Hurricane Harvey Event Analysis Report

Table of Contents

1. Disclaimer

Purpose

This report has been prepared by the Electric Reliability Council of Texas (ERCOT) solely for its own internal use regarding lessons learned related to system events, not for uses by third parties. This report may be shared or disclosed by ERCOT as a courtesy, but all information contained in this report is strictly provided "AS IS."

No reliance or warranty

This report contains data provided by ERCOT and/or third parties and might contain conclusions or forecasts and the like that rely on that data. This data, or any other information contained in this report, might not be free from errors or omissions. ERCOT does not warrant or represent that the data, conclusions, forecasts or any other information in this report are accurate, reliable, complete or current or that they are suitable for any particular purpose. You should verify and check the accuracy, completeness, reliability and suitability of this report or any information contained herein for any use to which you intend to put it, and seek your own independent expert advice before using it, or any information contained in it. ERCOT disclaims any and all express or implied warranties of any kind relating to this report.

Limitation of liability

To the fullest extent permitted by law, ERCOT and its advisers, consultants and other contributors to this report (and their respective associated companies, businesses, partners, directors, officers or employees) shall not be liable for any errors, omissions, defects or misrepresentations in the information contained in this report, or for any loss or damage suffered by persons who use or rely on such information (including by reason of negligence, negligent misstatement or otherwise). By reading any further in this report, you are acknowledging your agreement to the disclaimers, releases, and other terms or language on this Disclaimer page.

2. SUMMARY

Hurricane Harvey was a devastating Category 4 hurricane that struck the Texas Gulf Coast, with landfall occurring near Rockport, Texas. This region had not seen a Category 4 hurricane since Hurricane Carla in 1961, which made landfall near Port O'Connor, Texas with winds of 130 mph.

Hurricane Harvey's path after landfall was initially similar to that of Hurricane Carla, although it slowly tracked inland and eventually stalled between Victoria and Cuero, Texas for 48 hours after landfall. This stalling of Hurricane Harvey resulted in steady and consistent hurricane and tropical force winds along a larger portion of the Texas Gulf Coast, from Corpus Christi to Austin to Freeport, Texas for 48 to 60 hours. This stalling contributed to constant and torrential rains that continued to amass historic rainfall totals, especially in the southeastern corner of Texas, including the Houston, Galveston and Beaumont areas. After Harvey stalled, it began to backtrack into the gulf where it regained some strength before making a second landfall just east of Port Arthur, Texas, all the while delivering constant rainfall, with some areas near Houston receiving over 50 inches of rain between Aug. 25 and Sept. 1. Because of these factors, Hurricane Harvey caused more damage and was more disruptive than any other recent Texas hurricane.

As one would expect for a storm of this magnitude, the ERCOT system experienced significant transmission line and generator outages and loss of load. Under these extreme conditions, the ERCOT system performed well. Voltages and transmission line loadings remained within acceptable limits, and the system remained stable. Notwithstanding the loss of multiple Supervisory Control and Data Acquisition (SCADA) readings during the storm, system observability remained within acceptable parameters, and the ERCOT state estimator was able to solve.

Since the ERCOT network performed well under these adverse conditions, no protocol or operating guide revisions are proposed in this report. The remainder of this report contains details concerning ERCOT operations and network applications during the storm.

3. INCIDENT CLASSIFICATIONS & ABBREVIATIONS

Table 1: Incident Classifications

Date and Time of Incident	25 August 2017 @ 16:16 through 1 September 2017 @ 16:16
Affection Regions	Texas Gulf Coast from Corpus Christi to Houston areas
Event Type	Loss of BES Equipment and Loss of System Load
Primary Cause	Category 4 Hurricane

Table 2: Abbreviations and Symbols

Abbreviation	Term
ERCOT	Electric Reliability Council of Texas
SOL	System Operating Limit
IROL	Interconnection Reliability Operating Limit
SCED	Security-Constrained Economic Dispatch
MW	Megawatt
MVA	Megavolt-Ampere
kV	Kilovolt
SE	State Estimator
RTCA	Real-Time Contingency Analysis
EMS	Energy Management System
TO	Transmission Operator
OCN	Operating Condition Notice
SCADA	Supervisory Control and Data Acquisition
QSE	Qualified Scheduling Entity
BPUB	Brownsville Public Utility
TNMP	Texas New Mexico Power
STEC	South Texas Electric Co-op
EMMS	Energy and Market Management Systems
ANA	Advanced Network Applications
RFI	Request for Information
MTLF	Mid Term Load Forecast
WAN	Wide Area Network
PSTN	Public Switched Telephone Network
LDF	Load Distribution Factor

4. PRE-EVENT CONDITIONS

Before the event, local agencies and authorities advised residents in the Corpus Christi and surrounding areas to evacuate the region due to significant weather being expected. Storm surges over 15 feet were predicted, so flooding in areas along the coast was expected in advance of the storm. On Aug. 23, at 8:00 a.m., ERCOT Outage Coordination and System Operations advised the Transmission Operators (TOs) to restore any transmission equipment on planned maintenance, and to withdraw any new planned transmission outages in the South Texas area. ERCOT System Operators provided advanced notifications to Market Participants regarding Hurricane Harvey.

- On Aug. 23, at 10:30 a.m., ERCOT System Operations issued an Operating Condition Notice (OCN) for Tropical Storm Harvey to all Qualified Scheduling Entities (QSEs) and TOs with instructions to review fuel supplies, outages, and their respective emergency procedures.
- On Aug. 24, at 7:50 a.m., ERCOT System Operations issued an Advisory for Tropical Storm Harvey to all QSEs and TOs which repeated previous instructions as well as provided additional instructions regarding communications. On Aug. 24, 2017 at 11 a.m., ERCOT System Operations issued a Watch for Hurricane Harvey to all QSEs and TOs with additional instructions to prepare for anticipated system conditions and keep ERCOT notified of actual and anticipated Resource conditions.
- On Aug. 24, at 4:00 p.m., ERCOT had a phone call with gas pipeline companies serving the coast and Lower Rio Grande Valley generation facilities to determine potential impacts on gas supplies to those facilities. The gas companies indicated the potential for gas curtailments due to compressor stations being shut down due to the evacuations. One gas pipeline carrier reported it was blending raw gas to avoid curtailments and allow continued gas delivery to generators in the Rio Grande Valley.
- On Aug. 25, at 5:00 p.m., ERCOT System Operations issued an Emergency Notice for Hurricane Harvey to all QSEs and TOs with additional instructions to prepare for anticipated system conditions and keep ERCOT notified of actual and anticipated Resource conditions.

  QSEs were instructed to:
  - Be prepared to reduce generator output due to anticipated load loss and respond to voltage support issues as requested
  - Keep Current Operating Plans (COPs) and High Sustained Limits (HSLs) current

  TOs were instructed to:
  - Be prepared to lose load and expect high voltage conditions
  - Keep ERCOT informed of any issues

5. INCIDENT EVENT LOG

The summary sequence of events are itemized in Table 3 below. The incident spanned approximately seven Operating Days, from the initial outage of August 25, 2017 at 5:16 p.m. through September 1, 2017.

Timeline

Time	Event
8/23/2017 10:32	ERCOT issued Operating Condition Notice for future Tropical Storm Harvey
8/24/2017 08:00	ERCOT issued Advisory for Tropical Storm Harvey
8/24/2017 11:03	ERCOT issued Watch for Hurricane Harvey
8/24/2017 14:14	ERCOT is issuing an Advisory due to Physical Responsive Capability being below 3000 MW
8/24/2017 18:03	ERCOT cancels advisory for Physical Responsive Capability being less than 3000 MW.

8/25/2017 14:00	Harvey classified as a Category 2 hurricane and is 85 miles from Port O'Connor, with sustained maximum winds of 120 mph.
8/25/2017 15:00	Coastal Wind Generation Resources (WGRs) begin coming off-line due to high winds.
8/25/2017 16:59	ERCOT issued an Emergency Notice due to Hurricane Harvey having an adverse impact on the ERCOT System due to transmission line outages.
8/25/2017 17:04	ERCOT issued Emergency Notice due to Hurricane Harvey
8/25/2017 18:00	Harvey becomes a Category 4 storm, is 45 miles from Corpus Christi.
8/25/2017 21:40	At least 1,500 MW of coastal conventional generation has tripped off-line or decommitted due to Harvey related issues.
8/25/2017 22:00	Harvey makes landfall as a Category 4 hurricane between Port Aransas and Port O'Connor
8/26/2017 02:00	Harvey is centered 15 miles inland and has been downgraded to a Category 3 storm.
8/26/2017 05:00	Hurricane Harvey downgraded to a Category 1 storm
8/26/2017 22:00	Hurricane Harvey 40 miles NW of Victoria, 75 miles east of San Antonio. Storm would continue slowly moving southeast toward Houston area.
8/28/2017 21:00	Hurricane Harvey moves back into the Gulf of Mexico with sustained winds of 45mph.
8/29/2017 17:08	ERCOT is issuing an Advisory due to Physical Responsive Capability being below 3000 MW

6. IMMEDIATE ACTIONS

6.1. Staffing

Beginning the afternoon of Aug. 25, ERCOT increased on-site support staff throughout the weekend (on a 24 hour rotation) for the following support groups: Operations Support Engineering, EMMS Production Support and Advanced Network Applications. Additional Outage Coordination staff were also on-site during the weekend daytime hours of Aug. 26 and 27. ERCOT also increased System Operation's staff at the alternate control center to include two additional Real-Time/DC-Tie operators (a total of three) for support in case potential flooding in Bastrop County prevented additional operators from reaching the alternate control center.

6.2. Pre-Event System Assessments

Beginning the afternoon of Aug. 25, ERCOT Operations Support Engineering performed several off-line studies to begin evaluating potential impacts of the loss of multiple critical high voltage transmission lines and generators, including the potential outage of the South Texas Project nuclear facility. Since it was known that the generation plants in the Corpus Christi area would be evacuated, and ERCOT had been warned about potential gas restrictions on the pipelines serving generation in the Lower Rio Grande Valley, the scenarios studied below were determined to be appropriate assessments. These assessments also were devised based on experience gained from Hurricane Ike, which made landfall in the Houston area in 2008. Each of the scenarios listed below were evaluated for off-peak (HE08) and on-peak (HE17) time periods, and feasible solutions existed for each. While these studies did reveal some instances of potential congestion, no cascading, instability or uncontrolled separation was observed.

6.3. Load Forecast adjustments

The main challenge with load forecasting was due to load loss during the hurricane. ERCOT used manual intervention on the Mid-Term Load Forecast (MTLF) in order to create a forecast that was more in-line with actual loads during the hurricane. This was necessary since the existing models were forecasting based on historical load levels, which did not reflect the amount of outages that were present during the storm. For the Short-Term Load Forecast (STLF), ERCOT enabled purely autoregressive models (meaning the forecasts are based on lagged actual load values). This allowed for the STLF to rapidly adjust to the actual 5-minute loads during the storm.

6.4. Recalled Outages

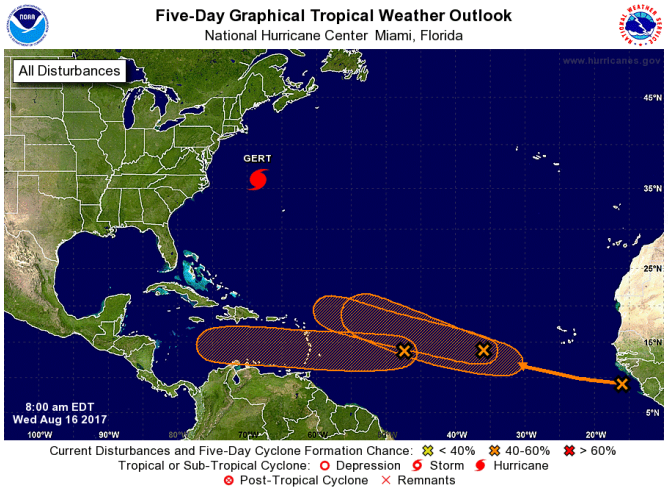
RFI responses from ERCOT Transmission Service Providers (TSPs) and Qualified Scheduling Entities (QSEs) identify one outaged transmission line in Austin Energy's footprint that was restored ahead of schedule in preparation for Hurricane Harvey's landfall. Circuit 985, Austin Dam to Beecreek 138kV line, was restored to service at 10:51 a.m. on Aug. 25.

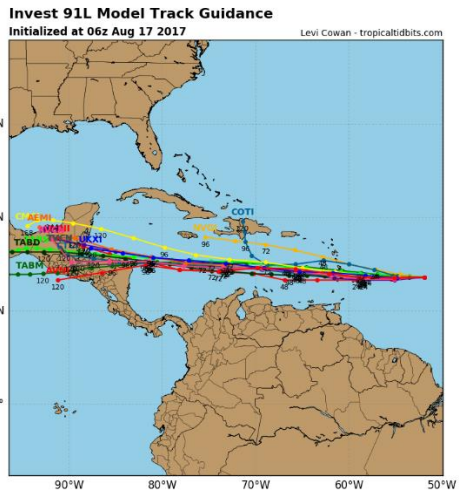
7. ANALYSIS

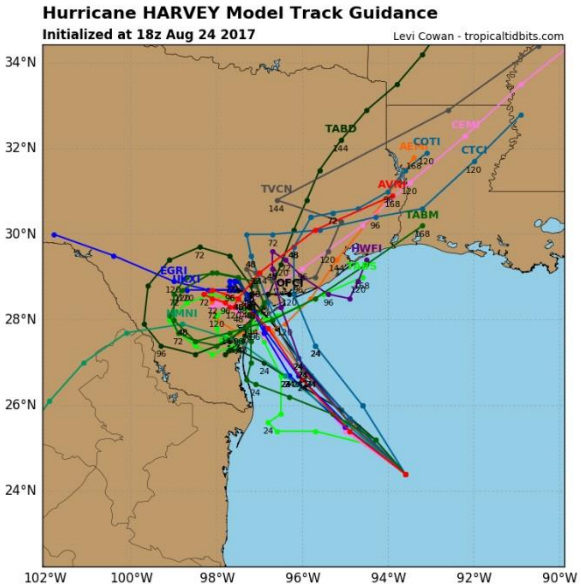
7.1. Storm Path

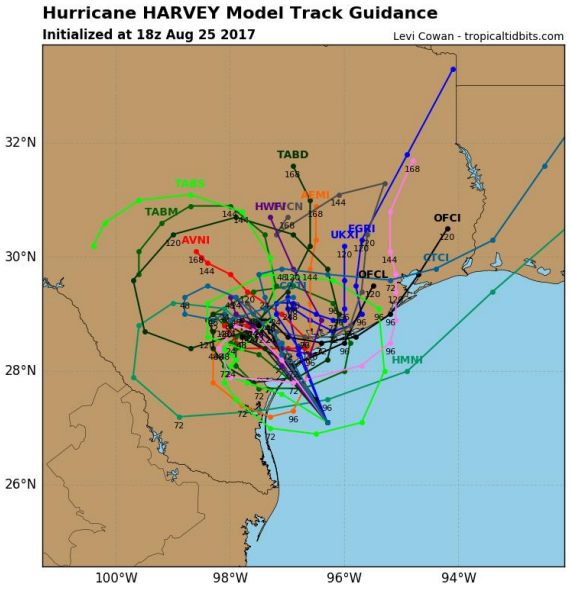
Predicting the storm path for Hurricane Harvey proved to be very difficult. Throughout much of the storm, the weather models used by ERCOT staff predicted varying outcomes as to the strength and path of the storm. The following are a series of graphics that illustrate the weather forecast models, as they adapted over time. Once it reached the Western Gulf of Mexico, the various weather models could not agree with the expected movement of the hurricane most of the time. The one piece of the models that were in agreement was that the storm would stall out somewhere north of the Corpus Christi area for a day or so before moving on.

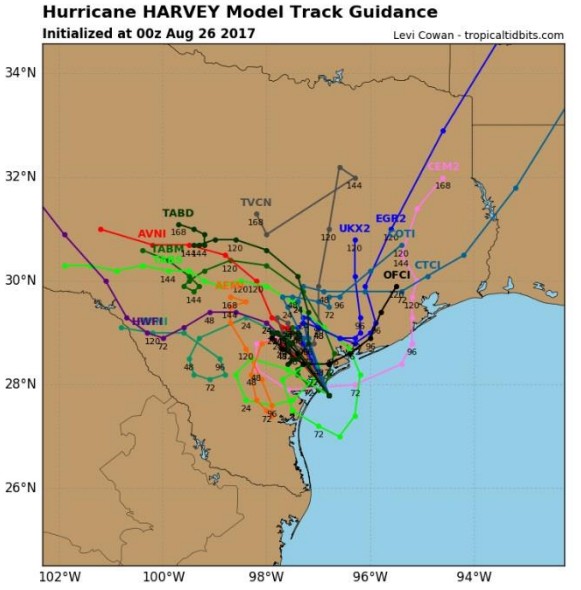
Additionally, comparing the potential track areas from the National Hurricane Center, the storm tracks were not consistent. As of 10:00 a.m. on Aug. 25, the prediction was that Harvey would move east towards Louisiana, but by 4:00 a.m. on Aug. 26, the prediction had Harvey potentially moving further west, possibly over the Texas Hill Country. The 4:00 a.m. update on Aug. 27 then changed the model back towards Louisiana, possibly moving off shore and rebuilding. After the 4:00 a.m. update, the storm future tracks began to be more consistent, moving the remnants of Harvey north and east. By then, significant damage and flooding had already occurred along the coastal region of Texas.

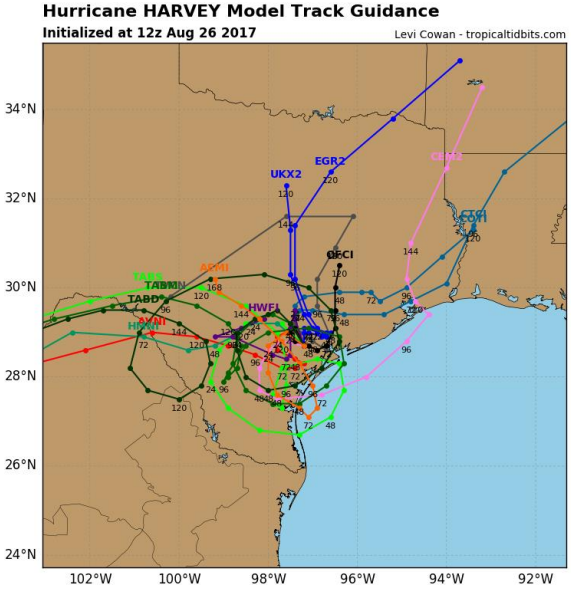


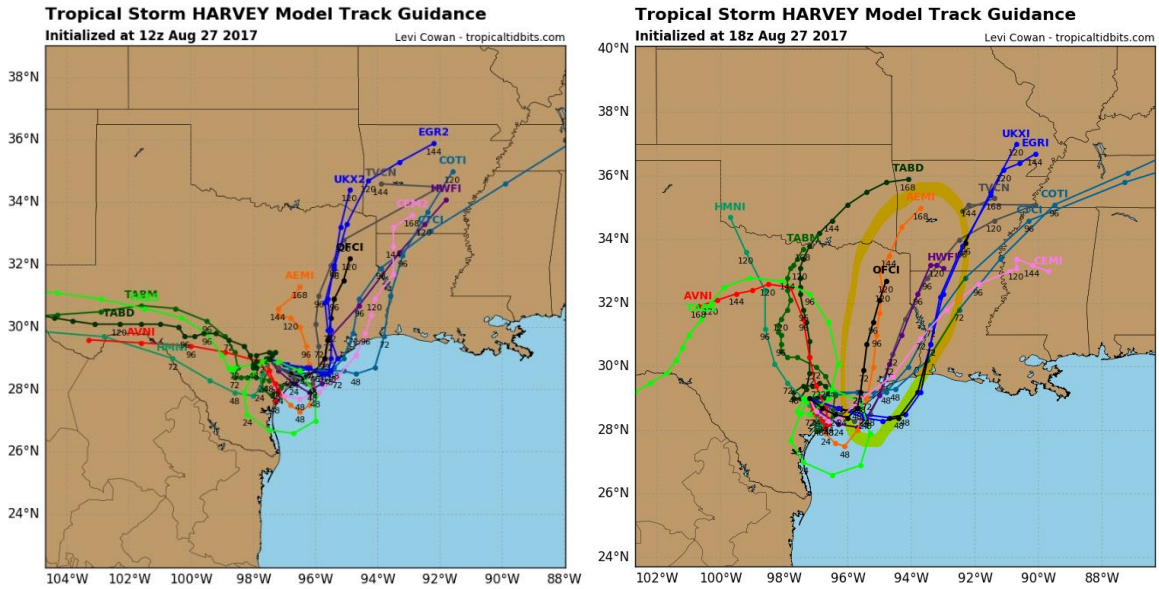




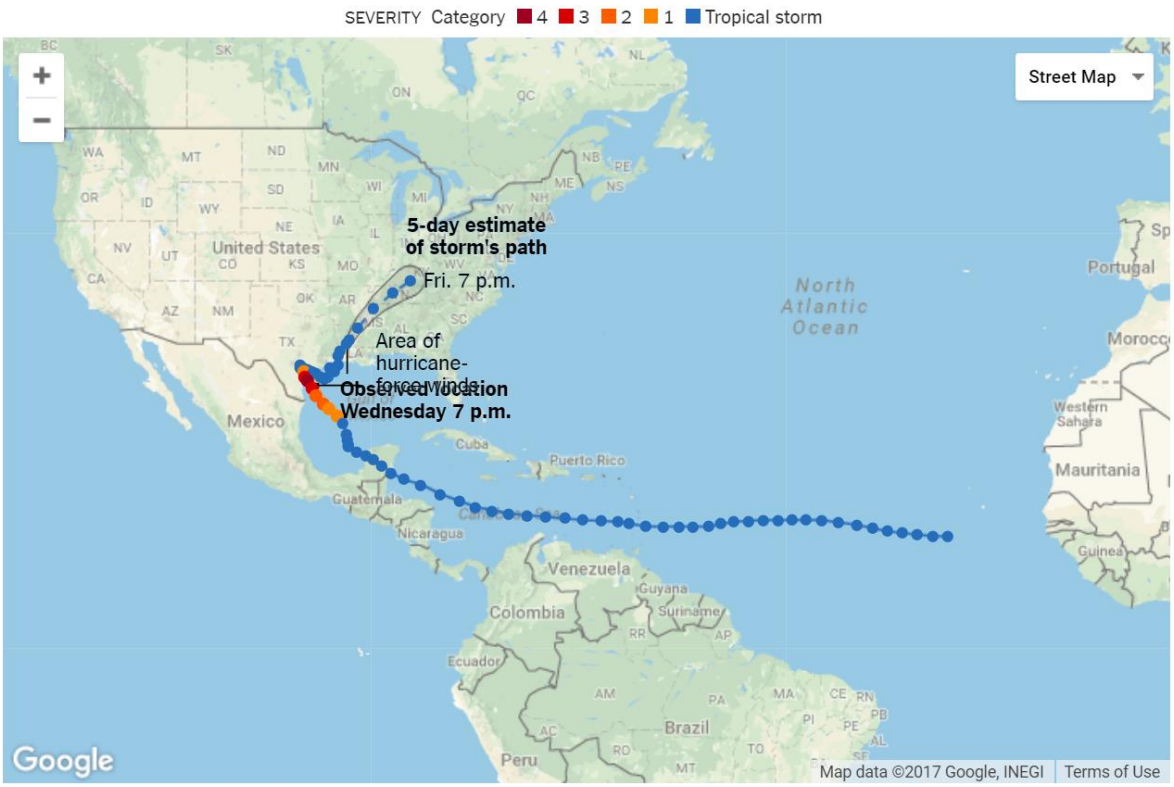




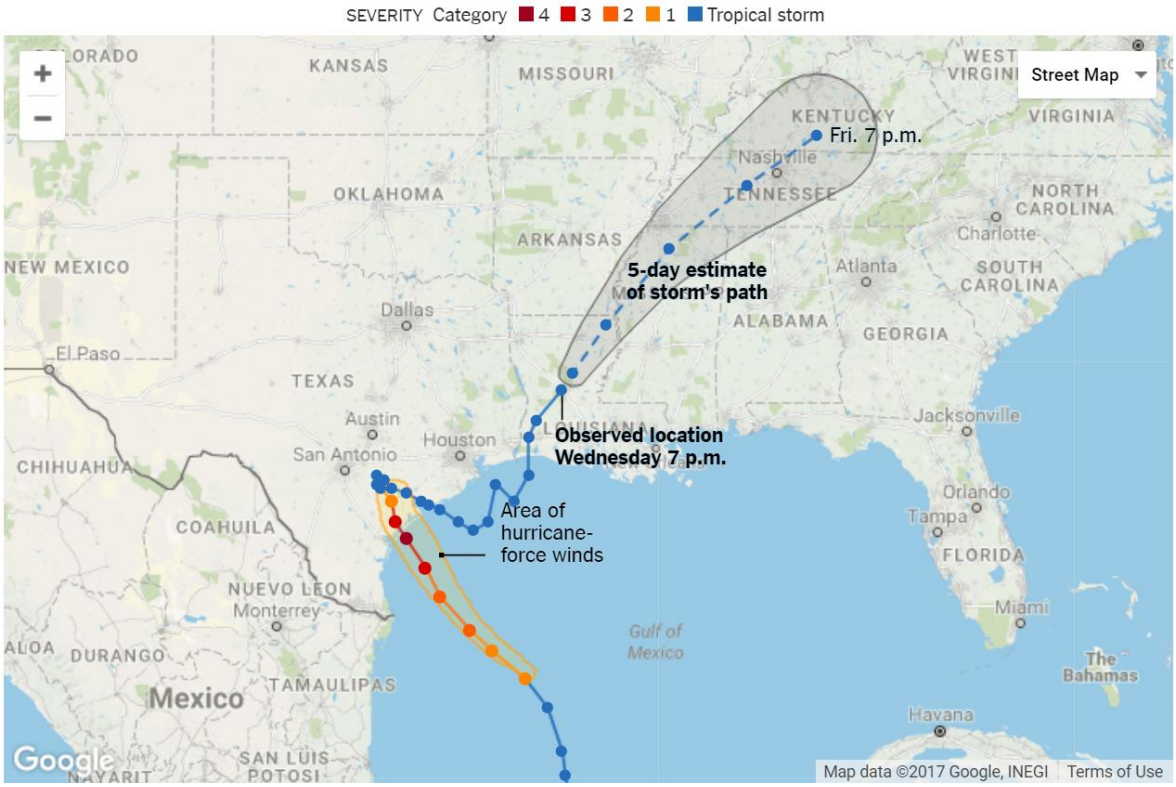




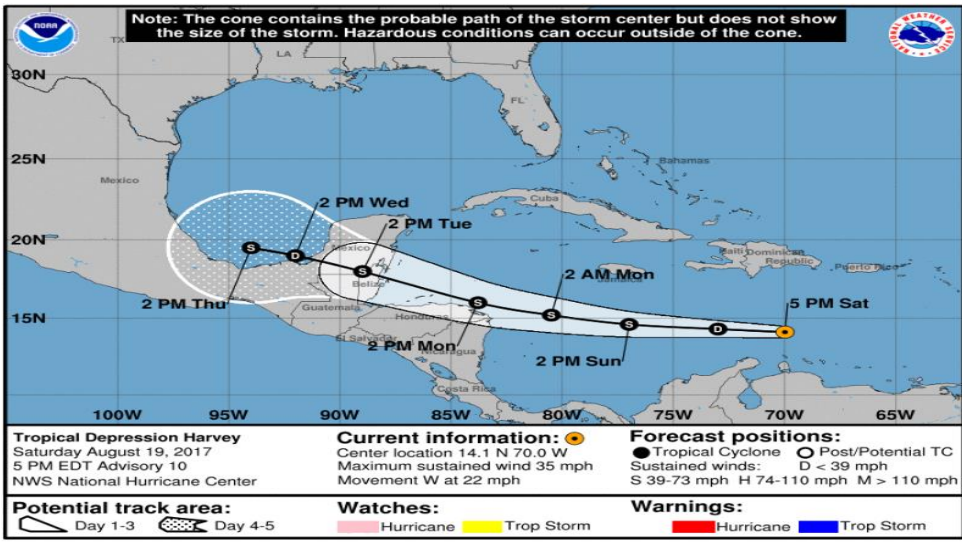
The following are a series of graphics from the National Oceanic and Atmospheric Administration and other websites showing the actual storm path. These images illustrate the expected path of Hurricane Harvey as it grew from a Tropical Storm to a Hurricane and back to a Tropical Storm. As ERCOT watched the developments in the Gulf of Mexico, it was determined on Aug. 19 that the storm had dissipated, only to re-emerge as a Tropical Storm on Aug. 23. The National Hurricane Center predicted Harvey to be a hurricane the evening of Aug. 23, only two days before Harvey made landfall, and at that time, Harvey was not predicted to even be a hurricane at landfall. That prediction was not issued until approximately 4 a.m. on Aug. 24, and that prediction was for landfall at 1:00 a.m. on Aug. 26, four hours later than the actual landfall. In other words, the hurricane arrived sooner and with higher winds than what was projected 48 hours prior to landfall.



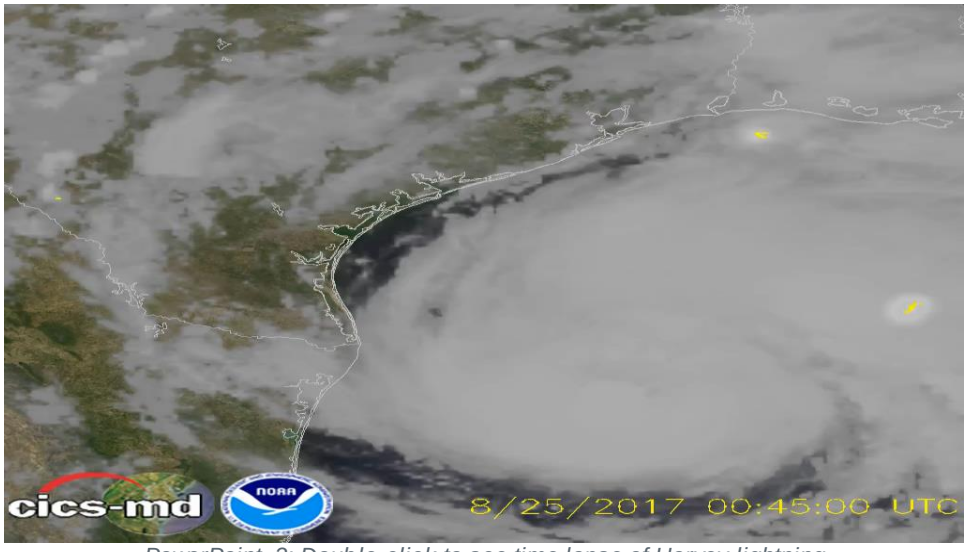
Website 1: source NY Times: Maps: Tracking Harvey's Destructive Path Through Texas and Louisiana



Website 2: source NY Times: Maps: Tracking Harvey's Destructive Path Through Texas and Louisiana



PowerPoint 1: Double-click to see time lapse of predicted storm path

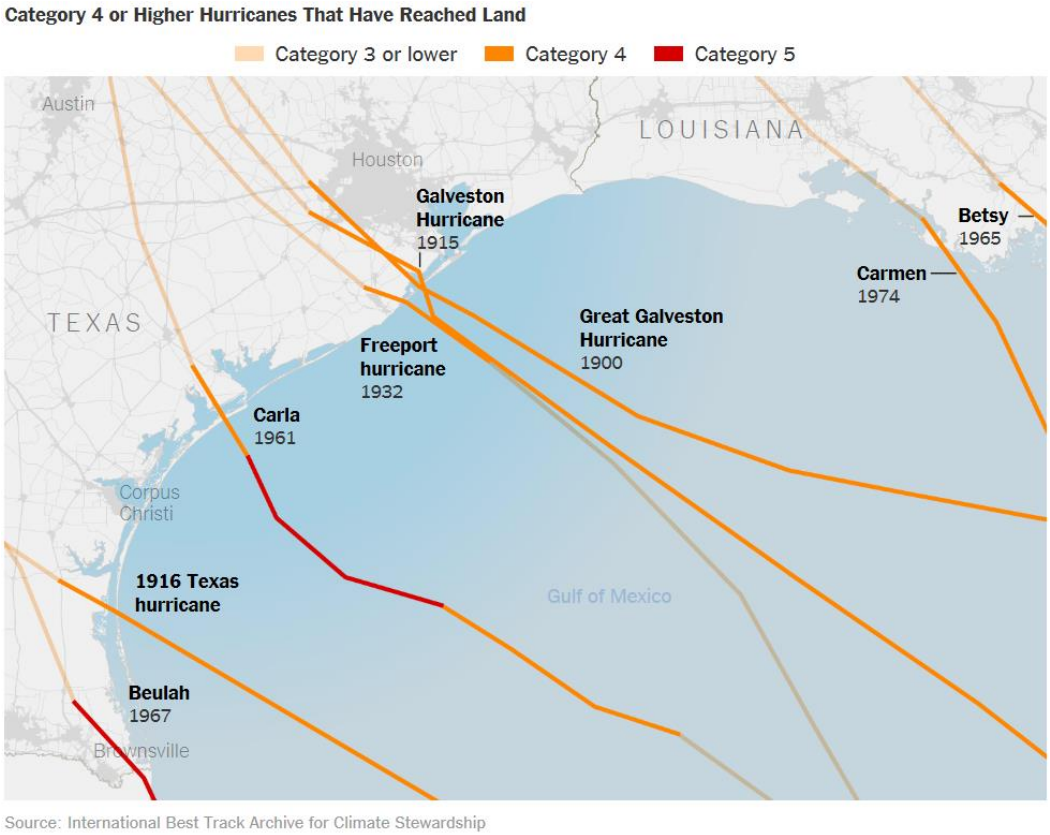


PowerPoint 2: Double-click to see time lapse of Harvey lightning

7.2. Meteorological Summary

On Aug. 26, at 10:00 p.m. Central Daylight Time, Hurricane Harvey made landfall in Rockport, Texas. This ended a string of nearly nine years since a hurricane last made landfall in Texas (Ike on Sept. 13, 2008). This was the second-longest period of time without a hurricane making Texas landfall in 1900.

Harvey made landfall as a Category 4 hurricane. This was the first major (Category 3 or greater) hurricane to make landfall in the U.S. since Hurricane Wilma in 2005. It was also the first Category 4 hurricane to make landfall in Texas since Hurricane Carla in 1961.



Website 3: source NY Times: Maps: Tracking Harvey's Destructive Path Through Texas and Louisiana

Harvey began as a tropical wave off the West Coast of Africa, on Aug. 13, 2017. Four days later, Harvey was classified as a tropical storm. For the next six days, Harvey saw no significant intensification as it tracked west through the Caribbean.

On Aug. 19, deterioration of the storm's structure led Harvey to be downgraded to a tropical depression and then to a tropical wave. However, there were several computer models suggesting it could reorganize and become a hurricane.

The remnants of Harvey moved across the Yucatan Peninsula on Aug. 22. It then reached a very favorable environment over the Bay of Campeche (southwestern Gulf of Mexico). Forecasters were anticipating Harvey to re-organize and intensify, but at that point (four days before U.S. landfall), hurricane Harvey was only expected to either be a tropical storm or Category 1 hurricane. Harvey's rapid intensification to a Category 4 hurricane caught both computer models and human forecasters by surprise.

Regardless of the intensity of Harvey, computer models were in agreement that upon making landfall in Texas, the storm would linger for multiple days, resulting in major flooding concerns. That was the forecast expressed by meteorologists two to three days prior to Texas landfall.

On the morning of Aug. 23, Harvey, which was located over the southwestern Gulf of Mexico and was upgraded to a tropical depression. That night, Harvey became a tropical storm. Intensification continued on the 24th of August. Harvey became a Category 1 hurricane by noon

that Thursday. Twenty-six hours later, on Aug. 25, Harvey intensified into a Category 3 major hurricane. Only six hours later, hurricane Harvey reached Category 4 strength.

Category 4 Hurricane Harvey made landfall at peak intensity at 10 p.m. on Friday, Aug. 25 in Rockport, Texas – just north of Corpus Christi. Winds were clocked at 130 MPH, and nearby Port Aransas measured wind speeds at 132 MPH. In 60 hours, Harvey had intensified from a tropical depression into a Category 4 major hurricane. In 32 hours, Harvey went from a tropical storm to Category 4.

Previously noted were the span of times from Harvey to both Ike (last hurricane to make landfall in Texas) and Wilma (last major hurricane to make landfall in the U.S.), but other milestones also were accomplished. Harvey had the strongest sustained wind speed of a hurricane to strike the U.S. since Hurricane Charley in 2004, and the strongest hurricane to make landfall in Texas since Hurricane Carla in 1961. Harvey also set an all-time Texas hurricane record for remaining a named storm 117 hours after landfall.

After making landfall at Rockport, Harvey moved slowly inland and became nearly stationary for almost three full days, encompassing the weekend of Aug. 26-27. Harvey diminished to tropical storm strength at noon CDT on Aug. 26. Harvey moved back into the Gulf of Mexico the morning on Aug. 28 and then made one final landfall the afternoon of Aug. 29 near Cameron, Louisiana – just east of the Texas border.

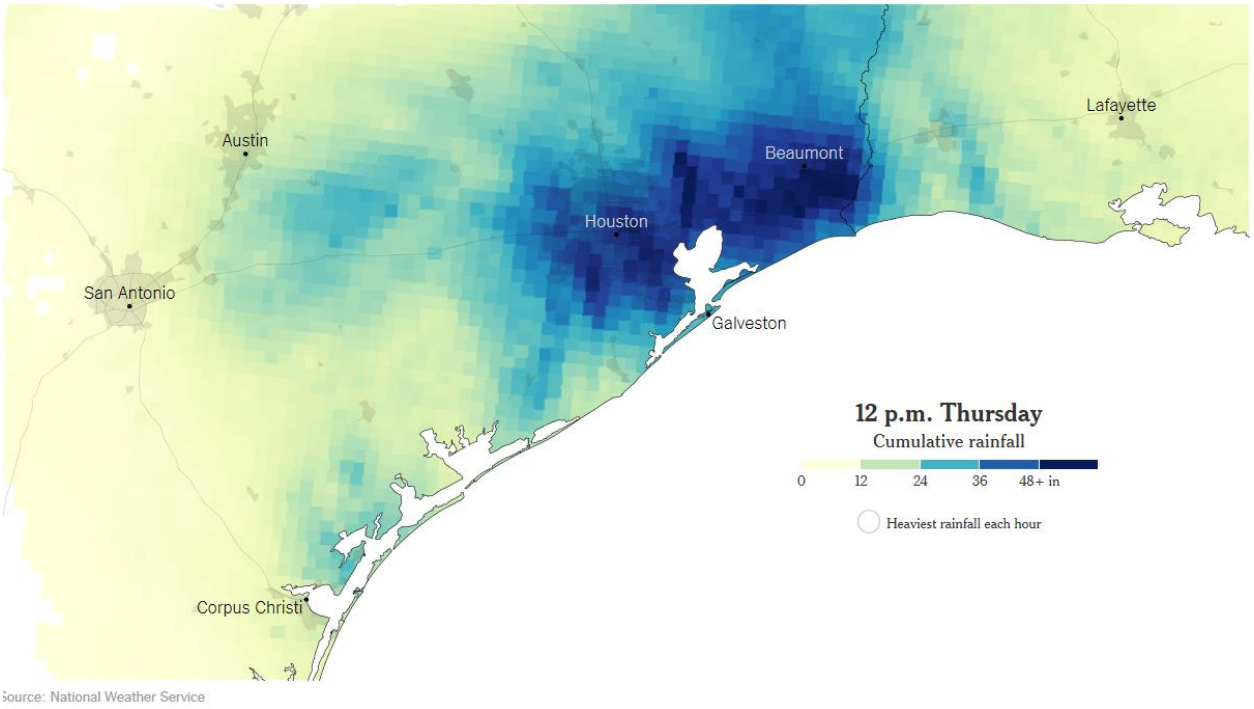
Harvey came ashore with powerful winds, reminiscent of Hurricane Carla in 1961. Harvey also showed similarities to the Indianola hurricane of 1886. However, its behavior over the next several days was more like Tropical Storm Allison in 2001. Allison was a major flooding event for Houston, as the storm lingered over the area for several days in June of that year. Allison also was the first tropical storm to have its name retired.

Major hurricane force winds inflicted significant damage across Aransas County. Nearly every structure in Port Aransas, Rockport and Fulton was damaged. Significant structural damage due to the winds was reported at Port Lavaca, Copano Village and Ingleside. The highest storm surge was recorded at the Aransas Wildlife Refuge, where a 12-foot surge was reported. Port Lavaca's storm surge topped 10 feet.

The extended duration of the hurricane caused widespread flooding that impacted Texas between Aug. 25 and 29. The flooding was caused by rivers that were flooded by extreme rainfall over multiple days and flash flooding due to intense periods of heavy rain.

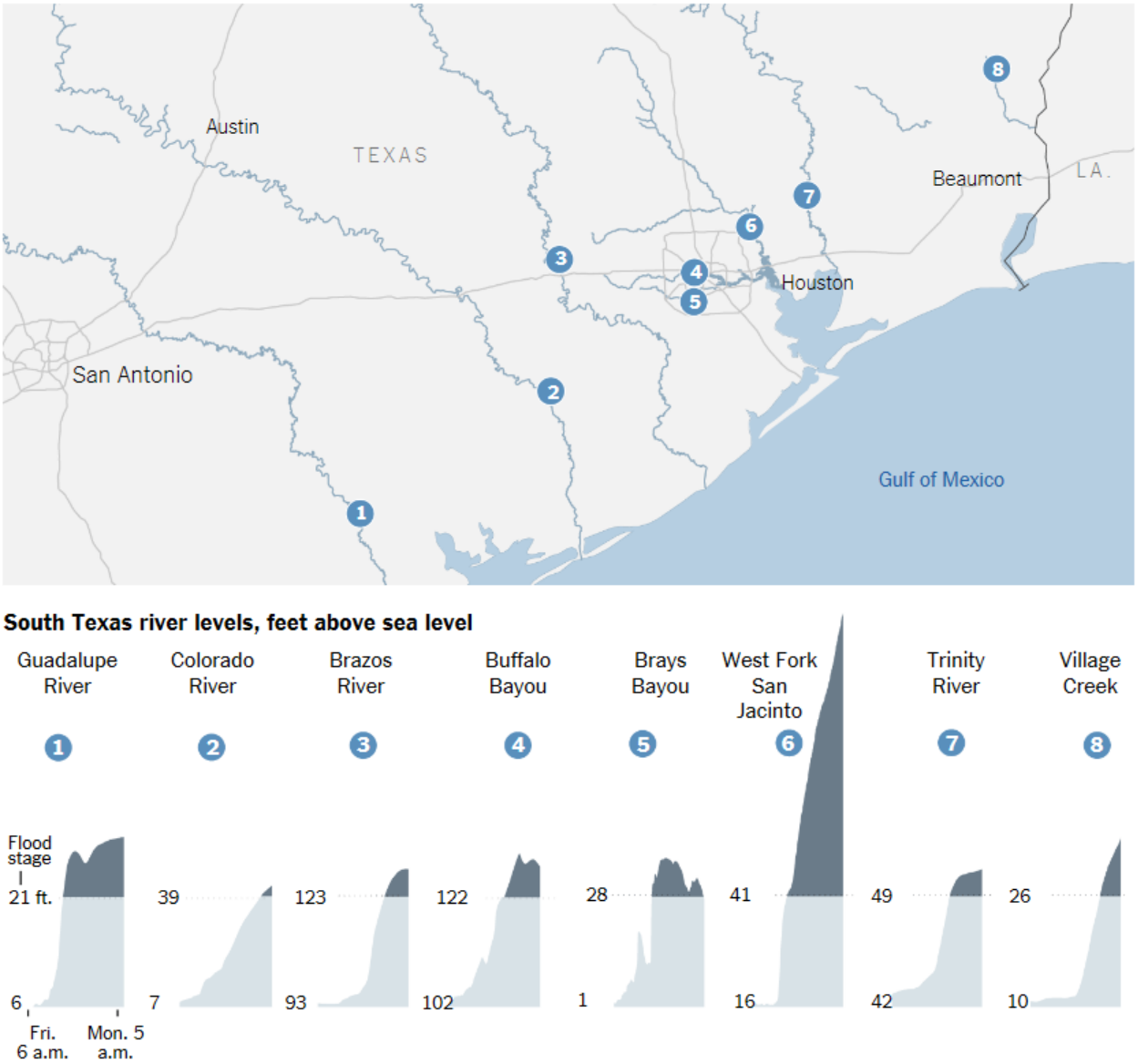
Most of the Houston metropolitan area recorded over 30 inches of rainfall. The maximum rainfall total was recorded at Cedar Bayou, where 51.88 inches fell. Harvey's rainfall totals made it the wettest tropical cyclone in the recorded history of the continental United States. Houston's total rainfall for the month of August was 39.11 inches, which was more than twice the previous record for the month.

Beaumont and Port Arthur also experienced extensive flooding, recording 47.35 inches of rain. At one point, the entire city of Port Arthur was submerged by flood waters. The graphic below shows the location and concentration of the rainfall.



Website 4: source NY Times: Maps: Tracking Harvey's Destructive Path Through Texas and Louisiana

Many rivers exceeded flood stage, including the Guadalupe, Colorado, Brazos, Buffalo Bayou, Brays Bayou, West Fork San Jacinto, Trinity River and Village Creek. Most rivers peaked on Monday, Aug. 28. In total, 50 Texas counties were impacted by Harvey-related flooding.



Website 5: source NY Times : Maps: Tracking Harvey's Destructive Path Through Texas and Louisiana

Finally, a total of 33 reported tornadoes resulted from Harvey.

In total, estimated losses in Texas from Harvey are projected to be between $150 and $190 billion, which would make it the costliest hurricane in U.S. history (ahead of Hurricane Katrina in 2005). As of mid-September 2017, 82 deaths had been recorded, and also dozens still reported as missing.

7.3. Transmission System Impact

7.3.1. Transmission Line Outages

Hurricane Harvey had a significant impact on transmission facilities along its path, causing severe damage in areas along the Coastal Bend. ERCOT conducted several ad hoc N-1-1 studies to determine what the post-contingency system state would be in anticipation of certain line outages ahead of the storm path. The heaviest concentration of transmission outages

occurred between 8 p.m. on Aug. 25 and 4 p.m. on Aug. 26. The figures below provide information on the frequency, quantity and KV breakdown of the transmission line outages.

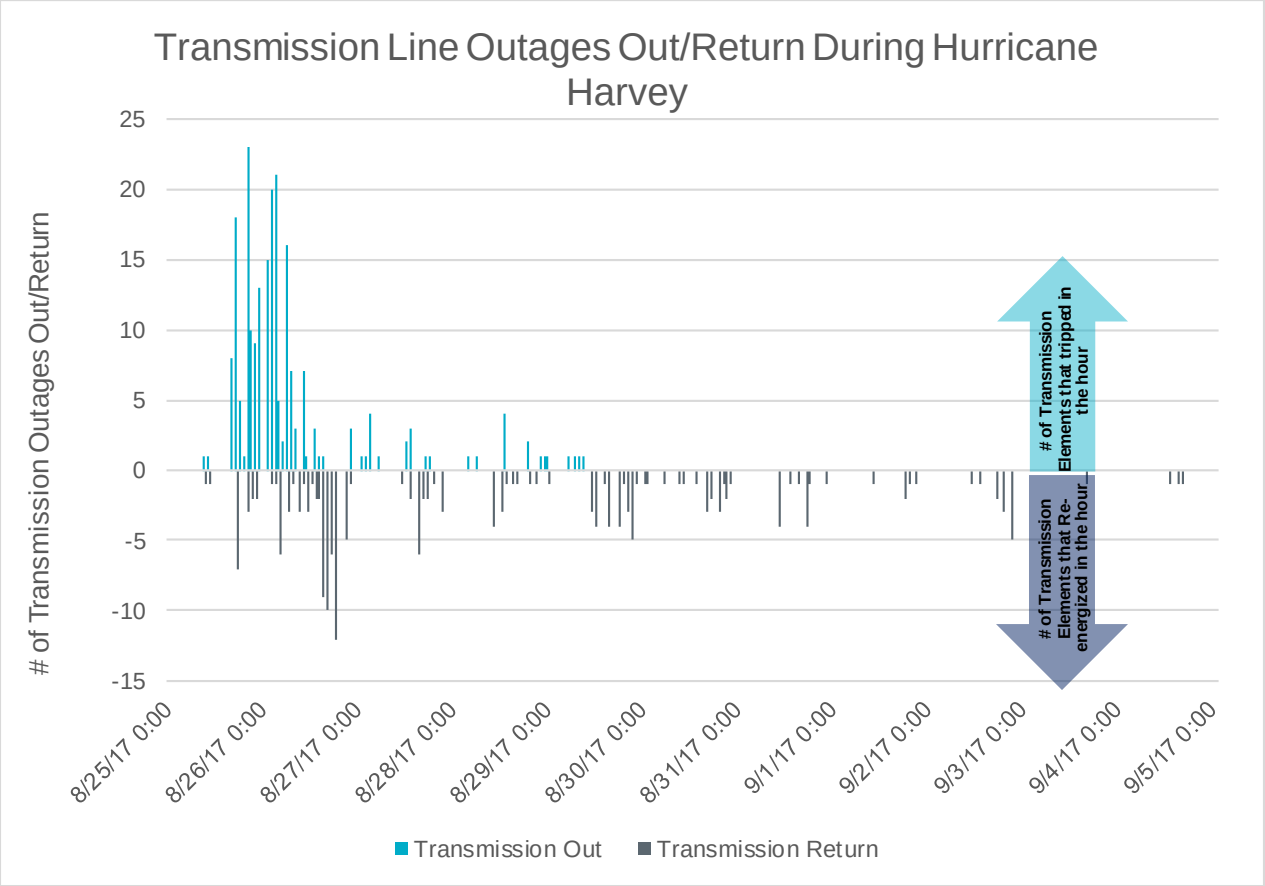


Figure 1: Transmission Line Outages during Hurricane Harvey

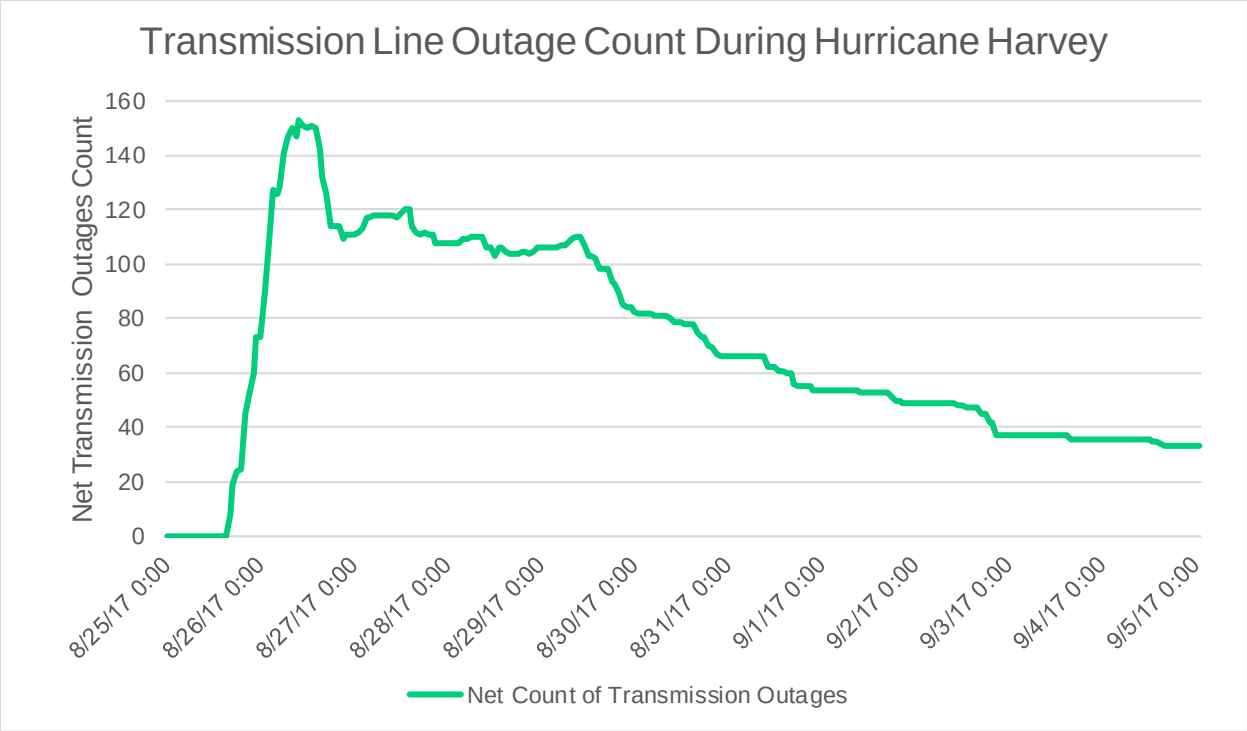


Figure 2: Net Transmission Line Outages during Hurricane Harvey

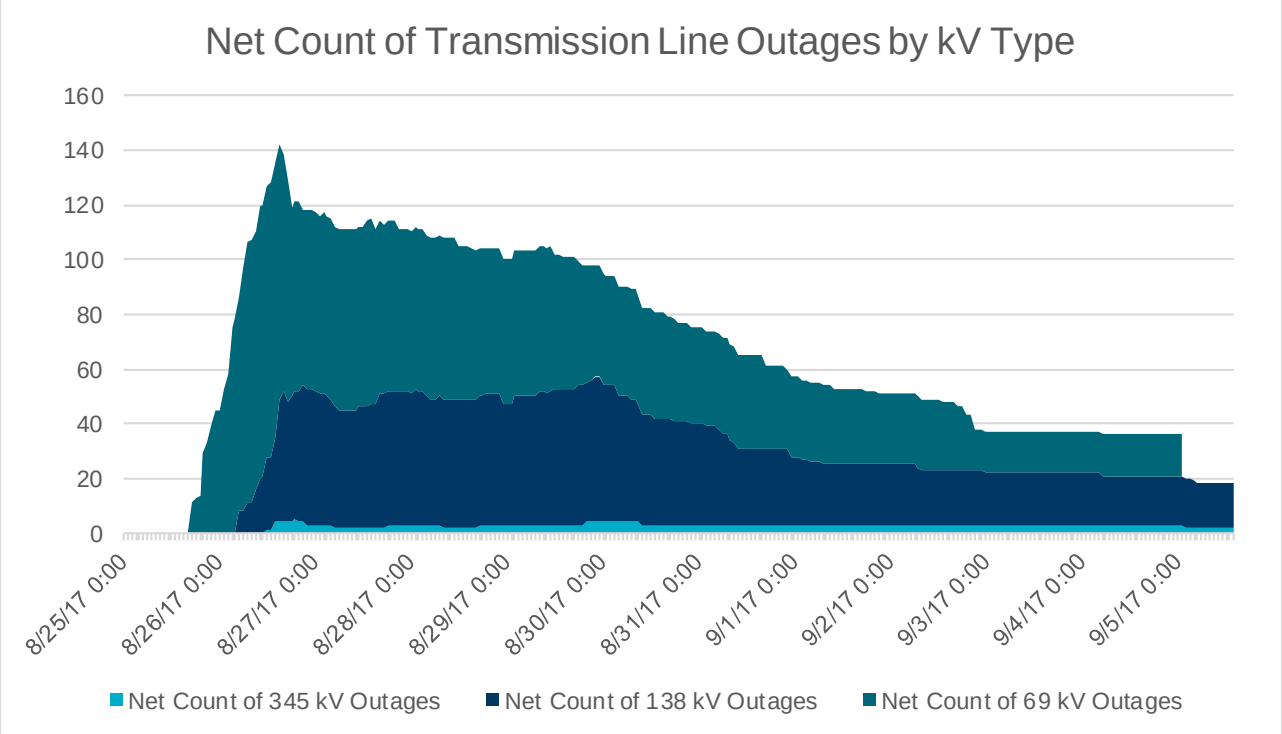


Figure 3: Net Transmission Line Outages by KV type during Hurricane Harvey

7.3.2. Misoperations

There were no protection system misoperations reported in the Request for Information (RFI) responses received by ERCOT from Market Participants.

7.4. Generation Impact

Hurricane Harvey also caused a significant impact to generation resources in the Coastal, Southern and South Central Weather Zones. Prior to landfall, several generation resources shut down and/or evacuated. An initial wave of generation resources was lost due to the hurricane force winds and associated severe weather, as well as a second wave due to the severe weather, rain and flooding that occurred in the Houston area. This loss of generation would typically stress the capability of the ERCOT system to serve load and provide its Ancillary Services. However, lower-than-normal electricity demand allowed the grid operator to balance demand and supply with no major issues.

Capturing the true impact on generation capability is difficult due to several factors. The Forced Outage Detection (FOD) application captures forced outages with the MWs lost at the time of outage. FOD does not capture de-rates or provide a seasonal or max capability impact. The impact of variable Resources, like Wind-powered Generation Resources (WGRs), also may only reflect the capability at the time of the forced outage in FOD. This may result in different values captured in different tools between Outage Scheduler, FOD, SCADA, PI historian and RFI responses that must be coordinated to evaluate the total generation impact. The below figures show different trends of the generation impact.

The first trend shows that 68 generators totaling 13,000 MW of capacity were outaged and unavailable during the hurricane's peak. Of those, 49 were likely hurricane-related. This value does not include the 19 de-rates and nearly 3,000 MW of outaged generation capacity that occurred prior to generation resources being removed from service in preparation for or as a result of Harvey. This data focused on only three Weather Zones that were mostly impacted by Hurricane Harvey.

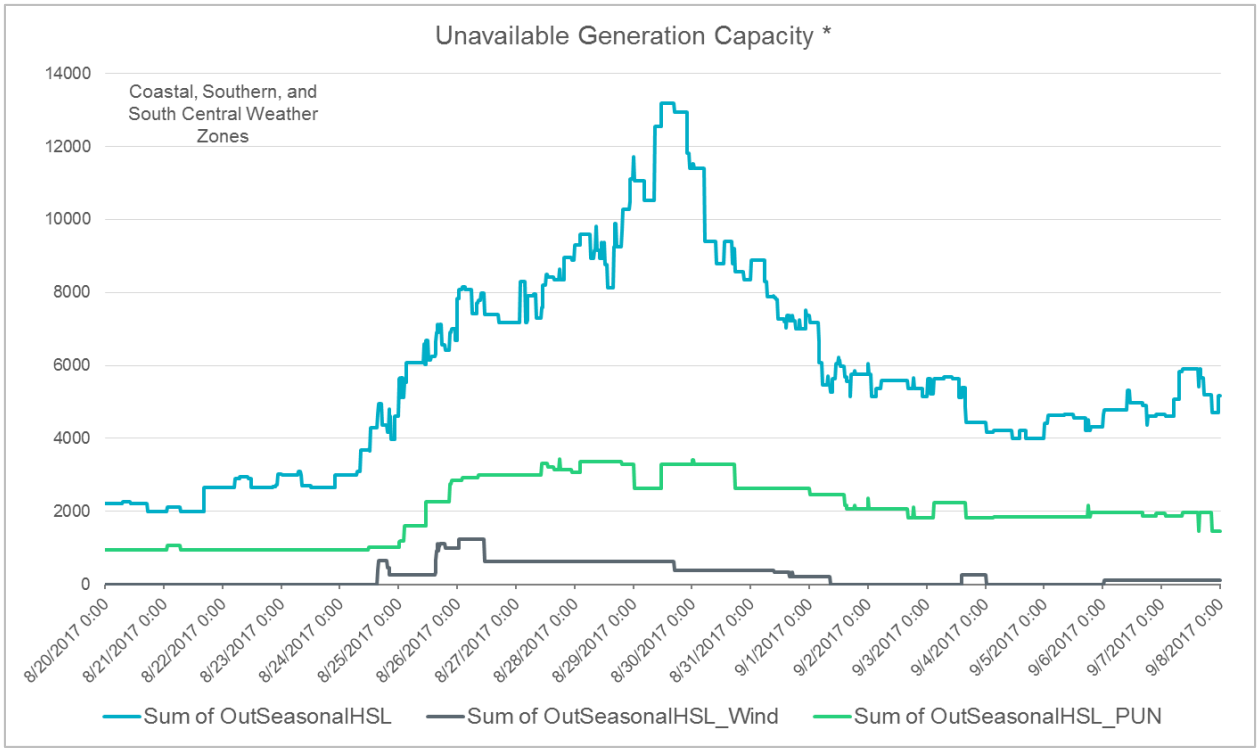


Figure 4: Sum of Seasonal HSL for Real Time Telemetered Status of OUT

The below figures are from Outage Scheduler information that detail both the complete picture of resource outages and de-rates from Outage Scheduler. Additionally, those 39 units shown in Table 1 below were filtered as being related to Hurricane Harvey, and have also been provided in a separate trend in Figure 7. Any outages taken prior to Hurricane Harvey due to the hurricane were identified as forced outages, which is why there were no planned outages related to Harvey. It should be noted that this only captures what was submitted into Outage Scheduler by Market Participants, which is why the numbers do not align with Figure 5. Outages and de-rates lasting less than two hours are not required by the ERCOT Protocols to be entered into Outage Scheduler by Market Participants.

Resource Unavailability Category	De-rated/Outaged MW's	# of Units
Wet Fuel	2490	8
Lack of Fuel	2545	12
Water Intrusion	2972	7
Evacuation	1092	8
Other	554	4

Table 1: Categories of Resource Unavailability for Outage Scheduler Related to Hurricane Harvey

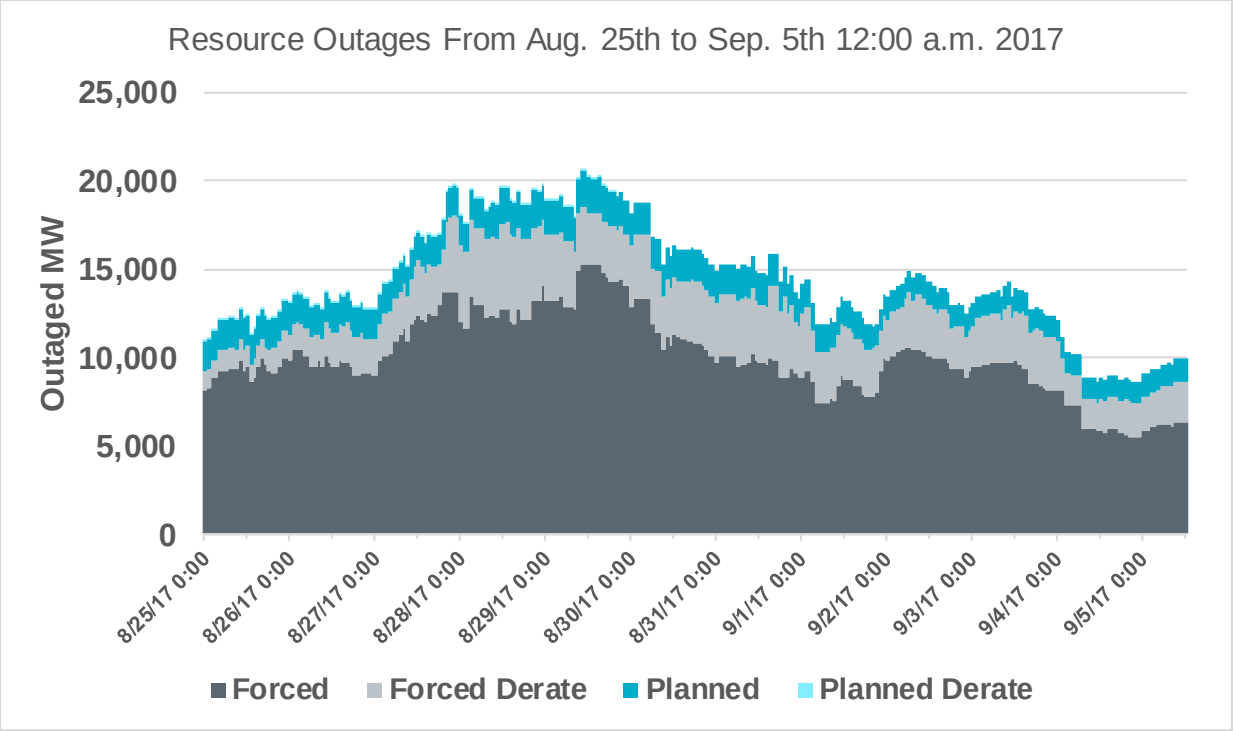


Figure 5: All Outage Scheduler Resource Outages and De-rates 8/25/17 to 9/5/17

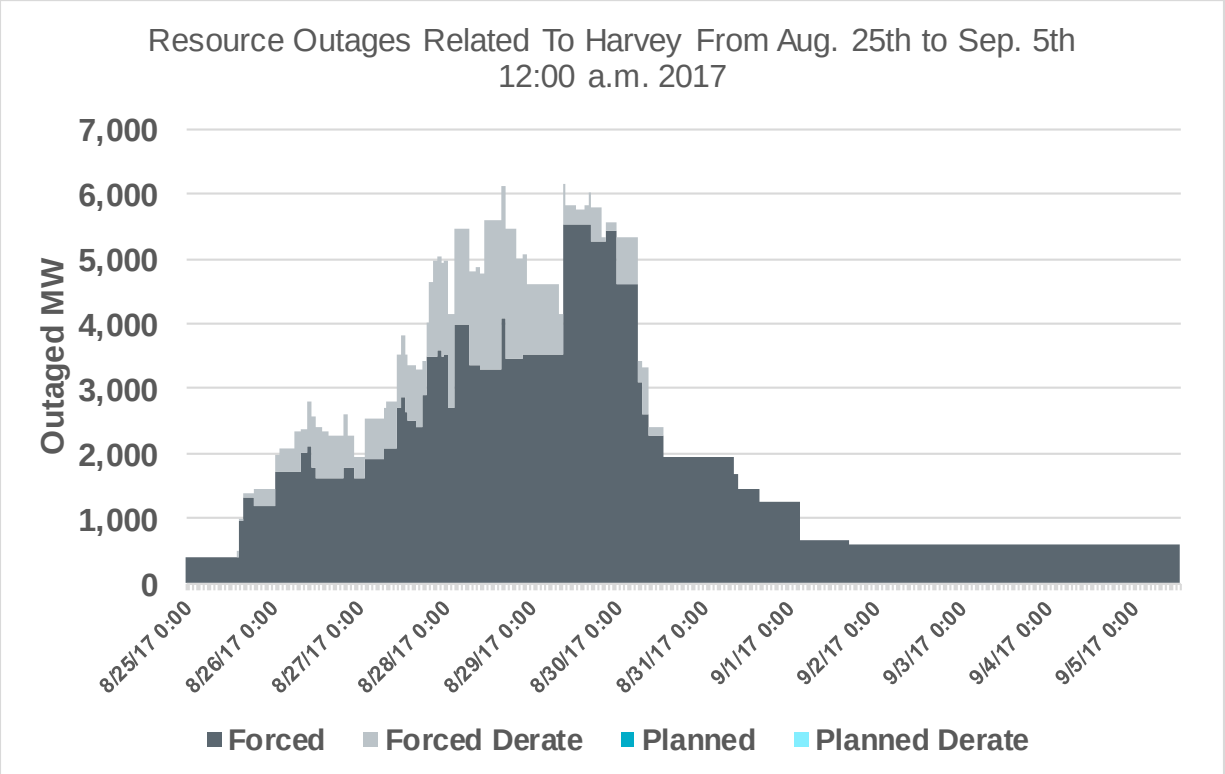


Figure 6: Outage Scheduler Resource Outages and Derates 8/25/17 to 9/5/17 related to Hurricane Harvey

- The following Black start generators experienced forced outages due to Hurricane Harvey: Rayburn G7 and G8 – Aug. 16 at 9:39 a.m. to 5:00 p.m., due to intermittent

power loss at the plant; and Rayburn G7 and G8 – Aug. 27 at 10:33 a.m. to 1:36 p.m., due to water in the switchgear.

7.5. Load Impact

It is very difficult to precisely determine the amount of system load lost due to a hurricane since system load is initially reduced by the weather itself (rain and cooler temperatures), and distribution load may be lost prior to the load serving transformer being outaged. The below graph shows the overall system load impact relative to previous week loading and previous year loading.

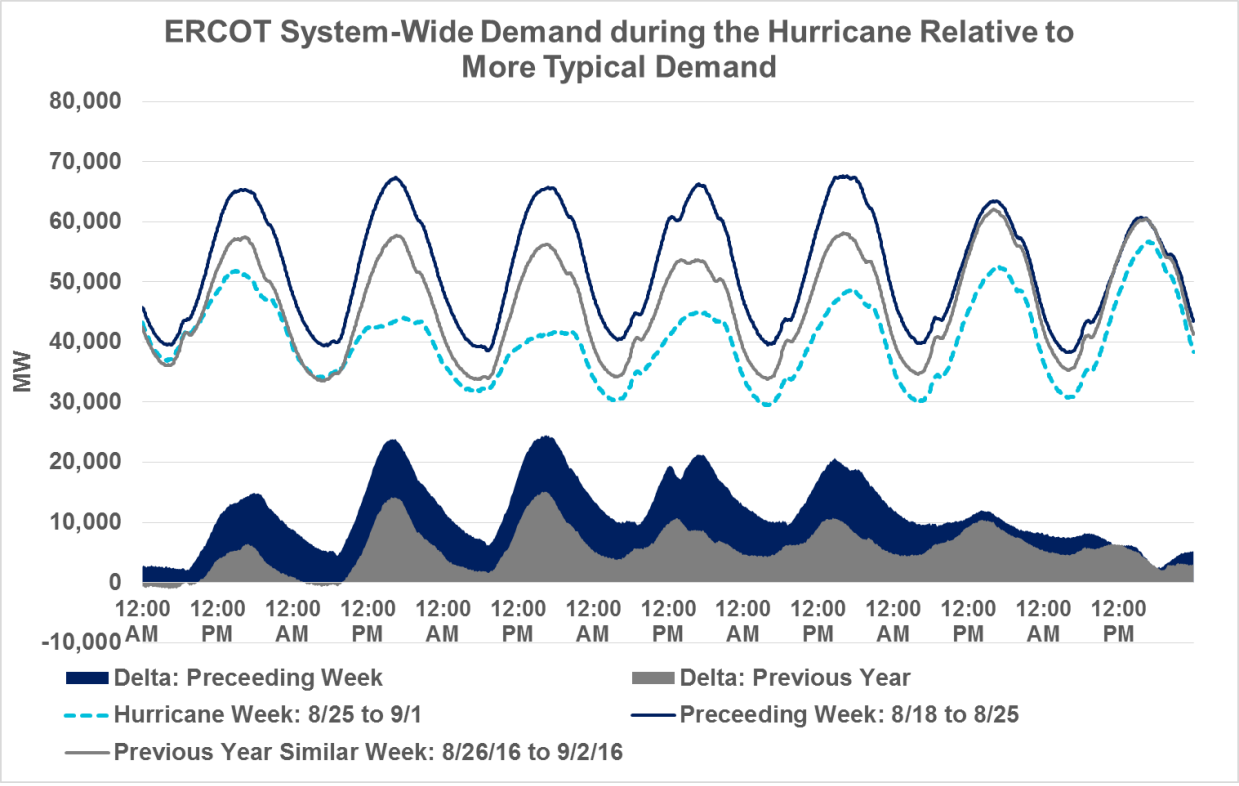


Figure 7: ERCOT System-Wide Demand impact due to Hurricane Harvey

7.6. ERCOT State Estimator Impact

To support its operations, ERCOT uses multiple systems, which include the Energy Management System (EMS) and the Market Management System (MMS). In EMS, there are several application functions running both in real-time and study mode. The real-time applications include State Estimator (also referred to as the Real-Time Network Analysis – (RTNET), Contingency Analysis (CA) and dynamic stability analysis tools.

STATE ESTIMATOR
The State Estimator (SE) plays a key role in ERCOT's energy and market management systems because the reliability and market tools depend on the results provided by the SE. During events such as Hurricane Harvey, the SE requires extra attention and continuous real-time support by operations personnel to ensure its ability to provide valid solutions. The Grid

Applications Support Group supports the EMS applications 24/7 for real-time operations. This group also maintains and provides 24/7 support for the SE and other associated network applications. This team provided on-site support between Aug. 25 – 30.

In preparation for Hurricane Harvey, which had reached Category 4 status, ERCOT's Operations Staff was required to be available on-site to support the control room starting at 5:00 p.m. on Aug. 25.

All of the EMS real-time assessment tools remained fully functional during Hurricane Harvey.

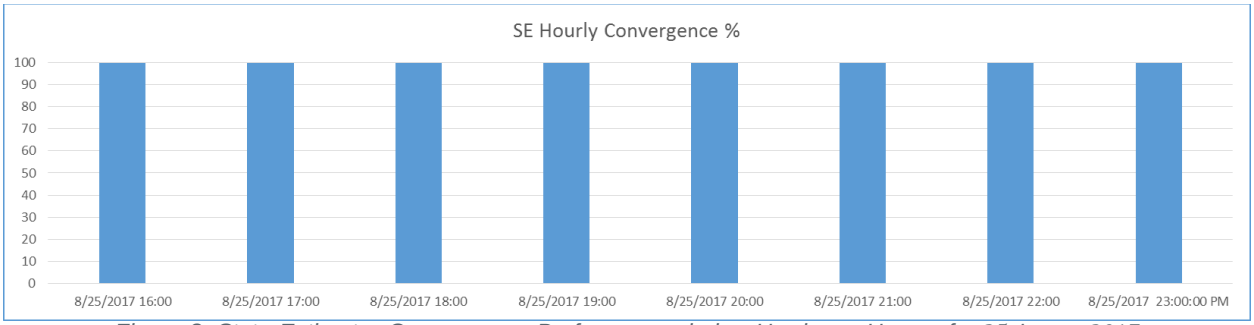


Figure 8: State Estimator Convergence Performance during Hurricane Harvey for 25 August 2017

SE solved with 100% convergence from 4:00 p.m.to 12:00 p.m. on Aug. 25. The convergence requirement for ERCOT's SE is that it must converge for 97% of the executions during a one month period. The SE converged better during Hurricane Harvey than Hurricane Ike. When Hurricane Harvey made landfall, the SE convergence performance was 100% in contrast with the convergence performance of approximately 52% when Hurricane Ike made landfall.

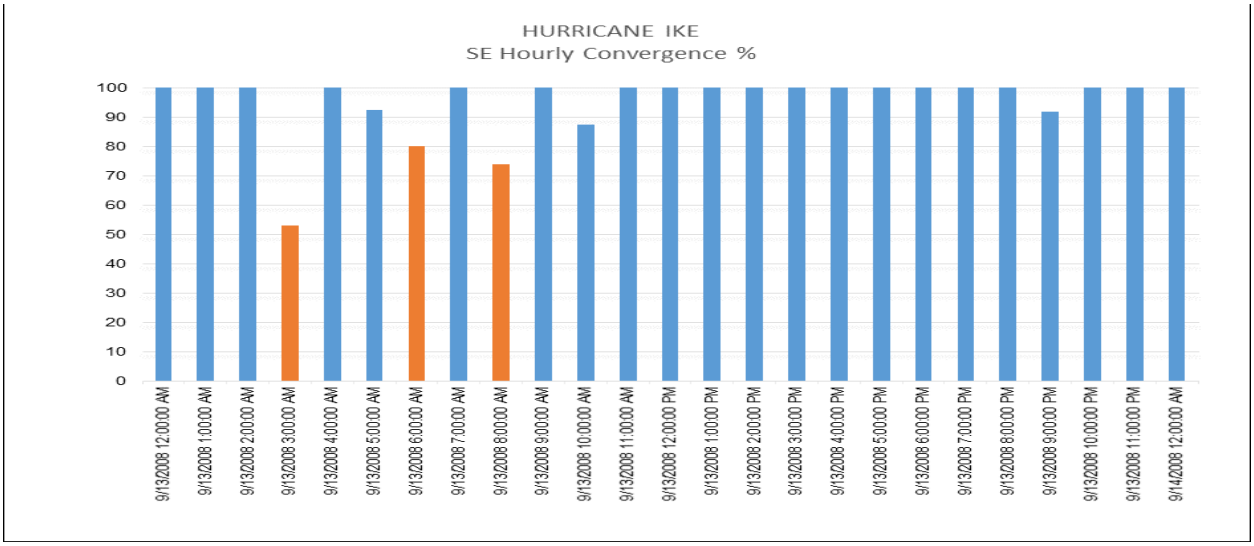


Figure 9: State Estimator Convergence Performance during Hurricane Ike

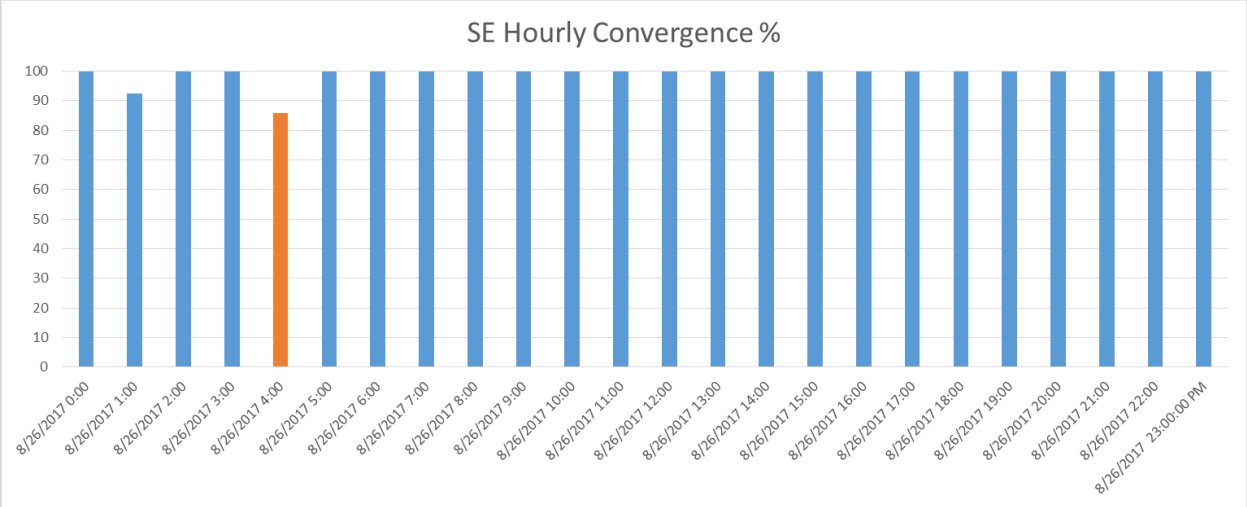


Figure 10: State Estimator Convergence Performance during Hurricane Harvey for 26 August 2017

The only time frames during which convergence was significantly impacted were on Aug. 26 at 1 a.m. and 4 a.m. SE solved with excessive mismatch around 1 a.m., which contributed to a 92.31% SE convergence for that hour.

For the hour ending 4 a.m., the convergence performance was reduced to approximately 85%. At this time, the AEP TDSP ICCP link went down. Discrepancies between out of service elements, telemetered MW generation, transmission flows and switching device status caused the SE to yield a 'solved with Excessive Mismatch Solution' status.

SESTATS

ERCOT Engineering Support personnel were able to utilize the State Estimator Statistical (SESTAT) application to quickly identify MW/MVar mismatches and topology coherency issues in order to validate the system status with QSEs and TSPs. Staff could then manually replace the SCADA value or status in the ERCOT EMS with correct values as needed.

RTCA

The-Real Time Contingency Application successfully ran for all State Estimator Valid Solutions during the event.

VSAT

The Voltage Security Assessment tool successfully ran for all SE and RTCA valid solutions during the event.

FOD

The Forced Outage Detection (FOD) application identified outages and classified them as either 'documented outage' or 'undocumented outage' based on whether the outage was in the Outage Scheduler or in the Current Operating Plan (COP).

The FOD application was instrumental in helping operators and support engineers identify the undocumented outages which were not entered in the outage scheduler during the hurricane.

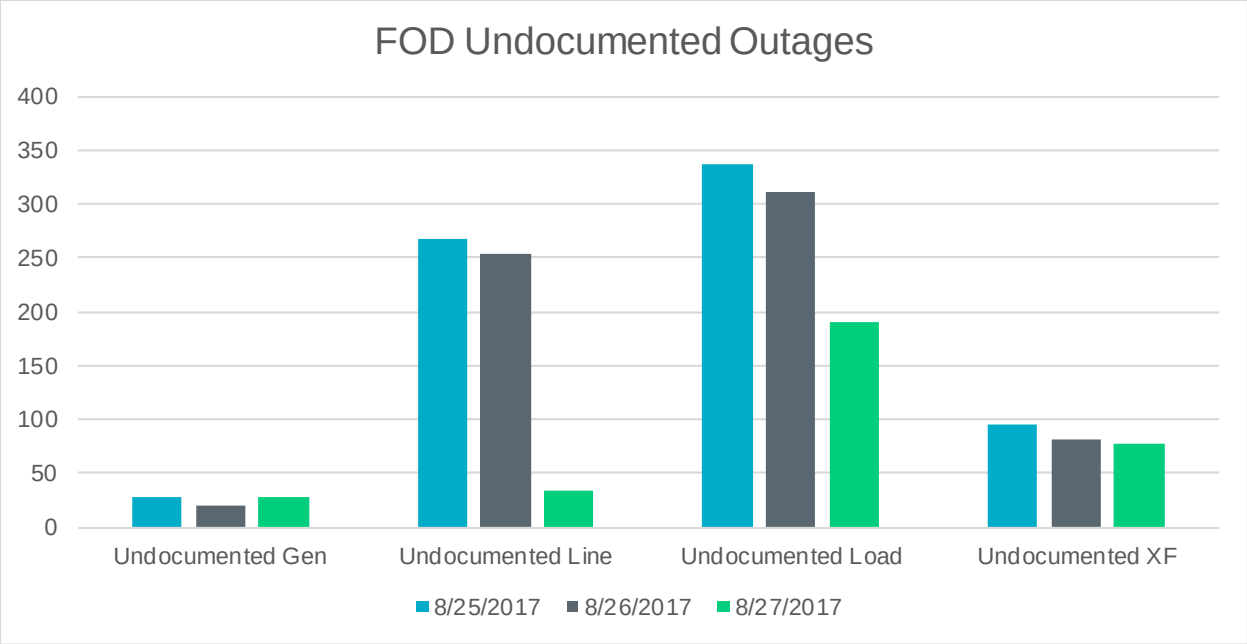


Figure 11: FOD Undocumented Outages (Lines, Load, Units, and Xfmers)

7.7. ERCOT EMS Impact

All applications performed as expected with EMS and MMS. EMMS Production Support had 24/7 on-site and off-site support from Friday, Aug. 25, on the morning when the storm hit through the Monday morning following the storm. During this time, there were no system or application issues.

7.8. Commercial Operations Impacts

The impacts on commercial systems and operations due to Hurricane Harvey and the subsequent flooding in the Houston area are summarized below. The analysis largely begins on Aug. 23 to provide a baseline perspective and continues through Sept. 2 to capture the beginnings of a return to more typical conditions.

Prices

The ERCOT market continued to run as expected during the event period. The graph below shows that Day-Ahead Market (DAM) energy Settlement Point Prices (SPP) and Ancillary Service (AS) prices trended as normal, with the exception of somewhat higher Regulation Down prices on Aug. 25 through Sept. 1. Higher Regulation Down prices generally indicate that Market Participants are expecting Real-Time Market (RTM) energy Settlement Point Prices (SPP) prices to be below their operating costs.

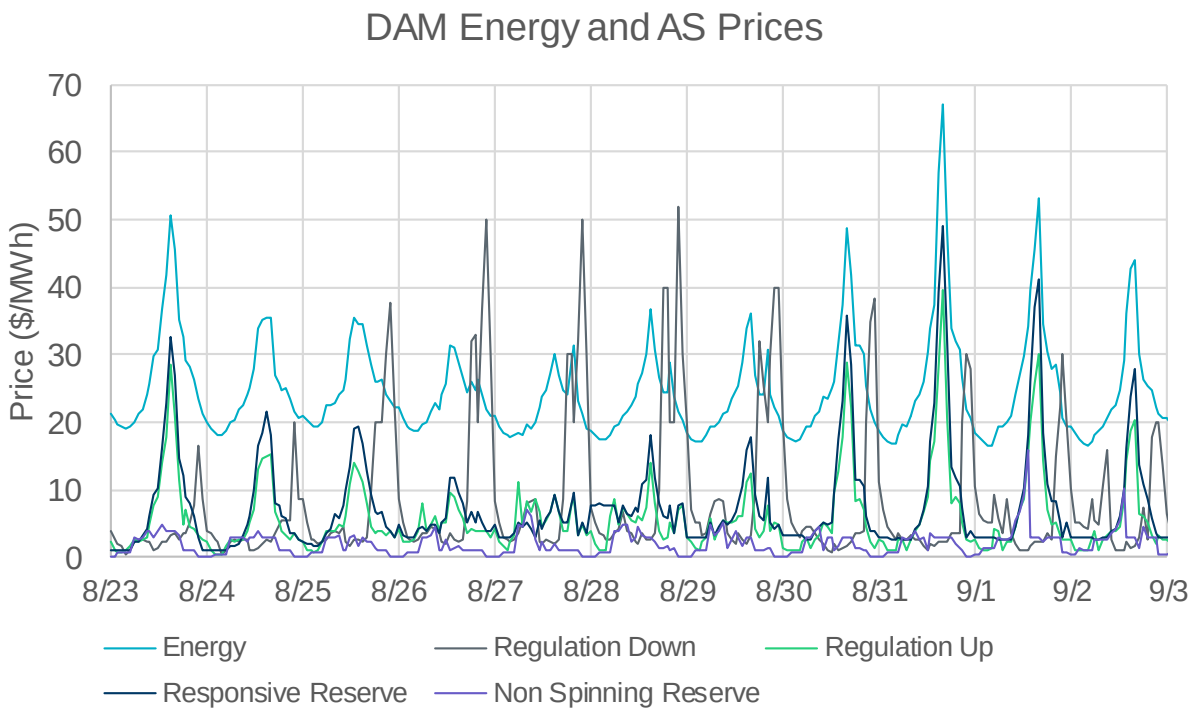


Figure 13: DAM Energy and AS Prices

DAM SPP to RTM SPP price convergence was within normal expectations. The graph below shows that DAM pricing was higher for the South Load Zone on Aug. 28 and Aug. 29 during peak hours due to transmission congestion in DAM. Real-time pricing was higher for the South Load Zone on Aug. 26, Aug. 29, and Aug. 30 due to transmission congestion in the RTM. Congestion rent due to these prices is presented later in this report.

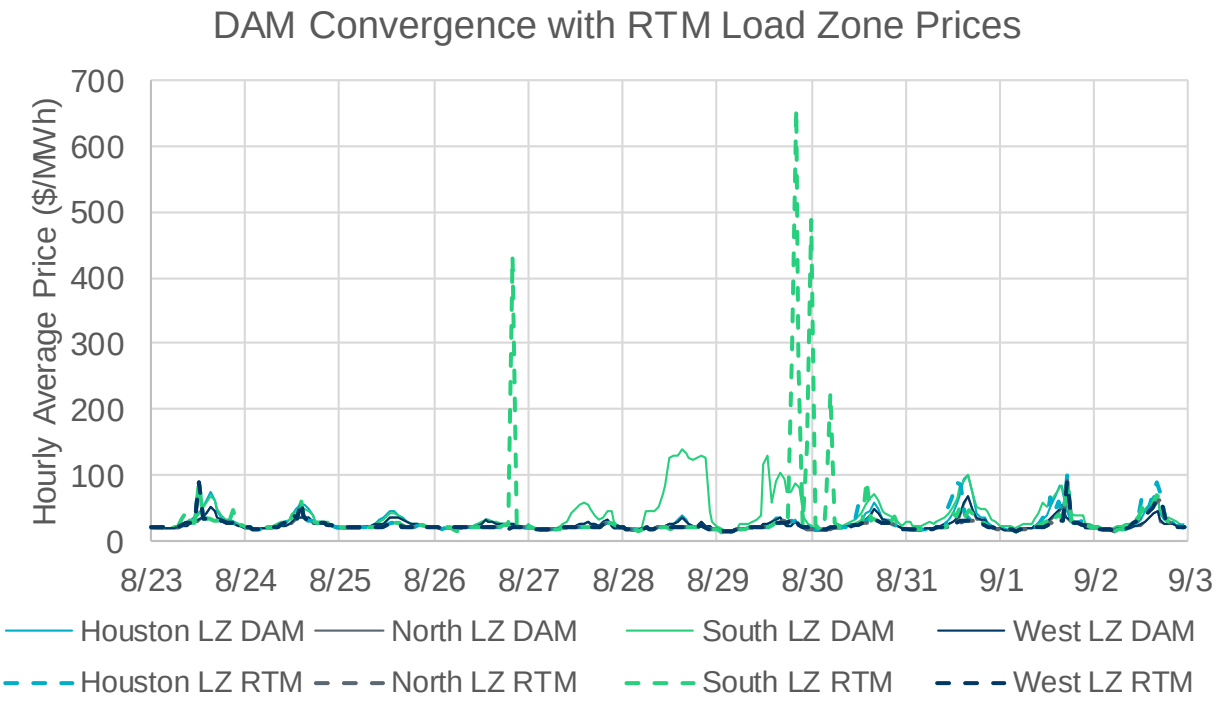


Figure 14: DAM Convergence with RTM Load Zone Prices

The graph below shows the same data as the graph above, with the South Load Zone data removed to more clearly show the remaining data. It shows that DAM and RTM price convergence was within normal expectations.

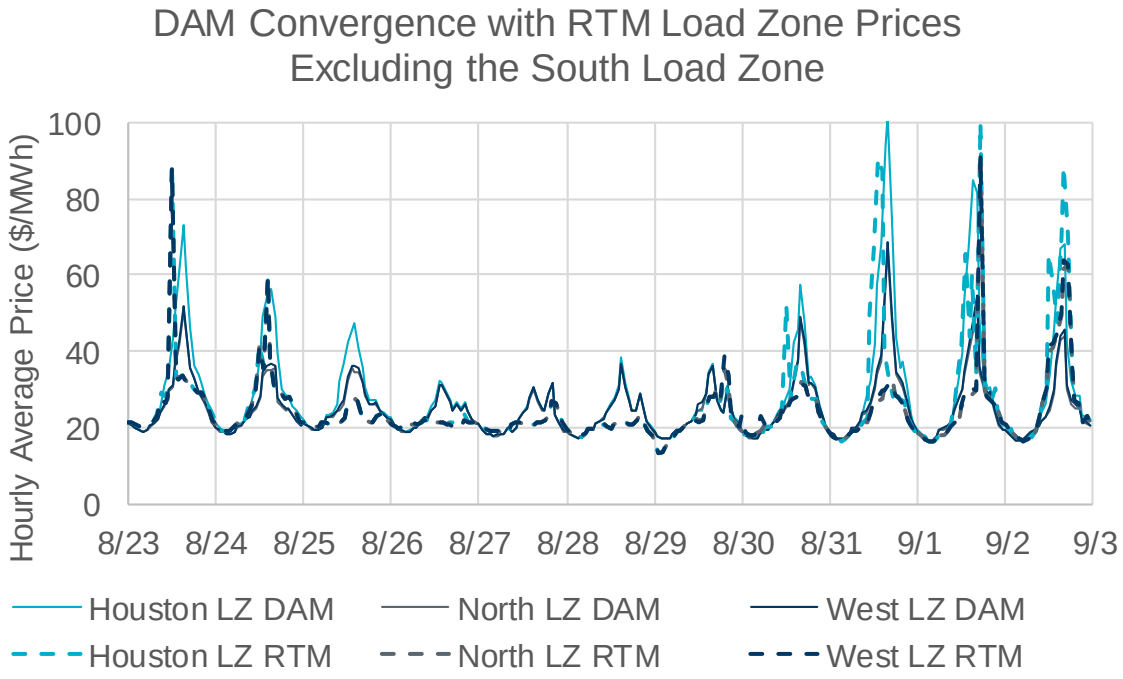


Figure 15: DAM Convergence with RTM Load Zone Prices (excluding South Load Zone)

Energy, demand and fuel mix

The types of generation online and available for dispatch in real time can have major impacts on prices. The graphs below begin on Aug. 23 and reflect a typical summer day overview by hour of online generation in the Coastal, Houston and South Weather Zones. The resources are aggregated by fuel type: Nuclear, Coal, Gas, Wind, and a small amount of other. The graphs for each of the following days reflect the diminishing resources along the coast and subsequently in the Houston area. By Sept. 2, many of the resources had recovered and were beginning to return to service. ERCOT had a robust amount of system-wide capacity and that, along with an extreme reduction in demand, resulted in prices within a normal range.

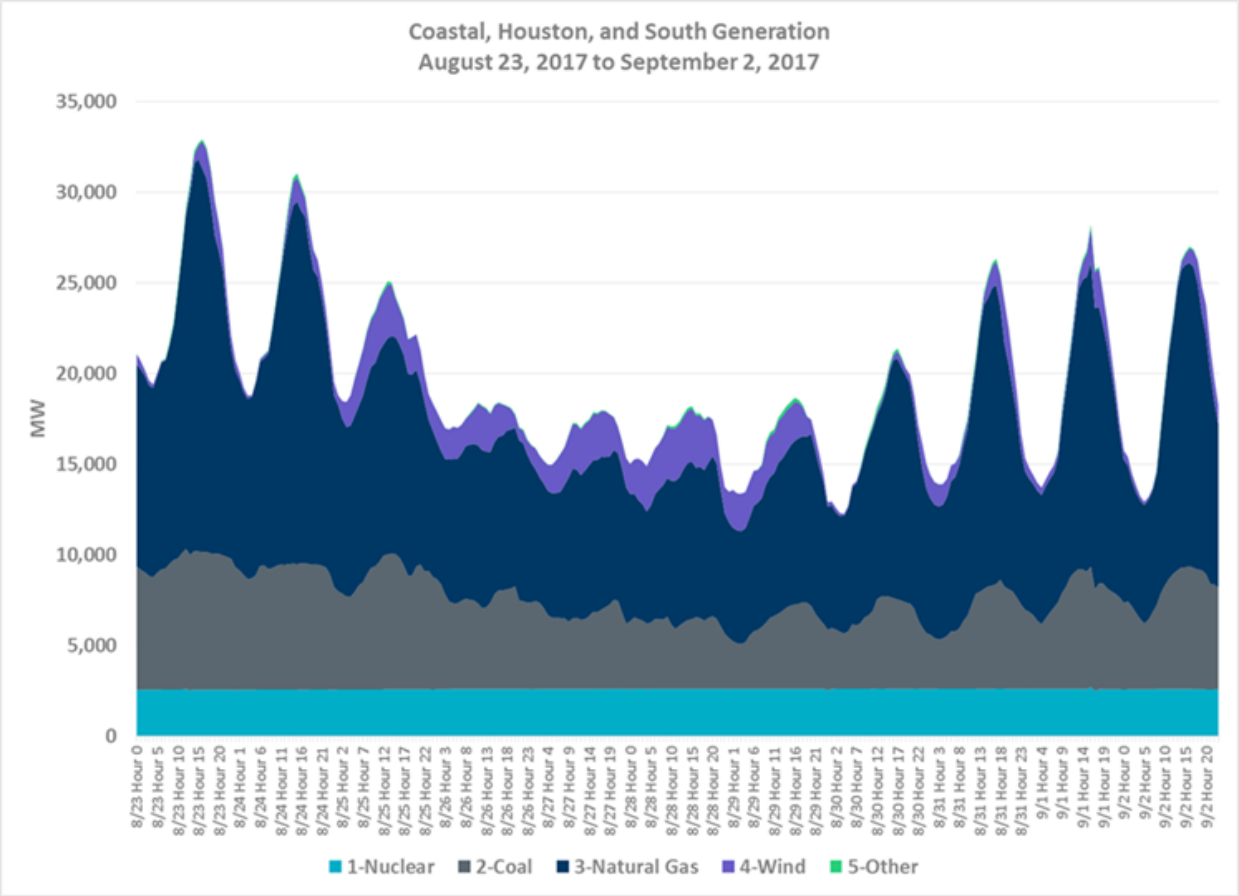


Figure 16: Coastal, Houston, and South Generation 8/23/17 to 9/2/17

This same informaton is presented for the entire ERCOT system in the graph below. This graph further emphasizes how demand across ERCOT was affected by the hurricane and associated weather.

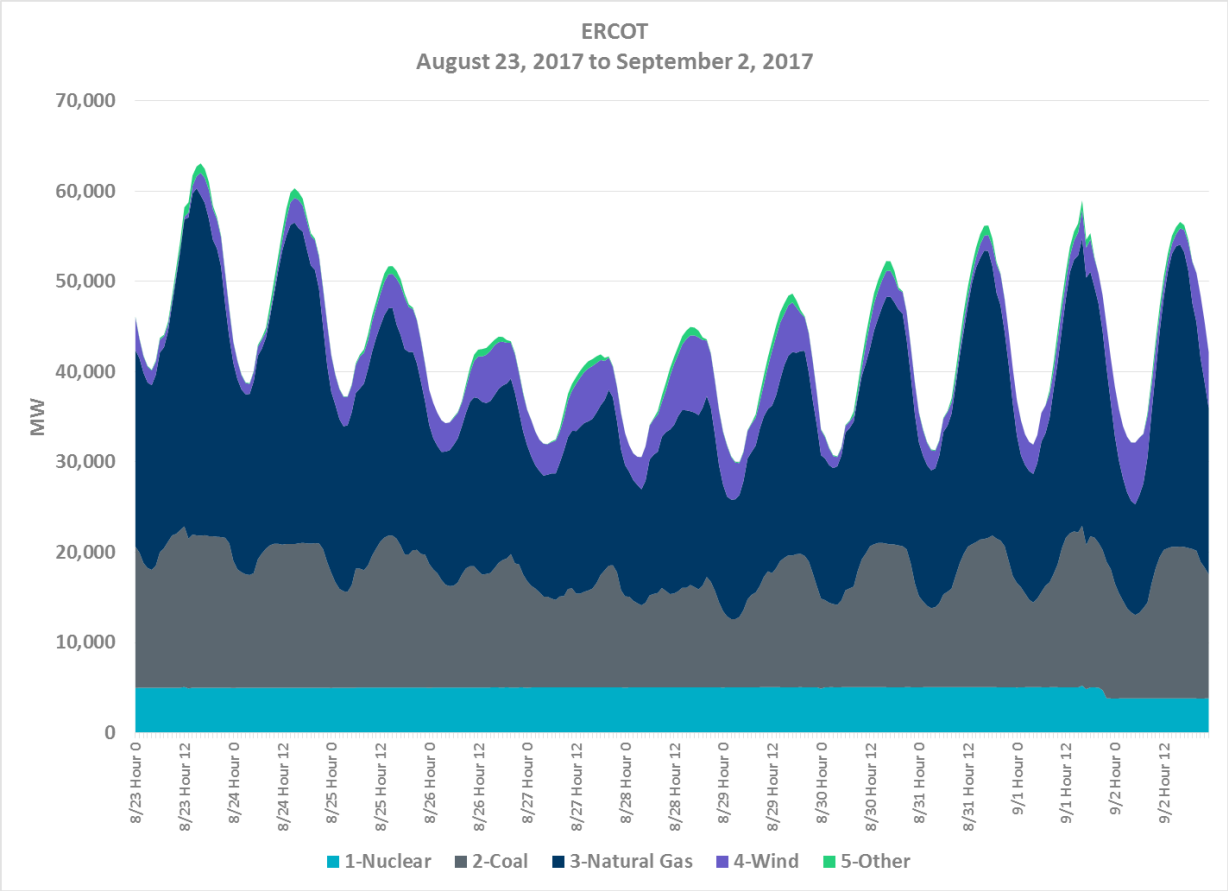


Figure 17: ERCOT Generation 8/23/17 to 9/2/17

Looking at the impacts to system-wide demand in another way, the graph below shows the reduction in demand for the period of the hurricane, relative to other historical, relevant time periods.

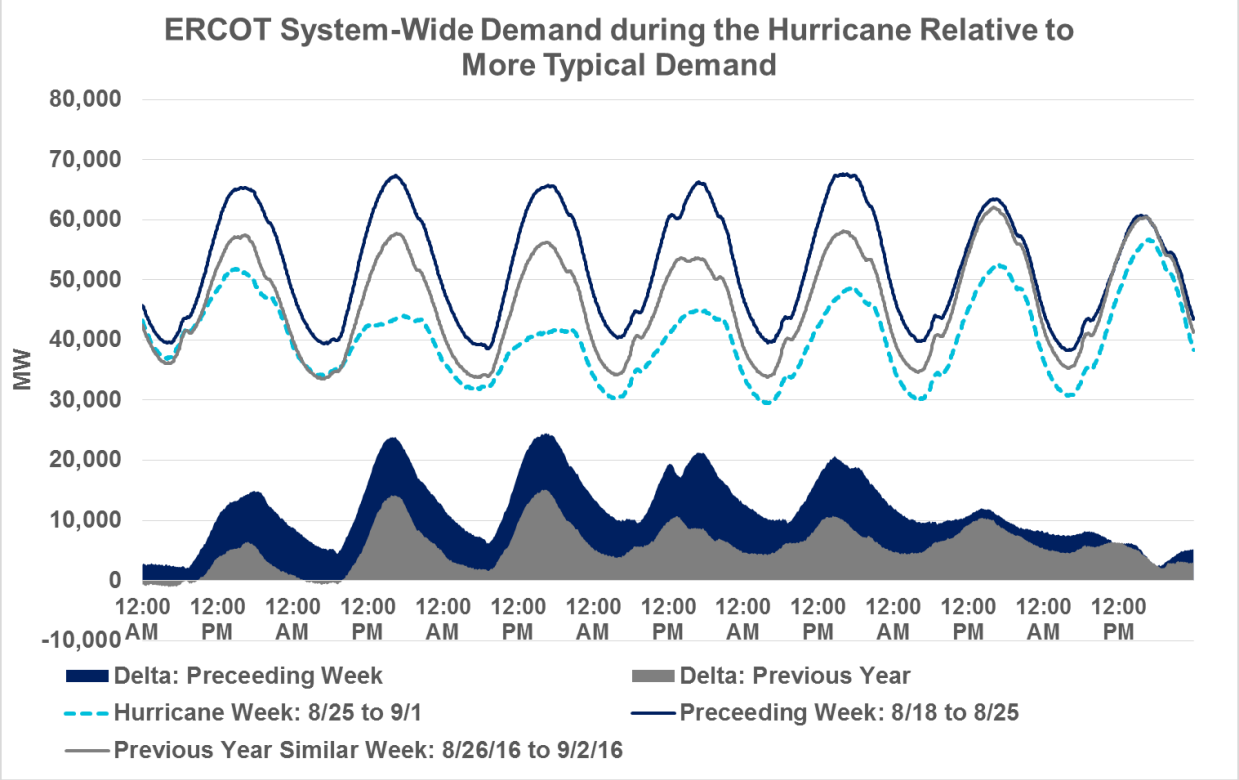


Figure 18: ERCOT System-Wide Demand during Hurricane Harvey

Likewise, the hurricane impacted the total energy being consumed on the system. The graph below shows the daily Real-Time Adjusted Metered Load during the period of the hurricane as well as several days leading into landfall on Aug. 25.

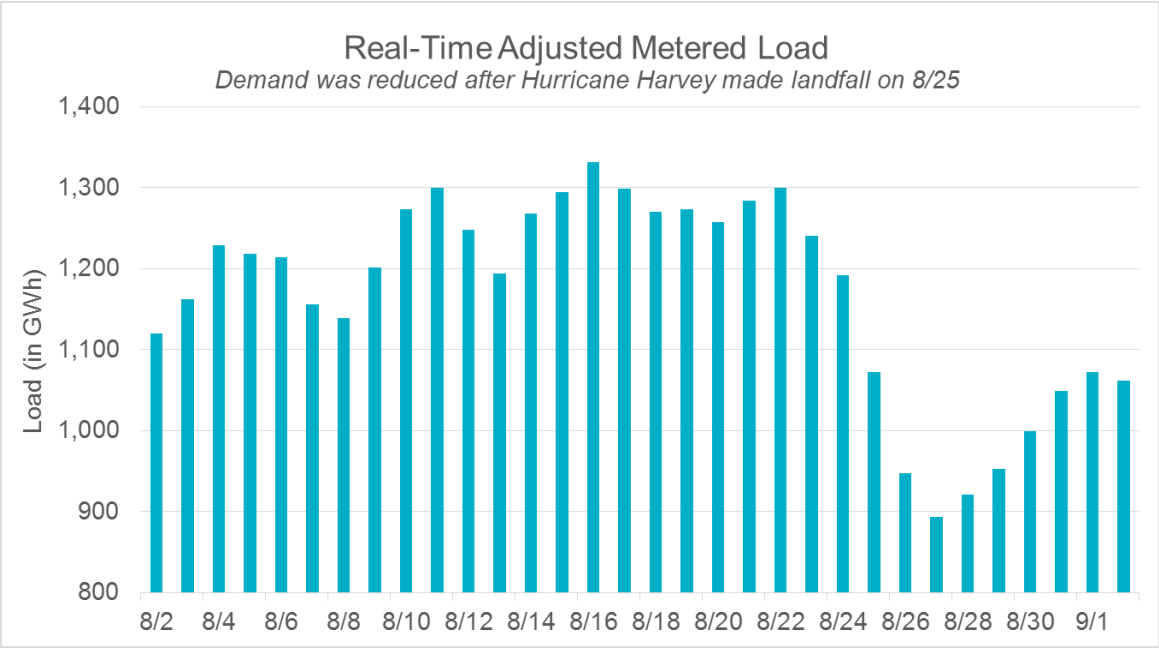


Figure 19: Real-Time Adjusted Metered Load

DAM execution and participation

The Day-Ahead Market (DAM) performed well. There were no disruptions, and the participation level from Qualified Scheduling Entities (QSEs) was within typical variation. Execution times also were within a normal range, and the DAM published on time daily. After the event, operators were responsible for implementing a large number of Downstream Production Changes (DPCs) to maintain alignment with manual contingencies and other changes being managed in real-time operations as a result of topology changes.

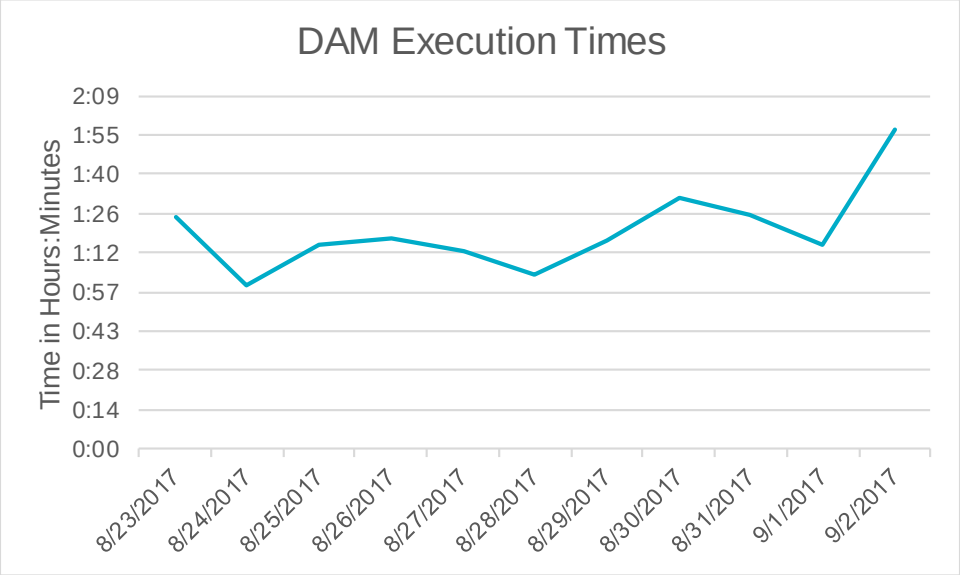


Figure 20: DAM Execution Times

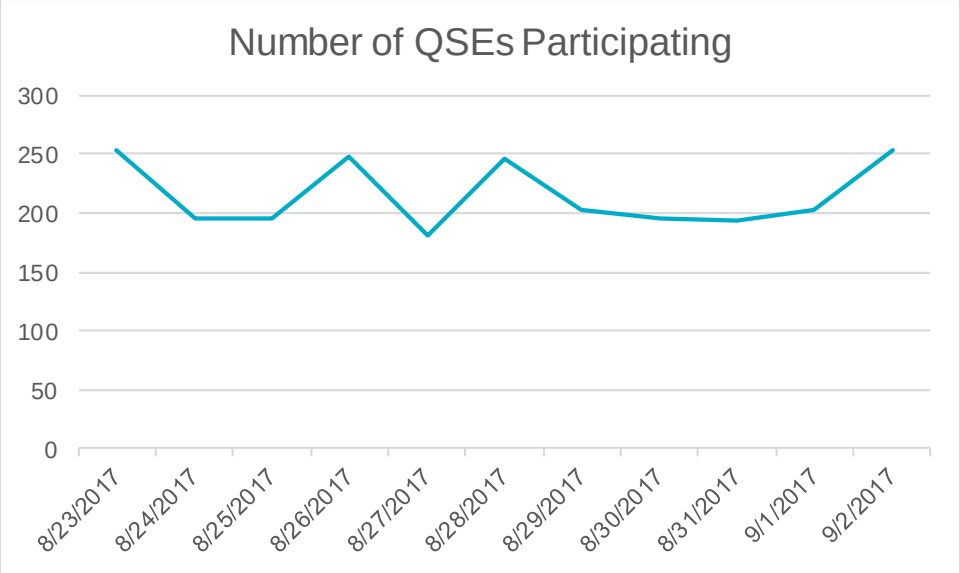


Figure 21: # of QSEs Participating

Load Distribution Factor (LDF) mismatch

Load Distribution Factors (LDFs) are used to distribute MWs bid into the DAM across each Load Zone. The LDFs used in the DAM are monitored and updated based on system conditions. This is generally done on a seasonal basis. When the weather changes, an updated seasonal value is manually loaded as needed. During Harvey, in the South Load Zone, the LDFs overestimated the load at particular load buses due to distribution-level outages as well as overall changes in the load pattern. This, combined with the high number of transmission outages in the area, caused localized high prices and resulted in LZ_SOUTH diverging significantly from HB_SOUTH. In the case of Hurricane Harvey, since system conditions were changing so rapidly, there was no way to anticipate where the outages would occur or how the specific pattern of demand would be affected. Therefore, the mismatches could not be avoided. ERCOT staff considered updating the LDFs, but; it was determined that the LDFs in use at the time of the events were known to the Market Participants and that accurate LDFs could not be ascertained. Therefore, any change to them during the event was not deemed by ERCOT to be the appropriate course of action.

The graphs below were derived from the "perfect" load forecasts and are distributed to each individual load using the LDFs. On each individual load, the absolute mismatch between distributed MW and real-time state-estimated MW was calculated and summed up based on the Weather Zones or Load Zones. The total of absolute mismatch is then normalized using the total of loads in the Weather Zones or Load Zones. The zones outside of the Southern and Coastal weather zones and the South and Houston load zones show typical levels of mismatch. The mismatches began to occur first in the Southern Weather Zone followed by the Coastal Weather Zone, which corresponds to the Load Zone mismatch occurring first in the South Load Zone followed by the Houston Load Zone, as load patterns changed as a result of weather and outages.

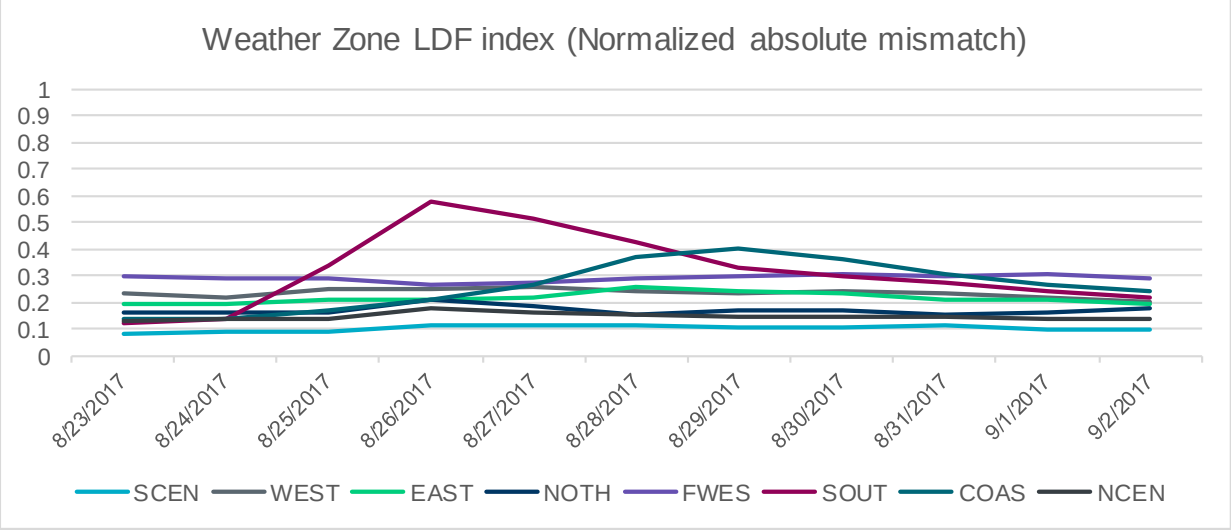


Figure 22: Weather Zone LDF index

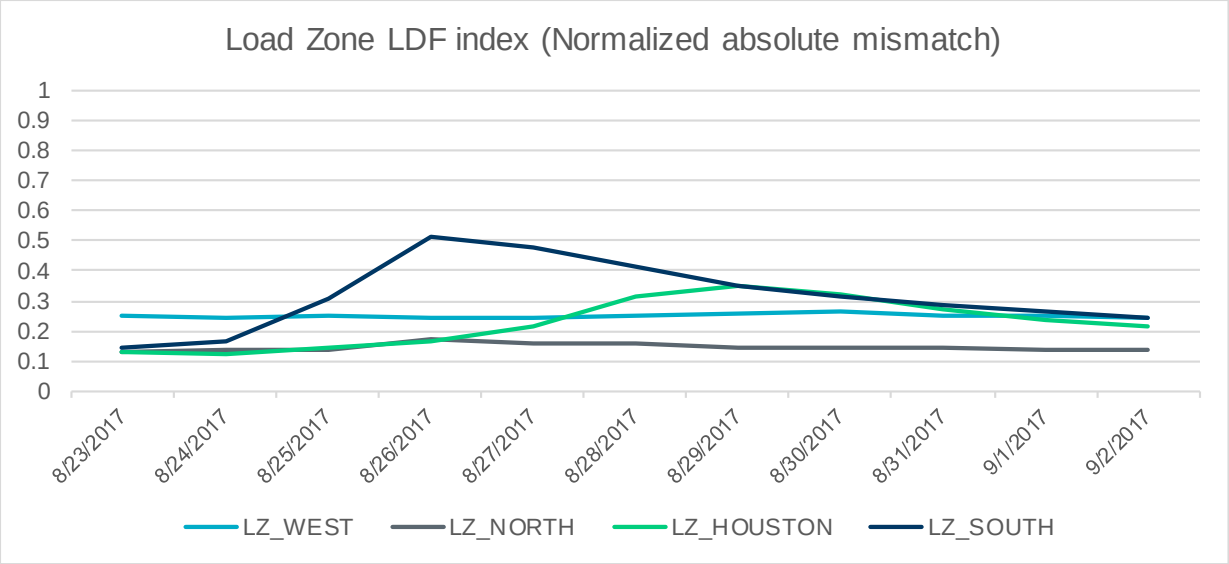


Figure 23: Load Zone LDF index

Real-time congestion

The total real-time congestion rent for the time period Aug. 23 – Sept 2, was approximately $16.5 million. The following is a break-down of notable congestion rent in the system:

- Approximately $9.6 million in congestion rent was directly related to Hurricane Harvey
- The Load Zone with the highest congestion rent was the South Load Zone with $10.6 million
- The Houston Load Zone had the second highest amount of congestion rent, with $5.5 million
- On Aug. 26, the total congestion rent was $1.9 million
    - South Load Zone contributed $1.88 million to this total
- On Aug. 29, the total congestion rent was $5.3 million
    - South Load Zone contributed $5.28 million to this total
- On Aug. 30, the total congestion rent was $2.9 million
    - South Load Zone contributed $2.38 million
- On Aug. 31, the total congestion rent was $3.3 million
    - Houston Load Zone contributed $2.71 million
- On Sept. 1, the total congestion rent was $1.3 million
    - Houston Load Zone contributed $1.14 million
- On Sept. 2, the total congestion rent was $1.2 million
    - Houston Load Zone contributed $1.12 million
- The most expensive real-time congestion occurred in the South Load Zone, SCOLLON5: LONHILL_PAWNEE_1 with $3.5 million

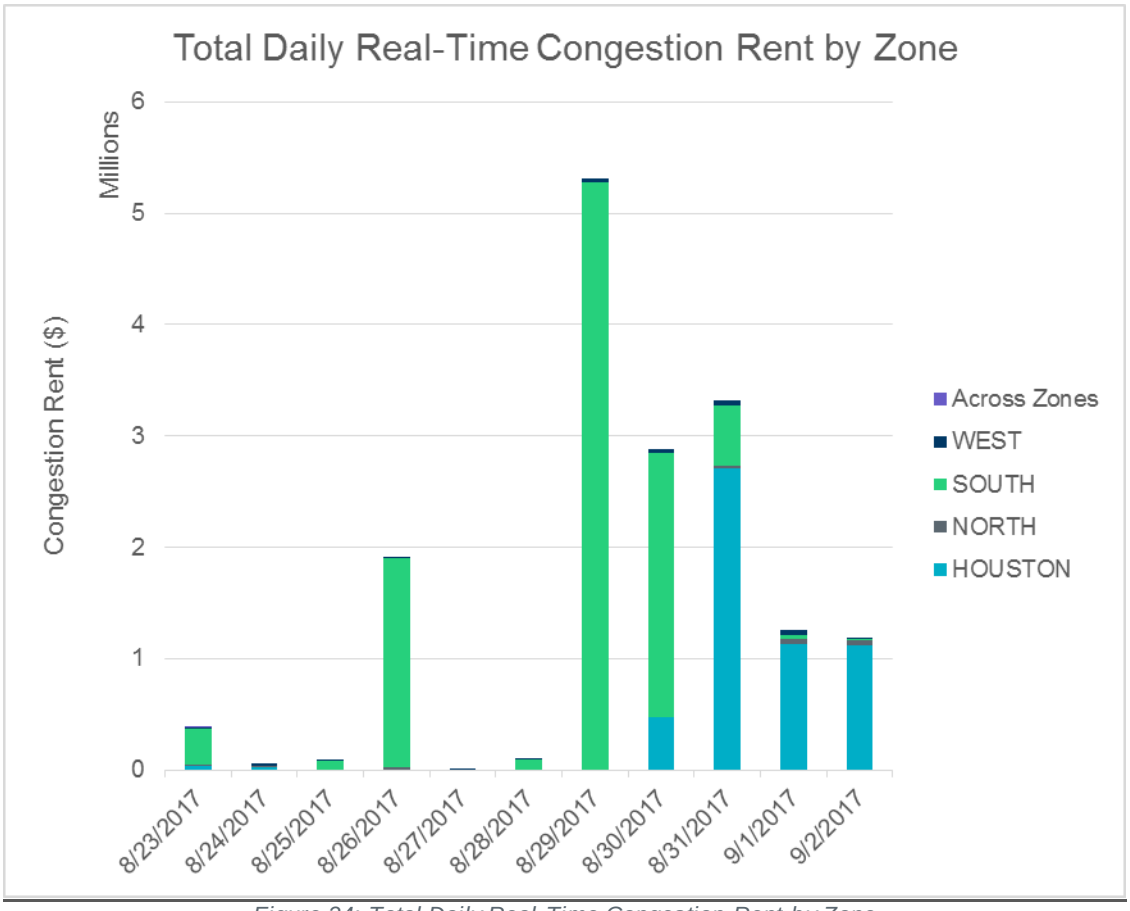


Figure 24: Total Daily Real-Time Congestion Rent by Zone

The primary contributors to the $10.6 million of congestion rent in the South Load Zone were:

- SCOLLON5: LONHILL_PAWNEE_1
  - Loss of the 345-kV line from Lon Hill to Coleto Creek overloads the 345-kV line from Lon Hill to Pawnee Switching Station
  - Total congestion rent: $3.5 million
  - Related to the forced outage of the South Texas Project – White Point 345-kV line due to Hurricane Harvey
- DELMSAN5: PAWNEE_SPRUCE_1
  - Loss of the 345-kV double circuit from Elmcreek to San Miguel Switchyards overloads the 345-kV line from Pawnee Switching Station to Calaveras
  - Total congestion rent: $2.4 million
  - Related to the forced outages of the Lon Hill – White Point and the South Texas Project – White Point 345-kV lines due to Hurricane Harvey
- SPOLPHA8: GCB_100_1
  - Loss of the 138-kV line from North Pharr to Polk Avenue overloads the 138-kV line from North McAllen to West McAllen
  - Total congestion rent: $1.95 million
  - Related to a combination of high DC Railroad export and high Valley load

The primary contributors to the $5.5 million of congestion rent in the Houston Load Zone were:

- SADKTHW5: LA_NB_95_A
  - Loss of the 345-kV line from Addicks to TH Wharton overloads the 138-kV line from North Belt to Lauder
  - Total congestion rent: $2.2 million
  - Related to the forced outage and subsequent reconfiguration of the Greens Bayou substation due to Hurricane Harvey
- DDPW_SC9: GF_UN_12_A
  - Loss of the 69-kV circuit between Deepwater, Mining, South Channel and Sr Bertron overloads the 69-kV line from University to Genral
  - Total congestion rent: $1.4 million
  - Related to the forced outage of the Greens Bayou substation

Day Ahead Market (DAM) and Real-Time Market (RTM) congestion convergence

Total congestion rent in the Day-Ahead Market for the period Aug. 23 –2, equaled $23.8 million, while total congestion rent in Real Time was $16.5 million. There was a large discrepancy between DAM and RTM congestion rent in the South Load Zone between Aug. 23 and Sept. 2, , with DAM totaling $16 million and RT totaling $10.6 million.

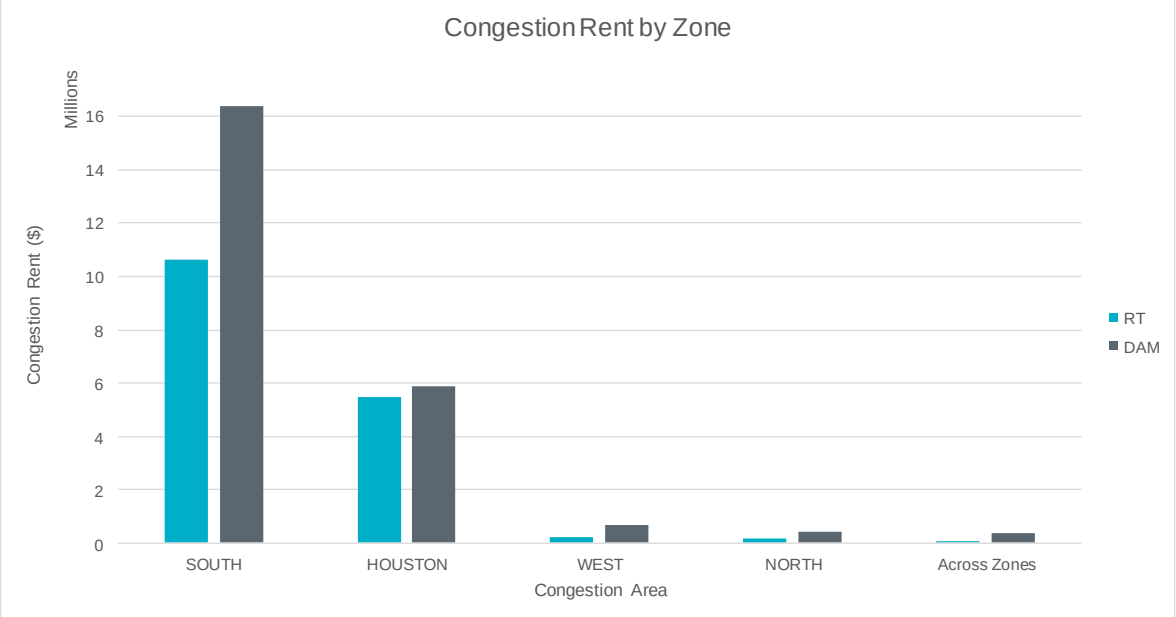


Figure 25: Congestion Rent by Zone

The following is a break-down of the days with the largest differences in congestion rent between DAM and RT for Load Zone South:

- On Aug. 26, DAM had total congestion rent of $220,000, while RT had total congestion rent of $1.88 million
  - The largest contributor to real-time congestion was constraint element PAWNEE_SPRUCE_1 (345-kV line from Pawnee Switching Station to Calaveras in the San Antonio area)

    - Related to the forced 345-kV line outages from Lon Hill to White Point and White Point to South Texas Project due to Hurricane Harvey.
- On Aug. 28, DAM had total congestion rent of $5.68 million, while RT had total congestion rent of $97,000
    - The largest contributor to day-ahead congestion was constraint element BEEVIL_THREE_1_1 (69-kV line from Beeville to Three Rivers in the Corpus Christi area)
    - Related to new sets of outages from Hurricane Harvey being incorporated into DAM and non-representative LDFs creating load patterns in DAM that were not seen in real-time
- On Aug. 29, DAM had total congestion rent of $2.88 million, while RT had total congestion rent of $5.28 million
    - The largest contributor to real-time congestion was constraint element LONHILL_PAWNEE_1 (345-kV line from Pawnee Switching Station to Lon Hill in the Corpus Christi area)
    - Related to the forced 345-kV line outage from White Point to South Texas Project due to Hurricane Harvey
- On Aug. 30, DAM had total congestion rent of $1.2 million, while RT had total congestion rent of $2.4 million
    - The largest contributor to real-time congestion was, similar to Aug. 26, constraint element PAWNEE_SPRUCE_1
- On Sept. 1, DAM had total congestion rent of $1.4 million, while RT had total congestion rent of $34,000
    - The largest contributor of day-ahead congestion was constraint element NCA_SMTP (69-kV line from North Calliham Sub to San Miguel Tap in the Laredo area)

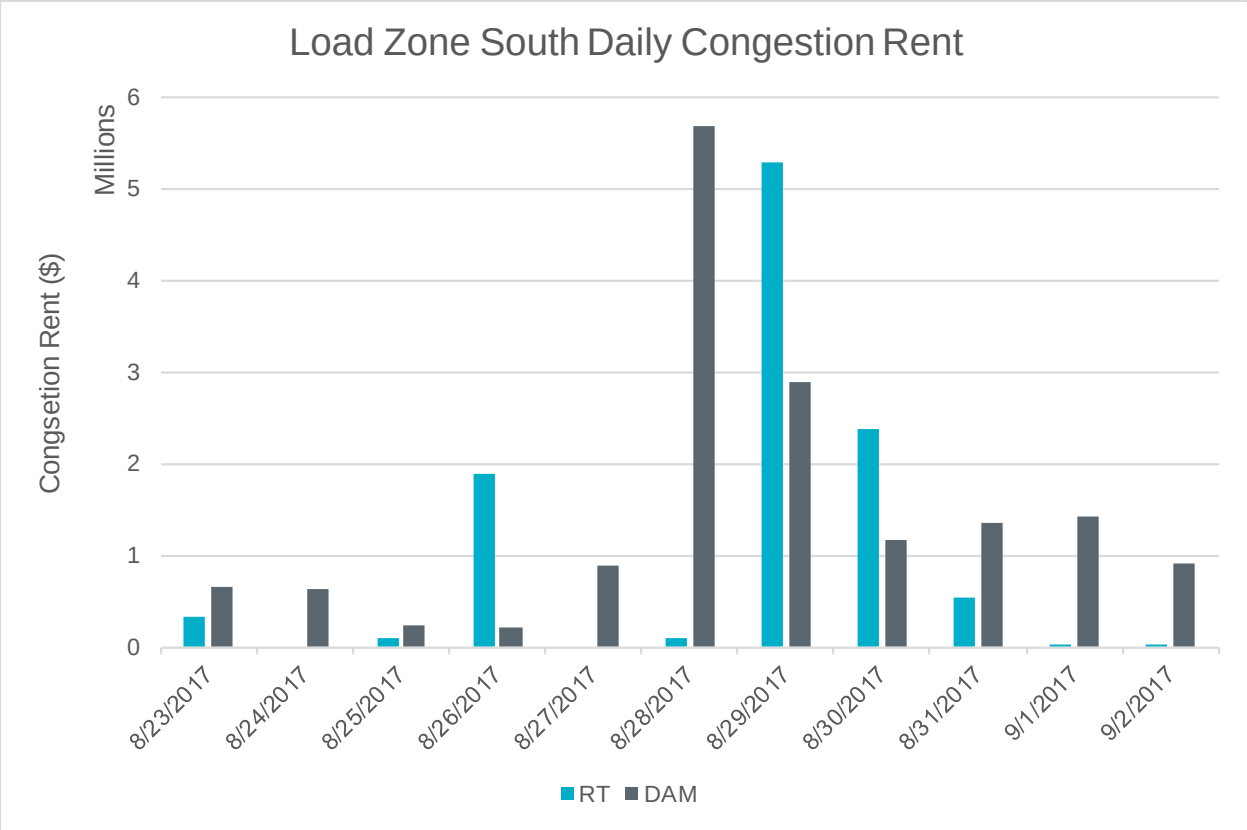


Figure 26: Load Zone South Daily Congestion Rent

Congestion Revenue Right (CRR) cost vs. DAM value

During Hurricane Harvey events, the overall CRR cost to value resulted in a $7 million net payment to account holders. The highest net payment occurred on Aug. 28 in the amount of $6.2 million.

High CRR net payout was primarily due to three constraints:

1. XKEN289 : BEEVIL_THREE_1_1 (From Three Rivers 69-kV to Beeville 69-kV - Corpus Christi) HE1-24
2. XLO2N58 : LON_HILL_381H (From Lon Hill 345-kV to Lon Hill 1-kV - Corpus Christi)
   HE1-2, 7-24
3. XLO2N58 : LON_HILL_381L (From Lon Hill 1-kV to Lon Hill 138-kV - Corpus Christi)
   HE1-2, 7-24

Multiple line outages in the Corpus Christi Area were primarily responsible for the significant spread between DAM Hub and DAM load zone pricing in the South.

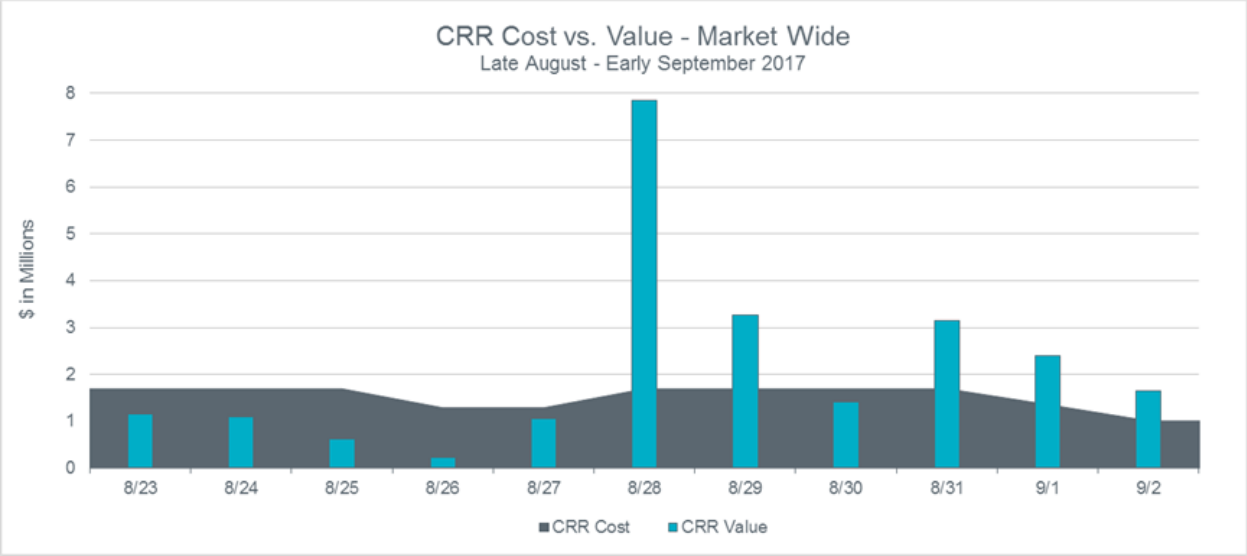


Figure 27: CRR Cost vs. Value-Market Wide

Congestion Revenue Right (CRR) funding

On Aug. 28, the DAM congestion rent collected was $5.8 million while the net of all CRR Credits and Charges was -$7.8 million, resulting in $2 million of short charges to CRR account holders. However, after the end of the month balancing account closing, there was sufficient funding available in the rolling balancing account to refund the short charged CRR account holders, and a $5.3 million surplus (over and above the fund cap of $10 million) was paid back to load.

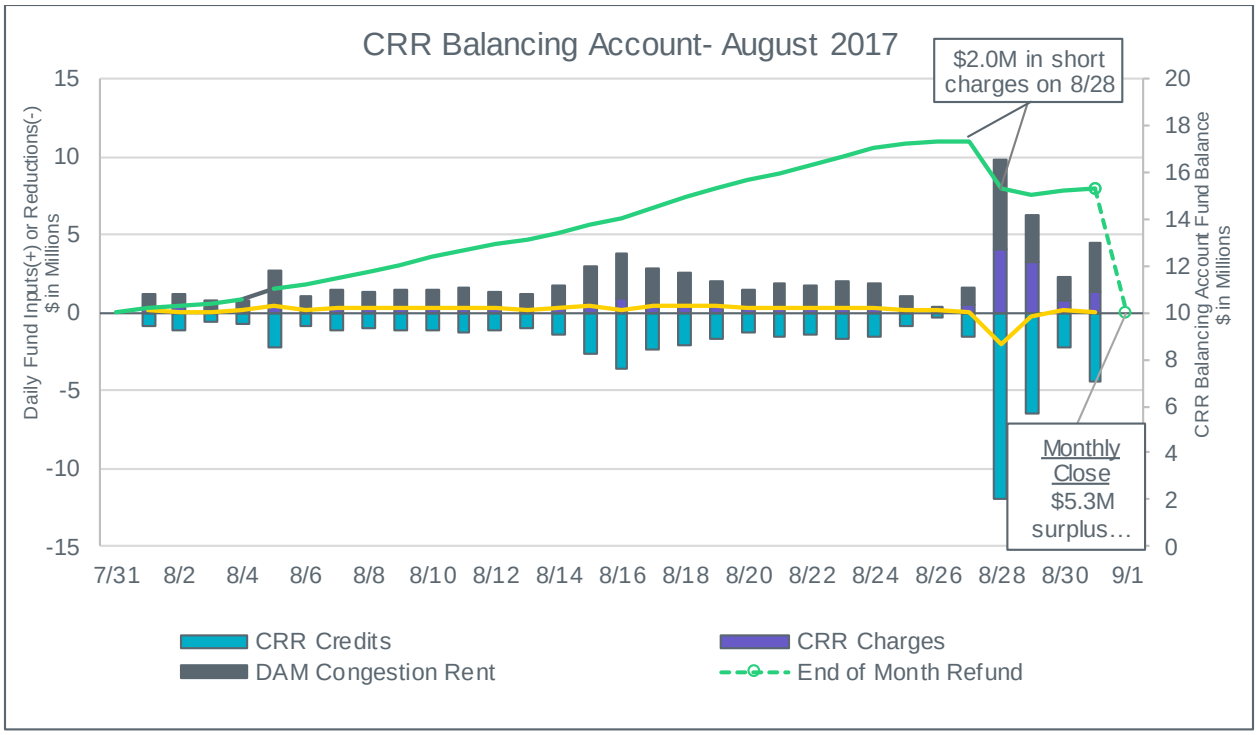


Figure 28: CRR Balancing Account - August 2017

Point-to-point cost vs. value – market-wide

The net PTP settlement for the time period below resulted in a $6.3 million charge to the market. Aug. 28 produced the highest net charge to the market in the amount of $3.4 million. Aug. 29 produced the highest net payment to the market in the amount of $1.7 million.

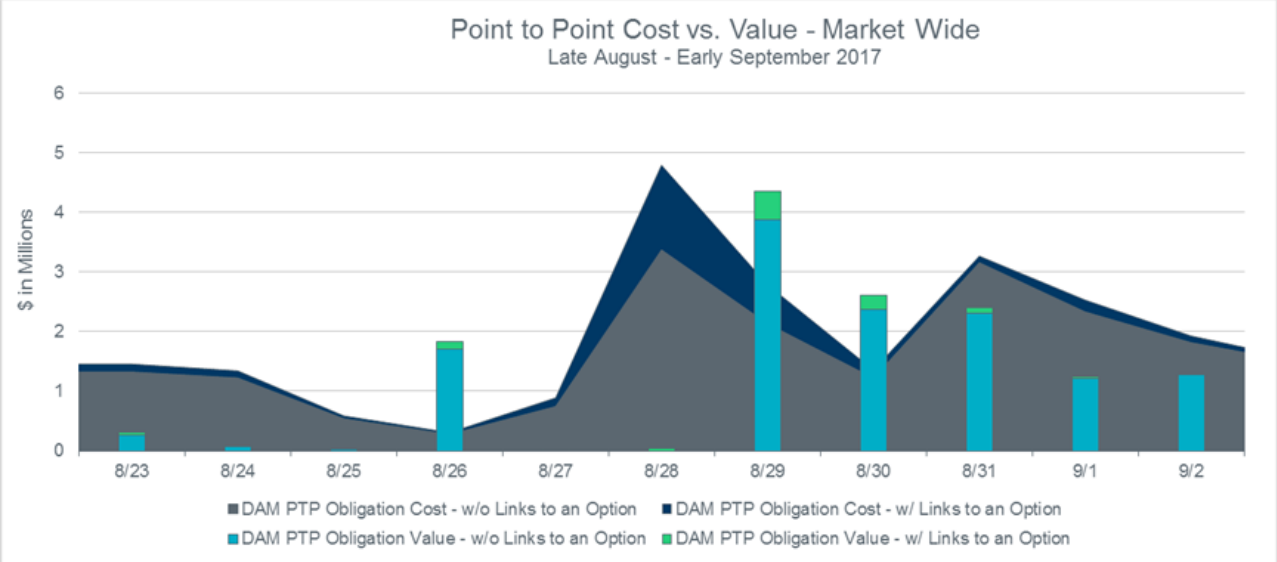


Figure 29: Point to Point Cost vs Value - Market Wide

Revenue Neutrality Uplift to Load

For the late August through early September 2017 dates presented in the following graphs, the Revenue Neutrality Uplift to Load amount resulted in a net payment to load of $372,000.

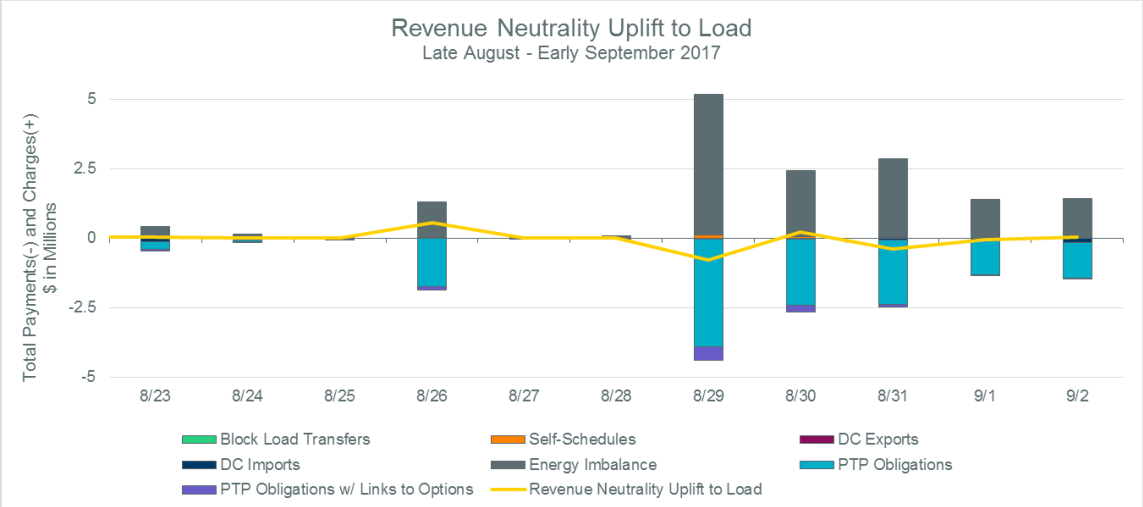


Figure 30: Revenue Neutrality Uplift to Load

Load forecast impacts

System-wide load dramatically decreased as Harvey came through. A look at the Coast Weather Zone shows a drastic decrease to half of peak load from the Wednesday and Thursday before the hurricane to the Monday and Tuesday after.

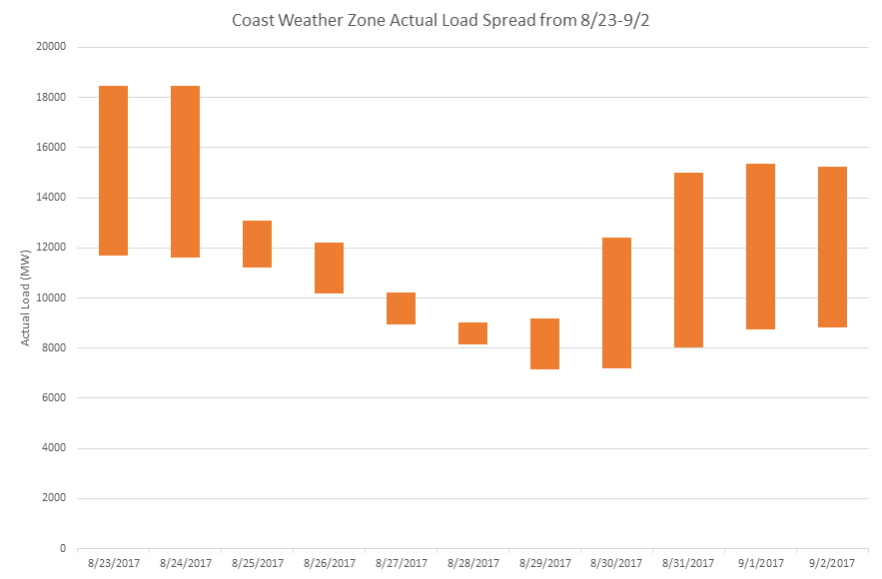


Figure 31: Coast Weather Zone Actual Load Spread 8/23-9/2

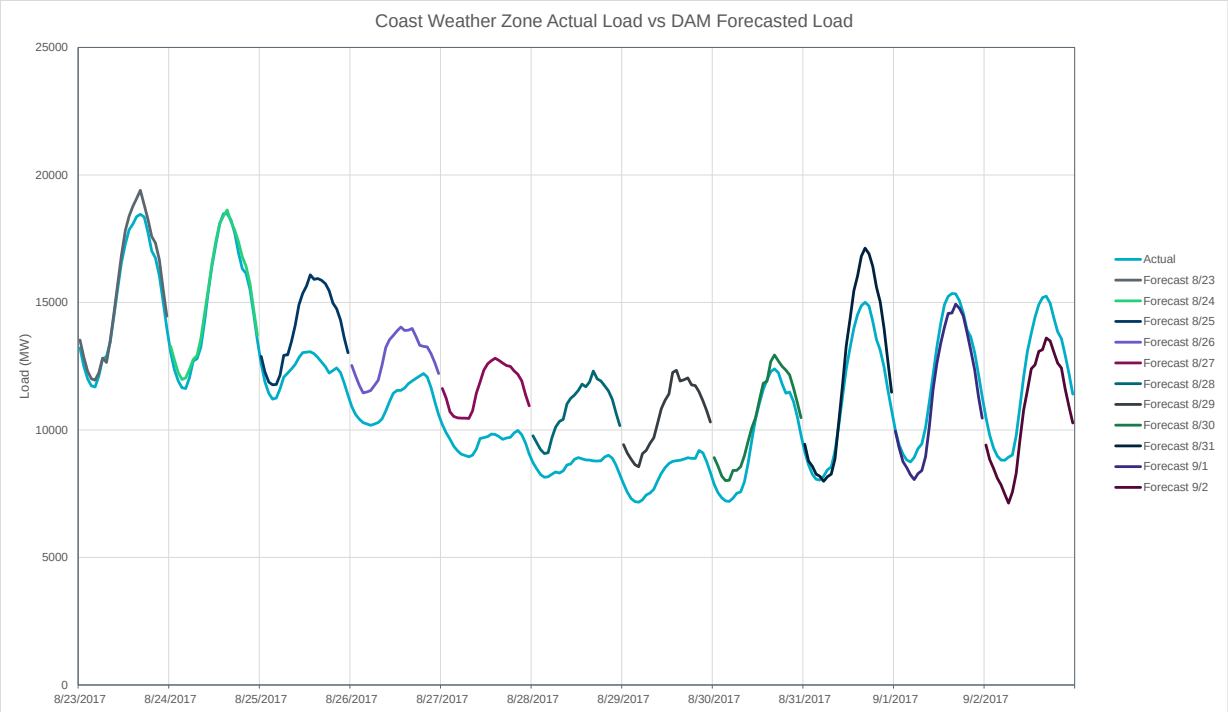


Figure 32: Coast Weather Zone Actual Load vs DAM Forecasted Load

Due to the downward trend of ERCOT load caused by Harvey, the forecast had a tendency to overforecast. When comparing the forecast snapshot prior to the Day-Ahead Market (DAM) closing, it over-forecasted all hours throughout the majority of the week. Although the Coast Weather Zone accounted for less than a quarter of the system-wide load during the height of the events, it accounted for almost all of the system-wide forecast error during some of the days. Along with mismatch from the LDFs, the missed forecasts may have also indirectly contributed to over congestion in the DAM. Additionally, the load over-forecast was also seen as the forecast approached the actual delivery hour. This contributed to Reliability Unit Commitment (RUC) seeing higher-than-actual loads both system-wide and on a regional basis.

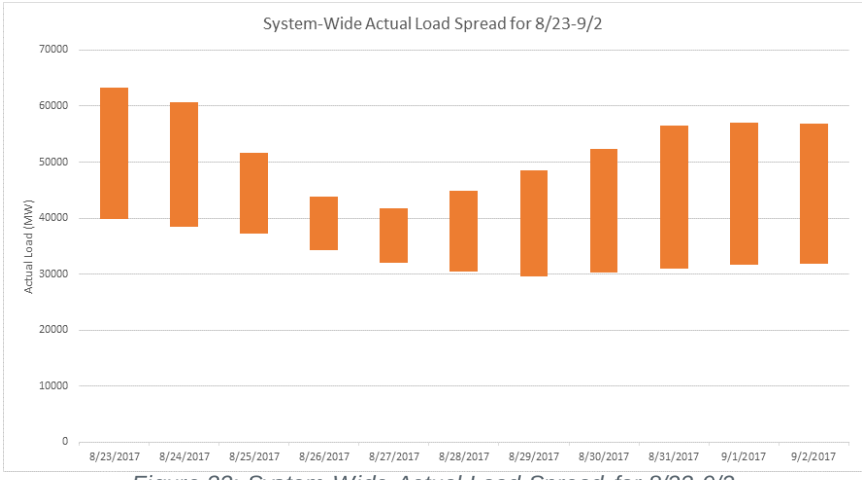


Figure 33: System-Wide Actual Load Spread for 8/23-9/2

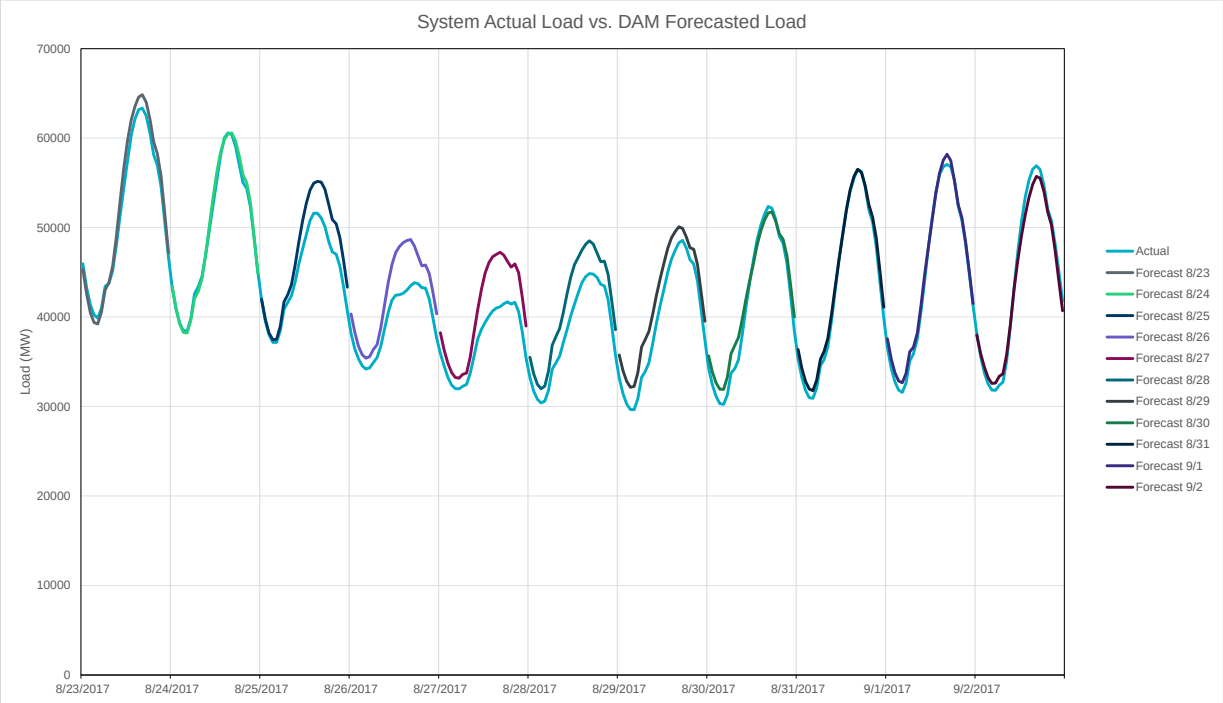


Figure 34: System Actual Load vs. DAM Forecasted Load

Reliability Unit Commitments (RUCs) and Real-Time Reliability Deployment Price Adders (RTRDPA)

There were Real-Time Reliability Deployment Price Adders (RTRDPA) on Aug. 26 from 1:05 a.m. to 11:55 a.m. RTRDPA reached a max of $1.60/MWh.

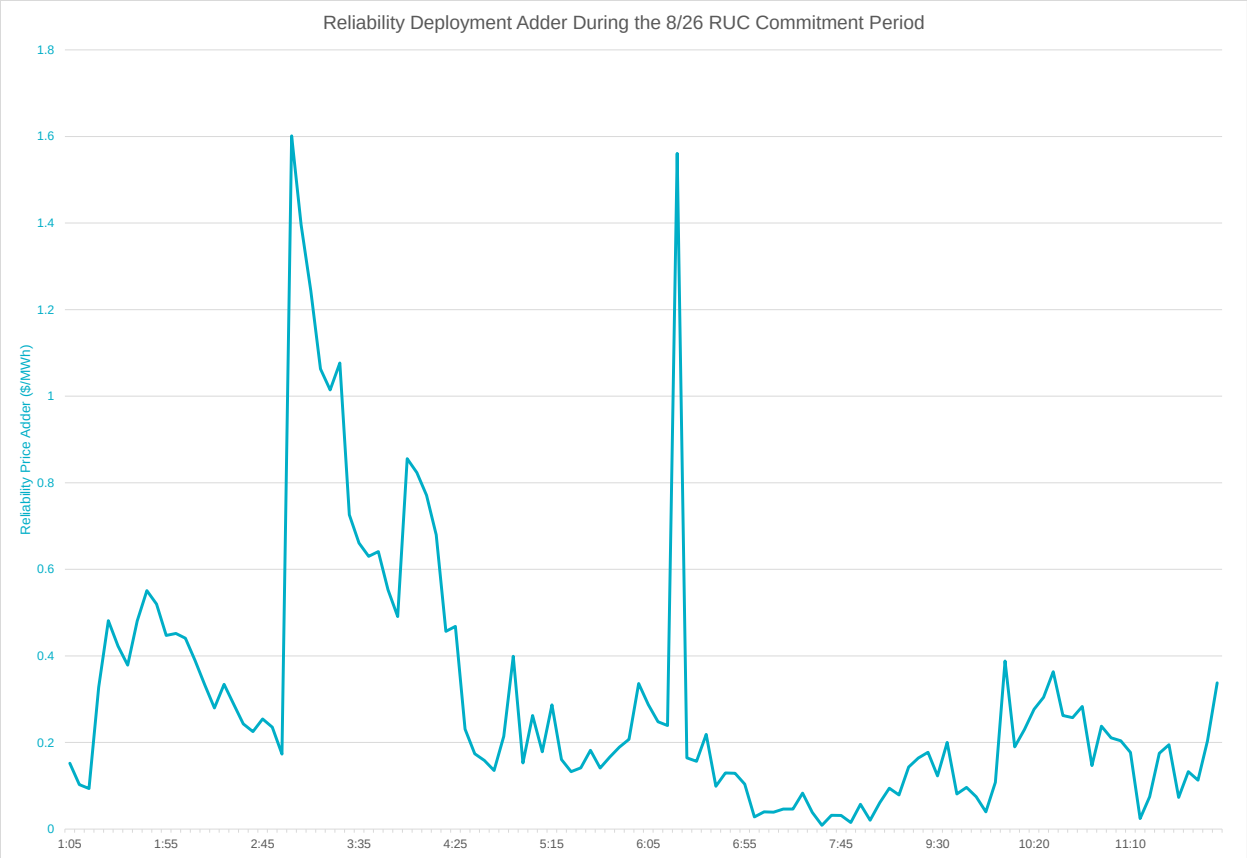


Figure 35: Reliability Deployment Adder During the 8/26 RUC Commitment Period

There were also RTRDPAs on Aug. 27 from 12:15 a.m. to 11:55 p.m. RTRDPA reached a max of $2.64/MWh.

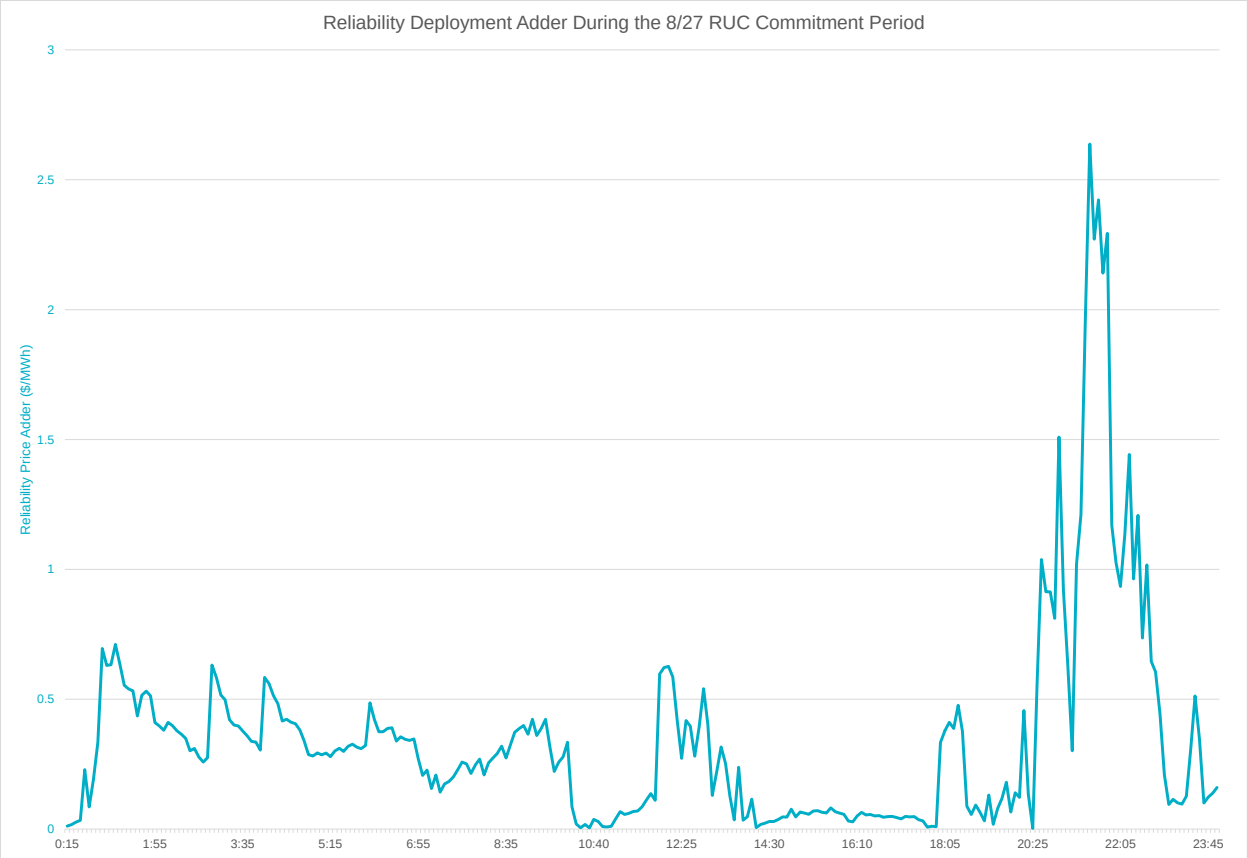


Figure 36: Reliability Deployment Adder During the 8/27 RUC Commitment Period

There were two Hourly Reliability Unit Commitments (HRUCs) during the period of Aug. 23 – Sept. 2, and no Day-Ahead Reliability Unit Commitments (DRUCs). On Aug. 26, one resource was committed for delivery hours 3:00 a.m. through 12:00 p.m. for Valley stability. On Aug. 27, a separate resource was committed for delivery hours 1:00 a.m. through Aug. 28, 12:00 a.m., due to numerous forced outages related to Hurricane Harvey.

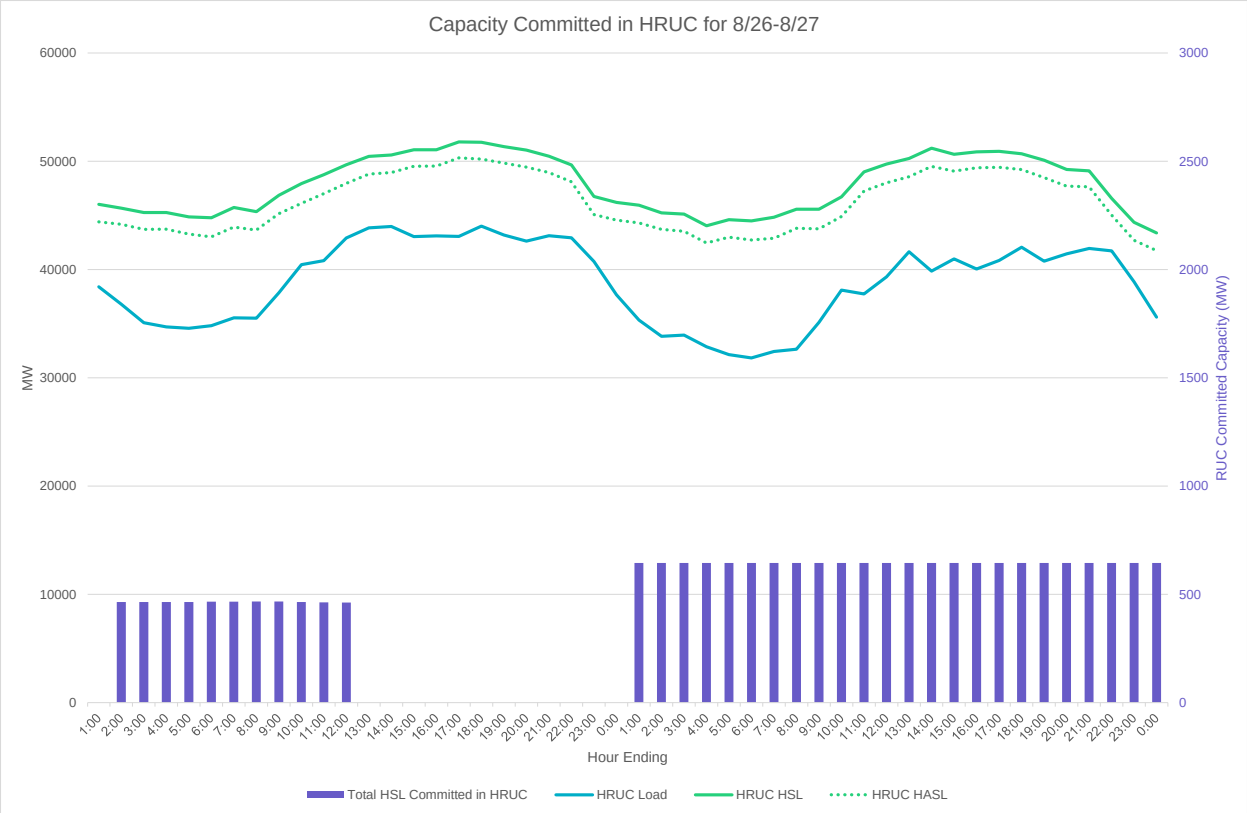


Figure 37: Capacity Committed in HRUC for 8/26-8/27

Supplementary Ancillary Service Markets (SASM)

A SASM was executed on Aug. 28 to replace a Responsive Reserve (RRS) obligation from HE5-HE14. Prices were $198/MWh for HE5-HE9 and $35/MWh for HE10-HE14. Non-controllable Load Resources were awarded until the 50% RRS limit was reached and the rest was awarded to three other resources.

SASM ID	AS TYPE	# Hours	AS Procurement Hours	Req Qty (MWh)	Award Qty (MWh)	Insufficiency (MWh)	MCPC ($/MWh)
8/28/2017 2:37	RRS	10	HE 5 - HE 14	217	214.8	2.2	35 to 198

Table 2: SASM

Load Resource availability and offers

The total amount of non-controllable Load Resources providing Responsive Reserve (RRS) across the ERCOT system fell by ~250 MW over the peak and ramping hours of the day while the off-peak hours saw a loss of over 400 MW when compared to normal levels before Hurricane Harvey made landfall on Aug. 25.

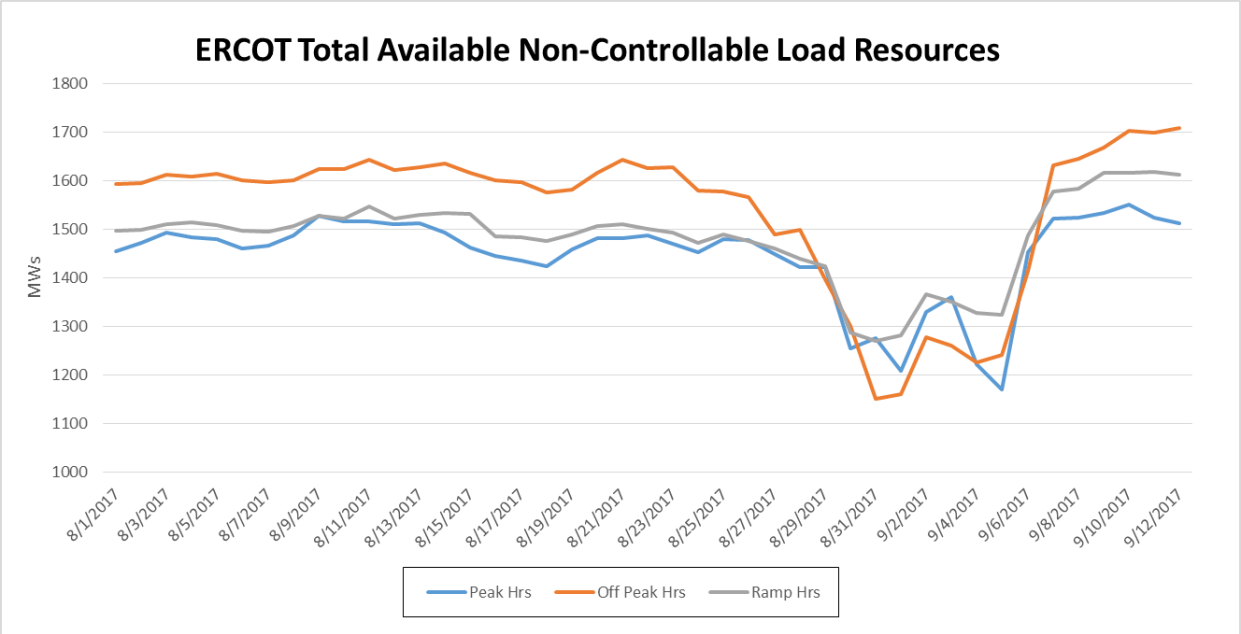


Figure 38: Daily average available MW of ERCOT wide non-controllable Load Resources grouped by Peak, Off Peak and Ramping Hours.

Hours	
Peak	14, 15, 16 ,17 ,18 ,19
Off-Peak	2, 3, 4, 5, 6, 7
Ramping	1, 8, 9, 10, 11, 12, 13, 20, 21, 22, 23, 24

Table 3: Hours system demand type breakdown as used in all graphs above

The loss of non-controllable Load Resources had a more concentrated effect on the Coast Weather Zone, which saw a sustained loss of ~500 MW.

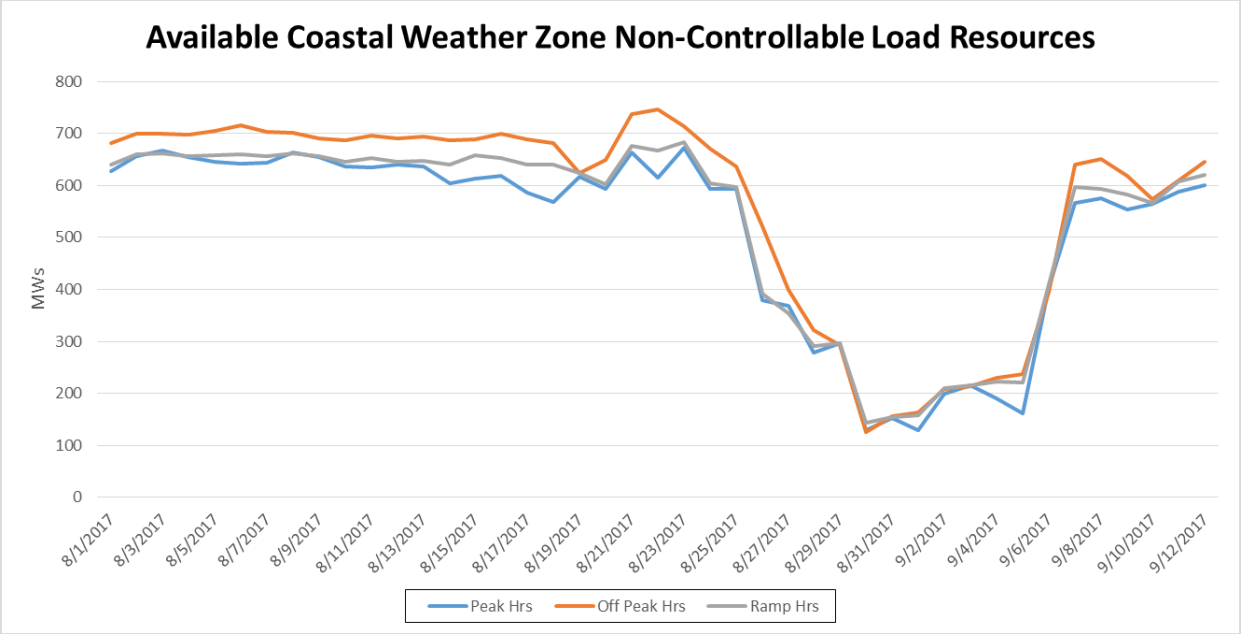


Figure 39: Daily average available MW of non-controllable Load Resources in the Coastal Weather Zone grouped by Peak, Off Peak and Ramping Hours.

In the months prior to the hurricane, about 50% of capacity offered to provide Responsive Reserve (RRS) from non-controllable Load Resources was actually procured to provide the service. Due to the unavailability of many of ERCOT's non-controllable Load Resources in the aftermath of the storm, this offer-to-award ratio was greatly reduced. Moreover, during peak hours from Aug. 30 through Sept. 5, all offers from this type of Resource were accepted with little to no proration for the service observed.

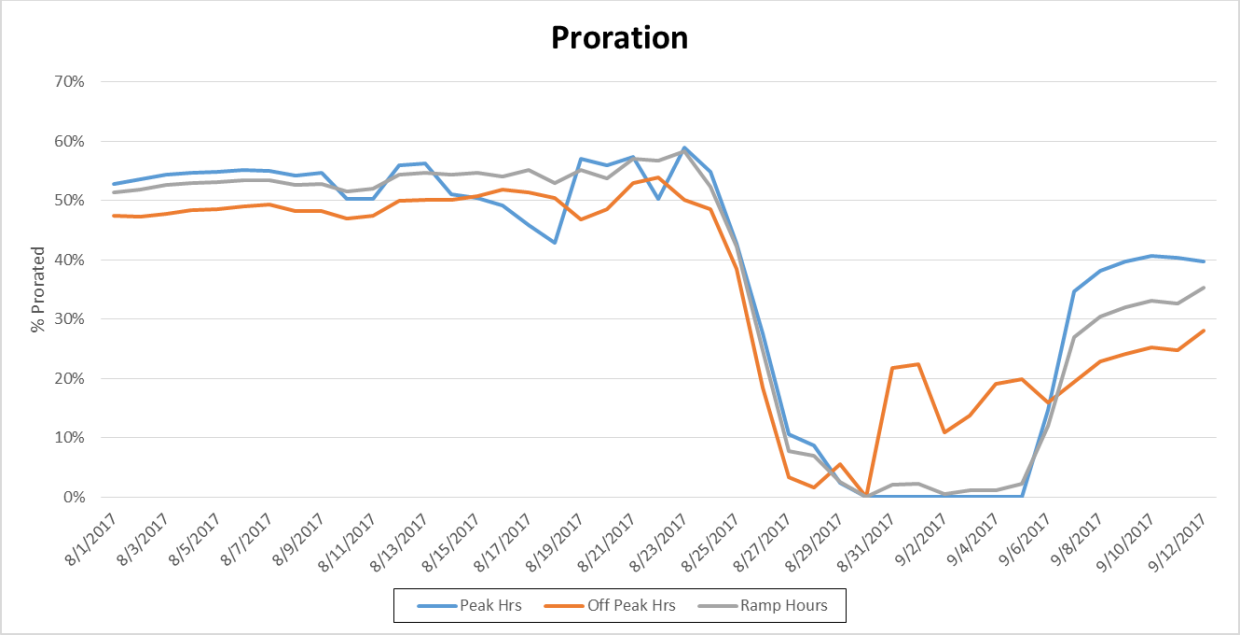


Figure 40: The daily average percentage of non-controllable Load Resource MW's not procured due to the offers exceeding the max allowed to participate grouped by Peak, Off Peak and Ramping Hours.

In addition, due to this reduction in available non-controllable Load Resources, the 50% limit on non-controllable Load Resources providing RRS was not reached. When this occurred, the resulting shortfall, as much as 439 MWs, was covered by other types of resources. That shortfall is depicted in the difference between the blue and black lines on figures 41 and 42.

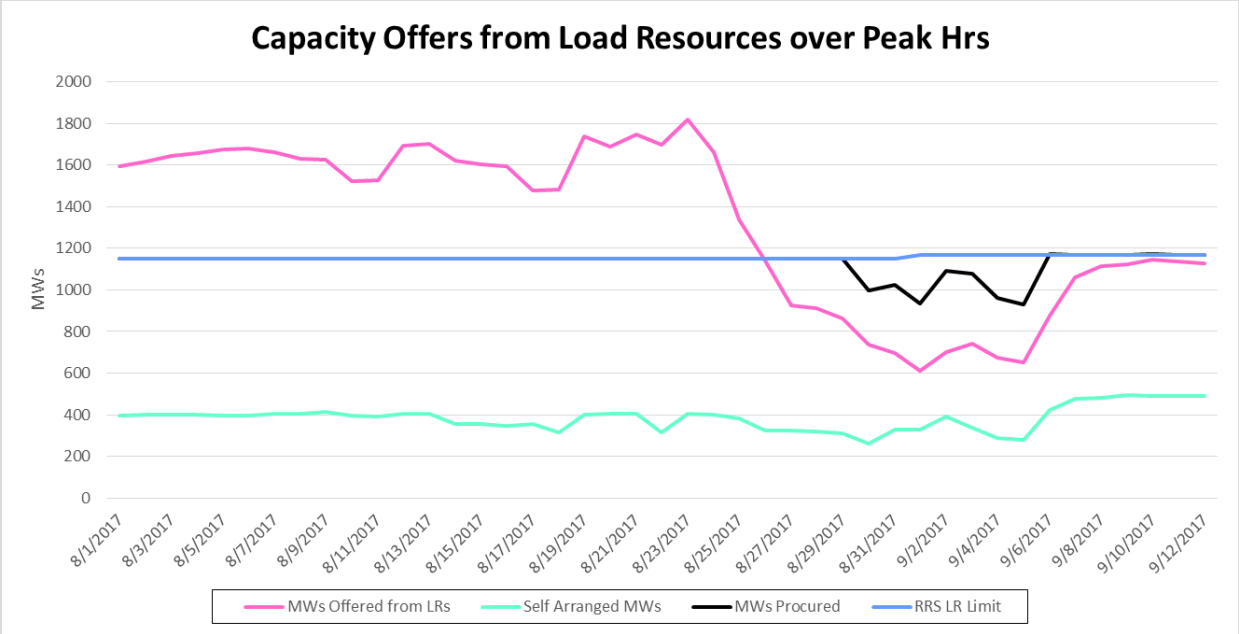


Figure 41: The daily average amount of non-controllable Load Resource MWs that were self-arranged or bid into the RRS market vs the maximum amount allowed to be procured from Non-Controllable Load Resources and the amount that was actually procured over peak demand.

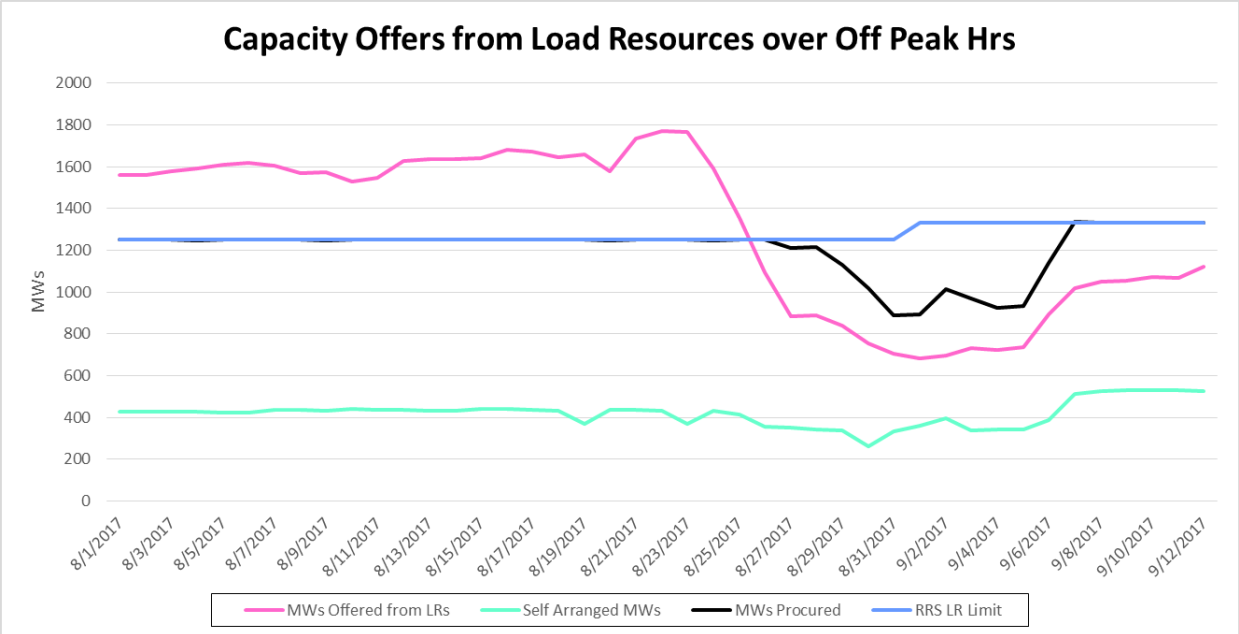


Figure 42: The daily average amount of non-controllable Load Resource MWs that were self-arranged or bid into the RRS market vs the maximum amount allowed to be procured from Load Resources and the amount that was actually procured over off-peak demand hours

Emergency Response Service (ERS) impacts

Approximately 2,300 out of 8,800 ERS participants were located in areas impacted by the hurricane. 350 of these had day-long service interruptions accounting for approximately 20 MW of ERS capacity reduction. The estimated premise-level reduction in load of ERS participants in the hurricane impacted areas was 80 MW starting on Aug. 25 and reaching a high of 200 MW on Aug. 29. The figure below provides an estimate of that reduction for all intervals during Aug. 29 but does not necessarily indicate a reduction in the MW of service available.

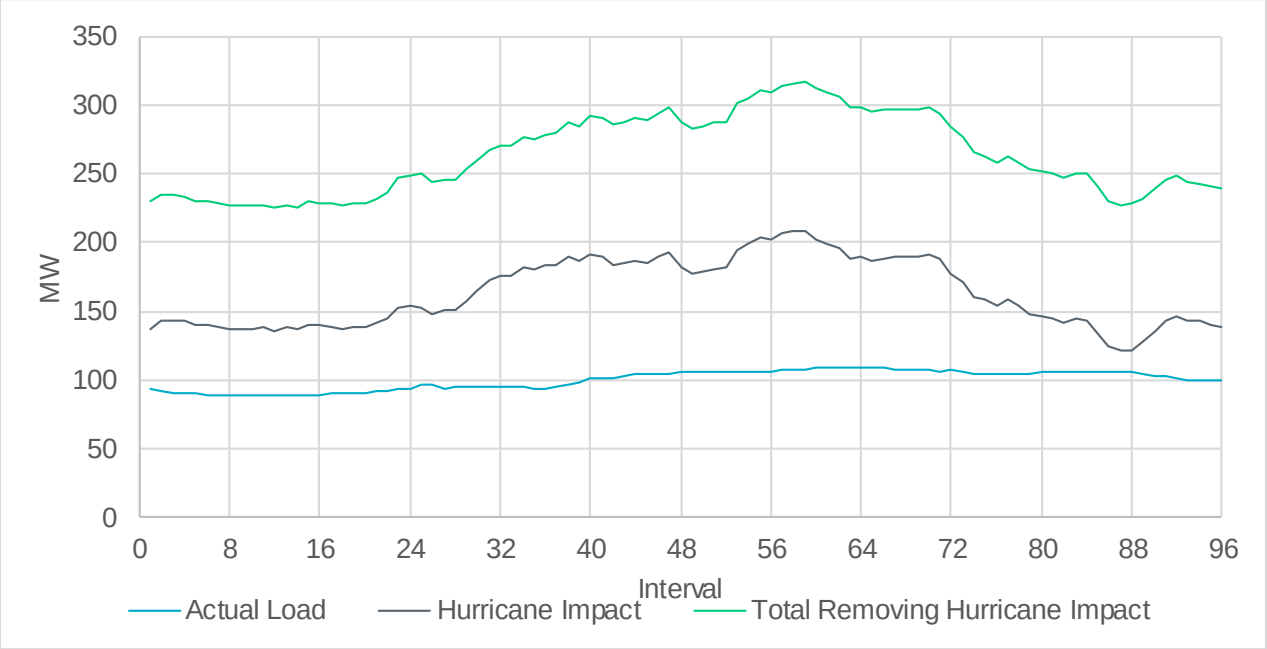


Figure 43: Estimated Premise-Level Load Reduction for ERS Participants in the Hurricane Effected Areas for August 29th, 2017

Meter reads

Below are some statistics regarding communication failures experienced in the aftermath of Harvey. As a baseline, communication failures for a typical operating day are generally less than 3%.

ERCOT worked with the Transmission and/or Distribution Service Providers (TDSPs) to provide data for settlements using the following strategies:

1. TDSP were able to gain access to site and retrieve actual meter data.
2. ERCOT identify telemetry representative of the line flows where the EPS meter is located to use as a proxy for the EPS Meter data.
3. Estimation utilized based on known conditions at a site, information with regards to specific outages provided by the TDSP or ERCOT Operations and/or historical information.

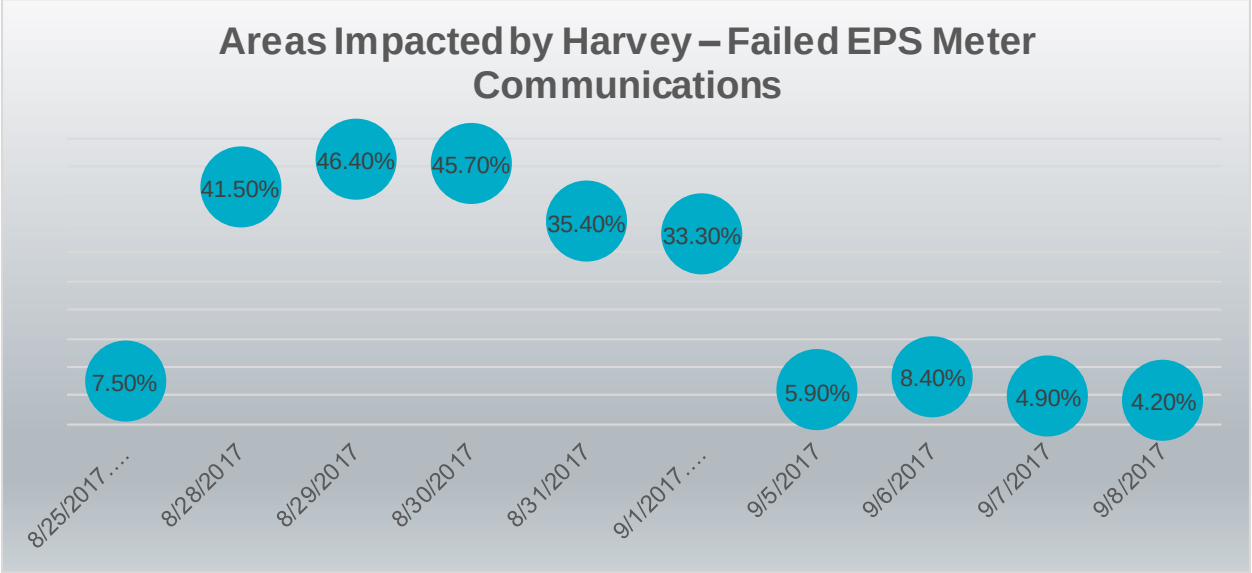


Figure 44: Failed EPS Meters in areas impacted by Harvey

8. CONCLUSIONS

ERCOT System Operators, in conjunction with resource operators (ROs) and Transmission Operators (TOs), prepared for, monitored and responded well to the historic Hurricane Harvey. The challenges of high winds, torrential rain, severe thunderstorms and historic flooding over a prolonged period of time were truly daunting. Ongoing training, tools, communications, awareness and advanced preparation all contributed to maintaining a reliable ERCOT system. Further enhancements should be explored to develop and enhance tools to monitor the system and severe weather in a cohesive fashion as well as allowing studies to screen for issues beyond the next contingency. Additionally, as System Operators, like ERCOT, are asked to maintain system security during events where conditions and topology can change rather quickly, the ability to validate forced outages in a near real-time environment should be explored.

9. LESSONS LEARNED

Positive observations

1. The Forced Outage Detection (FOD) application was instrumental in helping operators and support engineers identify undocumented outages which were not entered in the Outage Scheduler during the hurricane.
2. Grid Applications and Operations Support Engineers were able to utilize the State Estimator Statistical (SESTAT) application to quickly identify MW/MVar mismatches and topology issues from which validation of the system status for Qualified Scheduling Entities (QSEs) and Transmission Service Providers (TSPs) could be done.
3. Having on-site engineering support from the Advanced Network Analysis and Operations Support departments ensured quick evaluations of issues with ERCOT applications.

Issuance of regularly recurring updates in a pre-determined format to ERCOT management throughout the event to ensure efficient communications.

4. To aid in the development of the Next Day Study, which is performed to meet NERC IRO-008 Reliability Standard Requirements, Operations Support Engineering staff created an Excel spreadsheet that uses linkages to habCONNECT. This file pulls EMS study results into Excel and then evaluates potential options to mitigate base case and post-contingency overloads. This tool was leveraged for the Pre-Event System Assessments scenarios detailed in Section 6 of this report to identify potential mitigation measures for the constraints observed. This significantly lowered the amount of time needed to complete these assessments, and should be used as an example of innovative actions and great success.

Recommendations

1. Importing outages from Forced Outage Detection (FOD) application to future studies is needed
    - Real-time snapshot studies use the current network topology, but there is currently not a way to analyze a future system condition that uses the current topology. During significant weather events, Transmission Operators (TOs) typically have efforts directed at system restoration, and as such, updating outages in the Outage Scheduler may become a lower priority. Functionality should be considered within the Energy Management System (EMS) to import outages seen by the Forced Outage Detector (FOD) into an EMS savecase so that the real system topology can be evaluated for future hours during a severe event, if such functionality is feasible. This is an option that would only be used under circumstances where it is known that there are many outages that are not in the Outage Scheduler. Additionally, FOD could generate notifications to be sent to Market Participants to acknowledge and validate with default restoration times which could then be fed into the Outage Scheduler.

2. Future study conditions based on real-time load fractions is needed
    - Real-time snapshot studies use the current network topology, but there is no way to analyze a future system condition that uses the current topology. Specifically, during severe weather events when significant customer outages are being experienced, there should be functionality within the Energy Management System (EMS) to use the current load parent fractions from a real-time snapshot instead of the load parent fractions in the base case which are based on typical, all distribution load facilities in service. The latter can lead to an overestimation of load in areas that may have been evacuated, while underestimating load elsewhere. This functionality should allow load parent fractions to also be loaded into the Mid-Term Load Forecast (MTLF) application, and potentially into the Reliability Unit Commitment (RUC) application. This functionality would align future cases assessed during a weather emergency, such as a hurricane, to what would

be expected in future hours, resulting in more accurate system assessments during the weather emergency.

3. Communications “fact sheet” is beneficial for dissemination of Information
    - During the event, it was determined that updates needed to be provided to ERCOT Management and Corporate Communications staff on a regular interval, for issues such as trending customer outages, transmission outages and generation outages or de-rates, as well as any important information worthy of note. The established process for providing such regular reports during a Black Start event was modified to meet this need, but manual efforts were needed to catalog, organize and report as conditions changed. ERCOT needs to formalize the process for what information to collect and disseminate, as well as a defined interval for updating and issuing updated reports.
4. On-the-fly contingency definition change process needs improvement
    - During the event, due to the flooding, CenterPoint had to implement operational changes to their substations. These changes required modification to ERCOT’s contingency list for real-time and future study applications. Given that contingency definition changes are implemented through the Downstream Production Change process, it is difficult to implement changes during non-business hours when Network Modeling Staff is unavailable. To further complicate the issue, duplicative approval for Downstream Production Changes are required to satisfy various departments’ tracking processes, which creates confusion. Despite these difficulties, the associated contingency changes were accomplished. However, the “emergency” contingency definition change process should be improved to reduce roadblocks and prevent unnecessary paperwork.
5. Chief System Operator communication channel
    - During these extreme weather events, there should be a communication channel and/or conference bridge set up for Chief System Operators to facilitate communication for strategic and informative discussions, in addition to the normal communications that occur between System Operators. Currently these discussions occur in series and from point-to-point.
6. Wide area overview with weather overlay
    - ERCOT should accelerate the planned development of a geospatially correct, wide area view of the ERCOT transmission system with weather overlay to allow for System Operators to monitor radar, wind, lightning, severe weather watches/warning, etc. as it crosses the ERCOT system.
7. Enhance Wide Area Network (WAN) capabilities
    - ERCOT should review the Wide Area Network (WAN) routing between ERCOT and the Market Participants connected to the WAN to determine if there are improvements that can be made in diversification of WAN routing (e.g. using different PSTN) to minimize any potential single points of failure in Inter-Control Center Communication Protocol (ICCP) data availability.
8. Ad hoc real-time transient stability analysis

- ERCOT should accelerate the planned development of tools and processes to allow for ad hoc real-time transient stability analysis for issues (local or inter area) that could evolve during a significant weather event.

9. N-1-1 Automated Contingency Analysis capability
    - ERCOT should accelerate development of planned tool and processes to perform automated N-1-1 steady state contingency analysis to identify critical outages that would require atypical action to restore the ability to be N-1 secure following the outage.
10. Hurricane sensitivity as an input to Black Start unit selection process
    - ERCOT should factor in sensitivity to hurricanes as an input to Black Start selection process.
11. Market system Load Distribution Factors (LDFs)
    - ERCOT should look for opportunities to improve the LDFs used in the market system during similar events.
12. Event Analysis reporting tool
    - ERCOT should continue to pursue the Event Analysis reporting tool project and try to incorporate analysis from this report as part of its requirements. It would be ideal that any real-time reporting built for real-time communication of event information is aligned with the Event Analysis reporting tool.

Appendix A: Pictures of Damage

AEP – STP to Whitepoint 345 kV circuit damage

Transmission repair work

Distribution damage


Damage to Rockport, Texas


CenterPoint Energy Mobile Sub