StEER
STRUCTURAL
EXTREME EVENTS
RECONNAISSANCE

Hurricane Helene

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PRELIMINARY VIRTUAL RECONNAISSANCE REPORT (PVRR)

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DEDICATION

Helene is the second-deadliest hurricane to strike the United States mainland in the past 50 years, following Hurricane Katrina, which killed at least 1,833 people in 2005. This report is dedicated to the memory of all those who lost their lives in Hurricane Helene and in solidarity with those who were injured or displaced by this event. We also wish to honor those who labored tirelessly to rescue as many as possible under extremely challenging conditions. This report is a symbol of our ongoing commitment to learn from this disaster and work with colleagues in the region to build more resilient communities in the future.

PREFACE

The National Science Foundation (NSF) awarded an EAGER grant (CMMI 1841667) to a consortium of universities to form the Structural Extreme Events Reconnaissance (StEER) Network (see https://www.steer.network for more details). StEER was renewed through a second award (CMMI 2103550) to further enhance its operational model and develop new capabilities for more efficient and impactful post-event reconnaissance. StEER builds societal resilience by generating new knowledge on the performance of the built environment through impactful post-disaster reconnaissance disseminated to affected communities. StEER achieves this vision by: (1) deepening structural engineers' capacity for post-event reconnaissance by promoting community-driven standards, best practices, and training, as well as their understanding of the effect of natural hazards on society; (2) coordination leveraging its distributed network of members and partners for early, efficient and impactful responses to disasters; and (3) collaboration that broadly engages communities of research, practice and policy to accelerate learning from disasters.

Under the banner of the Natural Hazards Engineering Research Infrastructure (NHERI) CONVERGE node, StEER works closely with the wider Extreme Events consortium to promote interdisciplinary disaster reconnaissance and research. The consortium includes the Geotechnical Extreme Events Reconnaissance (GEER) Association and the networks for Interdisciplinary Science and Engineering Extreme Events Research (ISEEER), Nearshore Extreme Event Reconnaissance (NEER), Operations and Systems Engineering Extreme Events Research (OSEEER), Social Science Extreme Events Research (SSEER), Sustainable Material Management Extreme Events Reconnaissance (SUMMEER), and Public Health Extreme Events Research (PHEER), as well as the NHERI RAPID facility, the NHERI Network Coordination Office (NCO), and NHERI DesignSafe CI, curation home for all StEER products.

While the StEER network currently consists of the three primary nodes located at the University of Notre Dame (Coordinating Node), University of Florida (Southeast Regional Node), and University of California, Berkeley (Pacific Regional Node), StEER is currently expanding its network of regional nodes worldwide to enable swift and high quality responses to major disasters globally.

StEER's founding organizational structure includes a governance layer comprised of core leadership with Associate Directors for each of the primary hazards as well as the cross-cutting area of Data Standards, led by the following individuals:

- **Tracy Kijewski-Correa (PI)**, University of Notre Dame, serves as StEER Director responsible for overseeing the design and operationalization of the network and representing StEER in the NHERI Converge Leadership Corps.
- **Khalid Mosalam (co-PI)**, University of California, Berkeley, serves as StEER Associate Director for Seismic Hazards, serving as primary liaison to the Earthquake Engineering community.
- **David O. Prevatt (co-PI)**, University of Florida, serves as StEER Associate Director for Wind Hazards, serving as primary liaison to the Wind Engineering community.
- **Mohammad S. Alam (co-PI)**, University of Hawai'i at Manoa, serves as StEER Associate Director for Coastal Hazards, serving as a primary liaison to the coastal engineering community.
- **David Roueche (co-PI)**, Auburn University, serves as StEER Associate Director for Data Standards, ensuring StEER processes deliver reliable and standardized reconnaissance data suitable for re-use by the community.

This core leadership team works closely with StEER's Program Manager and Data Librarians in event responses, in consultation with its Advisory Boards for Coastal, Seismic and Wind Hazards.

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This report was developed to contribute to the efforts of the international research community with the ultimate goal of understanding certain scientific aspects of Hurricane Helene. No resources included in this report are used for commercial purposes and none of the authors receive remuneration directly related to the publication of this research document.

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ATTRIBUTION GUIDANCE

Reference to PVRR Analyses, Discussions or Recommendations

Reference to the analyses, discussions or recommendations within this report should be cited using the full citation information and DOI from DesignSafe (these are available at https://www.steer.network/responses).

Citing Images from this PVRR

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A number of VAST members contributed to the corresponding Media Repository, published under a separate DOI. Their photographic evidence and analysis was vital to this report:

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The sharing of videos, damage reports and briefings via Slack by the entire NHERI community was tremendously helpful and much appreciated. StEER recognizes the efforts of the DesignSafe CI team who continuously supported and responded to StEER's emerging needs.

For a full listing of all StEER products (briefings, reports and datasets) please visit the StEER website: https://www.steer.network/responses

COMMON TERMS & ACRONYMS

Acronym	General Terms	Brief Description
--	DesignSafe	Data Repository
--	DesignSafe-CI	Academic Organization within NHERI
ASCE	American Society of Civil Engineers	Professional Organization
ASTM	American Society for Testing and Materials (now ASTM International)	Standards Body
ATC	Applied Technology Council	Professional Organization
BOCA	Building Officials and Code Administrators	Code Body
CC-BY	Creative Commons Attribution License	Code/Standard
CESMD	Center for Engineering Strong Motion Data	Governmental Agency
CI	Cyberinfrastructure	Research Asset
CLPE	Critical Load Path Elements	StEER Term
CMU	Concrete Masonry Unit	Building Material
CPIC	Center for Public Interest Communication	Research Support Organization within University of Florida to study, test and apply strategic communication for social change
CWA	Central Weather Administration	Taiwan Governmental Agency
DBE	Design Basis Earthquake	Design Terminology
DEQC	Data Enrichment and Quality Control	StEER Term
DOI	Digital Object Identifier	Common Term
EARR	Early Access Reconnaissance Report	StEER Term
EERI	Earthquake Engineering Research Institute	Professional Organization
EEFIT	Earthquake Engineering Field Investigation Team	Professional Organization
EF	Enhanced Fujita Scale	Hazard Intensity Scale
EF	Equipment Facility	Academic Organization within NHERI
EIFS	Exterior Insulation Finish System	Building Component
FAA	Federal Aviation Administration	Governmental Agency
FAQ	Frequently Asked Questions	Common Term
FAST	Field Assessment Structural Team	StEER Term

FEMA	Federal Emergency Management Agency	Governmental Agency
FIRM	Flood Insurance Rate Maps	Regulatory Product
GEER	Geotechnical Extreme Events Reconnaissance	Academic Organization within NHERI
GPS	Global Positioning System	Measurement Technology
GSA	Government Services Administration	Governmental Agency
HVAC	Heating, ventilation and air conditioning	Building System
HWM	High Water Mark	Intensity Measure
IBC	International Building Code	Code/Standard
ICC	International Code Council	Code Body
IRC	International Residential Code	Code/Standard
ISEEER	Interdisciplinary Science and Engineering Extreme Events Research	Academic Organization within NHERI
LiDAR	Light Detection and Ranging	Measurement Technology
MCE	Maximum Considered Earthquake	Design Terminology
ME&P	Mechanical, electrical and plumbing	Building System
MMI	Modified Mercalli Intensity	Hazard Intensity Scale
NBC	National Building Code	Code/Standard
NCDOT	North Carolina Department of Transportation	Governmental Agency
NEER	Nearshore Extreme Event Reconnaissance	Academic Organization within NHERI
NFIP	National Flood Insurance Program	Government Program
NHERI	Natural Hazards Engineering Research Infrastructure	Academic Organization within NHERI
NIST	National Institute of Standards and Technology	Governmental Agency
NOAA	National Oceanic and Atmospheric Administration	Governmental Agency
NSF	National Science Foundation	Governmental Agency
NWS	National Weather Service	Governmental Agency
OSB	Oriented strand board	Construction Material
OSEEER	Operations and Systems Engineering Extreme Events Research	Academic Organization within NHERI
PEER	Pacific Earthquake Engineering Research center	Academic Organization (Earthquakes)

PGA	Peak Ground Acceleration	Intensity Measure
PHEER	Public Health Extreme Events Research	Academic Organization within NHERI
PVRR	Preliminary Virtual Reconnaissance Report	StEER Term
QC	Quality Control	Oversight process
RAPID	RAPID Grant	Funding Mechanism
RAPID-EF	RAPID Experimental Facility	Academic Organization within NHERI
RC	Reinforced Concrete	Building Material
SAR	Search and Rescue	Standard Hazards Terminology
SGI	Special Government Interest	FAA Process
SLP	Surface-Level Panoramas	Measurement Technology
SMS	Short Message Service	Communication Modality
SPC	Storm Prediction Center	Governmental Agency
SSEER	Social Science Extreme Events Research	Academic Organization within NHERI
StEER	Structural Extreme Events Reconnaissance network	Academic Organization within NHERI
SUMMEER	SUstainable Material Management Extreme Events Reconnaissance	Academic Organization within NHERI
TAS	Testing Application Standard	Technical Standard
UAS/V	Unmanned Aerial Survey/System/Vehicle	Measurement Technology
USD	US Dollar	Standard Currency
USGS	United States Geological Survey	Governmental Agency
VAST	Virtual Assessment Structural Team	StEER Term
WS	Windshield Survey	Measurement Technology

EXECUTIVE SUMMARY

Hurricane Helene made landfall as a Category 4 in the Big Bend region of Florida, near Perry, FL at approximately 0310 UTC September 27, 2024. The storm's intensity and northeastern track across the Gulf of Mexico produced coastal flooding along a large portion of Florida's Gulf Coast from Apalachee Bay to the north in the Big Bend, extending to just south of Naples. The most significant coastal flooding occurred in Florida's "Nature Coast" between Clearwater Beach and Apalachee Bay, and because much of this coastline is less developed than other parts of Florida's coast, potentially high economic losses were minimized there to some extent. Hurricane Helene's wind field was notably extensive, with hurricane force winds extending outward up to 60 miles but wind velocities at landfall were substantially lower than Category 4 strength and well below the design wind speed in this region.

Like Hurricane Harvey, Helene generated a series of cascading hazards as it moved inland, with a wide range of impacts across several other states as it moved through the Southeastern United States and into Appalachia. Beyond spawning tornadoes across Georgia, South Carolina and North Carolina, Helene produced rainfall values exceeding 35 cm (14 in) in parts of Florida, Georgia, and South Carolina, with at least one location in North Carolina exceeding 78 cm. North Carolina, despite being hundreds of miles north of Hurricane Helene's landfall site, arguably experienced the most severe impacts. The extreme precipitation in the western part of North Carolina resulted in unprecedented flooding. As a result, Hurricane Helene will be one of the deadliest and costliest natural disasters in US history with over 230 reported fatalities and damage and economic losses possibly surpassing 160B USD, though estimates are still quite fluid, with expected sizable gaps between total losses and insured losses.

While storm surge in excess of 10 feet caused significant damage to structures with insufficient freeboard, there were no significant wind losses in Helene. Instead, the vast majority of notable structural failures occurred well inland, emanating from an unprecedented intensity of rainfall, exacerbating a prior condition of heavily saturated soils and rivers at or near flood stage, leading to flash flooding, high-velocity flows, large debris fields, and widespread geotechnical failures that destroyed buildings, claimed lives, and cut entire regions of North Carolina off for extended periods of time. While there may be limited ability to engineer individual structures to resist such demands, it is important to document and learn from a disaster of this scale.

As such, StEER activated a Level 1 response to conduct building performance assessments following this event, initiating a Virtual Assessment Structural Team (VAST) on September 29, 2024, based on the event having the strong potential to generate new knowledge. The VAST was charged with the production of the primary product of StEER's Level 1 response: this **Preliminary Virtual Reconnaissance Report (PVRR),** intended to:

1. provide an overview of Hurricane Helene, particularly relating to coastal impacts, inland flooding, and wind damage impact on the built environment,
2. overview the regulatory environment and construction practices in the landfall area and other areas affected by the storm,
3. synthesize preliminary performance assessment reports for buildings and a range of infrastructure classes across multiple states,
4. provide recommendations for continued study on (1) Non-Stationary Hurricane Risk, (2) Drivers of Catastrophic Loss in North Carolina, (3) Housing Vulnerability, and (4) Future Reconnaissance Needs.

Note that this hurricane was geographically expansive and its impacts wide ranging, well beyond what could be documented through the volunteer efforts of a VAST. Moreover, since the VAST data collection initiated immediately following Hurricane Helene, at a time when access was limited to many areas and impacts were not fully known or reported, the observations herein may not capture the full scope of the impacts as now understood.

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1. Introduction

Hurricane Helene made landfall as a Category 4 in the Big Bend region of Florida, near Perry at approximately 03:10 UTC September 27, 2024 with maximum 1-minute sustained winds near 140 mph (225 km/h) at 10 m above ground level in open terrain and minimum central pressure of 938 mbar (27.70 inches). The storm's intensity and northeastern track across the Gulf of Mexico produced coastal flooding along a large proportion of Florida's Gulf Coast from Apalachee Bay to the north in the Big Bend, extending as far south as Ten Thousand Islands in Florida Bay south of Naples. The most significant coastal flooding occurred in Florida's "Nature Coast" between Clearwater Beach and Apalachee Bay. In Taylor and Dixie Counties, including Keaton Beach, Steinhatchee, and Horseshoe Beach, storm surges exceeded 15 feet above ground level (CERA, 2024). While this region is relatively undeveloped than other parts of Florida's coast, limiting some economic losses, the extreme surge caused significant environmental and infrastructural damage in the affected areas. Helene's wind field was also extensive, with hurricane-force winds extending outward up to 60 miles (NHC, 2024). However, wind speeds at landfall were substantially lower than peak Category 4 strength and well below the design wind speeds for buildings in the region (NIST/ARA, 2024), resulting in relatively minimal wind damage to Florida's structures.

Like Hurricane Harvey in 2017, Hurricane Helene generated a series of cascading hazards as it moved inland with a wide range of impacts across at least eight other states in the Southeastern United States (Fig 1.1). Beyond spawning tornadoes across Georgia, South Carolina and North Carolina, Helene produced rainfall values exceeding 35 cm (14 in) in parts of Florida, Georgia, and South Carolina, and at least one location in North Carolina exceeding 78 cm (30 in) from September 25, 2024 to September 28, 2024 (NWS, 2024a). North Carolina, despite being hundreds of miles north of Hurricane Helene's landfall site, arguably experienced the most severe impacts, particularly in its western regions, where unprecedented flooding occurred. The heavy rainfall exacerbated already saturated soils and rivers at or near flood stage from a prior unnamed storm, resulting in flash flooding, high-velocity flows, large debris fields, and widespread geotechnical failures. These conditions destroyed buildings, claimed lives, and isolated entire areas of the state, with many rivers exceeding their long-standing records set during the Great Flood of 1916 (Fox Weather, 2024). As a result, Hurricane Helene is projected to be one of the deadliest natural disasters in U.S. history, with over 230 reported fatalities and among the most costly, causing widespread damage across multiple states (AccuWeather, 2024).

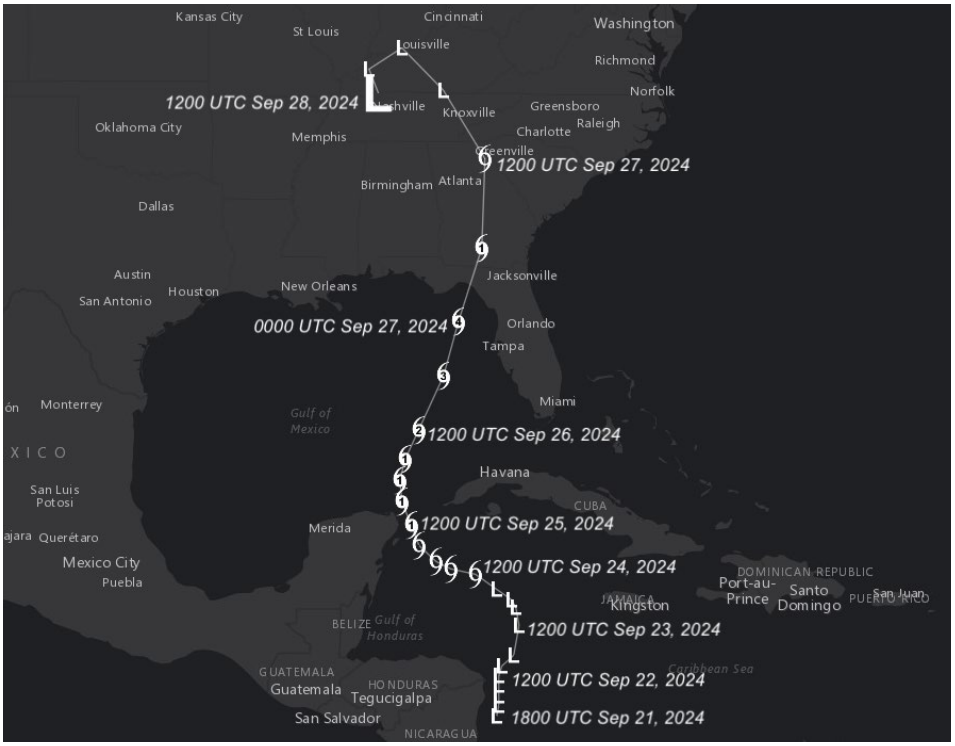


Figure 1.1. NOAA NHC ATCF Best Track Position and Intensity Data for Hurricane Helene (Source: Tropical Atlantic, 2024).

1.1. Societal Impact

The scale of Hurricane Helene's impact is vast considering both the extent and severity of damage across a wide range of infrastructure asset classes; with thousands becoming homeless (Time, 2024), the impacts to communities, their economies, and insurers will be considerable. Helene losses continue to be difficult to project, with early estimates in excess of $50 billion USD (CBS, 2024) and expected sizable gaps between total losses and insured losses. CoreLogic estimated $30.5B-47.5B in property damage across eleven (11) affected states from wind and flood, of which insured wind and flood losses is estimated to be $10.5B-$17.5B (Core Logic, 2024). Moody's RMS estimated private market insured losses to be $8B-$14B associated with wind, storm surge, and rain-induced flooding (Moody RMS, 2024). Karen Clark & Co. provided a preliminary estimate of $6.4 billion USD in privately insured losses across nine states (Insurance Business Magazine, 2024). These do not account for other economic impacts which could raise the toll of this disaster to over $160B (Budryk, 2024). For example, the United States Department of Agriculture estimates that insurers may pay out over $7 billion USD in claims for crop losses alone, noting that such estimates are highly uncertain due to the lack of precedent for major flooding in these areas (Farm Policy News, 2024). The most heavily affected counties in western North Carolina are small towns (largest was Asheville with 271,000 residents) in predominantly rural, mountainous regions that heavily rely on seasonal tourism; (NC Newsline, 2024) estimates that western North Carolina alone could lose out on as much as $1.8 billion USD in tourism this fall.

1.2. Loss of Life and Injuries

With over 230 reported fatalities, Hurricane Helene ranks as the second deadliest hurricane of the past half century, following 2005 Hurricane Katrina. Fatalities include 117 in North Carolina, 48 in South Carolina, 33 in Georgia, 20 in Florida, 12 in Tennessee, and 2 in Virginia (Sutton et.

al., 2024). Causes of death ranged from drowning, falling trees, and vehicle crashes. The National Guard conducted extensive search and rescue operations across the southeast, rescuing hundreds of people and clearing roads and bridges using helicopters, high-water vehicles and boats (National Guard Bureau, 2024).

1.3. Official Response

The National Hurricane Center (NHC) issued a tropical storm, storm surge, and hurricane watches on Sep 23, 2024 (11:00 AM EDT) for portions of the northeastern Gulf Coast. By Sept 24 (5:00 AM EDT), hurricane and storm surge watches were issued for parts along the Florida west gulf coast. Evacuation orders were issued for at least 20 counties in Florida (Florida Disaster, 2024). Later that day (5:00 PM EDT), the NHC upgraded to hurricane warning. An advisory on Sept 26 (11:00 PM EDT) categorized the storm as a “catastrophic and deadly” Category 4 hurricane. Warnings on Sept 27 (5:00 AM EDT) forecast destructive winds over portions of Georgia, the Carolinas, Tennessee, and Kentucky. Warnings of major riverine and urban flooding, and subsequent landslides, were issued across the southern Appalachians through the final advisory updates on Sept 28 (10:00 AM CDT).

On Sep 28, President Biden issued a Major Disaster Declaration for Florida and North Carolina and later extended it to Tennessee, South Carolina, Georgia, Virginia, and Alabama (The White House, 2024). The federal declaration provided direct support to states for life-saving activities and other emergency preparedness and supplies (FEMA, 2024c). As a result, the Federal Emergency Management Agency (FEMA) opened several Disaster Recovery Centers across different counties in Florida (e.g., Baker, Suwannee, and Manatee) to provide support to those affected (FEMA, 2024a). By October 3, FEMA had delivered over 9.3 million meals, 11.2 million liters of water, 150 generators and 260,000 tarps to the region (FEMA, 2024b). Additionally, FEMA provided over $45 million in direct financial assistance to individuals in affected communities (NBC News, 2024). At the state level, all impacted states declared a state of emergency (FMCSA, 2024). On September 23, Florida Governor Ron DeSantis declared a federal state of emergency for 41 counties (Griffin, 2024). Similarly, Georgia Governor Brian P. Kemp declared a federal state of emergency on September 25 (Georgia Emergency Management, 2024).

1.4. Report Scope

StEER activated a Level 1 response to conduct building performance assessments following this event. We initiated a Virtual Assessment Structural Team (VAST) on September 29, 2024, based on the event having the strong potential to generate new knowledge (evidenced by achieving more than 50% of the activation criteria in Table 1.1). The official response page was then instituted at the StEER website. The VAST was charged with the production of the primary product of StEER’s Level 1 response to this event: this **Preliminary Virtual Reconnaissance Report (PVRR),** intended to:

1. provide an overview of Hurricane Helene, particularly relating to coastal impacts, inland flooding, and wind damage impact on the built environment,
2. overview the regulatory environment and construction practices in the landfall area and other areas affected by the storm,
3. synthesize preliminary performance assessment reports for buildings and a range of infrastructure classes across multiple states,
4. provide recommendations for continued study of this event by StEER Network and the wider engineering reconnaissance community.

Table 1.1. Summary of Level 1 Activation Criteria

Hazard	Exposure	Feasibility
● Major Event ● Joint/Compounding Hazards	● Impacted Sufficiently Populated Areas ● Communities rarely exposed to events were impacted. ● Existence of Models or Measurements	● Available Resources ● Sufficient Media Coverage ● Sufficient Bandwidth of the StEER support team

2. Hazard Characteristics

2.1. Meteorological Background

The following subsections describe Hurricane Helene's early development as the NHC began to track it as a potential tropical cyclone, its evolution and landfall in Florida, and its progression northward towards Tennessee.

2.1.1. Early development

Hurricane Helene began as a disorganized system of low pressure in the Caribbean off the east coast of Nicaragua (13.6N, 82.7W) on September 21, 2024. By September 23, 2024, the disturbance tracked into the Yucatan Channel and was tracked by the NHC as a Potential Tropical Cyclone Nine. Tropical storm warnings were issued for portions of Mexico and Cuba, including the Yucatan Peninsula (Mexico), and the Isle of Youth, Artemisia and Pinar del Rio (Cuba) (NHC, 2024b). The storm remained mostly stationary as an area of low pressure until 11 am EDT on September 24, 2024 when Hurricane Helene became more organized and was upgraded to a tropical storm located near 19.4N, 83.7W and moving slowly to the northwest. The data acquired by the Hurricane Hunter aircraft indicated a well-defined center of circulation with a minimum central pressure of 1000 mbar (29.53 in) (NHC, 2024c).

Over the next 24 hours the storm strengthened further and was classified as a Category 1 Hurricane at around 10 am CDT on September 25, 2024 when it was about 85 miles (135 km) North-Northeast of Cozumel (Mexico) and 500 miles (810 km) South-Southwest of Tampa (Florida). The hurricane was moving towards the north-northwest at a speed of about 10 mph (17 km/h) with maximum sustained winds of about 80 mph (130 km/h) and a wind field of hurricane-force winds that extended outwards up to 25 miles (35 km) from the center (NHC, 2024d).

Hurricane Helene was upgraded to a Category 2 Hurricane around 7 am CDT on September 26, 2024, when its center was located about 320 miles (515 km) southwest from Tampa and 365 miles (585 km) from Apalachicola in Florida. The hurricane continued moving along a north-northeast track at an increased speed of about 12 mph (19 km/h) and with maximum sustained wind speeds of about 100 mph (155 km/h). Hurricane-force winds extended to an area of about 60 miles (95 km) away from the center (NHC, 2024e).

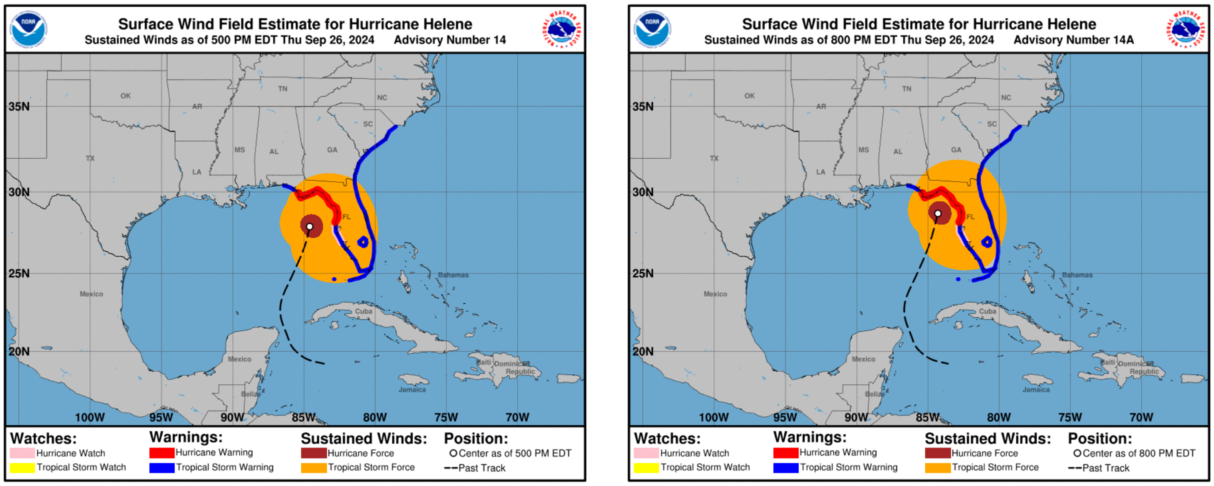


Figure 2.1. Surface wind field estimates and warnings as Hurricane Helene is declared a Category 3 (left) and Category 4 (right) hurricane on September 26, 2024 (Source: NHC HELENE Graphics Archive).

During the next 12 hours, Hurricane Helene rapidly intensified. By 2.25 pm EDT, the maximum sustained wind speeds measured by the Air Force Hunters were up to near 120 mph (195 km/h), and Hurricane Helene was classified as Category 3 Major Hurricane (NHC, 2024f). At 6:20 pm EDT on September 26, 2024, measurements from the NOAA Hurricane Hunter aircraft recorded wind speeds near to 130 mph (215 km/h) and Hurricane Helene was declared a Category 4 hurricane. The center was located about 120 miles (195 km) west of Tampa and 165 miles (265 km) south of Tallahassee, Florida, heading towards the Big Bend (NHC, 2024h). See Figure 2.1.

2.1.2. Landfall and progression inland

Hurricane Helene made landfall as a Category 4 in the Big Bend region of Florida, near Perry, on Thursday, September 26, 2024 at 11:10 pm EDT (Fig. 2.2) with maximum 1-minute sustained winds near 140 mph (225 km/h) at 10 m above ground level in open terrain and minimum central pressure of 938 mbar (27.70 inches) as estimated by the Air Force reconnaissance aircraft (NHC, 2024i).

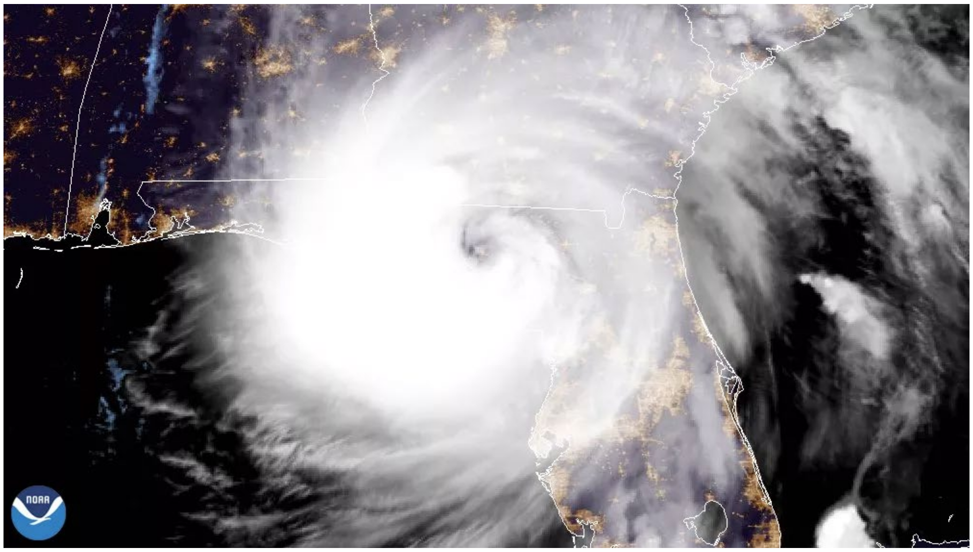


Figure 2.2. Satellite image of Hurricane Helene at landfall near Perry, Florida captured by NOAA's GOES East satellite (Source: NEDIS).

After landfall, Hurricane Helene moved rapidly towards Georgia, North Carolina and Tennessee and weakened as it progressed inland. At 2 am EDT on September 27, the hurricane was moving at a speed of nearly 26 mph (42 km/h) and produced maximum sustained winds of 90 mph (145 km/h) (NHC, 2024j). At 5 am EDT on September 27, 2024, Helene was downgraded to a tropical storm as the maximum sustained winds decreased to about 70 mph (110 km/h) (NHC, 2024k). At 2 pm EDT of the same day, the center of former Hurricane Helene was located about 125 miles (205km) to the south-southeast of Louisville, Kentucky. The storm was further downgraded to a Tropical Depression with maximum sustained winds of 35 mph (55 km/h) (NHC, 2024l). See Figure 2.3.

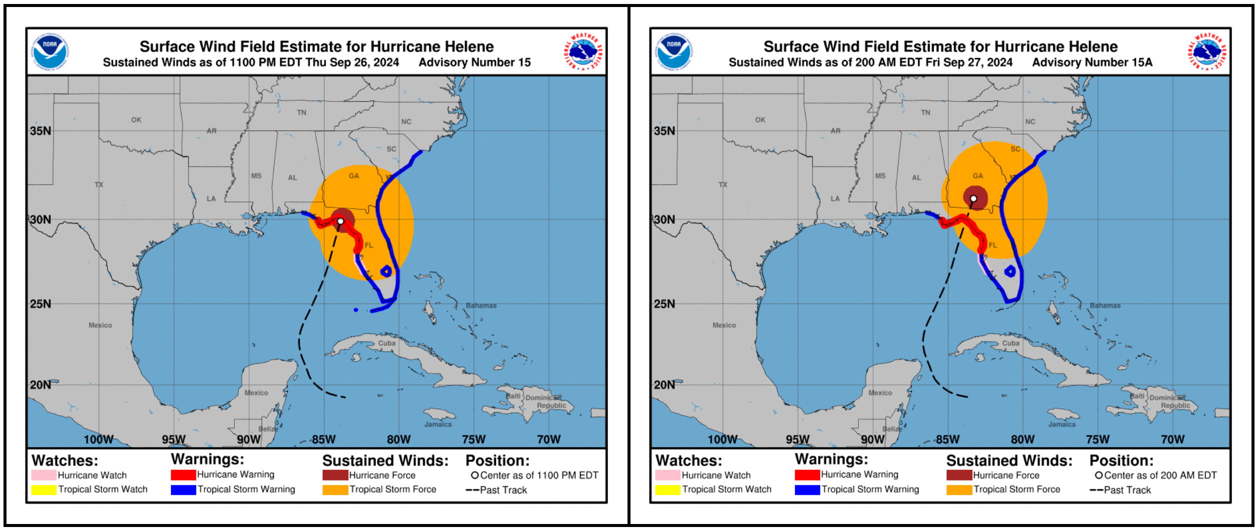
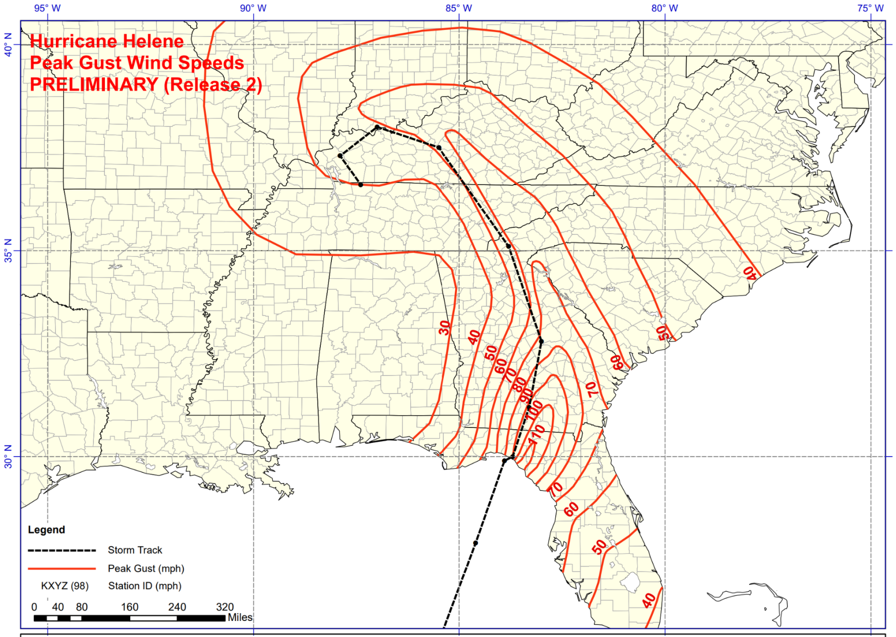


Figure 2.3. Surface wind field estimates and warnings at landfall and during Hurricane Helene's progression inland with hurricane force winds before being downgraded to a tropical storm (Source: NHC HELENE Graphics Archive).

2.2. Wind Field

Following landfall, Hurricane Helene's wind field was notably extensive, with hurricane force winds extending outward up to 60 miles (95 km) (NHC, 2024a). Figure 2.4 shows the 3-second gust wind speeds along the hurricane track as estimated by ARA/NIST (Release 2).



Hurricane Helene (2024): Preliminary Peak Wind Gust (mph)

Estimated 3-second gust wind speeds (mph) at 10 m above ground over flat open terrain from ARA model fit to surface level observations using storm track and central pressure data from NHC through Forecast Advisory Number 21 and observations through 1800 UTC on 9/27/2024. The values of peak gust winds in mph are shown after station names; Values have been adjusted for anemometer height and terrain; "-" means station failed before the arrival of the peak wind; "a" indicates a potentially anomalous value. The maps have been produced for the **National Institute of Standards and Technology** under Contract 1333ND22PNB730388. Maps are subject to change.
Created on: 10/1/2024 (Version 12)

Figure 2.4. Hurricane track and 3-second gust wind speeds at 10 m above ground estimated by NIST/ARA (Source: Release 2).

An automated surface observing system (ASOS) reported a maximum gust speed up to 99 mph (5-second gust, 10 m above ground) in Perry at landfall (Table 2.1). The peak wind speeds observed by stations part of the Florida Coastal Monitoring Program (FCMP) are also reported in Table 2.1 and suggest that the storm's wind speeds at landfall were significantly lower than expected for a Category 4 storm. However, there was a sparsity of surface wind measurements along the coast near the landfall region, with none directly in the right eyewall at landfall.

Table 2.1. Surface wind speeds measured in Hurricane Helene.

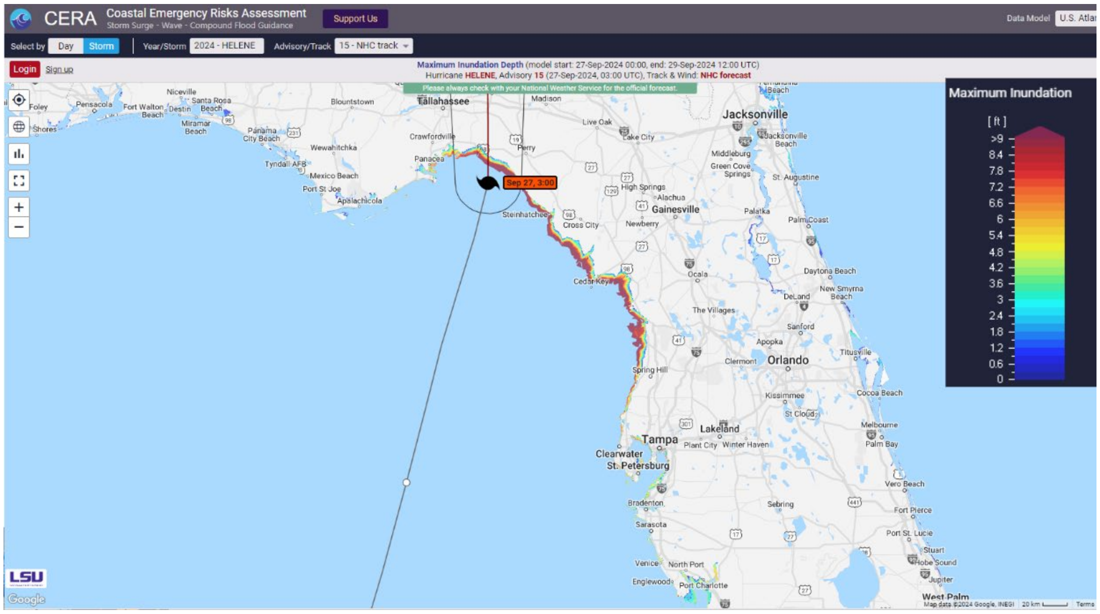
Station ID	Type	Latitude	Longitude	Elevation (ft)*	Maximum 5-sec Gust (mph)	Maximum 3-sec Gust (mph)
Perry (FPY)	ASOS	30.07081	-83.58154	33	99	--
St Petersburg (SPG)	ASOS	27.76511	-82.62697	33	82	--

Sarasota - Bradenton (SRQ)	ASOS	27.40139	-82.55861	33	74	--
T1	FCMP	30.0407	-83.7182	33	--	76.0
T5	FCMP	30.1912	-83.2126	33	--	50.8
T6	FCMP	29.7576	-83.4930	16.5	--	89.9
S2	Sentinel	29.1370	-83.0295	33	--	85.0

*ASOS stations are assumed to report at standard 10 m (33 ft) height.
Note: Data from FCMP portable instrumentation provided by Prof. Brian Phillips, University of Florida

2.3. Storm Surge and Coastal Flooding

Hurricane Helene generated a significant storm surge in Florida, particularly along the Gulf Coast spanning from Alligator Point to St. Petersburg, FL. The storm tide (storm surge + tide) above ground, as predicted by the Coastal Emergency Risks Assessment (CERA) for National Hurricane Center (NHC) Advisory #15, near the time of the storm's landfall, caused significant inundation, exceeding 9 ft above ground along Big Bend coastal areas (Figure 2.5). The National Hurricane Center reported that preliminary post-landfall modeling indicated that storm surge levels reached more than 15 feet above ground in parts of Taylor and Dixie Counties, specifically Keaton Beach, Steinhatchee, and Horseshoe Beach (NHC, 2024m).



CERA Coastal Emergency Risks Assessment
Storm Surge - Wave - Compound Flood Guidance

Select by: Day | Storm — Year/Storm: 2024 - HELENE — Advisory/Track: 15 - NHC track

Maximum Inundation Depth (model start: 27-Sep-2024 00:00, end: 29-Sep-2024 12:00 UTC)
Hurricane HELENE, Advisory 15 (27-Sep-2024, 03:00 UTC), Track & Wind: NHC forecast

Please always check with your National Weather Service for the official forecast.

Figure 2.5. Maximum inundation above ground in ft generated by Coastal Emergency Risks Assessment for National Hurricane Center (NHC) Advisory #15, for the Big Bend region of Florida, USA (Source: CERA, 2024).

Storm tide time series were recorded at NOAA Tides and Currents stations along the Big Bend region of Florida, spanning from Apalachicola west of the storm's landfall to Fort Myers southeast of the storm's landfall location. Figure 2.6 shows tidal predictions (blue curves) and preliminary observed water levels (red curves) in meters referenced to the North American Datum of 1988 (NAVD88) at NOAA stations 8728690 Apalachicola, 8727520 Cedar Key, 8726724 Clearwater Beach, 8726520 St. Petersburg, and 8725520 Fort Myers. Below each time series, the annual exceedance probability of the peak water level recorded at the station is shown based on the Coastal Hazards System (CHS) analysis, affirming that the water levels corresponded to a ~10-year event (10% annual exceedance probability) west of landfall in Apalachicola; water levels at Cedar Key and Clearwater Beach suggest the flood event was 500-year or greater (<0.2% annual exceedance probability).

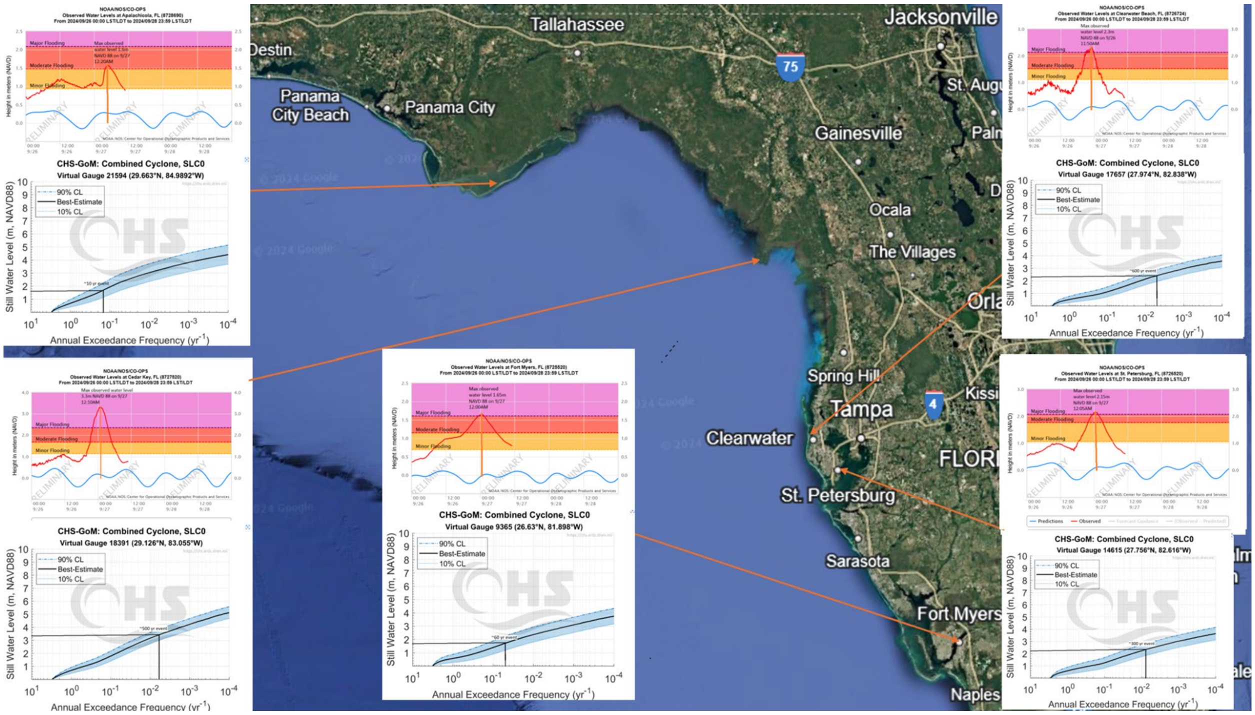


Figure 2.6. Water levels during Hurricane Helene measured at NOAA stations along the Big Bend region of Florida: 8728690 Apalachicola; 8727520 Cedar Key; 8726724 Clearwater Beach; 8726520 St. Petersburg; and 8725520 Fort Myers. Predicted (blue curves) and preliminary observed (red curves) are shown in meters relative to the North American Datum of 1988, along with thresholds for minor, moderate, and major flooding. Corresponding storm return periods (annual exceedance probabilities) from the Coastal Hazards System are shown below the storm tide time series for each station (Sources: NOAA, 2024; CHS, 2024).

The large wind field of Helene generated the significant wave heights and dominant wave periods shown in Figure 2.7, measured during the passage of Hurricane Helene from September 24 to 29, 2024 at National Data Buoy Center (NDBC) Station 42036, located 112 nautical miles WNW of Tampa, Florida. Offshore wave heights reached over 24.6 ft (7.5 m), with peak periods up to 16 seconds during the storm. The significant depths of water above ground as indicated in Figure 2.6 likely allowed for large breaking waves to develop over land that led to significant damage to coastal construction.

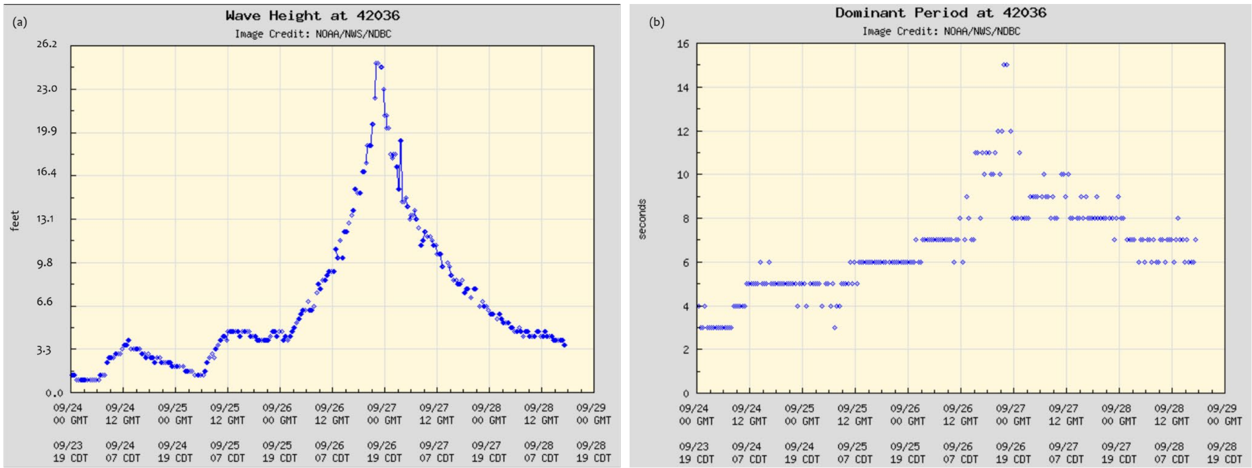
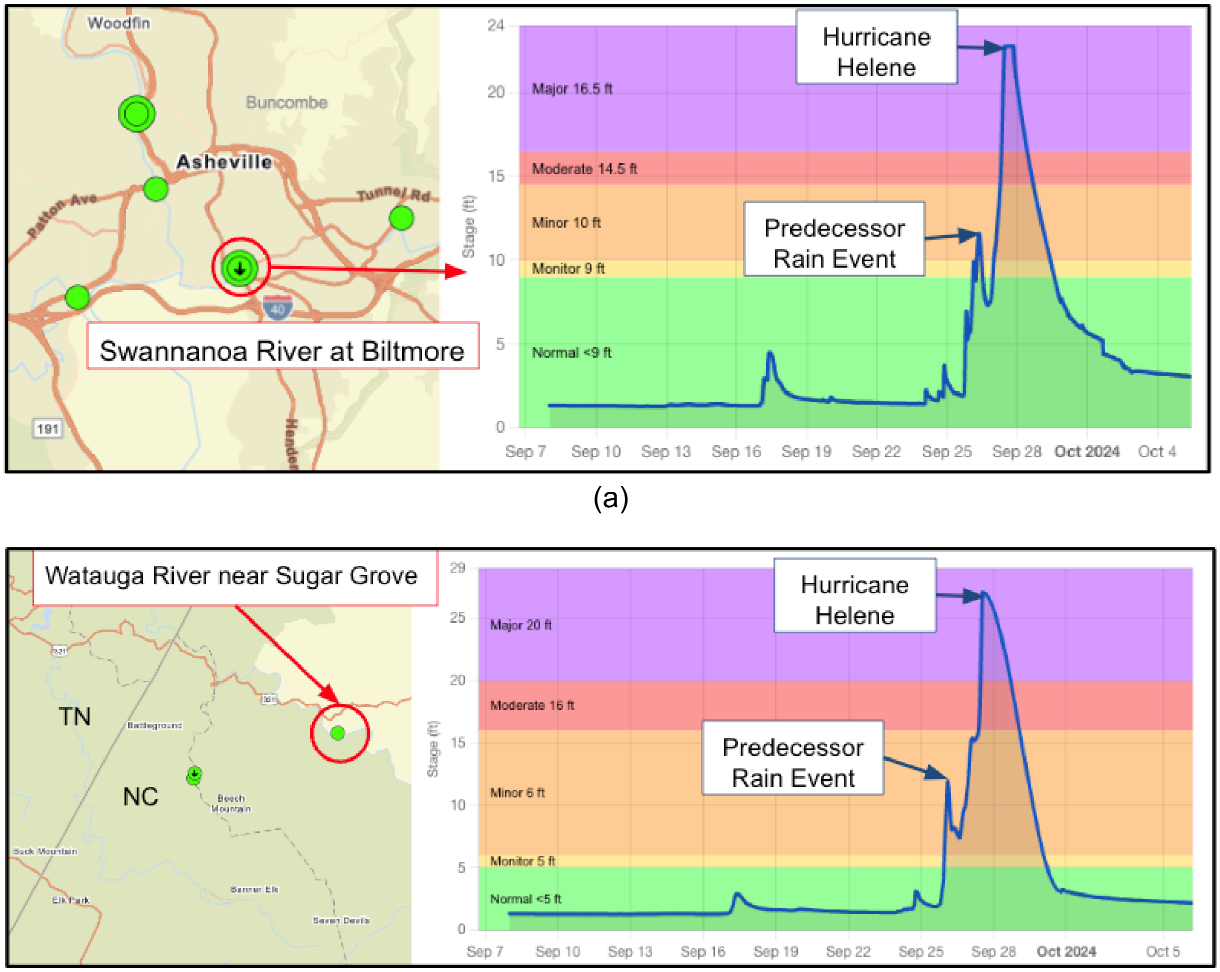


Figure 2.7. (a) significant wave heights (ft) and (b) dominant wave periods (s) measured at NDBC Station 42036, located 112 nautical miles WNW of Tampa, FL (Source: NDBC, 2024).

2.4. Rainfall and Inland Flooding

Hurricane Helene's formation over warm Gulf waters allowed for an uptake of moisture and its subsequent quick progress inland allowed for the storm to precipitate over Appalachia and cover a large area from Florida through Georgia, South Carolina, North Carolina, and Tennessee. While Hurricane Helene was still over the Gulf of Mexico, a separate low-pressure system formed over Kentucky with a cold front extending through Tennessee and a warm front over North Carolina and Virginia (WPC, 2024). This predecessor low-pressure system produced heavy rainfall, with some areas in the region experiencing over 7 inches (NWS, 2024b) prior to Helene's arrival. Helene's interaction with the existing low-pressure system over Tennessee, in what is termed the Fujiwara effect, allowed the remnants of Helene to drop excessive amounts of rainfall, especially in the Appalachian region, where flood gauges were already at minor flood stages (Fig. 2.8). Busick, NC (near Mt. Mitchell, northeast of Asheville) recorded the highest amount of rain at 30.78 inches between September 25th through 28th (Fig. 2.16). Some estimate that Helene produced more than 40 trillion gallons of rainfall over the Southeastern United States (PBS, 2024). That is roughly 151.4 billion cubic meters of water, or approximately the same volume of Lake Tahoe. If spread evenly over the state of North Carolina, that volume of water would produce a uniform depth of over 1 m (3.5 ft).



(a)

(b)

Figure 2.8. North Carolina Department of Public Safety (NCDPS) Flood gauge data: (a) near Biltmore Village in North Carolina and (b) in rural North Carolina near US 321 between TN and NC; west of Boone, NC and North of Banner Elk, NC (Source: NC FINMAN).

2.5. Tornadoes

As many as 33 possible tornadoes formed within the supercells of Hurricane Helene's rain bands (AccuWeather, 2024). Tornadoes were observed in Georgia, South Carolina, and Virginia, with the majority occurring in South Carolina (Fig. 2.9 and Appendix A). The earliest tornadoes were spotted in Georgia and South Carolina on the morning of September 26th. Most of the remaining tornadoes were observed in Charleston and Orangeburg, SC, primarily rated EF0 to EF1 (Iowa Environmental Mesonet, 2024), with wind speeds ranging from 75 to 95 mph. Later, from noon to the afternoon of September 27th, an EF3 tornado was observed in Nash, NC, and three tornadoes were recorded in Virginia: two EF1 and one EF2, with wind speeds between 90 and 118 mph. The EF3 tornado in Rocky Mount, NC injured 15 people and heavily damaged 14 buildings, tearing off roofs and walls from some structures (WRAL Staff, 2023). The EF2 tornado caused significant damage to 30 structures, including the complete destruction of a mobile home and remained on the ground for 18 minutes (NWS, Columbia, SC, 2024).

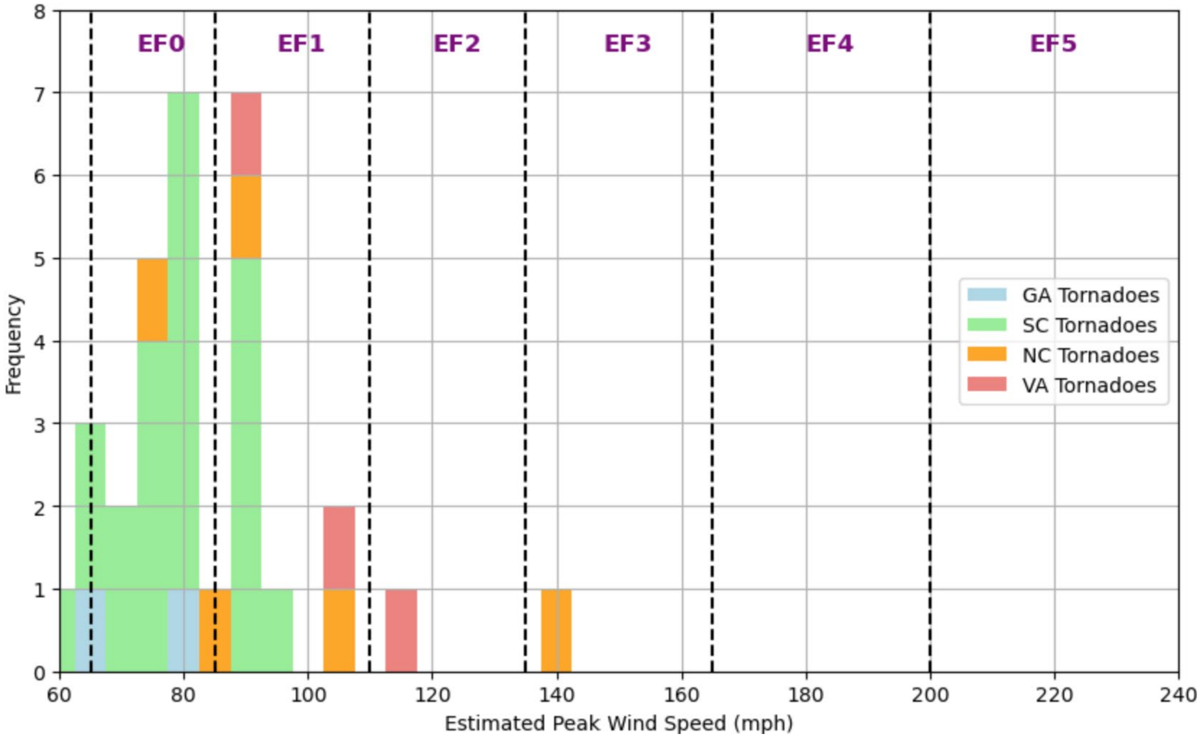


Figure 2.9. Tornado Frequency by Wind Speed, State, and EF Scale (Sources: National Weather Service, Columbia, SC, 2024; Iowa Environmental Mesonet, 2024).

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3. Local Codes and Construction Practices

The Insurance Institute for Business and Home Safety (IBHS) Rating the States report provides an evaluation of the code environments in all the affected coastal states (IBHS, 2024). Their rating in the IBHS system, scored from 0 to a maximum of 100, provides the basis for comparison in Table 3.1. The IBHS ranking is based on a matrix involving code adoption, enforcement, and contractor licensing. Focus in this section is placed on the states for which building performance case studies are presented in Section 4. A concise summary of the code environments in these states is provided in the following sections.

Table 3.1. Rating the State's Overall Score and Ranking (out of the 18 Atlantic and Gulf States) and I-Code Edition in Effect at the Time of this Report

State	Score	Rank (Out of 18)	Adopted I-Code Edition
Florida	95	2	2021
Georgia	67	12	2018
North Carolina	85	8	2015

3.1. Florida

Florida continues to be a leader in building code adoption and enforcement, earning 95 points in the 2024 edition of Rating the States (IBHS, 2024). Florida regulates most building construction through two primary codes: (1) the Florida Residential Code and (2) the Florida Building Code. The Florida Residential Code governs the construction of one- and two-family dwellings and townhomes less than 3 stories, while the Florida Building Code applies to all other permanent buildings and structures. The 8th Edition of the Florida Building Code went into effect in January of 2023 with new provisions on soffit and fascia attachments, as well as requiring a sealed roof deck. Florida also adopted the ASCE 7-22 wind design standard in advance of its adoption in the I-Codes. Notably, in 2000, as Florida prepared to implement its first statewide building code, legislation introduced the "Panhandle Exemption." This exemption allowed certain parts of the Panhandle to bypass stricter wind design requirements normally required for construction within a mile of the coast. Those stricter wind design requirements mainly focused on wind-borne debris regulations. While the rest of the state had to comply with wind-borne debris regulations anywhere the basic wind speed exceeded 120 mph, in the Panhandle, the requirements were enforced only within one mile of the coast. Following Hurricane Ivan, the exemption was repealed in 2006 by Legislation HB 7A (2007). See the PVRRs for Hurricanes Idalia (Kenawy et al., 2023) and Ian (Cortes et al., 2022) for further details on the Florida code environment and the history of code adoption in the state. The latter details the Coastal Construction Control Line (CCCL), which regulates activities and construction related to sandy beaches along Florida's coasts. The Nature Coast area that Hurricane Helene impacted is excluded from the CCCL regulations due to the lack of sandy beaches.

3.2. Georgia

Georgia regulates most building construction through two primary codes: (1) the Georgia State Minimum Standard Building Codes and (2) Georgia Residential Code. The 2020 editions of these codes are currently enforced, both of which are based on the 2018 I-Codes. The state has provisions that allow counties and jurisdictions to opt out of statewide code requirements, though no counties have done so yet. However, this option means that Georgia does not officially have a statewide enforced building code, leading it to be ranked in the bottom third of Atlantic and Gulf Coast states with a score of 67.

3.3. North Carolina

North Carolina follows the North Carolina State Building Code, which is based on the International Building Code (IBC) and International Residential Code (IRC), with amendments specific to the state. The state is currently enforcing the 2015 IRC, resulting in its score of 85 in the latest Rating the States. The state categorizes wind zones along the coast, requiring stricter building standards in vulnerable areas, such as the Outer Banks and other coastal counties. In these regions, design wind speeds can exceed 140 mph; windborne debris and other storm-related factors are also considered in these high-risk zones. In 2023, the State of North Carolina enacted legislation that replaced the existing Building Code Council with a new Residential Code Council that is only required to review and amend the code every six years (Hodges, 2024).

4. Building Performance

This section summarized observed building performance from Hurricane Helene across the Southeastern states that experienced the most severe impacts. This summary was compiled using a combination of publicly reported data, insights, and case studies from the VAST. For the most part, extensive damage was observed along the West coastline of Florida, primarily due to storm surge and wave loads. Significant damage due to wind and flood loads occurred in Northwestern Florida and regions of Georgia and North Carolina located along Hurricane Helene's path.

4.1. Florida Impacts

Table 4.1.1 provides a synthesis of typical building performance observed in Florida following Hurricane Helene, broken down by occupancy. Damage was reported in areas like Keaton Beach, Dekle Beach, Cedar Key, Steinhatchee, Horseshoe Beach, Suwannee, and Tallahassee.

The impacted region is mostly rural, with observed damage concentrated on site-built residential structures and manufactured homes. Some damage to commercial structures has also been reported.

Table 4.1.1. Summary of Building Performance in Florida, by Occupancy

Single-Family Residential Buildings	Storm surge and wave load caused building damage in several coastal towns in the Florida Big Bend coast. Older slab-on-grade residences and elevated ones were destroyed. Newer elevated constructions survived where their lowest occupied floors were above the storm surge and wave height. Elevated houses that had intermediate wood decks (some expanded staircase landings) raised the likelihood of total structural failure of the house. There was evidence of inadequate column foundations, particularly in concrete columns built on shallow foundations that failed due to scouring. Wind damage to roof cover and wall cladding systems was also observed.
Multi-Family Residential Buildings	Damage to multi-family residential buildings were also observed where lowest floor levels were impacted by storm surge and waves.

Commercial Buildings	Several commercial buildings in Perry, Steinhatchee, and Cedar Keys areas were damaged due to wind, storm surge, and waves. Only minor to moderate wind damage to the building envelope was observed, primarily affecting the roof cover.
Healthcare/Medical Facilities	The St. Petersburg, FL hospital was flooded despite installation of a flood barrier. Flood barriers installed around another hospital located in Tampa, FL, were able to protect the hospital from the storm surge.
Schools	Minor wind damage to schools reported, e.g., a blown down fence around a Sarasota, FL elementary school, and tree-fall damage. Flooding reported of several schools in Citrus County, impacting functionality.
Government Facilities	Power outages impacted functioning but no observations of direct damage were found by the authors.
Mobile/Manufactured Homes	Foundation failure and dislocation of mobile/manufactured homes has been reported in Steinhatchee, Florida, and other areas. Minor wind-induced damage to roofs was observed.
Critical Facilities	Critical facilities remained mostly operational.
Historical Buildings	No observations of direct impacts to historical structures were found by the authors.
Religious Institutions	No reports of significant damage to religious institutions observed.

4.1.1 Storm Surge and Wave Damage to Elevated structures

Many elevated structures that were impacted by storm surge and wave action washed away due to insufficient freeboard. Figure 4.1.1 presents examples of these failures in Cedar Key for structures on grouted masonry columns. The superstructures were dislocated by storm surge and wave loading; most of the piles remained undamaged during the storm, though some have been scoured, debonded or overturned. First floor elevations are estimated at 4.7 ft, readily exceeded by the reported storm surge of ~13 ft above MSL (reported in 8727520 NOAA Cedar Key station in Fig. 2.6).

Figure 4.1.1. Elevated structures washed away by storm surge and wave loads in Cedar Key, FL (Source: Greg Lovett).

Figure 4.1.2 presents another elevated structure in Dekle Beach that survived the storm surge with minor roof damage. This structure was elevated by a system of timber piles anchored to a concrete slab, elevated 18 ft above the slab.

(a) Before

(a) After

Figure 4.1.2. Elevated structure in Dekle Beach, FL, with minor roof damage (Source: Paul Ratje).

Elevated structures in other areas near Sarasota and Tampa also suffered damages due to surge and wave loading, but the damage was primarily limited to the ground floor: damage to garage doors and other break-away components (Fig. 4.1.3). Readers should recall, the storm surge levels were far less severe southwards from Tampa (2 m or less see Figure 2.6). Several nearshore elevated structures also suffered severe erosion, but did not experience collapse (Fig. 4.1.4).

Figure 4.1.3. Damage to non-structural elements at ground floor of elevated buildings in Siesta Keys, FL (Source: [Christian Casale](#)).

Figure 4.1.4. Beach erosion and wind-induced damage to the building on the right of the image in Longboat Key, FL (Source: [Thomas Bender](#)).

Figure 4.1.5 shows damage to the lower level of a multi-story wood-frame building located next to the Steinhatchee Marina. Surge- and wave-generate slamming-induced uplift forces dislocated the balconies. Surge level reaching above the first floor caused extensive damage to the facades and other non-structural components. The building was elevated on a pile system anchored to a concrete slab; no damage was observed to the piles or the slab.

Figure 4.1.5. Damage to balconies, facades and other non-structural elements of elevated buildings in Steinhatchee, FL (Source: [Kathleen Flynn, Reuters]()).

4.1.2 Surge and Wave Damage to Non-Elevated Construction

By comparison, non-elevated structures along the Gulf Coast of Florida were severely damaged, displaced, or destroyed by the storm surge and wave action. Figures 4.1.6-4.1.8 present examples of these failures, which include complete dislocation from the foundation (Fig. 4.1.6) with corresponding structural damage (Fig. 4.1.7) as well as damage to exterior walls with foundation scouring (Fig. 4.1.8).

(a) Multiple dislocated homes damming against each other

(b) Dislocated home with accumulation of debris

Figure 4.1.6. Manufactured homes dislocated from their foundation in Steinhatchee, FL (Source: [Aaron Rigsby]()).

Figure 4.1.7. Dislocated non-elevated structure in Bradenton Beach on Anna Maria Island, FL (Source: Thomas Bender).

Figure 4.1.8. Non-elevated building with damaged exterior walls and foundation scouring in Manatee County, FL (Source: Manatee County Government).

4.1.3 Wind-Induced Damage

While Helene's wind speeds were well below the design wind speed for this region, some wind damage was observed across the landfall areas. Figure 4.1.9 shows one such example, a commercial building in Perry, constructed in 1980 per property assessor records, with extensive loss of the cladding attached to its parapets. Preliminary wind field estimates suggest the building likely experienced peak wind gust speeds of about 110 mph, which is below the current design level of 120 mph for typical structures at this location. Another observed mode of wind-induced damage was due to tree falls impacting structures (Fig. 4.1.10) -- a source of both structural damage and loss of life.


(a) Before (b) After

Figure 4.1.9. Wind damage to cladding of a commercial building in Perry, FL, (a) before and (b) after the storm (Source: [Mark Bello, Reuters](#)).


(a) Fallen tree on wooden roof structure (b) View from interior of structure

Figure 4.1.10. Wind-felled tree on single-story residential structure in Monticello, FL (Source: [ABC27-WTXL](#)).

4.2. Georgia

Table 4.2.1 provides a summary of impacts in the state of Georgia, mainly due to flash flooding and tornadoes spawned by Hurricane Helene. Areas in central and northern Georgia experienced severe riverine flooding, with the cities of Macon and Augusta particularly hard hit (Insurance Business Magazine, 2024). Wind damages included severe roof and structural failures, with evidence of debris impacts and tree falls into structures. Flooding compounded the damage in low-lying areas, leading to extensive property damage, with reports of partial collapse due to flood-induced damages (Fig. 4.2.1).

Figure 4.2.1. Peachtree Creek in Atlanta before (top left) and (top right) after heavy rains; aerial (bottom left) and ground-level (bottom right) post-tornado views (Source: [Ben Gary from the Atlanta Journal-Constitution](#)).

Table 4.2.1. Summary of Building Performance in Georgia, by Occupancy

Single-Family Residential Buildings	Many reports of wind-induced tree-fall affecting homes, along with minor wind damage to building envelope. Multiple people were killed in their homes by falling trees. Flood damage to single-family homes was also prevalent, particularly in northern GA.
Multi-Family Residential Buildings	Specific damage reports to multi-family residential buildings were limited, but several communities near Atlanta were affected by major flooding; a few buildings in Valdosta were observed with roof cover damage and tree-induced damage.
Commercial Buildings	Damage to commercial buildings appears to be isolated. In Valdosta, there were multiple reports of commercial buildings with wind damage to roof cover and facade elements, and one brick wythe masonry building experienced partial wall and roof collapse. Elsewhere, many commercial buildings were also likely affected by the flooding in North Georgia, but specific reports or observations are lacking.
Healthcare/Medical Facilities	Power outages affected some hospitals and healthcare facilities, but no observations of direct damage were found by the authors.

Schools	Power outages affected some school facilities. Tree-fall damage was noted in a few news reports in the Valdosta area. Minor roof cover damage was noted to some older school buildings in Augusta, GA. No observations of widespread damage to school facilities were found by the authors.
Government Facilities	Power outages affected some government facilities, but no observations of direct damage were found by the authors.
Mobile/Manufactured Homes	Two people were killed in a mobile or manufactured home that was flipped by a tornado in Wheeler County. Several people also died due to trees falling on their mobile/manufactured homes.
Critical Facilities	Minor interruptions in service were reported, but facilities remained operational.
Historical Buildings	Isolated wind damage to some historical structures reported in Valdosta, GA.
Religious Institutions	Damage to religious institutions does not appear to be widespread, but some reports were found of religious facilities that experienced tree-fall induced damage, collapse of steeples, flooding, and significant wall cladding damage.

4.2.1 Masonry Construction

Multi-wythe brick buildings sustained significant damage due to strong winds and flying debris. Older brick structures, particularly those not designed for high wind resistance, experienced partial wall cracking, separation of brick facades, and out-of-plane failures of load bearing masonry walls, as well as roof damage. Damages were compounded by floodwaters. Figure 4.2.2 provides one example, showing partial wall collapse of the Chez What building before and after hurricane Helene in Valdosta, GA.

Figure 4.2.2. Chez What building before (top) and after (bottom) Hurricane Helene in Valdosta, GA (Source: Dominick Del Vecchoi, FEMA, Thedesck.net).

4.3. North Carolina

Preliminary damage and needs assessments prepared by state officials in North Carolina report damage and devastation on an unprecedented scale to the state (OSBM, 2024). Thousands of single-family residential structures were destroyed in Helene-caused flooding in Buncombe, Haywood and Watauga counties. The affected residential housing stock is a blend of single family detached homes, mobile and manufactured homes, and cabins in mountainous areas, as well as multifamily units and apartments in urban areas like Asheville. Impacts of fast-moving flood waters with large debris ranged from non-structural and contents loss due to standing floodwaters to scouring of shallow foundations sited close to river banks to complete foundation detachment, transporting the structure downstream or complete destruction (Fig. 4.3.1). Mobile homes were particularly vulnerable to detachment from foundation and displacement by fast-moving flood waters (Fig. 4.3.2). Table 4.3.1 summarizes the observed building performance in North Carolina following Hurricane Helene, with the subsequent sections providing additional details on notable impacts.

Figure 4.3.1. Outstanding examples of ravaged buildings across different regions in North Carolina: (a) Mill Creek in Old Fort, a timber residential house has been detached from foundation and carried several feet away, has sustained out-of-plane damage and debris can be seen around it (Source: Sean Rayford—Getty Images), (b) house in Cruso at a close distance to the riverbank has been swept away due to severe scouring that compromised its structural integrity (Source: Reuters, Jonathan Drake), (c) Barnardville, a house and other debris was found downstream hundreds of feet from its original location (Source: Reuters, Jonathan Drake), (d) Chimney Rock Village, houses made of timber have been completely destroyed and displaced by strong currents (Source: Associated Press, Mike Stewart).

Figure 4.3.2. Examples of impacts to mobile homes in North Carolina: (a) in Swannanoa, mobile homes and vehicles displaced by flood waters, the footing structure for one of the mobile homes can be seen in the bottom right of the picture (Source: Associated Press Photo, Mike Stewart), (b) mobile home in Cruso, swept away by surging creek (Source: Reuters, Jonathan Drake), (c) in Old Fort, vehicle and mobile home pushed into tree line (Source: Getty Images, Melissa Sue Gerrits), (d) in Barnardsville, a trailer home completely deformed and destroyed by the impacts of flooding (Source: Reuters, Jonathan Drake).

Table 4.3.1. Summary of Building Performance in North Carolina, by Occupancy

Single-Family Residential Buildings	Inland flooding caused catastrophic single-family residential structure failures. Damage results from tree fall impacts, floating debris, and out-of-plane failure of walls due to ramming forces from water flow and large debris. Structures were also shifted off ground piers and foundations. Some foundations suffered scouring failures and soil liquefaction.
Multi-Family Residential Buildings	Inland flooding completely destroyed some multi-family structures, including buildings being washed off the foundation and completely collapsed.
Commercial Buildings	Commercial buildings, primarily constructed using unreinforced

	masonry walls sustained severe damage, primarily out-of-plane wall failures. Larger commercial buildings appear to have at least experienced severe flood levels if not further damages.
Healthcare/Medical Facilities	Health care facilities across western North Carolina, including hospitals, nursing homes, adult care centers, family clinics, mental health services, and community health facilities, were forced to scale back operations due to flooding, structural damage, and power and water outages. Prolonged outages forced many hospitals onto backup generators, and about 145 facilities had to evacuate. Hurricane Helene also disrupted the medical supply chain, with damage to Baxter International's Marion plant causing a nationwide IV fluid shortage.
Schools	Several schools were destroyed, and many others sustained damage from flooded classrooms, structural issues, and power outages. Road and water system destruction in surrounding areas further prolonged closures. Ten K-12 school districts shut down for over 10 days, while 82 public schools, two community colleges, and one UNC institution remain closed for extended periods.
Government Facilities	No significant damage is reported.
Mobile/Manufactured Homes	Severe damages from strong winds, flood waters and floating debris impacts. Many were reported swept away by flash flooding that overcame minimal resistance of weak or non-existent connections of the superstructure to the ground. The high-water levels displaced many structures hundreds of feet from their pre-storm locations.
Critical Facilities	Water and wastewater systems sustained extensive damage, including water treatment plants, leaving numerous communities and emergency response facilities without essential services.
Historical Buildings	Reportedly, many of the old factory-repurposed buildings in the River Arts District, Asheville, NC were still structurally intact, although they experienced severe flooding. No further observations available for this class at time of this report.
Religious Institutions	Reported structural damage to masonry perimeter walls and wood-stud walls in several churches located in Asheville and Vilas, NC due to flooding and mudslide.

4.3.1 River Arts District, Asheville, North Carolina

Extreme water levels were recorded in Asheville's creative hub: the River Arts District (Fig. 4.3.3). This once industrial zone, is a vibrant business area supporting artists and creatives, with numerous galleries, restaurants and boutiques. Reports suggest that 80% of the district's buildings were damaged or destroyed due to a record-setting high 24-ft flood level on the nearby

French Broad River (Coffey, 2024). Figure 4.3.4 shows the flood level at a one-story brick bearing wall building located within the River Arts District, and its condition before, during and after the flood.

Figure 4.3.3. Flooded region before and after in the River Art District, Asheville, North Carolina (Source: Google Street View (before) and [@nctradlines / Reuters](after)).

Figure 4.3.4. The images on the left focus on a specific building (building 99 - Second Gear and Sugar and Snow Gelato, Asheville, North Carolina) within the district, that was repurposed to host commercial stores. The water levels reaching close to the roof can be seen in the upper right image and out-of-plane failure for one of the walls is visible in the bottom right photo. (Source: Google Street View (pictures before) and Citizen Times, Jacob Biba and detail of damage from Glen Miska (pictures after)).

4.3.2 Chimney Rock-Bat Cave, North Carolina

The small communities of Chimney Rock and Bat Cave, located in Rutherford County within the Hickory Nut Gorge of the Blue Ridge Mountains along the Rocky Broad River, experienced severe flooding due to the region's steep terrain and proximity to rivers. Structural failures due to fast-moving flood waters (Fig. 4.3.5) were observed; more prominent was the scouring of foundations and unseating of buildings located on river banks (Fig. 4.3.6-4.3.7).

Figure 4.3.5. Two-story timber structure in downtown Chimney Rock collapsed due to fast-moving flood waters. The flow of the water along the graded road in front of the damaged building is also indicated with a black arrow (Source: Google Street View (top), bottom right from James Spann via Threads, bottom left WSOC-TV).

Figure 4.3.6. Severe scouring effects on the riverbanks of Rocky Broad River in Bat Cave, North Carolina. (Source: Google Street View (before) and starting from top left and going clockwise: New York Times, Christian Monterrosa, and the right two from Reuters, Marco Bello).

Figure 4.3.7. Four different locations in Bat Cave, North Carolina: (a) (Source: Sean Rayford/Getty Images) and (b) (Source: New York Post, Ben Hendren) are locations along the Rocky Broad River area that experienced unprecedented flood levels that resulted in extreme scouring/erosion that swept entire houses made of timber, (c) landslides also caused damages to houses like the one shown here (Source: video from Forbes Breaking News) and (d) houses were also detached from foundations and were found stranded several feet away (YouTube video by Blaine Chappell).

4.3.3. Tornado Impacts

An EF1 tornado was reported in Blowing Rock, NC that caused roof damage and failures due to flying debris, falling trees and aerodynamic loads. Another short-lived tornado struck the city of Rocky Mount, in Nash County, causing up to EF-3 damage along a 0.1-mile path through the downtown region (Fig. 4.3.8). The tornado struck multiple occupied restaurants, resulting in 15 reported injuries, but fortunately no fatalities (Moore & Adam, 2024). The National Weather Service estimated peak wind speeds of 140 mph.


Source: The News & Observer

Source: The News & Observer

Source: WRAL News

Figure 4.3.8. Several commercial structures were destroyed in downtown Rocky Mount, NC by an EF-3 tornado (Sources: inset photographs from [Raleigh News & Observer](), base aerial image from [WRAL News]()).

4.4 Other States

Hurricane Helene impacted many other states, including Tennessee and South Carolina. Impacts were reported as far north as Kentucky and Virginia. In southwestern Virginia, torrential rains led to widespread evacuations across seven counties as rivers like the New River crested at dangerously high levels, surpassing 24 feet in some areas. More than 47 homes and businesses were reported as damaged or destroyed (Lucas, 2024)

Hurricane Helene also brought catastrophic flooding and damage to Erwin, Tennessee, particularly as the Nolichucky River overflowed, inundating homes, businesses, and even the Unicoi County Hospital. Figure 4.4.1 shows the extent of the floodwaters from all sides of the medical facility. The hospital faced an urgent crisis as floodwaters rose rapidly, forcing staff and patients to seek refuge on the roof, ultimately requiring airlifting by helicopter (Trethan and Loria, 2024).

Figure 4.4.1. Unicoi County hospital impacted by flooding along the French Broad River in Erwin, TN (Source: Wade Payne/Associated Press).

5. Infrastructure Performance

The following section summarizes the infrastructure performance of the areas affected by Hurricane Helene with Table 5.1 providing a high-level summary of each infrastructure class by location (Florida, Georgia, North Carolina, and other states). A more in-depth discussion of power and transportation network performance is presented in the sections that follow, with subsequent sections presenting case studies for these locations. Readers may refer to the imagery compiled in the accompanying Media Repository, curated with this report in DesignSafe, to access a richer collection of georeferenced visual evidence cataloged by infrastructure class. The Outage/Restoration Database is also curated with this report in DesignSafe and provides a chronology of disruption/outage/restoration data for power, telecommunications, and transportation networks.

Table 5.1. Summary of Performance by Infrastructure Class

Power and Telecommunications Infrastructure	Impacted a total of 1,608,798 customers in multiple states across the U.S. **Florida:** Multiple fallen power lines, power lines hanging near the road, affected gas stations. **North Carolina:** Multiple fallen power lines.
Airports	**Florida:** Interrupted service to pipeline carrying fuel to Orlando

	International Airport. The airport made use of 10-day supply available. **North Carolina:** No reported airport damage/closure
Roads & Bridges	**Florida:** Multiple sections of FL-789 and Cortez Road. Damage on bridges in Tampa Bay and Englewood. **North Carolina:** Over 1,000 roads and bridges, including major routes like I-40, were damaged or closed due to flooding and landslides, cutting off residents from external assistance and communication. Railways were also damaged in Asheville; multiple collapsed bridges along I-64. **Other States:** Damage in I-40 from Tennessee to North Carolina.
Other Lifelines	**Florida:** 21 water treatment systems serving 12 Florida counties issued boil-water orders. **North Carolina:** 160 boil water advisories were issued and 27 water plants were not producing water. **Tennessee:** 17 water treatment plants impacted.
Port Facilities	**Florida:** Damage to the waterfront (Safety Harbor) and pier and deck (Madeira Beach). **North Carolina:** No observations available for this class at time of this report.
Agricultural	**Florida:** Multiple damage to agricultural buildings. **North Carolina:** No observations available for this class at time of this report.

5.1. Power Outages & Restoration

Figure 5.1 depicts the daily total number of customers reporting power outages, along with the record peak outage numbers; the peak outage reached 5.94 million customers. The most severely impacted states include Florida, Georgia, South Carolina, and North Carolina. South Carolina experienced the highest number of outages with 1,372,295 customers affected. Florida and North Carolina followed, reporting 1,323,821 and 1,004,273 outages, respectively.

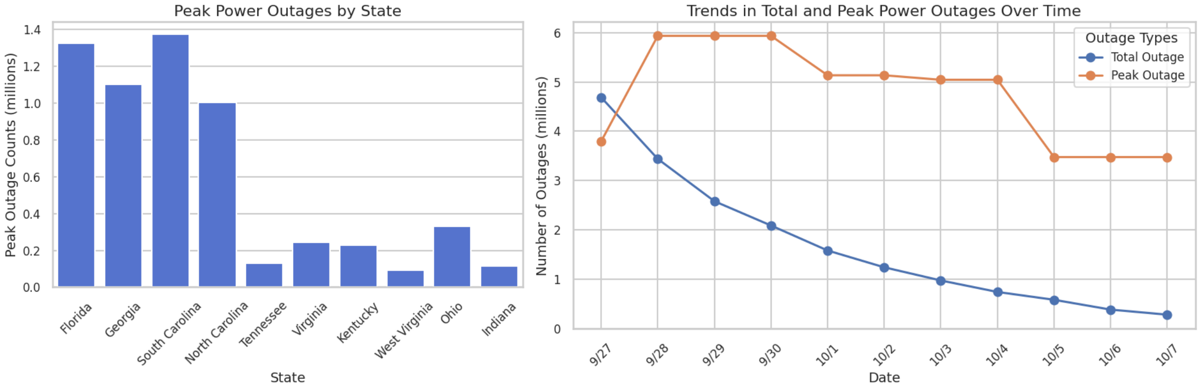

Figure 5.1. Peak power outage and the trend of Total outage change by states at 4 pm on Oct. 1st. Data source: Department of Energy, Office of Cybersecurity, Energy Security, and Emergency Response.

Figure 5.2 also shows the rate of restoration across the affected states, with North Carolina, South Carolina, and Georgia facing the most significant challenges in achieving full power restoration. Appendix B lists the peak outage and restoration status as of October 7, 2024.

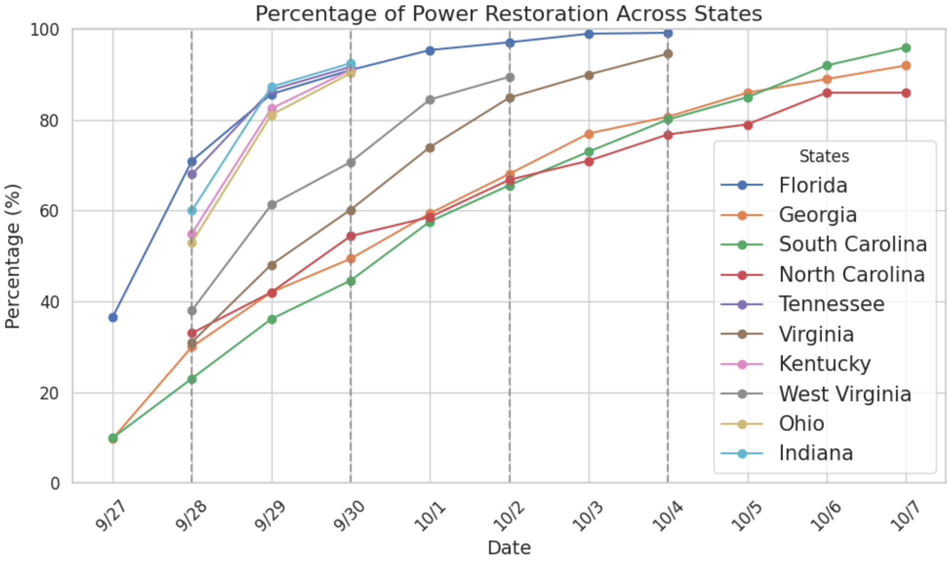

Figure 5.2. Trend of the percentage of power outage restoration and percentage of power outage ending at 4 pm on Oct. 7th (Data source: Department of Energy, Office of Cybersecurity, Energy Security, and Emergency Response).

5.2. Transportation Disruptions & Restoration

Hurricane Helene caused disruptions to transportation infrastructure across multiple states. Beyond flooding that rendered roads impassable, some transportation elements sustained structural damage. Flooding caused degradation or compromise of subsurface pavement layers, some of which may not be apparent from surface observations. A summary of the affected roads in each state is presented in Table 5.2; the sections that follow provide additional descriptions of the transportation impacts in each state. A number of these transportation failures were instigated by geotechnical failures: compromised coastal roadways and bridges in Florida and Georgia and inland roadways and railways in North Carolina and Tennessee; these are discussed more extensively in Section 6.

Table 5.2. Summary of Transportation Disruption by State

State	**Transportation infrastructure disrupted**
Florida (FL)	Parts of FL-789 and Cortez Road Multiple bridges damaged (Tampa Bay, Englewood)
Georgia	Erosion and slope failures due to flooding and heavy rainfall; landslides and road washouts.
North Carolina (NC)	Over 1,000 NC roadways were closed in Western North Carolina with severe disruptions in Asheville, NC Multiple road closures in Northwestern NC, across 19E and 221 Multiple bridges collapsed (I-64) Many sections along 50 miles of Norfolk Southern’s rail line between Marshall and Old Fort through Asheville were washed away.
Tennessee (TN)	Northeastern TN, along I-26, passed 107 Multiple roads covered with debris in Erwin Collapsed bridges (I-26) Extensive transportation disruptions and roadway damage in Washington, Carter, Unicoi, Johnson, Greene, and Cocke counties. Kinser Bridge over Nolichucky River on Highway 107 collapsed
Interstate Impacts	Multiple damage to I-40 from TN to NC More than 40 miles of CSX’s Railroad between Erwin, TN and Spartanburg, SC, lost, including two bridges

5.2.1. North Carolina Road & Rail Failures

With regards to infrastructure performance on a system level, western North Carolina was catastrophically impacted by heavy rain and extreme flooding. More than 1000 roadways were closed due to severe flooding. Multiple roads, including major highways, were washed out and isolated some areas from the rest of the state. By Friday, September 27th, highway signs in North Carolina were urging the public to not drive west as NCDOT had an advisory out for the entire region (Fig. 5.4). According to Apple Maps, Asheville, NC, the largest city in the region, was closed off for days: I-26, south out of Asheville, opened September 30th and I-40 eastbound out of Asheville opened October 1st. However, the more rural towns like Boone, remained isolated even longer. Those that relied on a single road in and out of town remained isolated eventually required pack mules to bring in supplies (USA Today, 2024). In addition, many sections along 50 miles of Norfolk Southern's line between Marshall and Old Fort through Asheville were washed away. With modern railway networks having limited redundancies, these failures are impacting the efficiency of freight travel by requiring rerouting of hundreds of miles (Gunnoe, 2024).

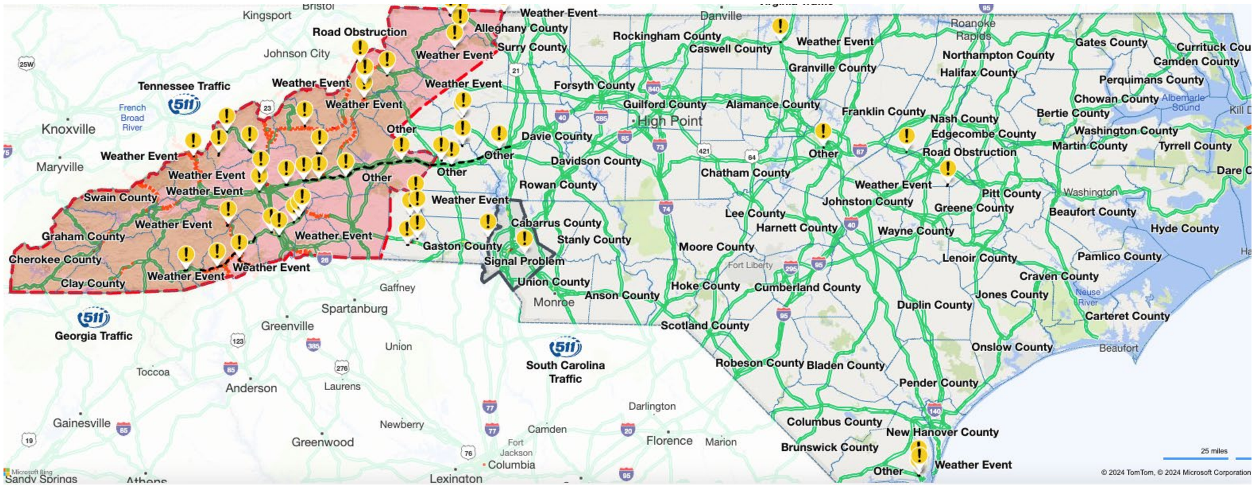

Figure 5.4. Western North Carolina advisories from the NCDOT.

5.2.2. Case study: I-40 Washout between North Carolina and Tennessee

Interstate 40, a major interstate highway between North Carolina and Tennessee, was washed out at multiple locations over a more than 30 mile stretch of I-40 along the Pigeon River. North Carolina Emergency Management's downstream gauge read a peak of 20-ft during the event, with another nearby gauge on the Cataloochee Creek registering a "moderate" flood stage (accessed via FINMAN on 10/07/2024). The flood severely eroded the subsurface soil, resulting in partial collapse of road segments that were subsequently washed away by the river (Fig. 5.5). In other locations, road drainage systems were exposed and/or failed.

Figure 5.5. Damage to I-40 near the TN/NC border (photos from helicopter video posted to X, and photos posted to Threads).

5.2.3. Dam Performance

Dams in multiple states were stressed by the high volume of rainfall. The opening of the Cowan Dam's floodgates, just west of Charlotte, NC, led to a flash flood downstream. Another dam to the west, the Lake Lure Dam, was also overwhelmed causing flash flooding and at one point was anticipated to fail. While the dam remained intact, the high flood waters resulted in erosion at its abutments (Jackson & Grubb, 2024). The Nolichucky Dam in Tennessee's Greene County experienced erosion at its abutments after being similarly overwhelmed (Fig. 5.6). The dam reached a Condition Red Warning (Jarnagin, 2024), with the Tennessee Valley Authority (TVA) reporting an over 30,000 cu.ft./sec flow rate (TVA, 2024).

Figure 5.6. Overtopping of the Nolichucky Dam with erosion damage (Photos from Tom Satkowiak via X).

6. Geotechnical Performance

This section provides a written synthesis of the geotechnical issues, largely induced by flooding, presented by state in the following sections. Some of these failures were previously discussed in Section 5.2.2. Readers may consult the imagery compiled in the accompanying Media Repository, curated with this report in DesignSafe, to access a richer collection of georeferenced visual evidence.

6.1. Coastal Flooding Failures

Coastal areas in Georgia and Florida reported erosion issues along the shoreline (Fig. 6.1). Sand deposition was also significant along the Florida Gulf Coast, e.g., along Gulf of Mexico Drive on Longboat Key and roadways on Anna Maria Island (Figs. 6.2 and 6.3, respectively). Gulf Boulevard (FL-699) in the Tampa Bay area experienced similar levels of sand deposition, where Florida Department of Transportation (FDOT) crews removed nearly 50,000 cubic yards of sand

and debris. These roadways were impassable for several days following the landfall of Hurricane Helene.

Figure 6.1. Asphalt pavement and soil subgrade washed away by Hurricane Helene storm surge (Source: FDOT West Central - Tampa Area).

Figure 6.2. Gulf of Mexico Drive on Longboat Key (Source: Thomas Bender/Sarasota Herald-Tribune).

Figure 6.3. Roadways on Anna Maria Island (Source: [Jesse Mendoza/Sarasota Herald-Tribune and Manatee County Government]).

6.2. Inland Flooding Failures

Across multiple states, bridges and roadways were undermined by floodwaters, with scouring around bridge abutments or erosion of underlying unbound granular layers of roadways diminished their load-bearing capacity, resulting in widespread failures. A cross-section of such failures in North Carolina is presented in Figure 6.4 depicting failures in Southport, Hot Springs and Rutherford County, as well as impacts to NC 211, NC 105 in Watauga County, and US 17 in Brunswick County. Similar failures were observed in Tennessee (Fig. 6.5). Railways, particularly in North Carolina, were extensively damaged by similar mechanisms (Fig. 6.6). Landslides and mudslides also played a considerable role in road closures, particularly in North Carolina, where an estimated 626 landslides were reported. Notable among these were the multiple landslides and mudslides in McDowell County along I-40, examples of which are provided in Figure 6.7.

Figure 6.4. Geotechnical failures of roadways in North Carolina: (a) East Moore Street, (b) Hot Springs, (c) N.C. 211, (d) Hwy 105, (e) Rutherford County, (f) sinkhole (Source: CBS17, RBP, Foxweather, 11Alive).

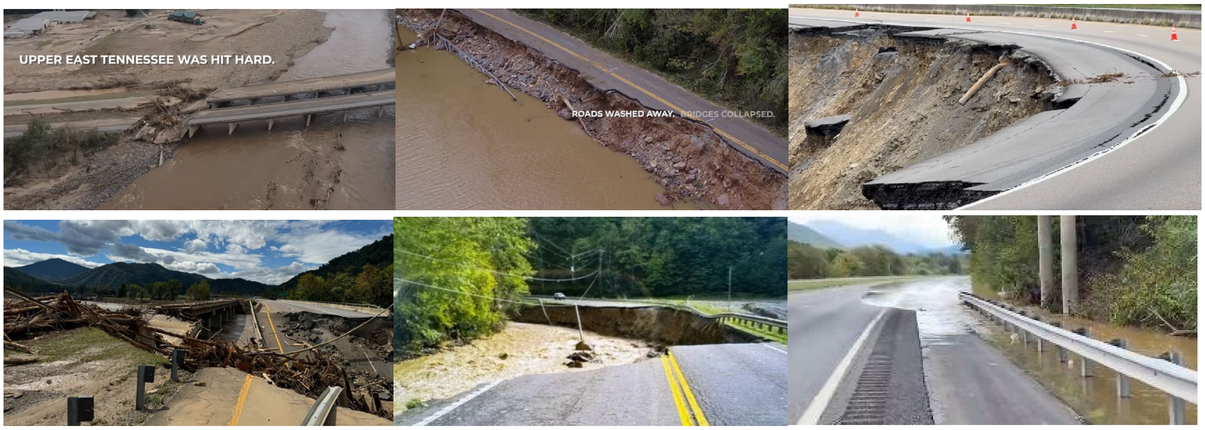

Figure 6.5. Examples of roadway failures due to geotechnical issues in Tennessee (Source: WSMV, WBIR, The Guardian).

(a) (b)

Figure 6.6. Example of Landslides in North Carolina: (a) I-40 near Old Fort and (b) I-40 near Black Mountain (Source: Clayton Henkel on NC newsline).

Figure 6.7. Undercutting of railway tracks in Asheville, NC (Source: Nate on X.com)

7. Coastal Protective Systems Performance

While no levee breaches or seawall collapses were reported along the Gulf Coast of Florida, the seawall in St. Petersburg was overtopped causing flooding. The hurricane did heighten concerns in the Palmetto Beach neighborhood of Tampa over potential deterioration of its seawall constructed in 1921 (Will, 2024). Readers may consult the imagery compiled in the accompanying Media Repository, curated with this report in DesignSafe, to access a richer collection of georeferenced visual evidence.

8. Recommended Response Strategy

Based on the information gathered by this Preliminary Virtual Reconnaissance Report (PVRR), StEER offers the following recommendations for future study.

TOPIC I. Non-stationary hurricane risk: Over the past two Atlantic Hurricane seasons, multiple hurricanes have impacted the Big Bend coast of Florida, each with different characteristics and landfalling in areas previously considered low-risk based on prior historical events. These events underscore the limitations of existing models in predicting storm risk, as the past no longer reliably forecasts the future. Compounding effects from consecutive storms further complicates risk forecasting based on past data. Furthering the research opportunities highlighted in the wake of Hurricane Otis (Balderrama Garcia Mendez, et al. 2024), there remains the need to re-examine hurricane hazard maps for both wind and storm surge and incorporation of climate projections that better anticipate hazard intensities under future climate scenarios, particularly for areas less frequently impacted by major hurricanes.

TOPIC II. Drivers of Catastrophic Loss in North Carolina

Hurricane Helene has tested many societal systems by triggering cascading hazards emanating from an unprecedented intensity of rainfall, exacerbating a prior condition of heavily saturated soils and rivers at or near flood levels. This resulted in widespread destruction of buildings and loss of life. Decades of land use, development decisions, floodplain management strategies, and infrastructure investments made such impacts possible. Understanding how these choices have been amplified by the changing climate is crucial for future resilience and adaptation planning.

- **II.1: Flood Risk Mitigation:** A systematic, interdisciplinary study of structures in affected riverine floodplains should be conducted to determine the factors that contributed to the observed failures and instigating causes from high-velocity flows to debris fields to identify what measures, if any, could have been taken to better protect lives and property under such high intensity rainfall events. Such strategies should consider floodplain management and zoning requirements, slope and bank stabilization strategies, and flood control measures including flash flood diversion techniques. The study should compare risk drivers and mitigation measures to those identified for the eastern half of North Carolina after Hurricane Matthew (2016), further examining the effectiveness of any policies or actions in the recovery from that storm. Studies should include cost-benefit analyses to determine the feasibility of mitigative measures and would necessarily engage hydrologists, geotechnical engineers, structural engineers and social scientists. A similar examination of the failures of the state's water and wastewater systems, transportation network and power grid would be equally warranted.
- **II.2: Risk Communications:** Helene reiterates the importance of heeding warnings, despite prior storm experiences. The failure to do so cost many lives. Both coastal storm surge in Florida and interior Appalachian flooding were predicted well in advance – and efforts to improve the reliability and lead time of such predictions must continue within the meteorology community. Those predictions enabled officials and other local actors to issue actionable guidance on how to prepare and mobilize support for the most vulnerable. Citizens need to heed that guidance. As the climate changes, there will be more extreme rainfall events. These storm events will exceed past precedent. An after-action review of the sequence of warnings and emergency preparedness actions, including messaging, should be conducted to determine the best preparedness guidance, how best to deliver that guidance, and which trusted actors should be engaged.
- **II.3: No-named Storms Impact:** Evidence suggests that warnings for Hurricane Helene were not fully heeded, partly because the preceding storm lacked a formal name. Unnamed storms are often perceived as lower risk, even when conditions like saturated soils and elevated river levels increase the potential for severe impacts from subsequent events as observed in Helene. Additionally, communities may be less responsive to warnings if prior unnamed events caused minimal damage, leaving them more vulnerable when a major storm like Helene strikes further inland from the coast. To address these issues, a systematic investigation is needed to understand how unnamed storms shape communities' perceptions of infrastructure vulnerability and preparedness for subsequent hazards. Insights from such research should inform the development of more effective

warning systems that combine social-science-based messaging with traditional hazard-based warnings—such as flood depth and wind speed– enhanced by infrastructure vulnerability forecasting. This multidisciplinary approach can enhance public understanding and readiness for future events.

TOPIC III. Housing vulnerability

Even in states like Florida with some of the most rigorous building codes, there is no mandate to upgrade homes built before those codes were enacted. As expected, non-elevated buildings in coastal inundation zones of Florida suffered extreme to complete damage, while those with sufficient freeboard were relatively undamaged. With mandated retrofits unlikely, questions remain regarding how to best protect vulnerable properties or when necessary, retreat. That is only possible when the growing risk and cost of living in hazard-prone areas is honestly and clearly communicated to the public in multi-generational terms.

- **III.1: Cost-Benefit Analysis of Mitigation**: A systematic evaluation of the performance of structures built to the Florida Building Code and meeting freeboard requirements in comparison to those not built to such standards should be conducted to monetize the impacts of mitigation. This should differentiate damage and loss associated with structural damages due to storm surge and wave action from those associated with the loss of cladding and non-structural elements. Studies may particularly target areas without CCCL line provisions. Cases of both new construction and retrofitted structures built to the Florida Building Code or to code-plus standards like IBHS Fortified should be included in this analysis. Availability of costing data can enable such a study to substantiate the cost-benefit ratios initially projected by the National Institute of Building Sciences (MMC, 2019).
- **III.2: Cost-Effective Retrofitting Strategies:** Retrofitting for coastal, and flood hazards, more broadly is prohibitive and lacking necessary policy mechanisms and financial instruments. This event could provide a notable case study to examine the cost effectiveness of various strategies to address existing construction with insufficient freeboard. These include quantifying the impact of grey and green coastal protection and other community resilience-based interventions compared to elevating of individual structures. A key consideration is whether there is any benefit to individual action -- elevating one's home -- if surrounding homes are not retrofitted and thus continue to adversely impact or isolate the elevated property in future storm events. The study may reveal potential new pathways or opportunities to address lingering housing vulnerabilities responsible for mounting losses -- and the technical and societal requirements to make them feasible.

TOPIC IV: Future Reconnaissance Needs

- **IV.1: Large-Scale Reconnaissance:** The large expanse of Hurricane Helene's damage path underscores the need to advance post-disaster reconnaissance techniques to more efficiently capture performance data across a large geography under multiple, potentially compounding hazards, and in more remote areas where reliable baseline inventory data may not be available and where permanent weather monitoring data may be scarce. Such data will be vital to developing multi-physics models capable of reproducing failure mechanisms and to inform economic modeling needed to ensure the intergenerational sustainability of communities through alternative policies for retrofitting and, when necessary, community relocation.

- **IV.2: Overland Flow Measurement:** The development of measurement techniques that can either directly or forensically measure overland flows can be helpful to determining the flow characteristics and load demands that precipitated the observed damage mechanisms.

ESCALATION DECISION

Having satisfied over 87.5% of the escalation criteria (see Summary in Table 8.1), **StEER's response to this event is escalated to Level 2**. A Field Assessment Structural Team (FAST) will be deployed to begin rapid assessment of the affected region using car-mounted panoramic imaging systems. The imaging campaign will be led by Florida-based contractor Site 360 capturing imagery in Dekel Beach, Keaton Beach, Cedar Island, Dark Island, Steinhatchee, Horseshoe Beach, Suwannee and Cedar Key. A Level 3 escalation is expected to follow.

Table 8.1. Summary of Escalation Criteria

Hazard	Exposure	Feasibility
● Design-level event ● Unique hazard characteristics	● Infrastructure of interest ● Community impacts ● Downtime or recovery issues	● Resources ● Access and safety

Appendix A: Tornado Observations

Table A.1. Chronological Summary of Tornado Events Associated with Hurricane Helene (Sources: National Weather Service, Columbia, SC, 2024; Iowa Environmental Mesonet, 2024)

No.	Date	Time	Rating	Max Wind Speed (mph)	Path Length (miles)	Max Path Width (yds)	Location (County, State)
1	26-Sep	4:09	EF0	80	2.3	50	Burke, GA
2	26-Sep	6:09	EF0	80	6.7	150	Beaufort, SC
3	26-Sep	6:09	EF0	76	1.3	100	Beaufort, SC
4	26-Sep	9:09	EF1	65	0.5	30	Coffee, GA
5	26-Sep	9:09	EF1	95	13.4	0	Orangeburg, SC
6	26-Sep	11:09	EF1	90	0.4	75	Wilkes, NC
7	26-Sep	11:09	EF1	90	7.8	150	Colleton, SC
8	26-Sep	19:09	EF0	85	0.3	50	Alamance, NC
9	26-Sep	21:09	EF0	80	1.3	50	Clarendon, SC
10	26-Sep	23:09	EF1	90	33.1	800	Orangeburg, SC
11	27-Sep	0:09	EF0	84	13.8	500	Orangeburg, SC
12	27-Sep	0:09	EF0	70	3.9	175	Beaufort, SC
13	27-Sep	0:09	EF1	90	14	710	Calhoun, SC
14	27-Sep	3:09	EF0	80	2	90	Charleston, SC
15	27-Sep	3:09	EF0	80	2.1	125	Charleston, SC
16	27-Sep	3:09	EF0	80	17	1200	Orangeburg, SC
17	27-Sep	3:09	EF0	70	2	90	Charleston, SC
18	27-Sep	3:09	EF1	90	2.5	150	Charleston, SC
19	27-Sep	3:09	EF1	90	2.5	150	Charleston, SC
20	27-Sep	3:09	EF0	77	1.5	180	Orangeburg, SC
21	27-Sep	4:09	EF0	75	4.6	1000	Sumter, SC
22	27-Sep	4:09	EF0	75	0.3	50	Clarendon, SC
23	27-Sep	5:09	EF0	65	2.4	20	Georgetown, SC

24	27-Sep	6:09	EF0	60	3.9	20	Marion, SC
25	27-Sep	6:09	EF1	0	3.2	100	Sampson, NC
26	27-Sep	6:09	EF0	65	6.7	20	Marion, SC
27	27-Sep	10:09	EF0	75	5	30	Bladen, NC
28	27-Sep	12:09	EF3	140	0.2	100	Nash, NC
29	27-Sep	14:38	EF2	118	0.7	50	Dry Folk, VA
30	27-Sep	15:25	EF1	90	0.35	50	Stoneville, VA
31	27-Sep	16:11	EF1	105	1.24	150	Bedford, VA
32	27-Sep	17:09	EF1	105	6.85	225	Vance, NC

Appendix B: Power Outage and Restoration, by State

State	**Peak Outage**	**Restoration Status as of Oct. 7**
Florida	1,323,821	99% restoration (less than 10000 customers without power)
Georgia	1,100,015	92% restoration
South Carolina	1,372,295	96% restoration
North Carolina	1,004,273	86% restoration
Tennessee	128,592	99% restoration (less than 10000 customers without power)
Virginia	243,827	99% restoration (less than 10000 customers without power)
Kentucky	226,810	99% restoration (less than 10000 customers without power)
West Virginia	91,399	99% restoration (less than 10000 customers without power)
Ohio	330,464	99% restoration (less than 10000 customers without power)
Indiana	114,114	99% restoration (less than 10000 customers without power)
Source: DOE (2024) Hurricane Helene Situation Reports		

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