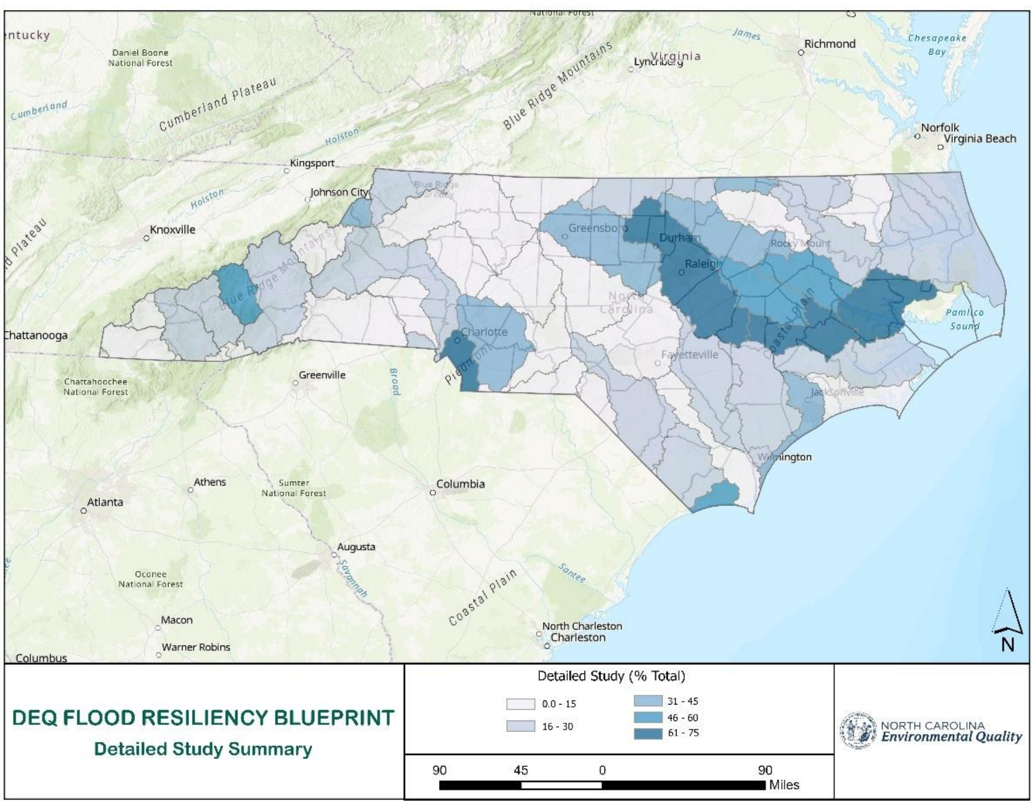

Figure 3: NCFMP Regulatory Modeling % Detailed Study

Table 3: NCFMP Regulatory Modeling Gap Analysis Criteria

HUC 8	Age (yrs)	Scale (%)	Level of Detail (%)	Modeling Platform Availability	Flood Hazards Modeled	Future Conditions (%)
03010102	16	45%	Detailed: 17.8% Limited Detail: 82.1% Redelineation: 0.1% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03010103	15	62%	Detailed: 4.4% Limited Detail: 89.3% Redelineation: 6.3% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03010104	17	63%	Detailed: 19.9% Limited Detail: 73.3% Redelineation: 6.8% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03010106	17	43%	Detailed: 32% Limited Detail: 52.6% Redelineation: 15.4% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03010107	17	51%	Detailed: 28.1% Limited Detail: 64.8% Redelineation: 6.5% Approximate: 0.6%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03010203	16	51%	Detailed: 2.6% Limited Detail: 92.4% Redelineation: 5% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03010204	16	68%	Detailed: 16.2% Limited Detail: 83.8% Redelineation: 0% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03010205	15	10%	Detailed: 24.8% Limited Detail: 72.6% Redelineation: 2.6% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03020101	17	55%	Detailed: 44% Limited Detail: 55.6% Redelineation: 0.4% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03020102	18	46%	Detailed: 8.8% Limited Detail: 82.8% Redelineation: 8.4% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%

HUC 8	Age (yrs)	Scale (%)	Level of Detail (%)	Modeling Platform Availability	Flood Hazards Modeled	Future Conditions (%)
03020103	17	50%	Detailed: 47.5% Limited Detail: 51.5% Redelineation: 0.8% Approximate: 0.2%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03020104	13	13%	Detailed: 70.3% Limited Detail: 27.8% Redelineation: 1.9% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03020201	13	73%	Detailed: 65.1% Limited Detail: 34.4% Redelineation: 0.5% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	16%
03020202	16	42%	Detailed: 65.1% Limited Detail: 33.6% Redelineation: 1.3% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03020203	16	51%	Detailed: 55.6% Limited Detail: 44.4% Redelineation: 0% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0.09%
03020204	17	22%	Detailed: 19.7% Limited Detail: 78.3% Redelineation: 2% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03020301	21	22%	Detailed: 6.8% Limited Detail: 87.7% Redelineation: 5.5% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03020302	19	40%	Detailed: 30.9% Limited Detail: 56.5% Redelineation: 12.5% Approximate: 0.1%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03030002	14	91%	Detailed: 32.4% Limited Detail: 52.2% Redelineation: 15.4% Approximate: 0%	Open: HEC-RAS, SWMM	10%, 4%, 2%, 1%, 0.2%	4.7%
03030003	18	74%	Detailed: 12.2% Limited Detail: 76.3% Redelineation: 10.5% Approximate: 1%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%

HUC 8	Age (yrs)	Scale (%)	Level of Detail (%)	Modeling Platform Availability	Flood Hazards Modeled	Future Conditions (%)
03030004	18	65%	Detailed: 13.6% Limited Detail: 62.6% Redelineation: 18.3% Approximate: 5.5%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03030005	17	33%	Detailed: 13.6% Limited Detail: 62.6% Redelineation: 18.3% Approximate: 5.5%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03030006	16	48%	Detailed: 18% Limited Detail: 80.8% Redelineation: 1.2% Approximate: 0%	Open: HEC-RAS. Proprietary: ICPR, XPSWMM	10%, 4%, 2%, 1%, 0.2%	0%
03030007	18	50%	Detailed: 18% Limited Detail: 76.3% Redelineation: 4.7% Approximate: 1%	Open: HEC-RAS. Proprietary: XPSWMM	10%, 4%, 2%, 1%, 0.2%	.9%
03040101	16	63%	Detailed: 7.9% Limited Detail: 76.1% Redelineation: 16% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03040102	16	61%	Detailed: 10.2% Limited Detail: 85.7% Redelineation: 4.1% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03040103	16	63%	Detailed: 13% Limited Detail: 60% Redelineation: 27% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03040104	16	62%	Detailed: 9.8% Limited Detail: 86.7% Redelineation: 3.3% Approximate: 0.2%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03040105	14	84%	Detailed: 42.9% Limited Detail: 51.5% Redelineation: 5.6% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	10.4%
03040201	16	57%	Detailed: 9.4% Limited Detail: 86.9% Redelineation: 3.7% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%

HUC 8	Age (yrs)	Scale (%)	Level of Detail (%)	Modeling Platform Availability	Flood Hazards Modeled	Future Conditions (%)
03040202	16	94%	Detailed: 0% Limited Detail: 100% Redelineation: 0% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03040203	18	52%	Detailed: 23.2% Limited Detail: 75.1% Redelineation: 1.7% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03040204	20	63%	Detailed: 9.5% Limited Detail: 90.5% Redelineation: 0% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03040206	17	40%	Detailed: 25.8% Limited Detail: 72.9% Redelineation: 0% Approximate: 1.3%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03040208	20	37%	Detailed: 51.1% Limited Detail: 45.7% Redelineation: 0% Approximate: 3.2%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03050101	16	65%	Detailed: 19.8% Limited Detail: 60.2% Redelineation: 20% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	3.4%
03050102	17	70%	Detailed: 12.8% Limited Detail: 57.6% Redelineation: 29.6% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
03050103	13	89%	Detailed: 63.6% Limited Detail: 34% Redelineation: 2.4% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	47%
3050105	16	61%	Detailed: 12.6% Limited Detail: 84.4% Redelineation: 0% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
3060101	15	61%	Detailed: 9.3% Limited Detail: 90.7% Redelineation: 0% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%

HUC 8	Age (yrs)	Scale (%)	Level of Detail (%)	Modeling Platform Availability	Flood Hazards Modeled	Future Conditions (%)
3060102	15	28%	Detailed: 0% Limited Detail: 94.3% Redelineation: 0% Approximate: 5.7%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
5050001	15	51%	Detailed: 25.6% Limited Detail: 43% Redelineation: 31.4% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
6010103	16	41%	Detailed: 44.5% Limited Detail: 44% Redelineation: 11.5% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
6010105	16	48%	Detailed: 20.7% Limited Detail: 51.4% Redelineation: 26% Approximate: 1.9	Open: HEC-RAS, HEC-2	10%, 4%, 2%, 1%, 0.2%	0%
6010106	15	27%	Detailed: 46.3% Limited Detail: 46.4% Redelineation: 6.4% Approximate: 0.9%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
6010108	15	43%	Detailed: 9.3% Limited Detail: 64.3% Redelineation: 24.4% Approximate: 2%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
6010202	14	36%	Detailed: 17.7% Limited Detail: 77.7% Redelineation: 0% Approximate: 4.6%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
6010203	15	35%	Detailed: 18.4% Limited Detail: 64% Redelineation: 17.1% Approximate: 0.5%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
6010204	12	66%	Detailed: 6.3% Limited Detail: 62.6% Redelineation: 0% Approximate: 31.1%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%
6020002	16	39%	Detailed: 13.9% Limited Detail: 76.5% Redelineation: 9.6% Approximate: 0%	Open: HEC-RAS	10%, 4%, 2%, 1%, 0.2%	0%

HUC 8	Age (yrs)	Scale (%)	Level of Detail (%)	Modeling Platform Availability	Flood Hazards Modeled	Future Conditions (%)
Total Average	16	52%	Detailed: 23.8% Limited Detail: 67.2% Redelineation: 7.7% Approximate: 1.3%	N/A	N/A	3.3%

Table 4 presents gaps identified in the NCFMP regulatory modeling dataset.

Table 4: NCFMP Regulatory Modeling Data Gaps

Identified Gaps	
Age	• The average age of the currently effective regulatory models across the state is 16 years. Many models are therefore based on outdated data (LiDAR, gauge records, hydraulic structures, etc.). Many models have already been updated and are either preliminary or planned preliminary and subject to change during their regulatory appeal period. These updated models may still be used as the best available data . Additional coordination with the NCFMP and use of the North Carolina Coordinated Needs Management Strategy Database would provide insight on the extent of completed studies not yet effective that could be available for use in the Blueprint.
Scale (Spatial Extent)	• The average coverage of effective regulatory studies over streams draining at least ½ sq mile is 52%.
Level of Detail	• Many studies are based on redelineation (typically dated HEC-2 models), approximate (model availability uncertain), or limited detail (no field survey). • NCFMP has performed "Model Upgrades" to add missing profiles to models for purposes of multi-return water surface elevation raster datasets needed for multi-return flood risk assessments. These models are only available through specific request to the NCFMP.
Modeling Platform Availability	• None
Flood Hazards Modeled	• Not all models have all noted frequency events. Approximate and Limited Detailed studies are limited to the 1% annual chance event. Older Detail studies do not include the 4% annual chance event. The 1%+ (statistical upper limit of 1% annual chance event) could be added for awareness and conservatism.
Future Conditions	• Only 3.3% of effective regulatory study mileage across the state includes consideration for future conditions.

NCFMP's regulatory modeling dataset is one of the most complete statewide datasets of its kind in the country. This modeling, where available, should be considered as a starting point for additional H&H modeling efforts identified as part of the Blueprint. The primary gaps noted for age, scale, level of detail, flood hazards modeled, and future conditions are all being incrementally addressed as annual funding cycles from FEMA and the North Carolina (NC) Cooperating Technical Partners program allow.

2.2 North Carolina Emergency Management Base Level Modeling

During Hurricanes Matthew and Florence, the NCFMP located within NCEM, identified a large number of buildings impacted by flooding that were not located in regulatory study areas. In 2020, NCFMP undertook a new effort to use rain-on-grid 2D modeling with HEC-RAS to model entire HUC 10 basins. The goal of this effort was to produce advisory flood hazard information in previously unmapped areas to supplement the existing regulatory data. Unlike the regulatory modeling, which primarily uses Detailed and Limited Detail study approaches as explained in the previous section, the advisory modeling was performed using base-level methods. Base-level models are considered approximate and use a relatively coarse grid cell (100-200 feet in most areas). The models do not include hydraulic structures (bridges, culverts). In addition, flows along mainstems in non-headwater basins use baseflow only and do not carry the modeled flow from the upstream basin. The NCFMP developed an enterprise database to house the H&H modeling results and mapping products made available in the Advisory Mapping Viewer. Table 5 provides summary information for the NCFMP advisory modeling dataset.

Table 5: NCEM Base Level Modeling Dataset Information

NCEM Base Level Modeling	
Source of Information	North Carolina Emergency Management – Floodplain Mapping Program
Link to Online Data	https://flood.nc.gov/advisoryflood/
Data Owner	State of North Carolina
Date Created	2022
Date of Access	February 2023
Frequency of Updates	Annual funding for cyclical updates throughout the state
Update Needed	No

Table 6 below describes the criteria used to perform the gap analysis . The actual criteria are presented in Table 7.

Table 6: NCEM Base Level Modeling Gap Analysis Criteria Description

Criteria Description	
Age	The average age of model is provided.
Scale (Spatial Extent)	The total miles of advisory study within each HUC 8 is added to the regulatory miles and compared to the total estimated miles of streams draining ½ square mile (considered to be a minimum drainage area feasible for a regulatory H&H model). Basins with no advisory mapping available receive a "0". Note the % may be greater than 100 if there are more advisory miles identified than estimated miles of streams draining ½ square mile.
Level of Detail	The study type – Base Level
Modeling Platform Availability	Open source or proprietary modeling software.
Flood Hazards Modeled	Flood recurrence interval events analyzed.
Future Conditions	The % of miles with future conditions compared to the total estimated miles of streams draining ½ square mile. For purposes of this dataset, future conditions are increasing the 1% annual chance rainfall by 10, 20, and 30% to simulate potential future climate change conditions .

The requested gap analysis criteria were analyzed by summarizing the advisory H&H model information available in the NCFMP enterprise database by HUC 8. Figure 4 below presents the advisory modeling dataset's scale (coverage) summarized by HUC 8. Table 7 summarizes the gap analysis criteria by HUC 8.

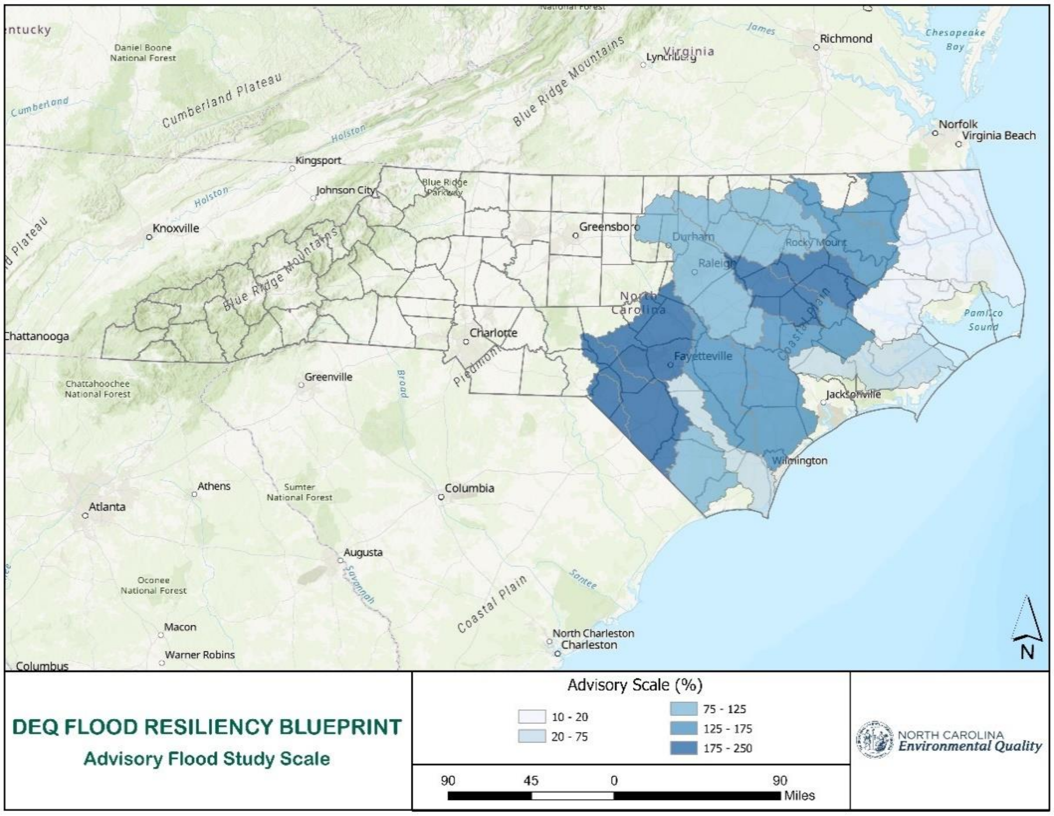

Figure 4: NCEM Base Level Modeling Scale (Coverage)

Table 7: NCEM Base Level Modeling Gap Analysis Criteria

HUC 8	Age (yrs)	Scale (%)	Level of Detail	Modeling Platform Availability	Flood Hazards Modeled	Future Conditions
3010102	NA	0%	NA	NA	NA	0%
3010103	NA	0%	NA	NA	NA	0%
3010104	NA	0%	NA	NA	NA	0%
3010106	NA	0%	NA	NA	NA	0%
3010107	2	150%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	150%
3010203	2	140%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	140%
3010204	NA	0%	NA	NA	NA	0%

HUC 8	Age (yrs)	Scale (%)	Level of Detail	Modeling Platform Availability	Flood Hazards Modeled	Future Conditions
3010205	2	17%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	17%
3020101	2	121%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	121%
3020102	2	118%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	118%
3020103	2	191%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	191%
3020104	2	13%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	13%
3020201	2	117%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	117%
3020202	2	163%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	163%
3020203	2	239%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	239%
3020204	2	47%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	47%
3020301	NA	0%	NA	NA	NA	0%
3020302	NA	0%	NA	NA	NA	0%
3030002	NA	0%	NA	NA	NA	0%
3030003	NA	0%	NA	NA	NA	0%

HUC 8	Age (yrs)	Scale (%)	Level of Detail	Modeling Platform Availability	Flood Hazards Modeled	Future Conditions
3030004	2	231%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	231%
3030005	2	62%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	62%
3030006	2	164%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	164%
3030007	2	125%	Base Level	Open: HEC-RAS	20-, 10-, 4-, 2-, 1-, 1+, 0.5-, 0.2-, 0.1%, and 1% with 10-, 20-, and 30% increases in rainfall	125%
3040101	NA	0%	NA	NA	NA	0%
3040102	NA	0%	NA	NA	NA	0%
3040103	NA	0%	NA	NA	NA	0%
3040104	NA	0%	NA	NA	NA	0%
3040105	NA	0%	NA	NA	NA	0%

Table 8 presents gaps identified in the NCEM base level modeling dataset.

Table 8: NCEM Base Level Modeling Data Gaps

Identified Gaps	
Age	• None currently, however, a maintenance cycle needs to be established to keep current.
Scale (Spatial Extent)	• Where advisory mapping exists, it provides particularly good coverage of flood hazards up to and beyond ½ sq mile in many locations. The dataset is not yet statewide although additional studies are ongoing.
Level of Detail	• The models are base-level. No field survey of hydraulic structures. • Downstream basins only include baseflow from upstream basins so mainstem flooding can be unconservative. However, mainstem flooding is covered by regulatory models in separate dataset.
Modeling Platform Availability	• Modeling software is open source, but models are not readily available for download. Coordination with NCEM needed.

Identified Gaps	
Flood Hazards Modeled	• None
Future Conditions	• Climate change runs consider increases to 1% rainfall depth only. Future land use depicting more development and increased runoff potential not analyzed.

North Carolina's initial efforts at developing an advisory modeling dataset has provided awareness of the capability of large-scale two-dimensional base-level modeling to improve flood hazard and risk identification for flooding sources not covered by regulatory modeling. The primary gap in the dataset at this time is the extent/scale across the state. Only a portion of the state has been modeled using this approach. Once this dataset's extent can be expanded to cover the state, it in addition to the regulatory modeling will likely provide the necessary foundation to develop and expand H&H modeling needs as identified as part of the Blueprint.

2.3 North Carolina Emergency Management Dam Breach Modeling

North Carolina Dam Safety maintains a hazard classification system including; "Class A (Low)" – Failure may damage uninhabited low value non-residential buildings, agricultural land, or low volume roads, "Class B (Intermediate)" - failure may damage highways or secondary railroads, cause interruption of use or service of public utilities, cause minor damage to isolated homes, or cause minor damage to commercial and industrial buildings, and "Class C (High)" - failure will likely cause loss of life or serious damage to homes, industrial and commercial buildings, important public utilities, primary highways, or major railroads. Following Hurricane Matthew in 2016, North Carolina Emergency Management (NCEM) piloted base-level 2D hydraulic modeling of dam breaches for a select group of dams. This pilot was later followed up by a much larger study intended to model the majority of high and intermediate hazard dams across the state. Results of these models are used in the State Emergency Response Application and DamWatch, a third-party remote monitoring application for dams. Table 9 provides summary information for the NCEM dam breach modeling dataset. Figure 5 below provides the spatial location of dams analyzed for this dataset.

Table 9: NCEM Dam Breach Modeling Dataset Information

NCEM Dam Breach Modeling	
Source of Information	North Carolina Emergency Management
Link to Online Data	https://sera.nc.gov/SERA/*
Data Owner	State of North Carolina
Date Created	2017
Date of Access	February 2023
Frequency of Updates	Uncertain
Update Needed	No

NCEM Dam Breach Modeling

* Site is access restricted

Table 10 below summarizes the criteria used to perform the gap analysis.

Table 10: NCEM Dam Breach Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	2-6 years
Scale (Spatial Extent)	The dataset is statewide and includes dam breach modeling and inundation mapping for over 1,500 dams out of the approximately 6,100 dams in the statewide dam inventory (~25%). However, the majority of the unstudied dams are low hazard and not anticipated to have significant impacts if breached.
Level of Detail	Base-level/approximate. Single breach scenario modeled. No field survey or modeling of hydraulic structures (bridges/culverts).
Modeling Platform Availability	Open source (HEC-RAS 2D)
Flood Hazards Modeled	Brim-up dam breach with 1% annual chance baseflow
Future Conditions	None considered

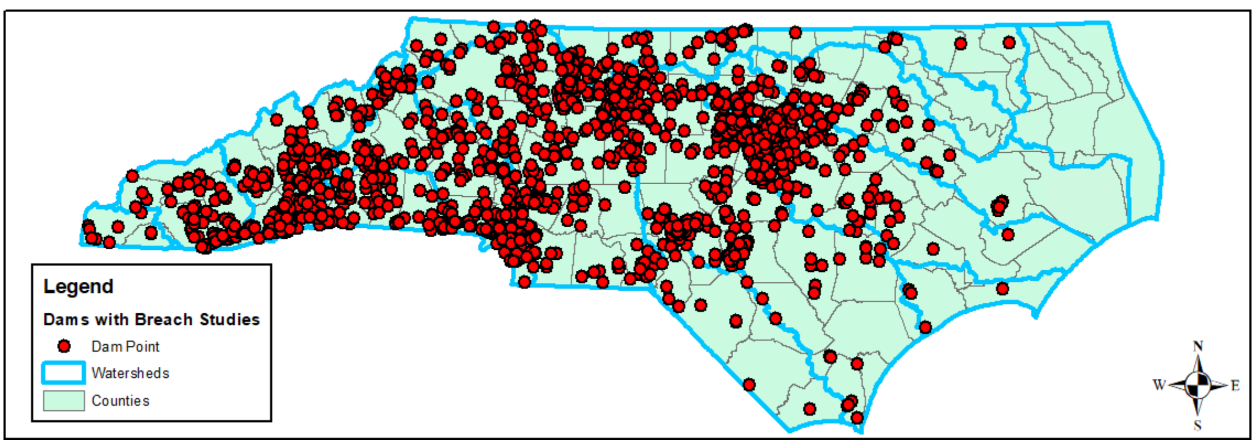

Figure 5: NCEM Dam Breach Modeling Spatial Extent

Table 11 presents gaps identified in the NCEM dam breach modeling dataset.

Table 11: NCEM Dam Breach Modeling Data Gaps

Identified Gaps	
Age	• Existing analyses sufficient for studied dams. New or significantly redesigned significant or high hazard dams would need analyzed.
Scale (Spatial Extent)	• None
Level of Detail	• Models are base-level and do not include field survey or modeling of hydraulic structures.
Modeling Platform Availability	• Modeling software is open source, but models are not readily available for download. Coordination with NCEM needed.
Flood Hazards Modeled	• Only a single breach scenario modeled. Additional analyses including Probable Maximum Flood iterations could be added but would require change in methodology.
Future Conditions	• Increases in future rainfall and/or development could be considered but would require a change in methodology.

NCEM's dam breach modeling dataset provides significant awareness of dam breach flood hazards for intermediate and high hazard dams (those most likely to cause significant impacts in the event of a failure). Depending on how dam breach flooding is accounted for in the Blueprint, the models provide a particularly good initial cut at identifying the hazard and impacts for a single hypothetical event. The models may be improved with additional data collection and breach scenarios under different conditions.

2.4 North Carolina Dam Safety and NCEM Dam Overtopping Modeling

In coordination with North Carolina Dam Safety, NCEM expanded upon an effort to develop dam overtopping modeling for a select group of dams, primarily in the western part of the state. Using the HEC-HMS hydrologic model, a series of annual chance recurrence interval events were analyzed to determine what event (if any) would overtop the dam. Results of these models are used in DamWatch, a third-party remote monitoring application for dams, to set alert thresholds based on available rainfall data sources from the National Weather Service (NWS).

Prior to this effort, NC Dam Safety had performed similar analyses in the Cape Fear and Neuse River basins. In total an estimated 555 dams were analyzed to determine overtopping events with HEC-HMS hydrologic models. Table 12 provides summary information for the NC Dam Safety and NCEM dam overtopping modeling dataset. Figure 6 below provides the spatial location of dams analyzed for this dataset.

Table 12: NCEM Dam Overtopping Modeling Dataset Information

NCEM Dam Overtopping Modeling	
Source of Information	North Carolina Emergency Management
Link to Online Data	https://ncdps.damwatch.us/main/admin-login.html*
Data Owner	State of North Carolina
Date Created	2020
Date of Access	February 2023
Frequency of Updates	Uncertain
Update Needed	No

* Site is access restricted

Table 13 below summarizes the criteria used to perform the gap analysis.

Table 13: NCEM Dam Overtopping Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	3-5 years
Scale (Spatial Extent)	The dataset is statewide but limited to only 530 dams out of the approximately 6,100 dams in the statewide dam inventory (~9%). Analyses heavily weighted towards the western part of the state.
Level of Detail	Limited. Existing datasets used for determination of critical dam and reservoir characteristics (surface area, volume, height, etc.). No site-specific field survey collected.
Modeling Platform Availability	Open source (HEC-HMS)
Flood Hazards Modeled	4-, 2-, 1-, 0.5-, 0.2-, 0.1% annual chance
Future Conditions	None considered

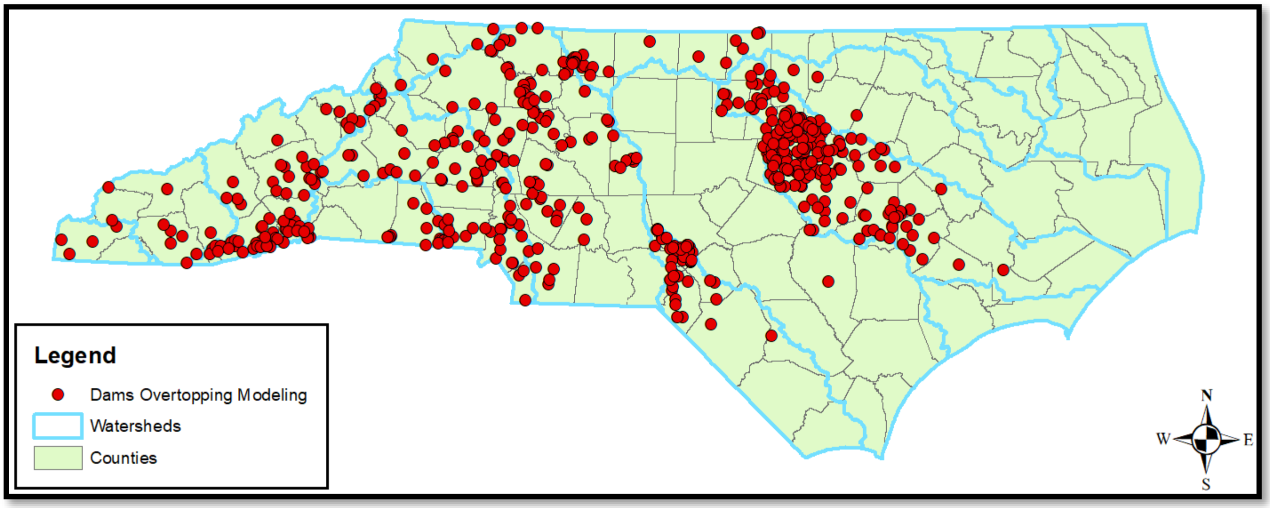

Figure 6: NCEM Dam Overtopping Modeling Spatial Extent

Table 14 presents gaps identified in the NCEM dam overtopping modeling dataset.

Table 14: NCEM Dam Overtopping Modeling Data Gaps

Identified Gaps	
Age	• Existing analyses sufficient for studied dams. New or significantly redesigned dams meeting analysis criteria would need analyzed.
Scale (Spatial Extent)	• Only a relatively small % of dams are included. Many additional high and significant hazard dams could be analyzed.
Level of Detail	• Models are base-level using the best available remote data or engineering plans/drawings. Additional/updated site-specific data could be collected to improve analyses. • Hydrologic parameters developed with simplified procedures and single-basin approach.
Modeling Platform Availability	• Modeling software is open source, but models are not readily available for download. Coordination with NCEM needed.
Flood Hazards Modeled	• None
Future Conditions	• Increases in future rainfall and/or development could be considered but would require a change in methodology.

In addition to its intended purpose to support the DamWatch monitoring application, NCEM's dam overtopping modeling provides a potentially valuable resource for accounting for flood storage volume available in basins across the state. The available stage/storage/discharge data in the models for the dams analyzed can be input into other more large-scale hydrologic models to better represent flood storage and attenuation available within the basin being studied. The largest gap identified is scale/extent of the completed modeling. Many other dams across the state could be analyzed.

2.5 North Carolina Emergency Management Basin Mitigation Modeling

Following Hurricanes Matthew (2016) and Florence (2018) elevated attention was given to flood-prone areas throughout eastern North Carolina. NCEM, in partnership with North Carolina Department of Transportation (NCDOT) began funding flood mitigation studies to identify primary sources of flooding and evaluate potential mitigation strategies to reduce flood impacts. These studies included development and calibration of watershed-scale hydrologic models and use of existing hydraulic models to support risk assessments used in benefit/cost analyses for proposed mitigation strategies. Table 15 provides summary information for the NCEM basin mitigation modeling dataset. Figure 7 below provides the spatial location of basins analyzed by NCEM to date.

Table 15: NCEM Basin Mitigation Modeling Dataset Information

NCEM Basin Mitigation Modeling	
Source of Information	North Carolina Emergency Management
Link to Online Data	https://www.rebuild.nc.gov/resiliency/river-basin-studies
Data Owner	State of North Carolina
Date Created	2018
Date of Access	February 2023
Frequency of Updates	Uncertain
Update Needed	No

Table 16 below summarizes the criteria used to perform the gap analysis.

Table 16: NCEM Basin Mitigation Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	2-5 years
Scale (Spatial Extent)	To date, the Tar, Neuse, Lumber, and Cape Fear watersheds have been studied (along with the Cashie River Basin within the Roanoke watershed), representing approximately 46% of the state. Within these watersheds, the studies focused on the mainstem flooding sources (the primary river that drains the total area of the watershed) and most significant tributaries.
Level of Detail	Limited. Watershed hydrologic models are coarse due to size. Existing regulatory hydraulic models used with limited adjustments.

Gap Analysis Criteria	
Modeling Platform Availability	Open source (HEC-HMS, HEC-RAS)
Flood Hazards Modeled	10%, 4%, 2%, 1%, 0.2%, 0.1% annual chance
Future Conditions	None considered

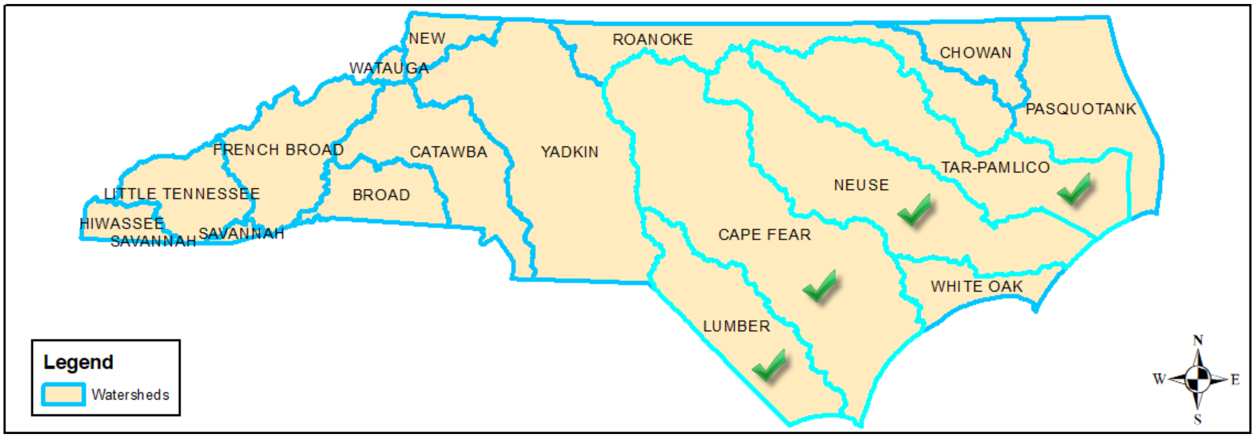

Figure 7: Completed NCEM River Basin Studies

Table 17 presents gaps identified in the NCEM basin mitigation modeling dataset.

Table 17: NCEM Basin Mitigation Modeling Data Gaps

Identified Gaps	
Age	• None
Scale (Spatial Extent)	• Not all basins within the state have been studied. • Studies focused only on the mainstem flooding sources and significant tributaries. Flooding impacts potentially receptive to mitigation strategies may be present on smaller tributaries adjacent to dense development.
Level of Detail	• None given scope of study. • More detailed modeling could be performed for smaller areas of particular interest.
Modeling Platform Availability	• Modeling software is open source, but models are not readily available for download. Coordination with NCEM needed.
Flood Hazards Modeled	• None
Future Conditions	• Increases in future rainfall and/or development could be considered in modeling.

NCEM's basin mitigation modeling provides valuable high-level hydrologic modeling that has been calibrated to significant flooding events experienced within the watershed. These models were used to analyze potential flood mitigation projects and could be used to analyze additional alternatives as they are identified. The models can be manipulated to add more detail in areas of interest or to model additional flooding scenarios including various future conditions. The largest gap identified is scale/extent as not all basins in the state have been studied .

2.6 North Carolina Dam Safety Emergency Action Plan Breach Modeling

The Coal Ash Management Act of 2014 requires that all owners of High (Class C) and Intermediate (Class B) hazard dams in North Carolina develop an Emergency Action Plan. The plan must include downstream inundation maps that are supported by and developed using engineering computer models. NC Dam Safety reviews and inventories these models for potential use/reference during emergency events. Table 18 provides summary information for the North Carolina Dam Safety emergency action plan breach modeling dataset.

Table 18: NC Dam Safety Emergency Action Plan Breach Modeling Dataset Information

NC Dam Safety Breach Modeling	
Source of Information	North Carolina Emergency Management
Link to Online Data	https://deq.nc.gov/about/divisions/energy-mineral-and-land-resources/dam-safety
Data Owner	Varies – Private landowners, HOAs, Municipalities, State Agencies, Federal Agencies
Date Created	Requirement for all high and intermediate hazard dams to have an Emergency Action Plan (EAP) with dam breach modeling began in 2014 with the due date of December 31, 2015. Annual updates to EAP (including insurance that dam breach modeling/mapping is updated) is required.
Date of Access	February 2023
Frequency of Updates	Uncertain
Update Needed	Annual reviews, modeling may not require update

Table 19 below summarizes the criteria used to perform the gap analysis.

Table 19: NC Dam Safety Emergency Action Plan Breach Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	1-9 years
Scale (Spatial Extent)	Statewide
Level of Detail	Varies. High hazard dams, in particular, typically require high level of detail
Modeling Platform Availability	Varies. Many are open source such as HEC-RAS however some may be proprietary such as FLO-2D, GeoHECRAS, MIKE 11/21.
Flood Hazards Modeled	Sunny-day and spillway design flood breach scenarios
Future Conditions	None considered

Table 20 presents gaps identified in the North Carolina Dam Safety emergency action plan breach modeling dataset.

Table 20: NC Dam Safety Emergency Action Plan Breach Modeling Data Gaps

Identified Gaps	
Age	None
Scale (Spatial Extent)	None
Level of Detail	Level of detail may vary significantly as the modeling is not performed in a consistent manner.
Modeling Platform Availability	Modeling software used may vary significantly and include the use of proprietary models. Models are not readily available for download and may not be public information. Coordination with Dam Safety needed.
Flood Hazards Modeled	None
Future Conditions	Increases in future rainfall and/or development could be considered.

NC Dam Safety's Emergency Action Plan breach modeling could provide value to the Blueprint depending on dam breach flooding's place in the program. The modeling available from NC Dam Safety is likely more detailed than the base-level dam breach modeling performed by NCEM. The modeling and data consistency may vary significantly and pose complications in its use. If available, dam breach modeling for the largest dams across the state in this dataset may be valuable to identify large areas of potential impacts during the most unlikely and conservative of events, the Probable Maximum Flood.

2.7 North Carolina Department of Transportation Hydraulic Design Modeling

NCDOT is responsible for management, maintenance, and replacement of a majority of roads and bridges across the state. There are some roads and bridges that are owned by counties or cites. Whenever NCDOT projects cross streams, a H&H modeling effort is undertaken to support the design of the new road and/or bridge. The models typically include multiple iterations of potential storm events of varying probabilities of occurrence (also known as design profiles) and if crossing a regulatory study stream, the effective regulatory study's modeled flood events as well. Projects crossing regulatory study streams also require a specific version of the model for a State Floodplain Compliance (SFC) review as part of a memorandum of agreement with the NCFMP. Since 2012 well over 1,000 SFC models have been submitted and reviewed for NCDOT projects. Table 21 provides summary information for the NCDOT hydraulic design modeling dataset.

Table 21: NCDOT Hydraulic Design Modeling Dataset Information

NCDOT Hydraulic Design Modeling	
Source of Information	North Carolina Department of Transportation
Link to Online Data	https://connect.ncdot.gov/resources/hydro/Pages/FEMA-Interagency-Design.aspx
Data Owner	NCDOT
Date Created	Varies
Date of Access	February 2023
Frequency of Updates	None – modeling performed per project during design phase
Update Needed	No

Table 22 below summarizes the criteria used to perform the gap analysis.

Table 22: NCDOT Hydraulic Design Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	Varies
Scale (Spatial Extent)	Statewide.
Level of Detail	High

Gap Analysis Criteria	
Modeling Platform Availability	Varies. Design models are typically open source (HEC-RAS) but may also be proprietary. Associated SFC models are in format consistent with the effective regulatory model.
Flood Hazards Modeled	Design specific. SFC model versions include profiles from effective regulatory model: 10-, 4-, 2-, 1-, 0.2% annual chance events.
Future Conditions	Design specific. SFC model versions will include future conditions profiles if the effective model had them.

Table 23 presents gaps identified in the NCDOT hydraulic design modeling dataset.

Table 23: NCDOT Hydraulic Design Modeling Data Gaps

Identified Gaps	
Age	None
Scale (Spatial Extent)	Each model may have limited extent only covering the reach of the stream affected by the project.
Level of Detail	None
Modeling Platform Availability	Modeling software used may vary significantly and include the use of proprietary models. Models are not readily available for download. Coordination with NCDOT needed.
Flood Hazards Modeled	None
Future Conditions	Increases in future rainfall and/or development could be considered.

NCDOT's hydraulic design modeling provides a valuable dataset that can be used to update NCFMP regulatory and/or advisory modeling in potentially a timelier manner than the typical flood study maintenance updates may allow. This improves the accuracy of the modeling by ensuring the hydraulic structures (bridges/culverts) in the model reflect current conditions with a high level of detail.

2.8 North Carolina Department of Transportation Resiliency Studies

NCDOT adopted an official resilience policy (NCDOT Policy F.35.0102) in September of 2021. As part of NCDOT's mission to create a more resilient transportation network, they have published and will continue to publish studies and reports assessing the state's current level of resilience, future needs, and upcoming projects. This work is also being done in accordance with Executive Order 80, which addresses climate change facing the state. NCDOT is currently developing climate adaptation strategies into planning and design. They consider sea level rise, rainfall, and extreme events when designing critical infrastructure. NCDOT has performed a number of resiliency and vulnerability studies for certain strategic highway corridors including US-74, NC-210, I-95, and I-40/US-17 that have incorporated sea level rise, heat, future rainfall, and extreme events. Portions of these studies have included both 1D and 2D (including rain on grid) H&H modeling to better understand current and future flood risk. Table 24 provides summary information for the NCDOT transportation resiliency modeling dataset.

Table 24: NCDOT Transportation Resiliency Modeling Dataset Information

NCDOT Transportation Resiliency Studies	
Source of Information	North Carolina Department of Transportation
Link to Online Data	https://www.ncdot.gov/initiatives-policies/Transportation/transportation-resilience/Pages/default.aspx
Data Owner	NCDOT
Date Created	Varies
Date of Access	February 2023
Frequency of Updates	Uncertain
Update Needed	No

Table 25 below summarizes the criteria used to perform the gap analysis.

Table 25: NCDOT Transportation Resiliency Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	Varies
Scale (Spatial Extent)	Statewide, focused on strategic highway corridors with known flood vulnerabilities.
Level of Detail	High
Modeling Platform Availability	Typically, open source (predominantly HEC-RAS), although proprietary models may be used. SRH2D is a preference of the Federal Highway Administration and although it is technically open source, often SMS (proprietary software developed by Aquaveo) is considered necessary for model development.
Flood Hazards Modeled	Uncertain
Future Conditions	Yes, compliant with Executive Order 80 to address climate change.

Table 26 presents gaps identified in the NCDOT hydraulic design modeling dataset.

Table 26: NCDOT Transportation Resiliency Modeling Data Gaps

Identified Gaps	
Age	None
Scale (Spatial Extent)	The current extent of modeling is unknown. Additional data collection and coordination needed.
Level of Detail	None
Modeling Platform Availability	None
Flood Hazards Modeled	Uncertain. Additional data collection and coordination needed.
Future Conditions	None

NCDOT's transportation resiliency modeling, although limited in extent, provides valuable insight and examples of how to integrate future conditions into H&H modeling to develop more flood resilient alternatives in areas at risk of flooding.

2.9 North Carolina Department of Environmental Quality Basin-wide Hydrologic Modeling

With a goal to improve water resources planning throughout the state, in 2010 the North Carolina General Assembly directed the North Carolina Department of Environmental Quality (NCDEQ) to develop basin-wide hydrologic models for all 17 river basins in the state. NCDEQ uses these models to evaluate potential impacts of proposed projects that affect water withdrawals or inter-basin transfers. The models are useful for growth planning and drought evaluations. Table 27 provides summary information for the NCDEQ basin-wide hydrologic modeling dataset. Figure 8 below provides the current status of basin-wide hydrologic modeling performed by NCDEQ.

Table 27: NCDEQ Basin-wide Hydrologic Modeling Dataset Information

NCDEQ Basin-wide Hydrologic Modeling	
Source of Information	North Carolina Department of Environmental Quality
Link to Online Data	https://deq.nc.gov/about/divisions/water-resources/water-planning/modeling-assessment/basinwide-hydrologic-modeling
Data Owner	NCDEQ
Date Created	Varies

NCDEQ Basin-wide Hydrologic Modeling	
Date of Access	February 2023
Frequency of Updates	Uncertain
Update Needed	No

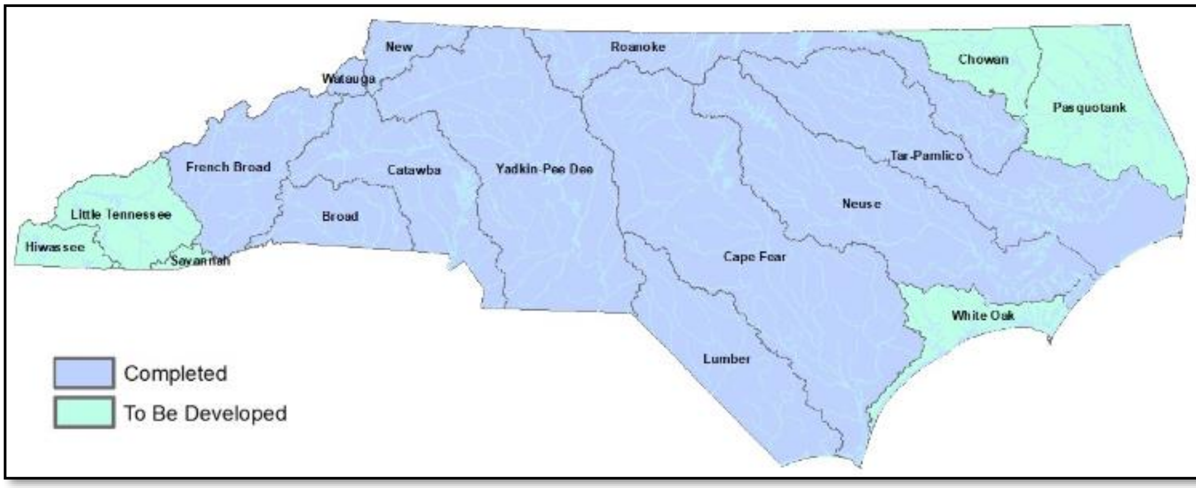

Figure 8: NCDEQ Basin-wide Hydrologic Modeling Status

Table 28 below summarizes the criteria used to perform the gap analysis.

Table 28: NCDEQ Basin-wide Hydrologic Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	Varies
Scale (Spatial Extent)	Statewide
Level of Detail	Uncertain
Modeling Platform Availability	Uncertain. OASIS model is proprietary.
Flood Hazards Modeled	Uncertain, if any. Model purpose is water use, not flooding.
Future Conditions	Uncertain

Table 29 presents gaps identified in the NCDEQ basin-wide hydrologic modeling dataset.

Table 29: NCDEQ Basin-wide Hydrologic Modeling Data Gaps

Identified Gaps	
Age	• None
Scale (Spatial Extent)	• None
Level of Detail	• Additional data collection, coordination needed.
Modeling Platform Availability	• Uncertain. The OASIS model is proprietary. Additional data collection, coordination needed.
Flood Hazards Modeled	• Uncertain. Additional data collection and coordination needed.
Future Conditions	• Uncertain. Additional data collection and coordination needed.

NCDEQ's basin-wide hydrologic modeling is performed with a focus on water supply and long-term planning, not flooding . Anticipated usefulness for the Blueprint is uncertain but expected to be minimal. As noted in the NCDEQ's documentation, "Modeling the Cape Fear and Neuse River Basins Operations with OASIS" by Hydrologics (dated November 2013), "OASIS is a generalized type of mass balance model used mainly in evaluating planning and management alternatives. It is not intended for use in hydraulic routing nor flood management, although it can be linked to other models for those purposes." As the OASIS model is proprietary, its availability for use in support of the Blueprint is uncertain.

2.10 North Carolina Department of Environmental Quality Water Quality Modeling

The NCDEQ Division of Water Resources uses water quality models for a variety of reasons including evaluation of waste-water discharges, analysis of pollutant load and reduction to water bodies, and support of nutrient management strategies or total maximum daily load allocations. Table 30 provides summary information for the NCDEQ water quality modeling dataset.

Table 30: NCDEQ Water Quality Modeling Dataset Information

NCDEQ Water Quality Modeling	
Source of Information	North Carolina Department of Environmental Quality
Link to Online Data	https://deq.nc.gov/about/divisions/water-resources/planning/modeling-assessment/water-quality-monitoring
Data Owner	NCDEQ
Date Created	Varies

NCDEQ Water Quality Modeling	
Date of Access	February 2023
Frequency of Updates	Uncertain
Update Needed	Uncertain

Table 31 below summarizes the criteria used to perform the gap analysis.

Table 31: NCDEQ Water Quality Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	Varies
Scale (Spatial Extent)	Statewide
Level of Detail	Varies
Modeling Platform Availability	Uncertain. Models include WARMF, EFDC, GWLF, SWAT, and HSPF.
Flood Hazards Modeled	Uncertain, if any. Model purpose is water quality, not flooding.
Future Conditions	Uncertain

Table 32 presents gaps identified in the NCDEQ water quality modeling dataset.

Table 32: NCDEQ Water Quality Modeling Data Gaps

Identified Gaps	
Age	• None
Scale (Spatial Extent)	• None
Level of Detail	• Additional data collection, coordination needed.
Modeling Platform Availability	• Uncertain if models are open source or proprietary. Additional data collection and coordination needed.
Flood Hazards Modeled	• Uncertain. Additional data collection and coordination needed.
Future Conditions	• Uncertain. Additional data collection and coordination needed.

NCDEQ's water quality modeling is not focused on quantity or flooding. The anticipated usefulness for the Blueprint is minimal.

2.11 North Carolina Floodplain Mapping Regulatory Coastal Modeling

As part of the North Carolina Floodplain Mapping Program introduced earlier in this section, coastal modeling has been performed using Advanced Circulation (ADCIRC) for storm surge and Simulating Waves Nearshore (SWAN) for waves to identify coastal flood hazards. Results of the coastal modeling are housed in the statewide enterprise FLOOD database along with the riverine modeling and can be viewed on the FRIS website.

Table 33 provides summary information for the NCFMP Regulatory Coastal modeling.

Table 33: NCFMP Regulatory Coastal Modeling Dataset Information

NCFMP Regulatory Coastal Modeling	
Source of Information	North Carolina Emergency Management – Floodplain Mapping Program
Link to Online Data	https://fris.nc.gov/fris/Home.aspx?ST=NC
Data Owner	State of North Carolina
Date Created	2010-2016
Date of Access	August 2023
Frequency of Updates	Annual funding for cyclical updates throughout the state based on age of existing study, need, and available data.
Update Needed	Yes – Regular updates necessary to maintain reliable products

Table 34 below summarizes the United States Geological Survey (USGS) National Hydrologic Model (NHM) criteria used to perform the gap analysis.

Table 34: USGS NHM Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	7 – 13 years
Scale (Spatial Extent)	Statewide along the coast
Level of Detail	High – Detailed study with defined base flood elevations based on storm surge and wave impacts. Combined probability of coastal and riverine impacts was considered in some, but not all areas studied.
Modeling Platform Availability	ADCIRC and SWAN are both open source; however, SMS (which is proprietary) is widely considered necessary for model use.

Gap Analysis Criteria	
Flood Hazards Modeled	10-, 4-, 2-, 1-, 0.2% annual chance
Future Conditions	None

Table 35 presents gaps identified in the NCFMP Regulatory Coastal modeling dataset.

Table 35: NCFMP Regulatory Coastal Modeling Data Gaps

Identified Gaps	
Age	• Modeling dataset is becoming dated and updated base data including new lidar are now available.
Scale (Spatial Extent)	• The coastal study was performed in parts by different contractors with shared boundary conditions. Some of the modeling may not be fully tied together.
Level of Detail	• Not all of the areas covered by the coastal modeling included combined probability for coastal/riverine interactions. In addition, combined probability with pluvial flooding was not considered.
Modeling Platform Availability	• Coastal modeling methodologies have not changed much and could be considered for update based on newer technology and data. The coastal models require supercomputers for computations.
Flood Hazards Modeled	• More extreme events such as 0.5- and 0.1% annual chance could be analyzed.
Future Conditions	• Many sea level rise studies have been performed and could be used to inform potential future conditions. In addition, Weather Research and Forecasting (WRF) modeling is available to analyze future climate/atmospheric conditions that may produce more extreme flooding events.

The NCFMP Regulatory Coastal modeling is a foundational model dataset critical in awareness and identification of coastal flooding hazards. However, there are several identified gaps that could be addressed to improve the dataset's usefulness in resiliency planning efforts. Coastal studies such as what the NCFMP performed for the North Carolina coast take a significant amount of time and effort. When used for regulatory and permitting purposes, significant outreach is also necessary.

3 Other North Carolina Models

3.1 County and Municipality Modeling

Counties and municipalities have a personal stake in high quality, reliable hydrologic and hydraulic modeling of the flooding sources that impact their residents and jurisdiction . Awareness of the extent and severity of potential flood impacts provides community officials with valuable information to ensure development is undertaken responsibly. Communities such as Raleigh, Durham, Charlotte, Fayetteville, Wilmington, and many others routinely perform and update basin studies to support planning, development, and design of capital improvement projects. Also of note, the Eastern Band of Cherokee Indians maintains H&H modeling as well. Table 36 provides summary information for county and municipality modeling.

Table 36: County and Municipality Modeling Dataset Information

County and Municipality Modeling	
Source of Information	Varies
Link to Online Data	Varies. Examples include: https://raleighnc.gov/projects/pigeon-house-branch-watershed-study
Data Owner	Each community
Date Created	Varies
Date of Access	NA
Frequency of Updates	Varies
Update Needed	Yes

Table 37 below summarizes the criteria used to perform the gap analysis.

Table 37: County and Municipality Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	Varies
Scale (Spatial Extent)	Varies. Not all communities statewide actively develop modeling and those that do have different expectations and requirements. Studies are commonly performed by basin, similar in size to a HUC 12.
Level of Detail	Varies. Most are highly detailed to support capital improvement project design.

Gap Analysis Criteria	
Modeling Platform Availability	Varies. Different communities require different modeling software, including some proprietary such as InfoWorks ICM and XPSWMM
Flood Hazards Modeled	Varies by community.
Future Conditions	Varies by community.

Table 38 presents gaps identified in the NC county and municipality modeling dataset.

Table 38: County and Municipality Modeling Data Gaps

Identified Gaps	
Age	Additional data collection and coordination with communities is needed.
Scale (Spatial Extent)	Additional data collection and coordination with communities is needed.
Level of Detail	Additional data collection and coordination with communities is needed.
Modeling Platform Availability	Additional data collection and coordination with communities is needed.
Flood Hazards Modeled	Additional data collection and coordination with communities is needed.
Future Conditions	Additional data collection and coordination with communities is needed.

- Although variable across different municipalities, county and municipality modeling is anticipated to be some of the most detailed modeling available. These models are often used in the design of capital improvement projects and must therefore contain significant detail. The largest gap for this dataset is awareness of the availability of the modeling. A significant outreach and coordination effort may be required to collect and inventory available modeling across the state. If and when the modeling becomes available, however, it could provide substantial value in evaluating flood vulnerabilities and potential mitigation alternatives. Examples of additional county/municipality modeling that may be available through additional outreach activities include: The Town of Cary requires flood studies to be performed and submitted by developers for non-FEMA regulated streams.
- Charlotte Mecklenburg is developing detailed 2-D modeling with structures incorporated .
- The City of Fayetteville has and is currently performing detailed 2-D modeling for several watersheds.

3.2 United States Army Corps of Engineers River Basin Feasibility Studies

Following the river basin mitigation studies performed by NCEM along the Tar, Neuse, and Lumber noted above, North Carolina received funding through the 2019 Additional Supplemental

Appropriations for Disaster Relief (H.R. 2157) for feasibility studies to assess and recommend actions that reduce flood risk and increase resiliency throughout the Neuse and Tar-Pamlico Basins. The USACE Wilmington District has released a report for the Neuse Basin while the Pittsburgh District is currently working on the Tar-Pamlico Basin. The studies use a combination of existing and new H&H models. Table 39 provides summary information for the USACE river basin feasibility modeling.

Table 39: USACE River Basin Feasibility Modeling Dataset Information

USACE River Basin Feasibility Studies	
Source of Information	USACE
Link to Online Data	https://www.saw.usace.army.mil/Missions/Flood-Risk-Management/Neuse-River-Basin/ https://www.lrp.usace.army.mil/Missions/Planning-Programs-Project-Management/Key-Projects/Tar-Pamlico-Feasibility-Study/
Data Owner	USACE
Date Created	April 2022
Date of Access	February 2023
Frequency of Updates	Uncertain
Update Needed	No

Table 40 below summarizes the criteria used to perform the gap analysis.

Table 40: USACE River Basin Feasibility Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	1-2 years
Scale (Spatial Extent)	Studies performed at a watershed level
Level of Detail	Limited. Models are coarse due to size of project area.
Modeling Platform Availability	Open. HEC-HMS, HEC-RAS
Flood Hazards Modeled	50-, 20-, 10-, 4-, 2-, 1-, 0.5-, 0.2% annual chance
Future Conditions	Future conditions are discussed in the report; however, the H&H modeling does not appear to include any future conditions.

Table 41 presents gaps identified in the USACE River Basin Feasibility study modeling dataset.

Table 41: USACE River Basin Feasibility Modeling Data Gaps

Identified Gaps	
Age	• None
Scale (Spatial Extent)	• Only two watersheds, Neuse (in Draft form) and Tar-Pamlico (in progress) have been studied to date.
Level of Detail	• None
Modeling Platform Availability	• None
Flood Hazards Modeled	• 1,000-yr (0.1% annual chance) not included as an extreme event
Future Conditions	• Increases in future rainfall and/or development could be considered in modeling.

The anticipated use and gaps for the USACE River Basin Feasibility modeling are similar to NCEM's basin mitigation modeling. The dataset provides valuable high-level hydrologic modeling that has been calibrated to significant flooding events experienced within the watershed. These models were used to analyze potential flood mitigation projects and could be used to analyze additional alternatives as they are identified. The models are able to be manipulated to add more detail in areas of interest or to model additional flooding scenarios including various future conditions. The largest gap identified is scale/extent as not all basins in the state have been studied.

3.3 Other Potential Modeling Sources

As the Blueprint is implemented across each of the 17 basins, we will leverage the stakeholder engagement process to identify additional sources of data within each basin that might add value to the flood hazard identification and visualization as part of the flood resiliency process. Examples of such datasets include:

- NC State University has completed flood mitigation studies in many watersheds including the Cashie River basin.
- Duke Energy may have modeling for major hydroelectric dams.
- The Tennessee Valley Authority has H&H modeling for many streams and dams in the western portion of the state .
- The Federal Energy Regulatory Commission may have available models for Dam Breach Analyses.
- USACE has Corps Water Management System models to support the regulation of flow through reservoirs, locks, and other water control structures.
- USACE has performed H&H modeling for a portion of the Tar basin in support of a flood risk management study for the Town of Princeville, NC. The study was conducted as a result of Executive Order 13146 in February of 2000 which established the "President's Council on the Future of Princeville." The study analyzed potential mitigation strategies such as raising roads,

extending the existing levee, and installing culvert backflow devices to reduce flooding within the Town.

- USGS has developed Soil and Water Assessment Tool (SWAT) water quantity models for the Yadkin-Pee Dee and the Cape Fear watersheds.
- The Nature Conservancy is developing a SWAT model for the Cape Fear Basin.
- East Carolina University is developing a SWAT model of the Tar-Pamlico Basin .

4 Nationwide/Regional Datasets

4.1 NOAA Office of Water Prediction National Water Model

The National Oceanic and Atmospheric Administration's (NOAA's) National Water Model (NWM) simulates observed and forecast streamflow for over 3.4 million miles of streams and rivers across the nation. The hydrologic model produces forecast streamflow for short (18 hours), medium (10 days), and long (30 days) range. Output from the model is available in NetCDF format. Table 42 provides summary information for the USACE river basin feasibility modeling. Figure 9 below provides a representative view of the NWM at the North Carolina state scale.

Table 42: NOAA NWM Modeling Dataset Information

NOAA National Water Model	
Source of Information	NOAA
Link to Online Data	https://water.noaa.gov/map
Data Owner	NOAA
Date Created	2015
Date of Access	February 2023
Frequency of Updates	Uncertain. Data products are "live"
Update Needed	No

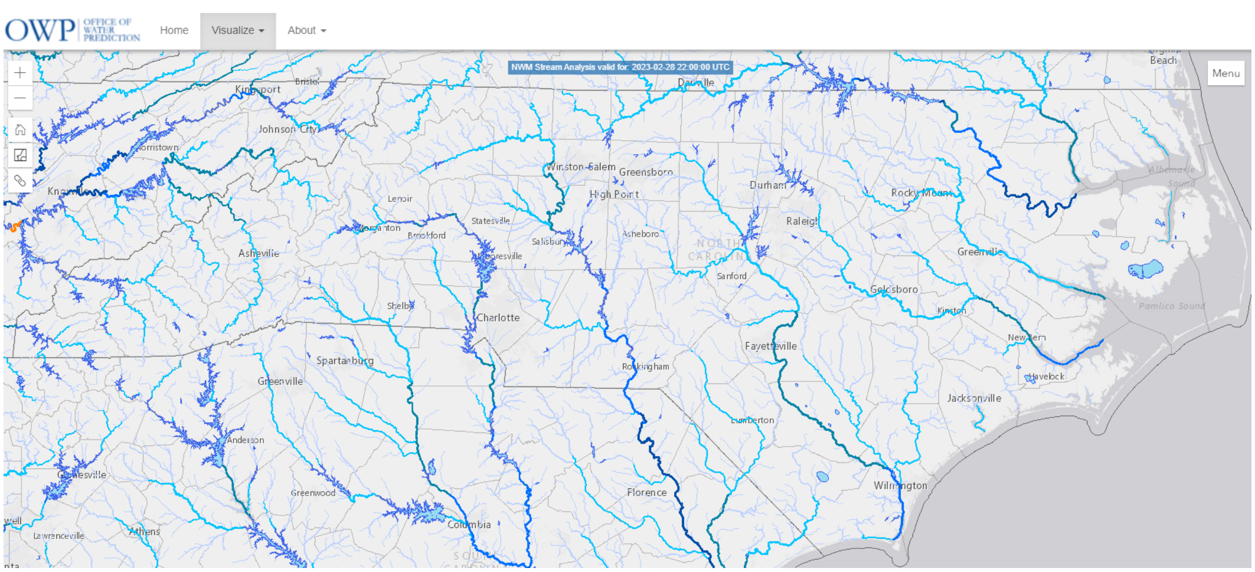

Figure 9: The NWM provides statewide current and forecast streamflow estimates.

Table 43 below summarizes the criteria used to perform the gap analysis.

Table 43: NOAA NWM Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	2 years
Scale (Spatial Extent)	Nationwide
Level of Detail	Medium
Modeling Platform Availability	Model not available, only model output/results . WRF-Hydro is the core model used and is open source.
Flood Hazards Modeled	Current observed and forecast stream flows provided are not tied to probabilistic events.
Future Conditions	Provides short, medium, and long-term forecasts out to 30 days. No “true” future conditions that consider climate change are provided.

Table 44 presents gaps identified in the NOAA NWM modeling dataset.

Table 44: NOAA NWM Modeling Data Gaps

Identified Gaps	
Age	None
Scale (Spatial Extent)	None
Level of Detail	Streamflow estimates from NWM can vary from actual gauge readings at the same location.
Modeling Platform Availability	WRF-Hydro is open source, however, the NWM Model itself is not available, only model products.
Flood Hazards Modeled	Annual exceedance chance flows based on regression/gauge data for each modeled reach added for reference could be particularly useful.
Future Conditions	None

NOAA’s National Water Model provides estimates of real-time streamflow across the nation. As the underlying model is not available for use/modification and the dataset does not include defined annual exceedance flood events its usefulness in the Blueprint is anticipated to be minimal. However, awareness of this tool, especially during flood events may be helpful and factor into decision-making during emergency planning and response for flooding.

4.2 National Weather Service River Forecast Centers

The NWS maintains 13 river forecast centers across the United States. North Carolina is primarily covered by the Southeast River Forecast Center with the exception of the most western watersheds that are within the Lower Mississippi River Forecast Center region. These centers provide river forecasts that vary in time scale from hours to days to months. The most common product of traditional flood forecasts is provided 5 days out to the general public, while as much as a yearly outlook is provided for water management agencies. These centers are responsible for issuing flood warnings for the protection of lives and property. Table 45 provides summary information for the NWS river forecast centers modeling. Figure 10 below provides an overview of the river forecast centers across the nation.

Table 45: NWS River Forecast Centers Modeling Dataset Information

National Weather Service River Forecast Centers	
Source of Information	National Weather Service
Link to Online Data	https://water.weather.gov/ahps/rfc/rfc.php
Data Owner	National Weather Service
Date Created	1971
Date of Access	February 2023
Frequency of Updates	Constant, in continuous operation.
Update Needed	No

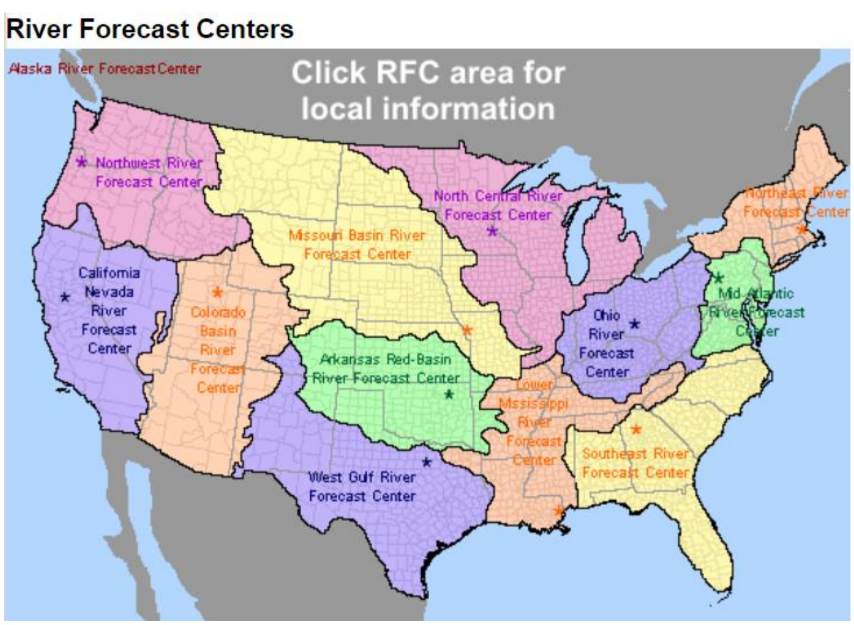

Figure 10: NWS River Forecast Regions across the Nation

Table 46 below summarizes the criteria used to perform the gap analysis.

Table 46: NWS River Forecast Centers Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	NA – Forecast centers are in constant operation.
Scale (Spatial Extent)	Statewide coverage, however actual forecast locations are fairly sparse and limited to primarily large rivers. River Forecast Center site claims 217 sites across the state (many not currently active).
Level of Detail	High
Modeling Platform Availability	Model not available, only model output/results.
Flood Hazards Modeled	Current observed and forecast stream flows are not tied to probabilistic (annual chance of exceedance) events.
Future Conditions	Provides short, medium, and long-term forecasts but no “true” future conditions that consider climate change are provided.

Table 47 presents gaps identified in the NWS River Forecast Centers modeling dataset.

Table 47: NWS River Forecast Centers Modeling Data Gaps

Identified Gaps	
Age	• None
Scale (Spatial Extent)	• More forecast locations could be considered. The National Water Model development may ultimately limit need for additional forecast points from the River Forecast Centers.
Level of Detail	• None
Modeling Platform Availability	• Model not available, only model products.
Flood Hazards Modeled	• None
Future Conditions	• None

The NWS River Forecast Centers provide extremely valuable information for potential flood conditions along major rivers across the country (including North Carolina). As the underlying models are not available for use or modification outside of the NWS it is anticipated that their usefulness for the

Blueprint will be minimal. Awareness of the forecast information provided by the river forecast centers may however prove to be a valuable dataset to be considered in portions of the Blueprint.

4.3 Pacific Northwest National Laboratory Rapid Infrastructure Flood Tool

Pacific Northwest National Laboratory (PNNL) developed the Rapid Infrastructure Flood Tool (RIFT) to better prepare authorities, emergency responders, and communities prior to, during, and following large-scale food events. The RIFT tool is a two-dimensional hydrodynamic model that estimates areas that will be most impacted and aims to provide awareness to authorities to more effectively organize and strategically place resources needed during flood response. Table 48 provides summary information for the PNNL RIFT modeling. Figure 11 below provides a sample dataset from the RIFT model output at the North Carolina state scale.

Table 48: PNNL RIFT Modeling Dataset Information

PNNL Rapid Infrastructure Flood Tool	
Source of Information	PNNL
Link to Online Data	https://open-rift-pnnl.hub.arcgis.com/
Data Owner	PNNL – United States Department of Energy
Date Created	Varies – Event Specific
Date of Access	February 2023
Frequency of Updates	Uncertain. Data products are near "real-time."
Update Needed	No

Table 49 below summarizes the criteria used to perform the gap analysis.

Table 49: PNNL RIFT Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	Uncertain. Model runs are event specific.
Scale (Spatial Extent)	Nationwide
Level of Detail	Low. Approximately 300-ft model cell resolution stated in metadata, however, smallest scale product cache appears to be ~2,500-ft cells.
Modeling Platform Availability	Uncertain. Model not available, only model products.

Gap Analysis Criteria	
Flood Hazards Modeled	Event-specific. Current and near-term forecast products are not tied to probabilistic events.
Future Conditions	None

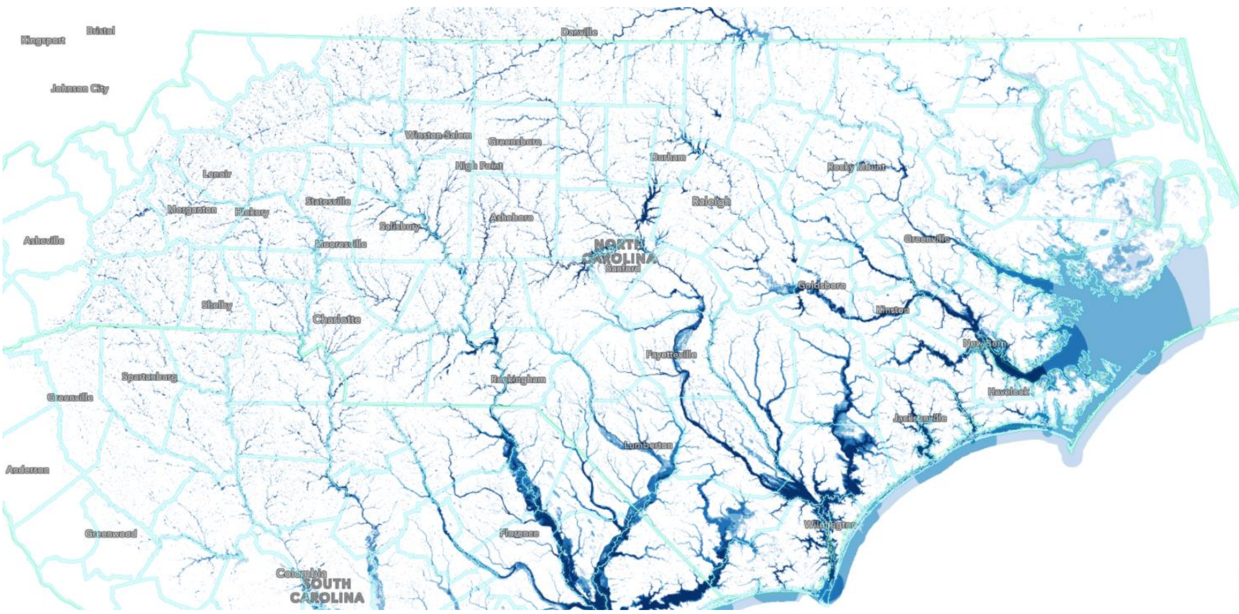

Figure 11: PNNL RIFT Modeling Output for Hurricane Florence

Table 50 presents gaps identified in the PNNL RIFT modeling dataset.

Table 50: PNNL RIFT Modeling Data Gaps

Identified Gaps	
Age	• None
Scale (Spatial Extent)	• None
Level of Detail	• Model products are very coarse and largely unusable beyond identifying areas to focus more refined modeling on. Products consistent with stated model resolution (90-m) or refined post-processing of results could result in data more actionable data for North Carolina.
Modeling Platform Availability	• Model not available, only model products.
Flood Hazards Modeled	• Model runs for annual exceedance chance events based on NOAA Atlas 14 rainfall intensity, duration, and frequency curves added for reference could be particularly useful.

Identified Gaps	
Future Conditions	• Model runs accounting for climate change for annual exceedance chance events and/or past events could be performed.

The PNNL RIFT modeling is able to quickly provide a high-level understanding of where flooding is anticipated to occur during major events. As the underlying model is not available for use/modification and the dataset does not include defined annual exceedance flood events its usefulness in the Blueprint is anticipated to be minimal. However, awareness of this tool, especially during flood events may be helpful and factor into decision-making during emergency planning and response for flooding. Although the model products are coarse, they can guide where to focus more detailed modeling efforts using other datasets.

4.4 United States Geological Survey National Hydrologic Model

The USGS developed the National Hydrologic Model (NHM) to support efficient development of local-, regional-, and national-scale hydrologic models across the nation. The NHM consists of three primary parts: a geospatial fabric of modeling units (NHDPlus version 1 data), a model input data archive (gridded climate datasets including Daymet and gridMET), and a repository of the physical model code bases (Monthly Water Balance Model [MWBM] and Precipitation-Runoff Modeling System [PRMS]) . Additional information regarding the use of the NHM can be found at the following links:

- http://pubs.er.usgs.gov/publication/tm6B9
- https://doi.org/10.1016/j.envsoft.2018.09.023

Table 51 provides summary information for the USGS NHM modeling.

Table 51: USGS NHM Modeling Dataset Information

USGS National Hydrologic Model	
Source of Information	USGS
Link to Online Data	https://www.usgs.gov/mission-areas/water-resources/science/national-hydrologic-model-infrastructure
Data Owner	USGS
Date Created	2018
Date of Access	February 2023
Frequency of Updates	Daymet version is updated through 2019, GridMET version is updated annually
Update Needed	Uncertain

Table 52 below summarizes the criteria used to perform the gap analysis.

Table 52: USGS NHM Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	Supporting model last release date 2 years or less
Scale (Spatial Extent)	Nationwide availability, but scalable with ability to extract subsets of the national application to run locally for NC watersheds.
Level of Detail	Flexible – Current NHM applications are to roughly a HUC 12 scale.
Modeling Platform Availability	Open – MWBM: Monthly time step water balance model. McCabe and Markstrom (2007) PRMS: Daily time step process-based hydrologic model. Markstrom and others (2015); Leavesley and others (1983).
Flood Hazards Modeled	Flexible. No established model results available. NHM-PRMS temporal resolution is daily timestep.
Future Conditions	Yes. Ongoing work through USGS Southeast Climate Adaptation Science Center is producing future simulations through the year 2100. NHM-PRMS and MWBM are compatible with various downscaled General Circulation Model outputs.

Table 53 presents gaps identified in the USGS NHM modeling dataset.

Table 53: USGS NHM Modeling Data Gaps

Identified Gaps	
Age	• None
Scale (Spatial Extent)	• None
Level of Detail	• Current applications to roughly a HUC 12 scale. Newer versions will provide more detail and new tools will allow for different spatial unit resolutions.
Modeling Platform Availability	• None
Flood Hazards Modeled	• Pre-determined model results for annual exceedance chance events of interest not available but would be useful.
Future Conditions	• Pre-determined model results for future conditions of interest not available but would be useful.

The USGS National Hydrologic Model is a support tool to help develop hydrologic models. This toolset may be helpful for the development of new hydrologic models if needed as part of Blueprint.

4.5 United States Army Corps of Engineers South Atlantic Coastal Study

Following the 2017 hurricane season, congress passed the Bipartisan Budget Act of 2018 which provided funds for the South Atlantic Coastal Study (SACS). Based on the USACE report, the SACS is a comprehensive study that applies watershed planning concepts to identify actions for advancing coastal resilience. The SACS included a Tier 1 Risk Assessment for the coast of North Carolina that included water levels for the 10% annual exceedance probability (AEP) from the USACE Engineering Research and Development Center (ERDC), 1 percent AEP from FEMA's National Flood Hazard Layer as well as a Category 5 hurricane Maximum of Maximum from NOAA's Sea, Land, and Overland Surges from Hurricanes (SLOSH) model. In addition, the Coastal Hazards System provided refinements to the Tier 1 hazard data with coupled hydrodynamic (ADCIRC) and wave (Steady-state spectral WAVE [STWAVE]) models populated with the most up-to-date elevation data and calibrated based on observed events. This modeling provided simulations for present-day mean sea level and two sea level rise (SLR) scenarios based on USACE estimates for intermediate and high SLR.

Table 54 provides summary information for the USACE SACS modeling.

Table 54: USACE SACS Coastal Modeling Dataset Information

USACE SACS Coastal Modeling	
Source of Information	United States Army Corps of Engineers
Link to Online Data	https://www.sad.usace.army.mil/SACS/ https://chs.erdc.dren.mil
Data Owner	United States Army Corps of Engineers
Date Created	October 2021
Date of Access	August 2023
Frequency of Updates	Unknown
Update Needed	No

Table 55 below summarizes the criteria used to perform the gap analysis.

Table 55: USACE SACS Coastal Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	2 years
Scale (Spatial Extent)	Southeast US Coast (including entire NC coast)
Level of Detail	High
Modeling Platform Availability	ADCIRC and STWAVE are both open source; however, SMS (which is proprietary) is widely considered necessary for model use.
Flood Hazards Modeled	1% annual chance
Future Conditions	Yes – 2 sea level rise scenarios

Table 56 presents gaps identified in the USACE SACS Coastal modeling dataset.

Table 56: USACE SACS Coastal Modeling Data Gaps

Identified Gaps	
Age	• None
Scale (Spatial Extent)	• None
Level of Detail	• None
Modeling Platform Availability	• The coastal models require supercomputers for computations.
Flood Hazards Modeled	• Uncertain but documentation indicates AEP data is available. Need to confirm with additional research/coordination.
Future Conditions	• None

The USACE SACS coastal modeling and associated study is a fairly recent, highly detailed resource focused on increasing coastal resilience. This resource/dataset has the potential to provide valuable input to Blueprint efforts within the coastal region.

4.6 National Oceanic and Atmospheric Administration Sea, Lake, and Overland Surges from Hurricanes Modeling

The NWS developed the SLOSH model to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes. The model is used to perform simulation studies for hurricane evacuation planning by FEMA, USACE, and emergency managers. In addition, the model is run by the National Hurricane Center (NHC) for real-time awareness when storms are threatening. To help reduce potential error that may occur with a single deterministic model run, the Probabilistic Storm Surge Model (P-Surge) relies on an ensemble of SLOSH runs based on past forecast performance. NOAA displays SLOSH model results on an experimental interactive website for P-Surge which includes past historic events. A SLOSH Display Program (SDP) is also available to display results of the SLOSH model.

Table 57 provides summary information for the NOAA SLOSH modeling.

Table 57: NOAA SLOSH Modeling Dataset Information

NOAA SLOSH Coastal Modeling	
Source of Information	NOAA/NWS
Link to Online Data	https://www.nhc.noaa.gov/surge/slosh.php https://slosh.nws.noaa.gov/sdp/index.php https://slosh.nws.noaa.gov/psurge/index.php
Data Owner	NOAA
Date Created	Model was developed in 1990s, but model runs are performed as needed and real-time during NHC advisories.
Date of Access	August 2023
Frequency of Updates	SLOSH model coverage is divided into 32 regions/basins. Typically, 3-6 basins are updated per year based on changes in topography/bathymetry from storms, vulnerability to storm surge, new data availability, and changes to the coast including the addition of engineered flood protection devices. Model results are available real-time during coastal storm events.
Update Needed	No

Table 58 below summarizes the criteria used to perform the gap analysis.

Table 58: NOAA SLOSH Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	Although the actual model is dated, model input for the 32 basins is updated cyclically each year based on factors outlined above. Model runs are performed as needed and real-time during NHC advisories.
Scale (Spatial Extent)	Nationwide (including entire NC coast)

Gap Analysis Criteria	
Level of Detail	High, but dependent upon base data (topography/bathymetry), used grid cell size (which are smaller closer to shore), and inclusion of major barriers and narrow canals/rivers. Accuracy of model results is estimated to be within about 20% of actual conditions. Inundation mapping results available on P-Surge website are coarse, however, experimental inundation mapping with higher precision is made available during NHC advisory model runs.
Modeling Platform Availability	SLOSH model results are publicly available through the P-Surge website and by using the SDP.
Flood Hazards Modeled	Coastal storm surge with probabilities of exceedance for various surge levels (5 feet operationally and 2 through 10 feet experimentally)
Future Conditions	None readily available, however, the SLOSH model can be used to model storm surge for hypothetical events.

Table 59 presents gaps identified in the NOAA SLOSH Coastal modeling dataset.

Table 59: NOAA SLOSH Modeling Data Gaps

Identified Gaps	
Age	• None
Scale (Spatial Extent)	• None
Level of Detail	• None
Modeling Platform Availability	• The coastal models require supercomputers for efficient computations.
Flood Hazards Modeled	• Various probabilities of exceedance for storm surge associated with an ongoing event are provided, however, AEP events do not appear to be available. • Model does not include wave action or interaction/influence of fluvial or pluvial flooding from rivers and rainfall.
Future Conditions	• No defined future conditions model runs are identified; however, the model could be used to compute hypothetical future events if provided with necessary input data from other sources that estimate future atmospheric conditions.

The NOAA SLOSH coastal modeling provides an extremely valuable tool for hurricane evacuation planning and real-time awareness of potential storm surge impacts from hurricanes and other significant coastal storms. The probabilistic modeling approach is less vulnerable to prediction error than a single deterministic model but can be more difficult to interpret. Model runs for typical AEP events based on previously completed computations for past storms and hypothetical future events could provide valuable information for the Blueprint within the coastal region.

4.7 University of North Carolina Renaissance Computing Institute ADCIRC Prediction System Modeling

ADCIRC was developed in the 1990s by Dr. Rich Luettich to model coastal circulation and storm surge water levels and currents. The model is used today by the USACE ERDC (see SACS section above), FEMA, and various universities including the University of North Carolina (UNC). UNC's Renaissance Computing Institute (RENCI) specifically uses the ADCIRC Prediction System (APS) to manage ADCIRC model runs on High Performance Computing systems. Model runs are generated daily based on North American Mesoscale Forecast System forecasts and when the NHC issues storm advisories. Although ADCIRC models are also run by other entities including Louisiana State University for publication to the Coastal Emergency Risk Assessment (CERA) web application, the model computed by RENCI uses a more refined/detailed mesh for North and South Carolina. The ADCIRC model is certified by FEMA for coastal surge analyses and has been used in many flood studies across the country, including North Carolina. The model is typically regarded as more complex and capable, although more time consuming and computational demanding than the SLOSH model.

Table 60 provides summary information for the RENCI ADCIRC modeling.

Table 60: RENCI ADCIRC Modeling Dataset Information

RENCI ADCIRC Coastal Modeling	
Source of Information	UNC RENCI/USACE
Link to Online Data	https://apsviz-terria-map-dev.apps.renci.org
Data Owner	UNC RENCI
Date Created	The original model was developed in the 1990s but has had many updates with the latest version (53) released in 2018. Model runs are performed as needed with best available data and real-time during NHC advisories.
Date of Access	August 2023
Frequency of Updates	Recent model versions have been released roughly every two to five years. Model results are available real-time during coastal storm events.
Update Needed	No

Table 61 below summarizes the criteria used to perform the gap analysis.

Table 61: RENCI ADCIRC Modeling Gap Analysis Criteria Summary

Gap Analysis Criteria	
Age	Most recent version (53) is 5 years old. Age of model runs/results are user dependent, and some are available daily.
Scale (Spatial Extent)	Nationwide (including entire NC coast)
Level of Detail	High, but dependent upon accuracy of base data (topography/bathymetry) and forcing factors such as storm track and wind intensity as well as used mesh cell size (which are smaller closer to shore. Inundation mapping results available on CERA and APS visualization system (APSViz) websites are coarse, however, improved mapping is possible using the model results and high-resolution topography.
Modeling Platform Availability	ADCIRC is free; however, SMS (which is proprietary) is considered necessary for computations. ADCIRC model results are publicly available through the APSViz and CERA websites.
Flood Hazards Modeled	Coastal storm surge. Also, can be paired with wave models such as SWAN or STWAVE for wave simulations. Multiple AEP scenarios such as those used in FEMA studies can be developed.
Future Conditions	None readily available, however, the ADCRIC model can be used to model storm surge for hypothetical events.

Table 62 presents gaps identified in the RENCI ADCIRC Coastal modeling dataset.

Table 62: RENCI ADCIRC Modeling Data Gaps

Identified Gaps	
Age	• None
Scale (Spatial Extent)	• None
Level of Detail	• None
Modeling Platform Availability	• The coastal models require supercomputers for efficient computations. • Proprietary software (SMS) is considered necessary for model use.
Flood Hazards Modeled	• Model does not include interaction/influence of fluvial or pluvial flooding from rivers and rainfall.
Future Conditions	• No defined future conditions model runs identified; however, the model could be used to compute hypothetical future events if provided with

Identified Gaps	
	necessary input data from other sources that estimate future atmospheric conditions.

The RENCI ADCIRC coastal modeling provides an extremely valuable tool for real-time awareness of potential storm surge impacts from hurricanes and other significant coastal storms. Many coastal studies performed by USACE and FEMA have used the ADCIRC model to develop coastal storm surge hazard information at various AEPs for risk assessments and design considerations. Although considered more complex and capable than the SLOSH model, it typically takes longer to run which is a disadvantage during storm preparations/planning. In addition, as a deterministic model, it is more susceptible to error with input data. Model runs for typical AEP events based on previously completed computations for past storms (hindcasts) and hypothetical future events could provide valuable information for the Blueprint within the coastal region.