Lights Out?

Storm Surge, Blackouts, and How Clean Energy Can Help

www.ucsusa.org/lightsout

Appendix: Technical Document

Union of Concerned Scientists

This document details the methods and data used in the Union of Concerned Scientists (UCS) analysis *Lights Out? Storm Surge, Blackouts, and How Clean Energy Can Help.* The full report and additional site-specific maps can be found online at *www.ucsusa.org/lightsout*.

The *Lights Out* analysis looks at the vulnerabilities of the electric grid to coastal flooding from storm surge and sea level rise, and the impacts on communities from the widespread outages that can result. The report also discusses solutions to this serious and worsening threat in the form of improved policies and planning, structural adaptation opportunities, and the integration of clean, resilient energy resources that can keep critical facilities powered up even when severe weather strikes. To support this evaluation, the report presents five site-specific analyses of electricity infrastructure in major metropolitan regions along the East and Gulf Coasts. This technical document focuses on the data used and procedures followed for the site-specific mapping.

Methods used in this report draw from the best practices established by the National Oceanographic and Atmospheric Administration (NOAA) Coastal Services Center, as described in its Mapping Coastal Inundation Primer (Coastal Services Center 2012). The report also builds on a growing suite of UCS analyses relating to coastal flooding and sea level rise including *Encroaching Tides: How Sea Level Rise and Tidal Flooding Threaten U.S. East and Gulf Coast Communities over the Next 30 Years* (October 2014) and *Stormy Seas, Rising Risks: What Investors Should Know About Climate Change Impacts at Oil Refineries* (February 2015).

Data Sources

For each site analyzed, mapped electricity infrastructure included power-generating plants and major electric substations. All substation data drew from the Platts Electric Substation geospatial data layer, representing transmission, sub-transmission, and some distribution substations in North America (Platts 2015). The dataset does not include the many smaller, lower-voltage substations used to convey electricity on the final leg of its journey to most end users. The Platts data are provided as point features, and include information—when available—on substation name, company ownership, voltage of largest connecting transmission line, total number of connecting transmission circuits, and distance within which position was verified.

Data on power-generating plants were drawn from SNL Financial (SNL 2015). For each power-generating unit, we tracked latitude and longitude, primary fuel type, operating status (only those listed as “operating” in 2014 were mapped in the analysis), net generation in 2014, and capacity data (for consistency, nameplate capacity is referenced throughout the report). Plants retired prior to 2014, and plants installed after 2014, were not mapped in this analysis.

For each region analyzed, we applied localized sea level rise projections for the years 2030, 2050, and 2070 (Climate Central n.d.). Methods used for generating these localized values are detailed in the Sea Level Rise Projections section below. We further modeled storm surge scenarios in each region based on the National Weather Service Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model’s maximum of maximums and high-resolution (1/3 arc second or finer) digital elevation models from the U.S. Geological Survey’s (USGS’s) National Elevation Dataset and NOAA’s Sea Level Rise and Coastal Impacts Viewer (NOAA Digital Coast 2015).

Local Sea Level Rise Projections

The most recent U.S. National Climate Assessment produced four global sea level rise projections (Walsh et al. 2014; Parris et al. 2012). We have chosen the mid-range Intermediate-High scenario from the National Climate Assessment as the basis for sea level rise projections in this study. This scenario represents the average of the high end of semi-empirical models that use observed data to extrapolate into the future (Jevrejeva, Moore, and Grinsted 2010; Vermeer and Rahmstorf 2009; Horton et al. 2008). In this scenario, ice loss increases throughout the twenty-first century and comes to dominate total sea level rise.

In addition, the projections we used include a local component of the sea level rise developed by Tebaldi, Strauss, and Zervas (2012) and obtained from Climate Central (Climate Central n.d.). Using the global Intermediate-High scenario as a basis, Climate Central has calculated a localized sea level projection for a suite of U.S. tide gauges on a decade-by-decade basis through 2100 (Climate Central n.d.). These projections build on the group's earlier, published work using a different global sea level rise projection (Tebaldi, Strauss, and Zervas 2012). To generate local projections, Climate Central has evaluated the historical rate of sea level rise at each gauge and separated out a local component (i.e., the difference between the global average rate and the rate at that gauge). They then add that local component (keeping it steady) to a global sea level rise projection to calculate a gauge-specific sea level rise projection. We have used the nearest available projection from Climate Central for each area analyzed in this study (Table A1).

TABLE A1. **Localized Sea Level Rise Projections**

Metropolitan Area	Tide Gauge Used for Sea Level Rise Projection	Sea Level Rise (feet)		
		2030	2050	2070
Delaware Valley	Reedy Point, DE	0.5	1.3	2.3
Southeastern Virginia	Sewells Point, VA	0.6	1.4	2.3
South Carolina Lowcountry	Charleston, SC	0.4	1.1	2.1
Southeastern Florida	Vaca Key, FL	0.5	1.2	2.1
Central Gulf Coast	Grand Isle, LA	0.8	1.9	3.2

Information specific to each site's nearest tide gauge was used to model local sea level rise projections. The five sites range in terms of projected rate and magnitude of sea level rise over the period of the analysis.

SOURCE: CLIMATE CENTRAL N.D.

Storm Surge Modeling

Inundation from storm surge was calculated using the SLOSH model's maximum of maximums (MOMs) at Gulf and East Coast sites. MOM data for each relevant SLOSH basin used were relative to the vertical datum NAVD88.

Using ArcGIS, we converted the MOM data files to raster format, removed the null values, and resampled to match the resolution of the digital elevation model (DEM) used for each area. We then extended the surge surface inland using the Focal Statistics tool such that future sea level rise would allow the surge to extend farther inland over areas that, in the present-day MOM files, have zero surge depth. Moreover, this technique minimizes distortions in the data that can be introduced by the more commonly used interpolation tools, such as splining.

The results of the Focal Statistics analysis are most reliable along the margins of the original MOM data set and become less so as one moves away from the original data. To ensure that the data we model based on the Focal Statistics analysis are of reasonable quality, we examined the results carefully, particularly within the "newly inundated" zone when sea level rise was incorporated, and compared them to the original MOM data. In addition, we verified that the present-day surge modeled using the Focal Statistics analysis matched the extent originally provided by the MOMs. With the exception of the Miami metropolitan area, our modeled surge extent for the present day matched the original MOM extent very well. In Miami, our modeled extent was greater than that originally modeled by the MOM. In this case, we suspect that differences in the DEMs underlying our analysis and NOAA's SLOSH analysis are driving the differences in the modeled extents.

After modeling each storm surge surface, we subtracted the DEM for all locations where the surge height exceeded the elevation of the site. To ensure that areas shown as inundated by this procedure were, ultimately, connected to the ocean, we assessed hydrologic connectivity using the Region Group and Extraction tools. Flooded areas were converted to polygons for vector graphics.

Electric Grid Infrastructure Exposure

To determine if a specific piece of electricity infrastructure could be exposed to flooding from a modeled scenario, we tested whether or not a component's point coordinates placed it fully within a mapped inundation area. If a component fell within an inundation area, it was marked as "exposed." If it did not, it remained "unexposed." This process was repeated for each time period and storm scenario. Importantly, the "exposed" label does not mean that a piece of infrastructure would definitively face flooding should a storm of given strength strike; instead, it indicates that the infrastructure's location has the *potential* to experience flooding.

In the maps displaying extent of inundation over time, an electricity infrastructure component was marked as "exposed" if at any time over the 2012 to 2070 window it was in the path of flooding. The number of components exposed per time period is shown in Table A2. And, while components were simply marked "exposed" in the inundation maps regardless of their depth of inundation, Table A2 provides more detailed data on numbers of components exposed by depth of inundation.

TABLE A2. **Potential Depth of Infrastructure Inundation from a Category 3 Hurricane, 2012–2070**

Depth of Inundation Interval	2012		2030		2050		2070	
	Substations	Power Plants	Substations	Power Plants	Substations	Power Plants	Substations	Power Plants
Delaware Valley								
>0–5 feet	23	6	21	7	17	6	16	8
>5–10 feet	31	18	33	18	37	18	31	15
>10–15 feet	22	8	24	8	26	9	33	12
>15–20 feet	3	3	3	3	3	4	6	5
>20 feet	0	0	0	0	1	0	1	0
TOTAL	*79*	*35*	*81*	*36*	*84*	*37*	*87*	*40*
Southeastern Virginia								
>0–5 feet	41	4	37	3	32	3	25	2
>5–10 feet	15	0	22	1	28	1	34	2
>10–15 feet	1	0	1	0	4	0	7	0
>15–20 feet	0	0	0	0	0	0	0	0
>20 feet	0	0	0	0	0	0	0	0
TOTAL	*57*	*4*	*60*	*4*	*64*	*4*	*66*	*4*

(TABLE CONTINUED ON FOLLOWING PAGE)

TABLE A2. **Potential Depth of Infrastructure Inundation from a Category 3 Hurricane, 2012–2070 (cont.)**

Depth of Inundation Interval	2012		2030		2050		2070	
	Substations	Power Plants	Substations	Power Plants	Substations	Power Plants	Substations	Power Plants
South Carolina Lowcountry								
>0–5 feet	26	3	26	3	23	2	25	2
>5–10 feet	18	3	17	3	22	4	21	4
>10–15 feet	9	1	10	1	13	1	19	1
>15–20 feet	1	0	1	0	1	0	2	0
>20 feet	0	0	0	0	0	0	0	0
TOTAL	*54*	*7*	*54*	*7*	*59*	*7*	*67*	*7*
Southeastern Florida								
>0–5 feet	36	2	53	2	78	2	111	2
>5–10 feet	1	0	0	0	3	0	7	1
>10–15 feet	0	0	1	0	1	0	1	0
>15–20 feet	0	0	0	0	0	0	0	0
>20 feet	0	0	0	0	0	0	0	0
TOTAL	*37*	*2*	*54*	*2*	*82*	*2*	*119*	*3*
Central Gulf Coast								
>0–5 feet	25	2	28	3	28	3	28	1
>5–10 feet	44	12	35	8	34	6	29	3
>10–15 feet	39	1	43	4	42	6	41	11
>15–20 feet	49	5	54	5	50	5	46	2
>20 feet	31	0	34	1	49	1	63	4
TOTAL	*188*	*20*	*194*	*21*	*203*	*21*	*207*	*21*

Electric substations and power plants were plotted in each region and listed as "exposed" if they fell fully within mapped inundated areas. Inundation data were further broken out by total numbers exposed per year of analysis, and the potential depth of flooding in a given year at the site of infrastructure placement. These numbers apply to a Category 3 hurricane scenario.

NOTE: Along the central Gulf Coast, a high proportion of the analyzed infrastructure falls within leveed areas. Because certain storm scenarios can still result in floodwaters overtopping or running around protective infrastructure, however, some of these elements falling within "protected" areas can still be exposed. For reference, 80 of the 188 exposed substations and four of the 20 exposed power plants fall outside of mapped leveed areas in 2012; by 2070, those numbers increase to 99 out of 207 exposed substations and five out of 21 exposed power plants.

Limitations

This analysis is intended to help illustrate the risks facing towns and cities up and down the East and Gulf Coasts, and the findings should be considered a general indicator of the magnitude of risk facing these areas. The results are not, however, appropriate for detailed analysis. Some limitations of the findings are related to the scale at which the analysis was conducted, while others are related to the methods used to model inundation from storm surge. These results are instead well suited for motivating additional localized, geographic- and grid-specific analyses.

DIGITAL ELEVATION MODELS

We used DEMs published by the USGS as part of its National Elevation Dataset, and by NOAA as part of its Sea Level Rise Viewer tool. For the Charleston, South Carolina, area, we note that there are inconsistencies in the DEM in the northeast corner of the map that affect the modeled depth of inundation in that area, likely making the depth shown in the map less than it should be. For the Miami, Florida, area, the DEM we used from NOAA Digital Coast (2015) does not extend far enough inland to fully capture the extent of inundation from a Category 5 storm. This does not, however, affect the number of electrical facilities affected by the storm, as there are relatively few in those inland areas.

LEVEES AND OTHER PROTECTIVE STRUCTURES

Levees, because they are elevated land structures, are typically apparent within the DEMs we used. In addition, the SLOSH model reflects flow relative to levees and other structures, though not those that are very small in size. DEMs may not reflect the most recent levee heights, as factors such as subsidence can alter levee heights over time. For the New Orleans, Louisiana, area, we mapped land areas that are protected by levees maintained by the U.S. Army Corps of Engineers (USACE), though it is important to note that the levees are not the only flood control structures in place in that region. Because our analysis did not explicitly incorporate flood protection measures such as pumps or gates that may decrease a region's exposure to storm surge, the maps we produced should be used for research and discussion purposes only. More detailed analyses—incorporating local knowledge and all possible flood control structures—should be undertaken for planning purposes.

INUNDATION OF SUBSTATIONS AND POWER PLANTS

This analysis relies on a simple binary label of "exposed" or "unexposed" for each piece of mapped electricity infrastructure. The label, however, only indicates the *potential* exposure of a substation or power plant's point location. It does not indicate whether or not the piece of equipment would be exposed to flooding, as the equipment could be elevated or surrounded by protective equipment. For this information, follow-up with the local utility is required.

This analysis also cannot definitively state whether or not a power outage will occur in a given storm scenario. Several areas of uncertainty contribute to this limitation, including whether or not a piece of infrastructure will actually face flooding from a specific storm, whether or not a substation or power plant will be knocked off-line should the component face flooding, and finally, whether or not the loss of a given piece of infrastructure will ultimately result in a power outage, as some redundancies may be built into a local grid. Additionally, this analysis does not include the many smaller, distribution-level substations that help carry electricity the last leg of the journey for most end users. Should any of these smaller elements go out further down the line than the larger, mapped substations, electricity customers could still face outages.

It is finally important to note that while this analysis studies the impact of specific hurricane categories, it does so only with an eye toward damage from storm surge flooding, and not the myriad other threats to the grid that can accompany such storms. These threats include direct wind damage to poles and wires, indirect wind damage from falling vegetation and lofted debris, worsened flooding from compound precipitation events that typically accompany severe storms, and other flooding-related threats such as damage from floating projectiles.

[REFERENCES]

Carlson, C., G. Goldman, and K. Dahl. 2015. *Stormy seas, rising risks: What investors should know about climate change impacts at oil refineries.* Cambridge, MA: Union of Concerned Scientists. February. Online at *www.ucsusa.org/sites/default/files/attach/2015/02/stormy-seas-rising-risks-ucs-2015.pdf*.

Climate Central. No date. Surging seas. Sea level rise analysis by Climate Central. Online at *http://sealevel.climatecentral.org/*.

Coastal Services Center. 2012. *Mapping coastal inundation primer.* Charleston, SC: National Oceanic and Atmospheric Administration. April. Online at *https://coast.noaa.gov/digitalcoast/_/pdf/guidebook.pdf*.

Horton, R., C. Herweijer, C. Rosenzweig, J. Liu, V. Gornitz, and A.C. Ruane. 2008. Sea level rise projections for current generation CGCMs based on the semi-empirical method. *Geophysical Research Letters* 35(2):L02715. Online at *http://doi.wiley.com/10.1029/2007GL032486*, accessed April 3, 2015.

Jevrejeva, S., J.C. Moore, and A. Grinsted. 2010. How will sea level respond to changes in natural and anthropogenic forcings by 2100? *Geophysical Research Letters* 37(7):1–5.

NOAA Digital Coast. 2015. Sea level rise data download. Charleston, SC: NOAA Office for Coastal Management. Online at *http://coast.noaa.gov/slrdata/*.

Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. 2012. *Global sea level rise scenarios for the United States National Climate Assessment*. NOAA technical report OAR CPO-1. Washington, DC: National Oceanic and Atmospheric Administration. December 6. Online at *http://scenarios.globalchange.gov/sites/default/files/NOAA_SLR_r3_0.pdf*.

Platts. 2015. Platts electric substation geospatial data layer. Westminster, CO: McGraw Hill Financial. Downloaded in May. Metadata online at *www.platts.com/im.platts.content/productsservices/products/gismetadata/substatn.pdf*.

SNL Financial (SNL). 2015. SNL interactive. Charlottesville, VA. Online at *www.snl.com* (paywall restricted).

Spanger-Siegfried, E., M. Fitzpatrick, and K. Dahl. 2014. *Encroaching tides: How sea level rise and tidal flooding threaten U.S. East and Gulf Coast communities over the next 30 years*. Cambridge, MA: Union of Concerned Scientists. October. Online at *www.ucsusa.org/sites/default/files/attach/2014/10/encroaching-tides-full-report.pdf*.

Tebaldi, C., B.H. Strauss, and C.E. Zervas. 2012. Modeling sea level rise impacts on storm surges along US coasts. *Environmental Research Letters* 7(1):014032.

Vermeer, M., and S. Rahmstorf. 2009. Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences* 106(51):21527–21532.

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. 2014. Our changing climate. In *Climate change impacts in the United States: Third national climate assessment*, edited by J.M. Melillo, T.C. Richmond, and G.W. Yohe. Washington, DC: U.S. Global Change Research Program, 19–67. DOI:10.7930/J0KW5CXT. May, revised October. Online at *http://s3.amazonaws.com/nca2014/low/NCA3_Full_Report_02_Our_Changing_Climate_LowRes.pdf?download=1*.