Natural Hazards Vulnerability Assessment of the NCDOT Ferry Division Assets

NCDOT Research Project 2023-14

July 9, 2024

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16. Abstract

There is a need to evaluate the vulnerability of North Carolina ferry system facilities across the state, both now and as climate change progresses. This will enable the North Carolina Department of Transportation (NCDOT) Ferry Division to plan for adaptation projects to ensure that the system operates successfully into the future.

As NCDOT plans for future transportation system resilience, there is a need for statewide assessment of current and future vulnerability of each of the transportation modes. The NCDOT Resilience Strategy Report (2021) describes NCDOT's short-term strategies for resilience, including to "address gaps in resilience planning and standards for ferry." This was further described as a need to "assess ferry channels and conduct vulnerability and criticality assessments to address future impacts." Having a ferry vulnerability assessment will allow for NCDOT to capture ferry adaptation needs in future updates to the Statewide Resilience Improvement Plan (2024).

The aims and scope of this study are to assess (a) the vulnerability of all of the Ferry Division's infrastructure assets with respect to natural hazards (present and forecast to the 2040 and 2060 planning horizons); (b) the criticality of assets, terminals and routes; (c) community impacts; (d) prioritize assets for adaptation measures where needed; and (e) provide recommendations on potential adaptation options as well as timeframes for implementation and comparative order of magnitude cost estimates.

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Executive Summary

The North Carolina Department of Transportation (NCDOT) ferry system consists of 21 ferries providing everyday service on seven regular routes across the Currituck and Pamlico Sounds as well as the Cape Fear, Neuse, and Pamlico Rivers. A seasonal passenger ferry provides service between Hatteras and Ocracoke Island from May through September. The ferry system infrastructure includes 12 terminals, a state-owned shipyard, four field maintenance shops, 21 ferries and a support fleet that consists of four tugs, three barges, one crane barge and one dredge. The NCDOT ferry system is the second-largest state-maintained ferry system in the United States (after the state of Washington).

The system plays a crucial role in the state's transportation network, both during regular operations and during coastal emergencies. During typical operations, the ferry system provides residents with transportation to work, emergency and routine medical services, and shopping for goods unavailable in local areas. The ferry system also transports building materials, fuel and other essential supplies, school and activity buses, and items for military installation maintenance on a regular basis. Storm response and recovery services include evacuating residents and visitors from coastal areas and providing transportation post-storm when portions of the roadway network are damaged.

The NCDOT Resilience Strategy Report (2021) describes NCDOT's short-term strategies for resilience, including the goal to "address gaps in resilience planning and standards for ferry." This is described as a need to "assess ferry channels and conduct vulnerability and criticality assessments to address future impacts." This research is aligned with this NCDOT resilience strategy by developing a criticality-vulnerability focused assessment.

The current vulnerability assessment is also informed by the Federal Highway Administration (FHWA) *Vulnerability Assessment and Adaptation Framework* (3rd Edition; FHWA-HEP-18-020) guidance. This federal framework is designed to help transportation agencies and their partners assess the vulnerability of transportation systems to extreme weather and climate effects.

To address this need, the aims and objectives of this study were to

1) Assess the vulnerability of all of the Ferry Division's infrastructure assets with respect to natural hazards (present and forecast to the 2040 and 2060 planning horizons)
2) Assess the condition of ferry channels at present as well as potential climate impacts;
3) Assess criticality of ferry system assets, terminals and routes;
4) Assess community impacts associated with ferry disruptions;
5) Provide an assessment that would allow assets to be prioritized for adaptation measures; and
6) Provide recommendations on potential adaptation options as well as timeframes for implementation and comparative order of magnitude cost estimates.

The results of this study will support NCDOT planning efforts to develop, prioritize, and implement adaptation measures to ensure sustainable and resilient ferry system operations.

The resulting criticality-vulnerability approach to natural hazard assessments can be incorporated into future updates of the NCDOT Statewide Transportation Resilience Improvement Plan (RIP). RIPs are federally supported resilience improvements plans referenced in the Infrastructure Investment and Jobs Act (IIJA) and eligible for Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) funding.

The overall terminal vulnerability results are presented in highlighting each terminal's overall vulnerability and the terminal criticality. Twelve of the ferry system facilities have either a high or medium vulnerability. Five of the facilities have both a high vulnerability and high criticality.

Exhibit 1: Overall Terminal Vulnerability and Criticality

Overall Terminal Vulnerability and Criticality

Terminal/Facility	Overall Terminal Vulnerability	Terminal Criticality
Currituck	High	Medium
Knotts Island	Low	Medium
Hatteras	High	High
Ocracoke South Dock	High	High
Ocracoke Silver Lake	High	High
Swan Quarter	Medium	High
Cedar Island	High	High
Bayview	Medium	Medium
Aurora	Medium	Medium
Cherry Branch	Medium	Medium
Minnesott Beach	Low	Medium
Southport	High	Medium
Fort Fisher	Medium	Medium
Manns Harbor Shipyard	High	High
Powell's Point Storage	Low	Medium

* Due to an asset based scoring method, the Rodanthe Emergency Terminal and Stumpy Point Emergency Terminal did not get an overall terminal vulnerability designation because there are no assets at the site.

The criticality-vulnerability table in Exhibit 2 presents the five most critical and vulnerable ferry facilities: Hatteras, Ocracoke South Dock, Ocracoke Silver Lake, Cedar Island and Manns Harbor Shipyard. Currituck and Southport have high vulnerability and medium criticality. No ferry system facility was determined to have low criticality and low vulnerability.

Exhibit 2: Overall Terminal-Level Vulnerability & Criticality Matrix

Terminal-Level Vulnerability and Criticality Matrix

Overall Vulnerability \ Terminal Criticality	Low	Med	High
High		• Currituck • Southport	• Hatteras • Ocracoke SD • Ocracoke SL • Cedar Island • Manns Harbor Shipyard
Med		• Bayview • Aurora • Cherry Branch • Fort Fisher	• Swan Quarter
Low		• Knotts Island • Minnesott Beach • Powell's Point Storage	

During the assessment, the two facilities that were found to be the most critical and most vulnerable are Ocracoke South Dock and Manns Harbor Shipyard. The Ocracoke South Dock facility is the most highly vulnerable site due to terminal flooding, terminal erosion, and highly vulnerable roadway access. Manns Harbor Shipyard is one of the most critical facilities for the ferry system as it is the maintenance and repair facility for the entire ferry fleet. A service disruption to Manns Harbor over a few days can have serious implications to the ferry system operations and fleet maintenance. The Manns Harbor Shipyard site has high flood vulnerability.

The detailed criticality-vulnerability assessment results are presented at the route level, terminal level and asset level in the following set of terminal summary sheets. The sheets include detailed vulnerability assessments based on planning horizon (present, 2040, and 2060); coastal and estuarine erosion; asset/terminal flooding; critical roadway vulnerability; community impact; and shoaling in the navigational channel. The summary sheets also present asset level adaptation options, including timeframe and a comparative order of magnitude cost (including cost uncertainty).

This final report documents the research study process, methodology, results, and potential adaptation options that were developed to assess and address natural hazard vulnerability for the NCDOT ferry system.

Terminal Summary Sheets

Currituck

AREA CHARACTERISTICS

Terminal: Currituck

County: Currituck

Area: Currituck serves a route that connects to the Knotts Island terminal, which serves as a school bus route and provides school access to children on the island.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality	
Knotts Island	5 miles	40 minutes	15,000+	◐	Drive around option; 65 minute drive (25 minutes longer to drive)

Route Vulnerabilities and Impacts

Shoaling Vulnerability	○	Dredging occurs less frequently than every 10 years.
Community Impact	○	73% of riders who took a 2017 onboard survey say they would have to find another way to make their trip if ferry was unavailable. Public school buses would have to drive through Virginia to transport children between the island and mainland.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	●	●	●
Erosion	○	○	○
Overall Terminal	●	●	●
Roadway Access	◐	◐	◐

Terminal Criticality and Vulnerabilities

Terminal Criticality	◐	Medium criticality as roadway alternatives exist but could have flooding issues.
Community Impact	○	Local residents depend on this route. Low Average Transportation Disadvantage Index of Riders: 7.4 (3-18 scale)
Terminal Flood Hazards	●	The most critical terminal assets have high flooding vulnerability making the terminal more vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	○	Bulkhead and breakwater in good condition.
Critical Roadways Vulnerability to Erosion	◐	Less than 5% of critical roadway length within 50 ft of unstabilized estuarine shoreline.
Critical Roadways Vulnerability to Flooding	●	Critical Roadways vulnerable to flooding from many sources, including multiple high risk segments

KEY: ○ Low ◐ Medium ● High

ITRE

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

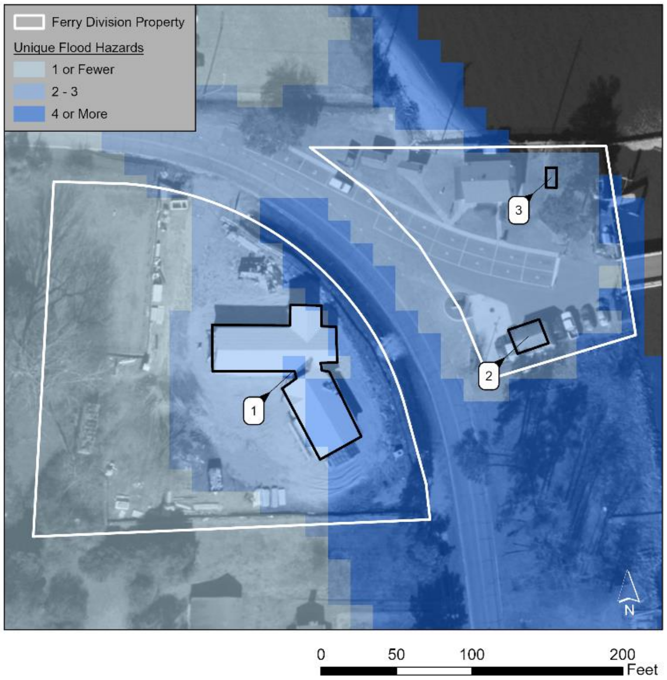
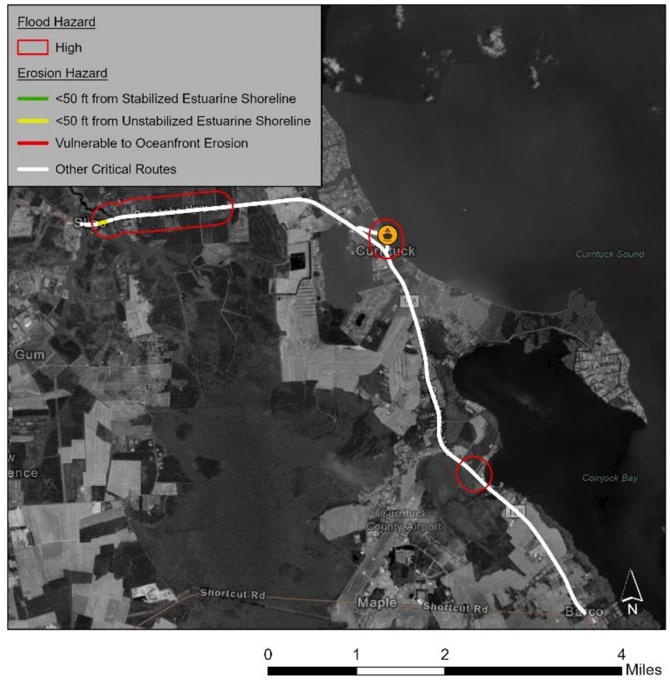


Figure 2: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	027-010-010	Currituck Ferry Operations Building	●	●
2	027-010-009	Storage Building	◐	◐
3	CU-Outbuilding	Veeder Root Building	○	◐

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
NC 615 Loop and NC 168 Between Sligo and Barco	○	◐	●

KEY: ○ Low ◐ Medium ● High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	High	High	Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Currituck Ferry Operations Building	High	High	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Storage Buildings	Medium	Medium	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Veeder Root Building	Low	Medium	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Erosion							
Roadways	High	High	Install Revetment Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	General permit available, relatively straightforward design
			Install Living Shoreline Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	Enhanced ecological function, nature-based solution, may require more design considerations
Property Shoreline	Low	Low	Maintain Existing Seawall/Bulkhead	Near Term	$ (Low)	◆ (Low)	Ensure seawall/bulkhead and breakwater remain in good condition
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Currituck Terminal has an overall high vulnerability rating with high flooding vulnerability and medium roadway access vulnerability. There is low erosion vulnerability at the terminal.

Terminal assets have medium and high vulnerability and is vulnerable to flooding hazards for critical terminal assets.

The terminal has an overall medium criticality. While there is an alternative highway route for local residents, it could add 25 minutes of trip travel time and alternative roads can be impacted by flooding. The Transportation Disadvantaged Index (TDI) community impact of this route is low.

Knotts Island

AREA CHARACTERISTICS

Terminal: Knotts Island

County: Currituck

Area: Knotts Island serves a route that connects to the Currituck terminal, which serves as a school bus route and provides school access to children on the island.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality
Currituck	5 miles	40 minutes	15,000+	(Medium) Drive around option; 65 minute drive (25 minutes longer to drive)

Route Vulnerabilities and Impacts

Shoaling Vulnerability	Medium	Dredging occurs approximately every 7 years.
Community Impact	Low	73% of riders who took a 2017 onboard survey say they would have to find another way to make their trip if ferry was unavailable. Public school buses would have to drive through Virginia to transport children between the island and mainland.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	**2040**	**2060**
Flooding	Low	Low	Low
Erosion	Low	Low	Low
Overall Terminal	Low	Low	Low
Roadway Access	High	High	High

Terminal Criticality and Vulnerabilities

Terminal Criticality	Medium	Medium criticality as roadway alternatives exist but could have flooding issues.
Community Impact	Low	Local residents depend on this route. Low Average Transportation Disadvantage Index of Riders: 7.4 (3-18 scale)
Terminal Flood Hazards	Low	The most critical terminal assets have low flooding vulnerability making the terminal somewhat vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	Low	Revetment in good condition.
Critical Roadways Vulnerability to Erosion	High	17% of critical roadway within 50 feet of unstabilized estuarine shoreline and 4% within 50 feet of stabilized estuarine shoreline.
Critical Roadways Vulnerability to Flooding	High	Critical Roadways vulnerable to flooding from many sources, including multiple high risk segments

KEY: Low Medium High

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

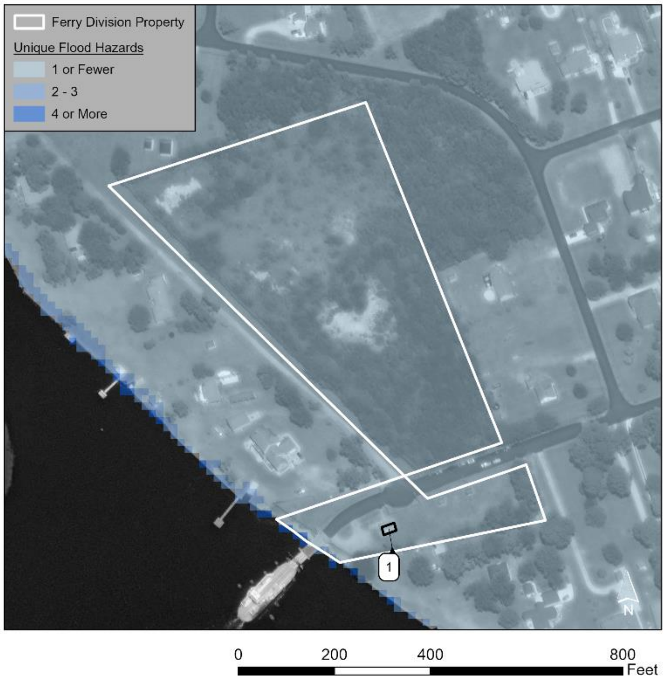
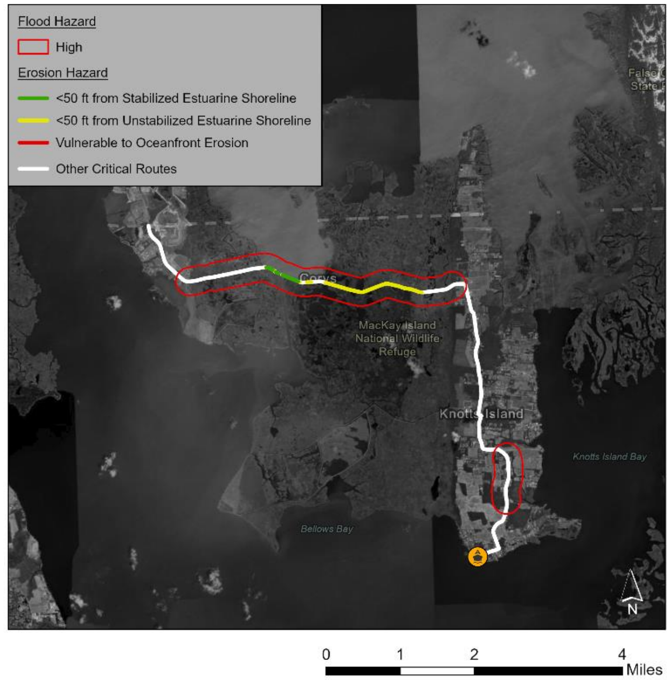


Figure 2: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	027-010-009	Knotts Island Restroom Building	Low	Low

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
NC 615 from State boundary to terminal	Low	High	High

KEY: Low Medium High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	●	●	Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Knotts Island Restroom Building	○	○	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Ex. installing drains, ensuring contents can withstand getting flooded
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Erosion							
Roadways	●	●	Maintain Existing Shoreline Stabilization	Near Term	$ (Low)	◆◆ (Med-Low)	Maintain existing revetment/bulkheads
			Install Revetment Along Unstabilized Shoreline	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	General permit available, relatively straightforward design
			Install Living Shoreline Along Unstabilized Shoreline	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Enhanced ecological function, nature-based solution, may require more design considerations
Property Shoreline	○	○	Maintain Existing Revetment	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Ensure revetment remains in good condition
			Raise Revetment	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on design parameters and elevation needed

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Knotts Island Terminal has an overall medium criticality and low vulnerability rating with high roadway access vulnerability and low terminal flooding and erosion vulnerability.

The single terminal asset is a restroom with low critically and low vulnerability.

The terminal has an overall medium criticality. While there is an alternative highway route for local residents, it could add 25 minutes of trip travel time and alternative roads can be impacted by flooding. The Transportation Disadvantaged Index (TDI) community impact of this route is low.

Hatteras

AREA CHARACTERISTICS

Terminal: Hatteras

County: Dare

Area: Hatteras, situated near numerous businesses, serves a popular tourist route for day and overnight trips that connects the island to Ocracoke South Dock terminal.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality
Ocracoke	4.5 miles	60 minutes	203,000+	● No highway access to Ocracoke Island.

Route Vulnerabilities and Impacts

Shoaling Vulnerability	●	Channels between Hatteras and Ocracoke South Dock Terminals are dredged multiple times a year by the U.S. Army Corps of Engineers.
Community Impact	●	Supports thousands of jobs and hundreds of millions in economic impact to the local economy, with 90%+ of riders who took a 2017 onboard survey for the Hatteras-Ocracoke route saying they would not or could not take their trip if the ferry was unavailable.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	●	●	●
Erosion	○	○	○
Overall Terminal	●	●	●
Roadway Access	●	●	●

Terminal Criticality and Vulnerabilities

Terminal Criticality	●	Limited access to island, only one ferry terminal providing access to Ocracoke South Dock.
Community Impact	●	Terminal serves emergency evacuation route. Moderate Average Transportation Disadvantage Index of Riders: 8.4 (3-18 scale)
Terminal Flood Hazards	●	The most critical terminal assets have high flooding vulnerability making the terminal more vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	○	Bulkhead/revetment in good condition.
Critical Roadways Vulnerability to Erosion	●	6% of critical roadway within 230 feet of ocean shoreline, less than 5% of critical roadway within 50 feet of estuarine shoreline. 20% of critical roadway vulnerable to sound-side breaching.
Critical Roadways Vulnerability to Flooding	●	Critical Roadways vulnerable to flooding from many sources, including multiple high risk segments

KEY: ○ Low ◐ Medium ● High

ITRE

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

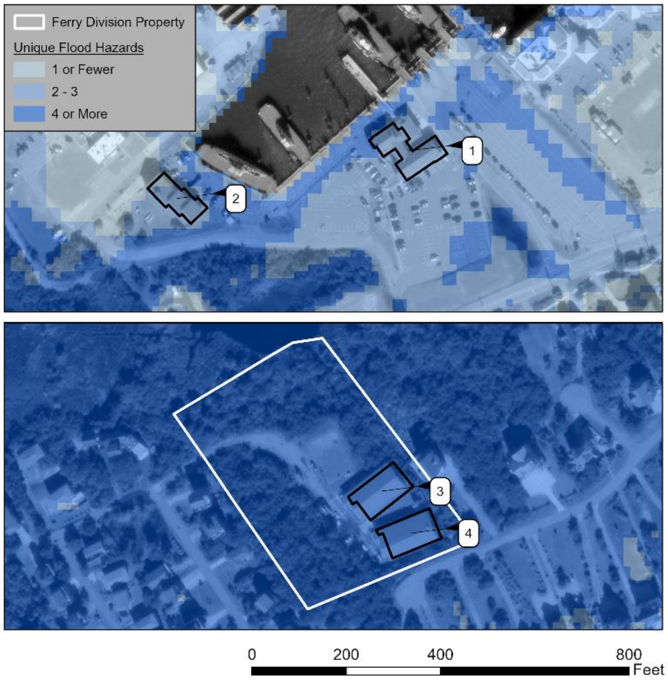
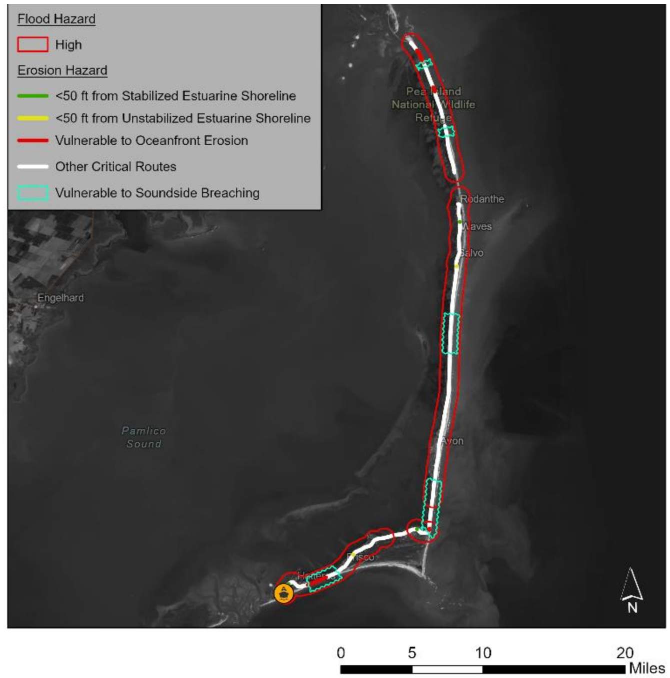


Figure 2: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	028-016-008	Hatteras Visitor Center & Office	High	Medium
2	028-016-020	Hatteras Maintenance Facility	High	Medium
3	028-016-021	Hatteras Dormitory #1	High	High
4	028-016-022	Hatteras Dormitory #2	High	High

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion / Breaching Vulnerability	Roadway Flood Vulnerability
NC 12 from Basnight Bridge to Hatteras Terminal	High	High	High

KEY: Low Medium High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	High	High	Beach Nourishment & Dune Construction	Near Term	$$$ (Med-High)	◆◆ (Med-Low)	Currently dune building is used, beach nourishment would allow for more time/less frequent overtopping/erosion
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Hatteras Visitor Center & Office	High	Medium	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Hatteras Maintenance Facility	High	Medium	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Event	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Hatteras Dorms #1 & #2	High	High	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Ramp & Gantry System	High	Medium	Raise Center Beam, Adjust Cables & Counterweights	Near Term	$$ (Med-Low)	◆ (Low)	Future ramp replacement may be needed at Hatteras

KEY: ○ Low ◐ Medium ● High

Erosion							
Roadways	●	●	Beach Nourishment & Dune Construction	Near Term	$$$ (Med-High)	◆◆ (Med-Low)	Along currently vulnerable and frequently impacted sections of the critical roadway, dune building/repair is used to reduce overtopping and erosion impacts. Larger scale beach nourishment could further reduce these impacts and extend the time before other adaptation measures (e.g. bridges, causeways) may be necessary
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Property Shoreline	○	○	Maintain Existing Seawall/Bulkhead/Revetment	Near Term	$ (Low)	◆ (Low)	Ensure seawall/bulkhead/revetment remain in good condition
			Raise Seawall/Bulkhead/Revetment	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS AND RECOMMENDATIONS

The Hatteras Terminal has an overall high criticality and high vulnerability rating with high flooding roadway access vulnerability and low terminal erosion vulnerability.

Terminal assets all have high critically and medium to high vulnerability. The critical terminal asset flooding hazard is high. The high criticality ramp and gantry system is anticipated to be replaced in the future.

The high criticality terminal supports thousands of jobs and hundreds of millions in economic impact to the local economy. There is no roadway connection to Ocracoke Island. The Transportation Disadvantage Index (TDI) community impact is a medium vulnerability rating.

NCDOT Ferry Vulnerability Study

Ocracoke South Dock

AREA CHARACTERISTICS

Terminal: Ocracoke South Dock

County: Hyde

Area: Ocracoke South Dock, located on the unpopulated end of Ocracoke Island, connects to the Hatteras terminal through a popular tourist route used for day and overnight trips.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality
Hatteras	4.5 miles	70 minutes	203,000+	High — No highway access to Ocracoke Island.

Route Vulnerabilities and Impacts

Shoaling Vulnerability	High	Dredging occurs multiple times a year.
Community Impact	High	Supports thousands of jobs and hundreds of millions in economic impact to the local economy, with 90%+ of riders who took a 2017 onboard survey for the Hatteras-Ocracoke route saying they would not or could not take their trip if the ferry was unavailable.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	High	High	High
Erosion	High	High	High
Overall Terminal	High	High	High
Roadway Access	High	High	High

Terminal Criticality and Vulnerabilities

Terminal Criticality	High	Limited access to island, there is only one ferry terminal (Hatteras) providing access to this terminal. The critical roadway between OSD and Ocracoke Village is frequently overwashed by ocean water causing a disconnection.
Community Impact	High	Terminal serves emergency evacuation route and ferry service serves as the only vehicle ferry to Ocracoke from Hatteras Island. Moderate Average Transportation Disadvantage Index of Riders: 8.4 (3-18 scale)
Terminal Flood Hazards	High	The most critical terminal assets have high flooding vulnerability making the terminal more vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	High	Visible damage to seawall/bulkhead adjacent to inlet. Ongoing erosion at inlet shoreline.
Critical Roadways Vulnerability to Erosion	High	21% of critical roadway within 230 ft of ocean shoreline, less than 5% within 50 ft of stabilized estuarine shoreline. 21% of critical roadway vulnerable to sound-side breaching.
Critical Roadways Vulnerability to Flooding	High	Critical Roadways vulnerable to flooding from many sources, including multiple high risk segments

KEY: Low Medium High

ITRE

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

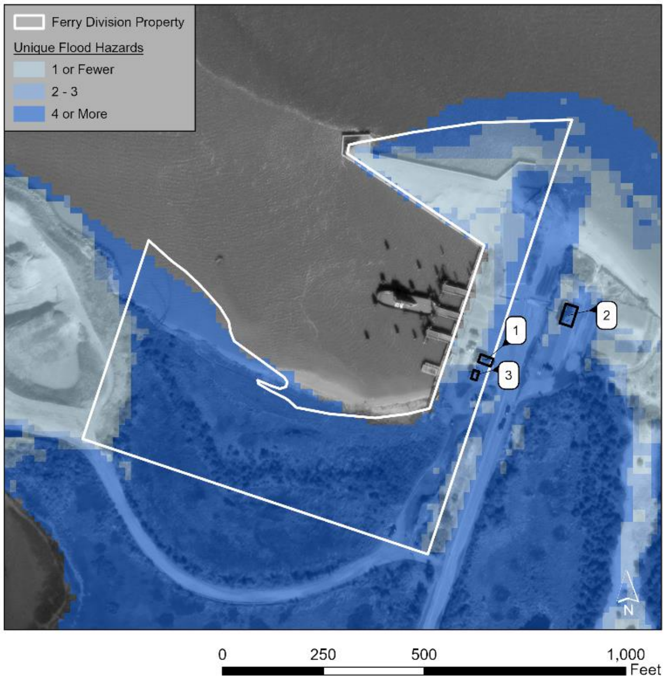
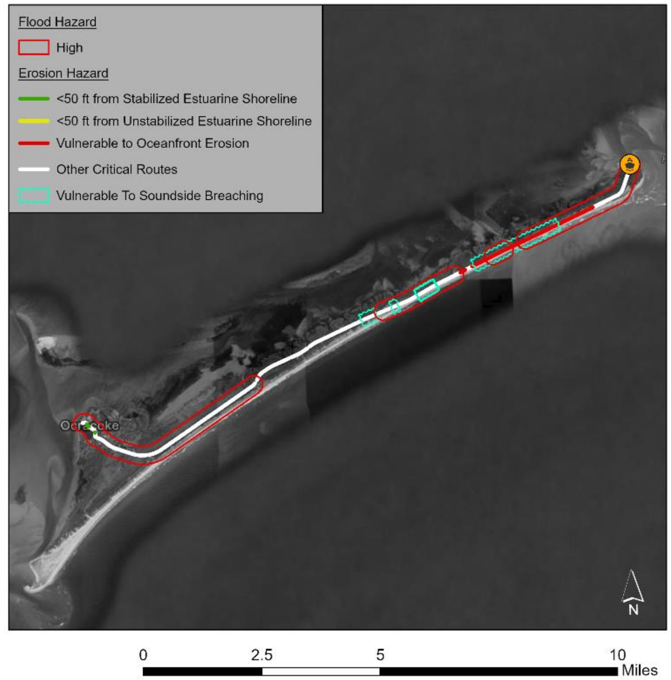


Figure 2: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	048-014-003	Ferry Office	High	High
2	048-014-005	Visitors Restroom Building	Medium	High
3	OSD-AST	Storage Building with Above-ground Storage Tank	Medium	High

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion / Breaching Vulnerability	Roadway Flood Vulnerability
NC 12 on Ocracoke Island	High	High	High

KEY: Low Medium High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	●	●	Beach Nourishment & Dune Construction	Near Term	$$$ (Med-High)	◆◆ (Med-low)	Currently dune building is used, beach nourishment would allow for more time/less frequent overtopping/erosion
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Entire Facility	●	●	Relocate Entire Terminal	Long Term	$$$$ (High)	◆◆◆◆ (High)	Will require land acquisition, rerouting of Hatteras-Ocracoke route, construction of new facility
Ferry Office	●	●	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Visitors Restroom Building	◐	●	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Ex. installing drains, ensuring contents can withstand getting flooded
			Convert to Semi-Permanent Facility	Long Term	$$ (Med-Low)	◆◆ (Med-low)	Use trailer or moveable facility
Storage Building with Above-ground Storage Tank	◐	●	Elevate/Floodproof	Near Term	$ (Low)	◆ (Low)	Elevate storage tanks and/or ensure contents can withstand being flooded
Erosion							
Roadways	●	●	Beach Nourishment & Dune Construction	Near Term	$$$ (Med-High)	◆◆ (Med-low)	Currently dune building is used, beach nourishment would allow for more time/less frequent overtopping/erosion
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Entire Facility	●	●	Relocate Entire Terminal	Long Term	$$$$ (High)	◆◆◆◆ (High)	Will require land acquisition, rerouting of Hatteras-Ocracoke route, construction of new facility
Property Shoreline	●	●	Repair Existing Seawall/Bulkhead	Near Term	$ (Low)	◆ (Low)	Repair existing seawall to stabilize inlet shoreline
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Ocracoke South Dock Terminal has an overall high criticality and high vulnerability rating with high flooding, erosion and roadway access vulnerability.

All terminal assets all have high flood vulnerability. High frequency of dredging is required to maintain the navigation channel due to the high level of shoaling.

The high criticality terminal supports thousands of jobs and hundreds of millions in economic impact to the local economy. There is no roadway connection to Ocracoke Island. The Transportation Disadvantage Index (TDI) community impact is a medium vulnerability rating.

The severe vulnerability to both the terminal site and the roadway access for both the near term and long term planning horizon suggest that the relocation of the terminal is a necessary adaptation option to consider.

Ocracoke Silver Lake

AREA CHARACTERISTICS

Terminal: Ocracoke Silver Lake

County: Hyde

Area: Silver Lake serves two ferry routes and is situated on Ocracoke Island, which is only accessible by a personal vessel or ferry. The island is a busy tourist destination with 16 miles of beaches and historic attractions.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality	
Swan Quarter	27 miles	2.5 hours	32,300+ (52% visitors, highly seasonal)	High	No highway access to Ocracoke Island.
Cedar Island	23 miles	2.25 hours	49,600+ (66% visitors, highly seasonal)	High	No highway access to Ocracoke Island.

Route Vulnerabilities and Impacts

Shoaling Vulnerability	High	Dredging occurs less frequently than every 10 years within the harbor by the U.S. Army Corps of Engineers (USACE), however, dredging the in channel outside the harbor (Big Foot Slough) occurs multiple times a year by the USACE.
Community Impact	High	Routes serve as emergency evacuation routes and critical supply lines for the island community.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	High	High	High
Erosion	Medium	Medium	High
Overall Terminal	High	High	High
Roadway Access	High	High	High

Terminal Criticality and Vulnerabilities

Terminal Criticality	High	Limited access to Ocracoke Island and is one of two ferry terminals providing access to island.
Community Impact	High	Terminal serves emergency evacuation route. Moderate Average Transportation Disadvantage Index of Riders: 8.9 (3-18 scale)
Terminal Flood Hazards	High	The most critical terminal assets have high flooding vulnerability making the terminal more vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	Low	Bulkhead/revetment in satisfactory condition.
Critical Roadways Vulnerability to Erosion	High	21% of NC 12 along Ocracoke Island within the 230 feet buffer indicating oceanfront erosion hazard. Multiple closures currently occur per year due to overwash. 21% of critical roadway vulnerable to sound-side breaching.
Critical Roadways Vulnerability to Flooding	High	Critical Roadways vulnerable to flooding and erosion from many sources, including multiple high risk segments.

KEY: Low, Medium, High

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 2: Flood Hazards Aerial

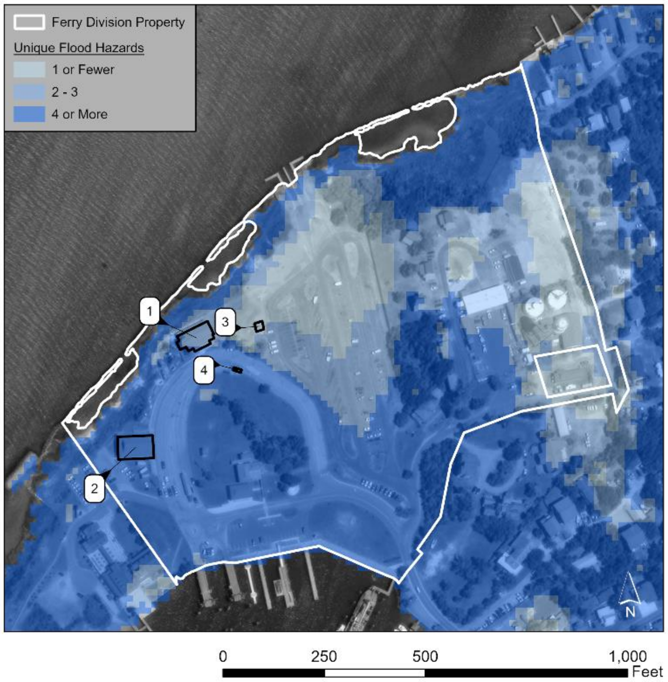
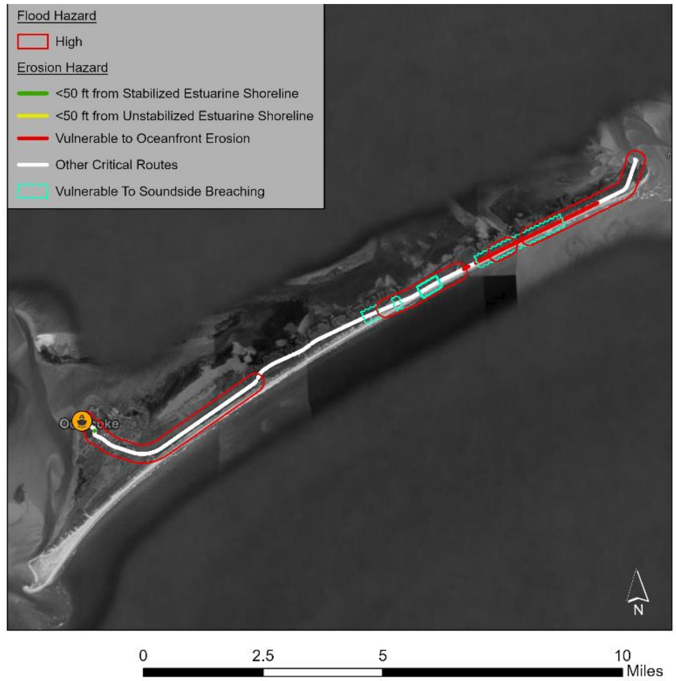


Figure 1: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	048-012-005	Ferry Dormitory Building	High	High
2	048-012-006	Visitors Center and Ferry Office	High	High
3	048-012-007	Amphidromia Equipment Building	High	Low
4	N/A	Ticket Booth	Low	High

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion / Breaching Vulnerability	Roadway Flood Vulnerability
NC 12 on Ocracoke Island	High	High	High

KEY: Low Medium High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	●	●	Beach Nourishment & Dune Construction	Near Term	$$$ (Med-High)	◆◆ (Med-Low)	Currently dune building is used, beach nourishment would allow for more time/less frequent overtopping/erosion
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Ferry Dormitory Building	●	●	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Visitors Center and Ferry Office	●	●	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Amphidromia Equipment Building	●	○	Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Elevate critical equipment, ensure contents can withstand being flooded
Ticket Booth	○	●	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Elevate critical equipment, ensure contents can withstand being flooded
			Convert to Semi-Permanent Facility	Near Term	$ (Low)	◆ (Low)	Use Trailer or Moveable Facility
Ramp & Gantry System	●	◐	Raise Center Beam, Adjust Cables & Counterweights	Near Term	$$ (Med-Low)	◆ (Low)	Not anticipated to be needed in near term
			Extend Ramps & Redesign to Accept Hatteras/River Class Vessels	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Planned for Ocracoke Silver Lake so docks can accept vessels that generally go to South Dock to ensure emergency operations capability
Erosion							
Roadways	●	●	Beach Nourishment & Dune Construction	Near Term	$$$ (Med-High)	◆◆ (Med-Low)	Currently dune building is used, beach nourishment would allow for more time/less frequent overtopping/erosion
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Property Shoreline	○	○	Maintain Existing Seawall/Bulkhead	Near Term	$ (Low)	◆ (Low)	Ensure seawall/bulkhead remains in good condition
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Maintain Existing Breakwaters	Near Term	$ (Low)	◆ (Low)	Ensure breakwaters remain in good condition

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Ocracoke Silver Lake Terminal has overall high criticality and high vulnerability with high flooding and roadway access vulnerability and low terminal erosion vulnerability.

Most of the terminal assets have high critically and high flood vulnerability. The high criticality and high vulnerability ramp and gantry system is anticipated to be replaced in the future to accommodate all classes of ferry vessel operated by NCDOT.

The high criticality terminal supports two ferry routes and serves as an emergency evacuation and critical supply route for Ocracoke Island. There is no roadway connection to Ocracoke Island. The Transportation Disadvantage Index (TDI) community impact is medium but the overall community impact is high.

NCDOT Ferry Vulnerability Study

Swan Quarter

AREA CHARACTERISTICS

Terminal: Swan Quarter

County: Hyde

Area: Swan Quarter serves the longest NCDOT ferry route, which connects mainland NC to the Ocracoke Silver Lake terminal, providing a key connection for tourists and local residents.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality	
Ocracoke	27 miles	2.5 hours	36,000+	High	No highway access to Ocracoke Island.

Route Vulnerabilities and Impacts

Shoaling Vulnerability	Low	Dredging occurs approximately every 15 years.
Community Impact	Medium	Used as an emergency evacuation route and critical supply line for island community.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	Medium	Medium	Medium
Erosion	High	High	High
Overall Terminal	Medium	Medium	Medium
Roadway Access	Medium	Medium	Medium

Terminal Criticality and Vulnerabilities

Terminal Criticality	High	One of two ferry terminals providing access to Ocracoke Silver Lake terminal. Ramp infrastructure not set up for low river class vessel: higher sound class vessels only.
Community Impact	High	Terminal serves emergency evacuation route. Moderate Average Transportation Disadvantage Index of Riders: 9.2 (3-18 scale)
Terminal Flood Hazards	Medium	The most critical terminal assets have medium flooding vulnerability making the terminal moderately vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	High	Shoreline not stabilized.
Critical Roadways Vulnerability to Erosion	Low	No critical roadway within 230 ft of oceanfront shoreline or within 50 ft of estuarine shoreline.
Critical Roadways Vulnerability to Flooding	High	Critical Roadways vulnerable to flooding from many sources, including multiple high risk segments

KEY: Low, Medium, High

ITRE

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

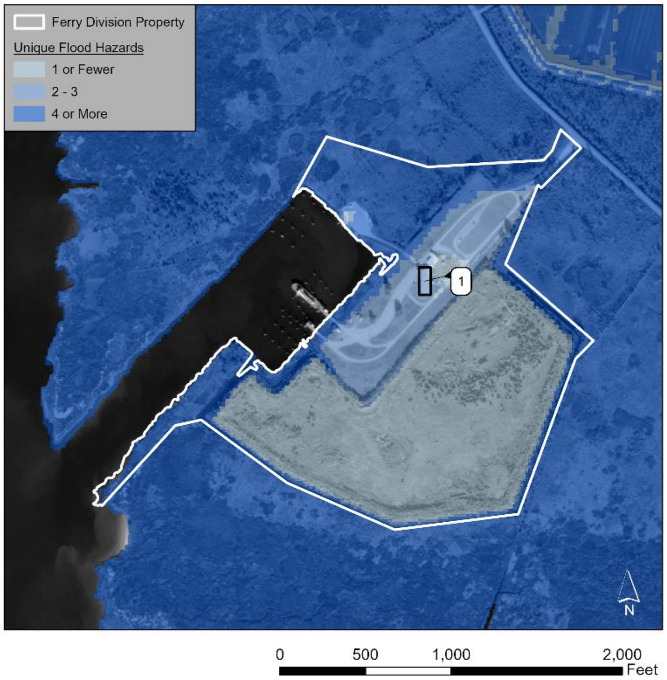
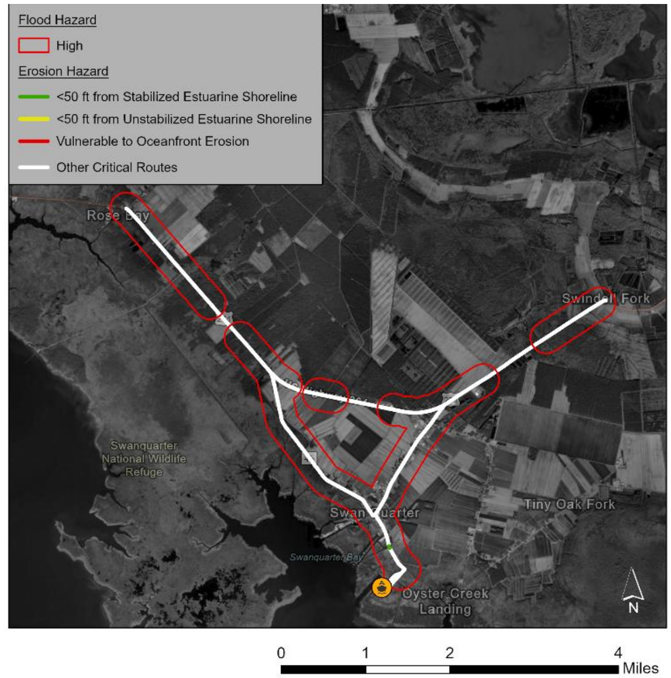


Figure 2: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	048-039-002	Ferry Operations Building	● (High)	◐ (Medium)

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
US264 from Swindell Fork to Rose Bay Turnpike Rd including NC 45 and NC 94 (Main St)	○ (Low)	○ (Low)	● (High)

KEY: ○ Low ◐ Medium ● High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	High	High	Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Ferry Operations Building	High	Medium	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Raise contents above flood levels and/or ensure contents can withstand being flooded
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Erosion							
Property Shoreline	Low	High	Install Bulkhead/Seawall Along Unstablized Shoreline	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Install Revetment Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	General permit available, relatively straightforward desig
			Install Living Shoreline Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Enhanced ecological function, nature-based solution, may require more design considerations

KEY: Low Medium High

ITRE

KEY TAKEAWAYS

The Swan Quarter Terminal has an overall high criticality and medium vulnerability rating with high terminal erosion vulnerability and medium flooding and roadway access vulnerability.

The terminal's ferry operations building is high criticality and medium flood vulnerability. The critical terminal asset flooding hazard is medium.

The high criticality terminal serves as an emergency evacuation and critical supply route for Ocracoke Island. There is no roadway connection to Ocracoke Island. The Transportation Disadvantage Index (TDI) community impact is a medium. The overall community impact is high.

NCDOT Ferry Vulnerability Study

Cedar Island

AREA CHARACTERISTICS

Terminal: Cedar Island

County: Carteret

Area: Cedar Island connects to the Ocracoke Silver Lake terminal, providing visitors and residents access to numerous tourist attractions and local sites of interest.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality
Ocracoke	23 miles	2.25 hours	42,000+	● No highway access to Ocracoke Island.

Route Vulnerabilities and Impacts

Shoaling Vulnerability	◐	Dredging occurs approximately every 12 years.
Community Impact	●	Used as an emergency evacuation route and critical supply line for the island community.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	●	●	●
Erosion	○	○	○
Overall Terminal	●	●	●
Roadway Access	●	●	●

Terminal Criticality and Vulnerabilities

Terminal Criticality	●	Limited access to Ocracoke Island and is one of two ferry terminals providing access to island.
Community Impact	●	Terminal serves as the emergency evacuation route and supply line. Moderate Average Transportation Disadvantage Index of Riders: 8.4 (3-18 scale)
Terminal Flood Hazards	●	The most critical terminal assets have high flooding vulnerability making the terminal more vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	○	Bulkhead in good condition.
Critical Roadways Vulnerability to Erosion	●	13% of critical roadway within 50 feet of unstabilized estuarine shoreline and 6% within 50 feet of stabilized estuarine shoreline.
Critical Roadways Vulnerability to Flooding	●	Critical Roadways vulnerable to flooding from many sources, including multiple high risk segments.

KEY: ○ Low ◐ Medium ● High

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

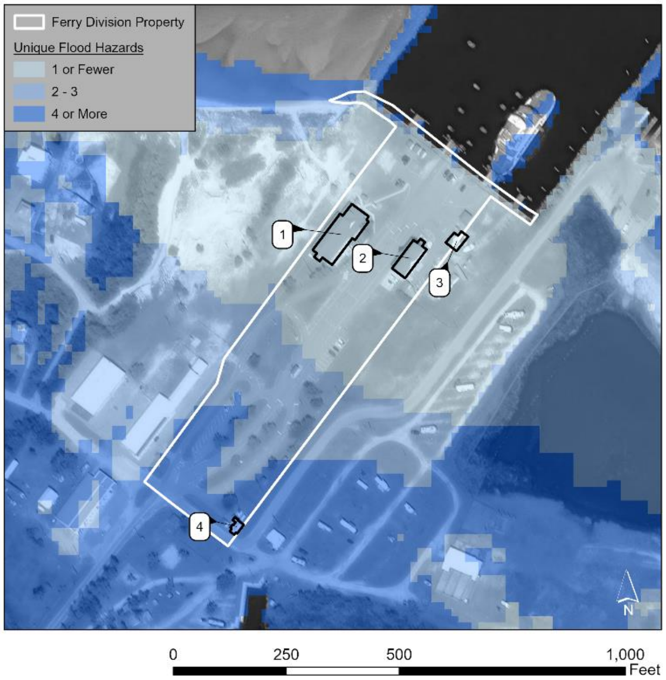
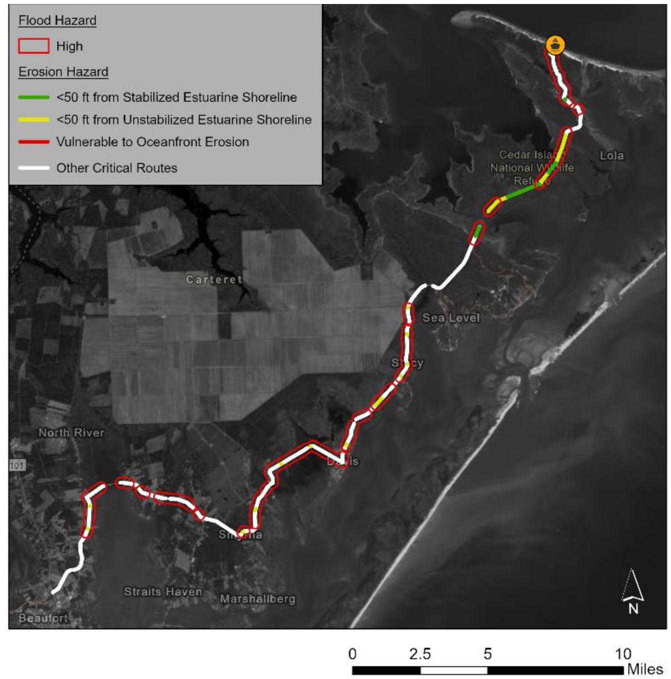


Figure 2: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	016-017-011	Visitors Center & Office	●	○
2	016-017-019	Marine Maintenance Building	●	○
3	CI-AST	Above-ground Storage Tanks	●	○
4	016-017-005	Pump House	●	●

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
NC 12 From Terminal to US 70, US 70 to NC 101 intersection in Beaufort	○	●	●

KEY: ○ Low ◐ Medium ● High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	●	●	Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Visitors Center & Office	●	○	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Long Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Marine Maintenance Building	●	○	Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Above-ground Storage Tank	●	○	Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Elevate storage tanks and/or ensure contents can withstand being flooded
Pump House	●	●	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Elevate pump controls and ensure contents can withstand being flooded
Erosion							
Roadways	●	●	Maintain Existing Shoreline Stabilization	Near Term	$ (Low)	◆◆ (Med-Low)	Maintain existing revetment/bulkheads
			Install Revetment Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	General permit available, relatively straightforward design
			Install Living Shoreline Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	Enhanced ecological function, nature-based solution, may require more design considerations
Property Shoreline	○	○	Maintain Existing Seawall/Bulkhead	Near Term	$ (Low)	◆ (Low)	Ensure seawall/bulkhead remains in good condition
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Cedar Island Terminal has an overall high criticality and high vulnerability rating with high flooding and roadway access vulnerability and low terminal erosion vulnerability.

The roadway to the terminal is vulnerable to both erosion and flooding impacts and disruptions. The pump house is high criticality and high vulnerability to flooding impacts.

The terminal has an overall high criticality as it provides access to Ocracoke Island and there is no roadway access alternative and serves as emergency evacuation route and critical supply route and has a medium Transportation Disadvantaged Index (TDI) impact. The overall community impact is high.

Bayview

AREA CHARACTERISTICS

Terminal: Bayview

County: Beaufort

Area: Bayview serves a route that connects to the Aurora terminal. The route connects local communities to essential services, including access to jobs at the PCS Phosphate Company, Inc. in Aurora, NC.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality
Aurora	3.5 miles	30 minutes	39,000+	Medium — Drive around option; 60-minute drive. (30 minutes longer to drive)

Route Vulnerabilities and Impacts

Shoaling Vulnerability	Medium	Dredging occurs approximately every 8 years.
Community Impact	High	Local residents depend on this route for access to essential services. More than half of the riders who took a 2017 onboard survey said they were traveling to work or school, with 80% of riders saying they would have to find another way to make their trip if ferry was unavailable.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	Medium	Medium	Medium
Erosion	Low	Low	Low
Overall Terminal	Medium	Medium	Medium
Roadway Access	Low	Low	Low

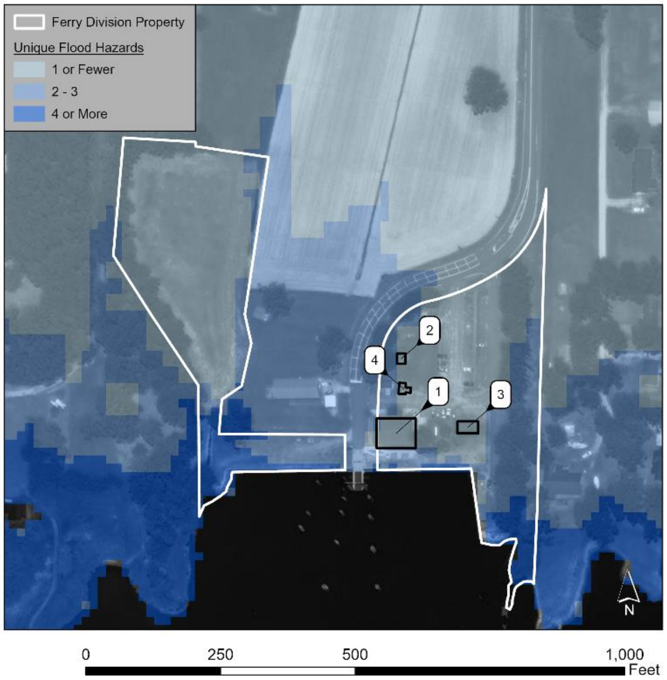
Terminal Criticality and Vulnerabilities

Terminal Criticality	Medium	Medium criticality as a moderate roadway alternative is available for local residents to connect to essential services.
Community Impact	High	Local residents depend on the route. High Average Transportation Disadvantage Index of Riders: 10.6 (3-18 scale)
Terminal Flood Hazards	Medium	The most critical terminal assets have medium flooding vulnerability making the terminal moderately vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	Low	Bulkhead in good condition.
Critical Roadways Vulnerability to Erosion	Low	No critical roadway within 230 feet of oceanfront shoreline or within 50 feet of estuarine shoreline.
Critical Roadways Vulnerability to Flooding	Medium	Critical Roadways vulnerable to flooding from some sources; including two high risk segments.

KEY: Low · Medium · High

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 2: Flood Hazards Aerial



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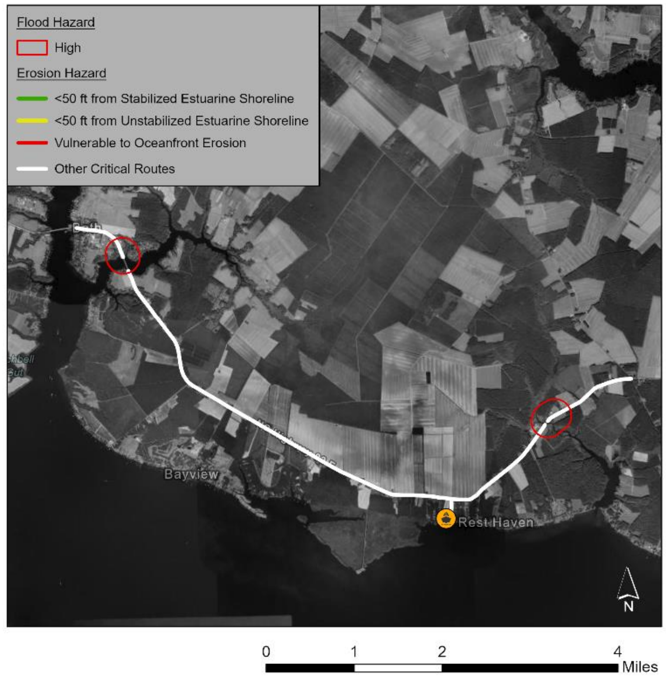


Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	007-017-015	Restroom	● (High)	◐ (Medium)
2	007-017-008	Emergency Generator Building	● (High)	○ (Low)
3	007-017-010	Storage Building	○ (Low)	○ (Low)
4	Ba-Storage	Storage	○ (Low)	○ (Low)

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
NC 306 from Terminal to NC 92, NC 99 to Burbage Rd., NC 92 to Bath	○ (Low)	○ (Low)	◐ (Medium)

KEY: ○ Low ◐ Medium ● High

ITRE

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	High	Medium	Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Office and Restroom	High	Medium	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Ex. installing drains, ensuring contents can withstand getting flooded
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Emergency Generator Building	High	Low	Construct Berm Around Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Bulk material around outside, depends on geotechnical information
			Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise generator above flood levels and ensure contents can withstand being flooded
Storage Buildings	Low	Low	Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Ramps & Gantry System	High	Medium	Raise Center Beam, Adjust Cables & Counterweights	Near Term	$$ (Med-Low)	◆ (Low)	Future ramp replacement anticipated at Bayview
Erosion							
Property Shoreline	Low	Low	Maintain Existing Seawall/Bulkhead	Near Term	$ (Low)	◆ (Low)	Ensure seawall/bulkhead remains in good condition
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements

KEY: ○ Low ◐ Medium ● High

ITRE

KEY TAKEAWAYS

The Bayview Terminal has an overall medium vulnerability rating with high flooding vulnerability and low erosion and roadway access vulnerability.

The terminal assets have low and medium flooding vulnerability. The ramp and gantry system has medium vulnerability and is anticipated to be replaced in future.

The terminal has an overall medium criticality and a high community impact rating with the route serving local residents for trips to work and school and has a high Transportation Disadvantaged Index (TDI) impact. There is an alternative highway route for local residents but it adds an additional 30 minutes trip travel time.

Aurora

AREA CHARACTERISTICS

Terminal: Aurora

County: Beaufort

Area: Aurora is located in Aurora, NC, home to the PCS Phosphate Company, Inc. phosphate mining and chemical plant. The terminal serves a route that connects to the Bayview terminal. This route connects local communities to essential services and reduces the travel time compared to roadway routes.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality	
Bayview	3.5 miles	30 minutes	39,000+	Medium	Drive around option; 60-minute drive. (30 minutes longer to drive)

Route Vulnerabilities and Impacts

Shoaling Vulnerability	Low	Dredging occurring less frequently than every 10 years.
Community Impact	High	Local residents depend on this route for access to employment opportunities and essential services. More than half of the riders who took a 2017 onboard survey said they were traveling to work or school, with 80% of riders saying they would have to find another way to make their trip if ferry was unavailable.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	Medium	Medium	Medium
Erosion	Medium	Medium	Medium
Overall Terminal	Medium	Medium	Medium
Roadway Access	High	High	High

Terminal Criticality and Vulnerabilities

Terminal Criticality	Medium	Medium criticality as a moderate roadway alternative is available for local residents to connect to essential services.
Community Impact	High	Local residents depend on the route. High Average Transportation Disadvantage Index of Riders: 10.6 (3-18 scale)
Terminal Flood Hazards	Medium	The most critical terminal assets have medium flooding vulnerability making the terminal moderately vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	Medium	Limited bulkhead/revetment in good condition, some shoreline adjacent to facility not stabilized.
Critical Roadways Vulnerability to Erosion	Low	No critical roadway within 230 feet of oceanfront shoreline or within 50 feet of estuarine shoreline.
Critical Roadways *Vulnerability to Flooding	High	Critical roadways vulnerable to flooding from many sources, including one terminal-adjacent high risk segment.

KEY: Low Medium High

ITRE

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 2: Flood Hazards Aerial

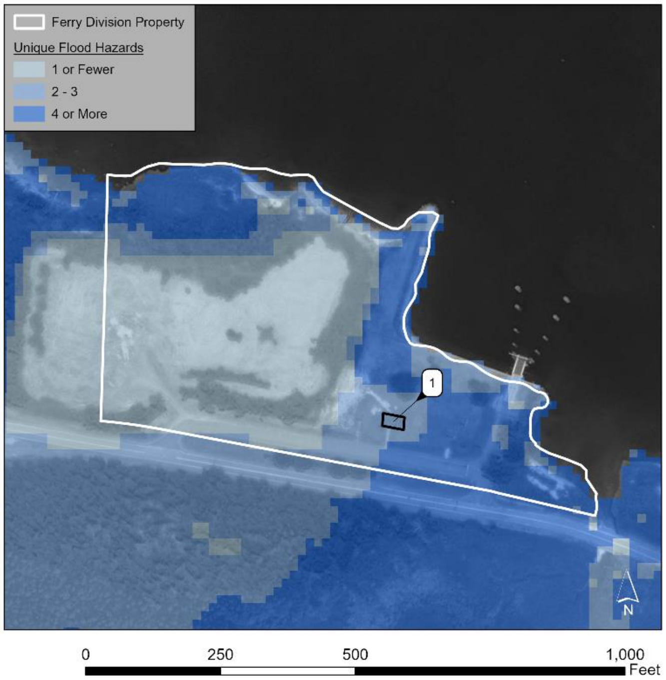
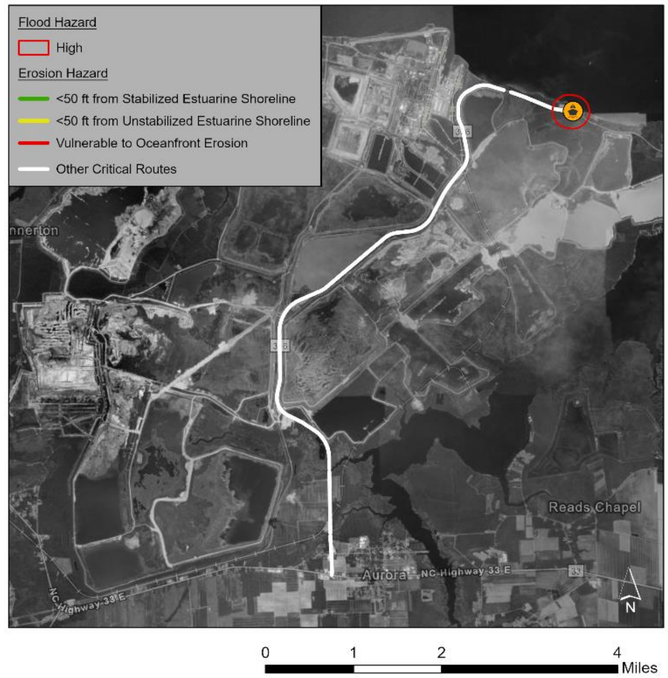


Figure 1: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	007-017-016	Restroom	○	◐

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
NC 306 from Terminal to Aurora	○	○	●

KEY: ○ Low ◐ Medium ● High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	●	●	Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Restroom	○	◐	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Ex. installing drains, ensuring contents can withstand getting flooded
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Ramps & Gantry System	●	◐	Raise Center Beam, Adjust Cables & Counterweights	Near Term	$$ (Med-Low)	◆ (Low)	Future ramp replacement anticipated at Aurora
Erosion							
Property Shoreline	○	◐	Install Revetment Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	General permit available, relatively straightforward design
			Install Living Shoreline Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	Enhanced ecological function, nature-based solution, may require more design considerations
			Maintain Existing Seawall/Bulkhead	Near Term	$ (Low)	◆ (Low)	Ensure seawall/bulkhead remains in good condition
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Aurora Terminal has an overall medium vulnerability rating with high roadway access vulnerability and medium terminal flooding and erosion vulnerability.

The single terminal asset is a restroom facility with low critically and a medium flooding vulnerability. The ramp and gantry system has medium vulnerability and is anticipated to be replaced in future.

The terminal has an overall medium criticality and a high community impact rating with the route serving local residents for trips to work and school and has a high Transportation Disadvantaged Index (TDI) impact. There is an alternative roadway route for local residents but it adds an additional 30 minutes trip travel time.

Cherry Branch

AREA CHARACTERISTICS

Terminal: Cherry Branch

County: Craven

Area: Cherry Branch, near Marine Corps Air Station Cherry Point in Havelock, serves a route that connects to the Minnesott Beach terminal.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality
Minnesott Beach	2.5 miles	20 minutes	207,000+	◐ Drive around option; 65 minute drive (45 minutes longer to drive)

Route Vulnerabilities and Impacts

Shoaling Vulnerability	◐	Dredging occurs approximately every 11 years.
Community Impact	◐	Local residents depend on the route, with 76% of riders who took a 2017 onboard survey saying they would have to find another way to make their trip if the ferry was unavailable. Route provides a key connection for military and support staff traveling to and from Marine Corps Air Station Cherry Point.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	◐	◐	◐
Erosion	◐	◐	◐
Overall Terminal	◐	◐	◐
Roadway Access	○	○	○

Terminal Criticality and Vulnerabilities

Terminal Criticality	◐	Medium criticality as a roadway alternative is available for local residents to connect to essential services.
Community Impact	◐	Local residents depend on this route. Moderate Average Transportation Disadvantage Index of Riders: 8.9 (3-18 scale)
Terminal Flood Hazards	◐	The most critical terminal assets have medium flooding vulnerability making the terminal moderately vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	◐	Bulkhead/seawall in fair condition, storm damage noted in field visit.
Critical Roadways Vulnerability to Erosion	○	No critical roadway within 230 feet of oceanfront shoreline or within 50 feet of estuarine shoreline.
Critical Roadways Vulnerability to Flooding	○	Critical Roadways not significantly vulnerable to flooding.

KEY: ○ Low ◐ Medium ● High

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 2: Flood Hazards Aerial

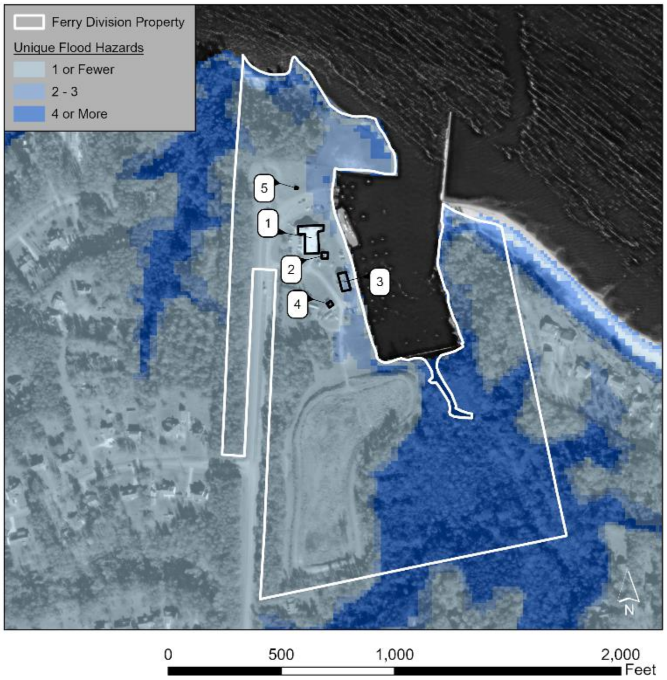
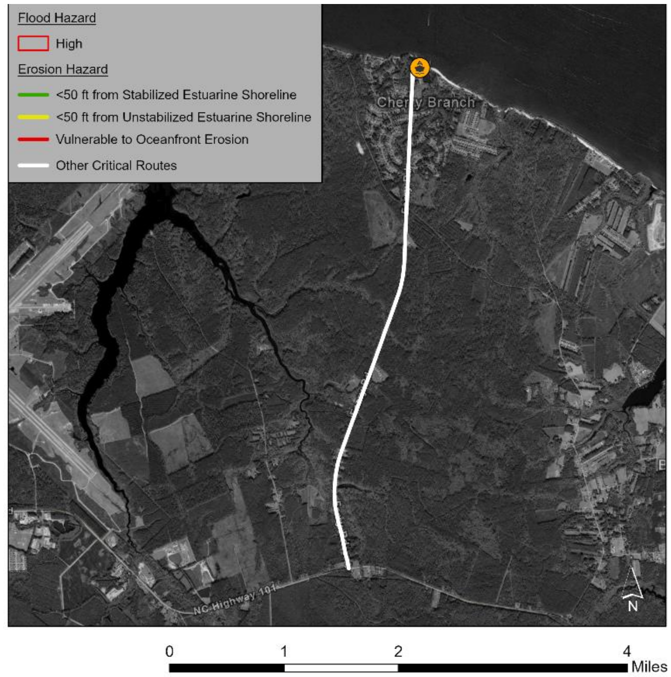


Figure 1: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	025-013-015	Visitors Center	High	Low
2	025-013-010	Generator Building	High	Low
3	025-013-009	Marine Maintenance Building	High	Medium
4	025-013-013	Uniform Storage Building	Low	Low
5	CB-Outbuilding	Outbuilding	Low	Low

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
NC 306 to NC 101	Low	Low	Low

KEY: Low Medium High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	●	○	Culverts & Drainage	Long Term	$ (Low)	◆◆ (Med-Low)	Install as become necessary in long-term
Visitors Center	●	○	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Ex. installing drains, ensuring contents can withstand getting flooded
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Generator Building	●	○	Construct Berm Around Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Bulk material around outside, depends on geotechnical information
			Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise generator above flood levels and ensure contents can withstand being flooded
Marine Maintenance Building	●	◐	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise contents above flood levels and ensure contents can withstand being flooded
			Construct Berm Around Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Bulk material around outside, depends on geotechnical information
Uniform Storage Building	○	○	Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Outbuilding	○	○	Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Ramp & Gantry System	●	◐	Raise Center Beam, Adjust Cables & Counterweights	Near Term	$$ (Med-Low)	◆ (Low)	Future ramp replacement anticipated at Cherry Branch
Erosion							
Property Shoreline	○	◐	Maintain Existing Seawall/Bulkhead	Near Term	$ (Low)	◆ (Low)	Ensure seawall/bulkhead remains in good condition
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Maintain Existing Breakwater	Near Term	$ (Low)	◆ (Low)	Ensure breakwater(s) remain in good condition

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Cherry Branch Terminal has an overall medium vulnerability rating with medium flooding and erosion vulnerability and low roadway access vulnerability.

The Marine Maintenance Building has high criticality and medium flood vulnerability. The ramp and gantry system has medium vulnerability rating and is anticipated to be replaced in future.

The terminal has an overall medium criticality and a medium community impact rating with the route serving local residents. There is an alternative highway route for local residents but it adds an additional 45 minutes to their trip travel time and there is moderate/average Transportation Disadvantage Index (TDI) impact.

NCDOT Ferry Vulnerability Study

Minnesott Beach

AREA CHARACTERISTICS

Terminal: Minnesott Beach

County: Pamlico

Area: Minnesott Beach serves a route that connects to the Cherry Branch terminal, which is near Marine Corps Air Station Cherry Point in Havelock.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality
Cherry Branch	2.5 miles	20 minutes	207,000+	◐ Drive around option; 65 minute drive (45 minutes longer to drive)

Route Vulnerabilities and Impacts

Shoaling Vulnerability	○	Dredging occurs less frequently than every 10 years.
Community Impact	◐	Local residents depend on route, with 76% of riders who took a 2017 onboard survey saying they would have to find another way to make their trip if ferry was unavailable. Route provides a key connection for military and support staff traveling to and from Marine Corps Air Station Cherry Point.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	○	○	○
Erosion	○	○	○
Overall Terminal	○	○	○
Roadway Access	○	○	○

Terminal Criticality and Vulnerabilities

Terminal Criticality	◐	Medium criticality as a roadway alternative is available for local residents to connect to essential services.
Community Impact	◐	Local residents depend on the route. Moderate Average Transportation Disadvantage Index of Riders: 8.9 (3-18 scale)
Terminal Flood Hazards	○	The most critical terminal assets have low flooding vulnerability making the terminal somewhat vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	○	Bulkhead and breakwater in good condition.
Critical Roadways Vulnerability to Erosion	○	No critical roadway within 230 feet of oceanfront shoreline or within 50 feet of estuarine shoreline.
Critical Roadways Vulnerability to Flooding	○	Critical Roadways not significantly vulnerable to flooding.

KEY: ○ Low ◐ Medium ● High

ITRE

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 2: Flood Hazards Aerial

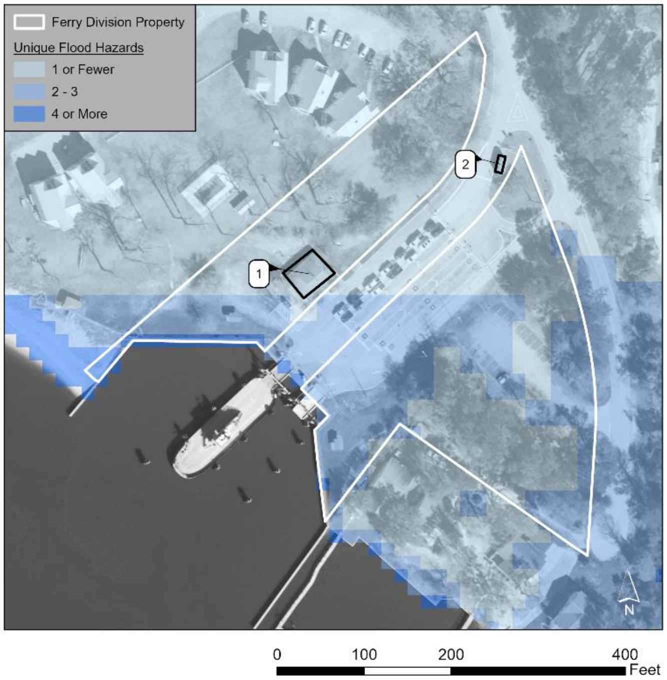
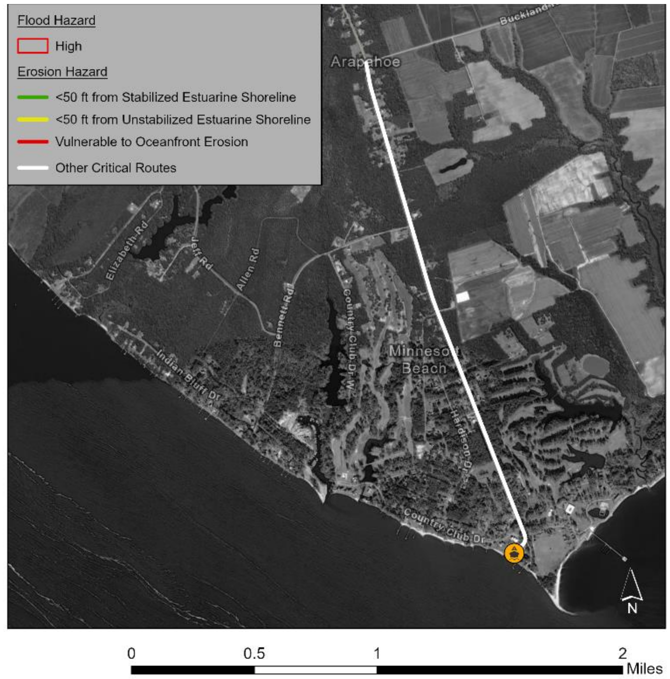


Figure 1: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	069-012-005	Currituck Ferry Operations Building	○	○
2	MI-Storage	Storage Building	○	○

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
NC 306 to Buckland Rd.	○	○	○

KEY: ○ Low ◐ Medium ● High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	High	Low	Culverts & Drainage	Long Term	$ (Low)	◆◆ (Med-Low)	Install as become necessary in long-term
Ferry Building	Low	Low	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Ex. installing drains, ensuring contents can withstand getting flooded
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Storage Buildings	Low	Low	Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise contents above flood levels and ensure contents can withstand being flooded
Ramps & Gantry System	High	Low	Raise Center Beam, Adjust Cables & Counterweights	Near Term	$$ (Med-Low)	◆ (Low)	Ramp replacement is planned for construction to begin in 2026.
Erosion							
Property Shoreline	Low	Low	Maintain Existing Seawall/Bulkhead	Near Term	$ (Low)	◆ (Low)	Ensure seawall/bulkhead remains in good condition
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Maintain Existing Breakwater	Near Term	$ (Low)	◆ (Low)	Ensure breakwaters remain in good condition

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

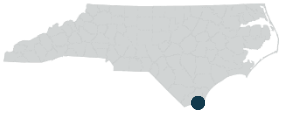
The Minnesott Beach Terminal has an overall low vulnerability rating with low flooding, erosion and roadway access vulnerability.

All the terminal assets are low criticality and low vulnerability. The ramp and gantry system could be replaced in future.

The terminal has an overall medium criticality and a medium community impact rating with the route serving local residents. There is an alternative highway route for local residents but it adds an additional 45 minutes to their trip travel time and there is moderate/average Transportation Disadvantage Index (TDI) impact.

Southport

AREA CHARACTERISTICS



Terminal: Southport

County: Brunswick

Area: Southport serves a route that connects to the Fort Fisher terminal. This route provides local residents with access to jobs and other basic needs and offer tourists a faster and more scenic way to access attractions like the North Carolina Aquarium at Fort Fisher and Carolina Beach.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality
Fort Fisher	3.5 miles	35 minutes	180,000+	Medium – Drive around option; 65 minute drive (30 minutes longer to drive)

Route Vulnerabilities and Impacts

Shoaling Vulnerability	High	Dredging occurs approximately every 2-3 years.
Community Impact	Medium	Supports 1000+ jobs on which the local community depends by providing faster and safer access to Fort Fisher.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	High	High	High
Erosion	Medium	Medium	Medium
Overall Terminal	High	High	High
Roadway Access	Medium	Medium	Medium

Terminal Criticality and Vulnerabilities

Terminal Criticality	Medium	Medium impact: drive option medium criticality.
Community Impact	Medium	Terminal serves emergency evacuation route. Moderate Average Transportation Disadvantage Index of Riders: 8.1 (3-18 scale)
Terminal Flood Hazards	High	The most critical terminal assets have high flooding vulnerability making the terminal more vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	Medium	Revetment in good condition, shoreline adjacent to docks not stabilized.
Critical Roadways Vulnerability to Erosion	Low	No critical roadway within 230 ft of oceanfront shoreline or within 50 ft of estuarine shoreline.
Critical Roadways Vulnerability to Flooding	High	Critical Roadways vulnerable to flooding from many sources; vulnerabilities diffuse and no specific high risk segments meet length criteria for mapping

KEY: Low Medium High

ITRE

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

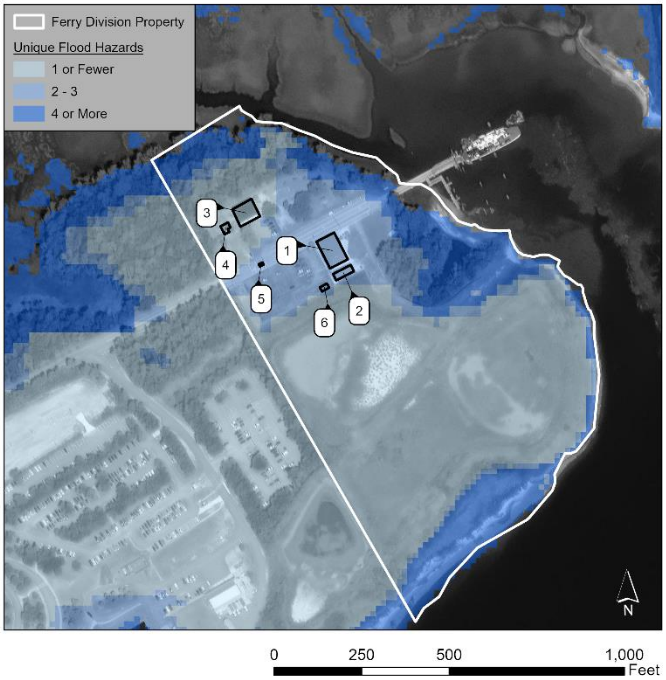
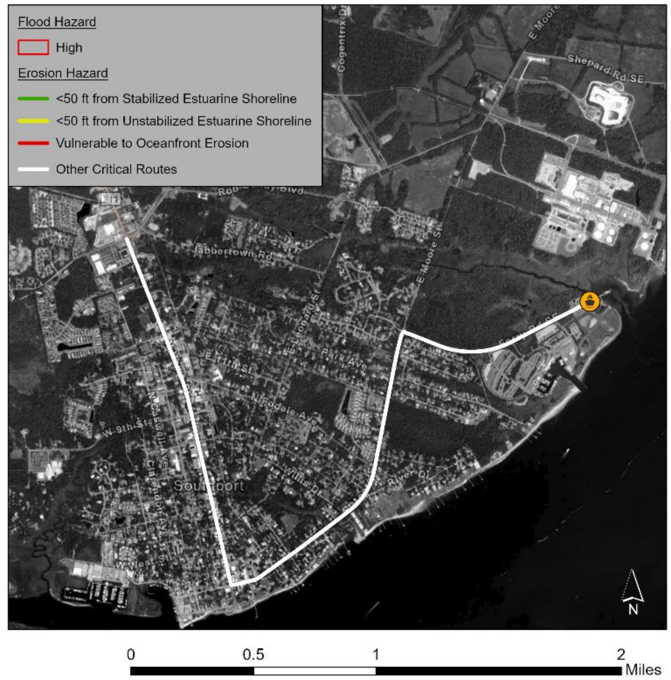


Figure 2: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	010-013-012	Visitor Center	High	High
2	010-013-013	Generator and Storage Building	High	High
3	SP-Dorms	Southport Dorms	High	Low
4	010-013-005	Storage Building	Low	Low
5	SP-Booth	Booth	Low	Medium
6	SP-Storage1	Drum Storage	Low	Medium

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
NC 211 from terminal to NC 87	Low	Low	High

KEY: Low Medium High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	●	●	Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Visitor Center	●	●	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Generator and Storage Building	●	●	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Construct Berm Around Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Bulk material around outside, depends on geotechnical information
			Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise generator above flood levels and ensure contents can withstand being flooded
Southport Dorms	●	○	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Long Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Storage Building	○	○	Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Booth	○	◐	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
			Convert to Semi-Permanent Facility	Near Term	$ (Low)	◆ (Low)	Use trailer or moveable facility
Drum Storage	○	◐	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Erosion							
Property Shoreline	○	◐	Install Revetment Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	General permit available, relatively straightforward design
			Install Living Shoreline Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	Enhanced ecological function, nature-based solution, may require more design considerations
			Maintain Existing Seawall/Bulkhead	Near Term	$ (Low)	◆ (Low)	Ensure seawall/bulkhead remains in good condition
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Southport Terminal has an overall medium criticality and high vulnerability rating with high flooding vulnerability and medium erosion and roadway access vulnerability. There are some terminal assets that have high criticality and high flood vulnerability.

The terminal has a medium community impact rating with the route serving local residents for trips. There is an alternative highway route for local residents that adds an additional 30 minutes to trip travel time.

Fort Fisher

AREA CHARACTERISTICS

Terminal: Fort Fisher

County: New Hanover

Area: Fort Fisher serves a route that connects to the Southport terminal, providing local residents with access to jobs and other basic needs. It also provides tourists a direct access to historic Southport.

Routes

Service	Distance	Travel Time	Vehicles (Annually)	Criticality
Southport	3.5 miles	35 minutes	180,000+	Medium — Drive around option; 65-minute drive. (30 minutes longer to drive)

Route Vulnerabilities and Impacts

Shoaling Vulnerability	High	Dredging occurs approximately every 3 years.
Community Impact	Medium	Supports 1000+ jobs on which the local community depends by providing faster and safer access to Southport.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	Medium	Medium	Medium
Erosion	High	High	High
Overall Terminal	Medium	Medium	Medium
Roadway Access	Medium	Medium	Medium

Terminal Criticality and Vulnerabilities

Terminal Criticality	Medium	Medium-low impact; drive option medium criticality.
Community Impact	Medium	Local community depends on this route. Moderate Average Transportation Disadvantage Index of Riders: 8.1 (3-18 scale)
Terminal Flood Hazards	Medium	The most critical terminal assets have medium flooding vulnerability making the terminal moderately vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	High	Shoreline not stabilized.
Critical Roadways Vulnerability to Erosion	Medium	Less than 5% of critical roadway length within 230 ft of ocean shoreline.
Critical Roadways Vulnerability to Flooding	High	Critical Roadways vulnerable to flooding from many sources, including two high risk segments.

KEY: Low Medium High

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 2: Flood Hazards Aerial

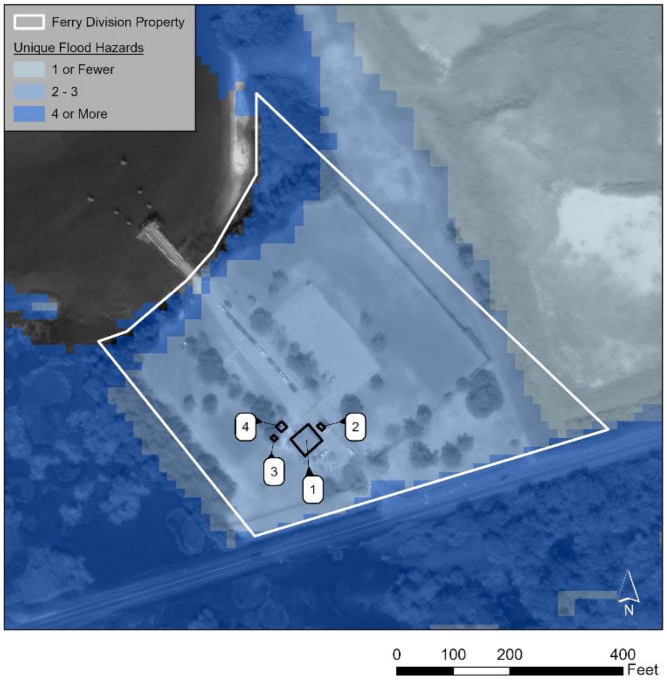
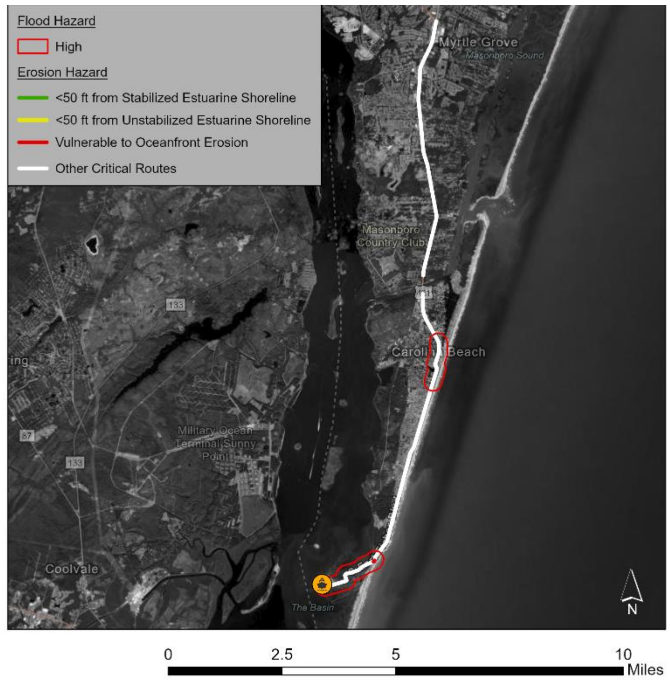


Figure 1: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	065-021-009	Ferry Building	Low	Medium
2	FF-Booth	Booth	Low	Medium
3	FF-AST	Above-ground Storage Tank	Low	Medium
4	FF_Storage	Storage	Low	Medium

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
US 421 from terminal to Myrtle Grove Junction (intersection with NC 132)	Medium	Low	High

KEY: Low Medium High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	High	High	Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Ferry Building	Low	Medium	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Booth	Low	Medium	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
			Convert to Semi-Permanent Facility	Near Term	$ (Low)	◆ (Low)	Use trailer or moveable facility
Above-ground Storage Tank	Low	Medium	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Elevate storage tanks and ensure contents can withstand being flooded
Storage	Low	Medium	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Erosion							
Roadways	High	Medium	Beach Nourishment & Dune Construction	Near Term	$$$ (Med-High)	◆◆ (Med-Low)	Beach nourishment & dune construction ongoing by USACE
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Property Shoreline	Low	High	Install Bulkhead/Seawall Along Unstablized Shoreline	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Install Revetment Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	General permit available, relatively straightforward design
			Install Living Shoreline Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Enhanced ecological function, nature-based solution, may require more design considerations

KEY: Low Medium High

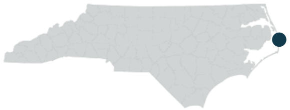
KEY TAKEAWAYS

The Fort Fisher Terminal has an overall medium criticality and medium vulnerability rating with high erosion vulnerability and medium flooding and roadway access vulnerability. The terminal assets have low criticality and medium flood vulnerability.

The terminal has a medium community impact rating with the route serving local residents for trips. There is an alternative highway route for local residents that adds an additional 30 minutes to trip travel time. The Transportation Disadvantaged Index (TDI) community impact of this route is medium.

Rodanthe Emergency Terminal

AREA CHARACTERISTICS



Terminal: Rodanthe Emergency Terminal

County: Dare

Area: This facility serves as an emergency response facility and does not have active ferry operations outside of emergency scenarios.

Route Vulnerabilities and Impacts

Shoaling Vulnerability	○	Dredging by the U.S. Army Corps of Engineers occurs less frequently than every 10 years.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding ^	N/A	N/A	N/A
Erosion	◐	◐	◐
Overall Terminal ^	N/A	N/A	N/A
Roadway Access	●	●	●

^ No assets are located at this terminal therefore no hazard rating was generated as the flooding vulnerability and overall terminal vulnerability methodology is based on asset exposure. The terminal property itself does have high compound flooding exposure.

Terminal Criticality and Vulnerabilities

Terminal Erosion Hazard Vulnerability	◐	Limited bulkhead in fair condition. Portion of the shoreline not stabilized.
Critical Roadways Vulnerability to Erosion	●	5% of critical roadway within 230 ft of ocean shoreline, less than 5% within 50 ft of estuarine shoreline. 24% of critical roadway vulnerable to sound-side breaching.
Critical Roadways Vulnerability to Flooding	●	Critical Roadways vulnerable to flooding from many sources, including multiple high risk segments

KEY: ○ Low ◐ Medium ● High

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

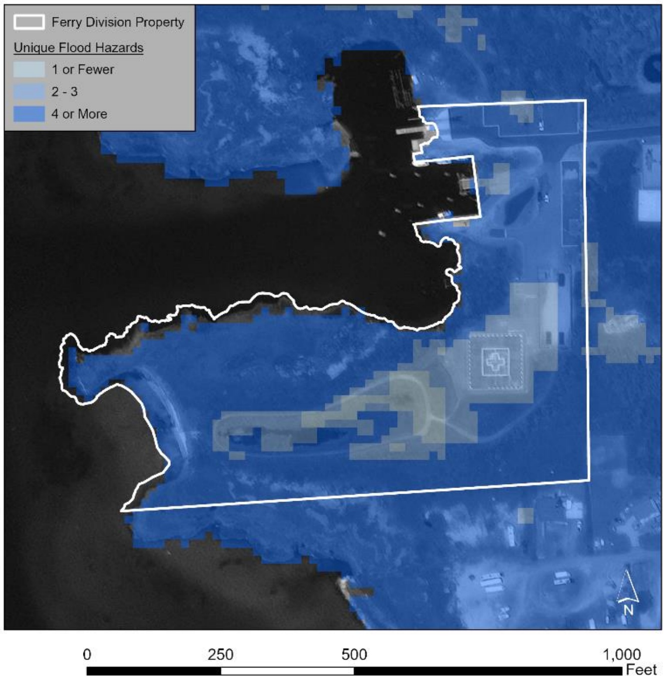
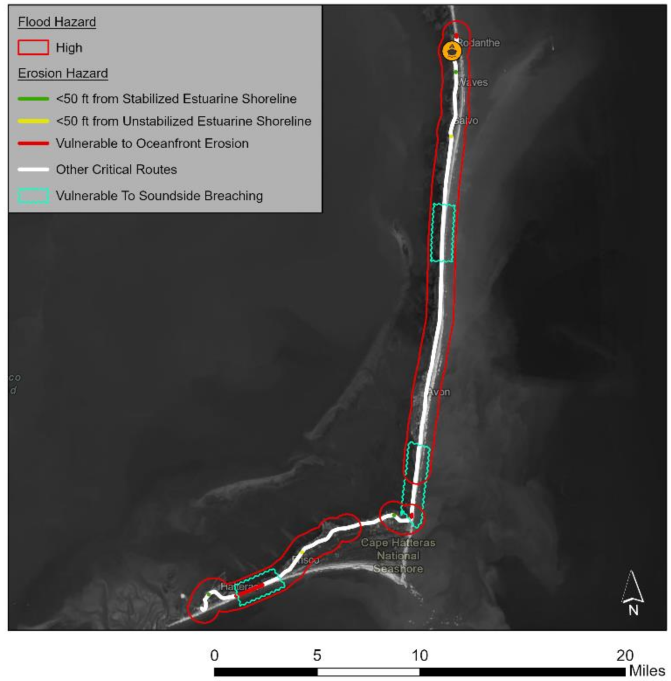


Figure 2: Critical Roadways Aerial



Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion / Breaching Vulnerability	Roadway Flood Vulnerability
Myrna Peters Rd., NC 12 from north side of Rodanthe to Hatteras	◐	●	●

KEY: ○ Low ◐ Medium ● High

ADAPTATION

Adaption

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	●	●	Beach Nourishment & Dune Construction	Near Term	$$$ (Med-High)	◆◆ (Med-Low)	Currently dune building is used, beach nourishment would allow for more time/less frequent overtopping/erosion
			Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Erosion							
Roadways	●	◐	Beach Nourishment & Dune Construction	Near Term	$$$ (Med-High)	◆◆ (Med-Low)	Currently dune building is used, beach nourishment would allow for more time/less frequent overtopping/erosion
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Property Shoreline	○	◐	Install Revetment Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	General permit available, relatively straightforward design
			Install Living Shoreline Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	Enhanced ecological function, nature-based solution, may require more design considerations
			Maintain Existing Seawall/Bulkhead	Near Term	$ (Low)	◆ (Low)	Ensure seawall/bulkhead remains in good condition
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Rodanthe Emergency Terminal has an overall high criticality and high flood vulnerability. It serves as an emergency response facility and does not have active ferry operations outside of emergency scenarios. No assets are located at the emergency terminal.

With no assets to score using the study the flood vulnerability methodology, no terminal flooding vulnerability or overall terminal vulnerability rating was assigned. However, the terminal property itself does have a high composting flooding exposure.

NCDOT Ferry Vulnerability Study

Stumpy Point Emergency Terminal

AREA CHARACTERISTICS

Terminal: Stumpy Point

County: Dare

Area: This facility serves as an emergency response facility and does not have active ferry operations outside of emergency scenarios.

Route Vulnerabilities and Impacts

Shoaling Vulnerability	●	Dredging occurs approximately every 2-3 years.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding ^	N/A	N/A	N/A
Erosion	●	●	●
Overall Terminal ^	N/A	N/A	N/A
Roadway Access	●	●	●

^ No assets are located at this terminal therefore no hazard rating was generated as the flooding vulnerability and overall terminal vulnerability methodology is based on asset exposure. The terminal property itself does have high compound flooding exposure.

Terminal Criticality and Vulnerabilities

Terminal Erosion Hazard Vulnerability	●	Shoreline not stabilized.
Critical Roadways Vulnerability to Erosion	●	10% of critical roadway within 50 ft of unstabilized estuarine shoreline and 9% within 50 ft of stabilized estuarine shoreline.
Critical Roadways Vulnerability to Flooding	●	Critical Roadways vulnerable to flooding from many sources, including multiple high risk segments

KEY: ○ Low ◐ Medium ● High

ITRE

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

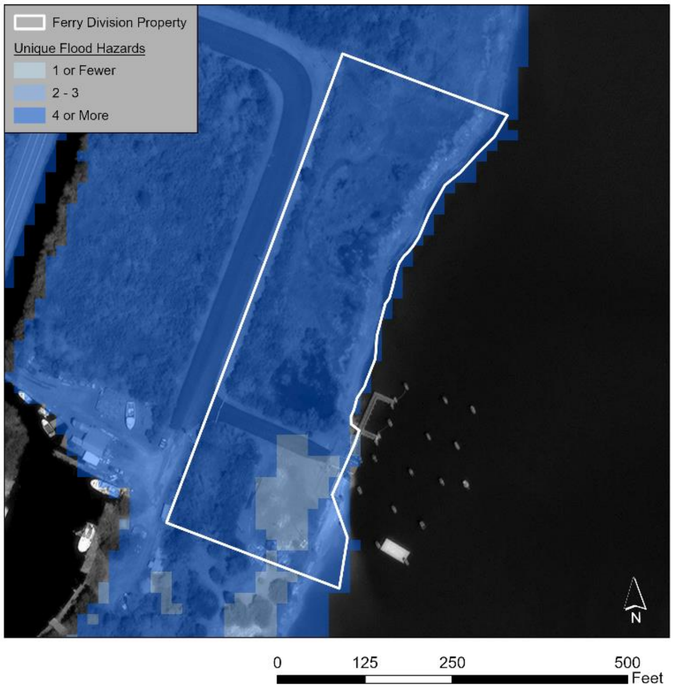
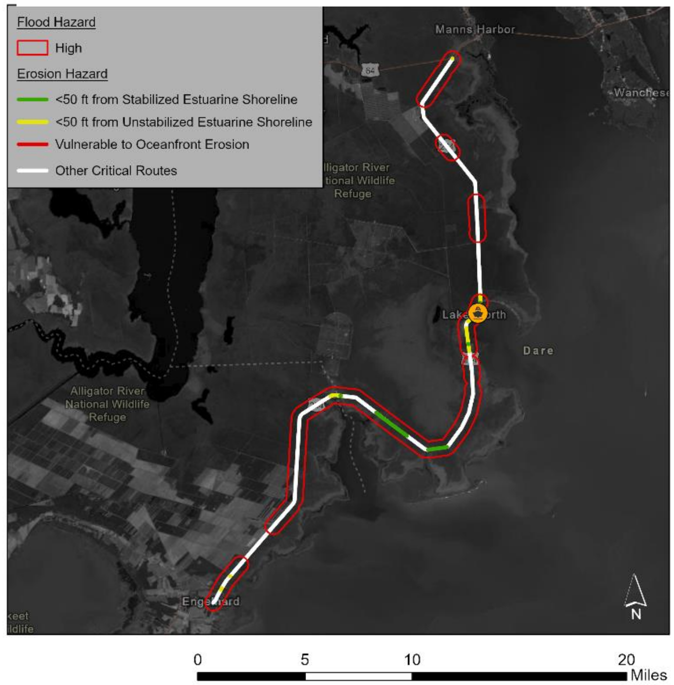


Figure 2: Critical Roadways Aerial



Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
Log Storage Rd., US 264 to US 64 on the north side, US 264 to Englehard on south side	○	●	●

KEY: ○ Low ◐ Medium ● High

ADAPTATION

Adaption

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	●	●	Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Erosion							
Roadways	●	◐	Maintain Existing Shoreline Stabilization	Near Term	$ (Low)	◆◆ (Med-Low)	Maintain existing revetment/bulkheads
			Install Revetment Along Unstabilized Shoreline	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	General permit available, relatively straightforward design
Property Shoreline	○	◐	Install Living Shoreline Along Unstabilized Shoreline	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Enhanced ecological function, nature-based solution, may require more design considerations
			Install Bulkhead/Seawall Along Unstablized Shoreline	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Install Revetment Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	General permit available, relatively straightforward design
			Install Living Shoreline Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Enhanced ecological function, nature-based solution, may require more design considerations

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Stumpy Point Emergency Terminal has an overall high criticality and high vulnerability. It serves as an emergency response facility and does not have active ferry operations outside of emergency scenarios. No assets are located at the emergency terminal.

With no assets to score using the study the flood vulnerability methodology, no terminal flooding vulnerability or overall terminal vulnerability rating was assigned. However, the terminal property itself does have a high composting flooding exposure.

NCDOT Ferry Vulnerability Study

Manns Harbor Shipyard

AREA CHARACTERISTICS

Terminal: Manns Harbor Shipyard

County: Dare

Area: Manns Harbor serves as the shipyard for the NCDOT Ferry Division. There are no ferry operations or passenger service to this facility.

Route Vulnerabilities and Impacts

Shoaling Vulnerability	Medium	Dredging occurs approximately every 10 years (to provide vessels access to the shipyard facility)
Community Impact	N/A	Manns Harbor is a high criticality facility and essential for Ferry Division maintenance and operations. It supports more than 30 ferry and support vessels. However, community impact was not assed for facilities that do have active ferry services.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	High	High	High
Erosion	Low	Low	Low
Overall Terminal	High	High	High
Roadway Access	Medium	Medium	Medium

Terminal Criticality and Vulnerabilities

Terminal Criticality	High	Short-term (up to a week) not as critical. Very critical for impacts longer than a week.
Community Impact	N/A	Manns Harbor is a high criticality facility and would have a high impact for disruptions lasting longer than a week. There is no 'backup' facility for vessel repairs and maintenance. However, community impact was not measured for facilities without active ferry service.
Terminal Flood Hazards	High	The most critical terminal assets have high flooding vulnerability making the terminal more vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	Low	Bulkhead and revetment in good condition.
Critical Roadways Vulnerability to Erosion	Medium	Less than 5% of critical roadway within 50 ft of estuarine shoreline.
Critical Roadways Vulnerability to Flooding	High	Critical Roadways vulnerable to flooding from many sources, including multiple high risk segments

KEY: Low Medium High

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

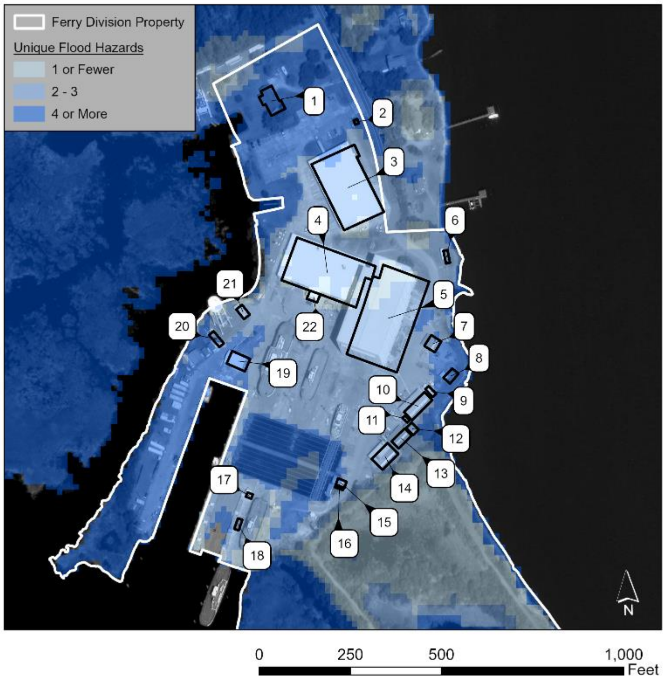
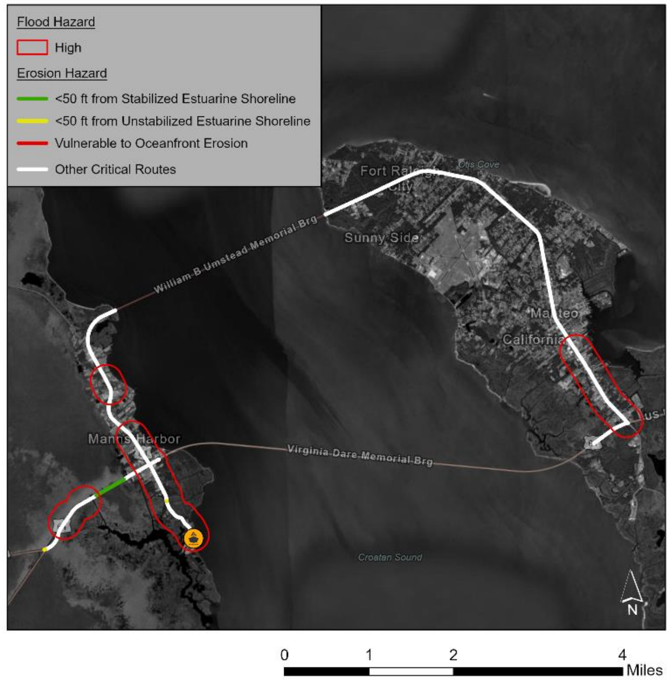


Figure 2: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	028-017-058	Manns Harbor Dormitory	High	High
2	028-017-054	Marine Security Booth	High	High
3	028-017-053	Marine Warehouse	High	Medium
4	028-017-011	Ferry Marine Maintenance Building	High	Medium
5	028-017-059	State Shipyard Paint Booth	High	Medium
6	MH-AST1	Above-ground Storage Tank - Propane	Unknown	Medium
7	MH-PSB	Paint Storage Building	High	High
8	MH-AST2	Above-ground Storage Tank Area - Oxygen	Unknown	High
9	MH-AST3	Above-ground Storage Tank - Diesel	Unknown	High
10	028-017-012	Generator Building	High	Medium
11	MH-AST4	Above-ground Storage Tanks - Generator Building	Unknown	Medium
12	028-017-046	Storage Building	High	Medium
13	028-017-043	Maintenance Shop and Tool Storage	High	Medium
14	028-017-050	Maintenance Garage	High	Medium

KEY: Low Medium High

15	028-017-026	Oil Water Separator Building	High	High
16	MH-AST5	Above-ground Storage Tanks - Used Oil	High	Medium
17	028-017-052	Syncrolift Building	High	Medium
18	MH-AST6	Above-ground Storage Tanks - Diesel Fuel	High	Medium
19	028-017-051	Paint Mixing Building	High	High
20	028-017-040	Well Pump Building	High	High
21	028-017-013	Fire Pump Building	High	Medium
22	028-017-055	Maintenance Tool Room & Observatory	High	Medium

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
Shipyard Rd to US 264/64 west to the US 64 split, US 64 east loop to North End bridge	Low	Medium	High

KEY: Low Medium High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	High	High	Culverts & Drainage	Near Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Entire Facility	High	High	Construct Flood Wall or Berm	Long Term	$$$$ (High)	◆◆◆◆ (High)	Install flood wall or berm around the entire facility to protect against significant flood damage. Requires significant design, engineering and construction effort
Manns Harbor Dormitory	High	High	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Marine Security Booth	High	High	Elevate Contents/Floodproof Building	Near Term	$$ (Med-Low)	◆ (Low)	Elevate critical equipment, ensure contents can withstand being flooded
			Convert to Semi-Permanent Facility	Near Term	$ (Low)	◆ (Low)	Use trailer or moveable facility
Marine Warehouse	High	Medium	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Ferry Marine Maintenance Building	High	Medium	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
State Shipyard Paint Booth	High	Medium	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Flood shield, other dry floodproofing techniques
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Above-ground Storage Tank - Propane	Unknown	Medium	Elevate/Floodproof	Near Term	$ (Low)	◆ (Low)	Elevate storage tanks and/or ensure contents can withstand being flooded

KEY: Low · Medium · High

ITRE

Paint Storage Building	●	●	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Elevate Contents/Floodproof Building	Near Term	$$ (Med-Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Above-ground Storage Tank Area - Oxygen	Unknown	●	Elevate/Floodproof	Near Term	$ (Low)	◆ (Low)	Elevate storage tanks and/or ensure contents can withstand being flooded
Above-ground Storage Tank - Diesel	Unknown	●	Elevate/Floodproof	Near Term	$ (Low)	◆ (Low)	Elevate storage tanks and/or ensure contents can withstand being flooded
Generator Building	●	◐	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Construct Berm Around Building	Near Term	$$ (Med-Low)	◆◆◆ (Med-High)	Bulk material around outside, depends on geotechnical information
			Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Raise generator above flood levels and ensure contents can withstand being flooded
Above-ground Storage Tanks - Generator Building	Unknown	◐	Elevate/Floodproof	Near Term	$ (Low)	◆ (Low)	Elevate storage tanks and/or ensure contents can withstand being flooded
Storage Building	●	◐	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Elevate Contents/Floodproof Building	Long Term	$$ (Med-Low)	◆ (Low)	Raise contents above flood levels and ensure contents can withstand being flooded
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Maintenance Shop and Tool Storage	●	◐	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Elevate Contents/Floodproof Building	Long Term	$$ (Med-Low)	◆ (Low)	Raise contents above flood levels and ensure contents can withstand being flooded
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Maintenance Garage	●	◐	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Elevate Contents/Floodproof Building	Long Term	$$ (Med-Low)	◆ (Low)	Raise contents above flood levels and ensure contents can withstand being flooded
			Elevate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Oil Water Separator Building	●	●	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Elevate Contents/Floodproof Building	Near Term	$$ (Med-Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Above-ground Storage Tanks - Used Oil	●	◐	Elevate/Floodproof	Near Term	$ (Low)	◆ (Low)	Elevate storage tanks and/or ensure contents can withstand being flooded
Syncrolift Building	●	◐	Elevate Contents/Floodproof Building	Near Term	$$ (Med-Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded

KEY: ○ Low ◐ Medium ● High

ITRE

Above-ground Storage Tanks - Diesel Fuel	●	◐	Elevate/Floodproof	Near Term	$ (Low)	◆ (Low)	Elevate storage tanks and/or ensure contents can withstand being flooded
Paint Mixing Building	●	●	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Well Pump Building	●	●	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Fire Pump Building	●	◐	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Maintenance Tool Room & Observatory	●	◐	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	$ (Low)	◆ (Low)	Temporary measure
			Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
			Elevate Building	Near Term	$$$ (Med-High)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements
			Relocate Building	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Assumes suitable location available & ability to move building
Erosion							
Roadways	●	◐	Maintain Existing Shoreline Stabilization	Near Term	$ (Low)	◆◆ (Med-Low)	Maintain existing revetment/bulkheads
			Install Revetment Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	General permit available, relatively straightforward design
			Install Living Shoreline Along Unstabilized Shoreline	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	Enhanced ecological function, nature-based solution, may require more design considerations
Property Shoreline	○	○	Maintain Existing Revetment	Near Term	$$ (Med-Low)	◆◆ (Med-Low)	Ensure revetment remains in good condition
			Raise Revetment	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on design parameters and elevation needed
			Maintain Existing Seawall/Bulkhead	Near Term	$ (Low)	◆◆ (Med-Low)	Ensure seawall/bulkhead remains in good condition
			Raise Seawall/Bulkhead	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Depends on geotechnical information & structural requirements

KEY: ○ Low ◐ Medium ● High

KEY TAKEAWAYS

The Manns Harbor Shipyard is a vital facility for the NCDOT Ferry System. The facility supports the entire system by maintaining and repairing the vessels in the fleet. The Manns Harbor Shipyard has a high critically due to the important nature of the facility and the system-wide impact an extended disruption would cause.

Manns Harbor has a high vulnerability with flooding vulnerability being the biggest hazard exposure. The facility has medium vulnerability for roadway access with high flooding exposure and medium erosion exposure for critical roadways. The erosion vulnerability is low for the shipyard site.

To protect the entire Manns Harbor Shipyard from flood damage and disruption, building a flood wall or berm around the entire facility could be considered. This adaption would require significant design, engineering and construction efforts.

Powells Point Storage

AREA CHARACTERISTICS

Terminal: Powells Point Storage

County: Currituck

Area: Powells Point is a marine maintenance unit that serves as a storage yard for piling equipment. This asset area has a small administrative footprint. There are no ferry operations or passenger service at this facility.

HAZARDS OVERVIEW

Terminal Hazards Overview

Terminal Scale	Vulnerability		
	Present	2040	2060
Flooding	Low	Low	Low
Erosion	Low	Low	Low
Overall Terminal	Low	Low	Low
Roadway Access	Low	Low	Low

Terminal Criticality and Vulnerabilities

Terminal Criticality	Medium	Marine Maintenance Unit; medium criticality.
Community Impact	N/A	Ferry system storage yard with no ferry service.
Terminal Flood Hazards	Low	The most critical terminal assets have low flooding vulnerability making the terminal somewhat vulnerable to flooding disruptions.
Terminal Erosion Hazard Vulnerability	Low	Facility not adjacent to shoreline.
Critical Roadways Vulnerability to Erosion	Low	No critical roadway within 230 ft of oceanfront shoreline or within 50 ft of estuarine shoreline.
Critical Roadways Vulnerability to Flooding	Low	Critical Roadways vulnerable to flooding from few sources.

KEY: Low Medium High

FLOOD HAZARD ANALYSIS AND CRITICAL ROADWAYS

Figure 1: Flood Hazards Aerial

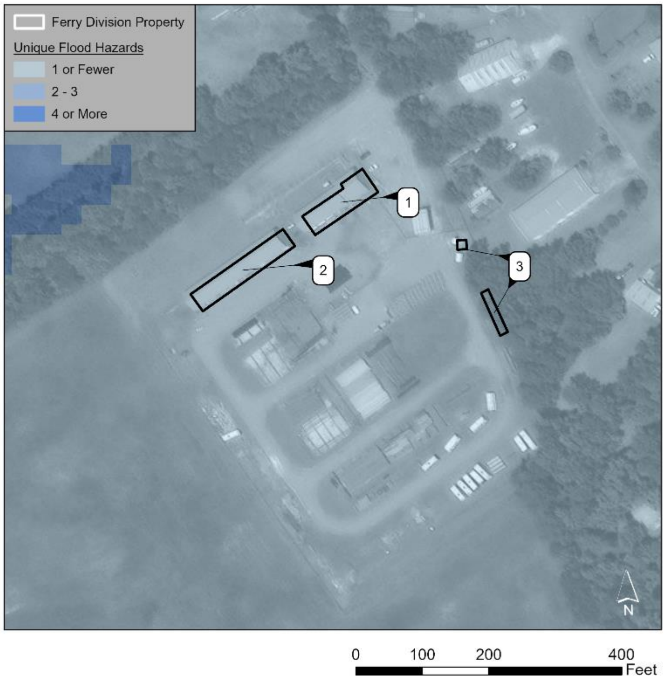
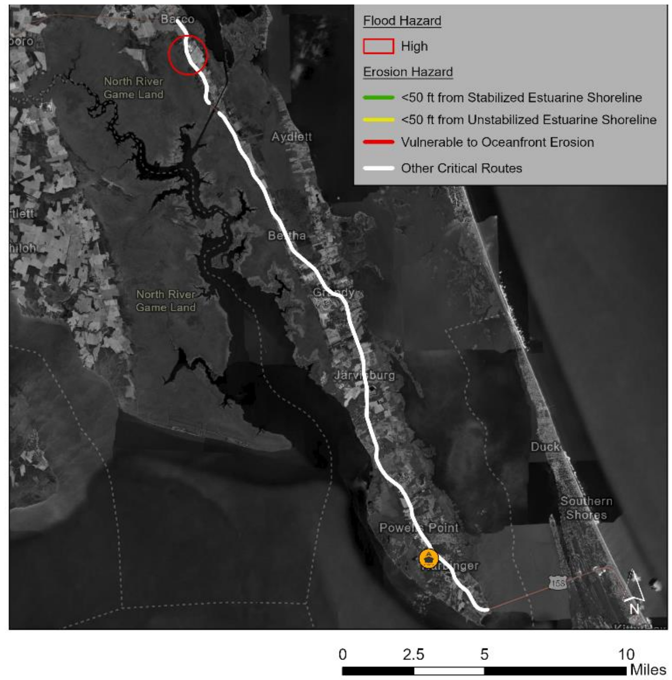


Figure 2: Critical Roadways Aerial



Flood Hazards by 2060

Location on Map	Asset No.	Name	Asset Criticality	Flood Exposure
1	027-018-001	Office / Warehouse Building	Medium	Low
2	027-018-002	Lumber Shed	Medium	Low
3	PP-AST	Above-ground Storage Tanks	Medium	Low

Critical Roadways by 2060

Critical Roadway	Roadway Oceanfront Erosion Vulnerability	Roadway Estuarine Erosion Vulnerability	Roadway Flood Vulnerability
US 158 from Bridge to Shortcut Rd, Access Road	Low	Low	Low

KEY: Low Medium High

ADAPTATION

Adaptation

Asset Name	Criticality	Vulnerability	Adaptation Options	Time Frame	Effort/Cost	Cost Uncertainty	Description/Notes
Flooding/Elevated Water Levels							
Roadways	High	Low	Culverts & Drainage	Long Term	$ (Low)	◆◆ (Med-Low)	Install at high flood risk locations
			Elevate Roadways	Long Term	$$ (Med-Low)	◆◆ (Med-Low)	Considered at high flood risk sections
			Constructed Wetlands/Surface Water Storage	Long Term	$$$ (Med-High)	◆◆◆ (Med-High)	Requires land acquisition, engineering, significant investment
			Relocate Roadway/Bridge/Causeway Construction	Long Term	$$$$ (High)	◆◆◆◆ (High)	May require land acquisition, rerouting, significant investment
Office / Warehouse Building	Medium	Low	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Long Term	$ (Low)	◆ (Low)	Temporary measure
			Floodproof Building	Long Term	$$ (Med-Low)	◆◆◆ (Med-High)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Lumber Shed	Medium	Low	Elevate Contents/Floodproof Building	Long Term	$ (Low)	◆ (Low)	Raise contents above flood levels and/or ensure contents can withstand being flooded
Above-ground Storage Tanks	Medium	Low	Elevate Contents/Floodproof Building	Near Term	$ (Low)	◆ (Low)	Elevate storage tanks and/or ensure contents can withstand being flooded

KEY: Low Medium High

KEY TAKEAWAYS

The Powells Point storage facility has an overall medium criticality and low flood vulnerability. It serves as a pile storage yard and does not have any ferry operations or passenger services.

Table of Contents

Table of Exhibits

Glossary

ACS	American Community Survey
CFEM	Coastal Flood Exposure Mapper
CRIS	Coastal Roadway Inundation Simulator
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GIS	Geographic Information System(s)
HTF	High Tide Flooding
IIJA	Infrastructure Investment and Jobs Act
LEP	Limited English Proficiency
MHHW	Mean Higher High Water
NCDCM	North Carolina Division of Coastal Management
NCDOT	North Carolina Department of Transportation
NFHL	National Flood Hazard Layer
NFIP	National Flood Insurance Program
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
PROTECT	Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation
RAFT	Resilience Analysis Framework for Transportation
RIT	Roadway Inundation Tool 2.0
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SLR	Sea Level Rise
SVI	Social Vulnerability Index
TDI	Transportation Disadvantage Index
USGS	U.S. Geological Survey

Introduction

The ferry system operated by the North Carolina Department of Transportation (NCDOT) consists of 21 ferries providing everyday service on seven regular routes across the Currituck and Pamlico Sounds as well as the Cape Fear, Neuse, and Pamlico Rivers. A seasonal passenger ferry provides service between Hatteras and Ocracoke Islands from May through September. The ferry system infrastructure includes 12 terminals, a state-owned shipyard, four field maintenance shops, 21 ferries and a support fleet that consists of four tugs, three barges, one crane barge and one dredge. The NCDOT ferry system is the second-largest state-maintained ferry system in the United States (after the state of Washington).

The system plays a crucial role in the state's transportation network, both during regular operations and during emergencies. During typical operations, the ferry system provides residents with transportation to work, emergency and routine medical services, and shopping for goods unavailable in local areas. The ferry system also transports building materials, fuel and other essential supplies, school and activity buses, and items for military installation maintenance on a regular basis. Storm response and recovery services include evacuating residents and visitors from coastal areas and providing transportation post-storm when portions of the roadway network are damaged.

The Ferry Division has faced a number of challenges in recent years, including Hurricane Dorian (2019) which caused extensive service disruptions as well as the need to use the ferry system to remove 9,000 truckloads of storm debris (totaling over 6,650 tons) from Ocracoke Island (Virginian-Pilot, 2020). Damage to the ferry facilities caused over $4 million in repair costs from Hurricane Dorian and subsequent nor'easters (Island Free Press, 2020). Damage to coastal roadways leading to the ferry facilities also added additional repair cost to the ferry system storm recovery efforts.

Shoaling caused by inlet processes has also caused delays and interruptions and necessitated frequent US Army Corps of Engineers (USACE) dredging along the Hatteras Island to Ocracoke Island route. For example, inlet channel migration and shoaling led to re-routing of the ferry channel resulting in longer travel times. Additionally, changes in channel depth and orientation have resulted in the Ferry Division having to re-direct ferry routes and implement structural stabilization measures (e.g. sheet pile walls).

Storms with extreme rainfall such as hurricanes Matthew (2016) and Florence (2018) can cause extensive flooding and problems for facilities on the sound-side shorelines. Sea level is currently rising, and rates of rise are predicted to increase for the foreseeable future, which will amplify storm surge and wave impacts.

There is a need to evaluate the vulnerability of the system's facilities across the state, both now and as climate change progresses into the future. To address this need, the aims and objectives of this study were to:

1) Assess the vulnerability of all of the Ferry Division's infrastructure assets with respect to natural hazards (present and forecast to the 2040 and 2060 planning horizons)
2) Assess the condition of ferry channels at present as well as potential climate impacts;
3) Assess criticality of ferry system assets, terminals and routes;
4) Assess community impacts associated with ferry disruptions;
5) Provide an assessment that would allow assets to be prioritized for adaptation measures; and
6) Provide recommendations on potential adaptation options as well as timeframes for implementation and comparative order of magnitude cost estimates.

The results of this study are designed to support NCDOT planning efforts to implement adaptation measures to ensure sustainable and resilient ferry system operations. The assessment results and adaptation options can be incorporated into updates of the NCDOT Statewide Transportation Resilience Improvement Plan (RIP) (2024).

Research Approach

As NCDOT plans for future transportation system resilience, there is a need for statewide assessment of current and future vulnerability of each of the transportation modes. The NCDOT Resilience Strategy Report (2021) describes NCDOT's short-term (6-12 months) strategies for resilience, including to "address gaps in resilience planning and standards for ferry." This is described as a need to "assess ferry channels and conduct vulnerability and criticality assessments to address future impacts." This research is aligned with this NCDOT resilience strategy and has developed criticality-vulnerability focused assessment.

The current vulnerability assessment is also informed by the Federal Highway Administration (FHWA) *Vulnerability Assessment and Adaptation Framework* (3rd Edition; FHWA-HEP-18-020) guidance. This federal framework is designed to help transportation agencies and their partners to assess the vulnerability of transportation systems to extreme weather and climate effects. FHWA outlines five steps to conduct a vulnerability assessment:

1) Set Objectives & Define Scope
2) Compile Data
3) Assess Vulnerability
4) Analyze Adaptation Options
5) Incorporate Results into Decision-Making

The resulting criticality-vulnerability approach to natural hazard assessments can be incorporated into future NCDOT Statewide Transportation RIP updates. RIPs are federally supported resilience improvements plans reference in the Infrastructure Investment and Jobs Act (IIJA) and eligible for Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) funding (see funding section for more detail).

This final report documents the research study process, methodology, results, and potential adaptation options that were developed to assess and address natural hazard vulnerability for the NCDOT ferry system.

Data Sources

Data sources employed for this project included existing GIS data layers provided by NCDOT, the NC Division of Coastal Management (NCDCM), and the National Oceanic and Atmospheric Administration (NOAA). Additional information regarding dredging, ferry operations, criticality, and previous adaptation projects was also provided by the Ferry Division. Exhibit 3 lists all data used for the project, the analyses completed using the data, and the source of the data. Each section details the information utilized for the specified analyses.

Exhibit 3. Vulnerability Assessment Data Sources

Data Set	Analysis	Description	Source
2020 Oceanfront Shoreline	Critical roadway oceanfront erosion hazard, sound-side breaching hazard	GIS feature class of wet-dry oceanfront shoreline	NCDCM Map Viewer NC Division of Coastal Management (arcgis.com)
2012 Estuarine Shoreline	Critical roadway estuarine erosion hazard, terminal shoreline erosion hazard, sound-side breaching hazard	GIS feature class of estuarine shoreline, classified by shoreline type	NCDCM Map Viewer NC Division of Coastal Management (arcgis.com)
Dredge Plan 2040	Shoaling hazard	Spreadsheet documenting dredging and future planned dredging through 2040	NCDOT
Roadway Centerlines	Critical roadway vulnerability assessment	GIS feature class of NC roadway centerlines	NCDOT GIS GIS Data Layers (ncdot.gov)
Ferry Facilities	Asset vulnerability assessment	GIS polygon and line feature classes showing Ferry Division assets and property boundaries	NCDOT Facilities Management Unit NCDOT - FMU - Buildings and Lands (arcgis.com)
NCDOT Structure Locations	Critical roadway vulnerability assessment	GIS feature class of NCDOT structures including culverts, bridges, pipes, ferry ramps, etc.	NCDOT GIS GIS Data Layers (ncdot.gov)
FEMA Flood Zones	Flood hazard vulnerability assessment	Locations of FEMA flood zones for zone A and V reflecting 1% annual chance and 0.2% annual chance flood plains	NOAA CFEM GIS Data Layers (coast.noaa.gov)

Data Set	Analysis	Description	Source
NHC Storm Surge	Flood hazard vulnerability assessment	Simulated extent of storm surge flooding for Cat 1, 2, and 3 storms scenarios	NOAA CFEM GIS Data Layers (coast.noaa.gov)
High Tide Flooding	Flood hazard vulnerability assessment	Locations of current (2018) high-tide flooding hazards	NOAA CFEM GIS Data Layers (coast.noaa.gov)
Sea Level Rise	Flood hazard vulnerability assessment	Locations of mean higher high water (MHHW) under scenarios of 1', 2', 3', and 4' of sea level rise. 3' and 4' scenarios are used as future high tide flooding hazard layers	NOAA CFEM GIS Data Layers (coast.noaa.gov)
U.S. Census Bureau American Community Survey 5-Year Estimates (2017-2021)	Community impact	Socioeconomic data used to formulate the Transportation Disadvantage Index for zip codes.	Accessed via Social Explorer

Field Work and Site Visits

During the summer of 2023, teams of two research assistants visited each of the active terminals to conduct assessments of current conditions with respect to access, infrastructure, and assets. In addition to a description of conditions, the field work teams took photos and made measurements of assets that are above ground level. Two senior members of the research team also visited Manns Harbor shipyard and the Stumpy Point emergency terminal and completed the same documentation for that site.

The field work data collection helped to inform asset-level vulnerability assessments by verifying the locations of assets in the Ferry Facilities data. Field work teams also discovered several assets (notably, above-ground storage tanks) that are important to terminal operations but that are not recorded in the Ferry Facilities data. The research team added these assets to assessments. All field data collected is included in Appendix A.

Criticality of Ferry Routes and Assets

To develop a criticality assessment consistent with the NCDOT Resilience Strategy Report (2021) and the FHWA *Vulnerability Assessment and Adaptation Framework* (3rd Edition; FHWA-HEP-18-020) criticality-vulnerability assessment approach, the research team established a multi-scale criticality framework that included ferry system routes, terminals, and individual assets. Informed by the project literature review (Appendix B) and a ferry operations meeting with NCDOT, the research team developed a criticality assessment for NCDOT ferry system assets.

In March 2023, the research team met with Ferry Division team leaders to evaluate the criticality of each of the ferry routes as well as specific assets at each terminal. This discussion included a comparison of travel times, alternative routes, and ferry operational needs. Informed by these discussions, a table of route, terminal, and asset criticalities was developed and sent to Ferry Division leadership for review. This table is included in Appendix C. The approved table was then used as the criticality measure in the criticality-vulnerability assessment approach.

Flood Hazards

Data from NOAA's Coastal Flood Exposure Mapper (CFEM) was used to evaluate vulnerability to flooding. As discussed in the Methods section of this report, the research team made minor modifications to the methodology of the CFEM to improve its suitability for this research effort.

The data sets employed by the CFEM and the research team's composite flood hazard analysis include certain Federal Emergency Management Agency (FEMA) flood zones, Storm Surge extents, High Tide Flooding extents, and Sea Level Rise extents. These layers were sourced from the CFEM, which in turn sourced data from FEMA and other NOAA resources. Each is described in more detail in the following subsections.

FEMA FLOOD ZONES

The FEMA flood zone data employed in this study originates primarily from the National Flood Hazard Layer (NFHL), a spatial database of effective flood zones produced by FEMA and used to support the National Flood Insurance Program (NFIP). Only Special Flood Hazard Areas that are especially high risk to flooding are included in this analysis. These layers describe the extent of 100-year and 500-year floodplains (FEMA, 2018).

STORM SURGE

Storm surge extent layers are based on near-worst-case scenarios of surge inundation modeled using the National Hurricane Center's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model (NOAA, n.d.).

HIGH TIDE FLOODING

The High Tide Flooding (HTF) layer employed in the CFEM and in this research uses inundation thresholds developed by NOAA to estimate high tide flooding extents above a "minor" events threshold. In North Carolina, such "minor" event thresholds range between 1.7 ft (Oregon Inlet) and 1.8 ft (Wilmington). Flood extents are modeled by adding threshold elevations to MHHW levels at local datums (Sweet et al., 2018).

SEA LEVEL RISE

Four sea level rise layers are used in the composite flood hazard analysis. These scenarios range from zero to four feet above MHHW. Sea level rise scenario extent layers were developed by NOAA using a 'bath-tub' based approach that accounts for local and regional variability through use of local datums and tidal gauges and also accounts for hydrological connections (NOAA, 2017).

Erosion and Shoaling

Data used to evaluate erosion and shoaling were obtained from the North Carolina Division of Coastal Management (DCM) and from NCDOT. DCM conducts aerial photographic surveys approximately every five years to document the oceanfront shoreline position and determine setbacks for construction. Shoreline positions are manually digitized using the visible wet-dry line as described by Dolan et al. (1980). In addition to the oceanfront shoreline positions, DCM has conducted two studies to evaluate the position and composition of the estuarine shoreline: Geis and Bendell (2010), and NCDCM (2015). These data sets include classification of the shoreline as natural (e.g. sediment bank, marsh, swamp forest), or modified (e.g. bulkhead, revetment, seawall, etc.). All of these data sets are available from the DCM Interactive Map Viewer (NC DCM 2024). The most recent oceanfront (2020) and most recent estuarine shorelines (2012) were used to assess vulnerability to oceanfront or estuarine erosion and sound-side breaching. To evaluate shoaling, the dredging schedule provided by NCDOT (Dredge Plan 2040) was examined.

Community Impact

To ensure that equity considerations and community impacts were considered in relationship to natural hazard induced ferry disruptions, the research team developed a community impact score as part of the vulnerability assessment. The community impact score also captures the community disruptions for economic impacts and community such as increased travel time, lost connectivity to employment opportunities, diminished access to essential services (such as healthcare and school), and emergency evacuation routes (for Ocracoke Island) that would be impacted with a prolonged ferry operations disruption. Community impact data includes the results of the NCDOT Ferry System Ridership Economic Impact Report (2017) and the use of the NCDOT Transportation Dependency Index (TDI), as further described in the Methods section of this report.

Adaptation

Adaptation alternatives were developed after review of literature as well as review of facilities by project engineers.

The review of adaptation planning, policy and literature for adaption option development yielded sources such as NCDOT ferry asset life-cycle planning (NCDOT, 2017), USDOT climate change and natural hazard sensitivity analysis for coastal infrastructure (USDOT, 2014), US Department of Defense best practices for coastal infrastructure adaptation (DOD, 2021), New York/New Jersey Port Authority climate resilience design guidelines (NY/NJ Port Authority, 2018), and the development of nature based solutions (Bertrand and Williams, 2022). These sources were used to inform the creation of the adaptation options for the ferry system facilities and assets.

Project engineers on the research team reviewed the terminal and asset specific vulnerability results and developed a list of adaptation options for each terminal asset. In addition to adaptation options, timeframe (near term and long term) is highlighted for each option. An engineering and construction cost estimator on the team evaluated a comparative order of magnitude cost estimate and cost uncertainty for each adaptation developed by project engineers. Cost uncertainty is due to the lack of site-specific survey and geotechnical information as well as lack of specific design details of existing infrastructure.

Methods

The research team developed a natural hazards vulnerability assessment for ferry system facilities and assets. Informed by the NCDOT Resilience Strategy Report (2021) and FHWA Vulnerability Assessment and Adaptation Framework (3rd Edition; FHWA-HEP-18-020) guidance, the assessment has been developed using a criticality-vulnerability focused approach. This approach provides a methodology that aligns with the NCDOT Statewide RIP (2024).

The hazards categories explored in this study are flooding, channel shoaling, and erosion (oceanfront, estuarine, and sound-side breaching). These hazards were assessed at the asset and terminal scale. The team also assessed these hazard impacts for critical roadways leading to and from the ferry terminal facilities. As part of the methodology, the research team established a series of criteria to identify the critical roadways to be studied.

The research team also considered assessing other natural hazards (temperature, active precipitation, wildfire and wind) but determined they should not be included in the full assessment. Through cursory exploration and confirmation with NCDOT, the research team eliminated temperature and active precipitation increase as natural hazards to explore. It was determined that ferry services operate even during increased heat and precipitation events. The effects of severe precipitation events are captured in the flooding assessment but in general ferry operations are not affected by typical (e.g. occurring on a yearly basis) rain events. Wildfires were eliminated from the analysis because it was determined that the wildfire impacts would be more of a regional roadway issue than a ferry-specific natural hazard impact. Increased wind events do have an impact on ferry operations as vessels do not operate in extreme winds. However, forecasting increased wind events to a 2060 planning horizon was outside of the scope of this study, therefore these impacts were not included.

A community impact method was also developed to ensure that equity and community impacts associated with ferry system disruption were captured. This section also documents the approach used to develop adaptation options to reduce the frequency and duration of disruptions to ferry operations associated with natural hazards.

Determination of Critical Roadways

Roadway centerlines and ferry facilities were compared in GIS and the critical roadways extents were identified based on the following criteria:

- Only roadway corridor leading to or from the terminal,
- Primary road pathway (i.e., side roads were not included in the case of NC 12 on Hatteras Island), and
- Critical roadway extents terminated at intersection with other major road/alternate route.

The extents of the critical roadways determined using this method are presented in Exhibit 4.

.

Exhibit 4: Extents of Critical Roadways

Terminal/Facility	Critical Access Road(s)	Boundaries
Currituck	NC 615, NC 168	NC 615 Loop and NC 168 Between Sligo and Barco
Knotts Island	NC 615	NC 615 from State boundary to Terminal
Hatteras	NC 12	NC 12 from Basnight Bridge to Hatteras Terminal
Ocracoke South Dock	NC 12	NC 12 on Ocracoke Island
Ocracoke Silver Lake	NC 12	NC 12 on Ocracoke Island
Swan Quarter	US 264, NC 45, NC 94	US264 from Swindell Fork to Rose Bay Turnpike Rd including NC 45 and NC 94 (Main St)
Cedar Island	NC 12, US 70	NC 12 From Terminal to US 70, US 70 to NC 101 intersection in Beaufort
Bayview	NC 92, NC 99, NC 306	NC 306 from Terminal to NC 92, NC 99 to Burbage Rd., NC 92 to Bath
Aurora	NC 306	NC 306 from Terminal to Aurora
Cherry Branch	NC 306	NC 306 to NC 101
Minnesott Beach	NC 306, NC 101	NC 306 to Buckland Rd.
Southport	NC 211	NC 211 from Terminal to NC 87
Fort Fisher	US 421	US 421 from terminal to Myrtle Grove Junction (intersection with NC 132)
Rodanthe	NC 12, Myrna Peters Rd.	Myrna Peters Rd., NC 12 from north side of Rodanthe to Hatteras
Stumpy Point	US 264, Log Storage Rd.	Log Storage Rd., US 264 to US 64 on the north side, US 264 to Englehard on south side
Manns Harbor Shipyard	US 64, Shipyard Rd.	Shipyard Rd to US 264/64 west to the US 64 split, US 64 east loop to North End bridge
Powell's Point Storage	US 158	US 158 from Bridge to Shortcut Rd, Access Road

Flood Hazards

This study used multiple flood hazard indicators to develop a composite of flood risk for ferry assets, terminals, and critical roadway locations. The methods are modeled on the methods used by NOAA to develop its coastal flood hazard composite layer used in the online CFEM tool. Like the CFEM tool, the flood analysis conducted for this research project uses the sum of total flood hazards to which an asset, terminal, or critical roadway segment is exposed to compare overall vulnerability levels to these hazards. The following describes this framework in greater detail.

COMPOSITE FLOOD HAZARD FRAMEWORK

The flood hazards assessed in the composite flood hazard analysis conducted for this study closely align with the NOAA CFEM, with two exceptions:

- Tsunami risk is considered by the CFEM but not by this study. Given the relatively low frequency of tsunamis affecting the eastern seaboard of the U.S. compared to other coastal areas (ten Brink et al., 2014), tsunami risk was not considered a high level of concern in this effort.
- This study employs additional NOAA sea level rise scenarios of 3 ft and 4 ft to represent future high tide flooding in the 2040 and 2060 analysis years. The CFEM does not assess future analysis years and does not include data for future high tide flooding. This study employs sea

level rise scenarios of 3 ft and 4 ft to estimate future high tide flooding levels 2 ft above MHHW in 2040 (MHHW = 1 ft SLR) and 2060 (MHHW = 2 ft SLR), respectively. This positions the future high tide flooding analysis layers just above the minor [1.7 ft – 1.8 ft] derived threshold used in the NOAA current high tide flooding layer, but well below the moderate [2.7 ft – 2.8 ft] derived thresholds for moderate high tide flooding (NOAA, 2018).

In addition to these differences in layers analyzed, the composite flood hazard analysis conducted in this study also deviates from the CFEM by conducting composite flood hazard analysis for three separate time scenarios (2020, 2040, and 2060). All scenarios consider baseline (2020) levels of high tide flooding, storm surge, and FEMA flood zone hazards. Scenarios for 2040 and 2060 include additional sea level rise and future high tide flooding layers. The 2040 sea level rise scenario is represented by 1 ft of sea level rise and the 2060 sea level rise scenario is represented by 2 ft of sea level rise. This approximation is based on the local scenarios provided in the NOAA Sea Level Rise Viewer (NOAA, 2023) which were evaluated as described in NOAA (2022). Scenario analyses were associated with the tide gauges located in Duck, Cape Hatteras, Beaufort, and Wilmington, NC, with elevations shown in Exhibit 5. The 1 ft and 2 ft elevations were determined to be representative of the intermediate to intermediate high expected sea level rise across the state based on the NOAA analysis.

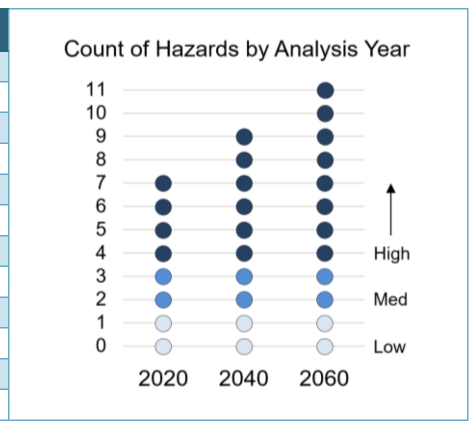
Exhibit 5: Sea Level Rise Scenarios for NC Tide Gauges (Source: NOAA Sea Level Rise Viewer)

Tide Gauge	2040 (Intermediate) (ft)	2040 (Intermediate High) (ft)	2060 (Intermediate) (ft)	2060 (Intermediate High) (ft)
Duck Pier	1.08	1.15	1.80	2.17
Cape Hatteras	1.05	1.12	1.74	2.13
Beaufort	0.98	1.05	1.64	2.03
Wilmington	0.89	0.98	1.54	1.94

Low, medium, and high vulnerability levels are defined at a consistent level across all years. This framework is further described in Exhibit 6.

Exhibit 6: Flood Hazards Included by Year

Flood Hazards Included by Year			
	2020	2040	2060
High Tide Flooding (Current)	✓	✓	✓
FEMA A Zone (1%)	✓	✓	✓
FEMA V Zone (1% + Storm Wave Risk)	✓	✓	✓
FEMA 500-Year (0.2%)	✓	✓	✓
Cat 1 Storm Surge	✓	✓	✓
Cat 2 Storm Surge	✓	✓	✓
Cat 3 Storm Surge	✓	✓	✓
1’ Sea Level Rise*		✓	✓
1’ Sea Level Rise + High Tide Flooding		✓	✓
2’ Sea Level Rise*			✓
2’ Sea Level Rise + High Tide Flooding			✓



FLOOD HAZARD ASSESSMENT FOR ASSETS & TERMINALS

The research team conducted the flood hazard assessment for assets by identifying the total number of flood hazards affecting any significant portion of an asset through spatial overlay with individual flood hazard layers. An asset was considered impacted by a flood hazard if a minimum of 5% of the asset area intersected the flood hazard area. The final count of flood hazards impacting an asset was derived by summing the number of impacting flood hazard layers, and vulnerability levels were assigned in accordance with the thresholds depicted in Exhibit 6.

The research team mapped flood hazard areas for use in the terminal summary sheets using the composite hazard layer for 2060. The composite flood hazard layer shows the count of spatially coincident flood hazards in a continuous raster format. It is important to note that hazard counts for the vulnerability analysis were not based on this layer, but rather on the total count of hazards impacting an asset whether or not those hazards were spatially coincident. In other words, the composite flood hazard layer shows a count of overlapping hazards, while assets may be impacted by non-overlapping hazards that contribute to their total hazard count. That said, the composite (overlapping) flood hazard layer closely approximates the hazard count analysis. As example map depicting the flood hazard composite layer and assets at the Currituck terminal is shown below as Exhibit 7, and a table of assets with flood hazard counts and vulnerability classification is provided as Exhibit 8.

Exhibit 7: Ferry Division Property; Currituck Terminal

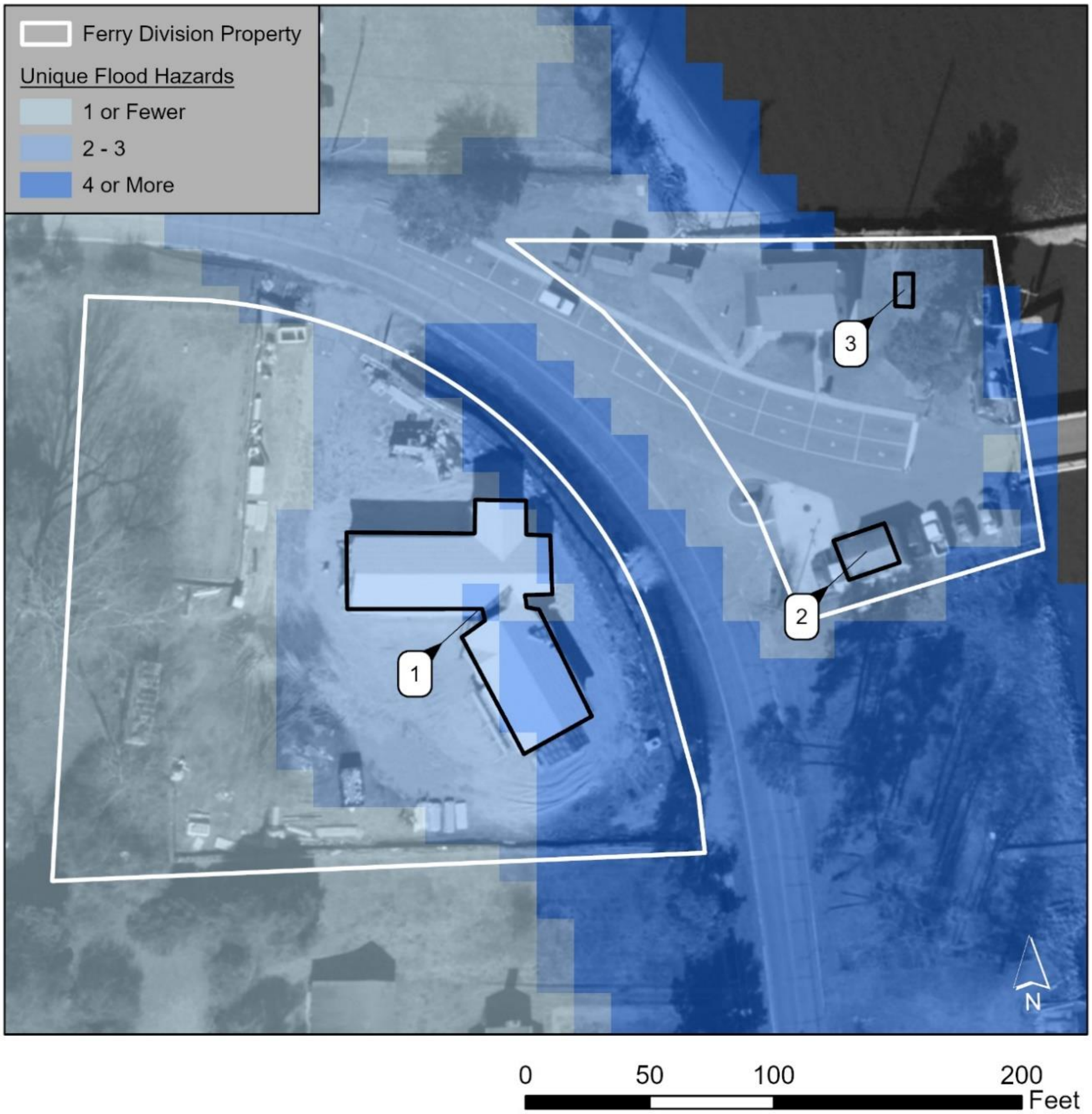


Exhibit 8: Currituck Terminal Flood Hazard Counts & Vulnerability Classification

Location on Map	Asset No.	Name	Flood Hazard Count	Flood Vulnerability Classification
1	027-010-010	Currituck Ferry Operations Building	5	High
2	027-010-009	Storage Building	3	Medium
3	N/A	Veeder Root Building	2	Medium

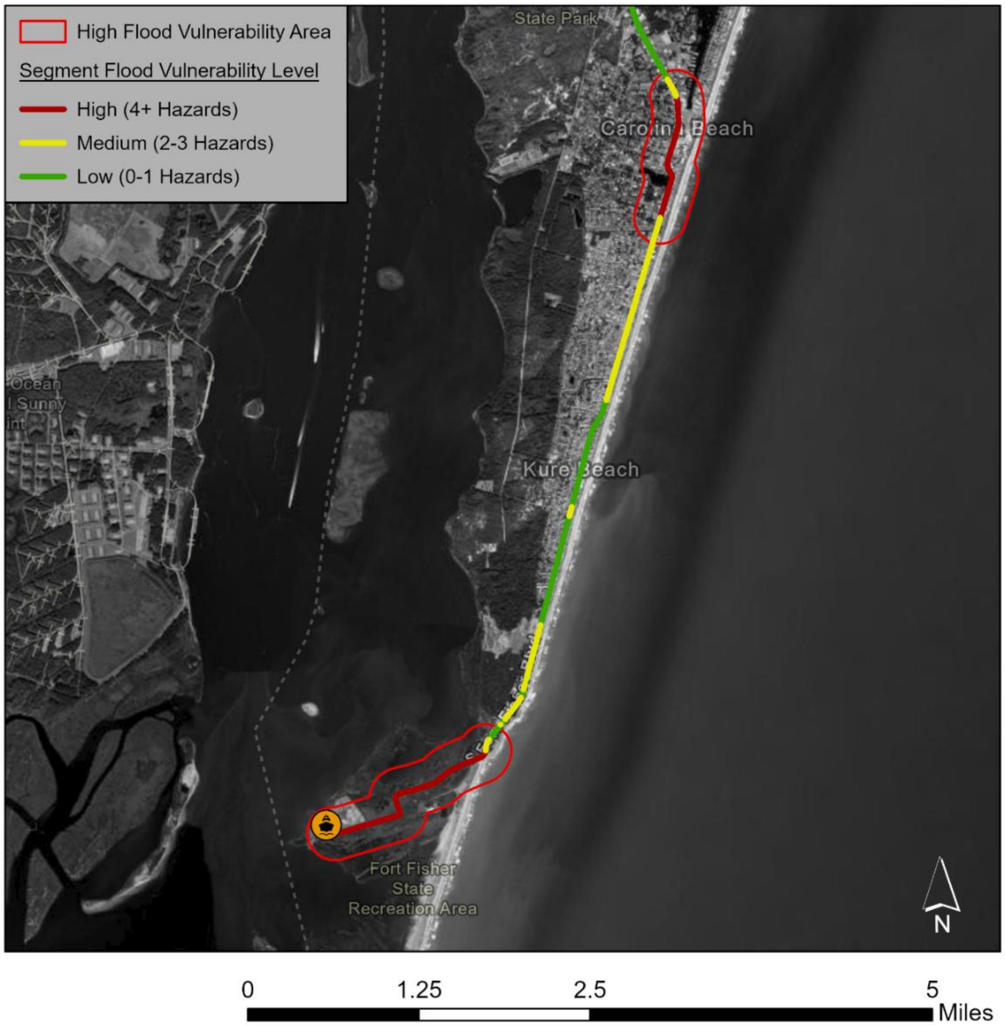
Terminal flood vulnerability and overall terminal vulnerability were assigned based on the most critical terminal asset with the most flooding vulnerability. Flood hazard assessment results for both assets and terminals are provided in the results section of this report.

FLOOD HAZARD ASSESSMENT FOR CRITICAL ROADWAYS

The research team conducted the flood hazard assessment for roadways by identifying the total number of flood hazards affecting any significant portion of a critical roadway. A roadway was considered impacted by a flood hazard if a minimum of 5% of the roadway area intersected the flood hazard area. The final count of flood hazards impacting an asset was derived by summing the number of impacting flood hazard layers, and vulnerability levels were assigned in accordance with the thresholds depicted in Exhibit 6. It is important to note that in this assessment, the hazards need do not need to be spatially coincident. Rather, the vulnerability level is defined by impacts to any part of the road.

The research team mapped high flood hazard segments of critical roadways using a modified version of this analysis to highlight contiguous segments with vulnerability from multiple hazards. High vulnerability segments were defined as those segments impacted by 4 or more spatially coincident hazards. After these segments were identified, they were buffered to define general areas along critical roadways where particularly high hazard levels exist. This analysis was conducted using the year 2060 scenario (all hazards) only. A map depicting flood vulnerability to roadway segments for a portion of the critical route for the Fort Fisher terminal is provided below as Exhibit 9.

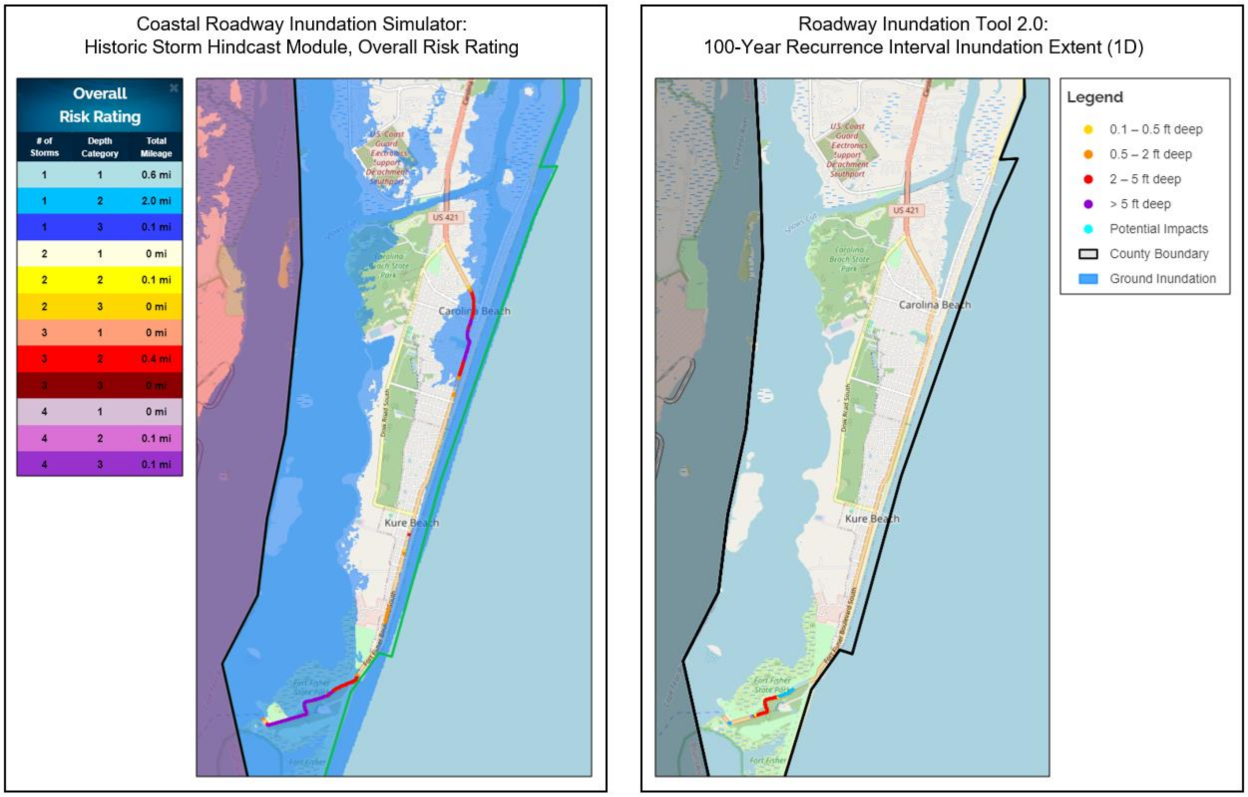
Exhibit 9: Fort Fisher Terminal Critical Roadway Flood Vulnerability



NCDOT RESILIENCY TOOLS FOR ANALYZING ROADWAY FLOODING

The research team chose to use the composite flood hazard overlay methodology to analyze roadway hazards to align this analysis with the asset level flooding analysis. Though not extensively explored in this report, this methodology can be augmented with analysis via two roadway flooding tools developed by NCDOT as part of the Resilience Analysis Framework for Transportation (RAFT). Specifically, the Roadway Inundation Tool 2.0 (RIT) gives the opportunity to look at roadway inundation effects due to floods at a variety of recurrence intervals, and the Coastal Roadway Inundation Simulator (CRIS) gives the opportunity to look at a historical flooding patterns via its Historic Storm Hindcast Module (NCDOT, 2021). Like the mapping effort for this project, these tools allow analysis of vulnerability at the road segment level. Images from these tools depicting flood hazards in the area of Fort Fisher terminal are provided as Exhibit 10 below. Note that the high risk rating segments correspond approximately to those identified in the present study.

Exhibit 10: Fort Fisher Terminal Flood Hazards



Shoaling and Erosion Hazards

Sediment transport related hazards examined as part of this study include channel shoaling and shoreline erosion adjacent to critical roadways and ferry facilities. For critical roadways on barrier islands east of Pamlico Sound, vulnerability to sound-side breaching was also evaluated. This section details how vulnerability to each of these hazards was assessed.

SHOALING

Data provided by NCDOT including the historical rates of dredging as well as the future planned dredging to the year 2040 were evaluated to assess potential shoaling hazards. These hazards were evaluated on a terminal level basis, recognizing that the entire route would be affected by shoaling. Channels with dredging needs more frequently than every 5 years were considered to be highly vulnerable to shoaling, channels dredged approximately every 6 to 10 years were considered to have medium vulnerability, and channels with dredging required less frequently than every 10 years were considered to have low vulnerability to shoaling.

OCEANFRONT EROSION

Terminal Shoreline

Because the ferry terminals are not located directly on the oceanfront, the terminal shoreline was not assessed for oceanfront erosion hazards.

Critical Roadway Shoreline

Oceanfront erosion hazards were evaluated for the critical roadway sections identified for each terminal using the 2020 oceanfront shoreline position determined by NC DCM. The road is determined to be potentially vulnerable to ocean-side erosion in areas in which the roadway is within 230 ft of the present ocean shoreline. This criterion was first defined for NC 12 by Stone et al. (1991) as the 230-ft critical buffer; it is based on the work of Cole (1989), who identified problem areas along the transportation corridor and typical distances at which NCDOT initiated previous remedial actions, including road relocation or nourishment projects. This criterion is currently being used in a long-term monitoring program along NC 12 as described by Velasquez-Montoya et al. (2021). Roadways were determined to have high vulnerability to oceanfront erosion where more than five percent (5%) of the critical roadway was within the 230-ft critical buffer. Medium vulnerability corresponded to the case where 5 percent (5%) or less of the critical roadway was within the 230-ft buffer, and low vulnerability roadways had no critical roadway within the 230-ft buffer.

ESTUARINE EROSION AND SOUNDSIDE BREACHING

Estuarine erosion hazards were evaluated for both the terminal shoreline as well as the critical roadway. In addition to estuarine erosion, for the critical roadways on barrier islands adjacent to the wide expanse of Pamlico Sound, vulnerability to sound-side breaching was evaluated.

Terminal Shoreline

Where the terminal shoreline was not stabilized or a structure was in poor condition, estuarine erosion vulnerability was considered to be high. If the terminal shoreline was stabilized, but the structure was considered to be in fair condition (i.e., visible concerns), the shoreline was considered to have medium vulnerability. For cases where the terminal shoreline was stabilized and the structure was in good condition, the estuarine erosion vulnerability was considered to be low.

Critical Roadway Shoreline

For the critical roadways, the estuarine shoreline GIS data were evaluated and classified as stabilized (shoreline types: Modified, Marsh shoreline waterward of a vertical structure, Marsh shoreline waterward of a sloped structure) or not stabilized (all other types). A visual inspection of stabilized estuarine shorelines adjacent to roadways was conducted and it was determined that most of these stabilized locations had a distance from the shoreline to the roadway of less than 50 ft. A 50-ft buffer was established from the estuarine shoreline to evaluate the critical roadway vulnerability to estuarine erosion. Cases where the estuarine shoreline was not stabilized and more than five percent (5%) of the critical roadway was within the 50-ft buffer were considered to be highly vulnerable. Medium vulnerability was classified for cases where the shoreline was stabilized and more than five percent (5%) of the critical roadway was within the 50-ft buffer or the shoreline was not stabilized and five percent (5%) or less of the critical roadway was within the 50-ft buffer. Where no critical roadway was within the 50-ft buffer or where five percent (5%) or less of the critical roadway was within 50 feet of a stabilized estuarine shoreline, vulnerability to estuarine erosion was classified as low.

Vulnerability to sound-side breaching was evaluated for the critical roadways on the barrier islands adjacent to the wide expanse of Pamlico Sound. This vulnerability was assessed by identifying the locations where the distance between the oceanfront shoreline and estuarine shoreline was less than 1000 ft. This criterion was established for long-term monitoring along NC 12 as described by Velasquez-Montoya et al. (2021) and is based on the width of the barrier island at locations where breaching previously occurred during Hurricane Irene in 2011. Where more than five percent (5%) of the critical roadway was identified as vulnerable to breaching, the vulnerability was considered high; all other critical roadways were considered to have low vulnerability to breaching.

Overall Terminal Vulnerability

The overall terminal vulnerability assessment captures the vulnerability of the most critical asset and most vulnerable on the terminal property. The methodology applies a 'weakest link' approach, whereby the most critical terminal asset with the most natural hazard vulnerability is used to assign overall terminal vulnerability. In the case of the ferry terminal sites, the assets are most exposed to flooding hazards. While terminal estuarine erosion has impacts to the overall property shoreline, the research did not capture direct erosion impacts to individual assets. The results of the overall terminal vulnerability assessments are provided in terminal summary sheets.

Community Impact

To capture equity and community impacts associated with ferry system disruption, the research team developed a community impact methodology utilizing the results of the 2017 onboard ferry ridership survey (Bert et al, 2020) and the NCDOT Transportation Disadvantage Index (TDI). The TDI is developed from six socioeconomic variables that describe relative concentrations of certain groups in a given census geography: carless households, low-income people, people with mobility impairments, youth, seniors, BIPOC (black, indigenous, people of color) population, and LEP (limited English proficiency) population (NCDOT, 2022).

Because the onboard ferry ridership data is based on zip codes, the research group used American Community Survey (ACS) data to replicate the TDI methodology at the zip code level. The research team formulated the TDI using a previous six-variable version that is better supported by available documentation. This six-variable version of the TDI does not include LEP population in the index. In the event updated documentation becomes available, the methodology could be repeated to include the LEP variable. TDI scores in the zip code layer created by the research team range from 6 (least transportation disadvantage) to 18 (most transportation disadvantage).

To estimate the relative transportation disadvantage of ridership by ferry route, the research team calculated a weighted average of zip code level TDI values for riders of each route. Zip code TDI values were weighted by the number of riders for whom the zip code was a home location, then summed and averaged. The result is a value for each terminal route between 6 and 18 that describes the TDI of its ridership. Values below 8 were classified as low; values between 8 and 10 were classified as medium; values above 10 were classified as high. TDI analysis was not conducted for asset areas without active passenger service.

Adaptation Alternatives

The suite of adaptation alternatives was developed with a combination of literature review and expert consultation. These alternatives present a range of adaptation options that are compared in terms of the timeframe of application as well as relative costs. Relative costs were developed in consultation with a cost estimator and are used to compare potential alternatives. These relative costs also have some uncertainty based on lack of detailed information on facility foundation(s), geotechnical information, environmental and other considerations. Future project implementation would provide specifics enabling more detailed cost estimates.

Facility purpose and criticality were considered when developing reasonable alternatives, for example, a security booth faced with flooding hazards could be converted to a semi-permanent, movable facility or floodproofed, whereas a dormitory would need more extensive retrofit.

The complete set of adaptation options are presented in Exhibit 20 in the results section and the terminal specific adaptation options are presented in the Executive Summary section.

Results

The vulnerability assessment results tables are presented below. The results include flooding, erosion and community impact result tables. The identified adaptation alternatives are also presented in this section. Detailed, terminal-focused results are presented in the Terminal Summary Sheets.

Flood Hazard Results for Assets & Terminals

This section describes the results of the flood hazard analysis for assets and critical roadways generally. A table of full results, including a table of individual assets and hazard impacts, is available in Appendix D.

Exhibit 11 presents a list of all assets classified in the high vulnerability class in any analysis year. High vulnerability assets are found in 6 asset areas in both 2020 and 2060. Of these asset areas with high vulnerability assets, Manns Harbor has the highest count (6) of high vulnerability assets, while Ocracoke Silver Lake has the highest rate (83%) of all assets classified as high vulnerability by 2060.

Exhibit 11: Assets Classified with High Vulnerability

Asset Area	Asset	2020	2040	2060
Currituck	Currituck Ferry Operations Building	✓	✓	✓
Hatteras	Hatteras Visitor Center & Office	✓	✓	✓
Hatteras	Hatteras Dormitory #1	✓	✓	✓
Hatteras	Hatteras Dormitory #2	✓	✓	✓
Ocracoke SL	Ferry Dormitory Building		✓	✓
Ocracoke SL	Visitors Center and Ferry Office	✓	✓	✓
Ocracoke SL	Ferry Office		✓	✓
Ocracoke SL	Visitors Restroom Building	✓	✓	✓
Ocracoke SL	Above-ground Storage Tank		✓	✓
Cedar Island	Pump House	✓	✓	✓
Southport	Visitor Center	✓	✓	✓
Manns Harbor	Manns Harbor Dormitory	✓	✓	✓
Manns Harbor	Marine Security Booth			✓
Manns Harbor	Paint Storage Building			✓
Manns Harbor	Above-ground Storage Tank Area - Oxygen	✓	✓	✓
Manns Harbor	Paint Mixing Building	✓	✓	✓
Manns Harbor	Well Pump Building			✓

The total number of assets classified into each vulnerability class is provided in Exhibit 12 below. Notably, the percentage of assets in the high vulnerability class more than doubles from 2020 to 2060, with the greatest change occurring in the period between 2040 and 2060. The number of assets in the low vulnerability class does not change in the different analysis years. However, the number of assets in the medium vulnerability class decreases as assets in this class are “pushed” into the high vulnerability class in future analysis years.

Exhibit 12: Number of Assets Classified in Each Vulnerability Class

Vulnerability	2020	2040	2060
High	11 (16%)	14 (21%)	17 (35%)
Med	31 (46%)	28 (42%)	25 (37%)
Low	25 (37%)	25 (37%)	25 (37%)

The changes observed by analysis year are driven primarily by increases in vulnerability levels of assets that are already at high vulnerability to many flood hazards in 2020. Exhibit 13 helps to further illustrate this finding. As shown in Exhibit 13, assets with 4 or 5 flood risk factors in 2020 experienced the highest rate of hazard count increase between 2020 and 2060, with over two-thirds of assets in these categories increasing their hazard count. The low, medium, and high classification scheme somewhat obscures the fact that vulnerability increases significantly for assets that are already within the high vulnerability classification. This underpins the need to implement adaptation measures for those assets currently in the high vulnerability classification.

Exhibit 13: Percentage of Assets with Increase to Hazard Count by 2060

Hazards Count Category in 2020	% Assets with Increase to Hazard Count by 2060
0	0%
1	0%
2	13%
3	33%
4	88%
5	67%

Terminal flood hazard vulnerability classes assigned based on the highest vulnerability level of the highest criticality asset are provided in Exhibit 14 below. These classes did not change across analysis years. The highest vulnerability asset areas based on this analysis are Cedar Island, Currituck, Hatteras, Manns Harbor, both Ocracoke terminals, and Southport.

Exhibit 14: Terminal Flood Vulnerability Level

Asset Area	Flood Vulnerability (all Years)
Currituck	High
Knotts Island	Low
Hatteras	High
Ocracoke South Dock	High
Ocracoke Silver Lake	High
Swan Quarter	Medium
Cedar Island	High
Bayview	Medium
Aurora	Medium
Cherry Branch	Medium
Minnesott Beach	Low
Southport	High
Fort Fisher	Medium
Manns Harbor	High
Powell's Point	Low

Flood Hazard Results for Critical Roadways

Exhibit 15 presents the critical roadways vulnerability results for flood hazards. No critical roadways experienced a vulnerability classification change across the analysis timeline. Critical roadways that are highly coastal were generally already vulnerable to numerous flood hazards in the 2020 scenario, and, as a result, are already classified as high vulnerability in that analysis year. While roadway vulnerability classifications do not change, many roadways do increase in the number of hazards to which they are vulnerable across the analysis years. For example, the critical roadways for Manns Harbor are impacted by 4 flood hazards in 2020 and 7 flood hazards in 2060. This indicates an overall increase in vulnerability, though the vulnerability classification remains high for all years. Similarly to the assets, the critical roadways with higher hazard counts in the 2020 scenario are more likely to have hazard count increases by 2060.

Exhibit 15: Flood Hazards to Critical Roadways

Asset Area	Vulnerability (All Years)	Hazard Count, 2020	Hazard Count, 2060	Increase in Hazard Count, 2020-2060
Currituck	High	4	5	1
Knotts Island	High	5	7	2
Hatteras	High	5	7	2
Ocracoke South Dock	High	6	9	3
Ocracoke Silver Lake	High	6	9	3
Swan Quarter	High	6	8	2
Cedar Island	High	5	7	2
Bayview	Medium	3	3	0
Aurora	High	4	4	0
Cherry Branch	Low	0	0	0
Minnesott Beach	Low	0	0	0
Southport	High	4	4	0
Fort Fisher	High	5	7	2
Rodanthe	High	5	7	2
Stumpy Point	High	5	8	3
Manns Harbor	High	4	7	3
Powells Point	Low	1	1	0

Shoaling and Erosion Hazard Results

This section details the results of the shoaling and erosion hazards analysis, including critical roadway vulnerability to sound-side breaching.

SHOALING

The results of the shoaling vulnerability assessment are presented in in Exhibit 16 Shoaling within the ferry channels is generally driven by currents and tidal inlet processes. The routes with the most frequent dredging requirements include Hatteras-Ocracoke (multiple dredging events per year, performed by the USACE), Big Foot Slough outside of Ocracoke Silver Lake terminal, affecting the Swan Quarter-Ocracoke and Cedar Island-Ocracoke routes (multiple dredging events per year, performed by the USACE), Southport-Fort Fisher (dredging occurring approximately every 3 years), and the Stumpy Point-Rodanthe emergency ferry route (dredging occurring approximately every 2 to 3 years).

Exhibit 16: Shoaling Vulnerability Assessment Results

Terminal	Route	Dredge Frequency (years)	Vulnerability Rating
Currituck	Knotts Island-Currituck	Not specified	Low
Knotts Island	Knotts Island-Currituck	7	Medium
Hatteras	Hatteras-Ocracoke	<1 (USACE)	High
Ocracoke South Dock	Hatteras-Ocracoke	<1 (USACE)	High
Ocracoke Silver Lake	Swan Quarter-Ocracoke, Cedar Island-Ocracoke	Big Foot Slough Channel <1 (USACE)	High
Swan Quarter	Swan Quarter-Ocracoke	15	Low
Cedar Island	Cedar Island-Ocracoke	12	Medium
Bayview	Bayview-Aurora	8	Medium
Aurora	Bayview-Aurora	Not specified	Low
Cherry Branch	Cherry Branch-Minnesott Beach	11	Medium
Minnesott Beach	Cherry Branch-Minnesott Beach	Not specified	Low
Southport	Southport-Fort Fisher	3	High
Fort Fisher	Southport-Fort Fisher	3	High
Rodanthe	Stumpy Point-Rodanthe (Emergency Route)	Not specified	Low
Stumpy Point	Stumpy Point-Rodanthe (Emergency Route)	2-3	High
Manns Harbor Shipyard	Vessel access to shipyard	10	Medium
Powells Point	N/A	N/A	N/A

OCEANFRONT EROSION

Terminal Shoreline

No ferry terminals were identified with direct oceanfront erosion hazard, with Ocracoke South Dock being the only terminal that has direct inlet shoreline erosion hazard, due to the presence of the inlet channel. This was considered as part of the estuarine erosion hazard assessment.

Critical Roadway Shoreline

Oceanfront erosion hazards contribute to the vulnerability of several of the identified critical roadways, as shown in **Error! Reference source not found.**. The longest critical roadway segment identified within the 2 30-ft buffer was along NC 12 on the northeast side of Ocracoke Island, between the Ocracoke South Dock terminal and the village of Ocracoke. Additional critical roadway within the 230-ft buffer was identified along NC 12 between the Basnight Bridge and the Hatteras terminal, a subset of which was also critical roadway for the Rodanthe emergency route terminal. A small segment of critical roadway associated with the Fort Fisher terminal in Carolina Beach was also identified within the 230-ft buffer.

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ESTUARINE EROSION AND SOUND-SIDE BREACHING

Terminal Shoreline

The terminal shoreline estuarine erosion vulnerability results are presented in **Error! Reference source not found.**. The terminal with the highest estuarine erosion vulnerability is Ocracoke South Dock, which is affected by the inlet channel migrating to the west. An emergency shoreline stabilization seawall was constructed at this terminal in 2020, but tiebacks have been exposed and erosion continues to threaten the property. Additional terminals that may have future estuarine erosion concerns include Swan Quarter and Fort Fisher, where the shorelines are not stabilized at the present time. Terminals with partial structures and a medium vulnerability include Aurora, Southport, and Rodanthe. During the field visit storm damage was observed at Cherry Branch, so this terminal shoreline was also assigned a medium vulnerability. All other terminals had shoreline stabilization structures in good condition (low vulnerability).

Exhibit 17. Terminal Shoreline Estuarine Erosion Hazard Assessment Results

Terminal	Property Shoreline Treatment	Structure Condition	Notes	Vulnerability Rating
Currituck	Bulkhead/Revetment	Good	Bulkhead and breakwater in good condition.	Low
Knotts Island	Bulkhead/Revetment	Good	Revetment in good condition.	Low
Hatteras	Bulkhead/Revetment	Good	Bulkhead/revetment in good condition.	Low
Ocracoke South Dock	Limited Bulkhead	Poor	Visible damage to seawall/bulkhead adjacent to inlet. Ongoing erosion at inlet shoreline.	High
Ocracoke Silver Lake	Bulkhead/Revetment	Good	Bulkhead/revetment in satisfactory condition.	Low
Swan Quarter	Not Stabilized	N/A	Shoreline not stabilized.	High
Cedar Island	Bulkhead/Revetment/ Breakwater	Good	Bulkhead in good condition.	Low
Bayview	Bulkhead/Revetment	Good	Bulkhead in good condition.	Low
Aurora	Limited Bulkhead/Revetment	Good	Limited bulkhead/revetment in good condition, some shoreline adjacent to facility not stabilized.	Medium
Cherry Branch	Bulkhead/Revetment/ Breakwater	Fair	Bulkhead/seawall in fair condition, storm damage noted in field visit.	Medium
Minnesott Beach	Bulkhead/Revetment/ Breakwater	Good	Bulkhead and breakwater in good condition.	Low
Southport	Partial Revetment	Good	Revetment in good condition, shoreline adjacent to docks not stabilized.	Medium
Fort Fisher	Not Stabilized	N/A	Shoreline not stabilized.	High
Rodanthe	Limited Bulkhead	Fair	Limited bulkhead in fair condition. Portion of the shoreline not stabilized.	Medium
Stumpy Point	Not Stabilized	N/A	Shoreline not stabilized.	High
Manns Harbor Shipyard	Bulkhead/Revetment	Good	Bulkhead and revetment in good condition.	Low
Powells Point	N/A	N/A	Facility not adjacent to shoreline.	Low

Critical Roadway Shoreline

Critical roadway was assessed for both estuarine erosion hazard as well as vulnerability to sound-side breaching, where applicable. The critical roadways most vulnerable to estuarine erosion as assessed by proximity to an unstabilized shoreline were NC 615 leading to the Knotts Island terminal, NC 12 leading to the Cedar Island terminal, and US 264 leading to the Stumpy Point facility. The critical roadways most vulnerable to sound-side breaching were NC 12 on Hatteras Island (associated with the Hatteras and Rodanthe terminals), and NC 12 on Ocracoke Island (associated with the South Dock and Silver Lake terminals). Smaller segments of critical roadway leading to the Currituck and Manns Harbor Shipyard facilities were identified as vulnerable to estuarine erosion, and were assigned medium vulnerability.

Exhibit 18. Critical Roadway Estuarine Erosion and Sound-Side Breaching Hazard Assessment Results

Terminal	Total Critical Roadway Length (ft)	Unstabilized Critical Roadway within 50 ft Buffer (ft)	In Buffer (%)	Stabilized Critical Roadway within 50 ft Buffer (ft)	In Buffer (%)	Estuarine Shoreline within 1000 ft of Oceanfront Shoreline along Critical Roadway (ft)	Percent Vulnerable to Sound-Side Breaching	Vulnerability Rating
Currituck	48,003	405	1%	-	0%	-	0%	Medium
Knotts Island	48,397	8,158	17%	1,914	4%	-	0%	High
Hatteras	255,278	383	0%	306	0%	50,722	20%	High
Ocracoke South Dock	72,917	-	0%	381	1%	15,566	21%	High
Ocracoke Silver Lake	72,917	-	0%	381	1%	15,566	21%	High
Swan Quarter	65,058	-	0%	133	0%	-	0%	Low
Cedar Island	195,226	26,335	13%	10,762	6%	-	0%	High
Bayview	44,830	-	0%	-	0%	-	0%	Low
Aurora	43,140	-	0%	-	0%	-	0%	Low
Cherry Branch	23,928	-	0%	-	0%	-	0%	Low
Minnesott Beach	11,266	-	0%	-	0%	-	0%	Low
Southport	19,644	-	0%	-	0%	-	0%	Low
Fort Fisher	72,990	-	0%	-	0%	-	0%	Low
Rodanthe	192,906	383	0%	306	0%	45,770	24%	High
Stumpy Point	201,531	20,402	10%	17,558	9%	-	0%	High
Manns Harbor Shipyard	100,908	123	0%	2,010	2%	-	0%	Medium
Powells Point	130,973	-	0%	-	0%	-	0%	Low

Community Impact Results

To ensure that equity and community impacts associated with ferry system disruption where captured within the vulnerability assessment, each ferry terminal has been scored for community impact. The four ferry sites without active ferry operations (Manns Harbor, Powells Point, Rodanthe, and Stumpy Point) were not scored for community impact.

Exhibit 19 presents a table with ferry terminal, route, ridership and community descriptions. The community impact column explains the vital services and functions that each ferry route provides for local communities. The TDI score is presented capture the relative transportation disadvantage of ridership by ferry route (see methodology section), and the final community impact determination is a provided in the rightmost column of the table.

Exhibit 19: Community Impact Results Table

County	Area	Distance	Estimated Ferry Time	Estimated Drive Time	Estimated Drive Time with Traffic	Annual Vehicles	Riders	Community Impact	TDI Score	Community Impact Ratings
Currituck	Currituck serves a route that connects to the Knotts Island terminal, which provides access to mainland NC by school bus for children on the island.	5 miles	40 mins.	55 mins.	65 mins.	15,000+	60%+ permanent residents, 38% seasonal residents or visitors in peak	Local residents depend on this route In the absence of the ferry, with 73% of riders who took a 2017 onboard survey saying they would have to find another way to make their trip if ferry was unavailable. Public school buses would have to drive through Virginia to transport children between the island and mainland.	7.4	Low
Currituck	Knotts Island serves a route that connects to the Currituck terminal, which provides access to mainland NC by school bus for children on the island.	5 miles	40 mins.	55 mins.	65 mins.	15,000+	60%+ permanent residents, 38% seasonal residents or visitors in peak	Local residents depend on this route In the absence of the ferry, with 73% of riders who took a 2017 onboard survey saying they would have to find another way to make their trip if ferry was unavailable. Public school buses would have to drive through Virginia to transport children between the island and mainland.	7.4	Low
Dare	Hatteras, situated near numerous businesses, serves a popular tourist route for day and overnight trips that connects the island to Ocracoke South Dock terminal.	4.5 miles	60 mins	Drive Route not possible	Drive Route not possible	203,000+	80%+ visitors in peak, highly seasonal	Supports thousands of jobs and hundreds of millions in economic impact to the local economy, with 90%+ of riders who took a 2017 onboard survey for the Hatteras-Ocracoke route saying they would not or could not take their trip if the ferry was unavailable.	8.4	Medium
Hyde	Ocracoke South Dock, located on the unpopulated end of Ocracoke Island, connects to the Hatteras terminal through a popular tourist route used for day and overnight trips.	4.5 miles	70 mins.	Drive Route not possible	Drive Route not possible	203,000+	80%+ visitors in peak, highly seasonal	Supports thousands of jobs and hundreds of millions in economic impact to the local economy, with 90%+ of riders who took a 2017 onboard survey for the Hatteras-Ocracoke route saying they would not or could not take their trip if the ferry was unavailable.	8.9	Medium
Hyde	Silver Lake serves two ferry routes and is situated on Ocracoke, which is only accessible by a personal vessel or ferry. The island is a busy tourist destination with 16 miles of beaches and historic attractions.	See Cedar Island and Swan Quarter	See Cedar Island and Swan Quarter	See Cedar Island and Swan Quarter	See Cedar Island and Swan Quarter	See Cedar Island and Swan Quarter	See Cedar Island and Swan Quarter	Used for emergency evacuation routes and critical supply lines for island community.	8.4	High
Hyde	Swan Quarter serves the longest NCDOT ferry route, which connects mainland NC to the Ocracoke Silver Lake terminal, providing a key connection for tourists and local residents.	27 miles	2.5 hours	230 mins.	160 mins.	36,000+	65%+ visitors in peak, highly seasonal	Used as an emergency evacuation route and critical supply line for island community.	9.2	Medium
Carteret	Cedar Island connects to the Ocracoke Silver Lake terminal, providing visitors and residents access to numerous tourist attractions and local sites of interest.	23 miles	2.25 hours	Drive Route not possible	Drive Route not possible	42,000+	65%+ visitors in peak, highly seasonal	Used as an emergency evacuation route and critical supply line for island community.	8.4	Medium
Beaufort	Bayview serves a route that connects to the Aurora terminal. The route connects local communities to essential services, including access to jobs at the PCS Phosphate Company, Inc. in Aurora, NC.	3.5 miles	30 mins.	60 mins.	70 mins.	39,000+	90%+ local permanent residents	Local residents depend on this route for access to basic needs. More than half of the riders who took a 2017 onboard survey said they were traveling to work or school, with 80% of riders saying they would have to find another way to make their trip if ferry was unavailable.	10.6	High
Beaufort	Aurora is located in Aurora, NC, home to the PCS Phosphate Company, Inc. phosphate mining and chemical plant. The terminal serves a route that connects to the Bayview terminal and connects local communities to essential services.	3.5 miles	30 mins.	60 mins.	70 mins.	39,000+	90%+ local permanent residents	Local residents depend on this route for access to basic needs. More than half of the riders who took a 2017 onboard survey said they were traveling to work or school, with 80% of riders saying they would have to find another way to make their trip if ferry was unavailable.	10.6	High
Craven	Cherry Branch, near Marine Corps Air Station Cherry Point in Havelock, serves a route that connects to the Minnesott Beach terminal.	2.5 miles	20 mins.	65 mins.	80 mins.	207,000+	90%+ local permanent residents	Local residents depend on route, with 76% of riders who took a 2017 onboard survey saying they would have to find another way to make their trip if ferry was unavailable. Route provides a key connection for military and support staff traveling to and from Marine Corps Air Station Cherry Point.	8.9	Medium
Pamlico	Minnesott Beach serves a route that connects to the Cherry Branch terminal, which is near Marine Corps Air Station Cherry Point in Havelock.	2.5 miles	20 mins.	65 mins.	80 mins.	207,000+	90%+ local permanent residents	Local residents depend on route, with 76% of riders who took a 2017 onboard survey saying they would have to find another way to make their trip if ferry was unavailable. Route provides a key connection for military and support staff traveling to and from Marine Corps Air Station Cherry Point.	8.9	Medium
Brunswick	Southport serves a route that connects to the Fort Fisher terminal. This route provides local residents with access to jobs and other basic needs and offer tourists a faster and more scenic way to access attractions like the North Carolina Aquarium at Fort Fisher and Carolina Beach.	3.5 miles	35 mins.	65 mins.	100 mins.	180,000+	50% permanent residents, 50% seasonal residents or visitors in peak	Supports 1000+ jobs on which the local community depends by providing faster and safer access to Fort Fisher.	8.1	Medium
New Hanover	Fort Fisher serves a route that connects to the Southport terminal, providing local residents with access to jobs and other basic needs. and tourists a direct access to historic Southport.	3.5 miles	35 mins.	65 mins.	100 mins.	180,000+	50% permanent residents, 50% seasonal residents or visitors in peak	Supports 1000+ jobs on which the local community depends by providing faster and safer access to Southport.	8.1	Medium
Currituck	Powell's Point is a marine maintenance unit that serves as a storage yard for piling equipment. This asset area has a small administrative footprint.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Adaptation Alternatives

The research team developed a full set of adaptation alternatives to mitigate impacts for flooding and erosion natural hazards. Adaptation options are presented for critical roadways, individual assets and the facility site as a whole. Exhibit 20 and Exhibit 21 present a general list of asset types, adaptation options, typical timeframe, and a description for flooding and erosion adaptation options. Specific adaptation options tailored to each terminal are provided in the Terminal Summary Sheets that can be found in the Executive Summary section of this report.

Exhibit 20: Adaptation Summary Table

Asset Type	Adaptation Options	General Time Frame	Description/Notes
Flooding/Elevated Water Levels			
Roadways	Culverts & Drainage	Near Term	Install at high flood risk locations
	Beach Nourishment & Dune Construction	Near Term	Currently dune building is used to mitigate oceanside erosion and flooding, beach nourishment would allow for more time/less frequent overtopping/erosion
	Elevate Roadways	Near Term/Long Term	Considered at high flood risk sections
	Constructed Wetlands/Surface Water Storage	Long Term	Requires land acquisition, significant investment
	Relocate Roadway/Bridge/Causeway Construction	Long Term	May require land acquisition, rerouting, significant investment
Visitor's Center, Restroom, Storage, Operations, Maintenance and Office Buildings	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	Temporary measure to mitigate flooding
	Floodproof Building	Near Term/Long Term	For example, installing drains, ensuring contents can withstand getting flooded
	Elevate Contents	Near Term/Long Term	Elevate contents of building to avoid flooding where possible
	Elevate Building	Long Term	Depends on geotechnical information & structural requirements
	Relocate Building	Long Term	Assumes suitable location available & ability to move building
Electrical Generators & Associated Buildings	Construct Berm Around Building	Near Term/Long Term	Bulk material around outside, depends on geotechnical information
	Elevate Contents/Floodproof Building	Near Term/Long Term	Raise generator above flood levels and ensure contents can withstand being flooded
	On-Site Solar and Battery Backup System	Long Term	Would need to meet the need satisfied by the generator to replace it, would need to be elevated or located away from flood zone
Above Ground Storage Tanks	Elevate Contents/Floodproof Building	Near Term/Long Term	Raise storage tank above flood levels and/or ensure contents can withstand being flooded
	Electric Fleet Conversion	Long Term	Eliminates need for above ground storage tanks, requires shore power and considers complete re-haul of fleet
Pump House, Veeder Root, or Amphidromia Equipment Building	Elevate Contents/Floodproof Building	Near Term/Long Term	Raise pump above flood levels and ensure contents can withstand being flooded
Ticket Booth/Security Gate	Elevate Contents/Floodproof Building	Near Term/Long Term	Elevate critical equipment, ensure contents can withstand being flooded
	Convert to Semi-Permanent Facility	Near Term/Long Term	Use trailer or moveable facility
Ferry Dormitory Building	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	Temporary measure

Asset Type	Adaptation Options	General Time Frame	Description/Notes
	Floodproof Building	Near Term/Long Term	Flood shield, other dry floodproofing techniques
	Elevate Building	Long Term	Depends on geotechnical information & structural requirements
	Relocate Building	Long Term	Assumes suitable location available & ability to move building
Large Buildings, Not Feasible to Elevate (e.g. Marine Warehouse/Paint Booth/Garage/Syncrolift)	Deploy Short-Term Dam Systems (e.g. Sandbags, AquaDam) During Events	Near Term	Temporary measure
	Floodproof Building	Near Term/Long Term	Flood shield, other dry floodproofing techniques
	Relocate Building	Long Term	Assumes suitable location available & ability to move building
Entire Facility	Construct Flood Wall or Berm	Long Term	Install flood wall or berm around the entire facility to protect against significant flood damage. Requires significant design, engineering and construction effort
	Relocate Entire Terminal/Facility	Long Term	Will require land acquisition, rerouting of route, construction of new facility
Ramp & Gantry System	Raise Center Beam, Adjust Cables & Counterweights	Near Term/Long Term	Allows for additional clearance due to elevated water levels.

Exhibit 21: Erosion Adaptation Summary Table

Asset Type	Adaptation Options	General Time Frame	Description/Notes
Erosion			
Roadways	Maintain Existing Shoreline Stabilization	Near Term	Maintain existing revetment/bulkheads
	Install Revetment Along Unstabilized Shoreline	Near Term	General permit available, relatively straightforward design
	Install Living Shoreline Along Unstabilized Shoreline	Near Term	Enhanced ecological function, nature-based solution, may require more design considerations
	Beach Nourishment & Dune Construction	Near Term	Currently dune building is used to mitigate oceanside erosion and flooding, beach nourishment would allow for more time/less frequent overtopping/erosion
Property Shoreline	Install Revetment Along Unstabilized Shoreline	Long Term	General permit available, relatively straightforward design
	Install Living Shoreline Along Unstabilized Shoreline	Long Term	Enhanced ecological function, nature-based solution, may require more design considerations
	Install Seawall/Bulkhead Along Unstabilized Shoreline	Long Term	Depends on geotechnical information & structural requirements
	Maintain Existing Seawall/Bulkhead/Breakwaters	Near Term	Ensure existing shoreline protection remains in good condition
	Raise Seawall/Bulkhead	Long Term	Depends on geotechnical information & structural requirements

Discussions & Implications of Results

The overall terminal vulnerability results are presented in Exhibit 22, highlighting each terminal's overall vulnerability and the terminal criticality. Twelve of the ferry system facilities have either a high or medium vulnerability. Five of the facilities have both a high vulnerability and high criticality. The criticality-vulnerability table in Exhibit 23 identifies the six most critical and vulnerable ferry facilities: Hatteras, Ocracoke South Dock, Ocracoke Silver Lake, Cedar Island and Manns Harbor Shipyard. Currituck and Southport have high vulnerability and medium criticality. No ferry system facility was determined to have low criticality and low vulnerability.

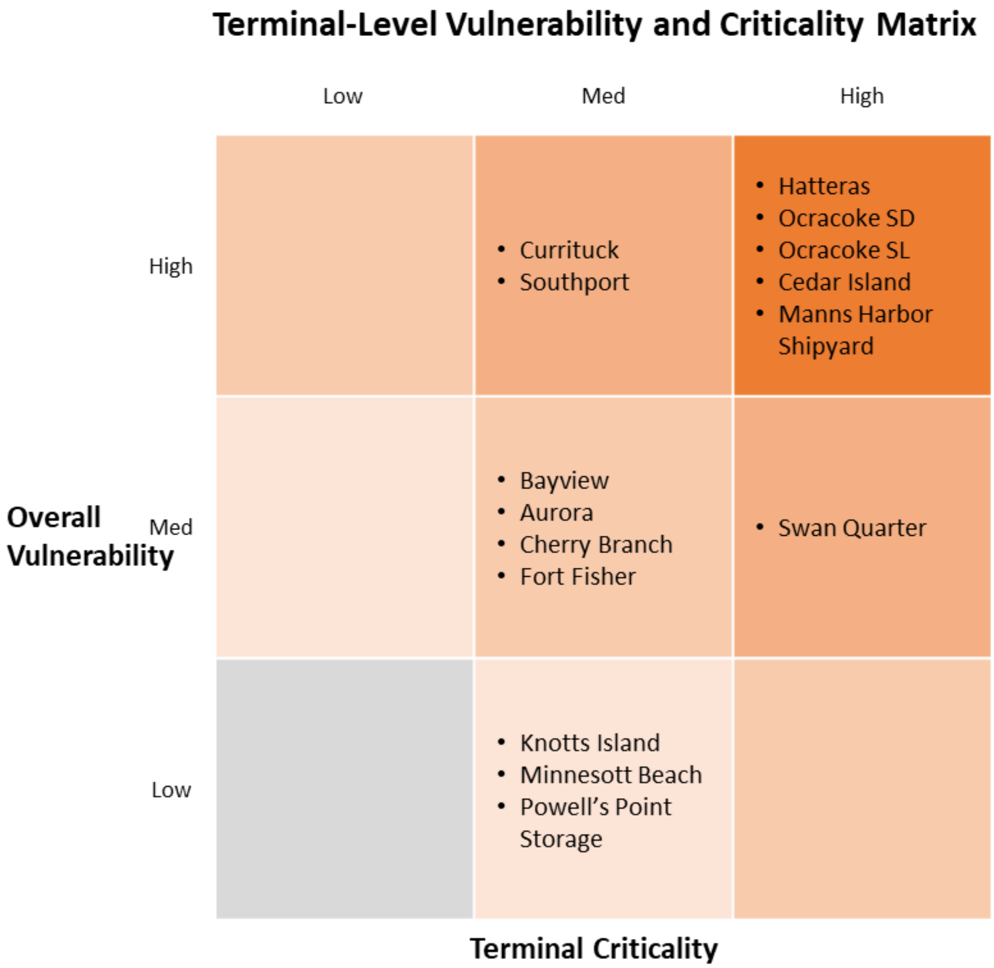
Exhibit 22: Overall Terminal Vulnerability and Criticality

Overall Terminal Vulnerability and Criticality

Terminal/Facility	Overall Terminal Vulnerability	Terminal Criticality
Currituck	High	Medium
Knotts Island	Low	Medium
Hatteras	High	High
Ocracoke South Dock	High	High
Ocracoke Silver Lake	High	High
Swan Quarter	Medium	High
Cedar Island	High	High
Bayview	Medium	Medium
Aurora	Medium	Medium
Cherry Branch	Medium	Medium
Minnesott Beach	Low	Medium
Southport	High	Medium
Fort Fisher	Medium	Medium
Manns Harbor Shipyard	High	High
Powell's Point Storage	Low	Medium

* Due to an asset based scoring method, the Rodanthe Emergency Terminal and Stumpy Point Emergency Terminal did not get an overall terminal vulnerability designation because there are no assets at the site.

Exhibit 23: Overall Terminal-Level Vulnerability & Criticality Matrix



During the assessment, the two facilities that were found to be the most critical and most vulnerable are Ocracoke South Dock and Manns Harbor Shipyard. The Ocracoke South Dock facility is the most highly vulnerable terminal site due to terminal flooding, terminal erosion and highly vulnerable roadway access. Manns Harbor Shipyard is one of the most critical facilities for the ferry system as it is the maintenance and repair facility for the entire ferry fleet. A service disruption over a few days to Manns Harbor can have serious implications to the ferry system operations and fleet maintenance. The Manns Harbor Shipyard site has high flood vulnerability.

The detailed criticality-vulnerability assessment results are presented at route level, terminal level and asset level in the set of terminal summary sheets in the Executive Summary. The sheets include detailed vulnerability assessments based on planning horizon (present, 2040, and 2060); coastal and estuarine erosion; asset/terminal flooding; critical roadway vulnerability; community impact; and shoaling in the navigational channel. The summary sheets also present asset level adaptation options, including timeframe and a comparative order of magnitude cost (including cost uncertainty). The complete set of vulnerability and criticality tables (flood vulnerability, erosion vulnerability, critical roadway vulnerability and overall terminal vulnerability) are presented in Appendix E.

Decision Making and Funding Opportunities

The results of this study were developed to be integrated into the NCDOT decision making process. The terminal summary sheets are designed to provide a clear, easy to read summary of the ferry system vulnerability assessment and potential adaptation options. These sheets were designed to allow a broad audience (such as NCDOT leadership, staff, external partners, and local officials) to better understand the vulnerability of ferry assets when making decisions about prioritizing project needs and funding resilience improvements.

Developing the vulnerability assessment based on NCDOT Resilience Strategy and the FHWA adaptation framework guidance, the results of this study will also be able to be incorporated into the NCDOT Statewide RIP. The results of this criticality-vulnerability approach to natural hazard assessments can be incorporated into future NCDOT RIP updates. RIPs are federally supported resilience improvements plans referenced in the *Infrastructure Investment and Jobs Act* (IIJA) and eligible for Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) funding. Projects included on a state’s RIP are eligible for a reduction in the required amount of non-federal matching fund for PROTECT funds. The non-federal match can be reduced from the standard 20% to the maximum reduction of 10% non-federal match.

Additional federal funding opportunities exist to fund ferry system improvements. A recent example is an FTA grant for ferry service that connect rural communities to economic opportunities and encourage the electrification of ferry fleets including Ferry Service for Rural Communities Program; Electric or Low-Emitting Ferry Pilot Program; and FTA's Passenger Ferry Grant Program. As a part of the grant program, NCDOT was awarded $1,345,241 in the rural communities category to modernize the Manns Harbor Shipyard paint facility.

Appendices

Appendix A: Field Work Data Sheets

ASSET AREA

AURORA

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
7/11/23	Sunny 82 degrees	Savannah Wright, Sagar Rijhwani, Abhiny Bawale

DESCRIPTION OF ROADWAY ACCESS

One entrance and one exit to ferry site, carpool line to go to Ferry entrance, clear road that has no outlet past ferry site

DESCRIPTION OF DOCK INFRASTRUCTURE

lifted one-way road leading to dock, protected area, fenced in area around doc, groups of wooden poles and water, where boat goes, puddles on the dock, guard rails on road

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Au	Restroom - South Dock	007-017-016	Au11 - Au17	N/A	No Damage to the structure
2	Au	Aurora - Dock Infrastructure	Aur-Dock	Au1 - Au10	N/A	No Cracks in the foundation, puddle found under the docks
3						
4						
5						

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1						
2						
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

Two picnic areas (Au20) and Underground Tank (Au18,Au19)

ASSET AREA

Bayview

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
7/19/23	Overcast, 91 degrees, warm	Savannah Wright, Sagar Rijhwani

DESCRIPTION OF ROADWAY ACCESS

Two-lane road leading to the ferry and looping around, small parking lot, signs directing people

DESCRIPTION OF DOCK INFRASTRUCTURE

Good condition, fenced in around water, no visible damage, few cracks in pavement but nothing major

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Ba	Emergency Generator Building	007-017-008	B19, 20, 21, 24, 25	N/A	old but overall good condition
2	Ba	Office and Restroom	007-017-015	B29, 30, 32 - 37	N/A	new and neat
3	Ba	Storage Building	007-017-010	B12 - 15	N/A	old but good condition
4	Ba	Bayview - Dock Infrastructure	Bay-Dock	B5 - 9, 31, 38 - 45	N/A	well kept
5						

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1	storage	35.42804 N	76.74001 W	B1 - 4	About 4 ft above ground	good condition but older
2	storage	35.42840 N	76.74018 W	B11, 16 - 18, 26 - 28, 46 -		good condition
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

picnic tables, house where workers may live, overall clean and well kept

ASSET AREA

Cedar Island

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
7/18/2023	Partly Cloudy, High: 88, Low: 79	Lauren Southworth and Kyra Stash

DESCRIPTION OF ROADWAY ACCESS

single lane leading to queueing lanes on the right hand side, continuing straight are lanes for people who don't have reservation, after recieving a ticket people are waiting in queueing lanes to get onto the ferry. Vegetaion is a mixutre of sand a grass. Visitor center to the left and maintenance building to the right. Minimal cracking on seawall, rust showing on rails for people (where water has reached these levels). wooden dock for personal use to the left of ferry dock, wooden dock in good condition. retaining wall is up to par and ferry dock is gated all the way around.

DESCRIPTION OF DOCK INFRASTRUCTURE

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Ce	Pump House	016-017-005	CI40-43	N/A	
2	Ce	Visitors Center & Office	016-017-011	CI44-57	1' 8"	
3	Ce	Marine Maintenance Building	016-017-019	CI34-39	N/A	
4	Ce	Above-ground Storage Tank	Ced-AST	CI1-15	5' 4", 2' (big tank), 1' 8" (smaller Used Oil tank)	Tank was elevated 2' over the platform at its lowest point and 5'4" at its feet. Platform elevation not obtained in the field, but estimated less than 6" from photograph.
5	Ce	Cedar Island - Dock Infrastructure	Ced-Dock	CI16-33	N/A	

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1						
2						
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

ASSET AREA

Cherry Branch

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
7/17/23	Gray, Overcast	Savannah Wright, Myah Owens

DESCRIPTION OF ROADWAY ACCESS

Long road leading in, single lane, security gate at front (was empty when we got there) drive-through lane onto dock for drop off, has visitor parking lot that wraps around and back out to main road

DESCRIPTION OF DOCK INFRASTRUCTURE

large dock with a lot of hurricane damage, we were told about how the docks had been hit a lot over time by hurricanes and rain. Lots of holes in the ground and exposed wires but the main dock onto the ferry looked good mainly and was sturdy

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Ch	Marine Maintenance Building	025-013-009	CB 1, 3-6	N/A	hurricane/water damage
2	Ch	Generator Building	025-013-010	CB 2,	N/A	very old and rusty
3	Ch	Visitors Center	025-013-015	CB 33, 34	N/A	very nice and well kept
4	Ch	Uniform Storage Building	025-013-013	CB 35	N/A	was repurposed so we did not see it but uniforms were moved inside
5	Ch	Cherry Branch - Dock Infrastructure	Che-Dock	CB 7-10, 12, 14-20, 22-28	N/A	hurricane/water damage as well as holes

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1						
2						
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

One of the staff members named either Mike or Mark walked us around and told us about the property and its damage. He said that there had been a lot of storm-related damage and erosion over time. He also said that during extreme storms and flooding, the ferry station becomes flooded and causes mechanical issues/damages that need to be repaired every time this occurs

ASSET AREA

Currituck

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
07/14/2023	Sunny (82F)	Sagar Rijhwani, Abhinay Bawale

DESCRIPTION OF ROADWAY ACCESS

There is one entrance & one exit to the ferry site attached to the main road and ferry operations building. There is carpool lane to go to the ferry. Clear road that has no outlet post ferry site.

DESCRIPTION OF DOCK INFRASTRUCTURE

Lifted one way road leading to dock - protected area. Area around the dock is protected by the fence. A series of docks at which boats are stationed.

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Cu	Currituck Ferry Operations Building	027-010-010	Cu1 - Cu9	N/A	No visual damage to the structure.
2	Cu	Storage Building	027-010-009	Cu10 - Cu16	N/A	Minor damage to the storage building due to the old wooden structure (small cracks at door)
3	Cu	Currituck - Dock Infrastructure	Cur-Dock	Cu17 - Cu33	N/A	No visual damage to the structure, but improper fencing found near the dock.
4						
5						

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1	Cu	02/05/00	10/14/99	Cu34 - Cu36	N/A	Veeder Root Building
2						
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

Unlocked electric duct (Cu37, Cu38, Cu39) , Picnic Areas (Cu40, Cu41), Gazebo

ASSET AREA

Fort Fisher

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
07/12/2023	Sunny	Lauren Southworth, Ray Olinger, Kyle Hardy

DESCRIPTION OF ROADWAY ACCESS

Puddles on main roadway. Inside the fence, roads are well kept.

DESCRIPTION OF DOCK INFRASTRUCTURE

No visual water damage. Sun damage on signs. Dead grass mixed with sand near entrance to dock. Surrounded by rusty fence.

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Fo	Ferry Building	065-021-009	FF15-22	N/A	
2	Fo	Fort Fisher - Dock Infrastructure	For-Dock	FF1-14, FF25	N/A	
3						
4						
5						

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1	picnic bench					
2	security					
3	visitor parking lot					no lines, no potholes
4	electric shell					rust around metal
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

No visible water damage anywhere, lack of rising tides

ASSET AREA

Hatteras

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
27-Jun	Approx. 85F, cloud cover varied from fair to mostly cloudy	Kyra Stash, Lauren Southworth, Brendan Kearns

DESCRIPTION OF ROADWAY ACCESS

Substantial water puddling on roadway during approach to visitor center due to recent rainstorm. At worst extent, puddle extended across about half of the roadway (i.e. close to or over the center yellow line).

DESCRIPTION OF DOCK INFRASTRUCTURE

Generally good - one sinkhole (see Photo Ha11). Minor concrete cracks in seawall. Concrete bulkhead in generally good condition; intermittent minor cracks in concrete. We observed one sinkhole behind the bulkhead.

LOG: ASSET INVENTORY

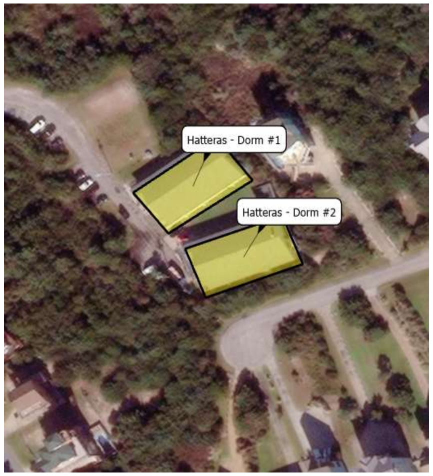
	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Ha	Hatteras Visitor Center & Office	028-016-008	Ha1, Ha2	0"	Most of the building was elevated, with measurements ranging from 1'11" - 5'4".
2	Ha	Hatteras Maintenance Facility	028-016-020	Ha3, Ha4	N/A	
3	Ha	Hatteras Dormitory #1	028-016-021	Ha5, Ha6	28"	
4	Ha	Hatteras Dormitory #2	028-016-022	Ha7, Ha8	70"	
5	Ha	Hatteras - Dock Infrastructure	Hat-Dock	Ha9 - Ha12	N/A	

LOG: ADDITIONAL ASSETS / STORAGE TANKS

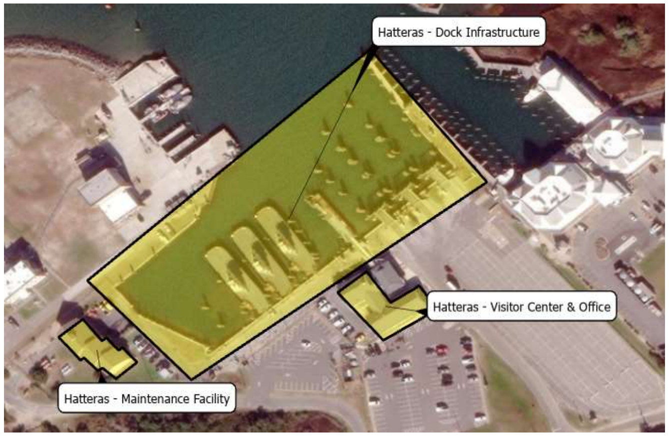
	Description	Lat	Long	Photo(s)	Measurement	Comments
1						
2						
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

Detail: Dorm Area



Detail: Terminal Area



ASSET AREA

Knotts Island

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
07/13/23	Sunny (88F)	Sagar Rijhwani, Abhinay Bawale

DESCRIPTION OF ROADWAY ACCESS

There is one entrance & one exit to ferry site. On one side of the road there is a car pool lane to go to ferry entrance. The road splits into two, one road leads to the ferry entrance and other road leads to the road nearby.

DESCRIPTION OF DOCK INFRASTRUCTURE

Lifted one way road leading to dock - protected area. Fenced area around the deck, Also found one solar panel near the entrance near the entrance. Groups of wooden poles in water where boat goes

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Kn	Knotts Island Restroom Building	027-010-009	Kn1 - Kn4	N/A	No visual damage, strong structure
2	Kn	Knotts Island - Dock Infrastructure	Kno-Dock	Kn5 - Kn13	N/A	Strong Structure, No cracks found in the foundation
3						
4						
5						

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1						
2						
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

Two picnic spots (Kn14, Kn15, Kn16, Kn17, Kn18), eletrical duct unit (Kn19, Kn20)

ASSET AREA

Manns Harbor

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
7/27/2023	Fair	D. Chase Nicholas

DESCRIPTION OF ROADWAY ACCESS

Roadway access clear with no signs of ponding. Roadway in good condition. Shallow drainage ditches on both sides of road held water; roaway is located in marshland and sits low.

DESCRIPTION OF DOCK INFRASTRUCTURE

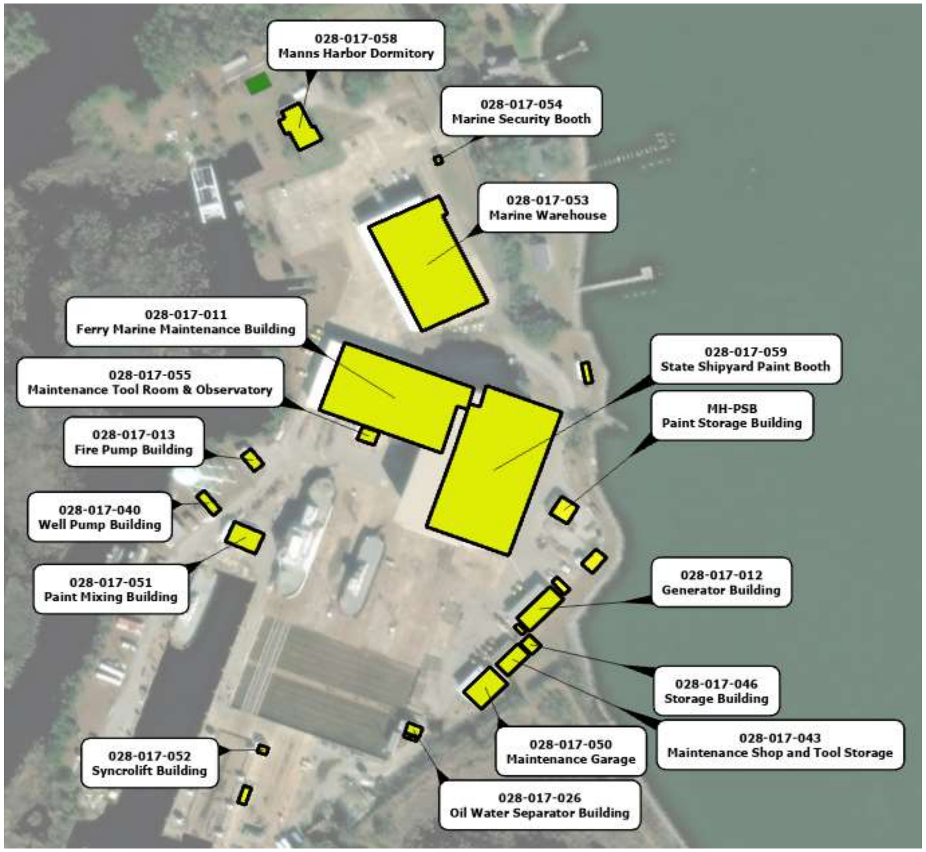
Major shipyard infrastructure appears in good repair and working condition. No evidence of infrastructure failure within the shipyard itself. Dock infrastruture behind dormitory (not used for shipyard purposes) in poor repair with some evidence of failure (see photos Ma20-21).

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Ma	Manns Harbor - Dormitory	028-017-058	Ma1-3	N/A	
2	Ma	Manns Harbor - Marine Security Booth	028-017-054	Ma4	N/A	
3	Ma	Manns Harbor - Marine Warehouse	028-017-053	Ma5-6	N/A	
4	Ma	Manns Harbor - State Shipyard Paint Booth	028-017-059	Ma7-8	N/A	
5	Ma	Manns Harbor - Paint Storage Building	MH-PSB	Ma9	N/A	
6	Ma	Manns Harbor - Generator Building	028-017-012	Ma10	N/A	
7	Ma	Manns Harbor - Storage Building	028-017-046	Ma11 (Left)	N/A	
8	Ma	Manns Harbor - Maintenance Shop & Tool Storage	028-017-043	Ma11 (Right	N/A	
9	Ma	Manns Harbor - Maintenance Garage	028-017-050	Ma12	N/A	
10	Ma	Manns Harbor - Oil Water Separator	028-017-026	Ma13	N/A	
11	Ma	Manns Harbor - Syncrolift Building	028-017-052	Ma14	N/A	
12	Ma	Manns Harbor - Paint Mixing Building	028-017-051	Ma15	N/A	
13	Ma	Manns Harbor - Well Pump Storage Building?	028-017-040	Ma16	N/A	
14	Ma	Manns Harbor - Fire Pump Building	028-017-013	Ma17	N/A	
15	Ma	Manns Harbor - Maintenance Tool Room & Observatory	028-017-055	Ma18	N/A	
16	Ma	Manns Harbor - Ferry Marine Maintenance Building	028-017-011	Ma18-19	N/A	

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1	Propane	35.872°N	75.753°W	Ma-AST1	1'	Tank above 1'; but many components below
2	Oxygen	35.871°N	75.753°W	Ma-AST2	2'	Platformed
3	Diesel	35.871°N	75.753°W	Ma-AST3	2'	Boxed by Concrete



4	Gen Bldg	35.871°N	75.754°W	Ma-AST4	0'	Lifeted but components lower
5	Used Oil	35.870°N	75.754°W	Ma-AST5	2'	Boxed by Concrete
6	Diesel	35.870°N	75.755°W	Ma-AST6	0'	Large Tank at grade

MISCELLANEOUS / ADDITIONAL PHOTOS

Additional photos show eastern revetment (Ma22), syncrolift system (Ma23), dock infrastructure (Ma24-26) and access roadway (Ma27).

ASSET AREA

Minnesott Beach

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
07/18/2023	Sunny (91F)	Sagar Rijhwani, Abhinay Bawale

DESCRIPTION OF ROADWAY ACCESS

One entrance and one exit to the ferry site. Six carpool lanes to go to ferry and one exit lane. Clear road that has no outlet past ferry site.

DESCRIPTION OF DOCK INFRASTRUCTURE

Lifted one way road leading to two protected dock areas. Area is protected by proper fencing. A series of docks at which boats are stationed. One parking lot next to the dock infrastructure.

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Mi	Ferry Building	069-012-005	Mi1 - Mi8	N/A	No visual damage to structure.
2	Mi	Minnesott Beach - Dock Infrastructure	Min-Dock	Mi9 - Mi19	N/A	No major damage to structure. (no cracks in foundation)
3						
4						
5						

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1						
2						
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

Picnic areas and a cabin (Mi20)

ASSET AREA

Ocracoke Silver Lake

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
7/17/2023	HIgh: 81 Low: 71, partly cloudy	Lauren Southworth and Kyra Stash

DESCRIPTION OF ROADWAY ACCESS

Queuening lanes get flooded, ranging from 5 inches out into the first lane to 48 inches in the 4th lane lining up to get on the ferry.

DESCRIPTION OF DOCK INFRASTRUCTURE

major rusting around seawall. it is gated all around the dock. wooden dock beside the main ferry dock is destroyed.

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	OSL	Ferry Dormitory Building	048-012-005	OSL21-32	2' 10"	
2	OSL	Visitors Center and Ferry Office	048-012-006	OSL33-41	3' 4"	
3	OSL	Amphidromia Equipment Building	048-012-007	OSL1-5	1"	
4	OSL	cracoke Silver Lake - Dock Infrastructu	OSL-Dock	OSL6-20	N/A	
5						

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1	OSL			OSL45-49	4"	Ticket Booth (across from dormitory building with a red roof)
2	OSL			OSL42-44		Flooding area
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

ASSET AREA

Ocracoke South Dock

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
7/17/2023	High: 81 Low: 71, Partly Cloudy	Lauren Southworth and Kyra Stash

DESCRIPTION OF ROADWAY ACCESS

Coming into the port from the water there is a walkway/dock, bad cracking, and pieces missing along the walls. Entering the ferry from roadway, it is a single road way to and from.

DESCRIPTION OF DOCK INFRASTRUCTURE

Wooden guides are up to par, the dock is made of iron so rust is starting to show, showing where the water hits daily and where water has touched it in the past. wires hanging down between dock and water.

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	OSD	Visitor Restroom Building	028-014-005	OSD10-13	1'	
2	OSD	Ocracoke SD - Dock Infrastructure	OSD-Dock	OSD1-9	N/A	
3	OSD	Queueing Area	OSD-Queue	OSD14-27	N/A	
4						
5						

LOG: ADDITIONAL ASSETS / STORAGE TANKS

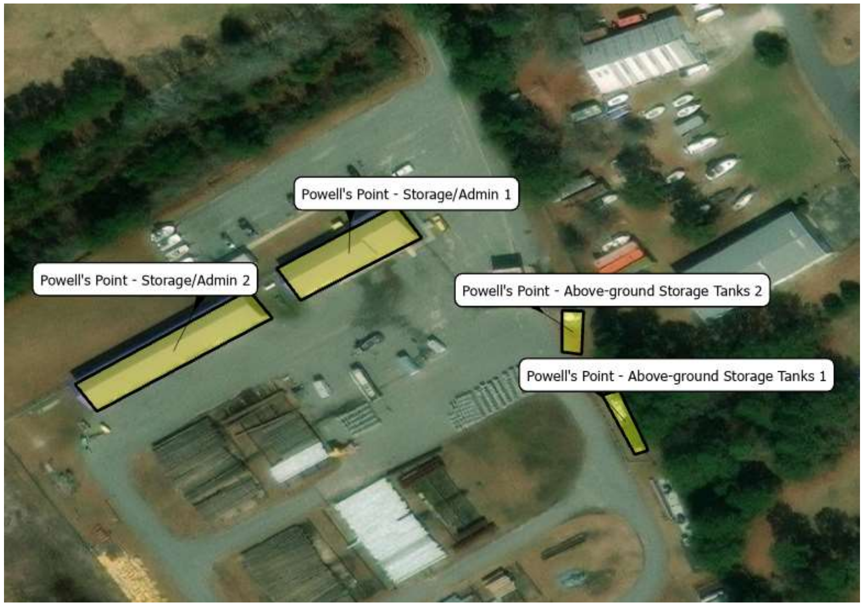
	Description	Lat	Long	Photo(s)	Measurement	Comments
1	Fuel Building/Area			OSD28-34	3' 8.5"	Stairs recently replaced
2	Operations Builiding			OSD35-40	6.5' (first floor) 5' 8' (second floor)	Building across from the 3rd dock is for employee use, on the front side (parallel to queueing area) this is elevated 6.5' off ground level keeping vending machines from getting wet. The second floor is on a platform that attaches to the first floor, but main door is on
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

ASSET AREA

Powell's Point

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
7/14/2023	Overcast, slight rain	Savannah Wright, Kyle Hardy



DESCRIPTION OF ROADWAY ACCESS

Cracked roadway with vegetation in the cracks. No potholes, lots of cracks in parking lots.

DESCRIPTION OF DOCK INFRASTRUCTURE

No access/unable to see dock

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Po	Storage/Admin	027-018-001	PP 1 - 7, 15, 18	N/A	Could not go inside or see much but could see the outside of the building. Photos may be of either storage/admin building; unable to tell which was which.
2	Po	Storage/Admin	027-018-002	N/A	N/A	
3	Po	Above-ground Storage Tank Group 1	PP-AST1	PP 11 - 14, 17	8'' (estimate)	The site looked somewhat different than the image and we could not measure but I believe these were the tanks maybe in a different place
4	Po	Above-ground Storage Tank Group 2	PP-AST2	PP 9, 10	5' (estimate)	We could not see or measure these tanks but maybe image 9 and 10 are them
5						

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1	Gas station					old, rusty
2	Generator					no damage
3	Tanks					between storage buildings, 3 at end
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

Many photos of surrounding areas and damage we noticed. We were unable to get into the area behind the fence so we took photos of what we could.

ASSET AREA

Southport

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
7/19/23	Sunny, temp 89 degrees	Lauren Southworth

DESCRIPTION OF ROADWAY ACCESS

Security gate to the entrance of the ferry, single lane queueing lined with sand on both sides as well as bike lanes. Parking lot to the side of queueing lanes, parking lots has cracks. No cracking or missing pieces on assets and sand was just replaced around the water/dock.

DESCRIPTION OF DOCK INFRASTRUCTURE

Poles have no cracks, rust forming to top of dock, gate to entrance, bike lanes on each side

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	So	Visitor Center	010-013-012	SP33 - 39	N/A	
2	So	Generator and Storage Building	010-013-013	SP23 - 24	N/A	
3	So	Dorm Building	Sou-Dorms	SP16 - 22	N/A	
4	So	Storage Building	010-013-005	SP25 - 32	N/A	
5	So	Southport - Dock Infrastructure	Sou-Dock	SP4 - 15	N/A	

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1						
2						
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

SP1-SP3 (miscellaneous photos)

ASSET AREA

Swan Quarter

OBSERVATION DATE(S)	WEATHER CONDITIONS	DATA COLLECTOR(S)
7/20/2023	Sunny 94 F	Kyle Hardy, Sagar Rijhwani

DESCRIPTION OF ROADWAY ACCESS

One entrance and one exit to ferry site, carpool line to go to Ferry entrance, clear road that has no outlet past ferry site

DESCRIPTION OF DOCK INFRASTRUCTURE

lifted one-way road leading to 2 docks , protected area, fenced in area around doc, groups of wooden poles and water, where boat goes

LOG: ASSET INVENTORY

	Asset Area	Asset Name	Asset No.	Photo(s)	Measurement	Comments
1	Sw	Ferry Operations Building	048-039-002	Sw1 - Sw7, Sw20 - Sw24	N/A	No visual damage to the structure.
2	Sw	Swan Quarter - Dock Infrastructure	Swa-Dock	Sw8 - Sw19	N/A	Strong Structure, No cracks found in the foundation
3						
4						
5						

LOG: ADDITIONAL ASSETS / STORAGE TANKS

	Description	Lat	Long	Photo(s)	Measurement	Comments
1						
2						
3						
4						
5						

MISCELLANEOUS / ADDITIONAL PHOTOS

2 picnic areas

Appendix B: Literature and State of Practice Review

Literature Review & Best Practices

RP 2023-14 Natural Hazards Vulnerability Assessment of the NCDOT Ferry Division Assets: Draft Interim Report 1

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Chase Nicholas
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February 2023

NC STATE UNIVERSITY
ITRE
Institute for Transportation Research and Education

Executive Summary

This report summarizes the literature and best practices review undertaken as part of RP 2023-14, Natural Hazards Vulnerability Assessment of the NCDOT Ferry Division Assets. The key findings of this review are:

- Because of the continued importance and emphasis on equity considerations in transportation systems planning, these considerations will be incorporated into the vulnerability assessment. Existing national-level resources as well as North Carolina-specific considerations will be used to evaluate social vulnerability in the areas served by the ferry system.
- A combined scenario and indexing approach is proposed to evaluate vulnerability of the NCDOT Ferry System at present and at the 2040 and 2060 planning horizon timeframes. This approach is consistent with the best practices found in the literature, and enables the combination of varying qualitative and quantitative factors with different units.
- A scoping level, scenario-based pathways approach is proposed to address potential systems level adaptation strategies for the NCDOT Ferry System, considering the 2040, and 2060 planning horizons.
- Existing mapping resources and datasets, particularly those tied to federal funding initiatives, will be incorporated into the research project to the extent practicable.

Table of Contents

1. Introduction and Purpose of the Report

This interim report is in fulfillment of Task 2 of the research project RP 2023-14, Natural Hazards Vulnerability Assessment of the NCDOT Ferry Division Assets. This task comprises a literature and best practices review for vulnerability assessment and adaptation planning, as recommended in the Federal Highway Administration's Vulnerability Assessment and Adaptation Framework (2020). The purpose of this report is to summarize previous work and inform the development of the final assessment objectives and scope defined in Task 3 of the research project.

This report considers not only the published peer-reviewed literature but additionally a number of reports developed in association with professional organizations, government agencies, and non-governmental organizations, because much of the work being done on vulnerability assessment and planning is being documented in those formats as well. A summary of the findings and recommendations for the continuation of the research are provided.

2. Review of Literature

This section describes the importance of the North Carolina Ferry System to the state's transportation network, and includes review of literature in four primary areas: a) operational and economic aspects of the NC ferry systems, b) equity considerations in recovery and resilience planning, c) assessment of vulnerability to natural hazards, and d) adaptation planning and pathways for ferry infrastructure.

2.1. The NCDOT Ferry System: An essential piece of North Carolina's transportation framework

The ferry system operated by the North Carolina Department of Transportation (NCDOT) consists of 21 ferries and everyday service on seven regular routes across the Currituck and Pamlico sounds as well as the Cape Fear, Neuse, and Pamlico Rivers (Figure 1). A seasonal passenger ferry provides service between Hatteras and Ocracoke Islands from May through September. The NCDOT ferry systems is the second-largest state-maintained ferry system in the United States, after the state of Washington. The system plays a crucial role in the state's transportation network, both during regular operations as well as coastal emergencies. During typical operations, the ferry system provides residents with transportation to work, emergency and routine medical services, and shopping for goods unavailable in local areas. Transportation of building materials, fuel and other essential supplies, school and activity buses, and items for military installation maintenance is undertaken on a regular basis. Storm response and recovery services include evacuating residents and visitors from coastal areas and providing transportation post-storm when portions of the roadway network are damaged. The ferry system infrastructure includes 12 terminals, a state-owned shipyard, four field maintenance shops, 21 ferries and a support fleet that consists of four tugs, three barges, one crane barge and one dredge.

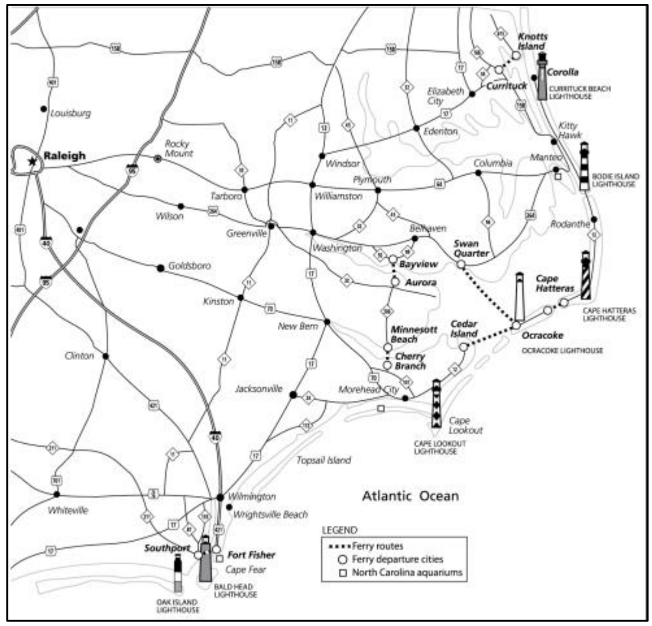

Figure 1: Ferry routes in eastern North Carolina. Figure courtesy NCDOT.

2.2. Economic Impacts

A 2020 study (Bert et al. 2020) documented the economic contribution of the NCDOT ferry system. North Carolina ferries transport over 800,000 vehicles, or approximately two million passengers a year. To model the economic contribution of the North Carolina Ferry System, an economic input-output model was developed and used expenditure data collected from 3,770 ferry ridership surveys. Annualized direct expenditures were then input into IMPLAN® to estimate input-output relationships for the local economies and estimate the indirect and induced effects of each ferry route. Overall, this analysis found that the vehicle ferries of North Carolina Ferry System supports a total of 5,860 jobs, $217.3 million in labor income, and $735.2 million in total economic output. The passenger ferry, the Ocracoke Express, had an additional impact of 55 jobs, $1.6 million in labor income, and $4.2 million in total economic output. The detailed economic contributions by route are presented in Table 1.

Table 1: Economic Contribution of the Ferry System by Route

Ferry Routes	Jobs	Labor Income	Output	State & Local Tax Revenue
Aurora - Bayview	120	$5,000,000	$17,900,000	$400,000
Cedar Island - Ocracoke	380	$13,800,000	$44,100,000	$2,400,000
Cherry Branch - Minnesott Beach	610	$24,000,000	$84,800,000	$2,600,000
Currituck - Knotts Island	60	$2,700,000	$9,100,000	$300,000
Hatteras - Ocracoke	3,360	$123,100,000	$414,000,000	$19,500,000
Hatteras - Ocracoke (Ocracoke Express Passenger Ferry)	55	$1,600,000	$4,200,000	$24,000
Southport - Fort Fisher	1,075	$39,600,000	$135,700,000	$5,700,000
Swan Quarter - Ocracoke	255	$9,100,000	$29,600,000	$1,600,000
All Ferry Routes	5,915	$218,900,000	$739,400,000	$32,524,000

2.3. Equity in Ferry Planning and Recovery

Community engagement findings from the research project *NCDOT RP 2021-19: Passenger Ferry Feasibility Study - Other Routes*, reinforced the importance of considering the wide range of socioeconomic situations experienced by individuals living in and around North Carolina coastal areas. Notably, while property owners in desirable environments may have higher income levels, the economies of coastal communities also often depend on seasonal and other types of workers who typically earn lower incomes. These workers are also more likely to commute from an inland coastal area with lower housing costs to work in coastal areas with higher property costs, and therefore may rely on ferry services for transportation.

Additionally, many minority communities in and around coastal areas have been pushed to marginalized land that is more prone to extreme weather events (EPA, 2021; NC Climate Risk Assessment and Resilience Plan, 2020). One of several examples in North Carolina is the Princeville community, located on a floodplain in Edgecombe County and founded by freed slaves, which has repeatedly been devastated by inclement weather events. Recovering from severe weather can be more difficult for minority and low-income communities. As a result, many people are forced to relocate away from coastal areas following events due to the cost and/or time to recover compared to their socioeconomic resources (Thomas et al., 2019; Anguelovski et al., 2016).

At the core of these issues is equity, which is increasingly being considered as part of transportation and planning decisions across the country. Equity is related to the just distribution and management of resources in communities (Lewis et al., 2021). Considering equity when deciding how and where to invest in transportation projects or improvements is essential because these investments may impact different types of communities in different ways. Transportation investments often either provide benefits or add burdens, with new project burdens often further compounding existing challenges already experienced by disadvantaged communities (Litman, 2021).

> Considering equity when deciding how and where to invest in transportation projects or improvements is essential because these investments may impact different types of communities in different ways.

As a result, several regions across the U.S. are improving how they evaluate ferry investments and are incorporating considerations for how decisions will impact disadvantaged communities. For example, the San Francisco Bay Area Water Emergency Transportation Authority has developed a set of equity and connectivity principles to guide their practices, with a recognition that many lower-income essential workers relied on the ferry system during the COVID-19 pandemic (San Francisco Bay Ferry, 2021). New Jersey's Hudson County Ferry Service Expansion Study (2021) also included outreach efforts that explored equity issues and related key takeaways that need to be incorporated into future decision-making (New Jersey Transportation Planning Authority). Similarly, the Puget Sound Passenger-Only Ferry Study (2021) highlighted the need to consider equity in service and resilience planning (Puget Sound Regional Council).

Because of the continued importance and emphasis on equity considerations in transportation systems planning, it is proposed that a preliminary consideration of these issues be included in the vulnerability assessment. These considerations were not included in the original proposal, however, existing state and national-level resources described in Section 2.6 are available to evaluate social vulnerability in the areas served by the ferry system. Additional ongoing NCDOT work may also be able to support this effort by providing information about North Carolina-specific considerations.

2.4. Vulnerability to Natural Hazards

Literature evaluating coastal areas and infrastructure to natural hazards was reviewed to determine best practices. One of the most common ways to evaluate vulnerability to natural hazards is with a variation of the coastal vulnerability index (CVI) first proposed by Gornitz (1990) to evaluate vulnerability to sea level rise. The index methodology allows comparison of both qualitative and quantitative information at different scales and units using a ranking scheme. Each variable is ranked from 1 to 5, with 5 representing the highest risk and 1 being the lowest (Gornitz, 1990); the CVI is then computed using a generalized formula (Eq. 1):

$$CVI = \left[\frac{1}{n}(a_1 * a_2 * a_3 * \dots a_n)\right]^{1/2}, \; where \;\; a_i \; = risk\ class\ for\ each\ variable \qquad \text{Eq. 1}$$

Studies that have employed a variation of the CVI include an early national assessment of coastal vulnerability for the U.S. (Thieler and Hammar-Klose, 1999) as well as multiple international applications reviewed in Anfuso et al. (2021) and Bukvic et al. (2020).

Other methods to assess infrastructure vulnerability to natural hazards reviewed in the literature included variations of index approaches (Balica et al., 2012; Chang et al., 2018), scenario analyses (Islam et al., 2021, WSDOT, 2011), fragility analysis (Darestani et al., 2021; Tomiczek et al., 2022), and network analysis (Aldabet et al., 2022; Demirel et al., 2015; Testa et al., 2015; Mattson and Jenelius, 2015). Combinations of scenario and index approaches have been employed; Drejza et al. (2019) proposed a Coastal Road Erosion and Flooding Vulnerability Index (CREFVI) for the short (2020), medium (2060) and long term (2100).

Studies specifically focusing on ferry systems are sparse. WSDOT (2011) ranked ferry facilities using a qualitative scale of low, moderate, and high vulnerability to varying sea level rise scenarios. Woods Hole Group (2021) performed a vulnerability assessment based on flooding scenario analysis and critical infrastructure elevation for a local community including a ferry dock. Aziz et al. (2018) examined resilience of transportation systems in Kochi City, India, and suggested that implementation of ferry services could lead to net emissions savings with environmental benefits, improving resilience. Islam et al. (2021) examined vulnerability of marine transport systems in Vancouver Island, Canada to a submarine landslide disaster scenario. Other ferry-focused vulnerability studies detail other specific disaster scenarios such as tsunami (Washington state, Stearns et al., 2022), or wildfire (Bowen Island, Washington, Krutein et al., 2022).

A summary table showing vulnerability factors considered in the reviewed literature is presented in Appendix A. The most common consideration found in the literature review was flooding, which was considered both separately as flooding and inundation or linked to storm surge and heavy precipitation. Linked considerations like sea level rise and erosion were also frequently included in vulnerability assessments. Other factors include geology/sediment transportation considerations, wave conditions and overtopping, winds, drought, and wildfire risk. Marine transport focused studies, including Islam et al. (2021), also considered factors such as vessel draft and community dependence on the marine transportation system. Population characteristics provide insight into the social aspects of vulnerability.

For the case of the NCDOT Ferry System, general vulnerability to multiple coastal hazards using a combined scenario and indexing approach is proposed to evaluate vulnerability at present and at the 2040 and 2060 planning horizon timeframes, as proposed. This approach is in line with the literature best practices and enables the combination of varying qualitative and quantitative factors with different units.

2.5. Adaptation

A review of the literature shows that sustainability and resiliency efforts for ferry transportation infrastructure situate into two categories: mitigation and adaptation. Mitigation efforts are the most common sustainability policies and plans for ferry systems across the country. These mitigation efforts focus on reducing environmental impacts and greenhouse gas (GHG) emissions, including more fuel efficient diesel engines; conversion to liquefied natural gas (LGN) and biodiesel engines, and adopting electric vessels as part of the fleet (BC Ferries, 2022; WSDOT, 2019; WETA, 2016). Washington State Ferries and San Francisco Bay Ferry both promote multimodal connectivity to terminals as a means of reducing environmental impacts associated with passengers connecting to the ferry.

While the literature and policy documents reveal sustainability plans to mitigate environmental impacts, only a few examples were found for systems developing resiliency plans utilizing adaptation planning approaches to address natural hazards. Much of the adaptation planning involves preparing emergency response plans to address large natural disasters, focusing on ferries supporting initial emergency response efforts and long-term community recovery efforts (WSDOT, 2019, WETA, 2016; MWA, 2013).

Adaptation planning for ferry terminal infrastructure was less common in the literature and practice review. The most developed ferry infrastructure plan found was the New York City Office of Climate Resiliency (2021) waterfront master plan. The plan includes incorporating ferry infrastructure and operations into a larger waterfront plan for the financial district and the seaport. This adaptation plan uses traditional 'gray' flood protection infrastructure and 'green' greenspace buffer infrastructure to prepare the shoreline from storm events. This approach assumes ferry vessels are moved to safer locations to ride out a storm event and terminals are designed for a quick recovery after an inundating storm event. The Washington State DOT (2019) ferry system long range plan recommends that ferry terminal maintenance prioritize emergency preparedness improvements to ensure terminals are prepared for seismic activity and sea level rise. The plan also recommends prioritizing 'lifeline' ferry routes that directly support the highway system and provide critical access in emergencies.

Transportation system adaptation plans are becoming an increasingly important element in maintaining operations during storm events and providing critical emergency support after storm events (Bucchin and Tuley, 2022; DeAngelis et al., 2019; Weilant et al., 2019; FHWA, 2015). Situated in increasingly vulnerable coastal areas, ferry systems could benefit from establishing comprehensive, long range adaptation plans. A common approach to adaptation planning is an adaptation pathways approach, ensuring that policy, planning and investment processes incorporate climate adaptable elements into long range decision making. There are several approaches to establish and measure adaptation pathway planning frameworks (Werners et al., 2021), including scenario based adaptation pathways planning (Ariza-Álvarez et al., 2022; Finn and Miller, 2022).

Adaptation pathways are laid out as a series of planning, policy, investment and infrastructure development options along a timeline that present options to address future climate and natural hazards impacts. These approaches are established by assessing current conditions and overlaying anticipated changes to the environment along a long range timeline. The pathways then represent potential options mapped in relation to the anticipated time at which infrastructure fails due to changing environmental conditions. Adaptation pathways include recommended implementation schedules to ensure infrastructure meets or exceeds the needs of an anticipated future climate and natural hazards impacts. Pathways must either be flexible, allowing pathway approaches to be changed as environmental conditions change, or robust, where the approach is substantial enough to perform beyond anticipated climate impacts. Adaptation pathways are currently used to address inland waterway infrastructure in Europe (PIANC, 2020) and provide a viable approach to ensure that ferry system infrastructure is prepared for future natural disaster and climate impacts. A scoping level, scenario-based pathways approach is proposed to identify potential systems level adaptation strategies for the NCDOT Ferry System in relation to the 2040 and 2060 planning horizons.

2.6. Existing Map-Based Resources

There are a number of existing online mapping resources developed by state and federal agencies addressing key aspects of social and natural hazards vulnerability. These tools can provide quantitative and qualitative information to contribute to the vulnerability assessment and adaptation pathways development. The North Carolina Equity & Transportation Disadvantge Screening Tool serves as the current state of the practice in North Carolina and consists of two mapping tools: the Environmental Justice (EJ) tool and the Transportation Disadvantage Index (TDI) tool. The EJ tool displays demographic data but is not focused specifically on transportation. The TDI tool considers multiple potential equity impacts to transportation including race, income, personal vehicle access, mobility impairment, and age. This tool displays a cumulative score ranking from 6 to 18, with higher scores indicating a greater level of transportation disadvantage.

The North Carolina-specific tool as well as other federal level tools are summarized in Table 2. Some of these resources can assist in identifying available federal funding programs to support climate resilience projects. We anticipate that these resources will be helpful in performing the proposed research. Two of the mapping resources, the Climate Mapping for Resilience and Adaptation (CMRA) portal and the Climate and Economic Justice Screening Tool, are tied to federal funding initiatives. The potential to seek federal funding for future adaptation projects makes these resources significant.

Table 2: State and Federal Mapping Resources for Climate Resilience and Social Vulnerability

Resource Name and URL	Description
NC Equity & Transportation Disadvantage Screening Tool https://storymaps.arcgis.com/stories/7e3bbd00fe014a77b5f1620334209712	NCDOT has developed web-based tools that display data to illustrate the disproportionate impact transportation barriers have on communities of color. The Environmental Justice (EJ) tool focuses on low-income and racial/ethnic minorities. The Transportation Disadvantage Index (TDI) tool is a multi-factor tool allowing users to see where transportation disadvantaged communities exist.
Climate Mapping for Resilience and Adaptation (CMRA) portal https://resilience.climate.gov/	NOAA and DOI jointly launched a new website to help communities across the nation understand the real-time climate-related hazards in their area, analyze projected long-term exposure to those hazards, and identify federal funds to support climate resilience projects for their communities.
Resilience Analysis and Planning Tool (RAPT) https://www.fema.gov/emergency-managers/practitioners/resilience-analysis-and-planning-tool	FEMA recently updated RAPT, an award-winning web map that allows users to visualize resilience in their community. The update includes new resilience indicators, the latest data from the U.S Census Bureau, and improved analysis tools.
Climate and Economic Justice Screening Tool https://screeningtool.geoplatform.gov/	The Climate and Economic Justice Screening Tool has been created by the White House Council on Environmental Quality (CEQ). The tool uses multiple datasets to identify disadvantaged communities that will benefit from programs included in the Justice40 Initiative. The Justice40 Initiative seeks to deliver 40% of the overall benefits of investments in climate, clean energy, and related areas to disadvantaged communities.
Minority Health Social Vulnerability Index (SVI) https://www.minorityhealth.hhs.gov/minority-health-svi/	The Centers for Disease Control and Prevention (CDC), Agency for Toxic Substances and Disease Registry (ATSDR) and the Health & Human Services Office of Minority Health developed the Minority Health SVI to enhance existing resources to support the identification of racial and ethnic minority communities at the greatest risk for disproportionate impact and adverse outcomes due to public health emergencies.

2.7. Potential Funding Sources

A scoping level overview of potential external funding opportunities for ferry operations, vessel and infrastructure resiliency and mitigation can be examined and presented with final project recommendations. Specifically, the research team can highlight potential funding sources from U.S. DOT, including the U.S. Maritime Administration (MARAD) and Federal Transit Administration (FTA). At the request of the project steering committee, the research team took a cursory look a current funding opportunities and will further explore these opportunities as a high-level overview as the project progresses.

In 2022, FTA provided grant funding for ferry service that connected rural communities to economic opportunities and encourage the electrification of ferry fleets as part of the Bipartisan Infrastructure Law. Programs include Ferry Service for Rural Communities Program; Electric or Low-Emitting Ferry Pilot Program; and FTA's Passenger Ferry Grant Program. As a part of the grant program, NCDOT was awarded $1,345,241 in the rural communities category to modernize the Manns Harbor Shipyard paint facility.

MARAD oversees U.S. waterborne transportation system, including the Marine Highway system, and supports the safe and efficient movement of people and goods along the America's waterways. MARAD provides technical support and funding grants to improve infrastructure and operations, national security and environmental sustainability. One grant program was found in the literature and state of practice review that could provide NCDOT with a potential future funding opportunity - the Maritime Environmental and Technical Assistance (META) Program. This program focuses on promoting, "research, demonstration, and development of emerging technologies, practices, and processes that improve maritime industrial environmental sustainability" (U.S. Maritime Administration, 2023). A cost sharing grant, this funding source could help fund innovative resiliency and mitigation recommendations that come out of this research. However, further exploration of the program is required to better understand the program, funding cycle and eligibility.

3. Best Practices and Recommendations

This section summarizes the best practices that are used to guide the project moving forward and the rationale. The literature review supports the approach presented in the research proposal, with a few modifications. Because of the continued importance and emphasis on equity considerations in transportation systems planning, these considerations will be incorporated into the vulnerability assessment, although this was not included in the original proposal. Existing national-level resources as well as North Carolina-specific considerations guided by NCDOT input will be used to evaluate social vulnerability in the areas served by the ferry system. A combined scenario and indexing approach is proposed to evaluate the vulnerability of the NCDOT Ferry System at present and at the 2040 and 2060 planning horizon timeframes. This approach is consistent with the best practices found in the literature, and enables the combination of varying qualitative and quantitative factors with different units. A scoping-level, scenario-based pathways approach is proposed to address potential systems level adaptation strategies for the NCDOT Ferry System in concert with the 2040, and 2060 planning horizons. Existing mapping resources and datasets, particularly those tied to federal funding initiatives, will be incorporated into the research project to the extent practicable.

4. References

Aldabet, S., Goldstein, E. B., & Lazarus, E. D. (2022). Thresholds in road network functioning on U.S. Atlantic and Gulf barrier islands. *Earth's Future*, 10, e2021EF002581. https://doi.org/10.1029/2021EF002581

Anfuso, G., Postacchini, M., Di Luccio, D., & Benassai, G. (2021). Coastal Sensitivity/Vulnerability Characterization and Adaptation Strategies: A Review. *Journal of Marine Science and Engineering*, 9(1), 72. MDPI AG. http://dx.doi.org/10.3390/jmse9010072

Anguelovski, I., Shi, L., Chu, E., Gallagher, D., Goh, K., Lamb, Z., Reeve, K. & Teicher, H., (2016). Equity impacts of urban land use planning for climate adaptation: Critical perspectives from the global north and south. *Journal of Planning Education and Research*, 36(3), 333-348. https://doi.org/10.1177/0739456X16645166.

Ariza-Álvareza, A., Soria-Laraa, J.A., & Aguilera-Benaventec, F. (2022). Planning adaptive strategies for urban transport and land use using scenario-building. *Transportation Research Procedia*, 60, 274-281.

Aziz, Z.,Ray, I., & Paul, S. (2018). The role of waterways in promoting urban resilience: The case of Kochi City, Working Paper, No. 359, Indian Council for Research on International Economic Relations (ICRIER), New Delhi, 22 pp. Retrieved from https://icrier.org/pdf/Working_Paper_359.pdf

Balica, S.F., Wright, N.G., & Vander Meulen, F. (2012). A flood vulnerability index for coastal cities and its use in assessing climate change impacts. *Natural Hazards*, 64, 73-105.

BC Ferries, (2022). Clean Futures Plan 2022 – An Update on Progress. 10 pp. Retrieved from: https://www.bcferries.com/web_image/hf0/hce/8910527397918.pdf

Bert, S., Norboge, N.D., Davis, J.,Head, W., Babich, J.. & Findley, D. (2020). Economic Contribution of North Carolina's Ferry System. Report prepared for the North Carolina Department of Transportation, 47 pp. Retrieved from: https://connect.ncdot.gov/projects/research/RNAProjDocs/2018-11%20Final%20Report.pdf

Buccin, M., & Tuley, A. (2022). Planning for Climate Mitigation and Adaptation. American Planning Association, Planning Advisory Service Report 601, 163 pp.

Bukvic, A., Rohat, G., Apotsos, A., & de Sherbinin, A. (2020). A Systematic Review of Coastal Vulnerability Mapping. *Sustainability*, 12(7), 2822. MDPI AG. http://dx.doi.org/10.3390/su12072822

Chang, S.E., Yip, J.Z.K, Conger, T., Oulahen, G., & Marteleira, M. (2018). Community vulnerability to coastal hazards: Developing a typology for disaster risk reduction, *Applied Geography*, 91, 81-88. https://doi.org/10.1016/j.apgeog.2017.12.017

Darestani, Y.M.,Webb, B., Padgett, J., Pennison, G. & Fereshtehnejad, E. (2021). Fragility analysis of coastal roadways and performance assessment of coastal transportation systems subjected to storm hazards. *Journal of Performance of Constructed Facilities*. 35. https://doi.org/10.1061/(ASCE)CF.1943-5509.0001650

DeAngelis, J., Briel, H., & Lauer, M., (2019). Planning for Infrastructure Resilience. American Planning Association, Planning Advisory Service Report 596, 122 pp.

Demirel, H., Kompil, M., & Nemry, F. (2015). A framework to analyze the vulnerability of European road networks due to Sea-Level Rise (SLR) and sea storm surges, *Transportation Research Part A: Policy and Practice*, 81,62-76. https://doi.org/10.1016/j.tra.2015.05.002

Drejza, S., Bernatchez, P., Marie, G., & Friesinger, S. (2019). Quantifying road vulnerability to coastal hazards: Development of a synthetic index, *Ocean & Coastal Management*, 181,104894. https://doi.org/10.1016/j.ocecoaman.2019.104894

Environmental Protection Agency. (2021). Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. U.S. Environmental Protection Agency, EPA 430-R-21-003. Retrieved from: https://www.epa.gov/cira/social-vulnerability-report

Federal Highway Administration (FHWA), (2015). Climate Change Adaptation Guide for Transportation Systems Management, Operations, and Maintenance. Report No. FHWA-HOP-15-026, prepared by Leidos, 86 pp.

Federal Highway Administration (FHWA), (2020). Vulnerability Assessment and Adaptation Framework, Third Edition, FHWA-HEP-18-020, 86 pp.

Finn, D., & Miller, N. (2022). Scenario Planning Using Climate Data: New Tools Merging Science and Practice. Working paper WP22DF1, Lincoln Institute of Land Policy, 24 pp.

Gornitz, V.M. (1990). Vulnerability of the East Coast, USA to future sea level rise. *J. Coast. Res.* 1990, 9, 201–237.

Islam, S., Goerlandt, F., Uddin, M. J., Shi, Y., & Abdul Rahman, N. S. F. (2021). Exploring vulnerability and resilience of shipping for coastal communities during disruptions: findings from a case study of Vancouver Island in Canada. *International Journal of Logistics Management*, 32(4), 1434-1460. https://doi.org/10.1108/IJLM-12-2020-0466

Krutein, K.F., McGowan, J., & Goodchild, A. (2022). Evacuating isolated islands with marine resources: A Bowen Island case study. *International Journal of Disaster Risk Reduction*, 72, 102865. https://doi.org/10.1016/j.ijdrr.2022.102865

Lewis, E. O. C., MacKenzie, D., & Kaminsky, J. (2021). Exploring equity: How equity norms have been applied implicitly and explicitly in transportation research and practice. *Transportation research interdisciplinary perspectives*, 9, 100332.

Litman, T. (2021). Evaluating transportation equity: Guidance for incorporating distributional impacts in transportation planning." Victoria Transport Policy Institute. Retrieved from: https://www.vtpi.org/equity.pdf

Mattsson, L.-G., & Jenelius, E. (2015). Vulnerability and resilience of transport systems – A discussion of recent research, *Transportation Research Part A: Policy and Practice*, 81, 16-34. https://doi.org/10.1016/j.tra.2015.06.002

Metropolitan Waterfront Alliance (MWA), (2013). Maximizing Ferries in New York City's Emergency Management Planning, 21 pp.

Moffatt & Nichol, (2022). US-64 Bridge Replacement Alligator River, North Carolina, Probabilistic Sea Level Rise Study. Prepared for the North Carolina Department of Transportation 65 pp.

New Jersey Transportation Planning Authority. (2021). Hudson County Ferry Service Expansion Study. 34 pp. Retrieved from: https://www.hcnj.us/wp-content/uploads/2022/02/Technical-Memorandum-1.pdf

New York City Office of Climate Resiliency, (2021). Financial District and Seaport Climate Resilience Master Plan, 17 pp.

North Carolina Climate Risk Assessment and Resilience Plan. (2020). Impacts, Vulnerability, Risks, and Preliminary Actions: A Comprehensive Strategy for Reducing North Carolina's Vulnerability to Climate Change. Retrieved from: https://files.nc.gov/ncdeq/climate-change/resilience-plan/2020-Climate-Risk-Assessment-and-Resilience-Plan.pdf

North Carolina Department of Transportation, (2021). NCDOT Resilience Strategy Report. March 2021 Annual Update, 26 pp.

PIANC, (2020). Climate Change Adaptation Planning for Ports and Inland Waterways. Report No. 178, Environmental Commission, 193 pp.

Puget Sound Regional Council. (2021). Puget Sound Passenger-Only Ferry Study. 95 pp. Retrieved from: https://www.psrc.org/media/2282

San Francisco Bay Ferry. (2021, Feb. 4). WETA Adopts Core Principles to Guide Ferry System Recovery [Press release]. Retrieved from: https://sanfranciscobayferry.com/weta-pandemic-recovery-program-ferry-core-principles

Stearns, C., Thio, H.K., Butkovich, J., Helland, C., Shahbazian, A., & Porter, A. (2022). Tsunami design approaches for resilient ferry terminals, *Ports 2022 : Port Planning and Development*, ASCE. https://doi.org/10.1061/9780784484401.092

Testa, A. C., Furtado, M. N., & Alipour, A. (2015). Resilience of coastal transportation networks faced with extreme climatic events. *Transportation Research Record*, 2532(1), 29–36. https://doi.org/10.3141/2532-04

Thieler, E.R. & Hammar-Klose, E.S. (1999). National Assessment of Coastal Vulnerability to Sea-Level Rise; U.S. Geological Survey Open-File Report 99-593; U.S. Geological Survey: Woods Hole, MA, USA.

Thomas, K., Hardy, R. D., Lazrus, H., Mendez, M., Orlove, B., Rivera-Collazo, I., Roberts, J. T., Rockman, M., Warner, B. P., & Winthrop, R. (2019). Explaining differential vulnerability to climate change: A social science review. *Wiley interdisciplinary reviews: Climate change*, 10(2), e565. https://doi.org/10.1002/wcc.565

Tomiczek, T., Sciaudone, E. J., Velásquez-Montoya, L., Smyre, E., Wargula, A., Fawcett, K., & Torres, J. (2022). Investigation of Barrier Island Highway and Marsh Vulnerability to Bay-Side Flooding and Erosion. *Journal of Marine Science and Engineering*, 10(6), 734. MDPI AG. http://dx.doi.org/10.3390/jmse10060734

U.S. Maritime Administration (2023), META Program, website access: https://www.maritime.dot.gov/innovation/meta/maritime-environmental-and-technical-assistance-meta-program; As of February 2023.

Velasquez-Montoya, L., Sciaudone, E.J., Smyre, E., & Overton, M. (2021). Vulnerability indicators for coastal roadways based on barrier island morphology and shoreline change predictions, *Natural Hazards Review*, 22(2), 04021003. doi.org/10.1061/(ASCE)NH.1527-6996.0000441

Washington State Department of Transportation (WSDOT), (2011). Climate Impacts Vulnerability Assessment. Report prepared for the Federal Highway Administration, 70 pp.

Washington State Department of Transportation (WSDOT), (2016). WSDOT's Statewide Climate Vulnerability Assessment: Working Toward a More Resilient Washington. Presentation to Tribal State Transportation Conference, Sept. 19, 2019.

Washington State Department of Transportation (WSDOT), (2019). Washington State Ferries 2040 Long Range Plan, 140 pp.

Water Emergency Transportation Authority (WETA), (2016). San Francisco Bay Area Water Emergency Transportation Authority 2016 Strategic Plan, 34 pp.

Woods Hole Group, (2021).Edgartown Climate Change Vulnerability Assessment and Adaptation Plan. Prepared for the Town of Edgartown, Massachusetts.

Weilant, S., Strong, A., & Miller, B. (2019). Incorporating Resilience into Transportation Planning and Assessment. Report prepared for the Transportation Research Board by RAND, 97 pp.

Werners, S.E., Wise, R.M., Butler, J.R.A., Totin, E., & Vincent, K. (2021). Adaptation pathways: A review of approaches and a learning framework. *Environmental Science and Policy*, 116, 266-275.

Appendix A. Natural Hazards Vulnerability Considerations

Vulnerability Consideration	Refererence(s)
Alternate routes	Darestani et al. 2021 Drejza et al. 2019 Demirel et al. 2015
Drought	FHWA 2020 NCDOT Resilience Strategy Report 2021 NC Climate Risk Assessment and Resilience Plan 2020
Erosion	Demirel et al. 2015 Drejza et al. 2019 Gornitz 1990 NC Climate Risk Assessment and Resilience Plan 2020 Tomiczek et al. 2022 Velasquez-Montoya et al. 2021
Flooding/Inundation	Aldabet et al. 2022 Aziz et al. 2018 Darestani et al. 2021 Demirel et al. 2015 Drejza et al. 2019 Gornitz 1990 Moffatt & Nichol 2022 NC Climate Risk Assessment and Resilience Plan 2020 Tomiczek et al. 2022 WSDOT 2016 Woods Hole Group 2021
Overtopping	Darestani et al. 2021 Woods Hole Group 2021
Population density/size	Balica et al. 2012 Chang et al. 2018 Drejza et al. 2019 Gornitz 1990 NC Climate Risk Assessment and Resilience Plan 2020
Salt intrusion	Balica et al. 2012 Gornitz 1990 Demirel et al. 2015 NCDOT Resilience Strategy Report 2021
Sea level rise	Aziz et al. 2018 Demirel et al. 2015 FHWA 2020 NC Climate Risk Assessment and Resilience Plan 2020 Moffatt & Nichol 2022

Vulnerability Consideration	Refererence(s)
	Velasquez-Montoya et al. 2021 WSDOT 2011 Woods Hole Group 2021
Sediment transport/deposits	Balica et al. 2012 Gornitz 1990 NC Climate Risk Assessment and Resilience Plan 2020 Velasquez-Montoya et al. 2021
Storm surge, Heavy precipitation	Balica et al. 2012 Darestani et al. 2021 Demirel et al. 2015 FHWA 2020 Mattsson & Jenelius 2015 Moffatt & Nichol 2022 NC Climate Risk Assessment and Resilience Plan 2020 NCDOT Resilience Strategy Report 2021 Testa et al. 2015 Velasquez-Montoya et al. 2021 WSDOT 2011 WSDOT 2016 Woods Hole Group 2021
Temperature change	FHWA 2020 NCDOT Resilience Strategy Report 2021 NC Climate Risk Assessment and Resilience Plan 2020 WSDOT 2011 WSDOT 2016
Tidal range, Tides	Gornitz 1990 Moffatt & Nichol 2022 NC Climate Risk Assessment and Resilience Plan 2020Velasquez et al. 2021
Wave attack/height	Darestani et al. 2021 Gornitz 1990 Velasquez-Montoya et al. 2021 Woods Hole Group 2021
Wildfire risk	Krutein et al. 2022 WSDOT 2011
Wind direction/speed	Balica et al. 2012 Demirel et al. 2015 NCDOT Resilience Strategy Report 2021 Velasquez-Montoya et al. 2021 Woods Hole Group 2021

Appendix C: Route, Terminal and Asset Criticality Assessment

Asset Area	Asset No	Name (Insp. Rep.)	First Floor Elev. (from GIS)	First Floor Above Ground Level?	Route Criticality	Facility Criticality	Notes
Aurora	007-017-016	Restroom - South Dock	8.3	No	Medium	Low	
Bayview	007-017-008	Emergency Generator Building		No	Medium	High	
Bayview	007-017-015	Office and Restroom	10.4	No	Medium	High	
Bayview	007-017-010	Storage Building	12	No	Medium	Low	
Cedar Island	016-017-005	Pump House		No	High	High	
Cedar Island	016-017-011	Visitors Center & Office	9.4	Yes	High	High	
Cedar Island	016-017-019	Marine Maintenance Building	9.3	No	High	High	
Cedar Island	N/A	Above-ground Storage Tank		No	High	High	
Cherry Branch	025-013-009	Marine Maintenance Building	15.2	No	Medium	High	
Cherry Branch	025-013-010	Generator Building	19	No	Medium	High	
Cherry Branch	025-013-015	Visitors Center	21.3	No	Medium	High	
Cherry Branch	025-013-013	Uniform Storage Building		No	Medium	Low	
Currituck	027-010-010	Currituck Ferry Operations Building		No	Medium	High	
Currituck	027-010-009	NOT INCLUDED			Medium	Medium	Storage Building
Fort Fisher	065-021-009	Ferry Building	12.6	No	Medium	Low	Unstaffed restrooms
Hatteras	028-016-008	Hatteras Visitor Center & Office	7.7	Yes	High	High	
Hatteras	028-016-020	Hatteras Maintenance Facility	7.7	No	High	High	
Hatteras	028-016-021	Hatteras Dormitory #1	11	Yes	High	High	
Hatteras	028-016-022	Hatteras Dormitory #2	11	Yes	High	High	
Knotts Island	027-010-009	Knotts Island Restroom Building		No	Medium	Low	No staff or admin space; no generator
Manns Harbor	028-017-011	Ferry Marine Maintenance Building	8	No	High	High	
Manns Harbor	028-017-012	Generator Building		No	High	High	
Manns Harbor	028-017-013	Fire Pump Building		No	High	High	
Manns Harbor	028-017-026	Oil Water Separator		No	High	High	
Manns Harbor	028-017-040	Well Pump Storage Building?		No	High	High	
Manns Harbor	028-017-043	Maintenance Garage & Tool Storage Building		No	High	High	
Manns Harbor	028-017-046	Dyno Building		No	High	High	
Manns Harbor	028-017-050	Maintenance Garage		No	High	High	
Manns Harbor	028-017-051	Paint Building		No	High	High	

Asset Area	Asset No	Name (Insp. Rep.)	First Floor Elev. (from GIS)	First Floor Above Ground Level?	Route Criticality	Facility Criticality	Notes
Manns Harbor	028-017-052	Syncrolift Building		No	High	High	
Manns Harbor	028-017-053	Marine Warehouse	8.25	No	High	High	
Manns Harbor	028-017-054	Marine Security Booth		No	High	High	
Manns Harbor	028-017-055	Maintenance Tool Room & Observatory	8	No	High	High	
Manns Harbor	028-017-058	Ferry Headquarters		Yes	High	High	
Manns Harbor	028-017-059	State Shipyard Paint Booth	6	No	High	High	
Manns Harbor	NA	Above-ground Storage Tanks		No	High	High	
Minnesott Beach	069-012-005	Ferry Building	13.4	No	Medium	Low	Unstaffed restrooms
Ocracoke Silver Lake	048-012-005	Ferry Dormitory Building	7.8	Yes	High	High	
Ocracoke Silver Lake	048-012-006	Visitors Center and Ferry Office	5.8	Yes	High	High	
Ocracoke Silver Lake	048-012-007	Amphidromia Equipment Building	7.1	Yes	High	High	
Ocracoke South Dock	048-014-003	Ferry Office	6.5	Yes	High	High	
Ocracoke South Dock	048-014-005	Visitors Restroom Building	6.9	Yes	High	Medium	
Powell's Point	027-018-001	Storage/Admin		No	Medium	Medium	Small admin footprint, pilings and other large items stored
Powell's Point	027-018-002	Storage/Admin		No	Medium	Medium	Small admin footprint, pilings and other large items stored
Powell's Point	N/A	Above-ground Storage Tank		No			
Southport	010-013-012	Visitor Center	12	No	Medium	High	
Southport	010-013-013	Generator and Storage Building		No	Medium	High	
Southport	N/A	Dorm Building		No	Medium	High	Not in GIS Data
Southport	010-013-005	Storage Building		No	Medium	Low	
Swan Quarter	048-039-002	Ferry Operations Building		No	High	High	

Appendix D: Flood Hazard Table

Appendix D. Hazard Vulnerability Assessment Results

Table 1. Assets

Asset Area	Asset	Flood Zone A	Flood Zone V	Flood Zone 500	SLOSH Cat1	SLOSH Cat2	SLOSH Cat3	SLR1	SLR2	HTF	SLR3	SLR4	2020 Haz Sum	2040 Haz Sum	2060 Haz Sum	2020 Vuln Class	2040 Vuln Class	2060 Vuln Class
Aurora	Restroom	0	0	0	1	1	1	0	0	0	0	0	3	3	3	Med	Med	Med
Bayview	Office and Restroom	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Bayview	Emergency Generator Building	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low	Low	Low
Bayview	Storage Building	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low	Low	Low
Bayview	Storage	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low	Low	Low
Cedar Island	Visitors Center & Office	1	0	0	0	0	0	0	0	0	0	0	1	1	1	Low	Low	Low
Cedar Island	Marine Maintenance Building	1	0	0	0	0	0	0	0	0	0	0	1	1	1	Low	Low	Low
Cedar Island	Above-ground Storage Tanks	1	0	0	0	0	0	0	0	0	0	0	1	1	1	Low	Low	Low
Cedar Island	Pump House	1	0	0	1	1	1	0	0	0	0	1	4	4	5	High	High	High
Cherry Branch	Visitors Center	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low	Low	Low
Cherry Branch	Generator Building	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low	Low	Low
Cherry Branch	Marine Maintenance Building	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Cherry Branch	Uniform Storage Building	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low	Low	Low
Cherry Branch	Outbuilding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low	Low	Low
Currituck	Currituck Ferry Operations Building	1	0	1	0	1	1	0	0	0	0	1	4	4	5	High	High	High
Currituck	Storage Building	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low	Low	Low
Currituck	Veeder Root Building	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low	Low	Low
Fort Fisher	Ferry Building	0	0	1	0	1	1	0	0	0	0	0	3	3	3	Med	Med	Med
Fort Fisher	Booth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low	Low	Low
Fort Fisher	Above-ground Storage Tank	0	0	1	0	1	1	0	0	0	0	0	3	3	3	Med	Med	Med
Fort Fisher	Storage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low	Low	Low
Hatteras	Hatteras Visitor Center & Office	1	0	1	1	1	1	0	0	0	0	0	5	5	5	High	High	High
Hatteras	Hatteras Maintenance Facility	0	0	1	0	1	1	0	0	0	0	0	3	3	3	Med	Med	Med
Hatteras	Hatteras Dormitory #1	1	0	0	1	1	1	0	1	1	1	1	5	6	8	High	High	High
Hatteras	Hatteras Dormitory #2	1	0	0	1	1	1	0	0	0	1	1	4	5	6	High	High	High
Knotts Island	Knotts Island Restroom Building	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low	Low	Low
Manns Harbor	Manns Harbor Dormitory	1	0	1	1	1	1	0	0	0	1	1	5	6	7	High	High	High
Manns Harbor	Marine Security Booth	0	0	0	1	1	1	0	0	0	0	1	3	3	4	Med	Med	High
Manns Harbor	Marine Warehouse	0	0	1	0	1	1	0	0	0	0	0	3	3	3	Med	Med	Med

Manns Harbor	Ferry Marine Maintenance Building	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Manns Harbor	State Shipyard Paint Booth	0	0	0	0	1	1	0	0	0	0	1	2	2	3	Med	Med	Med
Manns Harbor	Above-ground Storage Tank - Propane	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Manns Harbor	Paint Storage Building	0	0	0	1	1	1	0	0	0	0	1	3	3	4	Med	Med	High
Manns Harbor	Above-ground Storage Tank Area - Oxygen	0	0	1	1	1	1	0	0	0	0	1	4	4	5	High	High	High
Manns Harbor	Above-ground Storage Tank - Diesel	0	0	0	1	1	1	0	0	0	0	0	3	3	3	Med	Med	Med
Manns Harbor	Generator Building	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Manns Harbor	Above-ground Storage Tanks - Generator Bldg	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Manns Harbor	Storage Building	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Manns Harbor	Maintenance Shop and Tool Storage	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Manns Harbor	Maintenance Garage	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Manns Harbor	Oil Water Separator Building	0	0	0	1	1	1	0	0	0	0	0	3	3	3	Med	Med	Med
Manns Harbor	Above-ground Storage Tanks - Used Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low	Low	Low
Manns Harbor	Syncrolift Building	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Manns Harbor	Above-ground Storage Tanks - Diesel Fuel	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Manns Harbor	Paint Mixing Building	0	0	1	1	1	1	0	0	0	0	1	4	4	5	High	High	High
Manns Harbor	Well Pump Building	0	0	0	0	1	1	0	0	0	1	1	2	3	4	Med	Med	High
Manns Harbor	Fire Pump Building	0	0	0	0	1	1	0	0	0	0	0	2	2	2	Med	Med	Med
Manns Harbor	Maintenance Tool Room & Observatory	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low	Low	Low
Minnesott Beach	Ferry Building	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low	Low	Low
Minnesott Beach	Storage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low	Low	Low
Ocracoke SL	Ferry Dormitory Building	1	0	0	0	1	1	0	0	0	1	1	3	4	5	Med	High	High
Ocracoke SL	Visitors Center and Ferry Office	1	0	0	1	1	1	0	0	0	1	1	4	5	6	High	High	High
Ocracoke SL	Amphidromia Equipment Building	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low	Low	Low
Ocracoke SL	Ticket Booth	0	0	0	1	1	1	0	0	0	0	0	3	3	3	Med	Med	Med
Ocracoke SL	Ferry Office	0	0	0	1	1	1	0	0	0	1	1	3	4	5	Med	High	High
Ocracoke SL	Visitors Restroom Building	0	0	1	1	1	1	0	0	0	1	1	4	5	6	High	High	High
Ocracoke SL	Above-ground Storage Tank	0	0	1	0	1	1	0	0	0	1	1	3	4	5	Med	High	High
Powell's Point	Office / Warehouse Building	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low	Low	Low
Powell's Point	Lumber Shed	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low	Low	Low
Powell's Point	Above-ground Storage Tanks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low	Low	Low
Southport	Visitor Center	1	0	1	0	1	1	0	0	0	0	0	4	4	4	High	High	High
Southport	Generator and Storage Building	1	0	0	0	1	1	0	0	0	0	0	3	3	3	Med	Med	Med

Southport	Southport Dorms	0	0	1	0	0	0	0	0	0	0	0	1	1	1	Low	Low	Low
Southport	Storage Building	0	0	1	0	0	0	0	0	0	0	0	1	1	1	Low	Low	Low
Southport	Booth	0	0	1	0	0	1	0	0	0	0	0	2	2	2	Med	Med	Med
Southport	Drum Storage	0	0	1	0	1	1	0	0	0	0	0	3	3	3	Med	Med	Med
Swan Quarter	Ferry Operations Building	0	0	1	0	0	1	0	0	0	0	0	2	2	2	Med	Med	Med

Table 2. Critical Roadways

Asset	Flood Zone A	Flood Zone V	Flood Zone 500	SLOSH Cat1	SLOSH Cat2	SLOSH Cat3	SLR1	SLR2	HTF	SLR3	SLR4	2020 Haz Sum	2040 Haz Sum	2060 Haz Sum	2020 Vuln Class
Aurora	1	0	1	0	1	1	0	0	0	0	0	4	4	4	High
Bayview	0	0	1	0	1	1	0	0	0	0	0	3	3	3	Med
Cedar Island	1	0	1	1	1	1	0	0	0	1	1	5	6	7	High
Cherry Branch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Currituck	1	0	1	0	1	1	0	0	0	0	1	4	4	5	High
Fort Fisher	1	0	1	1	1	1	0	0	0	1	1	5	6	7	High
Hatteras	1	0	1	1	1	1	0	0	0	1	1	5	6	7	High
Knotts Island	1	0	1	1	1	1	0	0	0	1	1	5	6	7	High
Manns Harbor	1	0	0	1	1	1	0	1	0	1	1	4	5	7	High
Minnesott Beach	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Low
Ocracoke Silver Lake	1	0	1	1	1	1	0	1	1	1	1	6	7	9	High
Ocracoke South Dock	1	0	1	1	1	1	0	1	1	1	1	6	7	9	High
Powells Point	0	0	0	0	0	1	0	0	0	0	0	1	1	1	Low
Rodanthe	1	0	1	1	1	1	0	0	0	1	1	5	6	7	High
Southport	1	0	1	0	1	1	0	0	0	0	0	4	4	4	High
Stumpy Point	1	0	0	1	1	1	0	1	1	1	1	5	6	8	High
Swan Quarter	1	0	1	1	1	1	0	0	1	1	1	6	7	8	High

Appendix E: Criticality and Vulnerability Overview Tables

Flood Hazard Criticality-Vulnerability

Terminal Flooding Vulnerability

Terminal/Facility	Flood Vulnerability	Terminal Criticality
Currituck	High	Medium
Knotts Island	Low	Medium
Hatteras	High	High
Ocracoke South Dock	High	High
Ocracoke Silver Lake	High	High
Swan Quarter	Medium	High
Cedar Island	High	High
Bayview	Medium	Medium
Aurora	Medium	Medium
Cherry Branch	Medium	Medium
Minnesott Beach	Low	Medium
Southport	High	Medium
Fort Fisher	Medium	Medium
Manns Harbor Shipyard	High	High
Powell's Point Storage	Low	Medium

* Due to an asset based scoring method, the Rodanthe Emergency Terminal and Stumpy Point Emergency Terminal did not get a terminal flood vulnerability designation because there are no assets at the site.

Terminal-Level Vulnerability and Criticality Matrix: Flooding

Flood Vulnerability	Low	Med	High
High		• Currituck • Southport	• Hatteras • Ocracoke SD • Ocracoke SL • Cedar Island • Manns Harbor Shipyard
Med		• Bayview • Aurora • Cherry Branch • Fort Fisher	• Swan Quarter
Low		• Knotts Island • Minnesott Beach • Powell's Point Storage	

Terminal Criticality

Erosion Hazard Criticality-Vulnerability

Terminal Erosion Vulnerability Level

Terminal/Facility	Erosion Vulnerability	Terminal Criticality
Currituck	Low	Medium
Knotts Island	Low	Medium
Hatteras	Low	High
Ocracoke South Dock	High	High
Ocracoke Silver Lake	High	High
Swan Quarter	High	High
Cedar Island	Low	High
Bayview	Low	Medium
Aurora	Medium	Medium
Cherry Branch	Medium	Medium
Minnesott Beach	Low	Medium
Southport	Medium	Medium
Fort Fisher	High	Medium
Rodanthe	Medium	Medium
Stumpy Point	High	High
Manns Harbor Shipyard	Low	High
Powell's Point Storage	Low	Medium

Terminal-Level Vulnerability and Criticality Matrix: Erosion

Erosion Vulnerability \ Terminal Criticality	Low	Med	High
High		• Fort Fisher	• Ocracoke SD • Ocracoke SL • Swan Quarter • Stumpy Point
Med		• Aurora • Cherry Branch • Southport • Rodanthe	
Low		• Currituck • Knotts Island • Bayview • Minnesott Beach • Powell's Point Storage	• Hatteras • Cedar Island • Manns Harbor Shipyard

Roadway Access Criticality-Vulnerability

Terminal Critical Roadway Access Vulnerability

Terminal/Facility	Roadway Access	Terminal Criticality
Currituck	Medium	Medium
Knotts Island	High	Medium
Hatteras	High	High
Ocracoke South Dock	High	High
Ocracoke Silver Lake	High	High
Swan Quarter	Medium	High
Cedar Island	High	High
Bayview	Low	Medium
Aurora	High	Medium
Cherry Branch	Low	Medium
Minnesott Beach	Low	Medium
Southport	Medium	Medium
Fort Fisher	Medium	Medium
Rodanthe	High	Medium
Stumpy Point	High	High
Manns Harbor Shipyard	Medium	High
Powell’s Point Storage	Low	Medium

Terminal-Level Vulnerability and Criticality Matrix: Roadway Acces

Road Access Vulnerability \ Terminal Criticality	Low	Med	High
High		• Knotts Island • Aurora • Rodanthe	• Hatteras • Ocracoke SD • Ocracoke SL • Cedar Island • Stumpy Point
Med		• Currituck • Southport • Fort Fisher	• Swan Quarter • Manns Harbor Shipyard
Low		• Bayview • Cherry Branch • Minnesott Beach • Powell’s Point Storage	

Overall Terminal Criticality-Vulnerability

Overall Terminal Vulnerability and Criticality

Terminal/Facility	Overall Terminal Vulnerability	Terminal Criticality
Currituck	High	Medium
Knotts Island	Low	Medium
Hatteras	High	High
Ocracoke South Dock	High	High
Ocracoke Silver Lake	High	High
Swan Quarter	Medium	High
Cedar Island	High	High
Bayview	Medium	Medium
Aurora	Medium	Medium
Cherry Branch	Medium	Medium
Minnesott Beach	Low	Medium
Southport	High	Medium
Fort Fisher	Medium	Medium
Manns Harbor Shipyard	High	High
Powell's Point Storage	Low	Medium

* Due to an asset based scoring method, the Rodanthe Emergency Terminal and Stumpy Point Emergency Terminal did not get an overall terminal vulnerability designation because there are no assets at the site.

Terminal-Level Vulnerability and Criticality Matrix

Overall Vulnerability / Terminal Criticality	Low	Med	High
High		• Currituck • Southport	• Hatteras • Ocracoke SD • Ocracoke SL • Cedar Island • Manns Harbor Shipyard
Med		• Bayview • Aurora • Cherry Branch • Fort Fisher	• Swan Quarter
Low		• Knotts Island • Minnesott Beach • Powell's Point Storage	

Cited References

Bert, S., Norboge, N., Davis, J., Head, W., Babich, J., Findley, D. (2020). Economic Contribution of North Carolina's Ferry System. NCDOT- 87727.

Bertrand, S. and B. Williams. (2022). Environmental and Energy Study Institute (EESI). Issue Briefing: Climate Change Mitigation and Adaptation at U.S. Ports.

Cole, J. C. (1989). *A vulnerability analysis of North Carolina coastal highways*. Internal Rep. Raleigh, NC: North Carolina State Univ.

Dolan, R., B. P. Hayden, P. May, and S. May. (1980). "The reliability of shoreline change measurements from aerial photographs." *Shore & Beach* 48 (4): 22–29.

Federal Emergency Management Agency [FEMA]. (2018). "FEMA Flood Maps and Zones Explained." Retrieved from https://www.fema.gov/blog/fema-flood-maps-and-zones-explained

Federal Highway Administration (FHWA), (2020). Vulnerability Assessment and Adaptation Framework, Third Edition, FHWA-HEP-18-020.

Geis, S. and B. Bendell. (2010). "Charting the estuarine environment: A methodology spatially delineating a contiguous, estuarine shoreline of North Carolina." Report prepared for the North Carolina Division of Coastal Management. 36 pp + appx.

Island Free Press, 2020. "Dorian Damage to Ferry Division Tops $4M", https://islandfreepress.org/outer-banks-news/dorian-damage-to-ferry-division-tops-4m/

National Oceanic and Atmospheric Administration (NOAA). (n.d.). Coastal Flood Exposure Mapper: Exposure Data and Information. Retrieved from https://coast.noaa.gov/data/digitalcoast/pdf/flood-exposure-data.pdf

National Oceanic and Atmospheric Administration (NOAA). (2017). Detailed Method for Mapping Sea Level Rise Inundation. NOAA Office for Coastal Management. Retrieved from https://coast.noaa.gov/data/digitalcoast/pdf/slr-inundation-methods.pdf

National Oceanic and Atmospheric Administration (NOAA) (2022). 2022 Sea Level Rise Technical Report. https://cdn.oceanservice.noaa.gov/oceanserviceprod/hazards/sealevelrise/noaa-nos-techrpt01-global-regional-SLR-scenarios-US.pdf

National Oceanic and Atmospheric Administration (NOAA) (2023). Sea Level Rise Viewer https://coast.noaa.gov/digitalcoast/tools/slr.html

New York/New Jersey Port Authority. (2018). Climate Resilience Design Guideline. Engineering Department Manual: v1.2.

North Carolina Department of Transportation (NCDOT). (2017). "Ferry Life-Cycle Plan for Terminal Structure Repairs and Replacements". Presented by Baker, Sterling.

North Carolina Department of Transportation (NCDOT). (2022). N.C. Equity & Transportation Disadvantage Screening Tool Tutorial & Data Guide. Retrieved from https://storymaps.arcgis.com/stories/7e3bbd00fe014a77b5f1620334209712

North Carolina Department of Transportation (NCDOT). (2021). Resilience Analysis Framework for Transportation. https://raft.nc.gov/

North Carolina Division of Coastal Management (NCDCM). (2024). “DCM Interactive Map Viewer” https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=f5e463a929ed430095e0a17ff803e156

North Carolina Division of Coastal Management (NCDCM). (2015). “North Carolina Estuarine Shoreline Mapping Project 2012 Statistical Reports.” Report. 105 pp.

ten Brink, U.S., Chaytor, J., Geist, E., Brothers, D.S., and Andrews, B.D. (2014). Assessment of tsunami hazard to the U.S. Atlantic margin. Marine Geology 353: 31-54.

Stone, J., Overton, M. F., and J. Fisher. (1991). *Options for North Carolina coastal highways vulnerable to long term erosion*. Raleigh, NC: North Carolina State Univ.

Sweet, W.,V., Dusek, G., Obeysekera, J., Marra, J. J. (2018). Patterns and Projections of High Tide Flooding Along the U.S. Coastline Using a Common Impact Threshold. NOAA Technical Report NOS CO-OPS 086.

US Department of Defense (2021). Highlights and Examples Department of Defense Climate Adaptation Plan. Office of the Undersecretary of Defense (Acquisition and Sustainment).

US Department of Transportation (2014). Transportation Climate Change Sensitivity Matrix. Ports and Waterways.

Velasquez-Montoya, L., Sciaudone, E.J., Smyre, E. and M.F. Overton (2021). “Vulnerability indicators for coastal roadways based on barrier island morphology and shoreline change predictions.” *Nat. Hazards Rev.*, 2021, 22(2): 04021003 https://doi.org/10.1061/(ASCE)NH.1527-6996.0000441

Virginian-Pilot, 2020. “5 months after Hurricane Dorian, Ocracoke is nearly free of mounds of trash”, https://www.pilotonline.com/news/vp-nw-ocracoke-debris-20200206-avohwecjvjdptpqyxbcettmkra-,