Estimating Damage to Electric Power Distribution Caused by Hurricanes using the Hurricane Electrical Assessment Damage Outage Tool (HEADOUT)

Prepared by

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for

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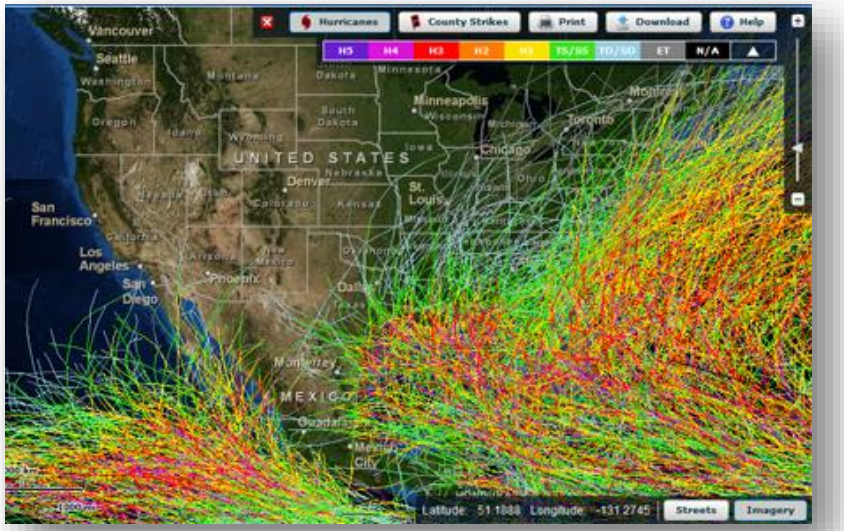
U.S. DEPARTMENT OF ENERGY

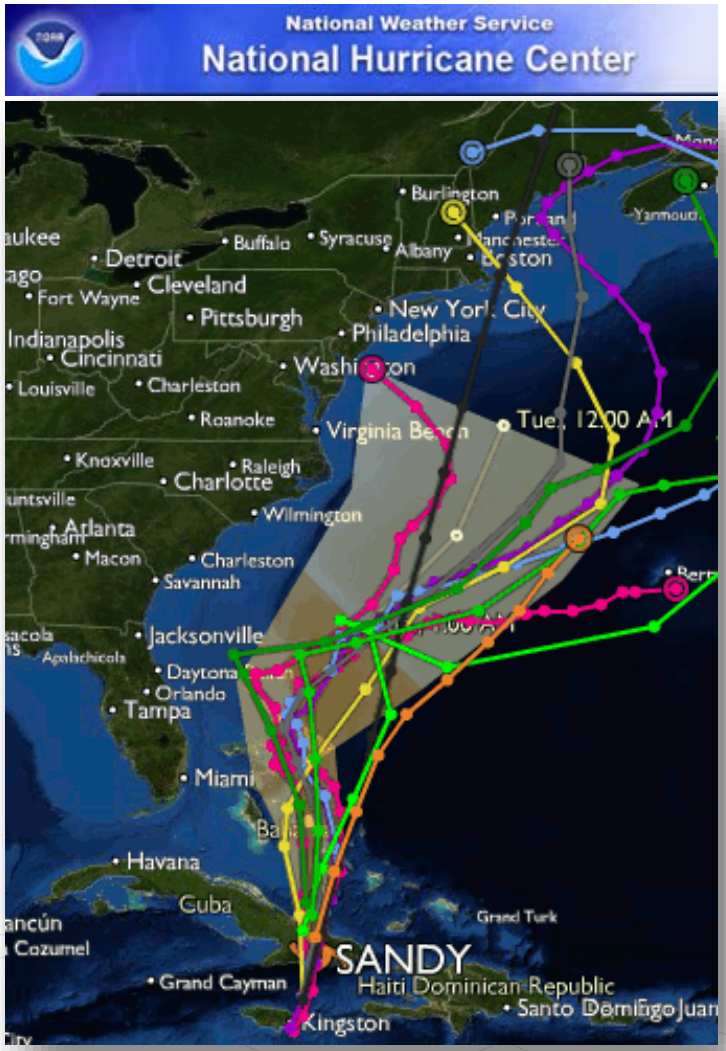
Background - Hurricane Tool

- All Atlantic and Gulf of Mexico coastal areas are subject to tropical cyclone/hurricanes.
- The Atlantic hurricane season lasts from June to November, with the peak season from mid-August to late September.

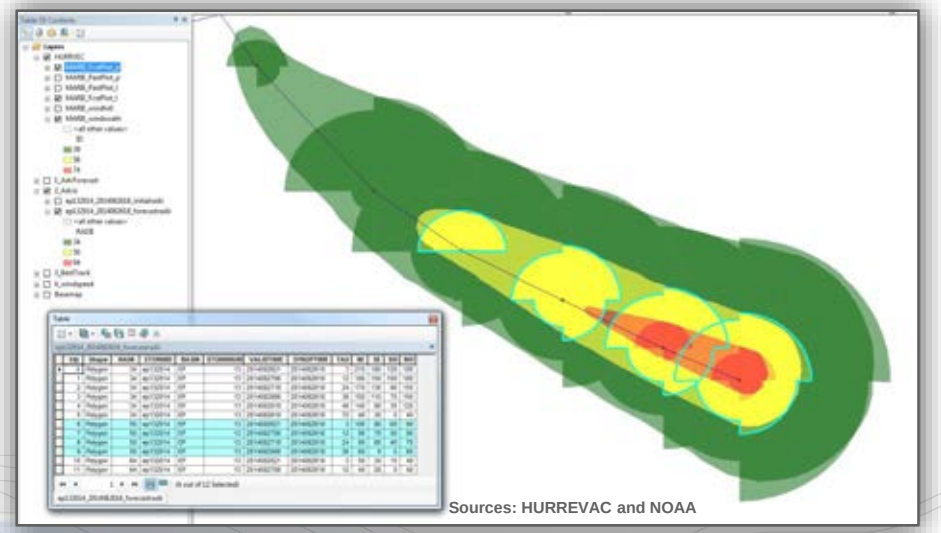


- Quick turn around tool for Federal Agencies.
- Emergency Response and Deployment of Resources
- Speed and Accuracy of Analysis is Important
- Restoration time NOT explicitly considered

Background - Hurricane Tool



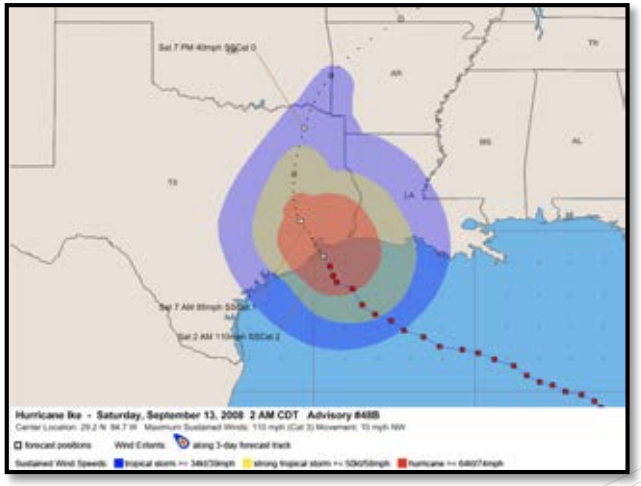
- The National Hurricane Center (NHC) monitors tropical cyclones
- Forecast/Advisories are issued on all Atlantic and eastern Pacific tropical and subtropical cyclones every six hours
  - *Dataset for storm tracks in shapefile and kml/kmz formats*
- HURREVAC creates 72-hour wind swath based on NHCs Advisory Wind Fields



Sources: HURREVAC and NOAA

Methods – Wind Damage & Electric Losses

- **Collect data from NOAA Advisory through HURREVAC as Tropical Cyclone makes landfall**
  - ***Maximum gust wind speeds, track and 72-hour wind swath (74, 58, and 39 mph)***
- **Apply contouring method developed to estimate wind speeds by interpolating :**
  - ***Spatial analyst tool provides a continuous surface for which wind contours are created using the HURREVAC wind swath data. Contours are created from this raster file.***
  - ***Apply fragility curve to produce damage fraction as a function of wind speed.***
- **Overlay wind speed swaths over Census population data:**
  - ***Estimate number of people per wind swath***
  - ***Determine as a function of State***
  - ***Determine households at-risk of electric outage by multiplying number of people in each swath by damage fraction***



Methods - Wind Damage Flow Diagram

Part 1

Gather Data

NOAA's National Hurricane Center (NHC) / HURRVEC

- 72-hour projected path
- 3 Intervals: 74, 58, 39 mph
- Max. center wind speed

Interpolate

Continuous Surface

- Natural neighbor technique

Contours

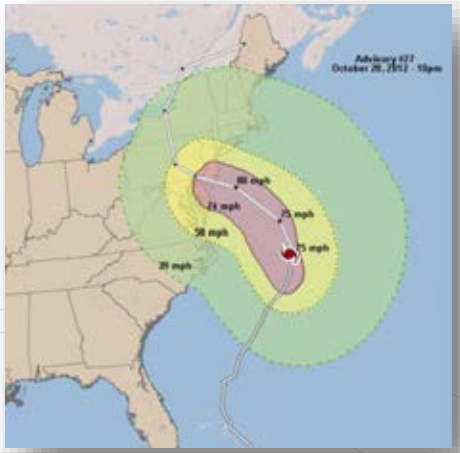
User-Defined Intervals

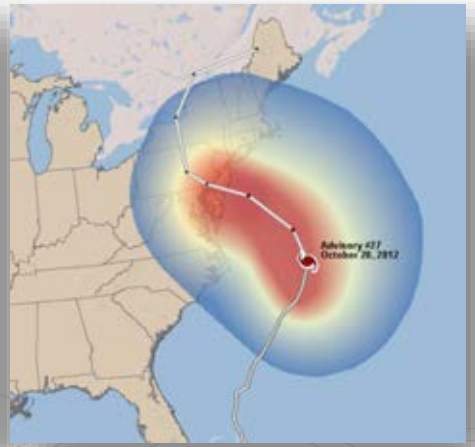
- Intervals of wind speed
- Smooth contour lines

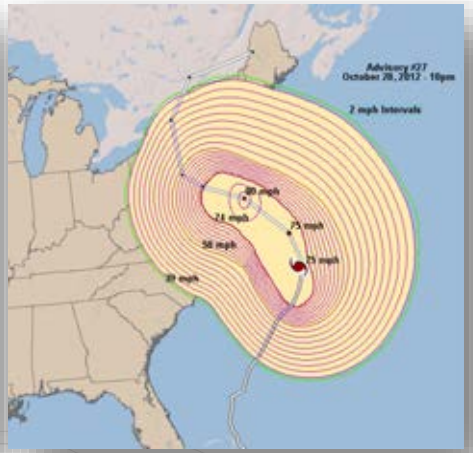
Apply Fragility Curve

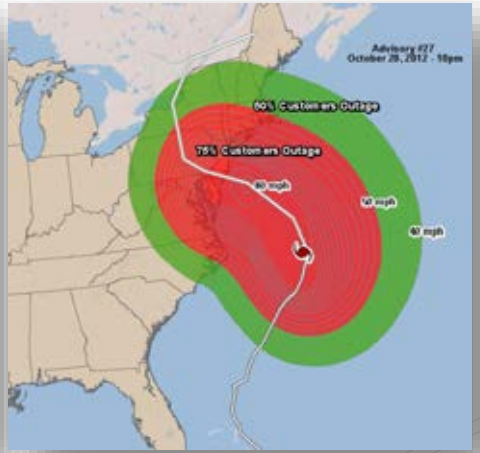
Pre-defined Tables

- Join to fragility curves









Methods - Estimate Customers Affected

Part 2

Select Census Tract Data

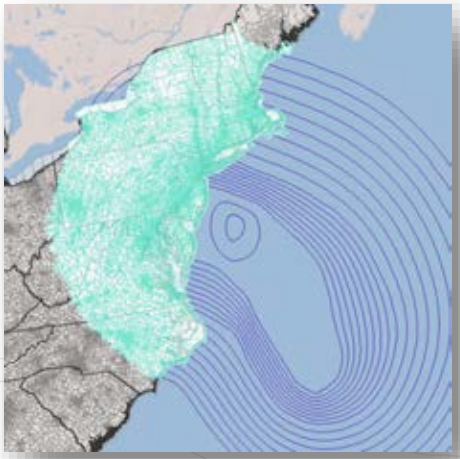
- Census Tracts shapefiles contain pre-populated information using 2010 Census data

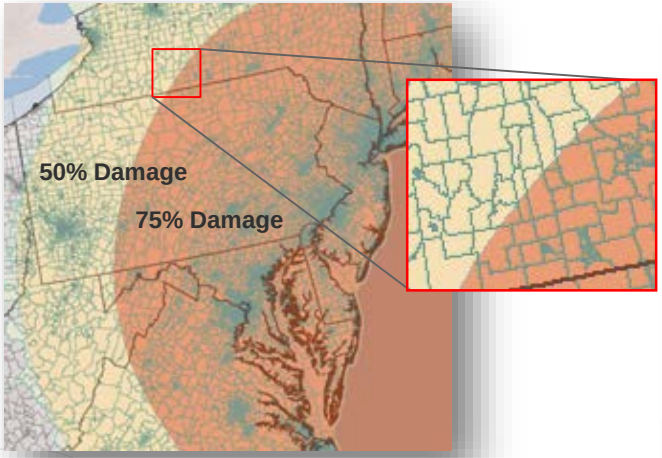
Split based on Damage Curve

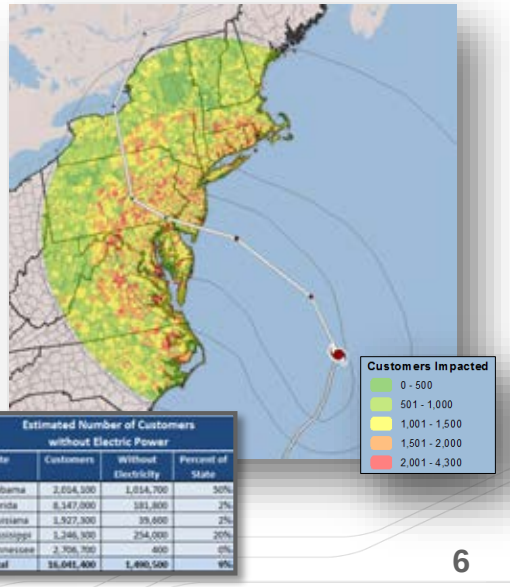
- Create feature class for census tracts that intersect contours
- Assume dispersed distribution of customers through census tract

Calculate Households Impacted

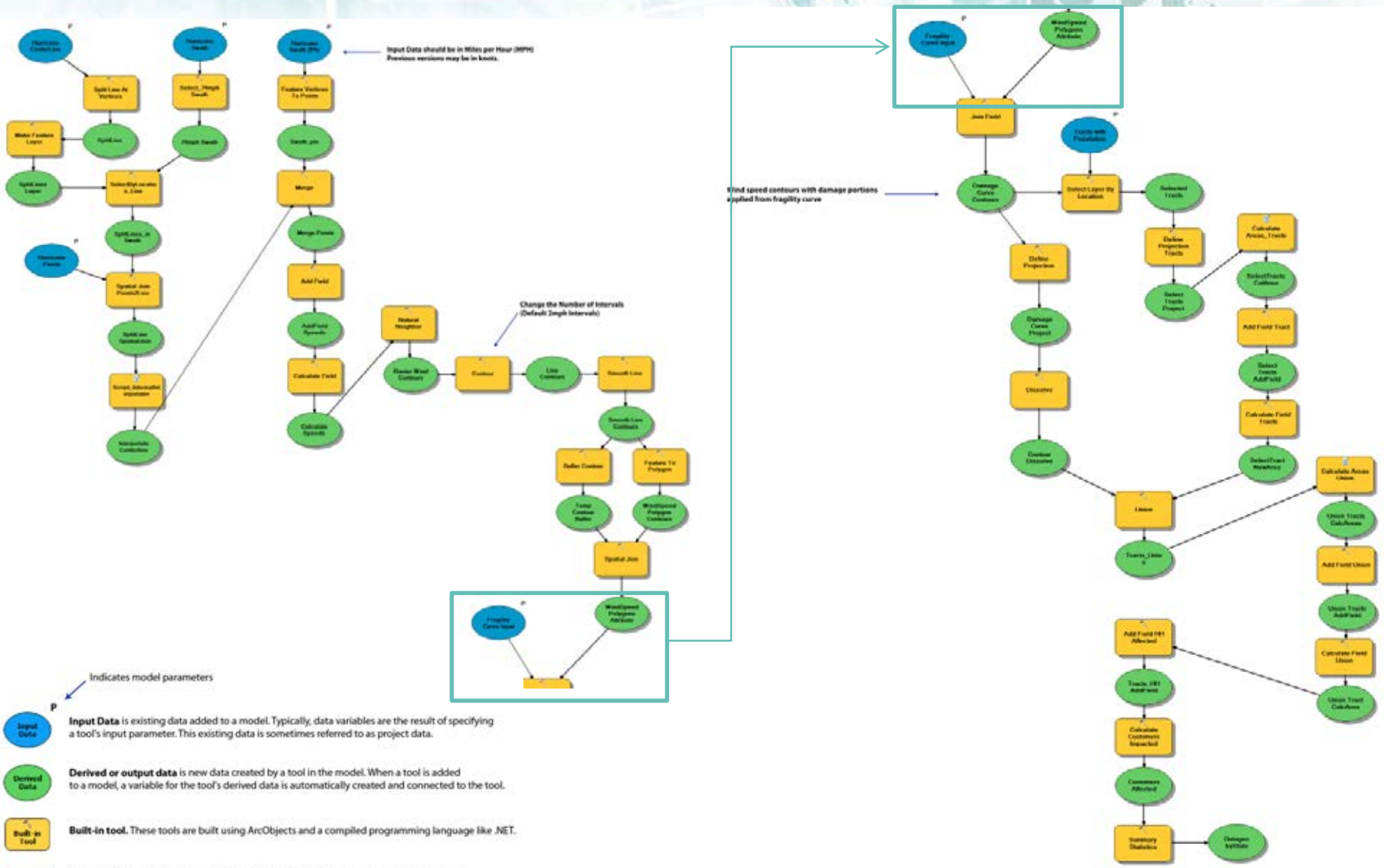
- Estimated Electric Customers without Power = ((New Area / Tract Area) * Number of Households) * Percent Damage





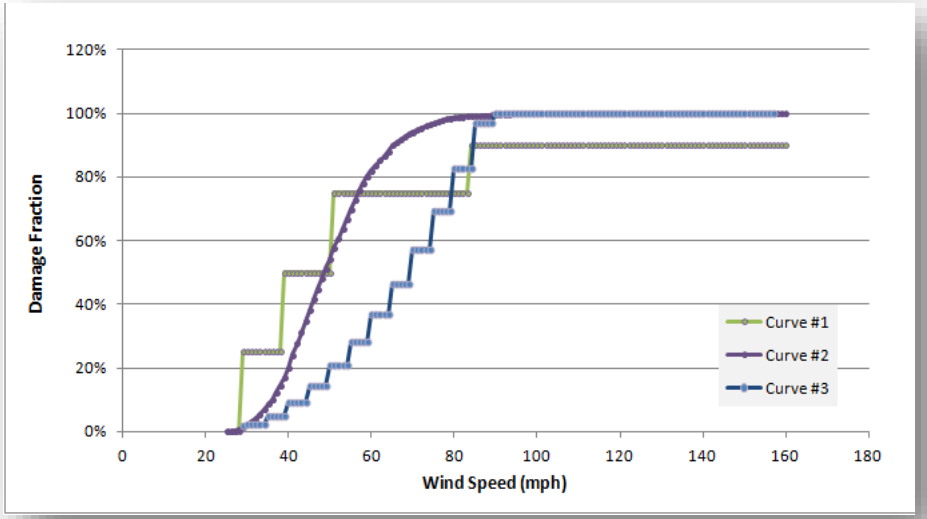


Model Schematic



Fragility Functions/Curves

- **Fragility curves are the cumulative distribution function of the capacity of the asset to resist a particular undesirable event. Curves developed are the damage fraction of customers impacted by wind speed.**



- **Development of fragility curves:**
  - ***Curve #1 – Commonly Used Curve; Five damage fractions applied***
  - ***Curve #2 – ANL Developed Fragility Curve; Interpolation of five damage fractions***
  - ***Curve #3 – ANL Developed; Based on data showing county level impacts***

Testing Fragility Curves

- **Testing Fragility Curves using data from DOE Situational Reports (SitReps):**
  - ***DOE Situation Reports available for 21 tropical cyclones, dating back to 2003.***
  - ***17 of those 21 events made landfall and contained usable data.***
- **NOAA Advisories for the tropical cyclone as it made landfall are compared to the SitReps**
  - ***Delay times for utilities to report the affects were taking into account***

Historical Tropical Cyclones Tested Using DOE Situational Reports

Storm	Year	Processed	Region	Area	Landfall State	Advisory	Data	Time (EDT)
Karen	2013	N/A	Gulf Coast	Alabama	*Louisiana	N/A	N/A	N/A
Sandy	2012	Yes (3)	Atlantic	New Jersey / New York	New Jersey	31	10/29/2012	11PM
Isaac	2012	Yes (3)	Gulf Coast	Louisiana	Louisiana/Mississippi	32	8/28/2012	11PM
Irene	2011	Yes (1)	Atlantic	Atlantic Coast	North Carolina	28A	8/27/2011	8AM
Alex	2010	Yes (1)	Gulf Coast	Southern Texas	Mexico	22	6/30/2011	11PM
Earl	2010	N/A	Atlantic	Atlantic Coast	N/A	N/A	N/A	N/A
Dolly	2008	Yes (3)	Gulf Coast	Southern Texas	Southern Texas	13A	7/23/2008	3AM
Edouard	2008	Yes (1)	Gulf Coast	Texas	Texas	8	8/5/2008	5AM
Gustav	2008	Yes (3)	Gulf Coast	Louisiana	Louisiana	32	10/1/2008	11AM
Hanna	2008	Yes (1)	Atlantic	Atlantic Coast - NC/SC	North/South Carolinas	37A	9/6/2008	2PM
Ike	2008	Yes (3)	Gulf Coast	Texas	Texas (Houston Area)	48B	9/13/2008	3AM
Dennis	2005	Yes (1)	Gulf Coast	Alabama	Florida/Alabama	25B	7/10/2005	3PM
Katrina	2005	Yes (1)	Gulf Coast	E. Louisiana	E. Louisiana	26B	8/29/2005	9AM
Ophelia	2005	N/A	Atlantic	Atlantic Coast	N/A	N/A	N/A	N/A
Rita	2005	Yes (1)	Gulf Coast	W. Louisiana / E. Texas	East Texas	26B	9/24/2005	3AM
Wilma	2005	Yes (1)	Florida	Florida	Florida	36A	10/24/2005	7AM
Charley	2004	Yes (1)	Florida / Atlantic	Florida / Atlantic Coast	Florida	19	8/13/2004	5PM
Frances	2004	Yes (1)	Florida	Florida	W. Florida	45A	9/5/2004	1PM
Ivan	2004	Yes (1)	Gulf Coast	Alabama	Alabama	55B	9/16/2004	3AM
Jeanne	2004	Yes (1)	Florida	Florida	E. Florida	50	9/25/2004	11PM
Isabel	2003	Yes (1)	Atlantic	North Carolina	North Carolina	50A	9/18/2003	1PM

Notes: (3) All three fragility curves were tested; (1) Only Walker Fragility Curve was tested; N/A - Storm did not make landfall

- **All three fragility curves were tested for the following events:**
  - ***Isaac 2012 (Louisiana)***
  - ***Sandy 2012 (New Jersey / New York)***
  - ***Ike 2008 (Texas)***
  - ***Dolly 2008 (Texas)***
  - ***Gustav 2008 (Louisiana)***

Results: Comparing 3 Curves

- **Curve #1 and #2 are more than double the number of reported customers impacted in three of the five cases.**
- **Curve #3 is the most accurate and therefore tested for the remaining cases.**

Examining Results by State

- **DOE Situational Report states, "combined total peak customer electricity outages from Hurricane Sandy was 8,511,251."**
  - ***Timing of reporting is not exact***
- **Curve #3 is most consistent with SitReport**
  - ***Inconsistencies at a state level, however, there may be discrepancies in reporting if utilities are multi-state***

Comparison of Three Fragility Curves

Storm	Year	Region	Landfall State	Curve #1	Curve #2	Curve #3	DOE Situational
Sandy	2012	Atlantic	New Jersey	19,985,731	20,591,201	8,940,233	**8,369,651**
Isaac	2012	Gulf Coast	Louisiana/Mississippi	1,371,874	1,442,131	713,664	**714,928**
Dolly	2008	Gulf Coast	Southern Texas	413,393	473,093	258,717	**209,332**
Gustav	2008	Gulf Coast	Louisiana	1,568,384	1,712,483	1,045,573	**1,128,181**
Ike	2008	Gulf Coast	Texas (Houston Area)	3,327,432	3,520,263	2,739,580	**2,825,082**

HURRICANE SANDY - Advisory #31 (Oct. 29, 2012 - 11 PM EDT)

State	Curve #1	Curve #2	Curve #3	SitReport #4 10/30/12 - 10am EDT
Connecticut	1,028,315	1,083,508	433,793	626,559
Delaware	256,723	326,077	193,759	45,137
District of Columbia	-	-	-	3,583
Maine	203,551	148,290	46,378	90,727
Maryland	1,609,881	1,734,845	709,583	311,020
Massachusetts	1,696,823	1,531,012	541,481	298,072
New Hampshire	269,473	267,286	93,733	141,992
New Jersey	2,410,770	2,991,750	1,634,969	2,615,291
New York	5,068,673	5,561,174	2,507,202	2,097,933
North Carolina	1,101,492	768,808	239,014	15,466
Ohio	198,660	114,988	36,156	267,232
Pennsylvania	3,383,101	3,630,654	1,683,888	1,267,512
Rhode Island	310,200	276,627	86,736	116,592
Vermont	136,083	111,899	36,089	17,959
Virginia	2,020,973	1,827,450	628,440	182,811
West Virginia	291,013	216,832	69,012	271,765
Total	**19,985,731**	**20,591,201**	**8,940,233**	**8,369,651**

Source: Number of Retail Customers by State by Sector (EIA-861)

Hurricane Sandy Situational Report #4: http://www.oe.netl.doe.gov/named_event.aspx?ID=67

Results: Fragility Curve #3

- **Curve #3 was tested for 17 of those 21 events where SitReports were available**
  - *Nine Gulf Coast storms,*
  - *Four Atlantic Coastal; and*
  - *Four impacting the State of Florida.*

- **Three of the four Florida cases, produced accurate results**
  - *Simulation for Jeanne (2004) overestimated the outages. However, portions of Florida were affected by Hurricane Ivan only nine days prior.*

Results of Customer Outages for Historical Tropical Cyclones using Curve #3

Storm	Year	Region	Landfall State	Curve #3	DOE Situational Report	Difference
Karen	2013	Gulf Coast	N/A	N/A	N/A	N/A
Sandy	2012	Atlantic	New Jersey	8,940,233	8,369,651	0.07
Isaac	2012	Gulf Coast	Louisiana/Mississippi	713,664	714,928	(0.00)
Irene	2011	Atlantic	North Carolina	10,807,394	6,690,907	0.62
Alex	2010	Gulf Coast	Mexico	N/A	N/A	N/A
Earl	2010	Atlantic	N/A	N/A	N/A	N/A
Dolly	2008	Gulf Coast	Southern Texas	258,717	209,332	0.24
Edouard	2008	Gulf Coast	Texas	474,789	303,000	0.57
Gustav	2008	Gulf Coast	Louisiana	1,045,573	1,128,181	(0.07)
Hanna	2008	Atlantic	North/South Carolinas	638,652	470,000	0.36
Ike	2008	Gulf Coast	Texas (Houston Area)	2,739,580	2,825,082	(0.03)
Dennis	2005	Gulf Coast	Florida/Alabama	751,893	682,703	0.10
Katrina	2005	Gulf Coast	E. Louisiana	1,779,786	2,567,666	(0.31)
Ophelia	2005	Atlantic	N/A	N/A	N/A	N/A
Rita	2005	Gulf Coast	East Texas	922,894	1,139,425	(0.19)
Wilma	2005	Florida	Florida	3,468,804	3,251,227	0.07
Charley	2004	Florida / Atlantic	Florida	2,232,211	2,177,000	0.03
Frances	2004	Florida	W. Florida	3,312,062	3,880,000	(0.15)
Ivan	2004	Gulf Coast	Alabama	1,400,662	1,475,301	(0.05)
Jeanne	2004	Florida	E. Florida	3,743,117	2,738,000	0.37
Isabel	2003	Atlantic	North Carolina	3,559,443	3,752,480	(0.05)

Notes: N/A - Storm did not make landfall

- **Largest discrepancy produced for Irene, partially due to variances in the NOAA forecast.**
  - *The intensity decreased as Irene moved up along the Atlantic Coast—sustaining max wind speeds of 75 mph opposed to the 90 mph wind projections.*

Discussion

Numerical Results:

- Projected results using Curve #1 and #2 are very poor relative to the DOE Situation Reports
- Each storm is unique with each being viewed as a case study
  - ***As seen with Jeanne (2004) and Irene (2012)***
- Discrepancies between the reported and simulated numbers can occur
  - ***Utilities estimate the number of outages based on customer phone calls and physical inspection***
  - ***Numbers may not be reported to DOE/OE in an accurate or punctual manner.***

Model Outcome:

- A benefit of this tool is that the damage curves can be easily modified.
  - ***Provides ability for empirical analysis to test fragility curves***
- Produces results quickly and can be recreated.
  - ***On average, it takes 5 minutes to run, down from 4 hours***
- Documentation of steps means consistency so that multiple users can perform the same work.
- Results are reproducible

Future Developments

- **Automation**
  - *Save files directly from NOAA to minimize user interaction with tool*
- **Refined fragility curve**
  - *Examine the impacts by county and utilities where data is available*
  - *Test and refine results for different regions in the U.S. if necessary*
- **Determine key factors that may influence damage by area**
  - *Whether utilities maintain underground distribution lines*
  - *Implementation of Hardening / Design Standards*
  - *Vegetation*

Limitations and Recommendations

- **Electrical distribution details are not available.**
  - ***Data is proprietary and typically closely held by the utility owners.***
  - ***Above verses underground, wooden verses metal poles, etc.***
- **Estimate customers base on household information. Does not include information on the number of commercial and/or industrial customers.**
  - ***Examine impacts by utilities***
- **Hardening practices vary on a utility-by-utility basis.**
  - ***May have to develop multiple generic fragility curves based on hardening practices for a region.***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Home > FPL to strengthen Florida's electric grid in preparation for hurricanes

FPL to strengthen Florida's electric grid in preparation for hurricanes

05/02/2013
By Editors of Electric Light & Power/ POWERGRID International

Sponsored by

As part of its annual company-wide hurricane season preparedness drill, Florida Power & Light Co. announced a three-year plan to continue and accelerate the strengthening of its electric system against high winds associated with hurricanes and other major weather events.

FPL expects to invest about half a billion dollars over the next three years to continue to improve the overall resiliency of the electric system for customers.

The plan builds on the utility's storm hardening initiative by incorporating additional lessons learned from Superstorm Sandy, such as those related to flooding, as well as from Florida storm activity in 2012.

These recent experiences show that electric infrastructure that has been strengthened performs better in preventing some storm-related outages, speeding restoration times following severe weather and delivering better overall everyday reliability.

The accelerated hardening effort will translate both into faster outage restoration during major storms and improved everyday reliability for customers. FPL's experience with the recent tropical storms shows main power lines that have been hardened are roughly half as likely to experience an outage during severe weather. In addition, under normal weather conditions, hardening a power line reduces the frequency of daily outages by up to 40 percent.

Source: http://www.elp.com/articles/2013/05/fpl-to-strengthen-florida-s-electric-grid-in-preparation-for-hur.html

References and Acknowledgements

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- **Acknowledgements**

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Questions or Comments?
Thank you!