NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Hurricane Irma Event Analysis Report

August 2018

RELIABILITY | ACCOUNTABILITY




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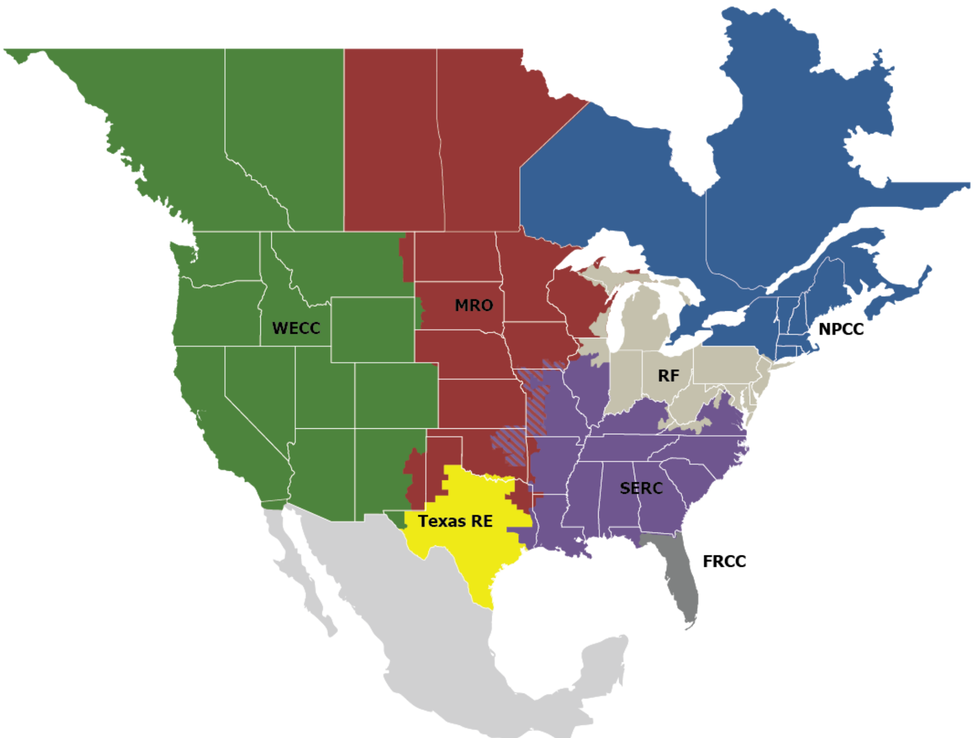
Preface

The vision for the Electric Reliability Organization (ERO) Enterprise, which is comprised of the North American Electric Reliability Corporation (NERC) and the seven Regional Entities (REs), is a highly reliable and secure North American bulk power system (BPS). Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

The North American BPS is divided into seven RE boundaries as shown in the map and corresponding table below. The multicolored area denotes overlap as some load-serving entities participate in one Region while associated Transmission Owners/Operators participate in another.



FRCC	Florida Reliability Coordinating Council
MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	ReliabilityFirst
SERC	SERC Reliability Corporation
Texas RE	Texas Reliability Entity
WECC	Western Electricity Coordinating Council

Objective

The purpose of this report is to provide an analysis of Hurricane Irma's impact on the BPS to ensure a complete, coherent review and documentation of the event and restoration efforts. The report focuses on three main areas: preparation, operations during the event, and restoration. The report is from the perspectives of the Reliability Coordinator (RC) and summarizes the event for the entire storm area. For any questions about the contents of this report, including corrections, improvements, and any suggestions, please contact NERC.EventAnalysis@nerc.net.

Executive Summary

Hurricane Irma made initial landfall in the United States on Cudjoe Key (20 miles north of Key West) in the Florida Keys at 9:34 a.m. Eastern on September 10, 2017, as a Category 4 storm with sustained winds of 130 mph. Later that same day, Irma weakened to a Category 3 storm with sustained winds of 115 mph and made a second landfall near Marco Island in Southwest Florida at 3:35 p.m. Eastern. Irma moved quickly northward, just inland from the West Coast of Florida on September 10 and 11. As Irma hit Florida, tropical storm force winds extended outward up to 400 miles from the center, and hurricane force winds extended up to 80 miles. Hurricane force wind gusts (74 mph or more) were reported along much of the East Coast of Florida from Miami to Jacksonville. In addition to the prolonged periods of heavy rain and strong winds, storm surge flooding also occurred well away from the storm center, including in the Jacksonville area, where strong and persistent onshore winds had been occurring for days before Irma's center made its closest approach.

When Hurricane Irma reached Northwest Florida (on the morning of September 11), the wind gusts were generally in the 45 to 60 mph range. Dry southwest winds made the storm system irregular, and conditions improved rapidly once the storm center passed over the state of Florida. Irma weakened to a tropical storm in South Georgia on the afternoon of September 11 and was downgraded to a tropical depression while moving north across Central Georgia in the evening.

As Hurricane Irma approached Florida, NERC, the REs, and the potentially affected registered entities continually monitored weather developments and exchanged information. Prior to the storm's landfall, the RC initiated daily calls with the Transmission Operators (TOPs) and Balancing Authorities (BAs) in the FRCC Region. The TOPs and BAs reported that the lines and generators that were previously shut down for maintenance were returned to service. The BAs reported that several generating units were placed into a preemptive shutdown condition to further protect assets from long-term damage due to the high winds and the predicted storm surge.

Over 100 high-voltage transmission lines, including one 500 kV line, 48 230 kV lines, and a total of 69 138 kV and 115 kV lines experienced storm-related forced outages. Several transmission lines (two 500 kV lines and five 230 kV lines) were opened in a controlled fashion to address high voltage conditions due to low loads. Numerous generation facilities (approximately 6,500 MW) were shut down in a controlled fashion to minimize storm-related damage. Approximately 3,300 MW of generation experienced storm-related forced outages, primarily from high winds, sustained storm surges, and transmission line forced outages. Customer outages in Florida exceeded six million.

The recovery effort was initiated by the transmission, distribution, and generation registered entities. The initial recovery consisted of inspections and asset assessments. The registered entities' initial assessments were greatly hampered by storm surge, storm damage, and the lack of accessibility into deep right-of-ways due to localized flooding and storm debris. The priority, as communicated by the RC and the TOPs, was to the restore transmission assets to generating facilities needed for distribution load recovery. While there was sufficient generation capacity available to meet the load as restoration progressed, there were some cases where customer restoration was hindered by local area transmission and distribution outages.

Most entities returned 95 percent of their customers to service between September 12 and 15, 2017. Areas along the Southern and Eastern coastlines, which were the areas experiencing the largest sustained storm surges, reported having prolonged restoration times beyond September 15, 2017.

Due to the unprecedented number of pole-mounted distribution transformers damaged, mutual aid and other non-conventional means were utilized to acquire enough units to complete restoration. Additionally, the extensive and longer-than-anticipated storm surge and storm debris presented many challenges to the recovery process.

The registered entities overcame these issues by using approaches that have not been used in previous weather-related events occurring in the Region:

- Unmanned aerial drones were used to perform damage assessments on inaccessible transmission and distribution lines.
- Amphibious vehicles and airboats were used to access flooded areas.
- A mobile application allowed damage reports to be sent back to the office where the process automatically mapped the damage location and then issued work orders to line workers in real time.

The following good industry practices were identified for Hurricane Irma:

- Pre-staging of equipment outside of the hurricane's projected path made the restoration process more effective.
- Pre-emptively removing generation prior to the hurricane making landfall protected equipment from damage and significantly shortened restoration times.
- Continuous communications between the RC, TOPs, and BAs in the FRCC Region ensured coordinated efforts throughout the event and the subsequent restoration.
- Advanced meters and intelligent grid devices were effective to pinpoint outages, operate equipment remotely, and increase efficiency.
- Installation of flood monitors in substations located within the 100-year flood plain resulted in the ability to de-energize substations at notification of rising water and avoiding catastrophic damage to sensitive station equipment.
- Leveraging social media enabled the first ever communications with Facebook live and other platforms, providing customers with the most current outage and restoration information.
- Aerial drones were effective to assess damage, evaluate work conditions, and enable real-time situational awareness. Infrared capabilities helped identify equipment that needed further inspection.
- Hardening and resiliency programs implemented prior to the hurricane significantly reduced the storm damage sustained due to high winds and storm surge.

Background

Pre-existing System Conditions

Pre-existing conditions for all areas were considered normal for September, which is generally considered a summer peak season for Florida. In the days leading up to September 10, 2017 (landfall), loads were slightly lower due to mandatory and voluntary evacuations. During summer peak, asset owners delay system maintenance and upgrades due to higher demand; therefore, there were not many planned transmission or generation outages prior to landfall.

Affected Areas

Hurricane Irma affected most of the state of Florida as a hurricane and some areas in Georgia as a tropical storm. The Florida Keys were devastated by Irma, and some areas may take years to rebuild. The most heavily affected areas were in South Florida—primarily Southeast Florida. The East Coast of Florida experienced storm surge and associated saltwater contamination while the West Coast also experienced some flooding due to heavy rainfall.

Time Frame for Outage and Restoration

There were no load curtailments to maintain reliability. Florida remained connected to the Eastern Interconnection despite the high number of transmission line outages. Throughout the storm and during the recovery period, there were no reported instability or cascading events. Most entities returned 95 percent of their customers to service between September 12 and 15, 2017. Some areas along the Southern and Eastern coastlines, which were the areas experiencing the largest sustained storm surges, reported having prolonged restoration times beyond September 15, 2017.

Chapter 1: Weather

Weather Systems and Notifications

Most of the FRCC entities use more than one source for weather information. The FRCC RC primarily shared data and information from the National Hurricane Center of the National Oceanic and Atmospheric Administration (NOAA). Some entities have meteorologists on staff that were able to help them in interpreting the information they were receiving. The control centers also use local and national forecasts from television and radio stations.

Timing of Warning Systems and Action Taken

Initial information regarding the potential threat of Hurricane Irma was received on September 5, 2017; entities were actively monitoring the storm and on September 7, 2017, the FRCC RC held their first call in accordance with the *FRCC Operations Hurricane Manual* to begin coordinating hurricane response activities. FRCC Regional conference calls include the RC, Southeast RC, FRCC TOPs and BAs, neighboring BAs and TOPs from the SERC area, FRCC Situational Awareness, and Florida natural gas pipeline operators. In many cases, senior management of registered entities were given updates that contained the information gained on these Regional calls.

NERC Bulk Power System Awareness (BPSA) also began holding conference calls on September 9, 2017, with FRCC, SERC and government agencies to gather and share information. Government agencies that were invited to attend these calls include the Federal Energy Regulatory Commission (FERC), Department of Energy (DOE), Department of Homeland Security (DHS), Nuclear Regulatory Commission (NRC), and Federal Emergency Management Agency (FEMA).

As a result of these preparatory calls, the following actions occurred:

- The status and readiness of generation and transmission resources were determined.
- The status of emergency response organizations was shared.
- Plans for supplemental operations and support staffing were shared.
- Maintenance outages that were postponed or brought back in service were discussed.

Storm Weather Updates during Event

The FRCC RC continued the regional calls throughout the storm providing updates on weather conditions. Utilities continued to independently monitor conditions using their preferred methods and communicated critical information to crews, neighboring utilities, and other impacted systems throughout the event.

The RC regional calls and the NERC BPSA calls were held daily through September 12, 2017 to monitor the impacts of Hurricane Irma.

Storm Weather Updates Following Event

The FRCC RC, BAs and TOPs continued monitoring the weather conditions to ensure worker safety during restoration. As Hurricane Irma dissipated, Hurricane Jose was active in the Atlantic Ocean and kept all at attention while in recovery mode. Jose continued tracking northeast and did affect the Southeast.

Weather Impacts on Restoration Efforts Gleaned from Comparable Storms

Though there has been a substantial number of tropical storms, hurricanes, and weather systems that threatened the Southeastern United States and primarily Florida over the last decade, Hurricane Irma was the first to make landfall in Florida since Hurricane Wilma in 2005.

In 2006, the Florida Public Service Commission (FPSC) held a workshop to discuss electric utilities' lessons learned during the 2004 and 2005 hurricane seasons following a string of major hurricanes. The workshop led to the development of the Electric Infrastructure Storm Hardening Initiatives. The initiatives were driven by three main recommendations: The first recommendation was for Florida to continue to maintain a high level of storm preparation, regardless of the recent hurricane seasons' activity. The second was to strengthen Florida's electric infrastructure to better withstand the impacts of severe weather events; this recommendation included a wide range of hardening activities that took years to complete. Finally, there was a need to establish additional comprehensive planning tools to enable the FPSC and utilities to identify existing overhead electric facilities that warranted conversions to underground where undergrounding is appropriate as a means of storm hardening.

As part of the Electric Infrastructure Storm Hardening Initiatives, the FPSC initiated the following actions:

- Annual hurricane preparedness briefings
- A formal electric utility pole inspection program
- Annual assessment of comprehensive reliability reports by the electric utilities
- 10 additional storm-hardening initiatives that include Florida-specific research
- University research on the measurement and effects of storm wind speeds on electric utility infrastructure
- University research on best practices for vegetation management
- Rules governing investor-owned utility storm restoration costs
- Rulemaking regarding overhead and underground storm hardening construction standards
- Rulemaking to expand the calculation of contribution-in-aid-of-construction (CIAC) for new underground facilities and conversion of existing overhead facilities to underground to reflect the cost impacts of storm hardening and storm restoration
- Tariffs promoting underground electric distribution facilities
- University research to develop cost/benefit methodologies to identify areas and circumstances to facilitate the conversion of overhead distribution facilities to underground facilities

More specific information on each of these initiatives can be found in the FPSC report entitled "*Report to the Legislature on Enhancing the Reliability of Florida's Distribution and Transmission Grids During Extreme Weather*."[1]

Although there were many transmission line outages, it is believed that, had this hardening effort not taken place in Florida over the last decade, the number outages would have been significantly higher and restoration times would have been extended due to the potential for more structural damage.

Storm Severity

Hurricane Irma was reported as the strongest Atlantic Basin hurricane ever recorded outside the Gulf of Mexico and the Caribbean Sea. According to weather reports, Irma maintained a wind speed over 185 mph for 37 hours, which tied the Cuba Hurricane of 1932 for the longest lifetime as a Category 5 in the Atlantic Basin.

This was the first time that two Category 4 storms made landfall in the United States in the same hurricane season with Irma following 16 days after Hurricane Harvey hit the state of Texas.

[1] http://www.psc.state.fl.us/Files/PDF/Publications/Reports/Electricgas/stormhardening2007.pdf

Wind Speed

Irma's estimated peak wind speed while in the Atlantic Ocean was at 185 mph. On the Saffir-Simpson Hurricane Wind Scale in **Figure 1.1**, Irma was clearly a Category 5 hurricane. Irma made seven landfalls, four of which occurred as a Category 5 hurricane across the northern Caribbean Islands. Irma made landfall as a Category 4 hurricane in the Florida Keys.

Category	Wind Speed (mph)	Damage at Landfall
1	74-95	Minimal
2	96-110	Moderate
3	111-130	Extensive
4	131-155	Extreme
5	> 155	Catastrophic

Figure 1.1: Saffir Simpson Hurricane Wind Scale

After devastating the Florida Keys, Irma made landfall on September 10, 2017, in Marco Island, Florida. Sustained winds speeds were around 112 mph with gusts around 129 mph (Category 3). There were additional unofficial reports in Naples, Florida, that recorded 140 mph wind gusts. Irma continued north across Central Florida and decreased in strength as Irma's center approached the Tampa and Orlando metropolitan areas. Tropical storm conditions were experienced on both the West and East Coasts of the state September 10–11, 2017. The center passed near Plant City, where a hurricane spotter measured sustained winds at 72 mph and gusts of 81 mph as the storm approached that area. Late in the day on September 11, 2017, and early September 12, 2017, Irma moved into Southeastern Georgia as a tropical storm while tropical storm conditions were still reported across North Florida.

Storm Surge[2]

The combined effect of storm surge and tides produced a maximum of five to eight feet of surge above ground level in the lower Florida Keys from Cudjoe Key east to Big Pine Key. Maximum water levels in the middle and upper keys were four to six feet (see **Table 1.1**).

Table 1.1: Maximum Water Levels by Area

Area	Maximum Water Levels in Feet
Caribbean	11
FL Keys	8
SW FL - Unpopulated	10
SW FL - Populated	5
FL East Coast	6
FL Central West Coast[3]	2
Georgia and South Carolina	5

Maximum surge and combined tides in Marco Island, where Irma later made landfall, was three to five feet above ground level. The National Ocean Service tide gauge in Naples measured water levels at 4.25 feet while Fort Myers was at 3.28 feet. Before the storm surge occurred, along portions of the Southwestern coast of Florida, strong offshore winds on the northern side of Irma's circulation initially blew water away from the coast and caused water levels to recede below normal levels. Once Irma moved north of Naples and the winds shifted to onshore, the water level at the site increased by nine feet in only three hours. Along the West coast of Florida north of Charlotte Harbor to Apalachee Bay, maximum water levels were one to two feet above ground level with one foot recorded in Tampa Bay. However, offshore winds on the northern side of Irma's circulation initially caused water levels to recede below normal levels along the West coast of Florida, including Tampa Bay (see **Figure 1.2**). Some normally submerged areas went dry, allowing people to (inadvisably) walk out onto the sea or bay floors while also stranding marine vessels and even manatees.

[2] Storm surge is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tide, and is expressed in terms of height above normal tide levels.

[3] Some areas of the Florida Central West Coast had a low water level of seven feet below ground level.

Figure 1.2: Dry Tampa Bay – Bayshore Boulevard

In the center of the storm, where the pressure is lowest, and the winds are converging, water piles up. Low pressure is basically a sucking mechanism that it draws the air inward. When the pressure is exceptionally low and the winds are very strong, it can create a bulge of ocean water under the center of the storm. When Hurricane Irma was spinning in the Gulf of Mexico, it pushed the water west, away from the Florida Gulf Coast.

More detailed information on wind speed and storm surge may be found in the *National Hurricane Center Tropical Cyclone Report*.[4]

Other Storm Severity Issues

Due to early predictions of Hurricane Irma's path making landfall in Southeast Florida and moving up the Florida East Coast, much of the population in the Southeast began to evacuate early, some due to mandatory orders but some also voluntarily. Based on the size of the hurricane, it was predicted that if Irma were to travel up the East Coast, the West Coast would be hit with hurricane force winds from the outer bands. These predications had Floridians on edge and ready to evacuate. As the "spaghetti" models began to change and move Irma towards the middle of the Florida, placing the eye over the center of the state, more of the population began to evacuate. The final predictions had Irma skirting the southernmost part of Florida and making landfall in the Naples/Fort Myers area (which proved to be accurate). At this point, much of the population in the Southeast and along the East Coast had already evacuated and now there were mandatory evacuations for low-lying areas in the Southwest and Central West Coast. Due to the early warnings of severe hurricane force winds, supplies had become scarce, and those without storm shutters could not find materials necessary to ensure their safety (e.g., corrugated metal, plywood, concrete screws, proper drills). This led to more voluntary evacuations from Florida. With all the evacuations, utilities were experiencing high voltage issues in load centers before the hurricane made landfall. Fuel was very difficult to find since gas stations were not able to keep up with the heightened demand. This made it very difficult for control center staff who were working the hurricane before, during, and after landfall.

[4] https://www.nhc.noaa.gov/data/tcr/AL112017_Irma.pdf

Storm Comparison

Comparison of Irma to Other Storms

Hurricane Irma was the first major hurricane to make landfall in Florida since Hurricane Wilma in 2005. In addition, Hurricane Irma was reported as the strongest Atlantic Basin hurricane ever recorded outside the Gulf of Mexico and the Caribbean Sea. This was one of the widest hurricanes in history, and it set records for the amount of cyclone energy generated in a single day. At one point, Irma was wider than the state of Florida, and it was expected that it would impact the entire state of Florida regardless of where it made landfall. Hurricane Wilma primarily affected Southern Florida while Irma impacted the enitre Florida footprint. Customer outages were significantly higher as well. Wilma and Irma were both Category 3 hurricanes when they made landfall on peninsular Florida. However, Irma was a Category 4 as it made landfall on the Florida Keys.

Table 1.2 shows a comparison of Irma and Wilma. It should be noted that, while it seems Wilma was a comparable hurricane to Irma, the difference in the Cyclone Damage Potential (CDP) index rating is significant between the two

$$CDP = 4\frac{[(\frac{v_m}{65})^3 + 5(\frac{R_h}{50})]}{v_t},$$

$$For\ v_m > 65;\ if\ v_t < 5,\ set\ v_t = 5;\ if\ CDP > 10\ set\ CDP = 10.$$

v_m - Maximum surface wind speed (knots)
R_h - Radius of hurricane force winds (newton meters)
v_t - Translation speed (knots)

(see **Figure** 1.3 for the CDP Potential Index Formula). The CDP index evolved from the Willis Hurricane Index (WHI). The CDP index provides a more comprehensive rating.

Table 1.2: Storm Comparison		
	Irma	**Wilma**
Year	2017	2005
Category	4	3
Maximum Sustained Winds: Landfall	130–156 mph	120–130 mph
Cyclone Damage Potential Index	5.9[5]	2.8
Customer Impacted	6.3 MM	3.2 MM

$$CDP = 4\frac{[(\frac{v_m}{65})^3 + 5(\frac{R_h}{50})]}{v_t},$$

$$For\ v_m > 65;\ if\ v_t < 5,\ set\ v_t = 5;\ if\ CDP > 10\ set\ CDP = 10.$$

v_m - Maximum surface wind speed (knots)
R_h - Radius of hurricane force winds (newton meters)
v_t - Translation speed (knots)

Figure 1.3: Cyclone Damage Potential Index Formula

[5] http://www.slate.com/articles/health_and_science/science/2017/09/a_better_metric_for_measuring_hurricanes.html

Chapter 2: Maps of Impacted Areas

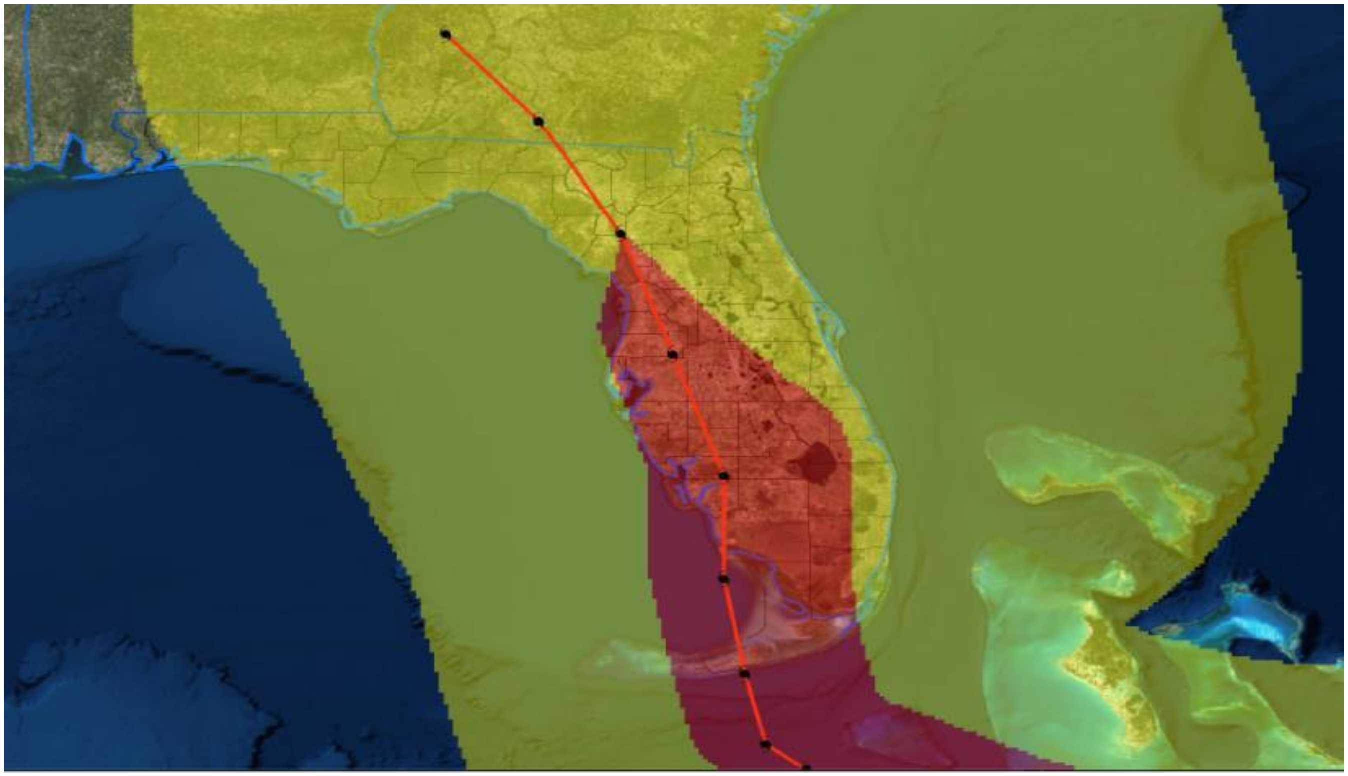


Figure 2.1: Hurricane Irma Track

Figure 2.2: Satellite Image of Hurricane Irma

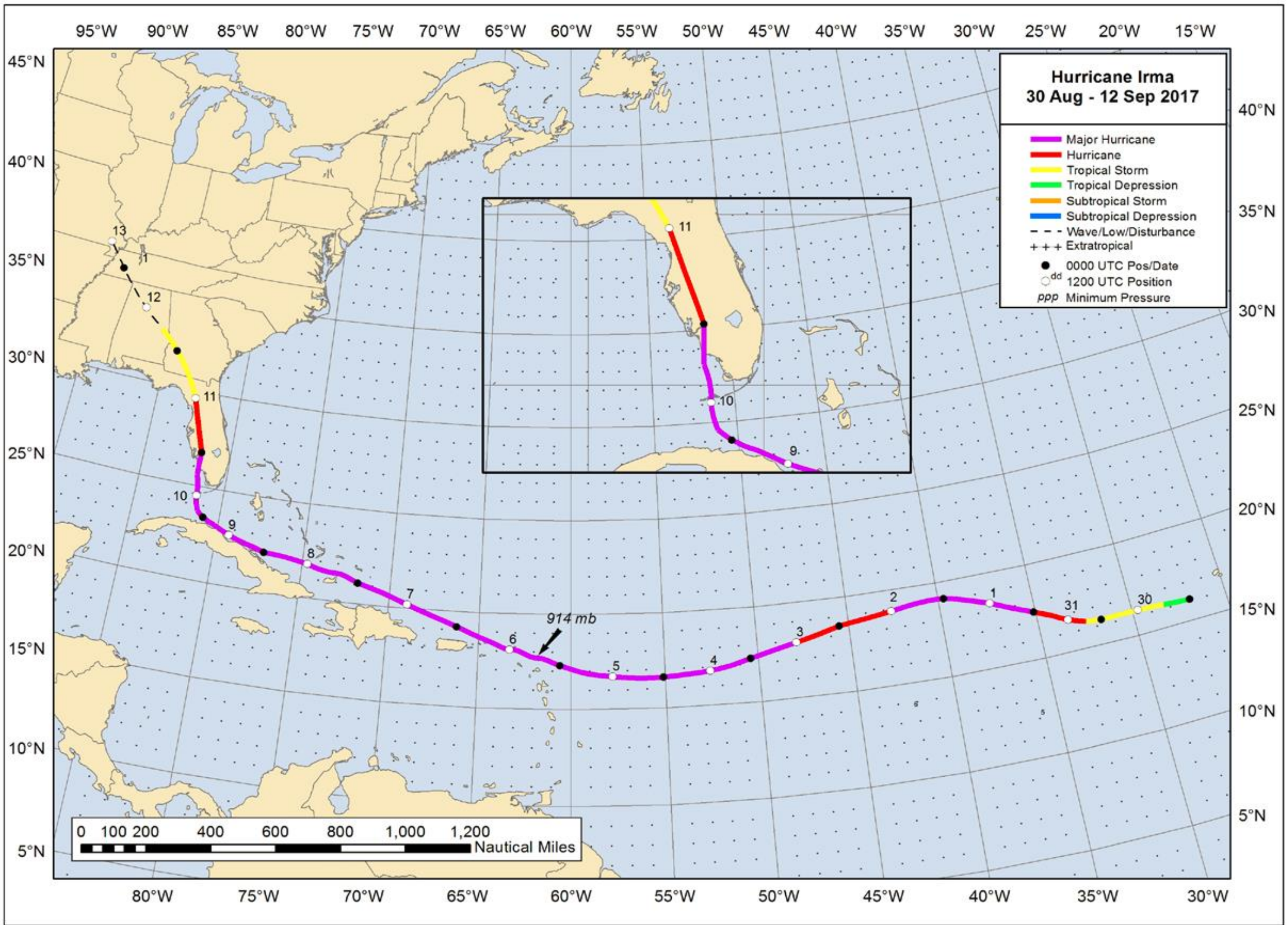


Figure 2.3: National Hurricane Center Official Path

Figure 2.4: Nighttime Satellite Images of Florida Before (left) and the night after (right) Hurricane Irma

Chapter 3: Preparation and Results Achieved

The Federal Communication Commission (FCC) and SERC, in conjunction with NERC BPSA, communicated storm preparation plans. Entities worked to ensure that sufficient numbers of additional field operation crews were scheduled and available to respond to the expected storm disruptions.

Where possible, previously scheduled outages were postponed, ensuring that facilities would be available over the next several days; generators were advised of expectations during the storm that included the potential for abnormal dispatch instructions.

Concerns regarding potential impacts of the coming storm included the following:

- The unpredictable nature of the impending load loss
- The potential for high voltages due to the load loss
- The potential for minimum generation emergency conditions due to the load loss
- The potential for substation flooding along the coastal shorelines
- The potential for post-storm restoration efforts that would be aided by having generators in a ready, or "hot," condition
- The need for fuel diversity across the system

Communications with Neighbors

Prior to the storm's landfall, FRCC's RC management initiated daily calls with the TOP's and BA's management in the FRCC Region. The TOPs and BAs reported that the lines and generators that were previously shut down for maintenance were returned to service. The BAs reported that several generating units were placed into preemptive shutdown condition to further protect assets from long-term damage due to the high winds and the predicted storm surge. These calls began September 8, 2017 and continued through September 14, 2017. Call frequency reduced during the storm and stopped during restoration since restoration is coordinated between the RC system operator and the TOP and BA System Operators.

Entities also communicated with the mutual assistance groups to which they belonged.

Regional and Inter-Regional Calls

FRCC and SERC, in conjunction with NERC BPSA, communicated storm preparation plans after receiving information from the RCs, TOPs, and BAs. NERC BPSA then hosted a call with the applicable governmental authorities to share information on the impending storm and the entities' preparation and readiness.

Additional Staffing (RC, TOP, and TO Levels)

Most entities staffed up control centers and manned backup control centers. Some entities arranged to have some staff on the property available to ride out the storm with all other line crews, including contractors reporting in when winds subsided and it was safe to drive. It is believed that Hurricane Irma was the largest use of mutual aid assistance (MAA) in Florida's history. MAA workers included lineman, tree trimmers, damage assessors, and call center personnel.

Sandbagging Facilities in Storm Surge Zone

Some entities placed sandbags at the entrance to the substation control houses on the barrier islands. Others monitored the storm's path, predicted tide/surge levels, and installed sand bags at key stations prone to flooding.

Some also had cameras or water intrusion monitoring equipment in stations to monitor flood levels. Entities also parked as many trucks/vehicles at elevated locations to avoid flooding and allow timely restoration.

Prepositioning Transmission and Distribution System Equipment

Entities took stock of inventory, reviewed current materials designated to other projects, and determined which would be diverted for storm restoration. Some utilities also prepositioned restoration equipment at strategic locations.

Prepositioning Storm Restoration Crews from Foreign Systems

Some entities prepositioned crews out of the storm's direct path at nearby locations they believed would not be heavily impacted to expedite immediate restoration opportunities. These crews included both native personnel and MAA workers. Prepositioning crews in certain locations was necessary due to accessibility issues but it came with challenges. Lodging was extremely limited due to the high number of voluntary and mandatory evacuations in Florida. Gasoline was scarce days before and days after Irma passed through Florida. Supplies were also limited since Florida had been in the projected path for many days prior to Irma making landfall. This allowed residents to stockpile supplies and clear the shelves at most grocery stores and home improvement centers. **Figure 3.1** shows an example of the shelves at a local home improvement center days before Irma made landfall.

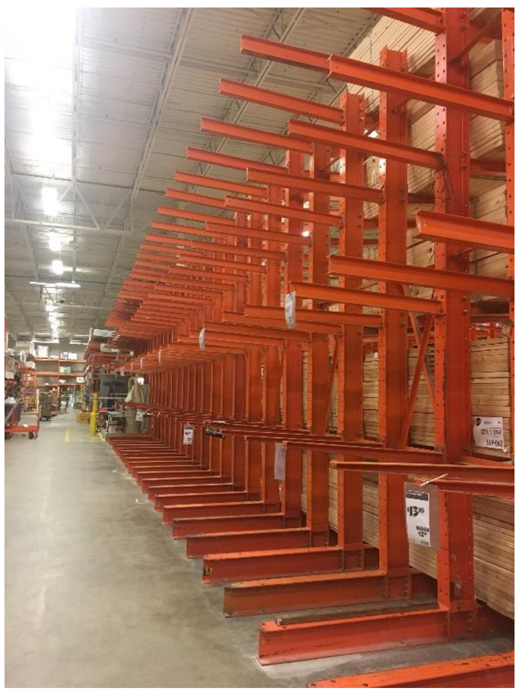


Figure 3.1: Empty shelves at a home improvement center

Chapter 4: Damage to Bulk Power System

Damage to BPS Facilities Due to Wind and Flooding

Several companies reported significant damage to BPS facilities and sub-transmission facilities. This damage also extended to the distribution level. Examples of the types of damage include the following:

- Conductor and static wire damage
- Broken poles and cross-arms
- Damage from trees being blown into the right-of-way
- Flooding
- Saltwater intrusion damage
- Broken or damaged insulators

Damage to BPS Reliability

The damage caused by Irma was significant and there were operational challenges before, during, and after Hurricane Irma passed through Florida, but at no time did Irma impact the overall reliability of the BPS.

Affected Transmission Facilities

Affected Transmission Facilities (by voltage class[6]):

- 500 kV lines (1)
- 230 kV lines (48)
- 138 kV lines (48)
- 115 kV lines (21)
- Full or partial BES substations (12)

Misoperations

There were no identified misoperations that contributed to BPS facilities being out of service during the storm.

Affected Generation Facilities

Nuclear Generation

Two nuclear facilities were affected by Hurricane Irma. The first was removed from service before the hurricane approached due to the expected track and projected wind speeds and the second tripped during Irma. There was no sustained damage to either unit as a result of Hurricane Irma.

Lessons Learned from Storm Preparation or Operations

The following good industry practices were identified for Hurricane Irma:

- Prestaging of equipment outside of the hurricane’s projected path made the restoration process more effective.
- Preemptively removing generation prior to the hurricane making landfall protected equipment from damage and significantly shortened restoration times.

[6] Best estimates of outages as provided by utilities during the storm.

Generation

Approximately 9,800 MW of generation capacity became unavailable as a result of Hurricane Irma. Because of the amount of load reduction due to evacuations and outages on the distribution system, this loss did not result in any capacity issues.

Generation Taken Off-line in Preparation of Storm

Approximately 6,500 MW were removed from service in anticipation of potential wind speeds or storm surge at specific plant sites.

Generation Tripped during Storm

Approximately 3,300 MW of generation capacity became unavailable as a result of the storm. This loss did not result in any capacity issues.

Generator Returns (Inhibition by Reduced Load, Transmission Damage)

There were no reports of difficulties returning generators to service after the storm once loads returned. One utility reported a need to make more purchases due to the removal of base-load units and the outage of generators due to the storm. The entity did not have issues purchasing power.

Chapter 5: Operations

Conservative Operations and Operational Challenges

Conservative Operations Mode or Emergency Procedures Implemented During Storm

Leading up to the storm, the FRCC RC implemented conservative operations by calling for all TOPs to recall any maintenance outages, if the TOP could do so, and cancel upcoming outages.

Challenges Associated with High-Voltage Issues

Some entities experienced high voltage as a result of the following:

- Open-ended high-voltage transmission facilities
- Significant loss of distribution load
- Lightly-loaded extra high-voltage facilities, such as 500 kV lines

Actions Taken to Maintain High Voltages

Entities that experienced high voltage de-energized equipment, removed lines from service, removed capacitor banks from service, operated reactors, and had generators lower their VAR output.

There were no significant BES thermal overloads before, during, or after the storm. There were reported issues related to significant loss of telemetry or ICCP. Energy management systems (EMSs) performed well throughout the storm with no significant issues. Some entities experienced intermittent real-time contingency analysis (RTCA) issues due to the amount of outages experienced through the storm; however, there were no instances reported that lasted over 30 minutes.

There were no reported voice communications issues that affected entities; however, it was noted that entities should consider adding telecommunication providers to the list of priority customers' list in restoration plans. Prolonged outages may lead to voice communication challenges that may be avoidable.

System Control

Challenges in Maintaining Load/Generation Balance during Storm

One utility reported a need to make more purchases due to the removal of base-load units and the outage of generators due to the storm. Although the entity did not have issues purchasing power, it did add a layer of additional work for System Operators to deal with.

FRCC had a 64 percent decline in energy usage during the peak of the storm. Natural gas facilities met the FRCC generating facilities' demand requirements with no limitations to electric operations.

Post-Storm Operations

Long-Term Effects that Could Impact Serving Firm Load

There were no significant long-term issues reported that impacted utilities ability to serve firm loads. In the areas most heavily hit, primarily in the Florida Keys, some homes and businesses will need to be rebuilt, therefore prolonging the return of those loads.

Chapter 6: Restoration

Timeline

Amount of Load Lost (MW)

Utilities determined the total number of customer outages exceeded six million. The U.S. Energy Information Administration (EIA) developed a webpage to track outages during the storm. Figure 6.1 and Figure 6.2 are from the EIA website, which shows the peak outage time for Florida. Over 60 percent of the load in Florida was interrupted due to the hurricane.

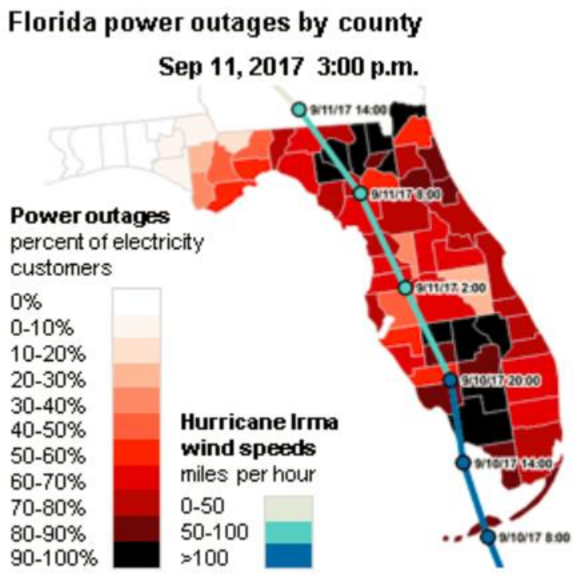


Figure 6.1: Peak Power Outages in Florida

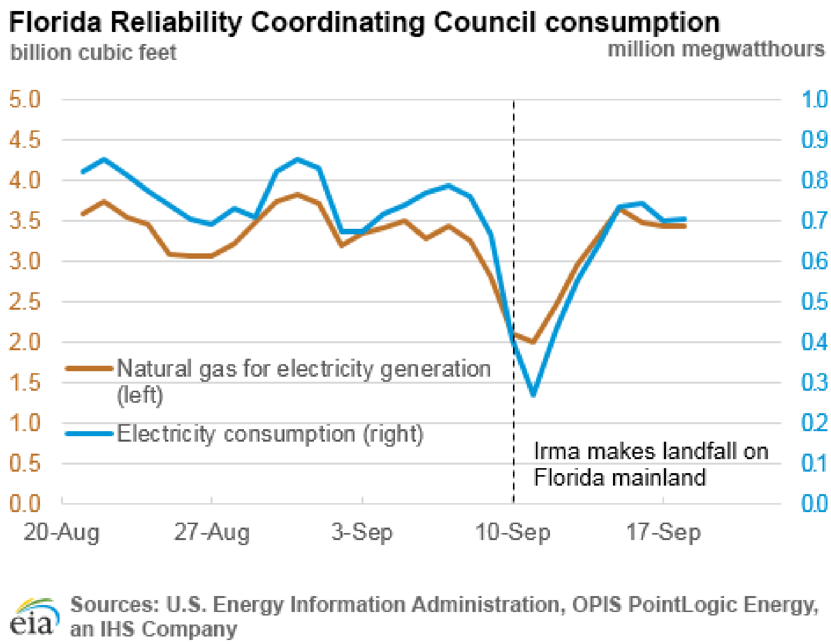


Figure 6.2: Energy Consumption in FRCC during Hurricane Irma

Duration Load Lost

Most entities returned the majority of their customers to service by September 17, 2017. **Figure 6.3** shows the progress made as soon as of September 14, 2017. Utilities do not allow employees in the field until the winds die down and they can begin work safely.

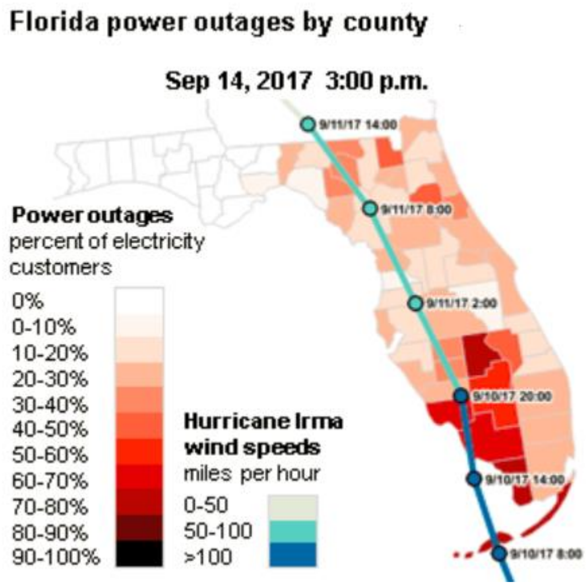


Figure 6.3: Progress of Power Outages in Florida

Challenges

Along with the previously stated challenges associated with lodging, logistics, and gasoline availability, road congestion due to returning evacuees created challenges getting crews and materials where they were needed.

As with all major hurricanes, Irma left a path of destruction, especially to vegetation. Naturally, some roads had to be cleared, but this did not particularly prolong restoration times since there were alternate routes. However, the situation in the Florida Keys was different: due to mandatory evacuations prior to Irma making landfall and the devastation Irma caused in the Florida Keys, access was highly restricted to the Keys until Tuesday, September 12, 2017. This posed difficulty for shipments of utility equipment used for restoration. Flatbed trucks that were carrying obvious utility equipment, such as pole top transformers, were granted access, but some box trucks and closed trailers that were carrying more inconspicuous utility equipment were embargoed. In other cases, freight companies refused to ship to areas known to have restrictions. The result was a minor delay in getting equipment needed to restore some customers but did not pose a significant long-term challenge. Utilities in the Keys are working with local government agencies to come up with a plan for future events.

Chapter 7: Considerations, Statistics, and Lessons Learned

Lessons Learned

The following good industry practices were identified for Hurricane Irma:

- Prestaging of equipment outside of hurricane's projected path made the restoration process more effective.
- Preemptively removing generation prior to the hurricane making landfall protected equipment from damage and significantly shortened restoration times.
- Continuous communications between the RC, TOPs, and BAs in the FRCC Region ensured coordinated efforts throughout the event and the subsequent restoration.
- Advanced meters and intelligent grid devices were effective to pinpoint outages, operate equipment remotely, and increase efficiency.
- Installation of flood monitors in substations located within the 100-year flood plain resulted in the ability to de-energize substations at notification of rising water and avoiding catastrophic damage to sensitive station equipment.
- Leveraging social media enabled first-ever communications with Facebook live and other platforms providing customers with the most current outage and restoration information.
- Aerial drones were effective to assess damage, evaluate work conditions, and enable real-time situational awareness. Infrared capabilities helped identify equipment that needed further inspection.
- Hardening and resiliency programs implemented prior to the hurricane significantly reduced the storm damage sustained due to high winds and storm surge.
- Utilities should consider working with local government agencies to develop plans for control and access to heavily impacted areas following a devastating event.

Chapter 8: Summary of Findings and Conclusions

The coordination and preparation by utilities proved to be very beneficial in operating the transmission network during the storm and restoring the system after the Hurricane Irma passed through Florida. Maximizing the availability of transmission and generation assets reduced the overall impact of Hurricane Irma on the BPS and allowed for an expedited restoration process.

Chapter 9: Storm Damage and Restoration Photos

Figure 9.1: Boats washed up on Route 1 in Florida Keys

Figure 9.2: Example of damaged high voltage transmission line

Figure 9.3: Example of damaged high voltage transmission line

Figure 9.4: Flooding in Southwest Florida

Figure 9.5: Flooding in Southeast Florida

Figure 9.6: Flooding in Alachua—North Central Florida

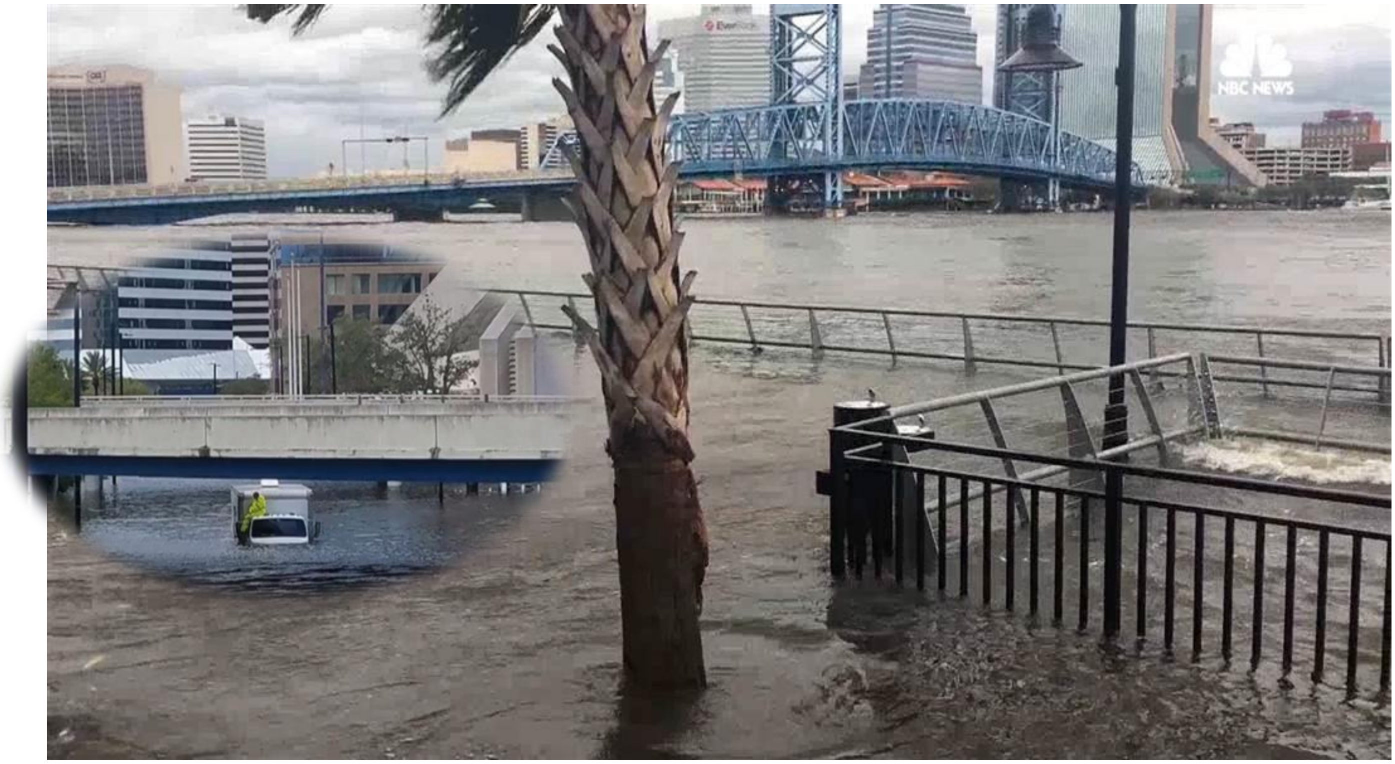


Figure 9.7: Flooding on the Saint Johns River in Downtown Jacksonville

Figure 9.8: Flooding on the Saint Johns River in Downtown Jacksonville

Figure 9.9: Damage at Substation

Figure 9.10: Damaged Transmission line with underbuilt distribution

Figure 9.11: Clearing vegetation in Orlando, Florida

Figure 9.12: Damage in Macon, Georgia

Figure 9.13: Restoration in Progress

Chapter 10: Follow-up Actions

Overall performance before, during, and after Hurricane Irma was very good. Some utilities have minor internal follow-up actions related to pre-storm preparations (e.g., avoiding lodging in low-lying areas that may not be in the current path of the storm but could be evacuated based on a change in the path). In the Florida Keys, utilities will be working with local governmental agencies to improve access to the area and expedite receipt of shipments of necessary equipment following a major storm.

Chapter 11: Contributions

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