Effect of Sea Level Rise on Energy Infrastructure in the New Orleans Metropolitan Statistical Area

Office of Electricity Delivery and Energy Reliability
U.S. Department of Energy

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Introduction and Key Findings

This report summarizes recent work undertaken by the Energy Infrastructure and Modeling and Analysis Division (EIMA) of the U.S. Department of Energy Office of Electricity Delivery and Energy Reliability (OE) to assess the potential exposure of energy facilities in the New Orleans Metropolitan Statistical Area (MSA)[1] to a general rise in sea level and from storm surge at these higher sea levels. The analysis focuses on the risk in 2050 and 2100, and includes more than 200 energy assets in the New Orleans MSA including electricity assets (power plants and substations), natural gas assets (processing plants, storage facilities, and pipelines), and petroleum terminals and pipelines.

The analysis indicates that under the U.S. National Climate Assessment (NCA) Low Sea Level Rise (SLR) Scenario, 2 feet of inundation will occur before 2100 in two of the parishes in the New Orleans MSA. Under the NCA Intermediate-High Scenario, 2 feet of inundation will occur prior to or just after 2050, 4 feet of inundation before 2100, and 6 feet of inundation around 2100 for the five parishes in the MSA with coastline. [2]

The analysis results show that with 2 feet of SLR under the NCA Intermediate-High Scenario, of the large energy assets analyzed four petroleum pipelines and 20 natural gas pipelines would be inundated in the New Orleans MSA by about 2050. However, a 2-foot SLR in conjunction with a storm surge associated with a Category 1 storm would inundate many large electricity and petroleum assets including:

- 36 substations (>230 kV)
- 2 power plants (>100 MW)
- 17 petroleum terminals (>100,000 bbl)
- 4 oil refineries
- 4 petroleum pipelines
- 3 natural gas processing plants
- 1 natural gas storage facility
- 20 natural gas pipelines

In 2100, with 6 feet of SLR under the NCA Intermediate-High Scenario, the SLR alone would permanently inundate:

- 7 substations (>230 kV)
- 1 power plant (>100 MW)
- 1 petroleum terminal (>100,000 bbl)
- 4 petroleum pipelines
- 3 natural gas processing plants
- 1 natural gas storage facility
- 20 natural gas pipelines

[1] The U.S. Census Bureau defines the New Orleans-Metairie MSA as consisting of the principal cities of New Orleans and Metairie and eight parishes: Jefferson, Orleans, Plaquemines, St. Bernard, St. Charles, St. James, St. John the Baptist, and St. Tammany. The area is referred to as the New Orleans MSA throughout the report for simplicity.

[2] Six feet is used in the figures presented in this report, representing the approximate level of inundation in the New Orleans MSA at the end of the century (i.e., 2100) under the NCA Intermediate-High SLR Scenario.

A storm surge associated with a Category 5 storm in combination with 2 feet of SLR in 2050 or 6 feet of SLR in 2100 under the NCA Intermediate-High SLR Scenario would inundate nearly all of the large energy assets in eight coastal parishes across the MSA.

The remainder of this report provides background on the analysis and describes important caveats. An Appendix presents the detailed information in a table and set of maps. A second Appendix provides additional detail on the approach to estimating SLR and storm surge.

Background and Approach

The EIMA Division within OE conducts studies of potential risks to the nation's energy infrastructure. EIMA's mission is to ensure the reliability and resiliency of U.S. energy infrastructure and systems through robust analytical, modeling, and assessment capabilities. The Division is focused on conducting risk analyses and predictive modeling, and providing analytical products intended to inform decision makers at the public and private levels.

In 2014, EIMA launched an effort to evaluate the effects of SLR on energy assets. A pilot study was conducted that examined the implications of SLR for energy assets in four MSAs—New York, Miami, Houston, and Los Angeles. The goal of the study was to demonstrate an effective approach to examining SLR that could be generalized and extended to other regions of the country. The final report, published in September 2014, describes the analytical approach and the results of the study. The study relied on scenarios of sea level rise developed by the NCA. These include a range of plausible trajectories of global mean SLR, ranging from 8 inches to 6.6 feet by 2100.[3] For the purpose of assessing the exposure of energy assets to SLR, the study used the NCA's SLR scenarios, adjusted for local factors, such as subsidence. For a detailed explanation of how the SLR analysis was conducted please see Chapter 3 of the report.[4]

The pilot study examined energy facilities at risk from SLR but did not take into account impacts from storm surge. In late 2014, the Oak Ridge National Laboratory (ORNL) published a report demonstrating a method for incorporating storm surge with SLR.[5] EIMA has adapted that approach and has begun to evaluate the combined effects of SLR and storm surge on energy assets.

The method employed for this analysis uses the approach from the pilot study for estimating sea level rise impacts and adapts the approach developed by ORNL that adds storm surge modeled inundations as developed by NOAA's National Weather Service using the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model. [6] Surge is estimated based on a composite of model runs assuming hypothetical hurricanes of varying characteristics. The result is a Maximum Envelope of Water (MEOW), which shows the highest surge values at each grid location for a given storm characteristic. This study uses the Maximum of MEOWs, or MOM, for estimates of storm surge heights. Storm surge associated with intense storms was mapped on top of the SLR. This calculated elevation was then extended toward

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[3] Parris, A., et al., 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1.

[4] A copy of the report, *Effects of Sea Level Rise on Energy Infrastructure in Four Major Metropolitan Areas* (2014), can be downloaded at http://energy.gov/oe/downloads/effect-sea-level-rise-energy-infrastructure-four-major-metropolitan-areas-september.

[5] Maloney, M.C. and B.L. Preston, 2014. A geospatial dataset for U.S. hurricane storm surge and sea-level rise vulnerability: Development and case study applications. *Climate Risk Management*, 2, 26-41.

[6] Available at: http://www.nhc.noaa.gov/surge/slosh.php.

the coast to find the extent of the possible inundation. These inundation layers were then intersected with the infrastructure locations to determine facilities that may be affected by such a combined impact (for example, what power plants might be inundated by a Category 5 storm occurring after 6 feet of sea level rise). No new numerical modeling was conducted for this study. (See Appendix B for additional details on the methodology.)[7]

During the course of this analysis, it became apparent that several assets, while not completely inundated, were obviously projected to be affected by SLR and storm surge. Assets were deemed to be *affected* if they are projected to be completely surrounded by water or if water encroaches the sites but does not completely envelop the facilities. A visual assessment was made to determine whether non-inundated large assets might be affected. Both types of impacts were identified in the analysis.

The levee system in the New Orleans area adds an extra layer of complexity in modeling sea level rise and storm surge. The NOAA sea level rise data used in this analysis do not project that sea level rise alone will overtop the levees, even with 6 feet of SLR, which is reflected in the results of this analysis. Storm surge in combination with sea level rise is project to result in overtopping of the levees and an inundation of a significantly larger part of the New Orleans MSA than sea level rise alone.

Another challenge in the New Orleans MSA is the variability in local sea level rise across the MSA. The parishes directly on the coast (Plaquemines and Jefferson) are closer to the Grand Isle tidal gauge, which is just offshore and reports a mean sea level trend of 9.03 millimeters per year (based on data from 1947 to 2014). Parishes further inland (St. Bernard, Orleans, and St. Tammany) are nearer to the New Canal gauge, which reports a mean sea level trend of 4.5 millimeters per year (based on data from 1982 to 2014).[8] This difference means that the coastal parishes experience local sea level rise at a more rapid rate than the parishes located further inland. Therefore, the timing of specific amounts of inundation (e.g., one foot, two feet, etc.) under specific NCA scenarios, which is based on measured sea level trends at local tidal gauges, will vary across the MSA (see Table 1 of Appendix A for more detail).

For the purpose of this analysis, two storm categories were examined. Category 1 storms were analyzed to illustrate the effects of exacerbation from SLR on smaller storms. This study does not address the potential changes in return intervals of hurricanes[9], which may be different under future conditions and affect coastal vulnerabilities.[10] To account for potentially stronger storms in the future, the study analyzed Category 5 storms.

The objective of this and the other studies has been to develop a first order estimate of the exposure of energy assets to SLR by itself and future storm surge at the higher sea levels forecast by the NCA. It is expected that where these studies identify potential exposure, more detailed studies could be undertaken to refine and better understand the risks. These studies aim to align the analysis and results

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[7] The SLOSH model estimates storm surge heights associated with hurricanes by simulating the effects of storm size, forward speed, track, wind speed, and atmospheric pressure on water heights in the coastal zone. Model output data are available for 39 basins along the Atlantic and Gulf coasts. The SLR data are from the NOAA Coastal Services Center (NOAA CSC) inundation maps showing shoreline effects of SLR between 1 and 6 feet in 1-foot increments. The land surface data are from USGS National Elevation Dataset output.

[8] Tidal gauges and SLR trends can be viewed at http://tidesandcurrents.noaa.gov/sltrends/sltrends.html.

[9] Melillo, J. M., T.C. Richmond, and G. W. Yohe, Eds., 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

[10] Maloney and Preston, 2014.

with the level of detail and certainty needed to inform decisions regarding which energy assets may be vulnerable to SLR and storm surge.

Caveats and Limitations

Because of the relatively high-level nature of the SLR and storm surge analysis, there are limitations that should be acknowledged. The study employs a method of moderate complexity that takes advantage of publicly available data and can be run with standard desktop processing power, while providing results at a level of certainty sufficient to identify the potential effects of combined SLR and storm surge. These features make the method useful for comparing results across multiple areas. The method also localized estimates of SLR from global projections using information about local SLR trends, improving the accuracy of results.

> ***Useful Life of Energy Assets*** – The SLR study extends beyond the economic life of most of the energy assets shown to be affected. Many of these assets could be retired within the next 25 to 30 years. The analysis does identify, however, the potential risk areas for the location of new assets.
>
> ***Asset Hardening and Protection*** – The data do not indicate whether utility or facility operators have undertaken projects to reduce exposure to higher sea levels. In some areas, asset owners have been making efforts to minimize exposure to high water—by the construction of berms, for example. However, information on the types of hardening or resilience measures taken by asset owners and operators is not accounted for in the study. Also not accounted for are sea walls, dunes, or other factors that would impede permanent inundation or temporary flooding.
>
> ***Asset Interdependencies*** – The study does not identify interdependencies among energy assets, such as for example, the effect of a substation outage on another energy asset.
>
> ***Data Limitations*** – The study relies on data regarding energy assets drawn from numerous sources. The scope of this study included hundreds of assets, including many small assets. (The accompanying maps show only the large energy assets.) Sometimes these data are incomplete or assets are not accurately located.
>
> ***Modeling Limitations*** – There are trade-offs regarding resolution and certainty of modeling results. The underlying models of future changes to global sea levels have various sources of uncertainty that also contribute to uncertainty of models of relative sea levels and the interactive effects of sea level rise and storm surge. The SLR analysis does not take into account erosion. The method used in this study takes an additive approach to SLR and storm surge, which does not fully capture the nonlinear interaction of SLR and storm surge;[11] therefore, in instances where there is less tolerance for uncertainty, surge modeling may need to be performed on the projected future local sea level.

[11] Zhang, K. Li, Y., and Liu, H. 2013. Comparison of three methods for estimating the sea level rise effect on storm surge flooding. Climatic Change 118:487–500.

The SLOSH model does not include wind-driven waves or waves on top of surge, rainfall amounts, or river flows when determining surge height.[12] The model also lacks processes such as coastal accretion and recession, changes in near-shore bathymetry, and coastal barrier features,[13] which can affect local estimates of total water height during a storm. The SLOSH model resolution is also coarse compared to state-of-the-art surge models, such as the ADCIRC model,[14] which contributes to uncertainty in the findings. In some cases this results in inundation mapping that appears not to follow a natural shoreline and are unnaturally straight or have geometric shapes.

Future Policy – The results, as presented, assess exposure of present-day energy infrastructure over the next 85 years to SLR and storm surge. Future changes to energy infrastructure—through modifications such as asset hardening and new construction, among others—are not accounted for in this study. Activities planned in the New Orleans area by local government are not reflected in the modeling.

Next Steps

EIMA is pleased to share this analysis with the hope that it fulfills the purpose for which it has been undertaken: to identify areas of potential exposure that can lead to more detailed analysis. EIMA hopes that this study will be useful in work ongoing in the New Orleans region with regard to energy asset impacts from sea level rise.

Contact

For more information about the analysis included herein, please contact:

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[12] Available at: http://www.nhc.noaa.gov/surge/faq.php#10.

[13] Maloney and Preston, 2014.

[14] Available at: http://adcirc.org/.

Appendix A: Table and Maps of Results

The following pages contain a table and maps from the results of the analysis. An explanatory note for the table is provided here. Maps are provided only for those scenarios and time periods (i.e., 2050 or 2100) where assets are projected to be inundated; under the Intermediate-High Scenario of approximately 2 feet of SLR in 2050 no electricity assets are projected to be inundated and no map is provided.

More than 200 assets were examined including 130 large energy assets:

- 8 power plants
- 59 substations
- 26 petroleum terminals
- 8 oil refineries
- 4 petroleum pipelines
- 4 natural gas processing plants
- 1 natural gas storage facility
- 20 natural gas pipelines

There are 1,876 miles of natural gas pipeline and 811 miles of petroleum pipeline in the MSA. This study analyzed potential inundation of these pipelines.

Asset data sources included the following: for electric assets: Homeland Security Infrastructure Protection Gold (HSIP Gold), 2011 and Ventyx, accessed November 2015; for natural gas assets: HSIP Gold, 2013; for petroleum assets: HSIP Gold, 2013 and Argonne National Labs, accessed 2013.

The maps present information on only the large energy assets in the MSA, specifically:

- power plants greater than 100 MW and substations greater than 230 kV
- petroleum terminals greater than 100,000 barrels storage capacity
- petroleum and natural gas pipelines

Table 1. Years Corresponding to SLR Increments in New Orleans MSA under Four NCA Scenarios

The analysis begins with SLR. Table 1 shows the years in which sea levels are projected to increase from their current level to 1 foot higher, 2 feet higher, and up through 6 feet of sea level rise under each of the NCA SLR scenarios. The SLR data are from the NOAA Coastal Services Center (NOAA CSC) inundation maps showing shoreline effects of SLR between 1 and 6 feet in 1-foot increments.[15] The calculation of the year takes into account local subsidence trends using tidal information from NOAA, National Ocean Service.[16] The columns highlighted in red are for SLR by 2050 (midcentury); the columns highlighted in yellow are for SLR by 2100 (end of century). The timing of inundation is important for informing risk management actions, and results from 2050 and 2100 are presented to give perspective on potential near-term and long-term levels of inundation, which may require different actions or affect different types of decisions.

Additional Figures

[15] Available at: http://coast.noaa.gov/slrdata/.

[16] Tidal Datums. Available at: http://tidesandcurrents.noaa.gov/datum_options.html.

Refer to Figures 1–6b for relevant maps displaying the impact of SLR in various scenarios.

Figure 1. Large Petroleum and Natural Gas Assets Inundated by 2 Feet of SLR under the NCA Intermediate-High Scenario in New Orleans MSA by ~2050

Figure 2a. Large Electricity Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario in New Orleans MSA by ~2100

Figure 2b. Large Petroleum and Natural Gas Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario in New Orleans MSA by ~2100

Figure 3a. Large Electricity Assets Inundated by 2 Feet of SLR under the NCA Intermediate-High Scenario and Category 1 Storm Surge in New Orleans MSA

Figure 3b. Large Petroleum and Natural Gas Assets Inundated by 2 Feet of SLR under the NCA Intermediate-High Scenario and Category 1 Storm Surge in New Orleans MSA

Figure 4a. Large Electricity Assets Inundated by 2 Feet of SLR under the NCA Intermediate-High Scenario and Category 5 Storm Surge in New Orleans MSA

Figure 4b. Large Petroleum and Natural Gas Assets Inundated by 2 Feet of SLR under the NCA Intermediate-High Scenario and Category 5 Storm Surge in New Orleans MSA

Figure 5a. Large Electricity Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario and Category 1 Storm Surge in New Orleans MSA

Figure 5b. Large Petroleum and Natural Gas Assets Inundated by 4 Feet of SLR under the NCA Intermediate-High Scenario and Category 1 Storm Surge in New Orleans MSA

Figure 6a. Large Electricity Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario and Category 5 Storm Surge in New Orleans MSA

Figure 6b. Large Petroleum and Natural Gas Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario and Category 5 Storm Surge in New Orleans MSA

Table 1. Years Corresponding to SLR Increments in the New Orleans MSA under Four NCA Scenarios

	NCA Low Scenario						NCA Intermediate-Low Scenario					
Parish	1 Ft	2 Ft	3 Ft	4 Ft	5 Ft	6 Ft	1 Ft	2 Ft	3 Ft	4 Ft	5 Ft	6 Ft
Jefferson	2044	2079	>2100	>2100	>2100	>2100	2039	2064	2087	>2100	>2100	>2100
Orleans	2080	>2100	>2100	>2100	>2100	>2100	2057	2092	>2100	>2100	>2100	>2100
Plaquemines	2044	2079	>2100	>2100	>2100	>2100	2039	2064	2087	>2100	>2100	>2100
St. Bernard	2080	>2100	>2100	>2100	>2100	>2100	2057	2092	>2100	>2100	>2100	>2100
St. Tammany	2080	>2100	>2100	>2100	>2100	>2100	2057	2092	>2100	>2100	>2100	>2100
	NCA Intermediate-High Scenario						NCA High Scenario					
	1 Ft	2 Ft	3 Ft	4 Ft	5 Ft	6 Ft	1 Ft	2 Ft	3 Ft	4 Ft	5 Ft	6 Ft
Jefferson	2032	2049	2064	2078	2090	2102	2027	2041	2053	2063	2073	2081
Orleans	2040	2061	2078	2093	>2100	>2100	2032	2048	2061	2072	2082	2091
Plaquemines	2032	2049	2064	2078	2090	2102	2027	2041	2053	2063	2073	2081
St. Bernard	2040	2061	2078	2093	>2100	>2100	2032	2048	2061	2072	2082	2091
St. Tammany	2040	2061	2078	2093	>2100	>2100	2032	2048	2061	2072	2082	2091

Notes:
* Red cells indicate when the inundation level (in feet) shown in the top row occurs around 2050 and well before 2100;
* Yellow cells indicate when inundation levels (in feet) shown in the top row occurs between 2050 and approximately 2100. In the NCA Intermediate-High scenario, six feet of inundation is projected at or near to 2100 and therefore shaded yellow.
* The analysis above incorporates the National Climate Assessment scenarios for SLR as described in *Global Sea Level Rise Scenarios for the U.S. National Climate Assessment. NOAA Tech Memo OAR CPO-1*. NOAA Climate Program Office (2012), http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf.
* The inundation levels are taken from NOAA, Coastal Services Center. *Method Description - Detailed Methodology for Mapping Sea Level Rise Inundation* (2012), http://www.csc.noaa.gov/slr/viewer/assets/pdfs/Inundation_Methods.pdf.
* The years in which the levels of inundation would occur under each NCA scenario are adjusted for local subsidence trends using tidal information from NOAA, National Ocean Service. *Tidal Datums.* http://tidesandcurrents.noaa.gov/datum_options.html.
* As noted in the text, a more detailed methodological discussion appears in *Effects of Sea Level Rise on Energy Infrastructure in Four Major Metropolitan Areas* (2014), http://energy.gov/oe/downloads/effect-sea-level-rise-energy-infrastructure-four-major-metropolitan-areas-september.
*Only parishes with coastal frontage are included in the table.

Figure 1. Large Petroleum and Natural Gas Assets Inundated by 2 Feet of SLR under the NCA Intermediate-High Scenario in New Orleans MSA by ~2050

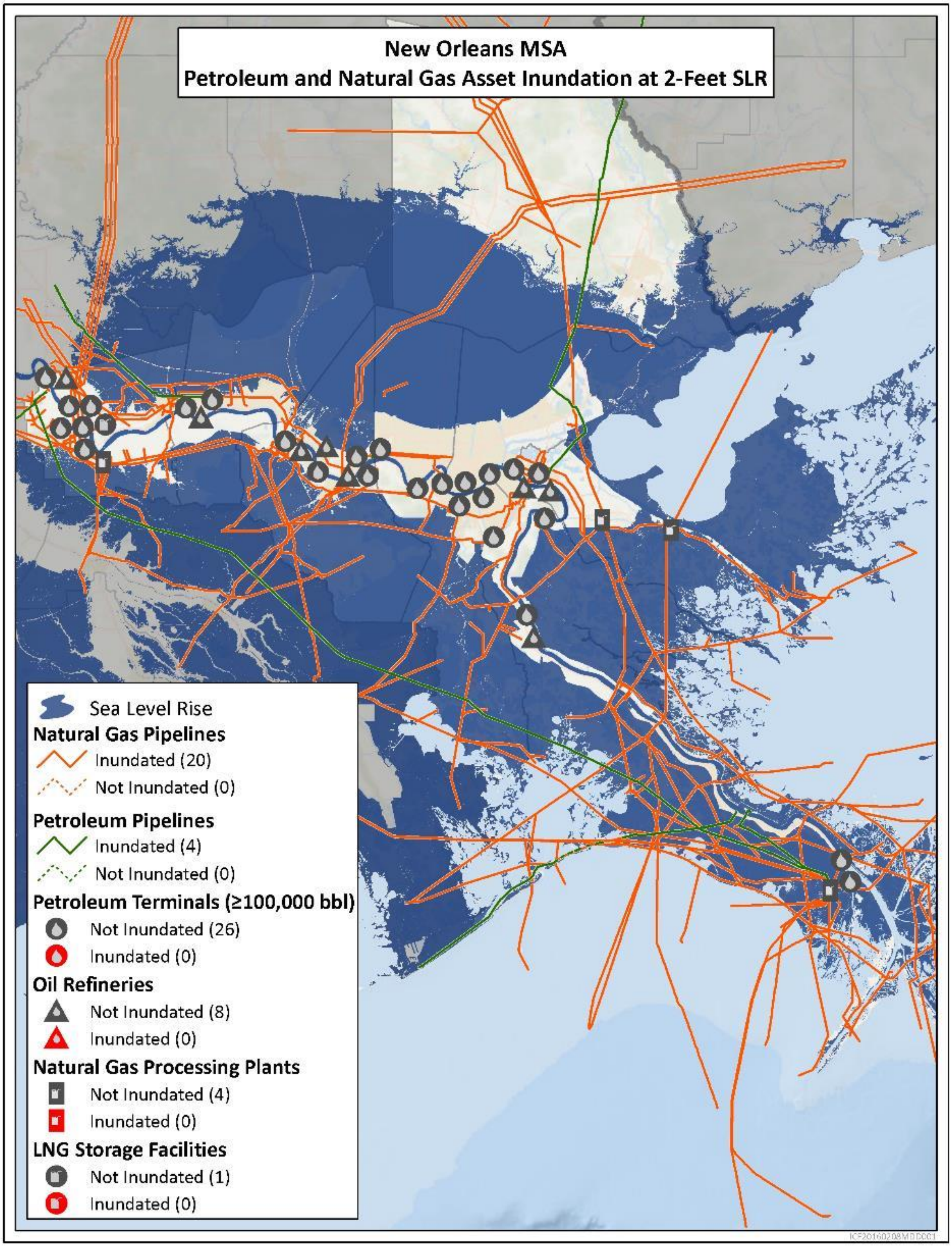


Figure 2a. Large Electricity Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario in New Orleans MSA by ~2100

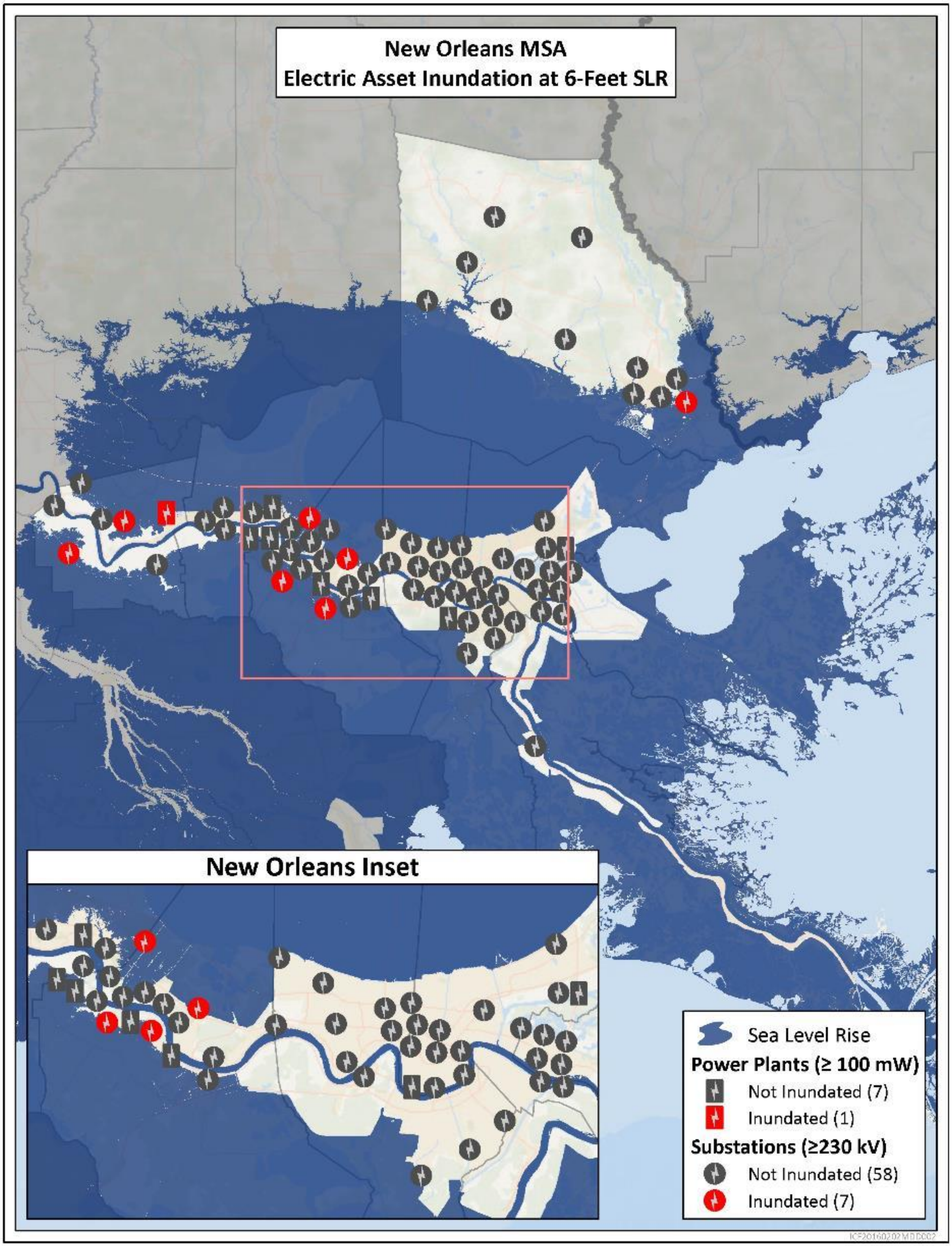


Figure 2b. Large Petroleum and Natural Gas Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario in New Orleans MSA by ~2100

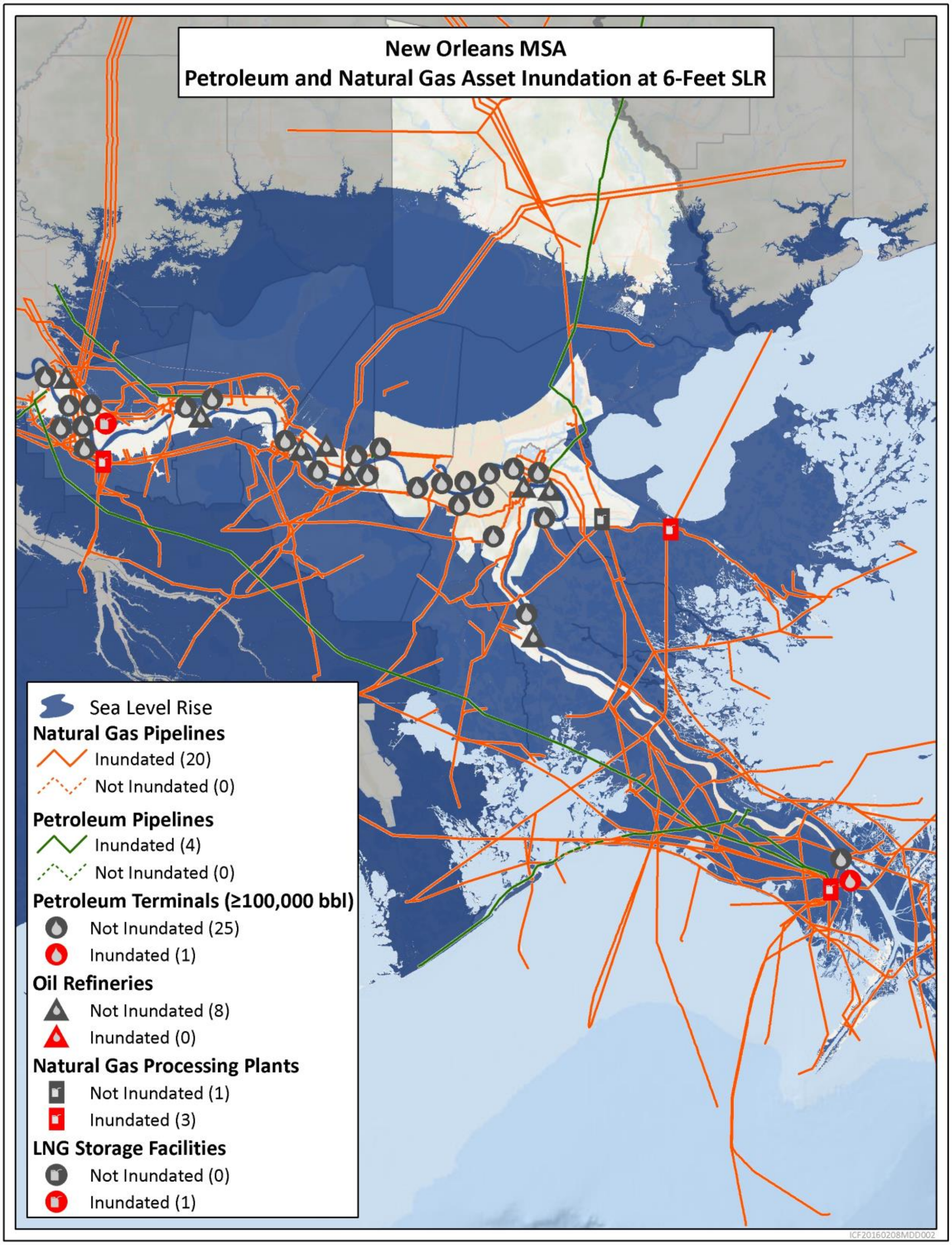


Figure 3a. Large Electricity Assets Inundated by 2 Feet of SLR under the NCA Intermediate-High Scenario and Category 1 Storm Surge in New Orleans MSA

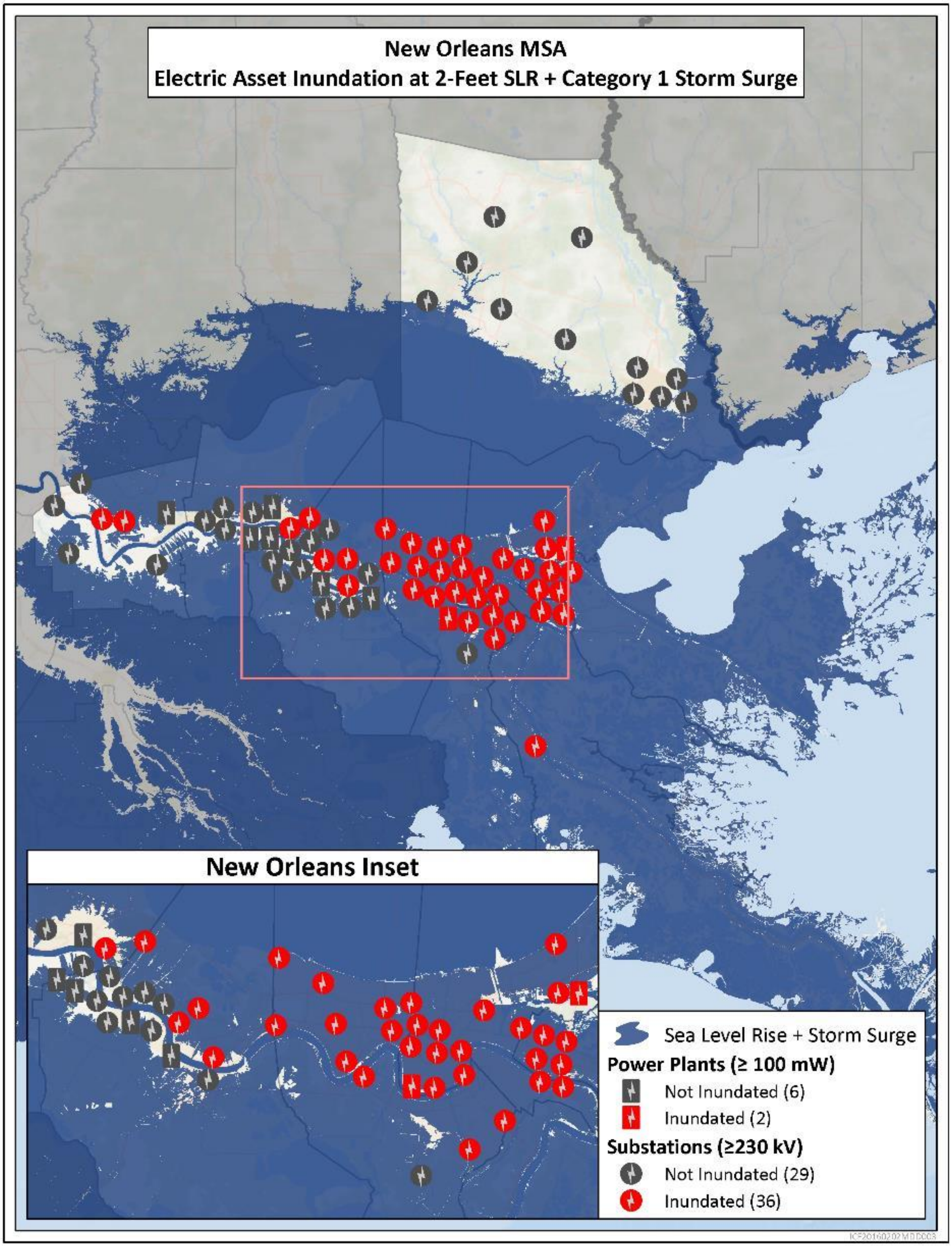


Figure 3b. Large Petroleum and Natural Gas Assets Inundated by 2 Feet of SLR under the NCA Intermediate-High Scenario and Category 1 Storm Surge in New Orleans MSA

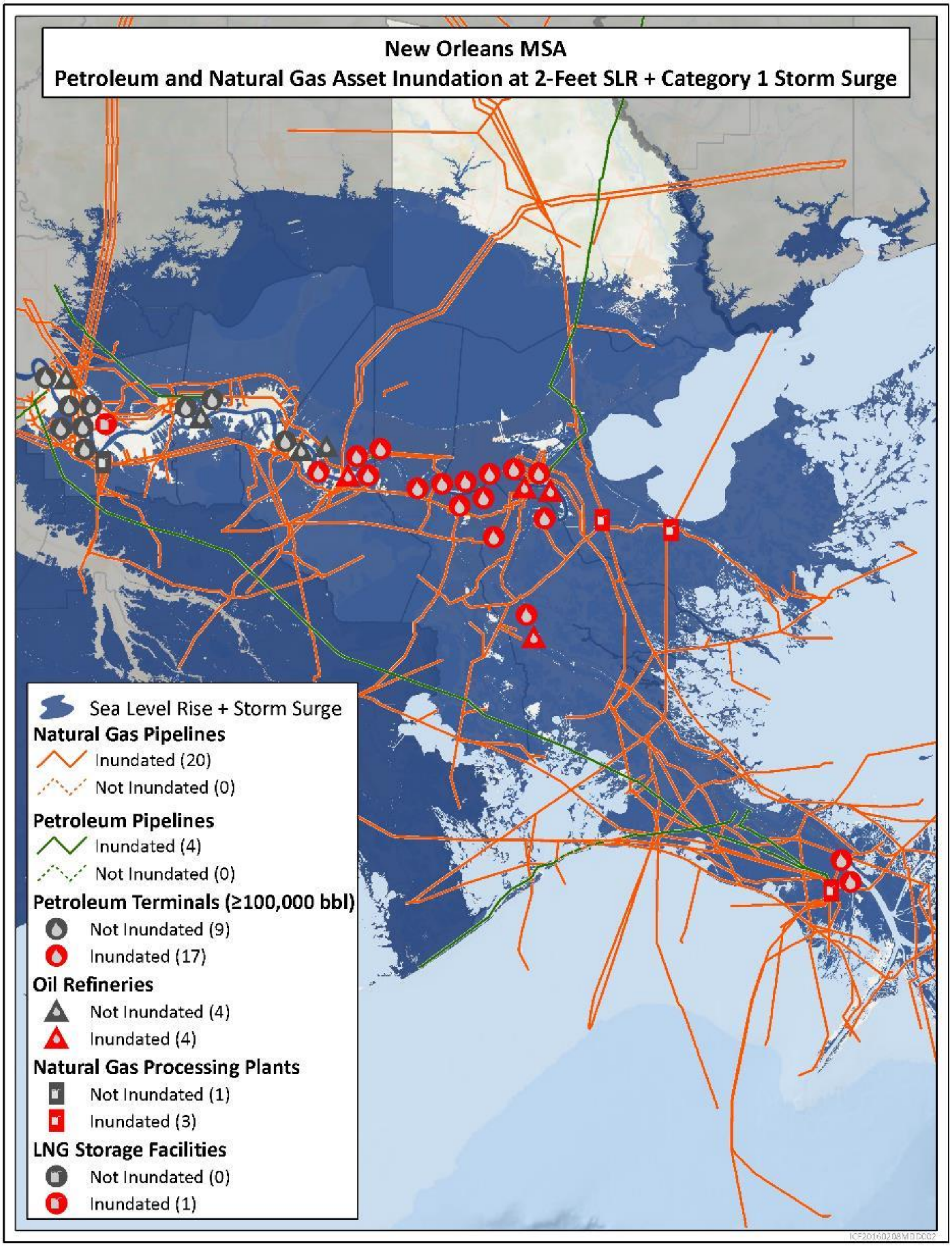


Figure 4a. Large Electricity Assets Inundated by 2 Feet of SLR under the NCA Intermediate-High Scenario and Category 5 Storm Surge in New Orleans MSA

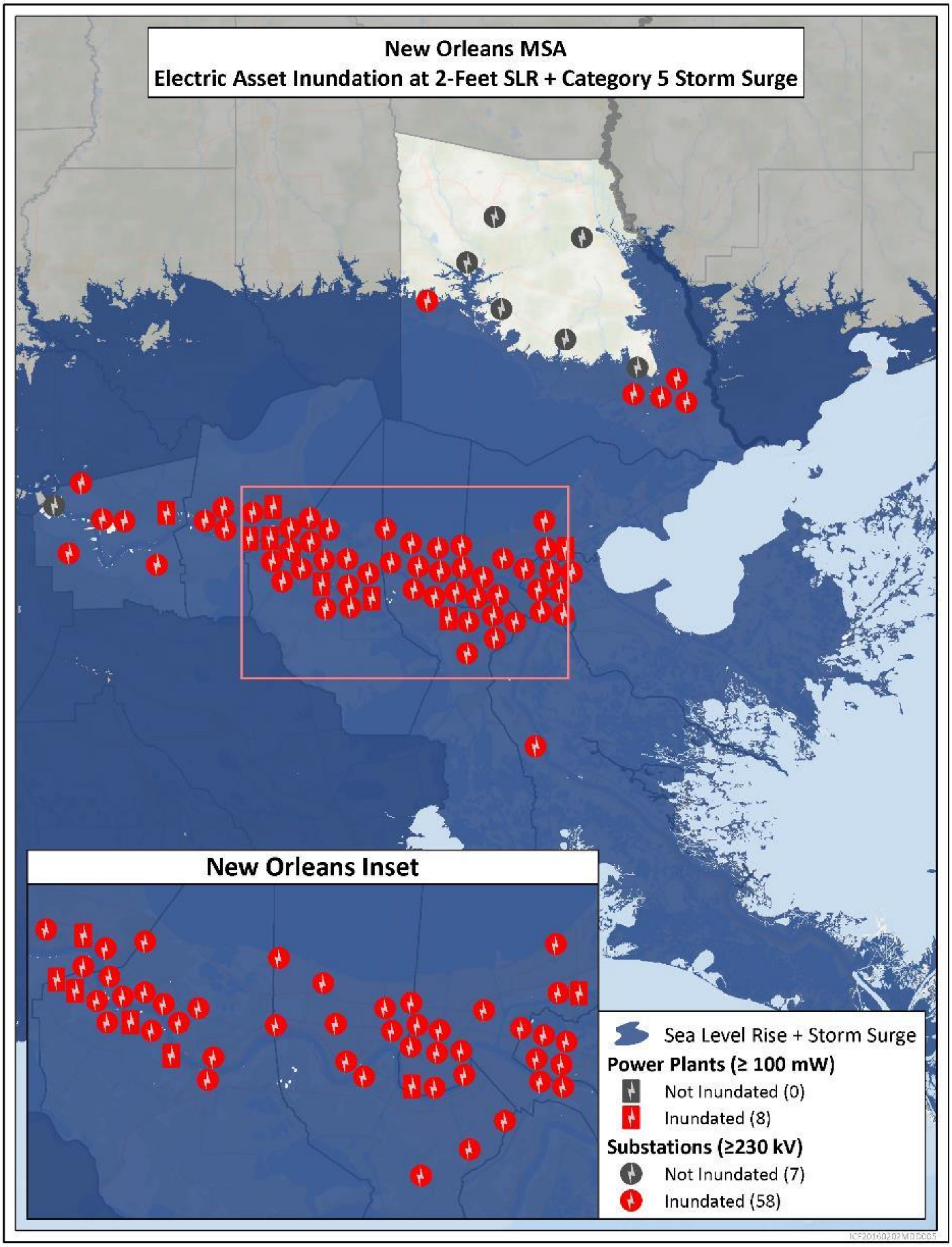


Figure 4b. Large Petroleum and Natural Gas Assets Inundated by 2 Feet of SLR under the NCA Intermediate-High Scenario and Category 5 Storm Surge in New Orleans MSA

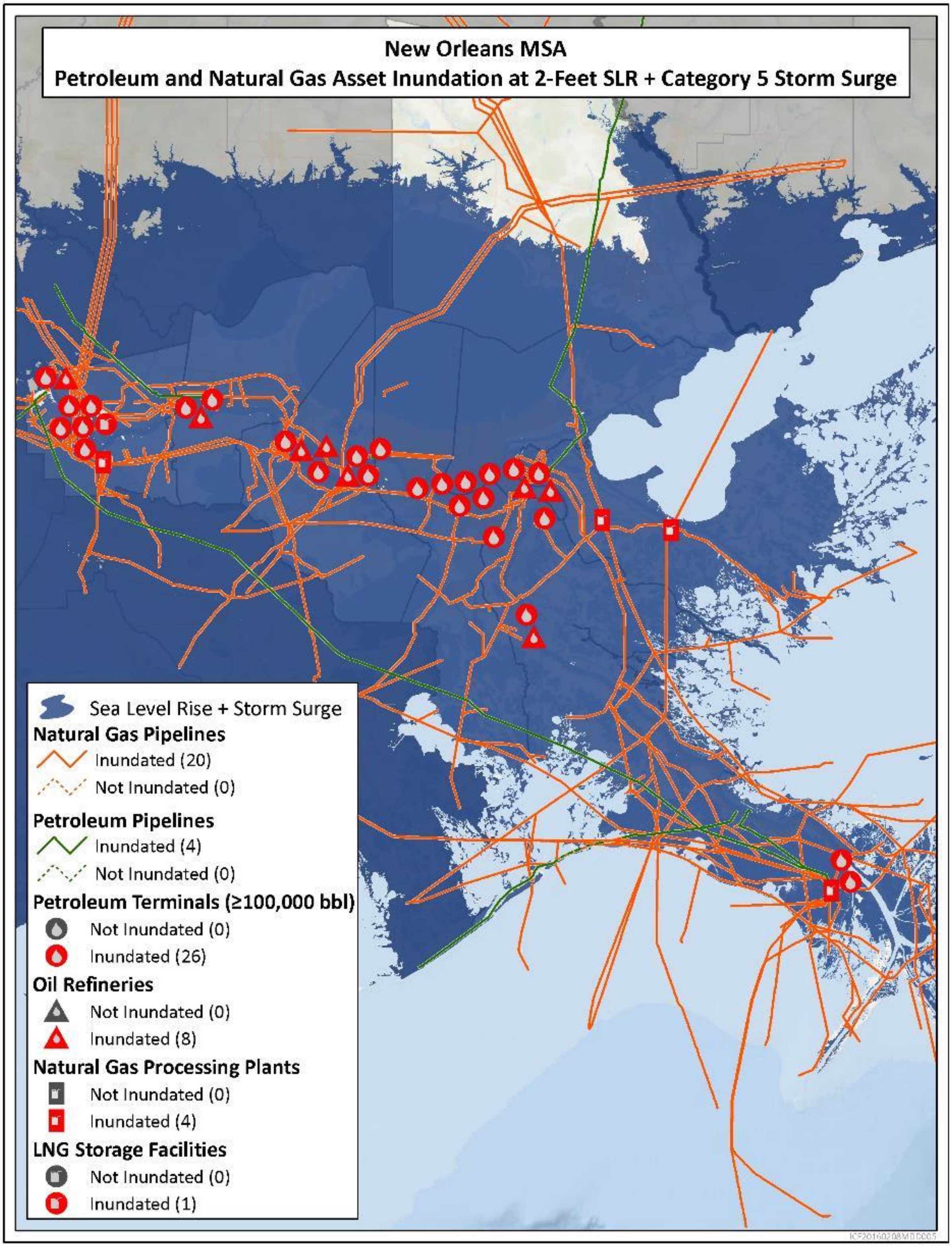


Figure 5a. Large Electricity Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario and Category 1 Storm Surge in New Orleans MSA

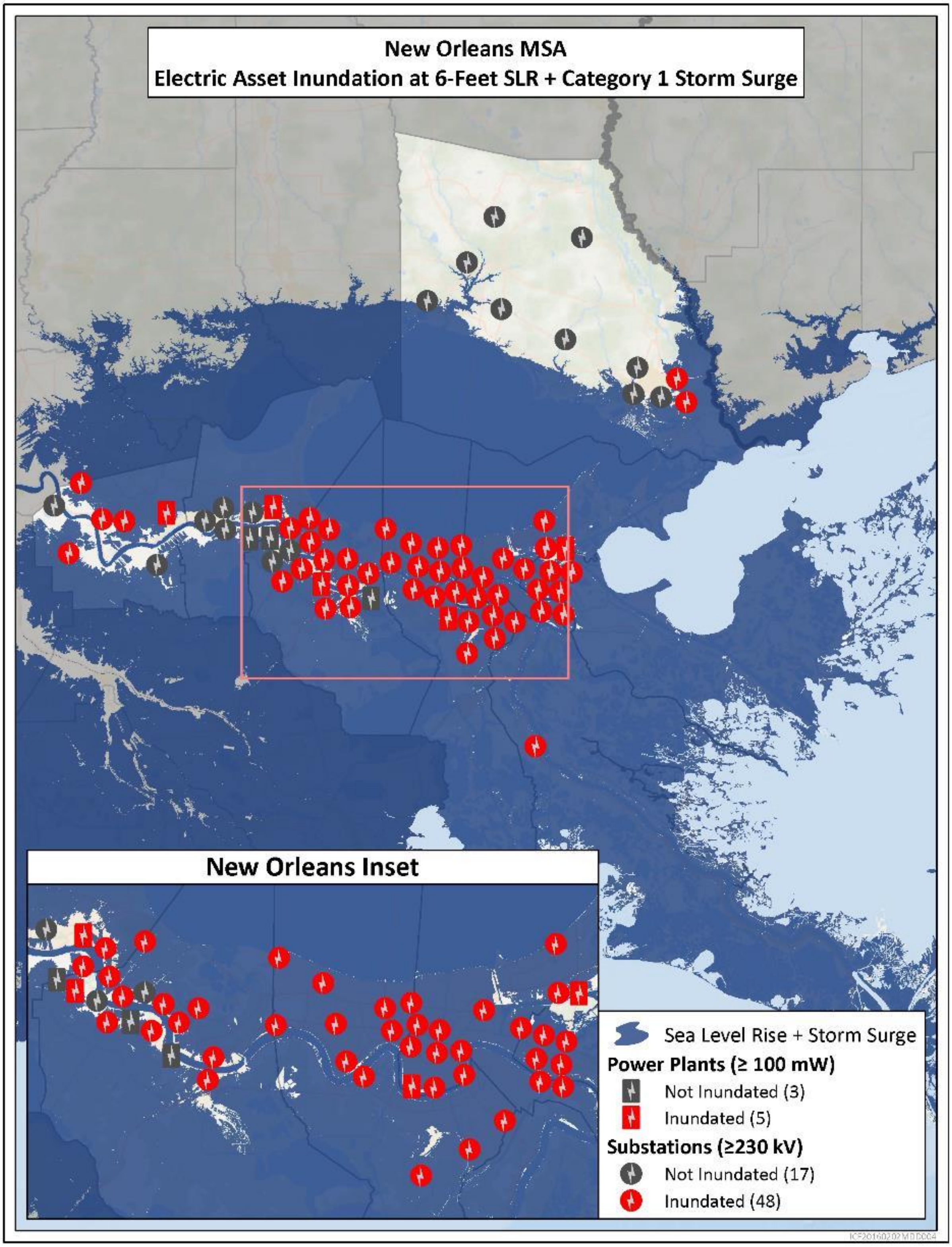


Figure 5b. Large Petroleum and Natural Gas Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario and Category 1 Storm Surge in New Orleans MSA

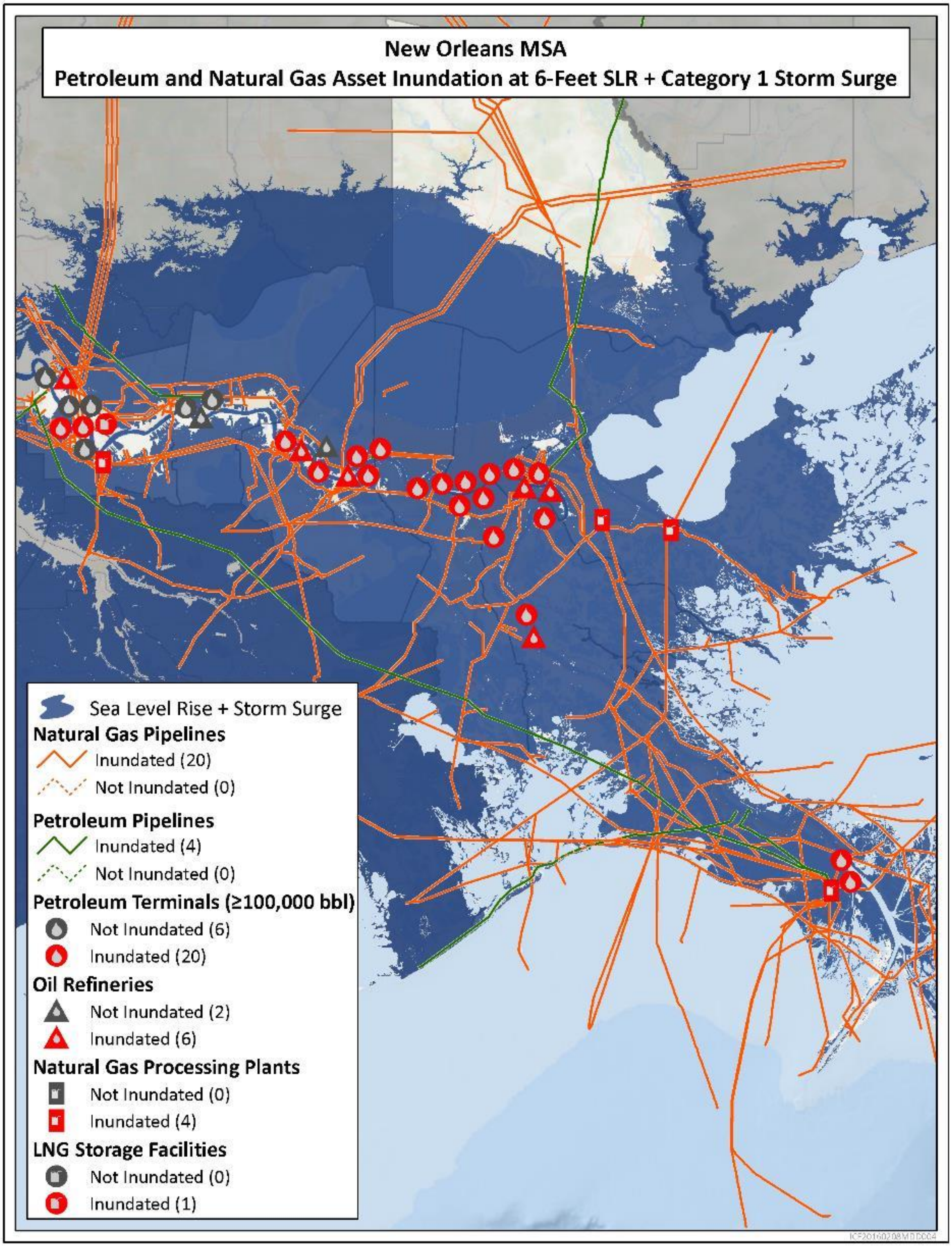


Figure 6a. Large Electricity Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario and Category 5 Storm Surge in New Orleans MSA

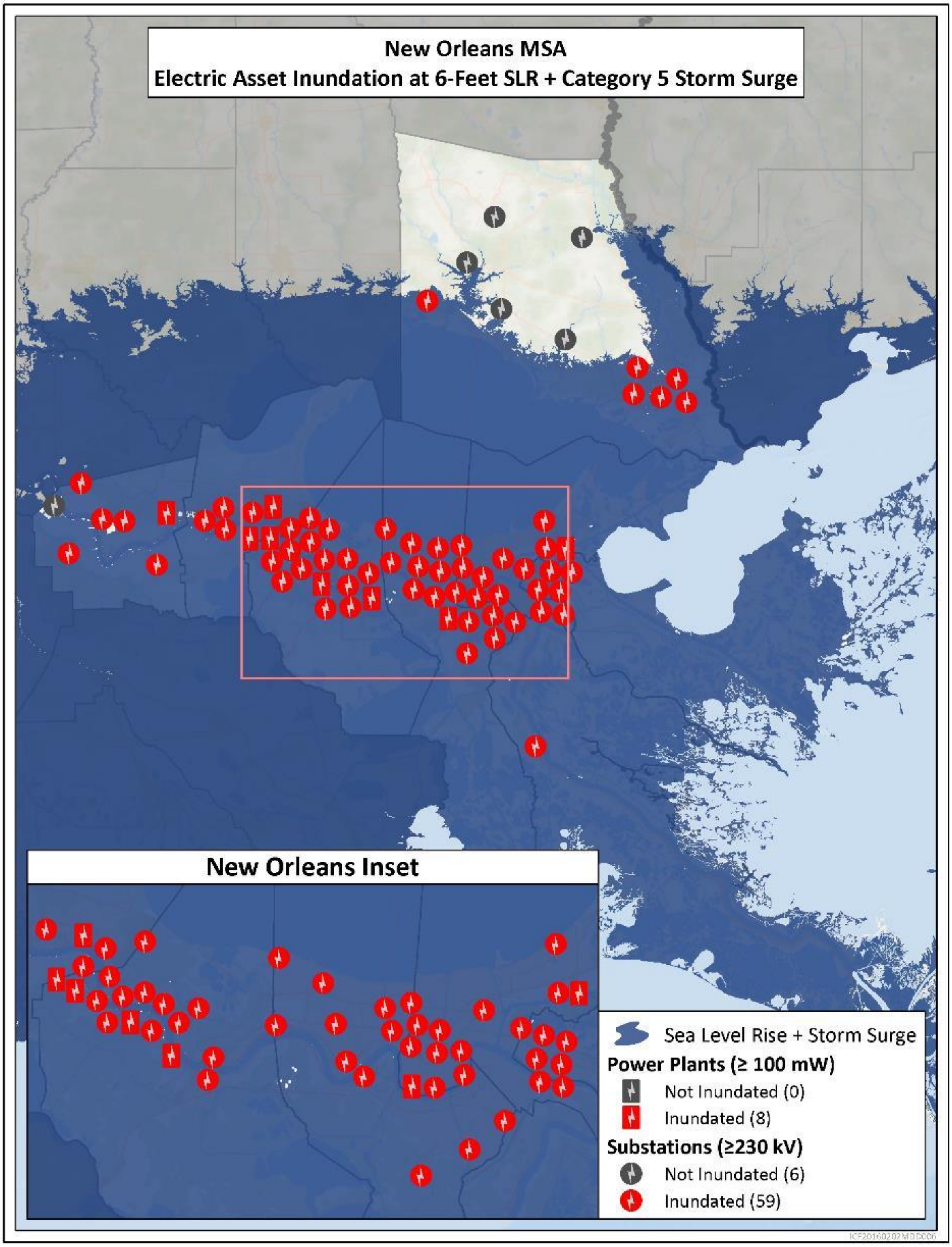
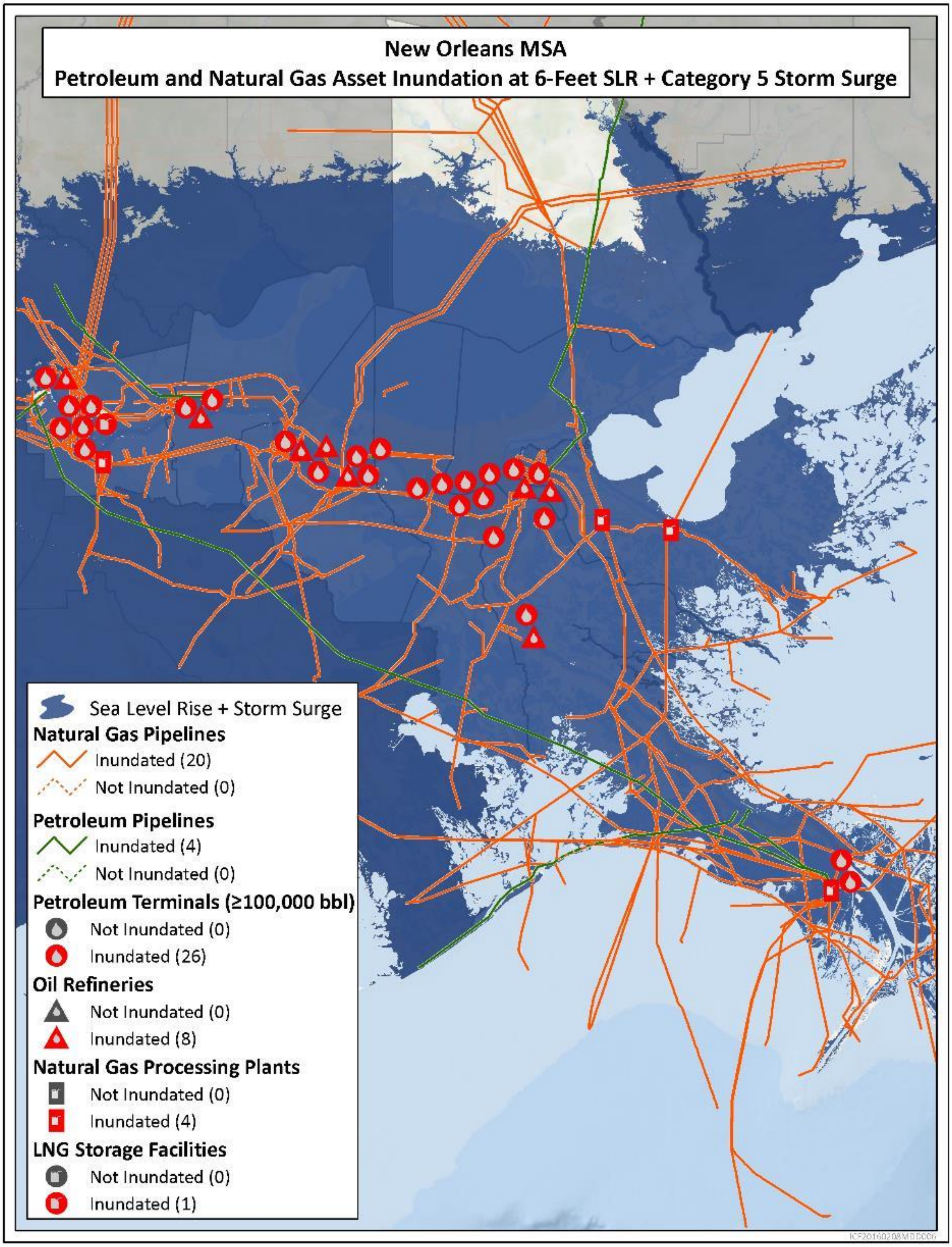


Figure 6b. Large Petroleum and Natural Gas Assets Inundated by 6 Feet of SLR under the NCA Intermediate-High Scenario and Category 5 Storm Surge in New Orleans MSA



Appendix B: Method for Estimating Areas of Inundation from Sea Level Rise and Storm Surge Combined

The method described below builds on techniques used in a recent study by Oak Ridge National Laboratory.[17]

Data Sources

In order to estimate inundation of both sea level changes and areas flooded due to storm surge, several data sets were needed. This analysis made use of existing and well-established data sets where possible and only created new data where necessary. The data sets used include:

- **Sea Level Rise –** While many methods to create sea level rise scenarios are available using geospatial technologies, this report made use of the well-established and accepted data available from the NOAA Coastal Services Center (NOAA CSC).[18] NOAA CSC has created polygons representing the coastline at mean high higher water (MHHW)[19] as sea level changes over time. These are available at 1-foot intervals from zero (present sea level) to 6 feet. The 2- and 6-foot increments were used for this specific study.

- **Storm Surge –** NOAA's National Weather Service created the Sea, Lake and Overland Surges from Hurricanes (SLOSH)[20] model used to estimate storm surge heights associated with hurricanes by simulating the effects of storm size, forward speed, track, wind speed, and atmospheric pressure on water heights in the coastal zone. Data products from the SLOSH model are available for 39 basins along the coasts of the Atlantic Ocean, Gulf of Mexico, Caribbean Sea, and Hawaii that are exposed to hurricanes. SLOSH basins consist of a grid definition as well as various geographic features that route and impede the flow of water. Storm surge within a basin can be represented using a polar, elliptical, or hyperbolic grid with a variable resolution, with the higher resolutions associated with the area of interest. For example, the grid used in the current study for the New Orleans MSA had a horizontal resolution of approximately 1.8 miles at its furthest point offshore and 0.06 miles at its most inland point.

  Surge is estimated in these regions by running the model several thousand times with hypothetical hurricanes of varying storm characteristics. A composite of these runs is then used to determine a Maximum Envelope of Water (MEOW), which shows the highest surge values at each grid location for a given storm category, forward speed, and general track direction. This study uses the Maximum of MEOWs, or MOM, for estimates of storm surge heights. This provides the "worst case" estimate for a particular storm category, rather than the specific flooding from a particular storm (http://www.nhc.noaa.gov/surge/momOverview.php).

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[17] Maloney and Preston, 2014.

[18] Available at: http://coast.noaa.gov/slrdata/.

[19] NOAA describes MHHW as "The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch." Available at: http://tidesandcurrents.noaa.gov/datum_options.html.

[20] Available at: http://www.nhc.noaa.gov/surge/slosh.php.

Although the latest science indicates that the intensity of the strongest storms may increase in the future,[21] the potential increase in intensity is difficult to quantify. This analysis includes storms that are stronger than what has previously been experienced in New Orleans. To account for potentially stronger storms in the future, the study analyzes Category 5 storms. Category 1 storms are also analyzed to illustrate the effects of exacerbation from SLR on smaller storms.

- **Elevation –** Land elevation data were used to calculate the sea level and storm surge inundation. The USGS produces the National Elevation Dataset (NED)[22] nationwide. This digital elevation model (DEM) is available in the New Orleans area at a horizontal scale of 1 arc-second (~30 meters) and was used for this study. The NED also includes a more detailed 10-meter resolution for many areas of the country including New Orleans, but the coarser elevation data were used to improve processing time and because the increase in elevation resolution would not enhance the results given the coarser resolution of the SLOSH model.

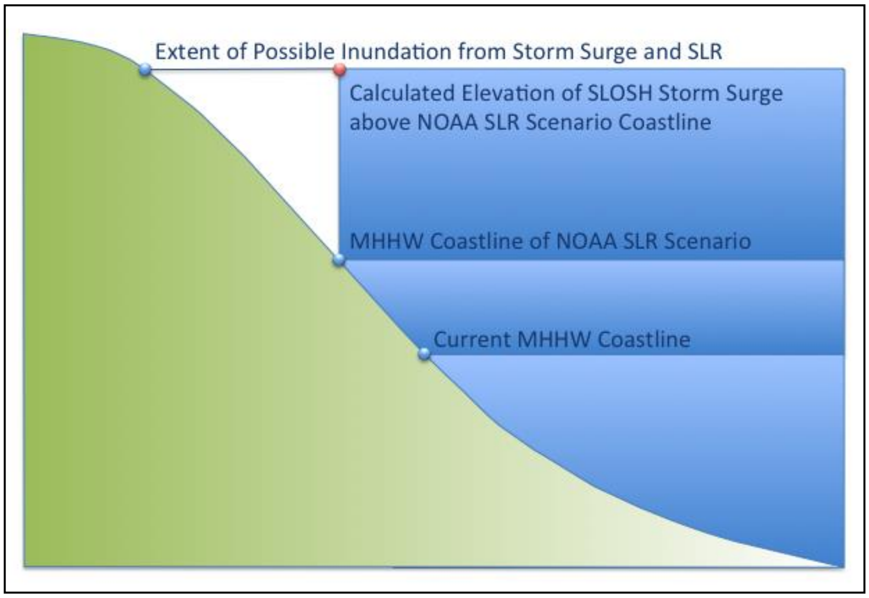
Approach to Estimating Storm Surge Flooding

In order to explore the effects of increased storm surge levels due to sea level changes, an estimate of the areas of potential flooding was made. Generally, and as illustrated in Figure 7 below, the method starts by using the MHHW coastline from the specific NOAA SLR scenario. The depth of inundation from the SLOSH model scenario was added to the depth of inundation from the sea level rise scenario to find the elevation of the storm surge above the SLR scenario. This calculated elevation was then extended toward the coast to find the extent of the possible inundation. These data could then be compared to the infrastructure to determine facilities that may be affected by such a combined scenario (for example, what power plants might be inundated by a Category 5 storm occurring after 6 feet of sea level rise).

[21] Melillo et al., 2014.

[22] Available at: http://ned.usgs.gov/.

Figure 7. Schematic of Sea Level Rise Plus Storm Surge Analysis



Specifically, the analysis goes through the following steps:

- Using ArcGIS 10.2 (Esri) to perform the spatial analysis functions, a series of observation points were created from the polygons of the specific NOAA CSC sea level rise scenario (2 and 6 feet).
- These points were spatially overlaid on the SLOSH model output for a specific Saffir-Simpson category of storm (Category 1 and Category 5) to join the depth of inundation at that location to the observation points.
- Those same points were compared with the NED elevation model to join the elevation to the observation points. Then, the elevation and depth of inundation values were added to get a height of water for that particular scenario at that observation point.
- With the series of points now having an estimate of inundation an Inverse Distance Weighting[23] was calculated from the observation points to create a continuous surface, modeling the given sea level and storm surge scenario. The output was set to same resolution as the DEM—30m.
- The resulting output surface was compared to the elevation of the DEM. Given that the vertical accuracy of NED elevation model is expressed as a root mean square error of 2.44 m [24] and the various uncertainties associated with the SLOSH model, the resulting inundation grids did not maintain any depth of inundation data. Instead, areas where the scenario was higher than the DEM elevation were considered inundated and conversely, areas where the scenario was lower than the DEM elevation were considered dry—or not inundated.
- The inundated cells were converted to polygons representing areas of inundation. These polygons were then used to identify which energy infrastructure facilities could be at risk of inundation based on the specific sea level rise and storm surge scenario.

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[23] Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points (Esri – 2014).

[24] Gesch, D.B., 2007. The national elevation dataset, Chap. 4 of Maune D., ed., Digital Elevation Model Technologies and Applications–The DEM Users Manual, 2nd ed. American Society for Photogrammetry and Remote Sensing, p. 99–118. Available at: http://topotools.cr.usgs.gov/pdfs/Gesch_Chp_4_Nat_Elev_Data_2007.pdf.