HURRICANE DORIAN

September 1, 2019

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PRELIMINARY VIRTUAL RECONNAISSANCE REPORT (PVRR)

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PREFACE

The National Science Foundation (NSF) awarded a 2-year 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 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. StEER works closely with other extreme event reconnaissance organizations and the Natural Hazards Engineering Research Infrastructure (NHERI) to foster greater potentials for truly impactful interdisciplinary reconnaissance after disasters.

Under the banner of NHERI's CONVERGE node, StEER works closely with the wider Extreme Events Reconnaissance consortium including the Geotechnical Extreme Events Reconnaissance (GEER) Association and the networks for Nearshore Extreme Event Reconnaissance (NEER), Interdisciplinary Science and Engineering Extreme Events Research (ISEEER) and Social Science Extreme Events Research (SSEER), as well as the NHERI RAPID equipment facility and NHERI DesignSafe CI, long-term home to all StEER data and reports. While the StEER network currently consists of the three primary nodes located at the University of Notre Dame (Coordinating Node), University of Florida (Atlantic/Gulf Regional Node), and University of California, Berkeley (Pacific Regional Node), StEER aspires to build a 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 cross-cutting areas of Assessment Technologies and 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, leading StEER's Pacific Regional node and 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, leading StEER's Atlantic/Gulf Regional node and serving as primary liaison to the Wind Engineering community.
- **Ian Robertson (co-PI),** University of Hawai'i at Manoa, serves as StEER Associate Director for Assessment Technologies, guiding StEER's development of a robust approach to damage assessment across the hazards.
- **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.

ACKNOWLEDGMENTS

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StEER recognizes our continued coordination with Manny A. Perotin, PE, FEMA MAT and Senior Project Manager with CDM Smith, whose exchange of information and perspective is always valued. Special thanks also go to Dinah Lawan, StEER Student Administrator, for her assistance in formatting the references. The contributions of StEER members Bilal Assaad and Wilfrid Djima to this document are also appreciated.

The sharing of videos, damage reports, data sources, observations 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/products

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EXECUTIVE SUMMARY

On September 1, 2019, Hurricane Dorian made landfall on Elbow Cay in the Bahamas at 16:40 UTC with sustained winds of 185 mph (295 km/h), wind gusts up to 225 mph (360 km/h), and a central pressure of 910 mb, tying Dorian with the 1935 Labor Day hurricane for the strongest sustained winds observed in a landfall in the Atlantic Basin. Shortly thereafter, Dorian made a second landfall in the Bahamas at Marsh Harbour on Great Abaco Island before continuing westward across Grand Bahama Island. After nearly two days pummeling Grand Bahama Island, setting records for the longest duration over land at a Category 5 intensity, Dorian approached the US in a weakened state with its most notable impacts confined to flooding and tornadoes in the Carolinas. The devastation to the Bahamas is staggering and driven in large part by storm surge, in excess of an estimated 20 feet above mean sea level in some locations. While dozens have been confirmed dead at the time of this report's release, the storm made landfall in informal settlements on Great Abaco Island that were home to a large number of undocumented migrants. Considering this along with the large number of yet accounted for documented citizens suggests the death toll is likely to substantially rise and may never be confirmed. Meanwhile, the survivors face a wide-spread humanitarian crisis with significant food and water deficits affecting more than 60,000 residents of Abaco and Grand Bahama Islands.

Preliminary losses (insured and uninsured) are estimated at $7B, not yet accounting for infrastructure losses. Rapid assessments suggest that more than 13,000 houses, or about 45% of the homes in Grand Bahama and Abaco, were likely severely damaged or destroyed. Significant impacts to healthcare facilities, airports, roadways and power infrastructure in Grand Bahama and Abaco islands have also been extensively documented. The full extent of damage to infrastructure in this event is likely obscured by the massive debris field instigated by Dorian's storm surge as well as the limited access to some of the most heavily affected areas. Specifically, the damage to major harbors and airstrips has posed significant logistical challenges for rescue, evacuation, recovery and humanitarian efforts currently unfolding across the two major affected islands, as well as a number of smaller islands and cays.

Hurricane Dorian thus offers the opportunity to investigate a powerful storm's impact over multiple geographies. The storm's slow evolution and sustained intensity presented numerous challenges in forecasting and preparation and imposed incredible stresses upon the built and natural environments as well as its victims. While in no way diminishing Dorian's impact on the Carolinas, the careful examination of properties in the Bahamas with little to no damage in this record-breaking event can serve as an important validation of design and construction practices. This **Preliminary Virtual Reconnaissance Report (PVRR)** represents StEER's first step in the process of learning from this disaster by (1) providing an overview of Hurricane Dorian's impact on the built environment, including the effects of its hurricane-force winds, coastal storm surge and cyclone-induced tornadoes, (2) overviewing the regulatory environment and construction practices in the Bahamas, (3) summarizing the preliminary reports of damage to a range of building and infrastructure classes, (4) establishing current conditions in the Bahamas with respect to access and services, and (5) providing recommendations to inform the continued study of this event.

1.0 Introduction

On September 1, 2019, Hurricane Dorian made landfall on Elbow Cay in the Bahamas at 16:40 UTC with sustained winds of 185 mph (295 km/h), wind gusts up to 225 mph (360 km/h), and a central pressure of 910 mb, tying Dorian with the 1935 Labor Day hurricane for the strongest sustained winds observed in a landfall in the Atlantic Basin (Fedschun, 2019). Shortly thereafter, Dorian made a second landfall in the Bahamas at Marsh Harbour on Great Abaco Island before continuing westward across Grand Bahama Island, where the storm's pace slowed to 1 mph. After nearly two days pummeling Grand Bahama Island, setting records for the longest duration over land at a Category 5 intensity, Dorian approached the US in a weakened state, hovering between Category 2-3 intensity as it continued its slow trek parallel to the Atlantic coast of Florida the week of September 2. By September 5, the effects of the storm were evident in the Carolinas, as Dorian continued to weaken to a Category 1, just brushing the coast of North Carolina, about 35 miles southeast of Wilmington. While not directly landfalling in the US, Dorian spawned tornadoes, triggered flash flooding, and delivered hurricane-force winds and life-threatening storm surge as it continued its slow trek along the North American Atlantic Coast toward Canada. Hurricane Dorian is part of a larger trend of tropical cyclones with reduced forward speeds caused by disruptions in the atmospheric circulation patterns that steer these weather systems, attributed to the warming of the atmosphere (Hall and Kossin, 2019). Devastating effects of stalled hurricanes like the remnants of Harvey and now Dorian are speculated to become increasingly common. While states from Florida all the way to Virginia have had some effect from Dorian, the sections that follow will focus on the hurricane's impact in the Bahamas, as well as the storm's implications for South and North Carolina.

1.1 Societal Impact

1.1.1 Societal Impact: Bahamas

On the islands where Dorian made direct landfalls (Elbow Cay, Grand Abaco and Grand Bahama Islands), the Bahamian National Emergency Management Agency (NEMA) estimates some 76,000 people were exposed to damaging winds (UN OCHA, 2019). Projections based on this level of exposure to damaging winds (see Fig. 1.1) suggests catastrophic losses of land cover and destruction of approximately a quarter of the housing stock in the Bahamas (IFRC, 2019), though it is unlikely this analysis was capable of factoring in Dorian's considerable storm surge and sustained exposure to damaging wind and waves. Even this basic analysis of wind-exposed populations suggests a significant shelter, food and water deficit for tens of thousands of residents on both Abaco and Grand Bahama Islands (UN OCHA, 2019). This was affirmed in the early days of damage assessments as the Red Cross estimated more than 13,000 houses, or about 45% of the homes in Grand Bahama and Abaco, were likely severely damaged or destroyed with about 62,000 people on these islands without clean drinking water (TWC, 2019a). UN officials said more than 60,000 are in need of food. Preliminary losses (insured and uninsured) were estimated by Karen Clark & Company at $7B inclusive of buildings, contents and business disruption for commercial, residential and industrial properties. A projection by island is presented in Figure 1.2.

This does not include infrastructure and auto losses (KCC, 2019). Much of the residential losses speculated to be uninsured (Campo-Flores and Ailworth, 2019).

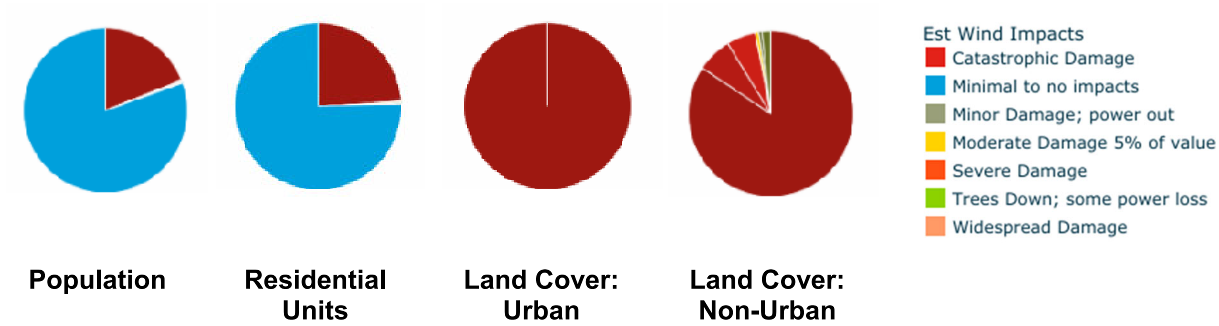

Figure 1.1. Projected wind-induced impacts to population, residential units and land cover (IFRC 2019).

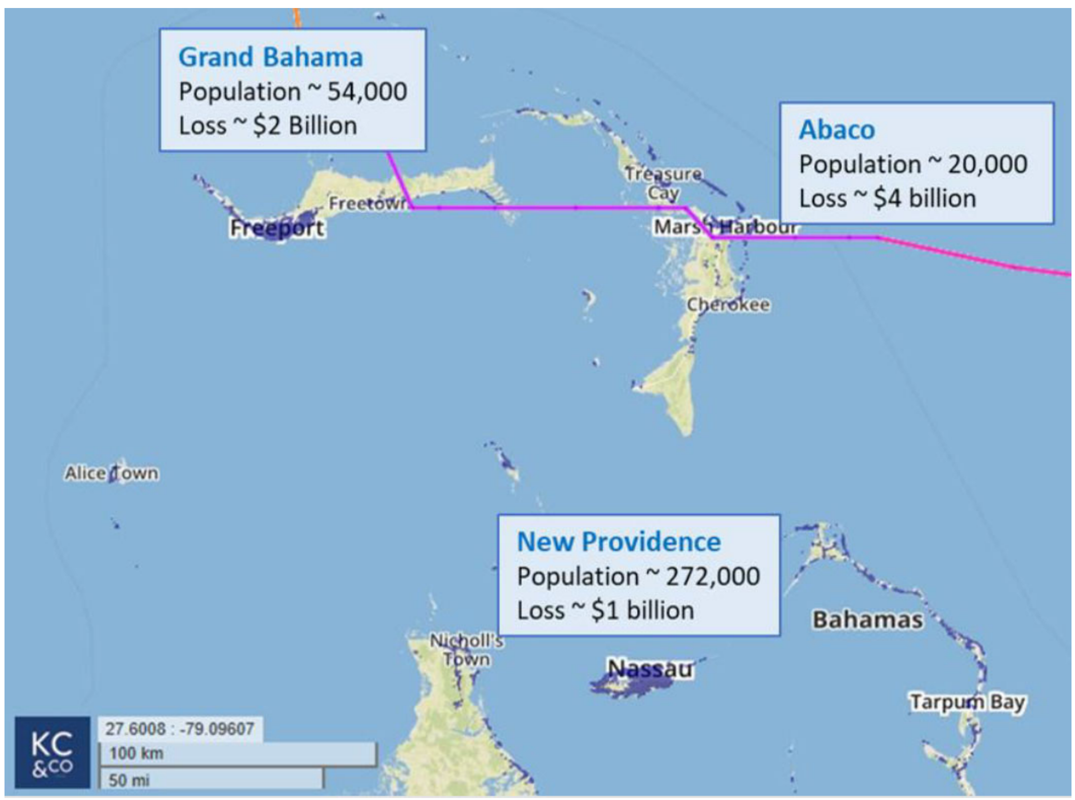

Figure 1.2. Preliminary loss estimates: total (insured and uninsured) losses to residential, commercial and industrial properties. Infrastructure and auto losses not included (KCC, 2019).

1.1.2 Societal Impact: United States

The impacts of Hurricane Dorian in the southeastern United States were largely confined to flooding and power outages, along with some wind damage due to a few cyclone-induced tornadoes. The coastal city of Charleston, SC, with an elevation of 20 feet above sea level and frequently afflicted with nuisance flooding, reported widespread flooding due to Dorian's rains and storm surge (Fig. 1.3). The Spatially Generalized Hurricane Power Outage Model (Guikema et al., 2014) predicted that 4 million US citizens lost power in Hurricane Dorian, with the spatial distribution of outages provided in Figure 1.4.

Figure 1.3. Flood damage to buildings in Charleston, SC (Source: https://www.instagram.com/p/B2BMAqYhfyl/).

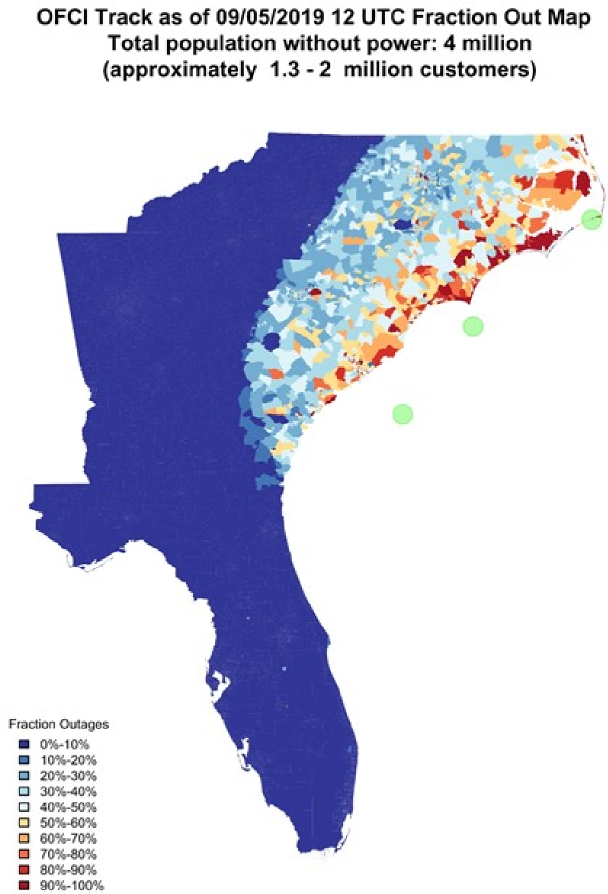

Figure 1.4. Spatial distribution of power outages across the southeast U.S. (Source: http://ioe-guikema.engin.umich.edu/Hurricane_Dorian.html).

1.2 Loss of Life & Human Impacts

1.2.1 Loss of Life & Human Impacts: Bahamas

As of September 10, 2019, fifty are confirmed dead in the Bahamas (Fageson et al., 2019), but this number is expected to be far higher with many still missing (Democracy Now!, 2019). Officials anticipate a large death count in large part due to the presence of two informal settlements in Marsh Harbour - The Mudd and Pigeon Peas - that experienced the worst of Dorian's winds and storm surge. These communities were primarily populated with immigrants, many of them undocumented. Some 70,000 traumatized survivors in desperate need of food and shelter, with nothing but wreckage encircling them and no way to communicate, are now overwhelmed by the prospect of rebuilding their lives. In the Abaco Islands, that process began simply by leaving: to date 3500 survivors have been transported by ferry to Nassau and thousands are evacuating by boat and plane to Florida, while others remain in the remnants of their communities in the only homes they have ever known (CBS News, 2019).

1.2.2 Loss of Life & Human Impacts: United States

Four fatalities in the US (3 in Florida, 1 in North Carolina) have been attributed to Dorian, all occurring during preparations for the storm (BBC, 2019). An additional death, associated with an existing medical condition, occurred in Pamlico County, NC (for a US total of 5) as a man attempted to secure his boat prior to the storm (Gilbert, 2019). Residents of Ocracoke Island, in the North Carolina Outer Banks, where 800 persons sheltered in place during the Hurricane, were stranded by a road failure, discussed later in Section 6.0, and continue to receive air lifts of provisions (Helsel and Burke, 2019).

1.3 Official Response

1.3.1 Official Response: Bahamas

This section reviews the official response to Hurricane Dorian in the Bahamas, which is still unfolding and will continue to expand both in the number of actors and strategy given the catastrophic damages. Appendix A offers a detailed reconstruction of the response timeline.

1.3.1.1 Preparations and Warnings

On August 28, the Emergency Operation Centre (EOC) in Grand Bahama was activated by NEMA, and, in a subsequent press release, Prime Minister Thompson urged residents of Abaco, Grand Bahama and Berry Islands to secure their houses and businesses before the hurricane (Fig. 1.5a). Government offices and schools were ordered closed. On August 30, voluntary evacuations started in Abaco and Grand Bahama via ferry boats and aircraft (Ward and Faiola, 2019a). While Bahamasair offered discounted rates to those seeking to leave the islands on flights before Dorian on August 30 and 31[1] (Fig. 1.5b), evacuation of low-lying archipelagos like the Bahamas is a logistically challenging and costly prospect. Prime Minister Thompson appealed to the northern cays and the North Abaco mainland to move to safer ground in the south. Residents of flood-prone areas, including informal settlements like The Mudd and Pigeon Pea in Abaco, about 70% of which are Haitian migrants[2], were urged to seek shelter during the storm[3]. Reports from survivors indicated many did not respond to the evacuation warnings, for a variety of reasons (Feliciano, 2019). The Prime Minister strongly urged "all residents of East End, West End, Sweetings Cay and Waters Cay on Grand Bahama Island migrate to the interior of the island for the duration of the storm. Dozens of residents were evacuated from Grand Cay by boat leading up to landfall. With many remaining on their islands, shelters were activated across the archipelago (Fig. 1.6)[4]. Unfortunately, during Hurricane Dorian's passage over the Grand Bahama, one of these shelters lost its roof after a window was opened. Occupants re-evacuated to a nearby church, reported as one of the few shelters on Grand Bahama that did not collapse or flood (Faiola et al., 2019).

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[1] https://www.facebook.com/242news/photos/a.191082291304823/707229643023416/?type=3&theater
[2] https://twitter.com/MalindaSmith/status/1168297116810133504?s=20
[3] Official Press Release, August 28, www.bahamas.gov.bs
[4] https://www.facebook.com/242news/posts/707874616292252?__tn__=K-R

bahamasair

We don't just fly here, we live here.

URGENT PUBLIC NOTICE

RE: ***HURRICANE DORIAN – ADVISORY 2***

ISSUED: ***Friday – August 30, 2019***

Bahamasair wishes to advise the traveling public of the following adjustments to the schedule based on new projected path and movement of Hurricane Dorian:

FREEPORT	For all those persons wishing to leave Grand Bahama due to the approaching storm, Bahamasair will provide a special fare of $150 round trip. Passengers seeking to travel to or from Grand Bahama must depart either today (Friday, August 30) or tomorrow (Saturday, August 31). Restrictions Apply. ***URGENT REMINDER: Please be reminded that the last flight into Ft. Lauderdale scheduled for this afternoon will not be pre-cleared by local US Customs and Border Protection and will be processed in the United States. PASSENGERS NOT HOLDING A US VISA WILL NOT BE PROCESSED.***
MARSH HARBOUR	Additionally, for persons wishing to leave Abaco due to the approaching storm, Bahamasair will provide a special fare of $150 round trip for service out of Marsh Harbour only. Again, passengers seeking to travel to or from the island must depart either today (Friday, August 30) or tomorrow (Saturday, August 31). Restrictions Apply. ***Be reminded that the Leonard Thompson International Airport will close at 3:00pm Saturday, August 31.***
ACKLINS/ CROOKED ISLAND	The flight normally scheduled for 8:30am Saturday, August 31 will be rescheduled to depart at 11:00am. All passengers booked on this flight are urged to take note of the time change.
NORTH ELEUTHERA	Bahamasair reminds those booked or ticketed passengers for our North Eleuthera flight normally scheduled for Saturday afternoon note that this flight has been rescheduled to leave Nassau at 9:00am with the return flight departing at 9:50am on Saturday, August 31.
FLORIDA STATIONS (MIA/MCO/FLL/WPB)	As of Sunday, September 1 all flights into our US stations will be suspended until further notice. Bahamasair will provide periodic updates regarding the status of these airports and resumption of service.

All ticketed passengers who wish to further alter their travel itineraries as a result of the Storm, will be allowed to do so penalty free for a period of thirty (30) days starting from yesterday Thursday, August 29. Bahamasair encourages the public to remain vigilant and attentive for further public advisories as we work to keep our passengers updated.

Tracy J. Cooper
Managing Director – Bahamasair

For Comments or Inquiries please contact:
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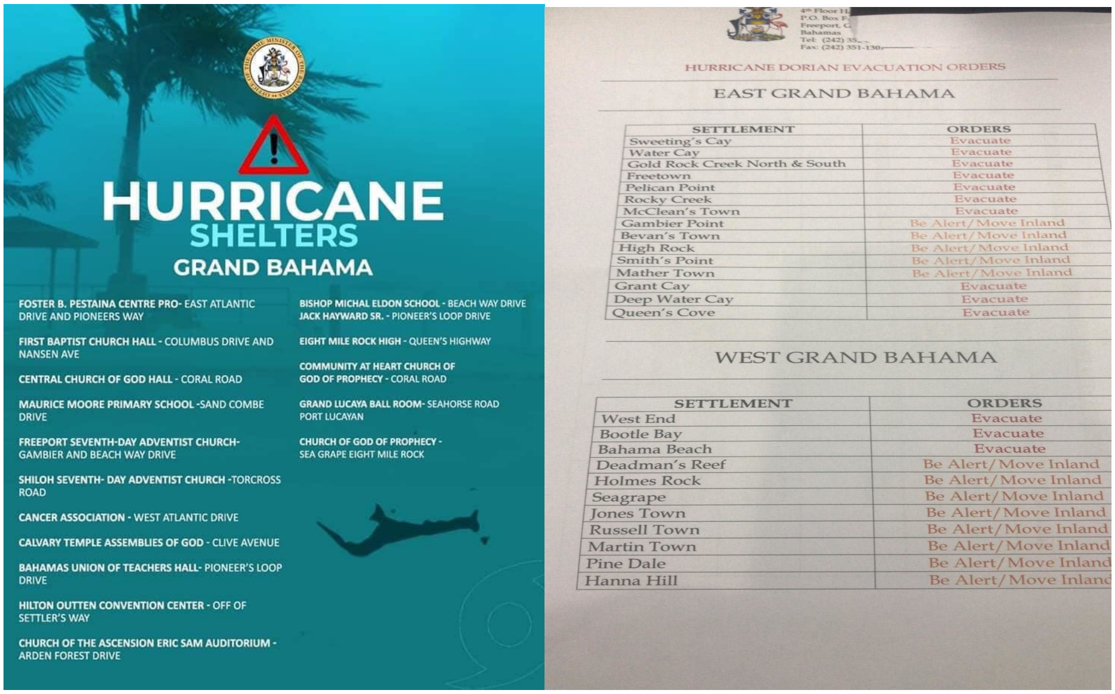
Stephen Gay stephen@bahamasair.com
Telephone: (242) 702 4113

(a) (b)

Figure 1.5. (a) Residents secure their house in Marsh Harbour (Source: Washington Post); (b) discounted rate advisory from Bahamasair (Source: Bahamasair).

As the storm lashed Abaco and Grand Bahama Islands for more than 36 hours, social media began circulating videos documenting the rising waters in many homes. Some residents were eventually trapped in their attics[5] or on their roofs by the rising storm surge. The storm's slow progression left these victims trapped in dark, flooded and life-threatening conditions for days. It is anticipated that the death toll reported in Section 1.2.1 will likely rise considerably as bodies of the drowned who sheltered-in-place in their homes are recovered.

[5] Video from residents trapped in unfinished attic in home flooded to the soffit level on Grand Bahama Island: https://twitter.com/i/status/1168599030261325825



HURRICANE DORIAN EVACUATION ORDERS

EAST GRAND BAHAMA

SETTLEMENT	ORDERS
Sweeting's Cay	Evacuate
Water Cay	Evacuate
Gold Rock Creek North & South	Evacuate
Freetown	Evacuate
Pelican Point	Evacuate
Rocky Creek	Evacuate
McClean's Town	Evacuate
Gambier Point	Be Alert/Move Inland
Bevan's Town	Be Alert/Move Inland
High Rock	Be Alert/Move Inland
Smith's Point	Be Alert/Move Inland
Mather Town	Be Alert/Move Inland
Grant Cay	Evacuate
Deep Water Cay	Evacuate
Queen's Cove	Evacuate

WEST GRAND BAHAMA

SETTLEMENT	ORDERS
West End	Evacuate
Bootle Bay	Evacuate
Bahama Beach	Evacuate
Deadman's Reef	Be Alert/Move Inland
Holmes Rock	Be Alert/Move Inland
Seagrape	Be Alert/Move Inland
Jones Town	Be Alert/Move Inland
Russell Town	Be Alert/Move Inland
Martin Town	Be Alert/Move Inland
Pine Dale	Be Alert/Move Inland
Hanna Hill	Be Alert/Move Inland

(a) (b)

Figure 1.6. (a) List of the shelters available in Grand Bahama (Source: 242 News Bahamas); (b) Evacuation orders and warnings released on August 30 (Source: 242 News Bahamas)

1.3.1.2 Response and Recovery

Rescue and recovery operations were largely impeded by the storm's slow progression through Grand Bahama Island, as well as weather systems after the Dorian's passage that continued blowing winds ashore in the Abaco Islands, preventing the flood waters from receding. The substantial debris, including parts of roofs, buildings and submerged boats, clogged waterways, making coastal depths unpredictable and navigation charts unreliable. These conditions only compound the understandable logistical challenges of rescue efforts spread across a number of islands in the archipelago whose main points of access (air or harbor) have themselves been significantly damaged. A number of international vessels are ready to assist by sea and assessment teams and provisions are mobilizing from Nassau. Unfortunately, the damage to airports in both Marsh Harbour and Freeport have both delayed the delivery of critical humanitarian aid and more critically the medical evacuation of injured patients.

The following summarizes the cooperative efforts that are currently unfolding through various governmental and non-governmental authorities at the national, regional and international level:

- As of August 31st, the Caribbean Disaster Management Agency (CDEMA) assumed the lead coordination role for the Regional Response Mechanism in support of the Bahamas (CDEMA, 2019), staging its assessment teams in Nassau with representation from CDEMA (Antigua and Turks and Caicos), Caribbean Media Corporation, Caribbean Public Health Agency (CARPHA), Pan American Health Organization (PAHO), Port Managers Association of the Caribbean (PMAC), private sector, United nations Office for the Coordination of Humanitarian Affairs (UNOCHA), the University of the West Indies (UWI),

and World Food Programme. A number of other international and regional governmental and non-governmental organizations are also mobilizing to assist.
- UN staff were pre-deployed in Nassau as part of a United Nations Disaster Assessment Coordination Team[6].
- On September 1, the European Commission's Copernicus emergency satellite mapping service was activated to provide satellite maps for the Abaco Islands[7].
- As of September 1, the Bahamian Department of Social Services (DOSS) was placed on full alert to respond to victim's needs; the DOSS team in Grand Bahama has been supplemented with recruits from the Royal Bahamas Police Force.
- As of September 2nd, the Bahamian NEMA is leading response coordination out of Nassau[8]. NEMA issued a list of shelters for each district on August 1, 2019 (Government of the Bahamas, 2019), which was revised September 2, along with an online survey for crowd-sourced damage and condition reports[9].
- As of September 2, 2019, US Coast Guard was assisting in Abaco and transporting the injured to Princess Margaret Hospital on New Providence (Bahamas Local, 2019)
- Rapid Assessment Teams from NEMA, the Red Cross and Bahamian Ministries of Health, National Security, Social Services and Works are working toward the heaviest impacted areas (Bahamas Local, 2019).
- The Bahamas Red Cross has requested assistance from the IFRC with some of its existing assets prepositioned to Grand Bahama Island before landfall; assessments were set to initiate on September 4 (IFRC, 2019).
- The Government of the Bahamas has also requested that the Food and Agriculture Organization of the United Nations perform an initial damage assessment.
- The Bahamian Government is forming a Hurricane Relief and Recovery Committee and authoring Exigency Orders to allow relief supplies from registered charitable organizations to enter the affected areas free of customs duty and VAT (Bahamas Local, 2019).

1.3.2 Official Response: United States

US preparations for Hurricane Dorian spanned a number of states for nearly a week as projections of the slow-moving storm's track were refined. Before Hurricane Dorian reached the United States, Florida, Georgia, South Carolina, North Carolina, and Virginia declared states of emergency, facilitating deployment of resources and personnel to prepare populations projected to be affected (Daugherty, 2019). Also, federal disaster declarations were requested by Florida (August 28th), Georgia (August 29th), South Carolina (August 31st), and North Carolina (September 1st)[10]. As Hurricane Dorian approached the United States, several states enacted mandatory evacuations:

- Mandatory evacuations were ordered for sixteen coastal Florida counties (Maxouris and Levenson, 2019). The state opened 85 general shelters and 25 special needs shelters. 93 nursing homes and assisted living facilities along the coast were evacuated. Seven hospitals fully evacuated and 1 hospital partially evacuated.

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[6] Source: GDACS / UNOCHA - GDACS message boards
[7] Source: EU - https://erccportal.jrc.ec.europa.eu/ECHO-Flash/ECHO-Flash-List/yy/2019/mm/09
[8] Source: GDACS - GDACS message boards
[9] https://survey123.arcgis.com/share/51622a76aecd4f579777ebd760d283c4
[10] https://www.fema.gov/disasters

- Georgia Governor Kemp issued an executive order requiring mandatory evacuations for six counties on 2 September[11]. The executive order also required Georgia Department of Transportation to establish westerly contraflow to allow evacuations to proceed more quickly.
- South Carolina Governor McMaster filed an executive order enacting a mandatory evacuation, including healthcare facilities, in eight coastal counties on 2 September[12]. The South Carolina Department of Transportation established westerly contraflow in the state to allow evacuations to proceed more quickly.
- North Carolina Governor Cooper ordered a mandatory evacuation of all barrier islands along the coast on September 4th (Fox 8 Staff, 2019).
- Parts of Virginia Beach were ordered to evacuate prior to Hurricane Dorian reaching the area (CBS 6 Staff, 2019).
- According to a September 3rd press release from the American Red Cross[13], over 12,200 people sheltered at 171 Red Cross and community evacuation shelters in Florida, Georgia, and South Carolina on the night of September 2. 11,700 of these stayed in 142 Florida shelters, 280 stayed in 10 Georgia shelters, and 290 people stayed in 19 South Carolina shelters.

1.4 Report Scope

Hurricane Dorian offers the opportunity to investigate a powerful storm's impact over multiple geographies. The storm's slow evolution and sustained intensity presented numerous challenges in forecasting and preparation and imposed incredible stresses upon the built and natural environments as well as victims who endured nearly two days of exposure to life-threatening wind, rain and storm surge. These conditions in the Bahamas led to considerable devastation, hindered response and recovery efforts, and have given rise to a dire humanitarian crisis. Building and infrastructure performance under such a record-breaking event (with respect to duration of exposure to winds of a Category 5 intensity) is an important learning opportunity for natural hazards engineering researchers. Although arriving with lesser intensity in the Carolinas, it is nonetheless important to document the impacts of this historic storm on the United States for completeness.

As such, the first product of the StEER response to Hurricane Dorian is this **Preliminary Virtual Reconnaissance Report (PVRR)**, which:

1. provides an overview of Hurricane Dorian's impact on the built environment, including the effects of its hurricane-force winds, coastal storm surge and cyclone-induced tornadoes,
2. overviews the regulatory environment and construction practices in the Bahamas,
3. summarizes the preliminary reports of damage to a range of building and infrastructure classes,

[11] Official Press Release: https://gov.georgia.gov/press-releases/2019-09-01/ahead-hurricane-dorian-gov-kemp-orders-evacuation-six-counties-starting

[12] https://governor.sc.gov/executive-branch/executive-orders

[13] Press release: https://www.redcross.org/about-us/news-and-events/press-release/2019/12-000-people-in-evacuation-shelters-as-red-cross-prepares-for-hurricane-dorian.html

4. establishes current conditions in the Bahamas with respect to access and services, and
5. provides recommendations to inform the continued study of this event.

The sections that follow will examine the hazard characteristics and impacts of Hurricane Dorian across multiple geographies, continuing the format introduced in Section 1: first documenting the impacts to the Bahamas with particular emphasis on the Abaco and Grand Bahama Islands, followed by a summary of impacts to the southeastern United States with emphasis on South and North Carolina. It is important to note that the situation in the Bahamas is extremely dire and continuously evolving. The discussions that follow represent the situation at the time this report was authored by StEER's Virtual Assessment Structural Team (VAST).

2.0 Hazard Characteristics

2.1 Meteorological Background

The following sections describe Hurricane Dorian's evolution through the Caribbean and along the Atlantic Coast of the United States through the Carolinas. Advisories issued by the National Hurricane Center form the basis for the following discussion related to the meteorological background and development of Hurricane Dorian (NHC 2019b). See CIRA and Weather Underground for additional details of the storm's characteristics throughout its evolution.

2.1.1 Early Development

As illustrated in Figure 2.1, Dorian began as Tropical Depression #5 in the south Caribbean and was upgraded to Tropical Storm Dorian on August 24, 2019. Dorian was first classified as a Category 1 Hurricane at around 2:00 pm (Eastern Daylight Time) on August 28, 2019 when it was near St. Thomas in the U.S. Virgin Islands. Puerto Rico and the Virgin Islands did feel the effects of Dorian but the impacts were minor. Once the storm moved away from Puerto Rico, it maintained a NW heading until it started turning towards the West at approximately 11:00 am EDT on August 30, 2019. During this stretch Hurricane Dorian was in open waters where it began to gather strength. At approximately 2:00 pm EDT on August 30, 2019, Dorian was classified as a Category 3 Hurricane with hurricane winds extending approximately 25 miles from the center of circulation and a central pressure of 970 MB. It was upgraded to a Category 4 about 6.5 hours later with a pressure of 950 MB. As it neared the Bahamas, it further strengthened to a Category 5 Hurricane on the Saffir-Simpson Scale at 8:00 am EDT on September 1, 2019 with a pressure of 927 MB and hurricane winds extending out 30 miles. Hurricane Dorian first made landfall on Elbow Cay just to the east of Great Abaco Island.

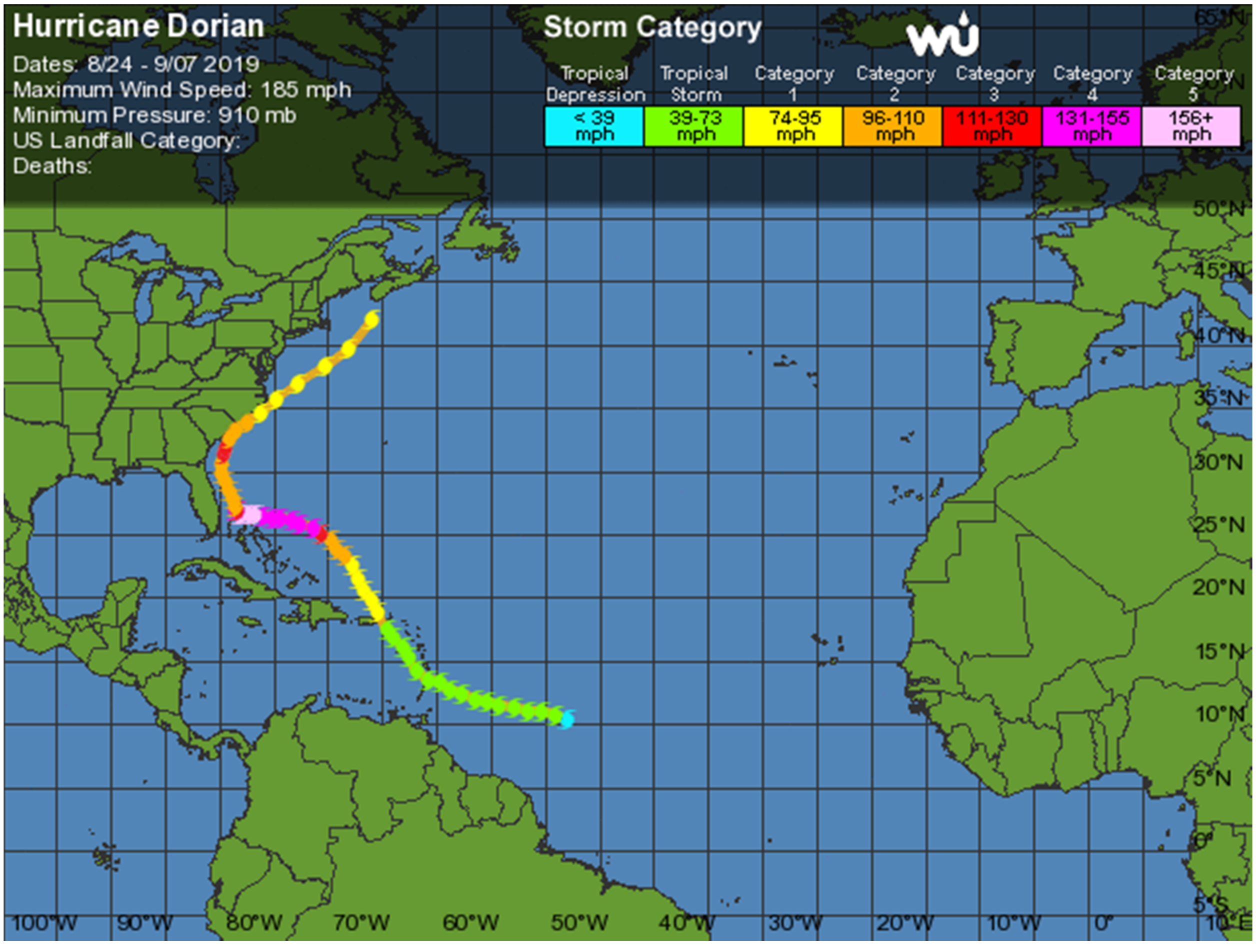


Figure 2.1. Hurricane Dorian's Track from Tropical Depression to Landfall in the Northwestern Bahamas (Source: Weather Underground)

2.1.2 Landfall on Abaco Islands

Hurricane Dorian made landfall on Elbow Cay at 12:40 pm local time as a Category 5 storm, with a central pressure of 910 mb, maximum sustained wind speeds of 185 mph, wind gusts up to 220 mph (NHC 2019b). Shortly thereafter, Dorian continued west and made landfall on Great Abaco Island (see Fig. 2.2). The Category 5 storm eyewall approached the island around 9:30 am EDT on September 1. At that time, the storm was moving at 8 mph nearly due west. During the entire time Dorian was traversing Great Abaco it maintained its status as a Category 5 storm. At 11:00 am EDT, with 180 mph sustained speeds and 913 MB pressure, Dorian became the strongest storm in modern records to hit the Northwest Bahamas. The sustained wind speed reached as high as 185 mph with gusts in excess of 220 mph. In addition to the increased wind speed, the translational speed of the storm decreased during the time it was affecting Great Abaco Island. By the time the eyewall was approaching the east end of Grand Bahama Island at 9:00 pm EDT on September 1st, the translation speed had reduced down to 5 mph. The time-stamped evolution of Hurricane Dorian across the Abaco and Grand Bahama Islands is documented in Figure 2.3. The resulting storm surge is reported later in Section 2.2.1.

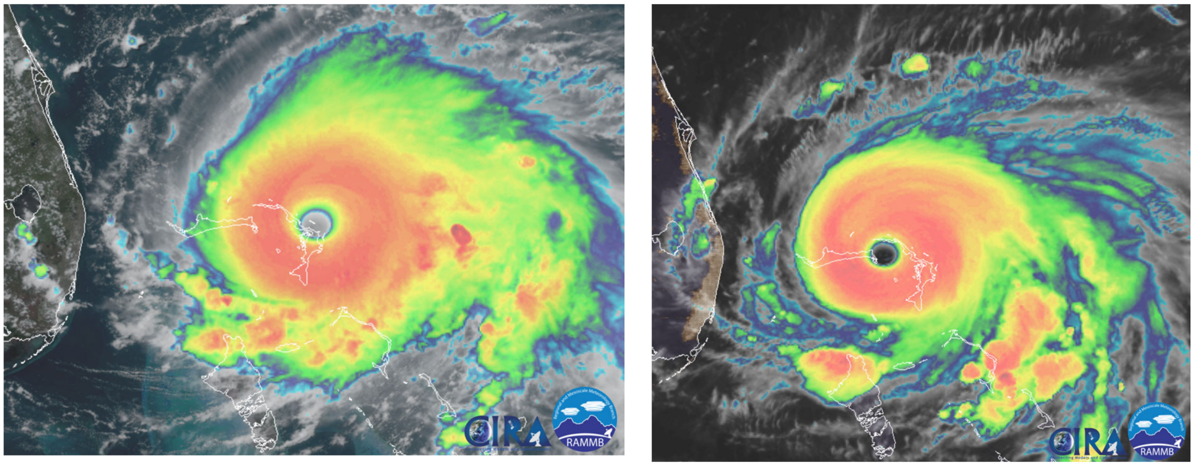


Figure 2.2. Band 13 Infrared from GOES-16 as Dorian makes landfall near (left) Great Abaco, Bahamas at 1800 UTC and (right) Grand Bahamas at 0300 UTC (imagery captured via CIRA/RAMMB).

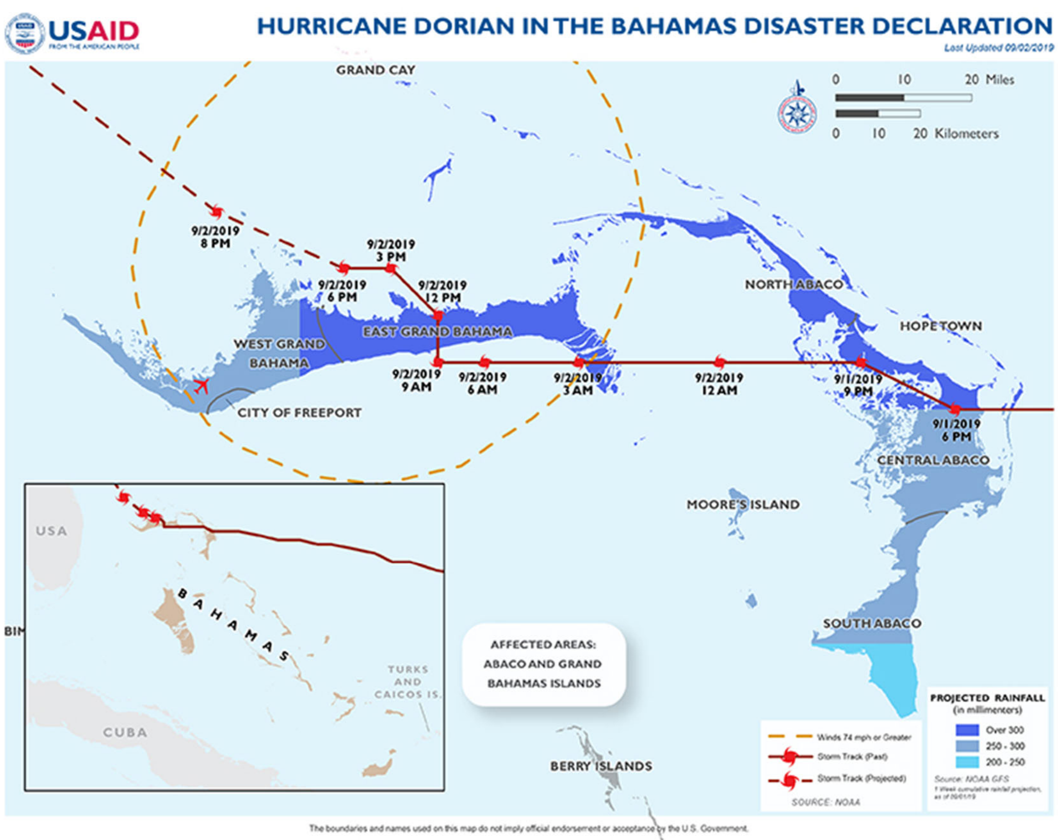


Figure 2.3. Evolution of Hurricane Dorian in the northern Bahamas (Source: USAID, https://www.usaid.gov/crisis/hurricane-dorian)

2.1.3 Landfall on Grand Bahama Island

The leading edge eyewall of Dorian arrived on the east end of Grand Bahama Island around 10:00 pm EDT (Figure 2.4). It was moving nearly due west at a speed of 5 mph with a central pressure of 915 MB and sustained wind speeds of 180 mph (NHC, 2019b). By around 3:00 pm EDT the translational wind speed had slowed to 2 mph with wind speeds reduced to 170 mph with gusts still around 200 mph. The storm continued to slow reaching a speed of 1 mph by 4:00 am EDT. It maintained this crawling speed across Grand Bahama while the wind speed continued to decrease. Through this time, it maintained heading nearly due west. At approximately 5 pm EDT on September 2nd, Dorian was classified as a stationary storm. This classification continued, with the storm moving very little until 8 am EDT on September 3 when it began moving at 1 mph along a NW heading. The eyewall of Dorian was finally north of Grand Bahama around 1 pm EDT. Even though the eye of the hurricane was off the island, significant winds and storm surge continued as the hurricane moved towards the southeastern United States. It was not until 5:00 am EDT on September 4th that all Tropical Storm Warnings were discontinued for the Grand Bahama Island. The slow movement of Dorian over the Bahamas caused large portions of the Grand Bahamas and Abaco Islands to experience Category 3 (or higher) wind speeds and ensuing storm surge (discussed later in Section 2.2.1), for over 12 hours, as shown in Figure 2.4.

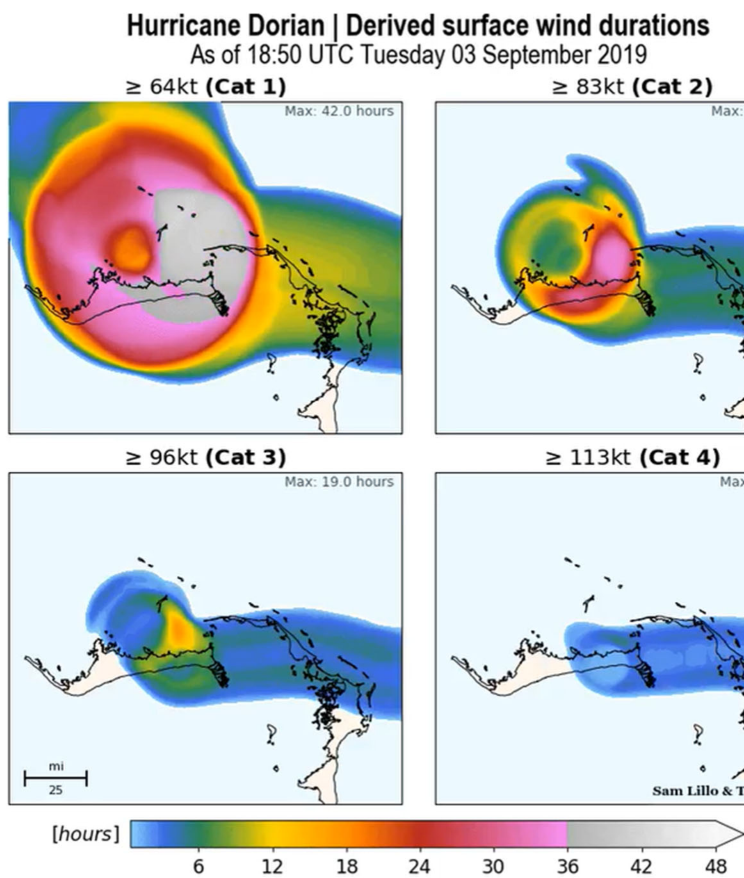


Figure 2.4. Wind duration swaths in the Grand Bahamas and Abaco Islands, estimated by Sam Lillo and Toomer Burg from NOAA reconnaissance data and satellite center fixes.

2.1.3 Progression along US Coast

Dorian left the Bahamas on a NW heading with a translational speed of 5 mph and sustained wind speeds of 110 mph. It generally paralleled the Florida coastline maintaining its direction, forward speed and sustained wind speed. During this time Dorian became larger with hurricane force winds extending out 60 miles (NHC, 2019b). While paralleling the Florida coastline, the storm was far enough from the coast that only Tropical Storm Force Winds (39-58 mph) affected the coastline, based on surface observations. At approximately 11:00 pm EDT on September 3rd, the storm heading turned towards the north with a slight increase in speed to 7 mph. At this point the storm was 95 miles east of Cape Canaveral, Florida. The storm continued to grow while maintaining generally the same heading such that 12 hours later, hurricane force winds and tropical storm force winds extended out 70 miles and 175 miles, respectively. By this time, the storm had slightly weakened to 105 mph sustained winds. The storm then regained its strength and continued to grow. At 5:00 pm EDT on September 4th Dorian started to gradually turn further north and by 12:00 am EDT on September 5th, its heading was NNE and it had again reached a sustained wind speed of 115 mph. The general trend continued with additional course changes to the east. The next significant event in the storm development was hurricane force gusts occurring along the South Carolina coast. This occurred at approximately 2:00 pm EDT on September 5th when Dorian was reported being 60 miles south of Myrtle Beach. The edge of the 60 mile radius of hurricane force winds was just touching the coastline. Figure 2.5 shows the hurricane track and the extent of the hurricane and tropical storm winds as of 5:00 pm EDT. Figure 2.6 simultaneously displays the GOES-16 Band 13 Infrared image of the storm.

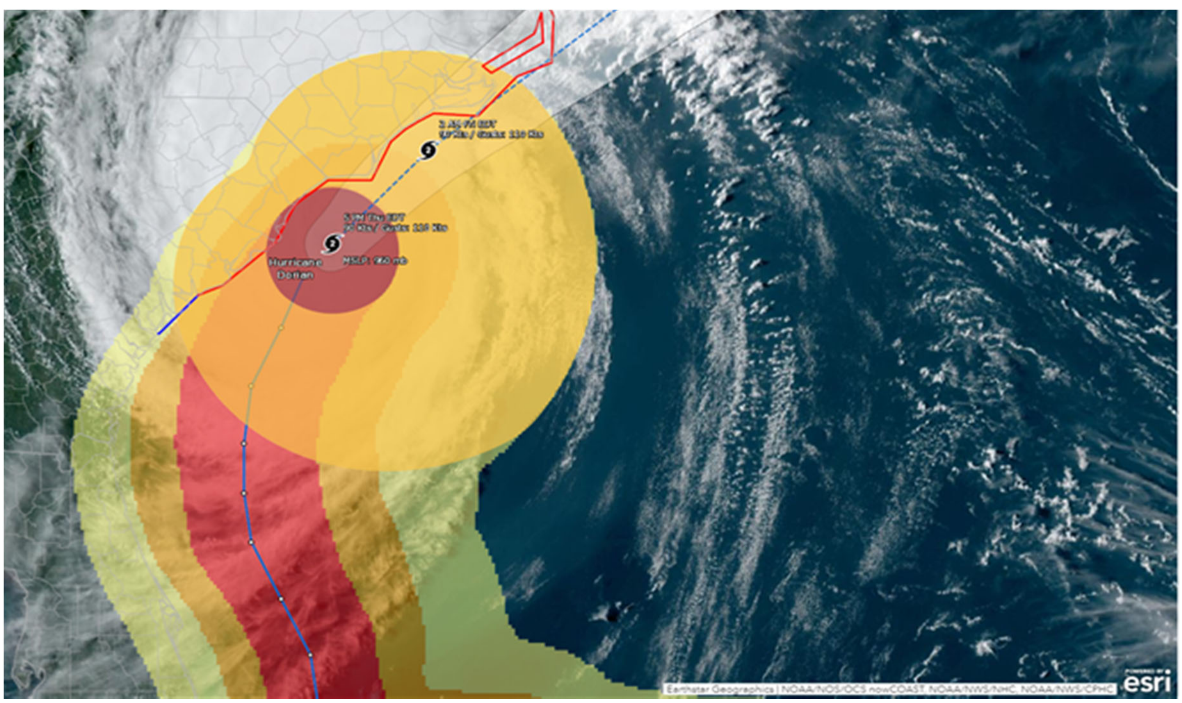


Figure 2.5. Track of Hurricane Dorian along the southeastern US coast at 5:00 pm EDT when hurricane force winds first impacted the US coastline (Source: NOAA 2019 Hurricane Tracker)

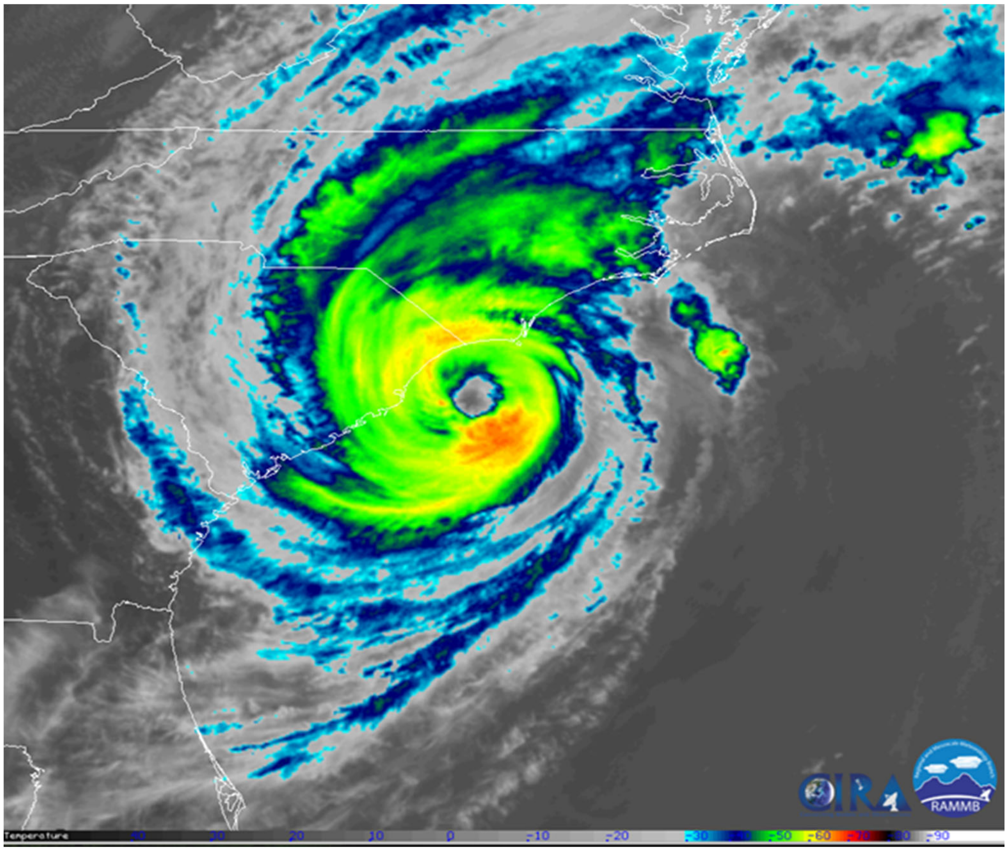


Figure 2.6. GOES-16 (East) Band 13 infrared imagery of Hurricane Dorian at approximate time when hurricane force winds first impacted the US coastline (imagery captured via CIRA/RAMMB)

2.1.4 Near-Landfall in US

Dorian continued to generally parallel the coast of South Carolina with continued hurricane force winds affecting the coastline. At approximately 10:00 pm EDT on September 5th the storm turned to a 45° heading and increased speed to 13 mph (NHC, 2019b). Multiple tornado warnings were issued for North Carolina on Thursday morning. By 1:00 am EDT on September 6th the sustained wind speed had dropped to 90 mph as hurricane force winds were just off Cape Lookout, North Carolina. The eyewall of Dorian passed just to the east of Cape Lookout at around 5:00 am EDT. Hurricane Dorian made landfall at approximately 8:35 am EDT on Cape Hatteras, North Carolina (Fig. 2.7). While Dorian was traversing Cape Hatteras, sustained and gust wind speeds were measured by a Weatherflow station at Hatteras High School of 77 mph and 89 mph, respectively (NHC, 2019b). By 11:00 am EDT the storm had moved off the Outer Banks and into the Atlantic Ocean. Figure 2.8 shows the progression of wind speed for the mobile monitoring tower T1 from the Florida Coastal Monitoring Program (FCMP) that was set up in Fort Fisher, NC during the time Dorian passed with its eye approximately 20 miles off the coast.

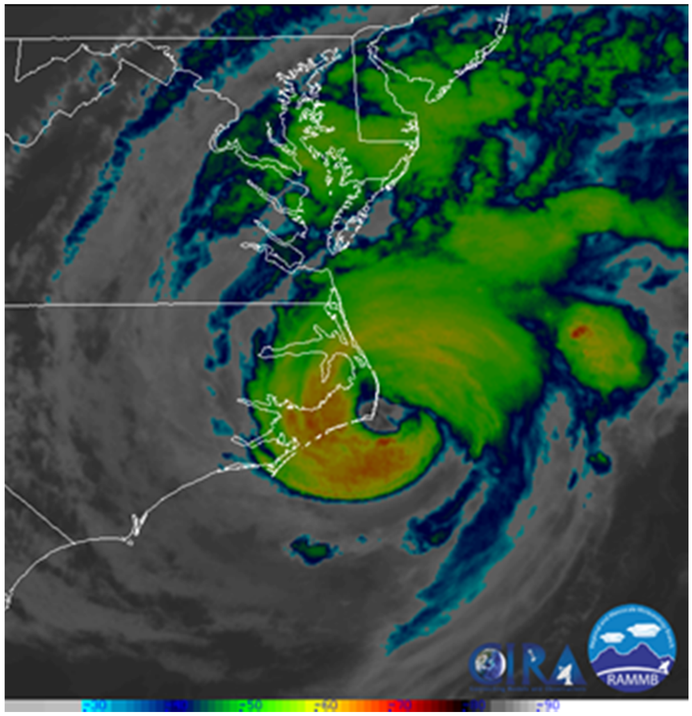


Figure 2.7. GOES-16 (East) Band 13 Infrared Imagery of Hurricane Dorian at Approximate Time when Hurricane Dorian Made Landfall on Cape Hatteras, NC (imagery captured via CIRA/RAMMB)

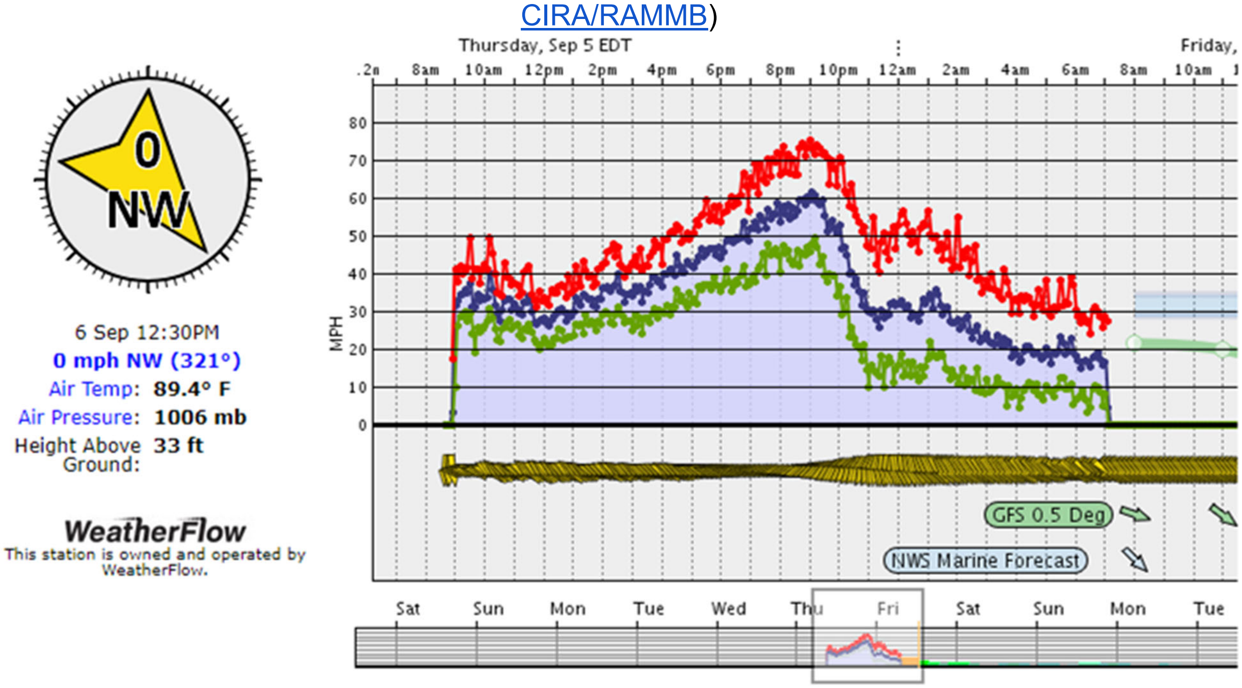


Figure 2.8. Wind speed time history from FCMP T1 in Fort Fisher, NC (33.97, -77.849) at a height of 33 ft (Source: http://ds.weatherflow.com/storm/dorian#33.97,-77.849,13,19,!187877,1)

2.1.5 Preliminary Wind Fields

Preliminary Dorian wind fields for the United States, developed by Applied Research Associates (ARA), were released as part of the rapid response to Hurricane Dorian by the National Institute of Standards and Technology (NIST). The wind field (completed on September 6, 2019) used the storm track and measured pressures from the National Hurricane Center advisories up to number 53 (NHC, 2019b) and surface level readings taken up until 8:00 am EDT on September 6, 2019. The values shown in Figure 2.9 are estimated peak 3-second wind gusts at an elevation of 33 ft (10 m). The methodology used to create these maps is similar to other products from past storms (e.g., Hurricanes Harvey and Michael) (ARA, 2019). Figure 2.10 was also released by the National Hurricane Center projecting the extent of Hurricane Force and Tropical Storm Force Winds along the path of Hurricane (NHC, 2019c). As this figure confirms, Dorian (as a post-tropical cyclone) continued to deliver hurricane-force winds all the way through its landfall near Sambro Creek in Nova Scotia, Canada, at 7:15 p.m. Atlantic Standard Time on September 7, 2019 (Ellis et al., 2019).

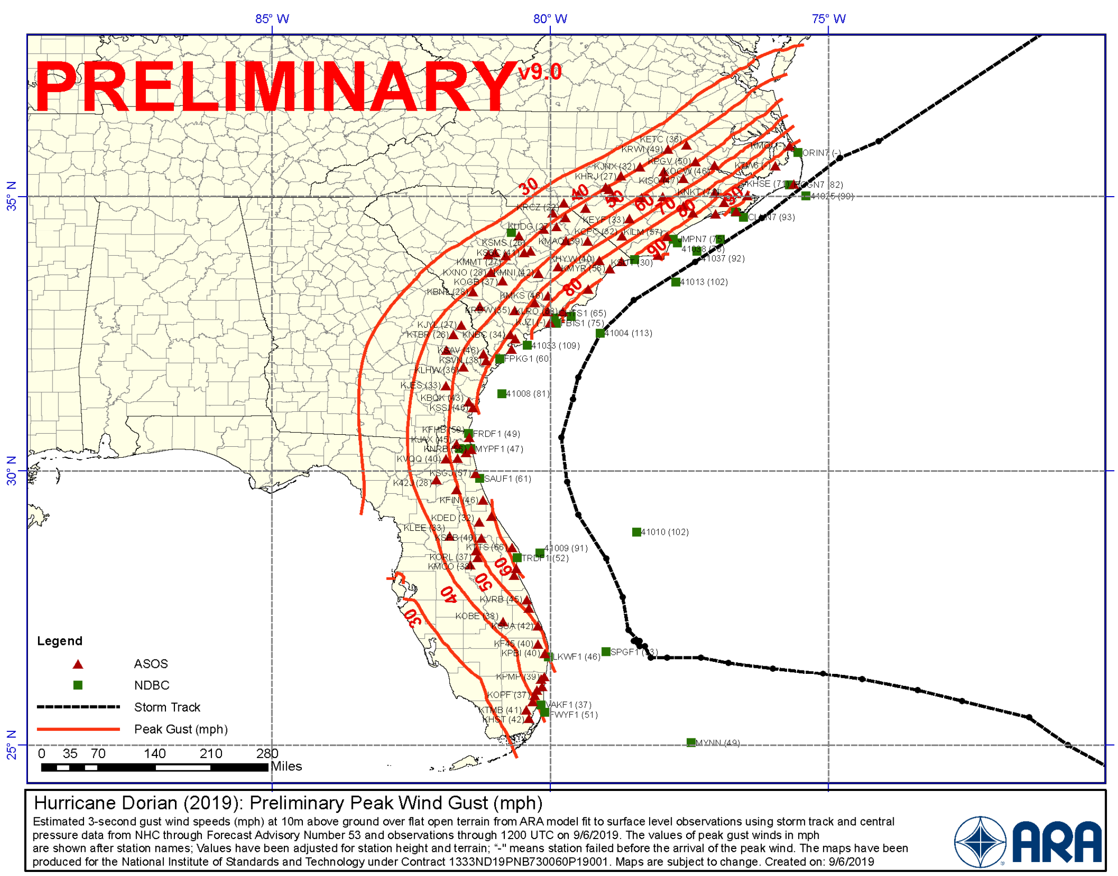


Figure 2.9. Preliminary wind speed maps of peak 3 second gusts at a 33 ft height from Hurricane Dorian in the US (ARA 2019) [Full resolution image and dataset available at DesignSafe Recon Portal]

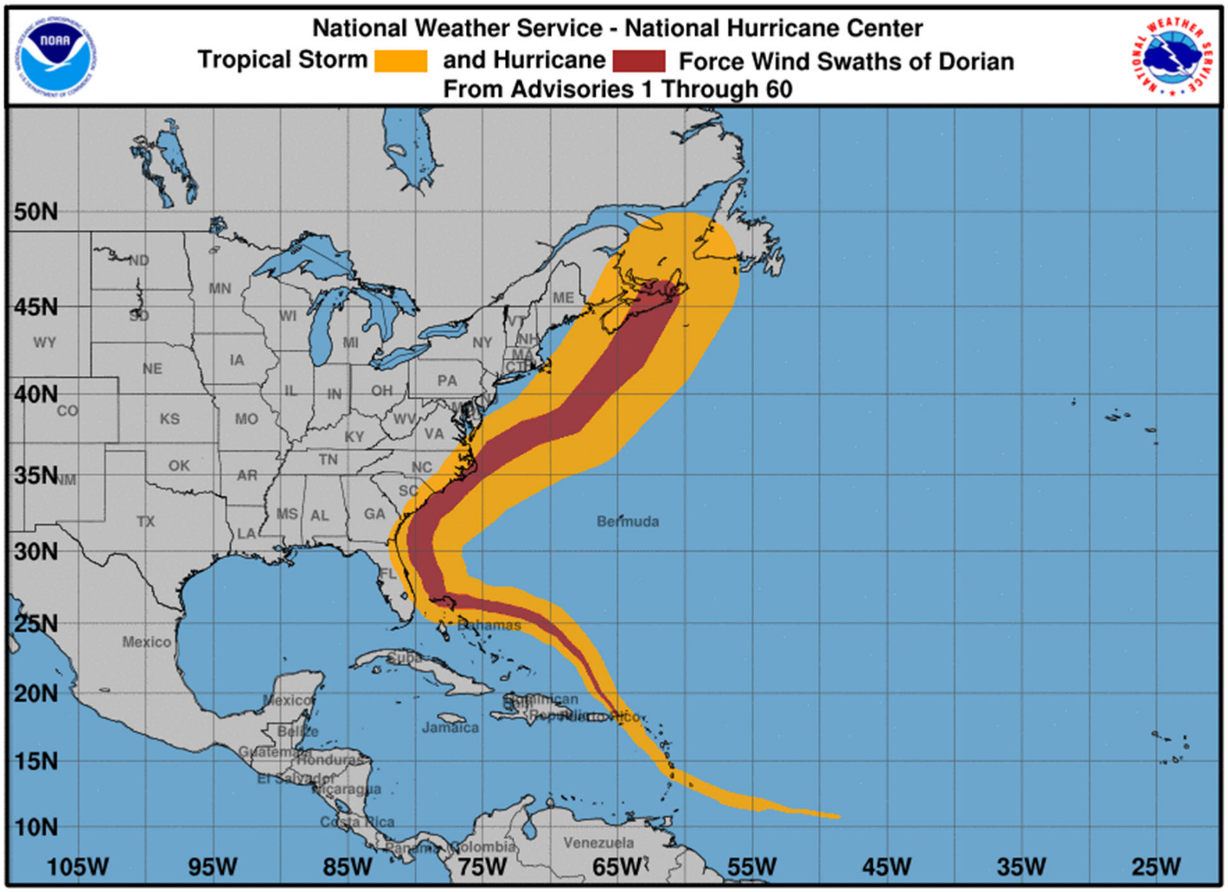


Figure 2.10. Cumulative wind history map of Hurricane Dorian (NHC 2019c) (Source: https://www.nhc.noaa.gov/refresh/graphics_at5+shtml/023607.shtml?swath#contents/)

2.2 Storm Surge and Coastal Flooding

2.2.1 Storm Surge and Flooding: Bahamas

Hurricane Dorian brought significant storm surge impacts to many coastal areas along or near the storm's path. On both Abaco and Grand Bahama Island, storm surge levels were expected to rise up to 23 feet (7.0 m) above normal tide levels, flooding inland areas, and accompanied by large, destructive waves near the coast. Observed storm surges of 12-18 ft (3.7-5.5 m) above normal tide levels were reported on Grand Bahama Island through the night of 2-3 September (NHC, 2019d). Figure 2.11 displays peak water levels above mean sea level (MSL) for Abaco and Grand Bahama Islands, projected by the Coastal Emergency Risks Assessment (CERA) based on an ADCIRC computational real-time forecast, using the September 1 and 2 hurricane forecast tracks, respectively.

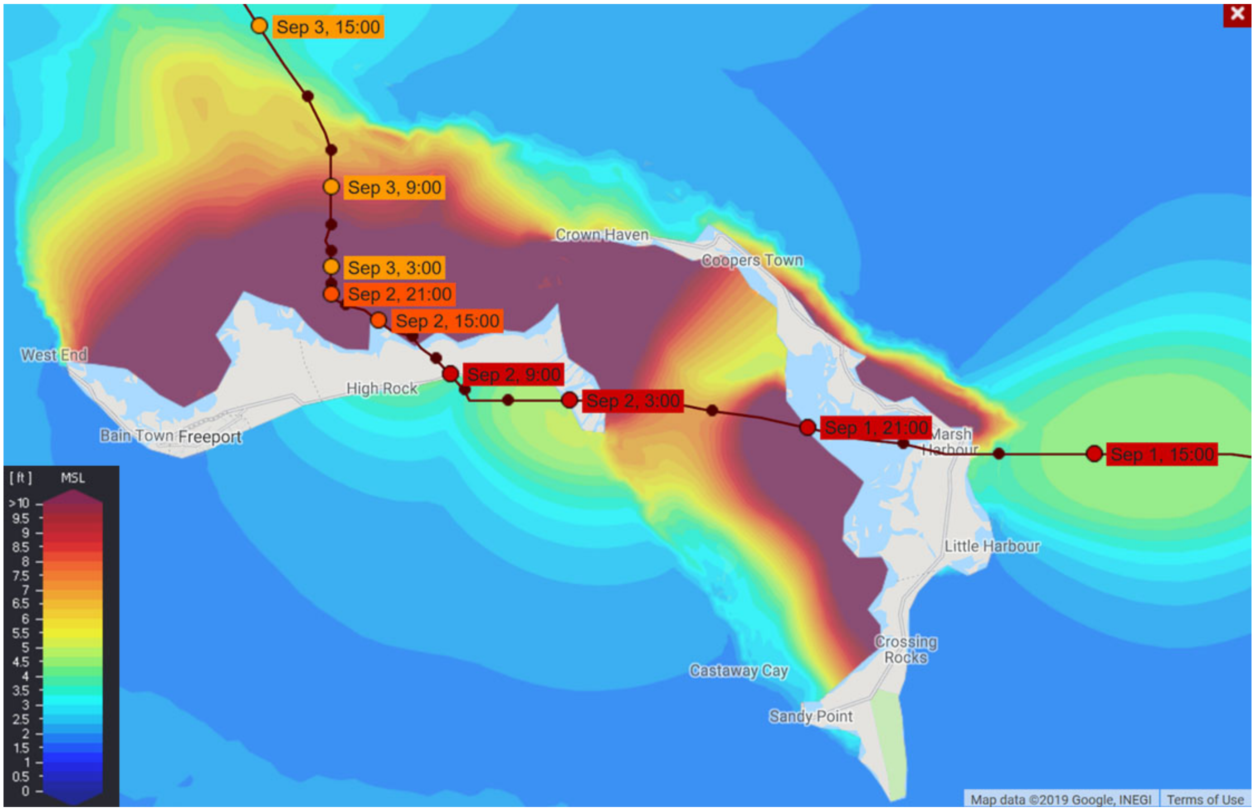


Figure 2.11. Projected maximum water heights above mean sea level near Great Abaco and Grand Bahamas (CERA, 2019a).

The satellite image from Google Maps in Figure 2.12 shows the Freeport District of Grand Bahama Island before/following Hurricane Dorian, noting vast areas submerged by coastal flooding. The yellow lines in Figure 2.12b outline the coastal boundary before the storm flooded the area.

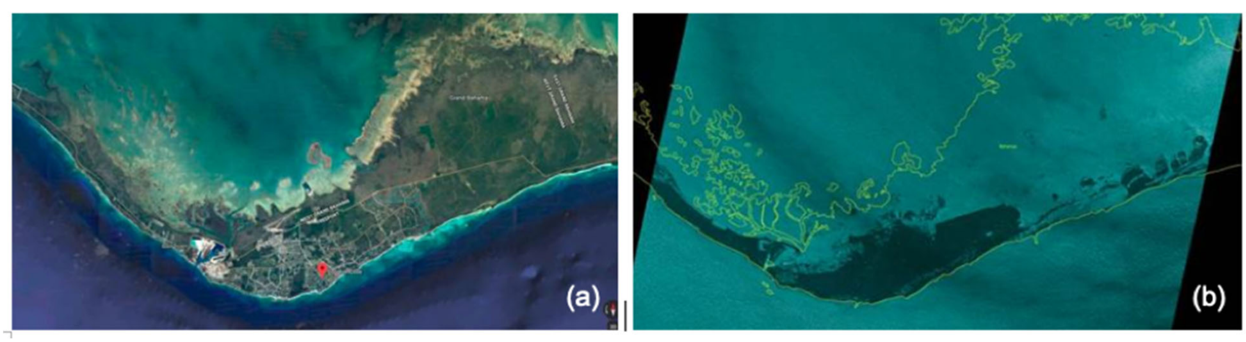


Figure 2.12. Satellite images of Grand Bahama Island (a) before and (b) after Hurricane Dorian passed through the region on Monday, September 02, 2019. (Source: https://www.cnn.com/2019/09/03/weather/hurricane-dorian-bahamas-before-and-after-wxc-trnd/index.html)

2.2.2 Storm Surge and Flooding in Southeastern United States

Hurricane Dorian's northward track brought considerable storm surge-related flooding to coastal counties in Florida, Georgia, and the Carolinas. Figure 2.13 shows the NHC's storm surge advisory forecast from 1100 EDT on 4 September 2019. Maximum water levels (conditioned on the coincident occurrences of peak storm surge and high tide) were projected to reach depths above ground between 2-8 feet (0.6-2.4 m) from northeastern Florida to Virginia. Figure 2.14 shows the CERA projected peak water levels in Florida, Georgia, South Carolina, and North Carolina based on NHC Advisories 45, 48, and 50. As suggested by Fig. 2.14, southeast Florida was spared from extreme coastal flooding due to Hurricane Dorian. Neighborhoods in St. Johns County, including the St. Augustine neighborhoods of Davis Shores, Lincolnville, the Castillo de San Marcus, and King and Granada Streets, experienced minor flooding (Fig. 2.15).

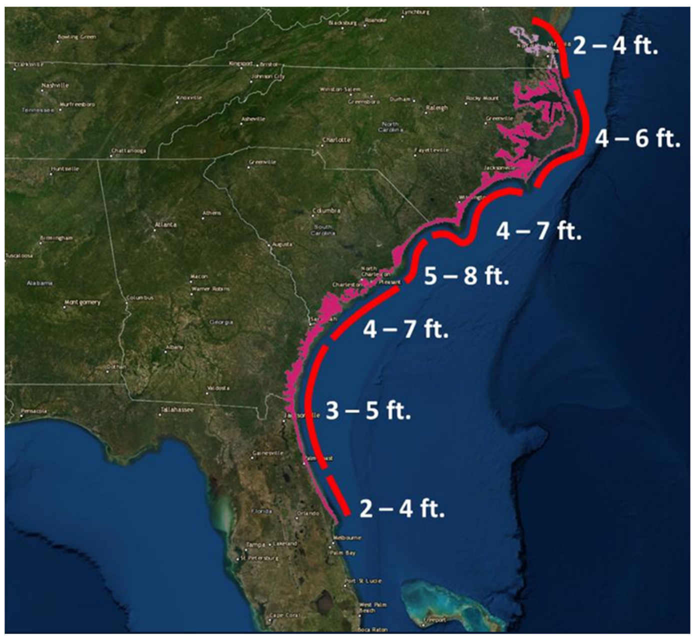


Figure 2.13. NHC maximum above-ground water depth projections for the U.S. East Coast, conditioned on the coincidence of peak storm surge with high tide, based on 1100EDT advisory forecast from 4 September 2019. (Source: https://twitter.com/NHC_Atlantic/status/1169276224197160960/photo/1)

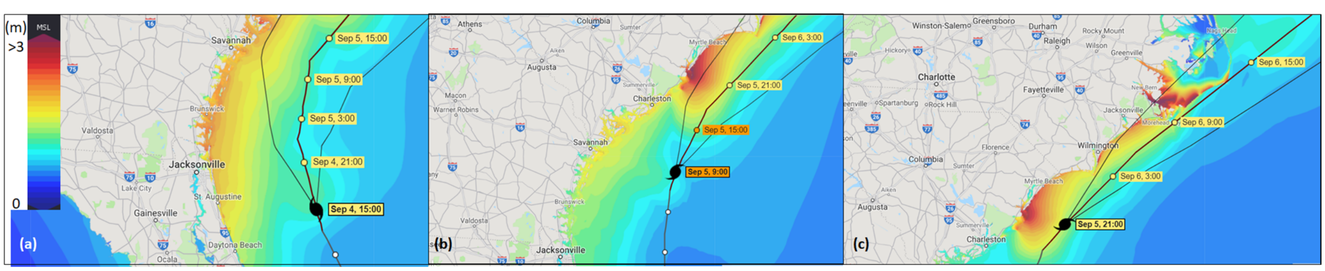


Figure 2.14. CERA forecast peak water levels for NHC Advisories 45, 48, and 50 (September 4-5, 2019) (CERA, 2019b).

Fig. 2.15. Flooding in Davis Shores, FL, a community on Anastasia Island (Gardner, 2019).

More significant coastal flooding was observed between Charleston, SC and New Bern, NC (Fig. 2.14b-c). While storm surge depths remained below worst-case predictions, over 50 streets were closed in Charleston, SC due to flooding from combined rainfall and storm surge impacts (City of Charleston, 2019; TWC, 2019b). Other areas along the North and South Carolina coastlines were affected, including Debordieu, SC and Garden City, NC.

Figure 2.16 shows the spatial distribution of peak water levels above mean sea level from the CERA forecast based on NHC advisory 52 (6 September, 2019, 6:00). As indicated in Figure 2.17, severe flooding occurred in North Carolina near the Outer Banks, where the storm made landfall as a Category 1 hurricane over Cape Hatteras. Figure 2.17 shows preliminary water levels recorded by NOAA near Cape Hatteras, where storm surge elevations exceeded the major flood threshold, reaching 5.3 feet (1.6 m) over the Mean High High Water (MHHW) datum. Nearby areas on the Outer Banks and Ocracoke Island experienced similar major flooding due to the hurricane's storm surge and rainfall. Figure 2.18 shows high water marks at an Ocracoke Island residence, with the height of Dorian flooding well above those of Hurricane Matthew (2016) and other past flood events. Other reports described catastrophic flooding, with waters rising up to 7 feet (2.1 m) on the Outer Banks.

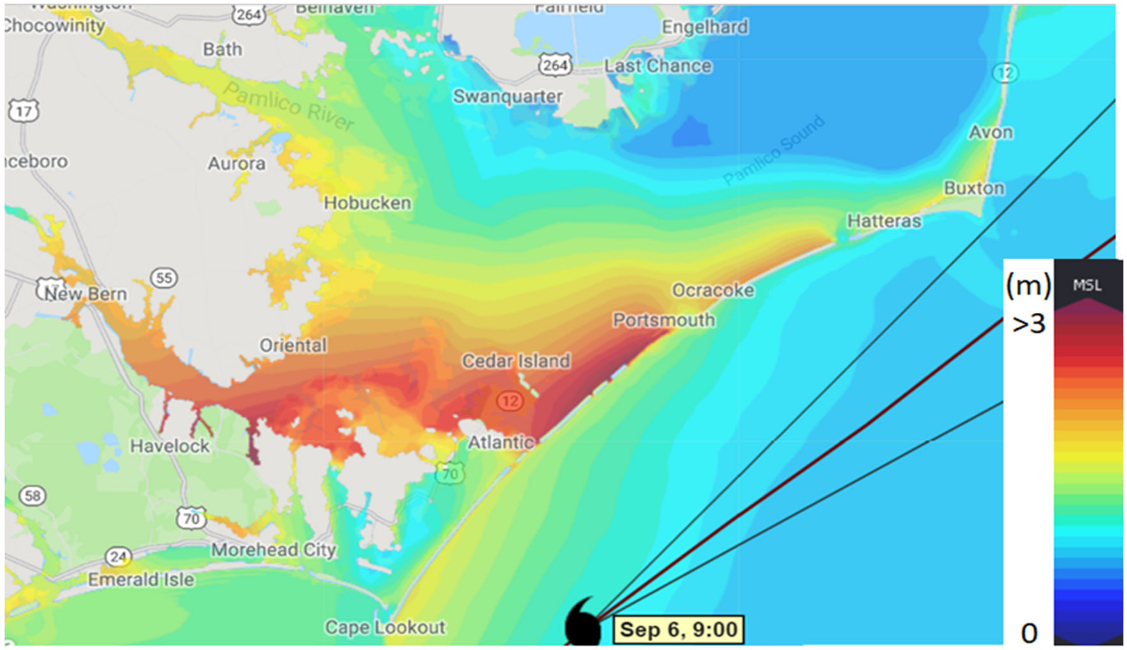


Figure 2.16. CERA peak water levels for NHC Advisory 52 (September 6, 2019) (CERA, 2019b)

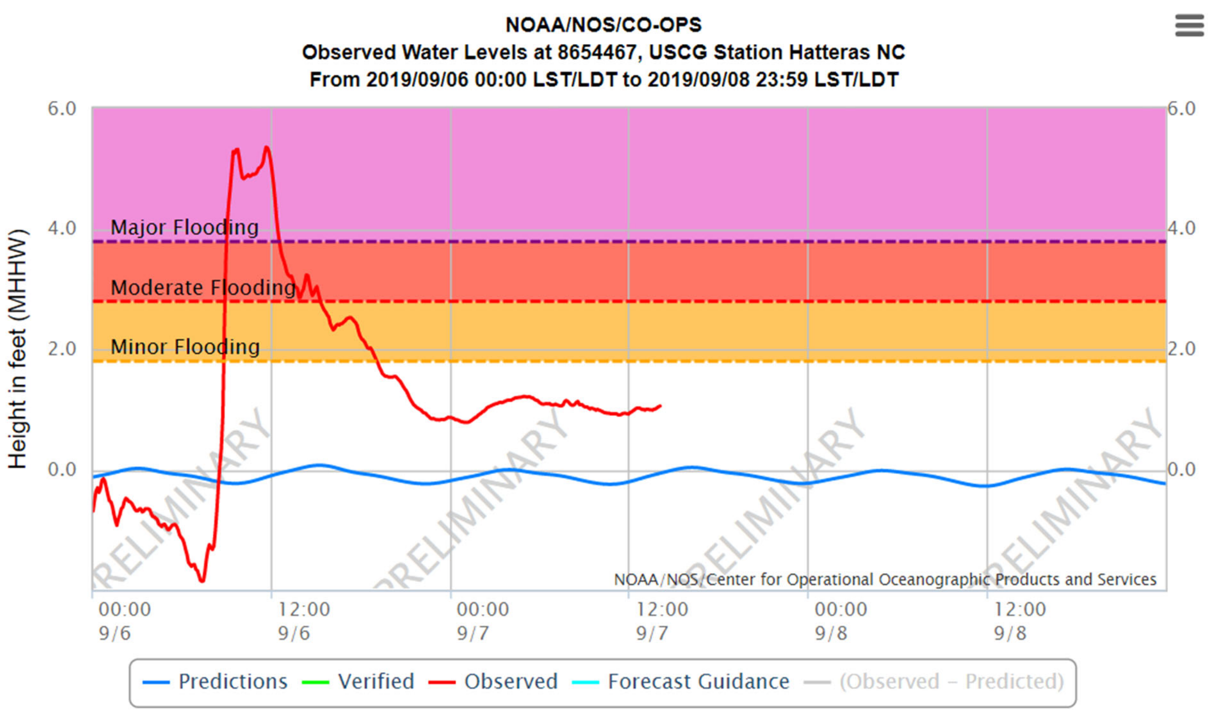


Figure 2.17. NOAA Preliminary observed water levels near Cape Hatteras, NC from 5-7 Sept., 2019 (NOAA, 2019b)

Figure 2.18. High water marks representing historic flood events on Ocracoke Island (Source: Scott McIntyre/New York Times).

2.4 Rainfall and Inland Flooding

Hurricane Dorian brought heavy precipitation that exacerbated flooding in the Bahamas. The storm's rainfall totals in the southeastern United States were less than those from Hurricane Matthew (2016) and Hurricane Florence (2018), with the heaviest rain bands remaining offshore as the storm propagated northward from Florida to Virginia. Rainfall accumulation totals were driven by the storm's size, forward speed, and strength of updrafts inside the hurricane (Kelley, 2019).

2.4.1 Rainfall: Bahamas

Figure 2.19 shows rainfall accumulations estimated by NASA for the Bahamas and other areas of the Caribbean from 0200 EDT on 28 August 2019 to 0500 on 3 September 2019 (NASA Goddard Space Flight Center, 2019). Rainfall estimates were obtained using observations from satellites in the Global Precipitation Measurement (GPM) mission and processed using NASA's Integrated Multi-satEllite REtrievals for GPM (IMERG) algorithm. Figure 2.19 indicates that rainfall totals exceeded 2 feet (0.6 m) over parts of Grand Bahama Island and The Abaco Islands by 3 September 2019; as of 4 September, rainfall accumulation estimates in these regions were increased to 3 feet (0.9 m) (Kelley, 2019).

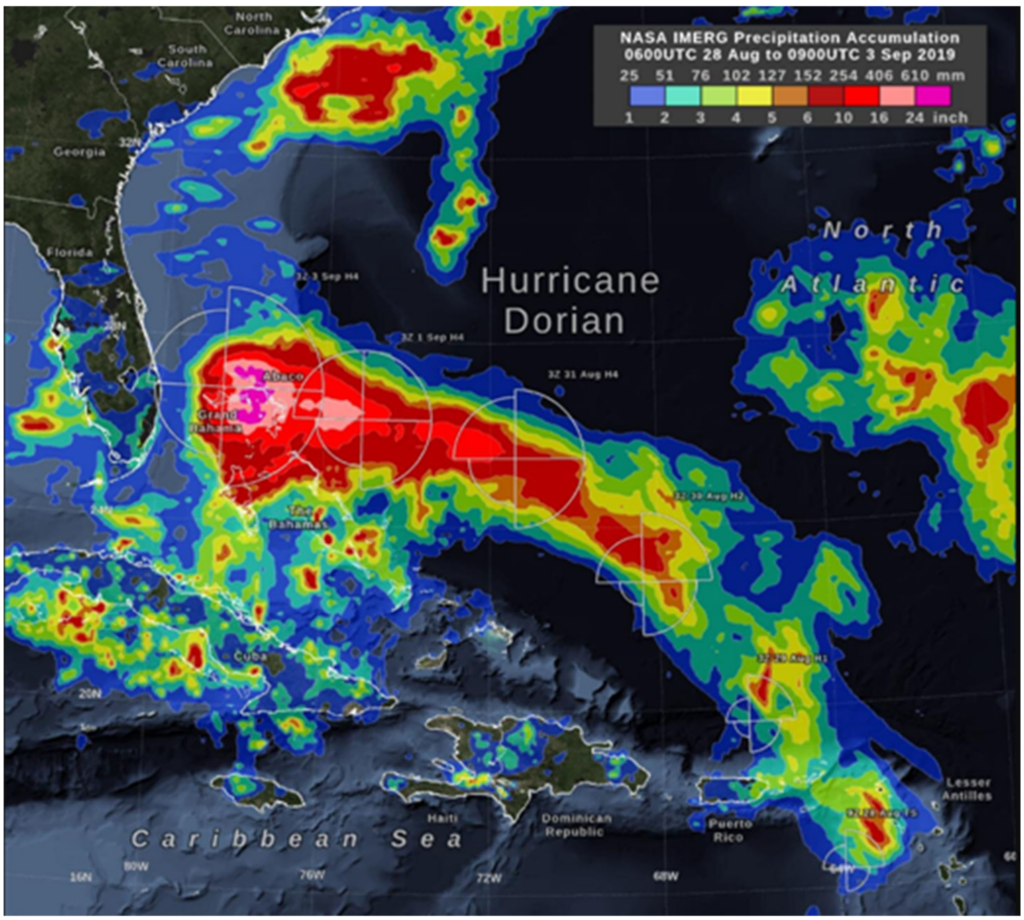


Figure 2.19. NASA IMERG Precipitation Accumulation Estimations, 28 August - 3 September, 2019 (Source: NASA Goddard Space Flight Center, 2019)

2.4.2 Rainfall and Inland Flooding: United States

Inland rainfall during Hurricane Dorian was less widespread than during previous Hurricanes Matthew (2016) and Florence (2018), in part due to the storm not crossing a frontal zone. Between 4 and10 inches of rainfall were expected within 50 miles of the coast, with higher rainfall totals in some local areas (Masters, 2019). Hurricane Dorian's heaviest rain bands remained offshore of

Florida and Georgia; coastal areas received between 1.84-5.68 inches (4.7-14.4 cm) of total rainfall. North and South Carolina received larger rainfall totals: between 0700 EDT on 1 September and 0400 EDT on 6 September, areas in North and South Carolina received between 5.54-10.64 inches (14.1-27.0 cm) of total rainfall. As of 6 September 2019, heavy rain continued in east and central North Carolina as rainfall rates increased in southeastern Virginia. Preliminary storm rainfall totals for selected locations in Florida, Georgia, South Carolina, and North Carolina are reported in Appendix B.

Preliminary rainfall totals in South Carolina and southern North Carolina ranged from 1.91 inches in Clio, SC (~120 km inland) and 3.73 inches in Lumberton, NC (~90 km inland) to 9.56 inches and 14.03 inches in the coastal communities of Myrtle Beach and Litchfield, SC, respectively (WDPE, 2019a). With these smaller inland rainfall totals, risk of inland riverine flooding was reduced in the Carolinas as shown in Figure 2.20. Only the Waccamaw River continued with a flood warning as of 6 September 2019 at 11:00 PM EDT. The river was expected to reach moderate flood levels on 6 September and steadily drop over the following days. However, flooding was anticipated in the communities of Lees Landing, Riverfront South, Pitch Landing, and Savannah Bluff, as well as surrounding swamps and marshes (WDPE, 2019b).

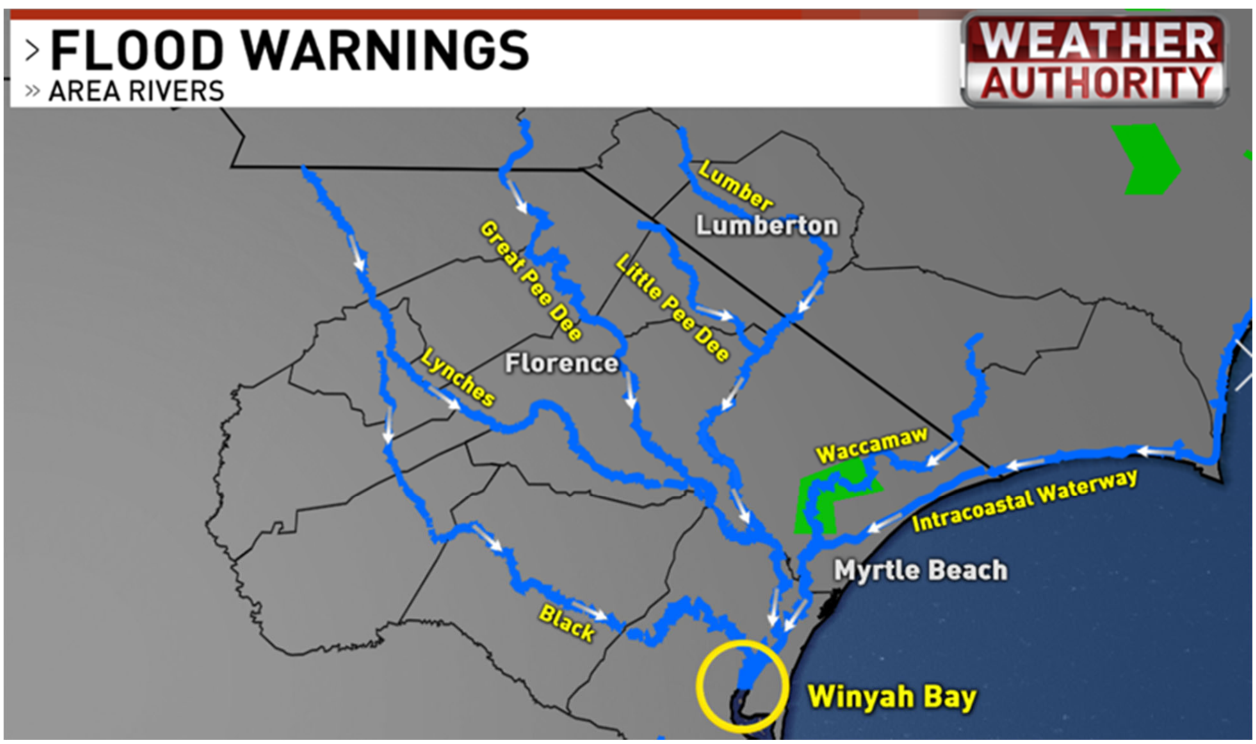


Figure 2.20. Flood warnings (indicated by green shading) for the Waccamaw River in the eastern Carolinas as of 6 September 2019 (WDPE, 2019b).

2.5 Tornadoes

As of 7 September 2019, there were 66 tornado warnings associated with Hurricane Dorian. The majority of these (59) were issued on 6 September in South Carolina and North Carolina as Hurricane Dorian approached offshore (Fig. 2.21). The NWS had not yet finalized intensity ratings at the time of this report, but early reports confirm tornado impacts in [Emerald Isle, NC] (area previously surveyed by StEER following Hurricane Florence in 2019), [North Myrtle Beach, SC], and Carolina Shores in [Brunswick County, NC], where a tornado damaged about 40 structures.

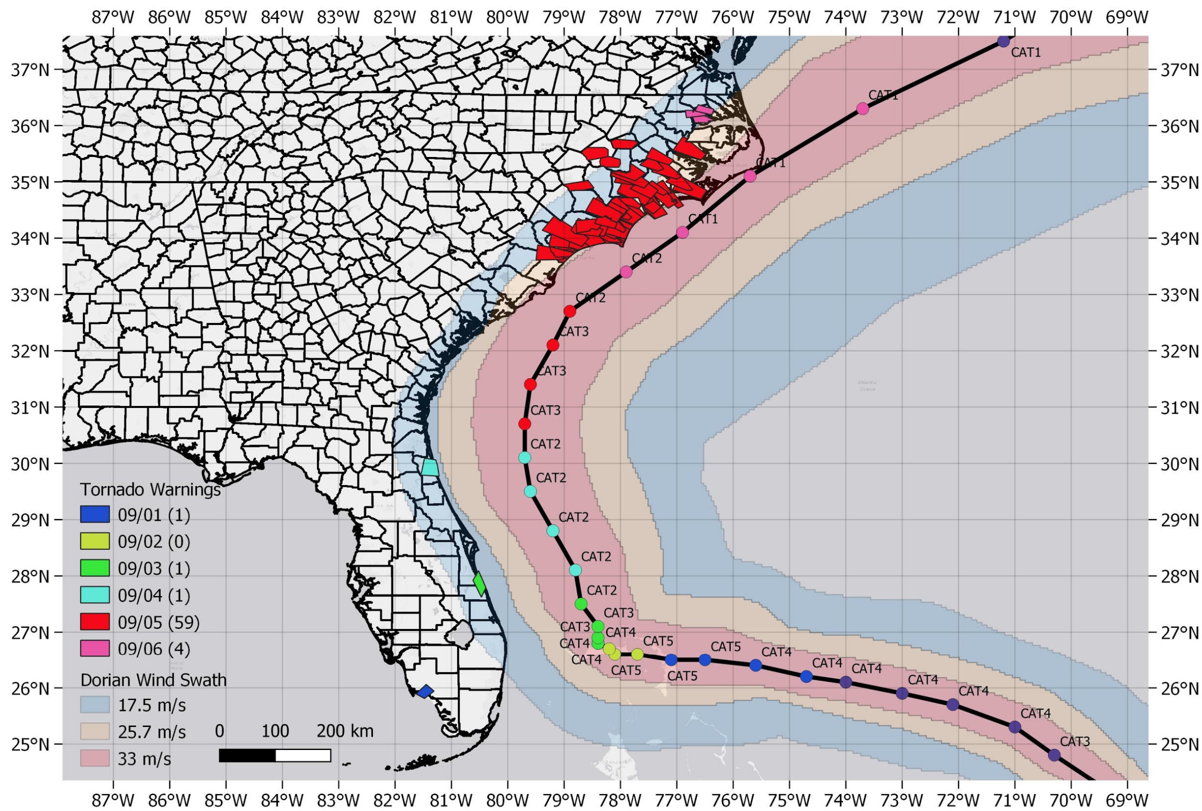


Figure 2.21. Cyclone-induced tornado warnings issued by the National Weather Service. Colored circles indicate the location of Dorian, with colors indicating the date, using the same color scheme as for tornado warnings (Source: National Weather Service).

3.0 Codes and Construction Practices: Bahamas

A summary of the building inventory's 96,863 building units and 126,493 dwelling units (see Appendix C) suggests that Abaco had 6,786 housing units and 8,113 building units and Grand Bahama had 13,697 housing units and 20,337 building units (Dept. of Statistics, 2017a). More up-to-date information on the housing stock may be inferred from the record of permits issued (Dept. of Statistics, 2017b). Reports suggest that the building inventory in the most heavily affected areas was low-rise and included single and multi-family homes (which may use wood, concrete or masonry typologies), resorts/hotels/rental properties, light industrial/marina facilities and commercial construction serving retail and tourism industries. The construction practices in some regions may be restricted by architectural requirements that further guide the typologies used, e.g., all buildings in Hope Town on Elbow Cay must adhere to Bahamian Architecture at the discretion of Town Planning. Quality of construction and construction material preferences are also shaped by economic capacity, as suggested by Silbert Mills of the Bahamas Christian Network, “[code] compliance is generally tight for those who can afford it. Risks are higher in poorer neighbourhoods, with wooden homes in low-lying areas” (Al Jazeera, 2019). This alludes to low-lying informal settlements such as The Mudd and Pigeon Peas in Abaco, occupied by low-income families who employed lightweight materials in unregulated construction activities.

As further observed by Mills, “The Bahamas archipelago is no stranger to hurricanes.” Elbow Cay (Abaco) had previously suffered significant damage from Hurricane Floyd (1999) and both Abaco and Grand Bahamas Islands were severely impacted by Hurricane Matthew in 2016 (IFRC, 2019). However it is unclear that substantive changes to building codes were enacted as a result of those experiences, as wind design in the Bahamas still regulated in accordance with the 2003 Bahamas Building Code (BBC), 3rd Edition, which references the 1988 standard of ASCE: “buildings and other structures, and every portion thereof, shall be designed and constructed to meet the requirements of Section 6 of Standard 7-88 of the American Society of Civil Engineers…, based on a fifty-year mean recurrence interval.” Some glimpse into construction practices is further offered by Mills who states that “homes are required to have metal reinforcements for roof beams to withstand winds into the upper limits of a Category 4 hurricane” (Aljazeera).

Specifically, the 2003 BBC specifies a minimum factor of safety of 1.5, that all buildings are required to be considered as located in Exposure D if 1500 ft within the coast (Exposure C elsewhere), and that all buildings be designated with an Importance Category I per ASCE 7-88 (Importance Factor equal to 0.88). While a design wind speed is not directly specified in the BBC, a review of local construction practice and accounts from design engineers indicates that 150 mph 3-second gust at 10 m height above ground level is currently used. Altogether, this design wind speed and relevant factors, including a directionality factor of 0.85, results in a minimum design velocity pressure of 64 psf for Exposure C, or 76 psf for Exposure D. There is no explicit specification of considerations for storm surge or other flood loads in the Bahamas Building Code.[14]

4.0 Damage to Buildings

4.1 Building Damage: Bahamas

Estimates suggest that 21,000 homes have been damaged by the wind, storm surge and flooding Dorian brought to the Bahamas (Miles, 2019; NHC, 2019). As of September 3, 2019, the Red Cross estimates more than 13,000 houses, or about 45% of the homes in Grand Bahama and Abaco Islands, were severely damaged or destroyed (Espinosa et al., 2019). Figure 4.1 provides

[14] https://www.bahamas.gov.bs/wps/wcm/connect/d7ebcbad-f9b6-42e3-aff2-79f83bd91810/Bahamas%2BBuilding%2BCode%2B3rd%2BEd.pdf?MOD=AJPERES

an overview of the damage extent based on analysis of satellite data by UN Office for the Coordination of Humanitarian Affairs and coordinating partners.

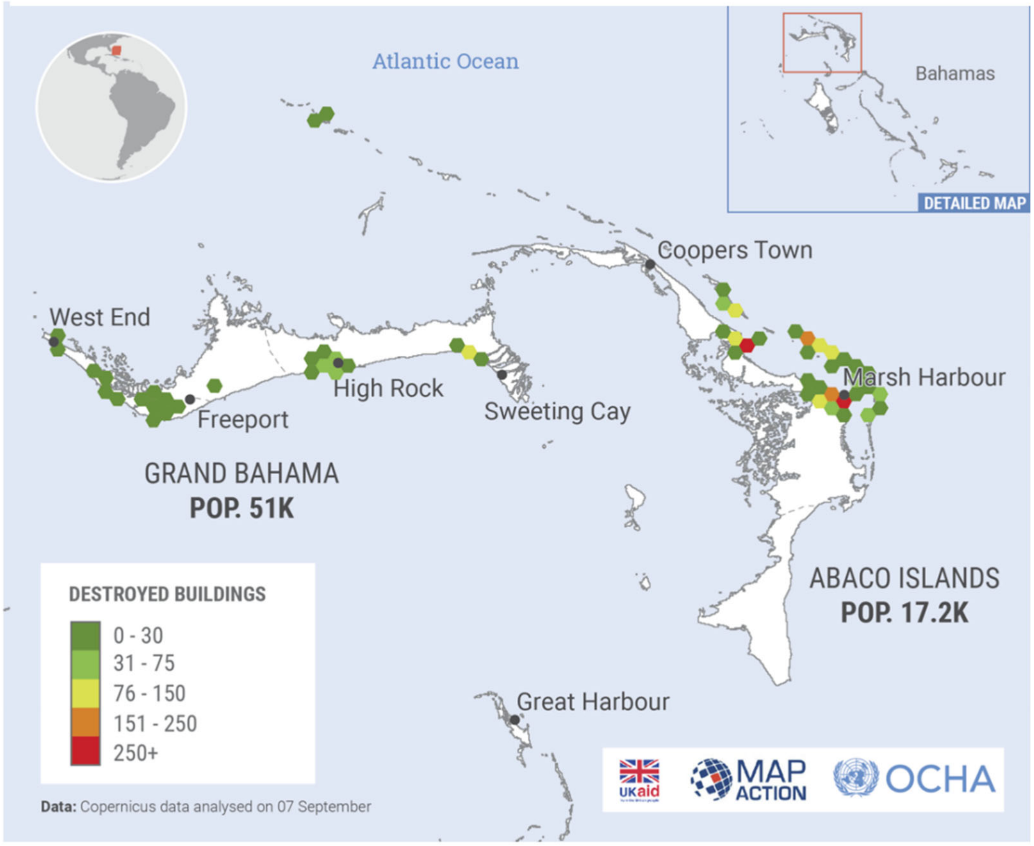


Figure 4.1. Overview of the extent of devastation in Abaco and Grand Bahama Islands, indicated by number of destroyed buildings within a 10 km^2 hexagonal grid (Source: UN Office for the Coordination of Humanitarian Affairs).

4.1.1 Abaco Islands

This section overviews the impacts to the Abaco Islands where Hurricane Dorian made its first (Elbow Cay) and then subsequent (Marsh Harbour, Great Abaco Island) landfalls. Each major district is examined, though cautioning that damage to some areas may be greater than reported herein as information is limited based on access and priority in the recovery effort.

4.1.1.1 Central Abaco District, Great Abaco Island

Marsh Harbour is the largest town in the Central Abaco District on Great Abaco Island, the site of Dorian's second landfall in the Bahamas. The building inventory in Marsh Harbour includes commercial and residential construction catering both to residents and tourists, as well as several informal settlements including **The Mudd** and **Pigeon Peas** where an estimated 600 residences and 45 commercial shops were located per a 2013 report by the Department of Environmental

Health Services[15]. The Central Abaco District experienced severe storm surge, with the National Hurricane Center predicting 5.5-7 m of storm surge above the normal tide levels with even higher wave impacts. Early reports indicate most buildings were significantly damaged by wind and/or storm surge, with numerous roofs removed and wall collapses in both commercial and residential construction (Figs. 4.2, 4.3). Even with near-universal damage, there are a number of buildings that exhibited little if any significant damage under these extreme demands and are deserving of closer examination in on-site investigations.

Figure 4.2. Aerial photo of the damage from Dorian at Marsh Harbour on Great Abaco Island. The center of the photograph is located at approximately [26.531406, -77.063431], taken facing West. (Source: CNN)

[15] https://eh.gov.bs/wp-content/uploads/2016/10/Shanty-Town-Bahamas-Report.pdf

Figure 4.3. (top) Aerial photo of the damage from Dorian in Marsh Harbour, Great Abaco Island showing the performance across a range of building occupancy classes including metal building systems [Approximate Location: 26.537017, -77.063145 (Looking West)] (Source: CNN); (bottom) Closer view of the Pea, informal settlement located behind the metal buildings at the center of the top image (Source: Orlando Sentinel)

Notable properties in this community include the **Island Breeze Hotel,** whose roof was badly damaged (Wesner Childs and Brackett, 2019), **Abaco Lodge**, which was destroyed, and **Abaco Club at Winding Bay** and **Abaco Beach Resort and Boat Harbour Marina**, which both report damages but not as significant as other properties nearby (Nagle Myers, 2019). Regulated home construction demonstrated mixed performance, with a key factor being the level of storm surge at that location (Fig. 4.4) and the structure's elevation above grade (Fig. 4.5). The eye of Dorian directly passed over the informal settlements at **The Mudd** and **Pigeon Peas** (adjacent to The Mudd to the southeast), which is the lowest-elevation area on Great Abaco Island with peak elevation around 20 m above sea level (see Topographic Map in Appendix D). These settlements were decimated by the storm surge reported previously in Section 2.2.1 (see Fig. 4.6). As homes in these communities are typically constructed on grade with discarded metal and wood without any regulation, their performance is unsurprising, although nonetheless tragic.

Figure 4.4. Aerial photo of debris field of largely residential construction destroyed by storm surge in Marsh Harbour in Great Abaco Island, Bahama (Source: Orlando Sentinel)

Figure 4.5. Damage to roof and walls of a pair of homes at an upper elevation on Great Abaco Island (Source: Orlando Sentinel)

While not diminishing the catastrophic damage, particularly to residential construction in the Marsh Harbour landfall region, a cross section of residential, commercial and industrial buildings did appear to perform well, sustaining only minor damage when subjected to these long-duration, high intensity wind fields, e.g., see Figures 4.7 and 4.8. A case in point is the **Marsh Harbour Healthcare Center,** which just opened in 2017 (construction began in 2012). This critical facility shows no visible structural damage from wind or flooding and was functional, serving as a shelter during landfall, and treating patients injured in Dorian at the time this report was authored. Roof cover loss was observed in accessory buildings, as shown in Figures 4.9 and 4.10. Evidence of the intensity of winds in this locale can be inferred from the loss of dense foliage in the vegetation surrounding the hospital (Fig. 4.9b) and the light pole snapped at the base near the accessory buildings (Fig. 4.10). Another case in point is the **Marsh Harbour Government Complex,** which became a makeshift shelter for those fleeing collapsing buildings during the hurricane's passage over Abaco[16]. The exact status and performance of other critical facilities is not known at this time, but the Bahamian government reports that all of the shelters on Abaco are open and functioning with generators (Maura, 2019).

[16] https://www.accuweather.com/en/videos/w3v2wkzq

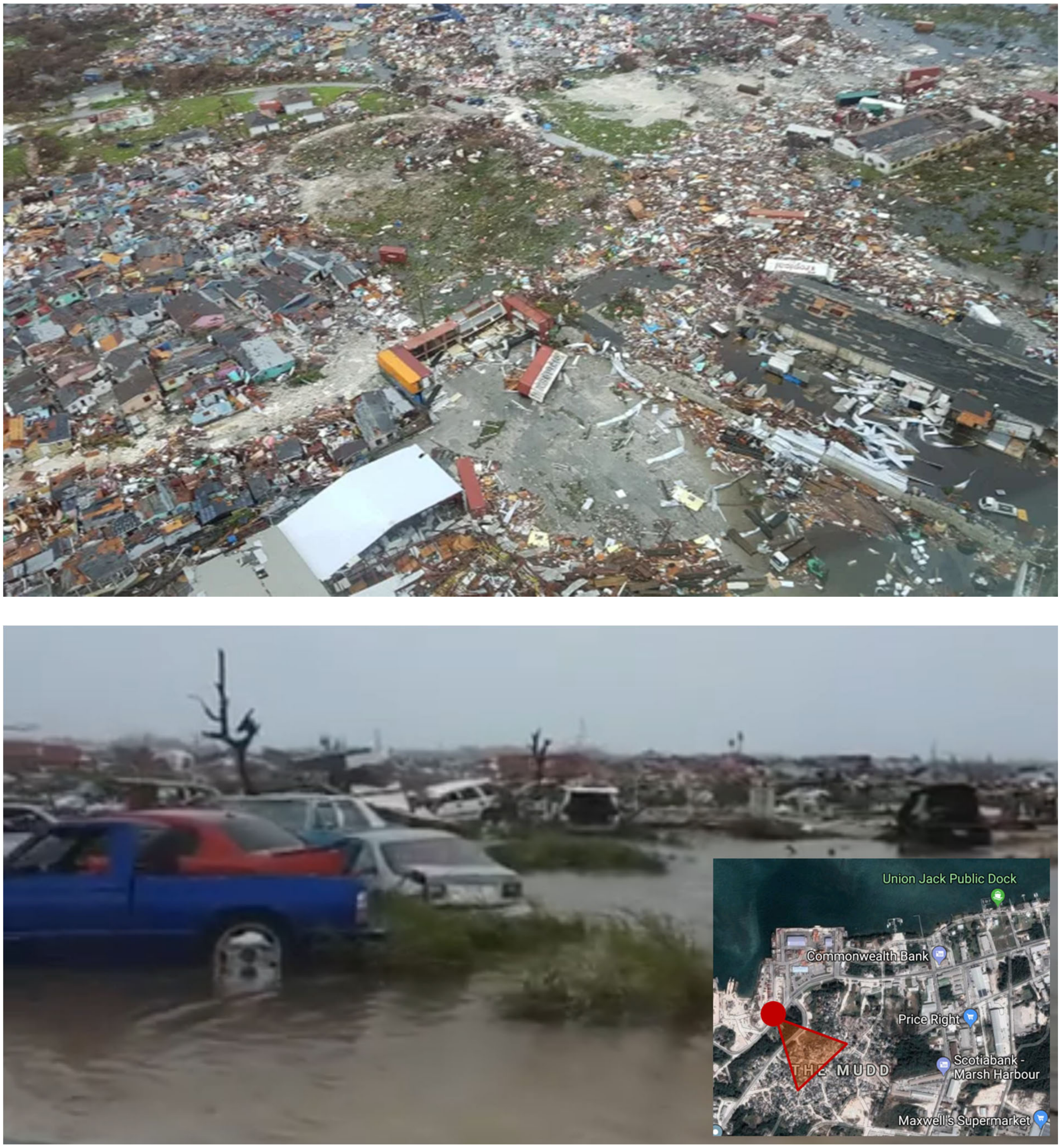


Figure 4.6. Aerial imagery of The Mudd and Pigeon Pea on Great Abaco following the passage of Hurricane Dorian (Source: Our News Bahamas); (bottom) view looking inland towards The Mudd, (Source: still frame taken from a video by Seaport Secrets Cafe and Seafood Market with Google Maps overlay).

Figure 4.7. Aerial photo of the damage from Dorian at Marsh Harbour on Great Abaco Island, Bahamas. Note the surviving commercial and industrial buildings with minor roof damage. [The large building in the center is located at 26.532695 / -77.062676]. The photo was taken facing SW. (Source: CNN)

Figure 4.8. Aerial photo with a number of larger residences with minimal exterior signs of damage in Marsh Harbour on Great Abaco Island. [The blue home at the center of the photo is located at 26.555458, -77.023363], with the photo taken facing East. (Source: Daily Mail UK)

(a)

(b)

Figure 4.9. Aerial view of Marsh Harbour Healthcare Center [Located at 26.534, -77.070] and accessory buildings (a) before Hurricane Dorian and (b) afterward, exhibiting no significant structural damage. Nearby trees are debarked. (Source of pre-event image: Google Maps; Source of post-event image: U.S. Coast Guard)

Figure 4.10. Roof cover loss at accessory buildings at Marsh Harbour Healthcare Center accessory structures [Located at 26.534, -77.070]. Note the snapped light pole in the foreground (Source: https://twitter.com/StevenCejas/status/1168910504183652353)

Examples of damage sustained to community buildings like the **Forest Heights Academy**, a private high school, and **St. Frances De Sales Catholic Church** in Marsh Harbour are shown in Figures 4.11 and 4.12, respectively. Forest Heights Academy (Fig. 4.11) experienced significant flooding, nearly complete loss of roof cover and structural damage. St. Frances De Sales Catholic Church (Fig. 4.12) does not have visible structural damage, with the exception of some roof cover loss.

Figure 4.11. Aerial view of Forest Heights Academy, a private high school in Marsh Harbour [Located at 26.517871, -77.070266] (Source: Weather Channel)

Figure 4.12. Aerial view of St. Frances De Sales Catholic Church in Marsh Harbour [Located at 26.227, -77.0655] (Source: Weather Channel)

4.1.1.2 Elbow Cay

Dorian's first landfall in the Bahamas was at Elbow Cay, an 8-mi (13-km)-long, narrow barrier island off the mainland of Great Abaco whose main settlement is Hope Town (the seat of the district bearing the same name). This cay is 4 mi (6.4 km) east of Marsh Harbour, with the Atlantic Ocean running along its east coast and South Abaco Sound on its western coast. The cay has a number of residences, small businesses and rental properties/hotels, including the **Hopetown Harbour Lodge** which appears to have sustained damage (Fig. 4.13). The conditions on the island following Dorian's landfall were documented by eyewitnesses as "catastrophic" (Wnek, 2019). Some of the limited aerial (Fig. 4.14) and surface (Fig. 4.15) imagery provides an illustration of the damage observed.

Figure 4.13. Before and after Photo of Hope Town Harbour Lodge [26.536, -76.958] on Elbow Cay (Source: https://twitter.com/JohnMoralesNBC6/status/1168638139163906052/photo/1)

(a) 

(b) 

Figure 4.14. Aerial photos of extensive building damage in Elbow Cay. (a) This photograph is located at approximately (26.503268, -76.980198), facing West (Source: Time.com); (b) the pink house on the shore at the top left of this site near Hope Town is located at (26.540680, -76.960133), with the photo taken looking West. (Source: UK Daily Mail)

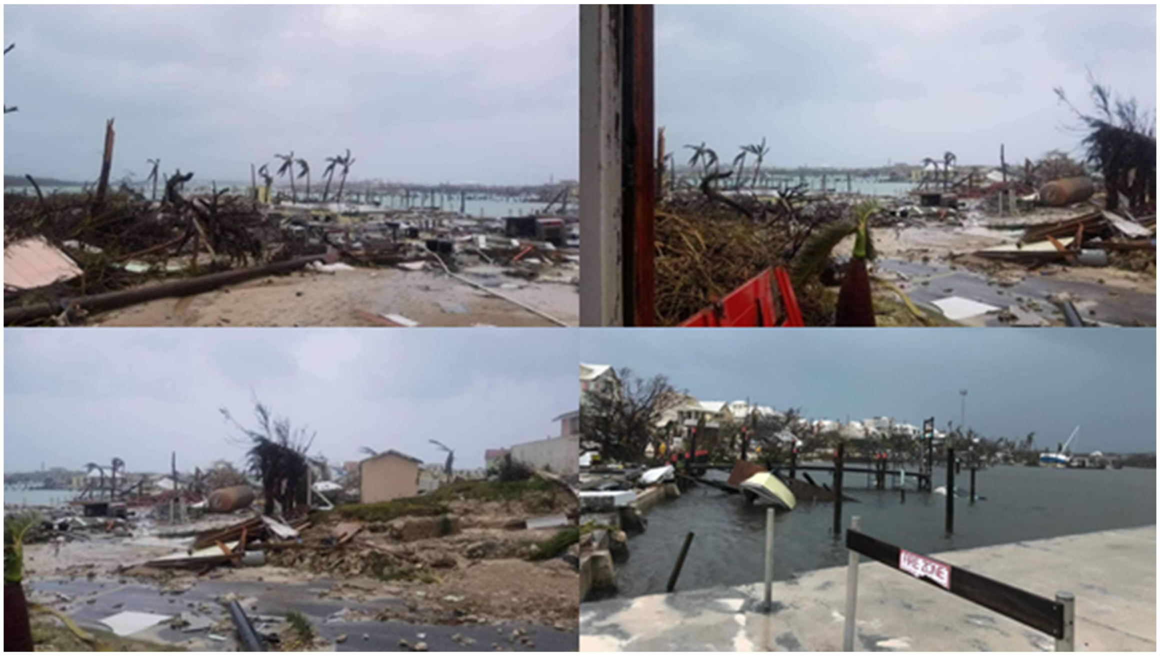


Figure 4.15. Photos from Hope Town on Elbow Cay following the passage of Hurricane Dorian (https://twitter.com/JohnMoralesNBC6/status/1168639807997796354?s=20)

4.1.1.3 Grand Cay Island

Grand Cay is one of the smaller districts of the Bahamas and part of the Abaco Islands, located south of Walker's Cay. With a population of 383 people in 102 occupied dwellings (2010 Census data, Bahamas.gov), mostly fishermen. Grand Cay is typically accessed via boat. Limited information is available at this time but social media reports suggest it may have not been significantly impacted[17].

4.1.1.4 Green Turtle Cay

Green Turtle Cay is a small barrier island to the northeast of Great Abaco Island. It is approximately 3 miles (4.8 km) long by 0.5 miles wide. The main settlement is known as New Plymouth and the population is estimated to be less than 500 people. The architecture of some of the older homes in the village is unique in the Bahamas with steep-pitched roofs that came from the original settlers from New England. Due to the fact that the cay has very minimal elevation, flooding and wave impacts added significantly to the wind hazard during the passage of Hurricane Dorian. Several videos (Video 1, Video 2) show flooding (~1 m) prior to the peak of Dorian's intensity. Pre- and post-Dorian imagery is shown in Fig. 4.16. Post-landfall information with respect to structural performance is still limited at the time of this report. Second hand reports from Green Turtle Cay indicate "total devastation, people trapped in collapsed homes, the primary

[17] https://twitter.com/_CharismaL/status/1168228827048435712

school shelter failed, roads impassable" (Source: Twitter). Fortunately, all persons are accounted for based on limited communication via satellite phones (Abaco Forum); no fatalities reported.

Figure 4.16. Before Hurricane Dorian struck Green Turtle Cay (satellite image taken Oct. 25, 2018) and after Hurricane Dorian struck Green Turtle Cay (satellite image taken Sept. 5, 2019). Images processed by Maxar Technologies via Reuters (Source: ABC News)

4.1.1.5 Moore's Island

No information on the condition of Moore's Island has become available at this time. Its location was exposed to a direct hit from the eyewall of Dorian, so impacts of severe storm surge and high winds are expected. Pre-Dorian, major improvements were scheduled for infrastructure, including roads, the airport runway, water mains, and key structures (Bahama Press, 2016), but it is unknown whether these improvements were implemented or how they performed.

4.1.1.6 North Abaco District, Grand Abaco Island

Footage driving through Cooper's Town[18] documents damage to multi-family residential construction ranging from loss of roof cover and sheathing to complete detachment of the roof system (Fig. 4.17). Evidence of vehicles transported by storm surge is also evident in the footage. **Treasure Cay Resort** lost its roof, reported some wall collapses and significant flood damage (Nagle Myers, 2019). An aerial perspective of the impacts is offered by Figure 4.18.

Figure 4.17. Damage to roofs of multi-family residential construction in Cooper's Town in North Abaco District of Abaco Island. (Source: https://twitter.com/i/status/1168701649847820289, Footage by Amanda Degregory)

[18] https://twitter.com/i/status/1168701649847820289 (Footage by Amanda Degregory)

Figure 4.18. Aerial view of damage in Treasure Cay showing varying levels of performance, from minor roof cover loss to complete collapse. Photo is taken looking north towards (26.672372, -77.279685). (Source: Association of Bahamas Marinas).

4.1.1.7 South Abaco District, Grand Abaco Island

Limited information is available for South Abaco District. The Facebook page for a local establishment reported minimal damage overall in Sandy Point and the surrounding area, including the **Sandpiper Inn** (Nagle Myers, 2019).

4.1.2 Grand Bahama Island

This section similarly documents reports from various districts on Grand Bahama Island.

4.1.2.1 Freeport City District

The second largest city in the Bahamas, Freeport and its famous oceanfront district, Lucaya, experienced significant damage in Hurricane Dorian (Fig. 4.19), in great part due to the storm surge previously discussed in Section 2.2.1. Freeport remained largely inaccessible until September 5, limiting the rescue and recovery efforts and delaying assessments of damage.

Eyewitnesses reported the need to relocate shelters frequently as the surge continued to rise during Hurricane Dorian's stall over Grand Bahama Island. These rising floodwaters also reached the emergency room of the **Rand Memorial Hospital** in Freeport, which forced the evacuation of patients seeking treatment for Dorian-related injuries[19]. Similar impacts were experienced at most of the healthcare facilities in the area (Espinosa et al., 2019). Imagery that has circulated affirms significant damage to residential construction (e.g., Figs. 4.20-4.22). The **Pelican Bay Hotel at Lucaya** in Freeport has also reported damage (Nagle Myers, 2019). Damage to engineered buildings was also noted, including the **University of Bahamas North Campus** (Fig. 4.23). Several marinas and clubs on the south side of Freeport reported little to no damage to their buildings. In fact, despite being positioned in the southern eyewall of Dorian for a number of hours, structural damage does not appear to be uniformly extensive (see Figs. 4.24-4.25), but more isolated than what has been revealed in Marsh Harbor and other areas in the Abaco Islands. Figure 4.1 demonstrates that, based on analysis of satellite data, the density of destroyed buildings in Freeport was much lower than in Marsh Harbor.

Figure 4.19. Aerial photo of severe flood-induced damage to buildings in Freeport, note the displaced shipping containers. (Source: Adam DelGiudice/AFP/Getty Images/Vox).

[19] https://twitter.com/i/status/1168731060458467328

Figure 4.20. Failed roof and partial failure of upper story walls of residential structure in Freeport (Source: [Scott Olson/Getty Images/Vox])

Figure 4.21. Remains of an unreinforced concrete block masonry single-family dwelling destroyed in the Pine Bay neighborhood of Freeport on Grand Bahama Island (Source: [NPR])

Figure 4.22. Unreinforced concrete block wall blowout in Freeport (Source: [Matias J. Ocner/Miami Herald]).

Figure 4.23. Wall cladding damage at the University of the Bahamas Northern Campus (Source: [Dorothy Hall St. James]).

Figure 4.24. Aerial view of the damage to residential homes in Freeport (Source: NY Times)

Figure 4.25. Varying levels of structural damage to residential homes in Lady Lake, Freeport (Source: Miami Herald)

4.1.2.2 East Grand Bahama District

Pelican Point is a rural community in East Grand Bahama Island and is not highly populated. This area was subjected to high winds for 25 hours, experiencing the eyewall of the hurricane. Reports from Pelican Point do note minor damage to hotels (Baran, 2019). Residents of East Grand Bahama District stated that the majority of homes were destroyed (Oppmann et al., 2019), e.g., Figure 4.26. High Rock is located in the East Grand Bahama District and was also heavily impacted. The police station and clinic located in High Rock were severely damaged (Figs. 4.27 and 4.28, respectively) along with wood-framed and concrete/masonry residences (Figs. 4.29-4.31).

Fig. 4.26 Residential home in the East Grand Bahama Island (Source: CNN)

Fig. 4.27 Structural damage to the police station in High Rock, Bahamas. Source: [CNN]

Fig. 4.28 Total building collapse of clinic in High Rock, Bahamas. Source: [CNN]

Figure 4.29. Inside view of home damaged in High Rock, Bahamas. (Source: Angel Valentin and Oliver Laughland)

Figure 4.30. Wood-framed residential damage in High Rock, Bahamas. (Source: SkyNews)

Figure 4.31. Damage to concrete/masonry residential construction in High Rock, Bahamas. (Source: SkyNews)

4.1.2.3 West Grand Bahama District

Limited information is available about the performance of specific buildings in West Grand Bahama, including West End, the oldest town and westernmost settlement on Grand Bahama Island. Figure 4.1 indicates some buildings were destroyed, but damage does not appear to be as widespread as in other parts of the island. However, the need for aid suggests damage in this district. It is reported that **Old Bahama Bay Resort** at West End, a luxury resort complete with a 72-slip marina for yachts, is functioning as a command center for all donated supplies from nearby Florida (Borygass, 2019). The need for the resort to fill this role is not new; it did the same in 2016 when 95% of the buildings in Eight Mile Rock and Holmes Rock were damaged by Hurricane Matthew (Ward and Faiola, 2019b).

4.1.4 Other Bahamian Islands

New Providence Island, which houses the capital of Nassau and is the most populous island with (246,329 reported in the 2010 census), did report flooding (Fig. 4.32). Flooding was also documented in Atlantis Resort in New Providence[20]. Islands in the southeastern and central Bahamas were also spared by Hurricane Dorian. That includes the Exumas, Cat Island, San Salvador, Rum Cay, Long Island, Acklins/Crooked Island, Ragged Island, Mayaguana, and Inagua.

[20] https://twitter.com/i/status/1168478898620981253

Figure 4.32. Flooded gas station [Located at 25.061413, -77.347805] on New Providence Island (Source: https://twitter.com/mvp242/status/1168469847992426496).

4.2 Building Damage: United States

Structural damage in Hurricane Dorian, in the US, was largely confined to properties affected by tornadoes spawned during the hurricane's approach (see Section 2.5). The New Brunswick, NC tornado is reported to have damaged 40 structures, including a number of single family site-built homes (Figs. 4.33 & 4.34). A separate tornado in Emerald Isle, NC (preliminary rating of EF1 by the NWS) damaged a mobile home park (Figure 4.35) though thankfully no injuries or fatalities were reported. The same area in Emerald Isle, NC experienced an EF2 tornado in 2018. A number of buildings in North and South Carolina also experienced flood damage, though these damages are largely non-structural in nature.

Figure 4.33. Failure of roof structure of single family home in Brunswick County, NC [Located approximately 33.921079, -78.576802] (Source: CNN)

Figure 4.34. Envelope and structural damage to a row of single family homes in Brunswick, NC [Located approximately 33.921079, -78.576802] (Source: CNN)

Figure 4.35. Boardwalk RV park in Emerald Isle, NC damaged by a tornado induced by Hurricane Dorian (Source: Patch.com). From available photographs, the RVs had minimal anchorage to resist the tornado-induced winds.

5.0 Damage to Infrastructure

5.1 Infrastructure Damage: Bahamas

At the time this report was authored, the extent of impacts to infrastructure is not yet fully known as much of the area remains unassessed due to the level of devastation, debris and logistical challenges. As the infrastructure in the affected islands of the Bahamas was largely submerged by the storm surge, damage is projected to be “unprecedented” (Ortiz, 2019). A notable infrastructure deficit will be drinking water distribution systems as well as freshwater sources of drinking water, given the strong likelihood of saltwater intrusion. Severe impact to communications, power and transportation are also projected (UN OCHA, 2019):

- In both the Abaco and Grand Bahama Islands, there are considerable access restrictions due to flooding and debris fields (Fig. 5.1) which have hindered recovery efforts substantially.

- There was widespread damage to transmission lines and poles across the Abaco and Grand Bahama Islands (Fig. 5.2). Power losses were widespread not only in these islands, but also across New Providence (attributed to moisture ingress at a primary substation, resulting in a cascading failure of the system).

The following subsections summarize specific known impacts to infrastructure such as roads and bridges, power and telecommunications, ports and other lifelines at the district-level in some of the most impacted islands.

Figure 5.1. Flooded roads and spread damage in Freeport (Source: Fox 13 News)

Figure 5.2. (left) Downed power lines, stripped trees and collapsed homes in Marsh Harbour, Bahamas, Sept. 1st (Source: ABC News); (right) snapped utility poles in Spring City (Source: News Press)

5.1.1 Abaco Islands

Leonard M. Thompson International Airport, formerly known as The Marsh Harbour International Airport, experienced significant flooding in Hurricane Dorian (Fig. 5.3). However, at the time of this report, the airport was being used again for mobilizing relief efforts. Great Abaco Island's other means of access (boat) has also been affected by Dorian with damage to its many harbors. For example, the **Marsh Harbor Government Port** serves as the main entry point for access to Abaco was unable to accept ships early on in the recovery. Figure 5.4 provides a visual depiction of its condition shortly after the storm. Another air strip in South Abaco District, **Sandy Point Airport**, was unaffected by the storm (Law, 2019). The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) reports the following as of 10 September (UN OCHA, 2019b):

"Most seaports are operational, with the exception of those located in East Grand Bahama. Airports are becoming increasingly operational: Grand Bahama International Airport, West End (private), Walkers Cay, Moore's Island, Cistern Field, Great Harbour Cay, Treasure Cay and Sandy Point. The following airports have limited operational capacity: Spanish Cay (private), Scotland Cay, and Leonard M Thompson International (Marsh Harbor)."

Figure 5.3. Comparison of the Leonard M. Thompson International Airport [26.511, -77.085] serving in Marsh Harbour before (above) and after (below) the Hurricane Dorian 2019.) (source: above: Google Maps, below: U.S. Coast Guard via Weather Channel)

Figure 5.4. Comparison of marina (26.532, -77.054) in Marsh Harbor, Bahamas, before (above) and after (below) Dorian's storm surge on September 2, 2019. (Sources: before image: Google Maps, after image: U.S. Coast Guard via Weather Channel)

5.1.2 Grand Bahama Island

Grand Bahama Island was largely inaccessible until September 5, with severe damage to roadways on this island inhibiting rescue efforts and aid distribution. **Grand Bahama Highway** was completely submerged and blocked by debris (Figs. 5.5-5.6). Similar conditions were noted at a number of other primary and secondary roads in the Freeport area (Figs. 5.7-5.8).

Figure 5.5. Grand Bahama Highway blocked by debris (Source: Miami Herald)

Figure 5.6. Grand Bahama Highway at Fortune Bay, Freeport. (Source: Miami Herald)

Figure 5.7. Freeport main road on September 3 (Source: NY Times. Ramon Espinosa/Associated Press)

Figure 5.8. Aerial view of damaged roads near Freeport. Source: NY Times

Grand Bahama International Airport in Freeport was submerged (Fig. 5.9) with a reported 6 feet (2 m) of standing water (Espinosa et al., 2019). Live reports on CNN on September 4 confirmed that the domestic terminal has been completely destroyed; the international terminal is still standing but has obvious damage and is without power (Fig. 5.10). Small planes were damaged to an unrecognizable extent, with parts washed into the surviving terminal building. All the airport's perimeter fencing was stripped, and the runway was completely covered in debris. Notwithstanding, the airport is currently operational for humanitarian efforts (UN OCHA, 2019b).

Figure 5.9. Comparison of Grand Bahama International Airport in Freeport (26.548, -78.696) in 2005 (left) and on September 2, 2019 after (right), flooded with Dorian's storm surge (Source: CNN)

Figure 5.10. Damage to terminal building at Grand Bahama International Airport in Freeport (26.548, -78.698): (left) exterior view and (right) interior view (Sources: left image: Orlando Sentinel, right image: Getty Images)

Reports are also documenting damage to the **Burmah Oil Terminal** on Grand Bahama Island. Pre-event imagery suggests that all the tanks on this site were capped with domed tops that appear to be missing from several of the tanks (Fig. 5.11). The operator has mobilized response teams to conduct an assessment on 8 September, as well as a vessel with equipment to start repairs -- expected to arrive on 10 September (UN OCHA, 2019b).

Figure 5.11. Burmah Oil Terminal at South Riding Point on the east side of Grand Bahama Island [26.626, -78.232] before Hurricane Dorian (left) and after (right) (Source of after image: New York Times, Source of before image: Google Maps)

5.2 Infrastructure Damage: United States

Damage to infrastructure in the southeastern United States was minimal. Outside of damage to piers and docks in the Carolinas, the most noteworthy infrastructure impact was NC-12, the main road linking North Carolina's barrier islands to the mainland, which was damaged by flood waters. The damage to NC-12 prevented rescue crews from accessing boat docks near Ocracoke Island, where over 1,000 people were stranded, which made rescue efforts more difficult (Fig. 5.12).

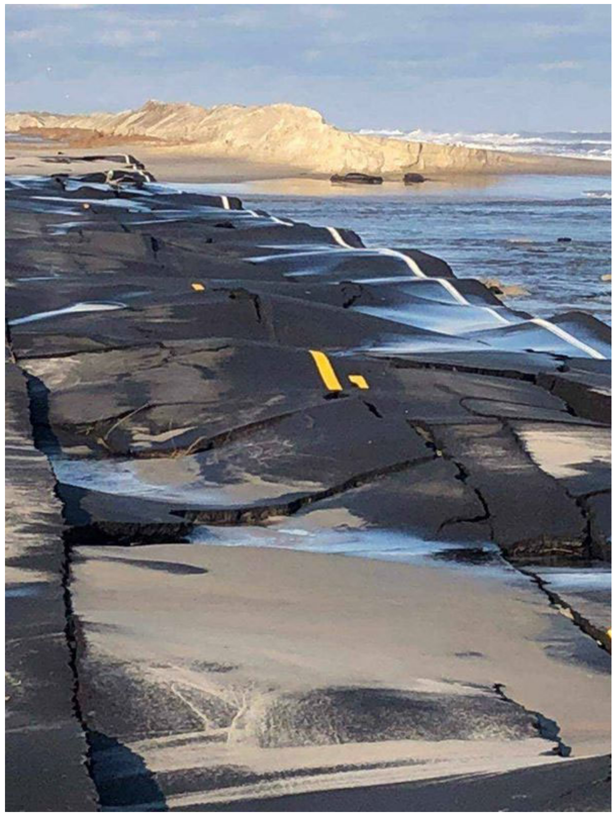


Figure 5.12. Geotechnical failure of portion of NC-12 along North Carolina barrier islands. (Source: NCDOT)

6.0 Observed Geotechnical Failures

Given the level of destruction to the built environment and the considerable debris fields in the Bahamas, geotechnical failures are largely obscured or underreported at this time. Undoubtedly the coastlines of the Bahamian islands were modified by Hurricane Dorian and evidence of erosion, scour and other geotechnical failures is expected. These will affect not only buildings, but also transportation infrastructure (similar to the effects observed in Fig. 5.12) and even other lifelines like water supply.

7.0 Current Conditions and Access

There are no major access issues noted for the US with the exception of the situation on the island of Ocracoke (see Sec. 5.2). The islands in the Bahamas have a number of constraints on on-land transport, e.g., no vehicles, and access, even under normal operating conditions. The following subsections report any unique constraints known in these locales, such as restricted vehicular traffic or access by ferry, as well as early reports of further restrictions/loss of access due to Hurricane Dorian. The level of destruction and priority for rescue, recovery and humanitarian assistance will all take priority for the foreseeable future, so access for reconnaissance missions in support of research will be substantially delayed. Direct impacts to a number of airports in the region will make access to the most affected islands challenging for some time[21].

7.1 Abaco Islands, Bahamas

7.1.1 Great Abaco Island

- **Leonard M. Thompson International Airport** (formerly named Marsh Harbour International Airport) serving Marsh Harbour was discussed in Section 5.1.1. Amateur video suggests that the facilities of multiple air carriers in this airport have been destroyed, and the airport has experienced heavy flooding. It was officially listed as closed from 31 August 19:00 UTC until 3 September 09:49 UTC 2019 (Source: NOTAM). It is reported as of 5 September that this airport is open to private planes. NEMA permits are required to land here.
- Sandy Point Airport (with a single runway) is open and was unaffected by the storm and is receiving aircraft. NEMA permits are required to land here.
- Treasure Cay Airport (single runway and one terminal building) is open but only to rescue and recovery helicopters. NEMA permits are required to land here.
- Marsh Harbour serves as the main entry point for access to Abaco; it appears to be accepting ships again. NEMA is currently developing other points of access.

7.1.2 Elbow Cay

- Ferries are usually used to connect Marsh Harbour to Hope Town at the northern end of Elbow Cay or the mid-island harbor of White Sound; ability to access either of these locations is unknown.
- The island has restricted vehicular traffic in its normal operations.

7.1.3 Grand Cay Island

- Normally accessible by boat; no information regarding access at this time.

[21] Airport status can be monitored at https://share.geckoboard.com/dashboards/CULY2F454IQUNWPX

7.1.4 Green Turtle Cay

- There is no airport on Green Turtle Cay, so it can only be reached via a ferry or boat.

7.1.5 Moore's Island

- Normally accessible by boat; no information regarding access at this time.

7.2 Grand Bahama Island

- **Grand Bahama International Airport** was discussed in Section 5.1.2 and was reported as CLOSED from 30 August 02:00 UTC until 3 September 10:00 UTC 2019 (Source: NOTAM).

7.3 Other Bahamian Islands

- **Lynden Pindling International Airport** in Nassau was CLOSED from 1 September 10:00 PM local time until 2 September 07:00 AM local time (Source: ICAO).

8.0 Recommended Response Strategy

Based on the information gathered by this Preliminary Virtual Reconnaissance Report (PVRR), StEER offers the following recommendations for future study. While in no way diminishing the opportunities to learn from Hurricane Dorian's impacts in the United States, given the absence of substantive structural damage in the Carolinas, StEER will confine its recommendations for further study to the Bahamas.

THEME 1: Performance of engineered construction during long-exposure to significant storm surge and/or strong hurricane force winds

Document the mixed performance of different classes of construction on Great Abaco Island and Grand Bahama Island, e.g., Figure 8.1, with specific emphasis on successes, i.e., properties with little to no damage in this event despite major structural damage to the majority of adjacent properties. Classes worthy of investigation include, but should not be limited to:

a. Residential (single and multi-family)
b. Commercial (including metal building systems used in airports, marinas and industrial zones)
c. Resorts and hotels
d. Critical facilities including hospitals, airports and shelters

Surveys should ideally move along identified transects to distinguish the wind-resistance of buildings inland of the inundation zone. When possible, surveys should identify comparative case studies between the islands to discern the differences in performance observed in Great Abaco Island vs. Grand Bahama Island, which may be in part attributed to characteristics of the wind field and/or duration of exposure as the storm stalled.

THEME 2: Verify hazard characteristics using mixture of aerial and ground-based observations, geospatial data analysis and computational simulation

As Dorian's strongest winds and storm surge were in the Bahamas, measurements/observations and hindcasts will not be undertaken by US federal agencies. Thus, the ability to relate damage/performance observed under Theme 1 to realistic hazard intensities will require attention from the research and international community (non-governmental and governmental actors). Coastal surveys should be undertaken to document forensic evidence suggestive of storm surge depth, extent and velocity, as well as the presence of breaking waves, to aid in the interpretation of damage observations. Bathymetric and topographic factors, as well as storm characteristics, responsible for the large storm surges witnessed in Dorian should be identified. When possible, similar forensic evidence should be gathered (e.g., overturned rigid bodies, hinged poles, snapped/stripped trees) to generate spot evidence of surface wind speeds. Such field observations should be used to develop hindcasts of the wind field and storm surge for this event on Great Abaco Island and Grand Bahama Island (or possibly refine preliminary hindcasts as they become available).

Figure 8.1. Aerial photo of the damage from Dorian on Great Abaco Island demonstrating the mixed performance of buildings across occupancy classes. (Source: CNN)

THEME 3: Leverage virtual reconnaissance technologies for assessment of damage in the early weeks of recovery

As the humanitarian response and recovery efforts in the Bahamas will be unfolding for several weeks, key forensic data will be disturbed or removed by the time teams of reconnaissance researchers physically reach the islands. If possible, Bahamian engineers and researchers should be engaged to make observations at noteworthy sites as soon as it is safely possible. In the interim, researchers outside the Bahamas are encouraged to engage aerial and satellite imagery to begin initial assessments of damage, particularly to roofs, as well as debris fields, to preserve as much of the original forensic evidence as possible. Resources useful in such endeavors are already being assembled by StEER as well as groups like Zooniverse, which is crowdsourcing using satellite imagery to create heat maps of building damage and underwater hazards[22], and the Humanitarian OSM Team, which has set up a platform for collaborative mapping of Abaco[23]. This will further allow any time spent on the ground to be better directed to the assessments that can only be made through in-situ, detailed, on-site inspection.

[22] https://www.zooniverse.org/projects/mrniaboc/planetary-response-network-hurricane-dorian/classify
[23] https://tasks.hotosm.org/contribute?difficulty=ALL&text=Dorian

THEME 4: Geotechnical failures and impacts to coastlines
As discussed in Section 6, given the strong sizeable storm surge in this event and the long-duration exposure generating significant wave action, it is anticipated that geotechnical failures and coastal impacts have not been documented/reported due to the present focus on damage to the built environment. Dorian undoubtedly has had significant impact on the coastlines, riverine systems, and ecology of the affected islands that should be documented given their important ramifications for recovery as well as long-term recovery.

In addition to the themes above, StEER also recognizes the importance of investigating the topics below, which fall outside the purview of natural hazards engineering research but are nonetheless critical opportunities to learn from this disaster to inform research, policy and practice in the future.

TOPIC 1: Addressing informal settlements in land use planning and development
Informal settlements are a historical legacy in Latin American and the Caribbean and thus are an inescapable reality in these regions. It well understood that the social vulnerability of these populations results in construction with equally high degrees of structural vulnerability, situated often on undesirable land that tragically has the highest degrees of hazard exposure. Seeing this disproportionate level of risk may prompt the dismissal of the outcomes in The Mudd and Pigeon Peas as inevitable; however, the tragic lesson of these informal settlements provides an opportunity to re-examine the structural barriers facing disaster risk reduction among populations with undocumented status and without land rights. The settlements lost in Dorian were built over decades and the consequences of where survivors will settle and whether these low-lying plots of land are ever developed again will reach far beyond the memories of persons directly affected by this disaster. The survivors of The Mudd and Pigeon Peas, as well as internally displaced persons (IDPs) who now lack shelter as a consequence of Dorian, will need to be managed with innovative approaches to resettlement, regulation, and integration of informal settlements to prevent future tragedies and possibly head off the formation of high-vulnerability IDP zones in the immediate term.

TOPIC 2: Impacts of slow-progression hurricanes on storm preparedness and evacuation
Hurricane Dorian's slow progression and even stall in the Bahamas not only intensified the exposure to winds and storm surge, but also made the storm notoriously difficult to predict. With communities in multiple states undertaking preparations and evacuations for a week or more before the storm arrived, it is important to examine the impact of Dorian "fatigue" on preparations and compliance with evacuation orders. With recent studies suggesting that slow forward speeds are becoming increasingly common (Hall and Kossin, 2019), emergency managers will need to contend with both the realities of rapidly intensifying storms in warm Gulf waters (like Hurricanes Harvey and Michael), as well as disruptions in the atmospheric circulation patterns that result in slow-moving storms like Dorian (and even the stalling of hurricanes post-landfall, such as Harvey over Houston). This dichotomy in storm characteristics makes the phasing and timing of warnings and evacuation orders increasingly difficult. Communities will similarly have to prepare for greater periods of self-sufficiency, particularly when sheltering in place, given the increasing likelihood of stalled storms.

TOPIC 3: Reframing disaster risk for small island nations
Hurricane Dorian is yet another powerful illustration of the amplified effect hurricanes of this size and intensity can have on small island nations. As was the case with Irma and Maria's impacts on the US Virgin Islands and Puerto Rico, the projected losses in Hurricane Dorian are a sizeable percentage of the annual GDP of the Bahamas and likely more when infrastructure losses are considered. This has serious implications for the recovery timeline, particularly considering the impacts to the tourism industry vital to this nation's economy. Thus the levels of acceptable risk in these settings requires careful consideration. As noted by Prevatt et al. (2010), "Hurricane risk models for [the Caribbean must consider] the consequences of damage in these small islands where the economic cost of hurricane disasters can easily exceed the annual GDP of an island's economy." The relative economic impact of these events (particularly considering the extent of uninsured losses), the infeasibility of evacuations in small islands nations without vertical evacuation options, and the logistical challenges of response and recovery across archipelagos highlighted by Dorian reiterates the continued need to re-examine disaster risk reduction and emergency management strategies in the context of policy and practice for small island nations.

Given the magnitude of Hurricane Dorian and the impacts documented in this PVRR, and recommendations for further study articulated under the themes itemized above, **StEER anticipates deploying a Field Assessment Structural Team (FAST) to the Bahamas to conduct reconnaissance on the Abaco and Grand Bahama Islands**. The FAST will include Level 3 and 4 StEER members with expertise in characterizing wind and coastal hazards and their impact on the built environment, as well as 1-2 Level 2 members serving as FAST Trainees for this event. The exact timing of this mission remains dependent on the progress of response and recovery activities in the affected areas and will not deploy until immediate humanitarian needs are met. StEER will particularly focus on Themes 1 and 2 outlined above. In the interim, StEER will continue to examine how to mobilize its membership in support of Theme 3 to maximize the potential to remotely learn from imagery preserving key forensic information likely to be disturbed by the time the FAST arrives on the islands. StEER is coordinating with points of contact in the Bahamas as well as other organizations responding to this event to further develop its FAST strategy and will encourage other extreme events organizations under Converge to examine the remaining themes and topics outlined in this section.

Appendix A. Timeline of Bahamas Response

Source: Private Twitter accounts of Responsible Party.

Key Abbreviations:

- In Period column: B = Before, D = During, A = After Hurricane Dorian's landfall
- NEMA: National Emergency Management Agency of the Bahamas
- PMOB: Prime Minister of Bahamas

Responsible Party	Position	Action	Period			Date & Time
			B	D	A	
James Albury MP	Member of Parliament for Abaco	Announced Abaco Shelter	●			8/29/2019 at 3:46 PM
James Albury MP	Member of Parliament for Abaco	Noticed all Travel and Flight are suspended on Saturday August 31	●			8/29/2019 at 9:55 PM
Dr. Hubert Minnnis	PMOB	Announced the emergency evacuation in Abaco and Grand	●			8/30/2019 at 5:13 PM
Dr.Hubert Minnnis	PMOB	Said "now Dorian is dangerous and reached Category 4 .be ready and get all supplies"	●			8/30/2019 at 10:19 PM
NEMA	Government	Announced all shelters in Abaco	●			8/31/19 at 1:49 PM
Dr.Hubert Minnnis	PMOB	He traveled to Abaco check in on the progress of evacuation	●			8/31/19 at 2:09 PM
Dr.Hubert Minnnis	PMOB	Announced the effect of hurricane started on Grand Bahama and give Warning		●		9/1/19 at 4:18 AM
Dr.Hubert Minnnis	PMOB	Announced hurricane is Category 5 and give Warning, Also meeting NEMA		●		9/1/19 at 10:30 AM
NEMA Bahamas	Government	Distributed survey link online and let them to do it and to make sure where they are located and safe or not		●		9/2/19 at 1:38 AM
ZNS Bahamas	Broadcasting Corporation of the Bahamas	Ministry of health resumed all hospital in New Providence and rescheduled all shifts		●		9/2/19 at 1:22 PM

Responsible Party	Position	Action	Period			Date & Time
			B	D	A	
Dr.Hubert Minnnis	PMOB	Announced to rescue and recovery for Grand Bahama		●		9/2/19 at 9:39 AM
Dr.Hubert Minnnis	PMOB	Confirmed 5 deaths in Abaco and provide a relief and assistance for the rest		●		9/2/19 at 8:53 PM
U.S Embassy Nassau	Embassy	Sent helicopters (U.S Coast Guard) to evacuate injured from Abaco and flying back to Nassau		●		9/2/19 at 11:52 PM
IOM-UN Migration	Organization	Began assessing Damage from hurricane in 13,000 houses Bahamas			●	9/3/19 at 7:24 AM
ZNS Bahamas	Broadcasting Corporation of the Bahamas	Official announced from University of the Bahamas to be closed until further details			●	9/3/19 at 9:02 AM
Dr.Hubert Minnnis	PMOB	Continuing to monitor and posted an Emergency numbers and U.S Coast Guard started rescue			●	9/3/19 at 11:34 AM
Minister of Social Affairs	Minister	Seeking Relief initiative items for Abaco and Grand Bahama people			●	9/3/19 at 5:27 PM
Royal Caribbean	Cruise	Donated $1 million to Dorian disaster relief			●	9/3/19 at 7:09 PM
NEMA Bahamas	Government	Posted a donation information to donate to Bahamas			●	9/3/19 at 7:55 PM
World Health Organization (PAHO/WHO)	Organization	Working with health authorities in the Bahamas			●	9/3/19 at 8:34 PM
ZNS Bahamas	Broadcasting Corporation of the Bahamas	Prime Minister Confirmed 3 deaths in Abaco			●	9/3/19 at 8:40 PM
Dr.Hubert Minnnis	PMOB	Do an initial air reconnaissance of Abaco and asked for food, water, shelter for Abaco's people			●	9/3/2019 at 11:34 PM

Responsible Party	Position	Action	Period			Date & Time
			B	D	A	
Ministry of Defense of UK	Ministry	Sent Royal Navy to assess damage and help government of Bahamas			●	9/4/19 at 9:35 AM
Justin Trudeau	Prime Minister of Canada	Initial donated $2 million to Dorian disaster relief			●	9/4/19 at 12:47 PM
ZNS Bahamas	Broadcasting Corporation of the Bahamas	Government Announced all Schools with the exception of Abaco and Grand Bahama, will revert back to normal on 9/9			●	9/4/19 at 1:03 PM
Saint Lucia	Government	Pledged support to the recovery efforts, cash donation can be made it			●	9/4/19 at 2:27 PM
Foreign office(UK)	Ministry	Delivered 1200 cases of water,1300 food ration packs and 500 shelter kit			●	9/4/19 at 3:17 PM
ZNS Bahamas	Broadcasting Corporation of the Bahamas	The Ambassador of the People's Republic of China and behalf his country donated $20,000 in goods			●	9/4/19 at 3:52PM
Carnival	Cruise	Donated $2 million to Dorian disaster relief			●	9/4/19 at 6:02 PM
The United Nation Central (CERF)	Organization	Donated $1 million to Dorian disaster relief			●	9/4/19 at 7:58PM
Antonio Guterres	Secretary – General of the United Nation	Continue to support relief and recovery efforts			●	9/4/19 at 8:10 PM
U.S Coast Guard	U.S Government support team	Response operations are underway in support of Bahamas			●	9/4/19 at 9:10 PM
Dr.Hubert Minnnis	PMOB	United States President and Prime Minister of Canada expressed their support and pledged their assistance			●	9/5/2019 at 12:05 AM

Responsible Party	Position	Action	Period			Date & Time
			B	D	A	
Disney	Cruise	Donated $1 million to Dorian disaster relief			●	9/5/2019 at 2:59 AM
LPIA Nassau Airport	Airport	Open normally			●	9/5/19 at 6:28 AM
U.S Coast Guard	U.S Government support team	Rescued 135 people and 6 pets			●	9/5/2019 at 9:00 AM
Caribbean Community (CARICOM)	Organization	Announced that “Caribbean is in full solidarity with the Government and people of Bahamas			●	9/5/19 at 9:29 AM
U.S Embassy Nassau	Embassy	Supplies arrived From USAID to help 31,500 people			●	9/5/2019 at 9:34 AM
ZNS Bahamas	Broadcasting Corporation of the Bahamas	Commonwealth Bank Managing Director Raymond Winder made donation to RED Cross			●	9/5/2019 at 11:40 AM
Kevin McAleenan	Homeland Security Acting Secretary	Confirmed the request of the Prime Minister to the President of U.S to support GOV. of the Bahamas.			●	9/5/2019 at 1:46 PM
Nassau Guardian	Newspaper	Health Minister Dr.Duane Sands confirmed 23 deaths			●	9/5/2019 at 2:28 PM
Andrew Holness	Prime Minister of Jamaica	Sent Jamaica Defense Force soldiers to help			●	9/5/19 at 6:00 PM
UNICEF Latin America	Organization	Sent team to provide humanitarian aid to affected children and families			●	9/5/19 at 6:45 PM
Dr.Keith Rowley	Prime Minister of Trinidad and Tobago	Announced the CARICOM support for Bahamas which is $500,000, 100 people from the Defense Force for maintenance and 7 technical for electrical power			●	9/5/19 at 6:59 PM

Responsible Party	Position	Action	Period			Date & Time
			B	D	A	
Dr.Hubert Minnnis	PMOB	Welcomed a Caribbean Community (CARICOM) and their support and assistance			●	9/5/2019 at 11:14 PM
U.S Coast Guard	U.S Government support team	Rescued 205 people			●	9/6/2019 at 9:00 AM
Dr.Hubert Minnnis	PMOB	Traveled to Abaco with CARIOM and CDEMA officials team to assess damage and give supplies, also Free air evacuations on Bahamasair from Abaco who want to leave the islands			●	9/6/19 at 10:08 AM
Foreign office(UK)	Ministry	Allocating 1.5 million pounds to help Bahamas people			●	9/6/19 at 12:44 PM
U.S Coast Guard	U.S Government support team	Rescued 290 people			●	9/7/2019 at 9:00 AM
USAID/OFDA U.S. Foreign Disaster Assistance	U.S Government support team	USAID disaster team members ,including VATF1 are search and rescue now in Abaco			●	9/7/2019 at 12:26 PM
U.S Coast Guard	U.S Government support team	Rescued 308 people			●	9/8/2019 at 9:00 AM
NEMA Bahamas	Government	Posted to sign up information for who is interested in helping either individually or organization			●	9/8/19 at 5:08 PM
Dr.Hubert Minnnis	PMOB	Visited all shelters in New Providence to check the evacuees From Abaco and Grand Bahama and told them that they are starting rebuilding their home			●	9/9/19 at 5:43 PM

Appendix B: Preliminary rainfall totals in United States

Source: NCEP (2019) for states of Florida, Georgia, South Carolina and North Carolina

State	Location	Total Rainfall in cm (in)
Florida	Palm Coast 4.5 SSW	14.42 (5.68)*
Florida	Deland 0.6 SSE	11.53 (4.54)*
Florida	Lake Mary	9.96 (3.92)*
Florida	Flagler Beach 2.3 SSE	9.42 (3.71)*
Florida	St. Augustine Airport	6.81 (2.68)*
Florida	Cape Canaveral	6.75 (2.66)*
Florida	Daytona Beach Intl Arpt	6.55 (2.58)*
Florida	Orlando/Sanford Arpt	6.42 (2.53)*
Florida	Melbourne	5.87 (2.31)*
Georgia	Savannah 9.6 E	6.04 (2.38)*
Georgia	Jekyll Island 0.6 E	4.67 (1.84)*
South Carolina	McClellanville 7 NE	27.03 (10.64)
South Carolina	Cainhoy 4 SSE	25.00 (9.84)
South Carolina	Myrtle Beach Intl Arpt	22.53 (8.87)
South Carolina	Socastee 3.3 SW	19.10 (7.52)
South Carolina	Georgetown County Arpt	15.72 (6.19)
South Carolina	Charleston Intl Arpt	14.07 (5.54)
North Carolina	Castle Hayne	26.03 (10.25)
North Carolina	Wilmington INtl Arpt	25.20 (9.92)
North Carolina	Duplin County Arpt	16.02 (6.31)
North Carolina	Sampson County Arpt	15.31 (6.03)
North Carolina	Soules Swamp	13.59 (5.35)
North Carolina	Sunset Beach	12.95 (5.10)
North Carolina	Calabash 1.2 NNW	12.83 (5.05)

*event has ended

Appendix C: 2010 Census Building and Housing Stock (Bahamas)

Source: Dept. of Statistics (2017a)

2010 CENSUS BUILDING AND HOUSING STOCK

TABLE 3.0

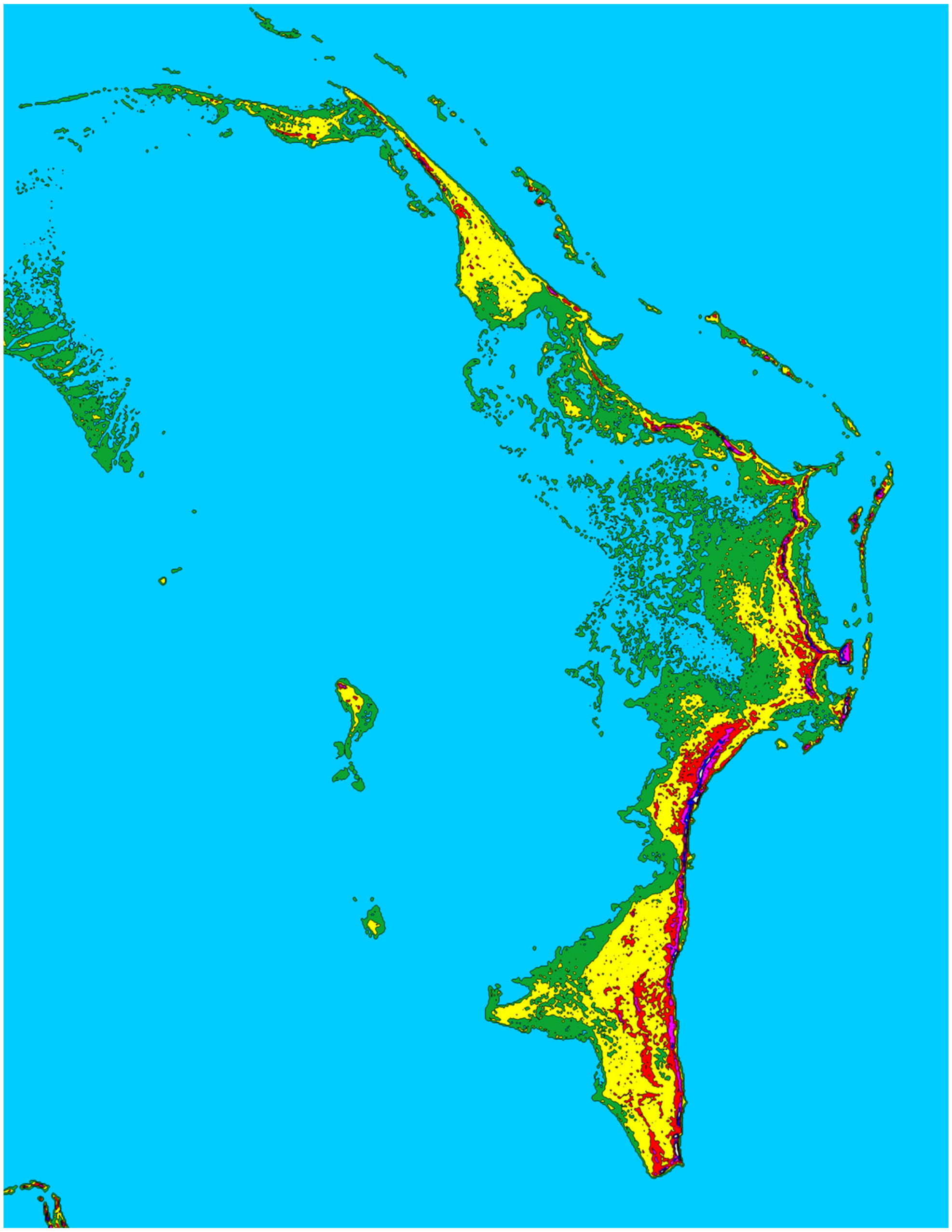
ISLAND/ SUPERVISORY DISTRICT	NUMBER OF BUILDING UNITS	NUMBER OF DWELLING UNITS	NUMBER OF OCCUPIED DWELLING UNITS	NUMBER OF VACANT DWELLING UNITS
ALL BAHAMAS	**96,863**	**126,493**	**102,862**	**23,631**
NEW PROVIDENCE	**57,642**	**79,311**	**70,222**	**9,089**
YAMACRAW	1,925	2,537	2,305	232
ELIZABETH	2,123	3,859	3,451	408
ST. ANNE'S	2,365	2,801	2,484	317
FOX HILL	2,182	2,876	2,542	334
MONTAGU	2,834	3,954	3,234	720
SEA BREEZE	2,424	3,295	3,025	270
MARATHON	2,101	2,718	2,485	233
ST. THOMAS MOORE	3,215	3,532	3,166	366
FARM ROAD AND CENTREVILLE	2,837	3,277	2,989	288
ENGLERSTON	2,630	3,301	2,994	307
GARDEN HILLS	2,256	3,585	3,288	297
KENNEDY	1,819	2,691	2,428	263
SOUTH BEACH	1,992	2,920	2,624	296
BAIN AND GRANTS TOWN	2,469	2,728	2,493	235
ST. CECELIA	2,360	2,863	2,614	249
GOLDEN GATES	1,690	2,250	2,077	173
BAMBOO TOWN	2,071	3,138	2,838	300
PINEWOOD	1,818	2,290	2,152	138
BLUE HILLS	2,432	4,039	3,608	431
CARMICHAEL	1,808	2,440	2,243	197
GOLDEN ISLES	2,820	4,587	4,028	559
FORT CHARLOTTE	1,977	3,106	2,639	467
MOUNT MORIAH	1,799	2,509	2,307	202
CLIFTON	3,026	4,048	2,868	1,180
KILLARNEY	2,669	3,967	3,340	627
GRAND BAHAMA	**13,697**	**20,337**	**15,140**	**5,197**
WEST END	1,472	1,618	1,264	354
EIGHT MILE ROCK	2,774	3,354	2,704	650
PINERIDGE	2,249	2,851	2,329	522
LUCAYA	2,267	5,223	3,327	1,896
MARCO CITY	1,962	2,654	2,349	305
HIGH ROCK	2,973	4,637	3,167	1,470

2010 CENSUS BUILDING AND HOUSING STOCK

TABLE 3.0 CONT'D

ISLAND/ SUPERVISORY DISTRICT	NUMBER OF BUILDING UNITS	NUMBER OF DWELLING UNITS	NUMBER OF OCCUPIED DWELLING UNITS	NUMBER OF VACANT DWELLING UNITS
ABACO	**6,786**	**8,113**	**5,197**	**2,916**
NORTH ABACO	3,388	4,193	2,681	1,512
SOUTH ABACO	3,398	3,920	2,516	1,404
ACKLINS	416	328	209	119
ANDROS	**3,482**	**3,280**	**2,373**	**907**
NORTH ANDROS	1,614	1,525	1,189	336
SOUTH ANDROS	1,868	1,755	1,184	571
BERRY ISLANDS	645	758	342	416
BIMINIS	1,186	1,385	751	634
CAT ISLAND	608	990	608	382
CROOKED ISLAND	291	228	124	104
ELEUTHERA	**4,371**	**4,267**	**2,718**	**1,549**
NORTH ELETHUTHERA	1,571	1,693	1,071	622
SOUTH ELEUTHERA	2,800	2,574	1,647	927
EXUMA AND CAYS	2,901	2,875	2,028	847
HARBOUR ISLAND	876	966	597	369
INAGUA	443	383	319	64
LONG ISLAND	1,981	1,769	1,119	650
MAYAGUANA	180	160	107	53
RAGGED ISLAND	64	51	26	25
RUM CAY	100	83	40	43
SAN SALVADOR	523	469	342	127
SPANISH WELLS	671	740	600	140

Appendix D: Topographic Map of Abaco Islands



MAP KEY

Light Blue:
0 ft
(0.0 m)

Green:
0-15 ft
(0.0-4.6 m)

Yellow:
15-30 ft
(4.6-9.1 m)

Red:
30-45 ft
(9.1-13.7 m)

Violet:
45-60 ft
(13.7-18.3 m)

Blue:
60-75 ft
(18.3-22.9 m)

White:
75+ ft
(22.9+ m)

Topographic map of the Abaco Islands, Bahamas shaded at 15 foot (4.572 meter) contour intervals. Map created with SRTM3 digital elevation data (http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/). Resolution is ~90 meters. By Lithium6ion - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=18458689

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