Evaluation of Remedy Resilience at Superfund NPL and SAA Sites

Following a very active hurricane season in 2017, EPA gathered information on the performance of remedies in areas impacted by Hurricanes Harvey, Irma and Maria. The report was developed for internal use to provide a program-level analysis of remedy resilience at Superfund National Priorities List (NPL) and Alternative Approach (SAA) sites in affected areas. The findings will inform the Superfund remedial program's climate change adaptation efforts. EPA has decided to release this internal report due to public interest in how Superfund remedies responded to the 2017 hurricanes, and as part of a Freedom of Information Act request.

United States
Environmental Protection
Agency

Office of Land and Emergency Management
Final August 2018

Evaluation of Remedy Resilience at Superfund NPL and SAA Sites

Final Report

NOTICE AND DISCLAIMER

Preparation of this report has been funded wholly or in part by the U.S. Environmental Protection Agency (EPA) under contract number EP-W-14-001 with ICF. This report is intended for internal use by EPA and is not intended for public release.

ACKNOWLEDGEMENTS

The following individuals contributed to the development and review of this document:

Carlos Pachon - Headquarters

Anne Dailey - Headquarters

Stephanie Vaughn – Region 2

Hilary Thornton – Region 4

Raji Josiam – Region 6

Table of Contents

Tables

Figures

1. Introduction

The Office of Superfund Remediation and Technology Innovation (OSRTI) prepared this report to continue its effort to determine how resiliency measures are considered in conceptual site models, remedy system designs and operations, and how resilience is built into remedies at National Priority List (NPL) sites and sites with Superfund Alternative Approach agreements (hereinafter referred to as SAA sites for brevity). Following a very active hurricane season in 2017, EPA sought to gather information on the performance of remedies in areas recently impacted by Hurricanes Harvey, Irma and Maria. This effort was a "desktop analysis", gathering information from existing sources, such as the Superfund Enterprise Management System, media, site reports, etc., and where needed by contacting remedial project managers (RPMs). The report is intended as a program level analysis of remedy resilience, and the findings serve to continue to inform the Superfund remedial program's climate change adaptation efforts, including training RPMs, providing adaptation tools, and capturing and sharing best practices. The report focuses on remedial actions at Superfund NPL and SAA sites. The report does not cover non-remedy related impacts, or impacts to non-NPL removal sites or cleanups under other cleanup programs.

In June 2011, EPA issued a *Policy Statement on Climate-Change Adaptation* (revised 2014; EPA, 2014) which recognized that climate change can pose significant challenges to EPA's ability to fulfill its mission. It called for the agency to anticipate and plan for future changes in climate and incorporate considerations of climate change into its activities. OSRTI conducted a program-wide vulnerability analysis in 2011-2012 that resulted in the internal February 2012 report *Adaptation of Superfund Remediation to Climate Change* (EPA, 2012). This analysis considered to what degree Superfund NPL and SAA sites were vulnerable to flooding and sea-level rise, and selected candidate sites to use as case studies for assessing how project managers evaluated and responded to the effects of climate change on Superfund remedial actions. In 2013, Federal Agencies were directed by Executive Order 13653 to consider how climate change may affect their capacity to implement their core missions. Based on the findings of the 2012 report, and as part of the Agency and the Office of Land and Emergency Management's (OLEM) response to the executive order, EPA determined that the existing regulatory framework included the authorities and guidance needed to address the challenge, and no changes were needed. Therefore, EPA focused on developing technical guidance, information tools, and training to raise awareness among stakeholders, including our remedial project managers. The technical guidance tools were designed to be "program neutral", and could be used at any contaminated site cleanup, regardless of the regulatory framework under which it was conducted.

OLEM participated in the cross-agency workgroup that developed EPA's Climate Change Adaptation Plan. The final Climate Change Adaptation Plan released in 2014 (EPA, 2014b) examined how EPA programs may be vulnerable to a changing climate and how the Agency can accordingly adapt in order to continue meeting its mission of protecting human health and the environment. In addition to the Agency Plan, the 2011 *Policy Statement* also directed every EPA program and regional office to develop an Implementation Plan that provides more detail on how it will meet the priorities and carry out the work called for in the agency wide plan. In June 2014,

OSWER released its *Climate Change Adaptation Implementation Plan* (EPA, 2014c) which described OSWER's process for identifying climate change impacts to its programs and the plan for integrating consideration of climate change impacts into the office's work. Furthermore, OLEM continued to monitor the status of climate science, particularly as it relates to known or anticipated impacts on OLEM's program areas, as well as the effectiveness of its program activities under changing conditions, and update or adjust its direction as necessary. As part of this commitment to develop technical guidance, OSRTI released a series of Climate Change Adaptation Technical factsheets (EPA, 2013; EPA, 2014a; and EPA, 2015) focusing on adaptation measures that may be considered to increase a remedy's resilience to climate change impacts.

In 2017, Hurricanes Harvey, Irma and Maria served as stark reminders that the remedies at Superfund sites need to be resilient to the impacts of extreme weather. The 2017 hurricane season provided EPA an opportunity to assess how the initiatives taken by the Agency and Program Office over the previous years may have affected the performance of remedies in areas impacted by these three storms.

The 2017 Atlantic hurricane season was an extremely active[1] hurricane season that produced 10 hurricanes including 6 major hurricanes[2], category 3 and higher. Hurricane Harvey was the first major hurricane to make continental U.S. landfall since 2005, arriving at the Texas coast as a category 4 hurricane on August 25, 2017 (NOAA, 2018a). Two weeks later, Hurricane Irma made landfall in the northern Caribbean four times as a category 5 hurricane, passing 50 nautical miles north of Puerto Rico on September 6, 2017. Four days later on September 10, the hurricane reached the Florida Keys as a category 4 hurricane, and made landfall in southwestern Florida as a category 3 hurricane later that day (NOAA, 2018b). The Caribbean again experienced a category 5 hurricane in Hurricane Maria, which hit Puerto Rico as a high-end category 4 hurricane on September 20, 2017, the strongest hurricane to hit the island in 90 years (NOAA, 2018c). Preliminary estimates suggest the U.S. damage from these three storms exceeded $200 billion, making it the costliest hurricane season on record (Masters, 2017). More than 400 Superfund sites are located in the states and territories that prepared for the landfall of these three hurricanes. As part of EPA's emergency response efforts, EPA responders worked with EPA RPMs and other partners, including other federal, state, tribal, and local agencies, to assess potential impacts of the hurricanes on these sites. Their efforts, along with those of the National Hurricane Center and other organizations, provided information to help OSRTI in examining the resilience of remedies at Superfund NPL and SAA sites.

[1] The National Atmospheric and Oceanic Administration (NOAA) defines an extremely active season as having an Accumulated Cyclone Energy (ACE) index above 152.5 x 104 kt2 (corresponding to 165% of the 1981-2010 median), with at least two of the following three conditions: 13 or more named storms, 7 or more hurricanes, and 3 or more major hurricanes. Additional information is available at http://www.cpc.ncep.noaa.gov/products/outlooks/archives/hurricane2017/August/NorATL_Background.shtml

[2] A major hurricane is defined as category 3 or higher using the Saffir-Simpson hurricane wind scale, where category three corresponds to hurricane with wind speeds of 111-129 mph, category four is 130-156 mph and category 5 is 157 mph or higher.

For this study, EPA defined sites as being impacted by the hurricanes if a site experienced winds of tropical force or greater or was flooded. To identify these sites, EPA compiled a list of all Superfund NPL and SAA sites in EPA Regions 2 (Puerto Rico and the U.S. Virgin Islands only), 4 and 6, and compared site location to geographic information system (GIS) datasets containing wind and flood data for all three hurricanes.

EPA then gathered available information about how the remedies at the impacted Superfund NPL and SAA sites were affected by the hurricanes. This included identifying sites with potential damage to the remedies and sites where no damage was observed. In addition, available information was collected about resiliency measures at these sites. It is important to note that the information that was available for this study was not comprehensive and in some cases very limited. Therefore, the study is intended to provide only general observations about remedy resilience at Superfund NPL and SAA sites.

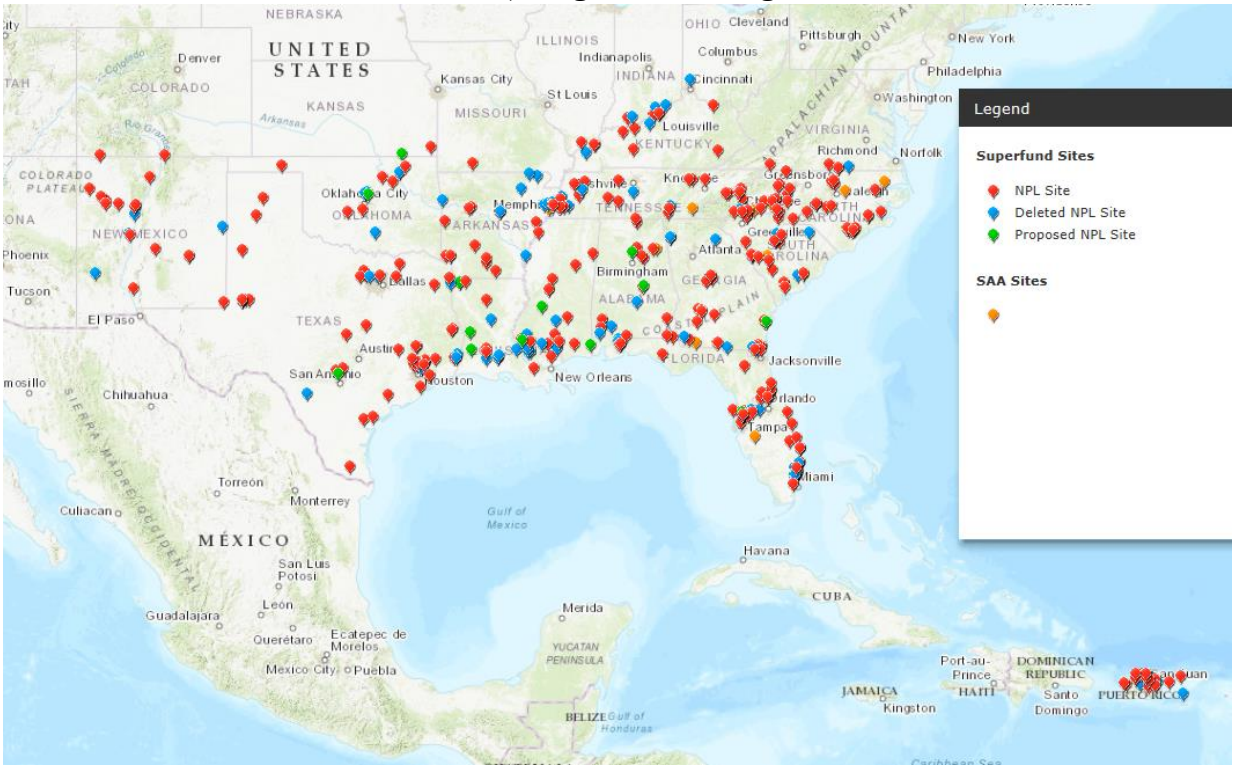
This report includes the following: a description of the methodology and data used in screening for impacted remedial sites; an analysis of the nature of impacts; a discussion of the sites that were not damaged by these hurricanes; and a summary of available information about implemented resiliency measures. An overview of each of the three hurricanes is included in Appendix A, and a list of impacted sites in Regions 2 (Puerto Rico and the U.S. Virgin Islands), 4 and 6 is included in Appendix B.

2. Identifying Superfund NPL and SAA Sites Impacted by Hurricanes Harvey, Irma and Maria

EPA used a step-wise approach to identify NPL and SAA sites that were impacted by Hurricanes Harvey, Irma and Maria. EPA first developed a list of remedial sites located in Regions where the hurricanes made landfall, Region 2 (Puerto Rico and the U.S. Virgin Islands only), Region 4 and Region 6. The list of sites was acquired from EPA.gov[3], and contained proposed, final, and deleted NPL sites and SAA sites. The dataset included 445 remedial sites. Site locations are single-point latitude and longitude coordinates as provided by EPA. Figure 1 shows the location of the 445 NPL and SAA sites. The data was mapped using ArcGIS to allow the depiction of floodplains, experienced wind swath and inundation data in relationship to the site locations.

[3] https://www.epa.gov/superfund/search-superfund-sites-where-you-live , accessed September 29, 2017

Figure 1. Superfund NPL and SAA Sites in Region 2 (Puerto Rico and the U.S. Virgin Islands), Region 4 and Region 6



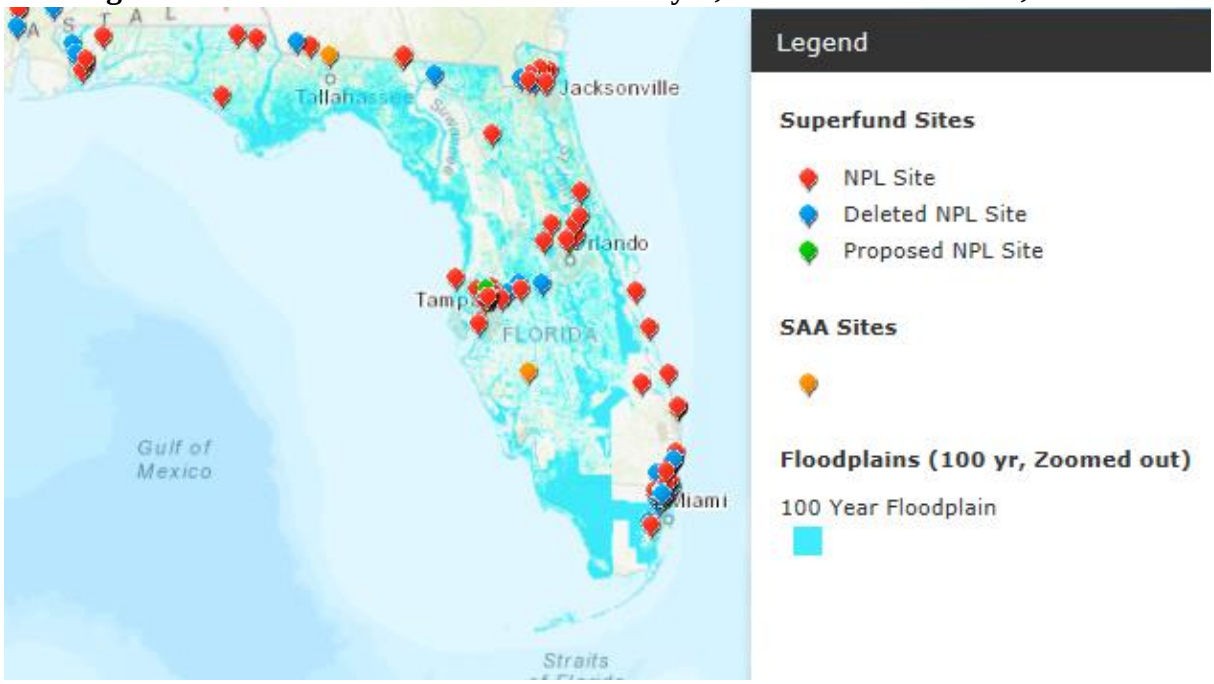
- Number of Sites in Region 2 (Puerto Rico and the U.S. Virgin Islands), Region 4 and Region 6 = 445.

Identifying Superfund NPL and SAA Sites in Floodplains

The Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL)[4] was compared to site locations to identify those sites situated in floodplains. This dataset represents current effective flood data for the country, where available, and is a compilation of data from the effective Flood Insurance Rate Map databases and Letters of Map Change. The sites were categorized as located in a 100 year floodplain, 500 year floodplain, floodway, or minimal flood hazard. Sites in areas where no information was available were designated as "Floodplain Designation Unavailable." Figure 2 is an example of Superfund NPL and SAA sites in the 100 year floodplain for Florida.

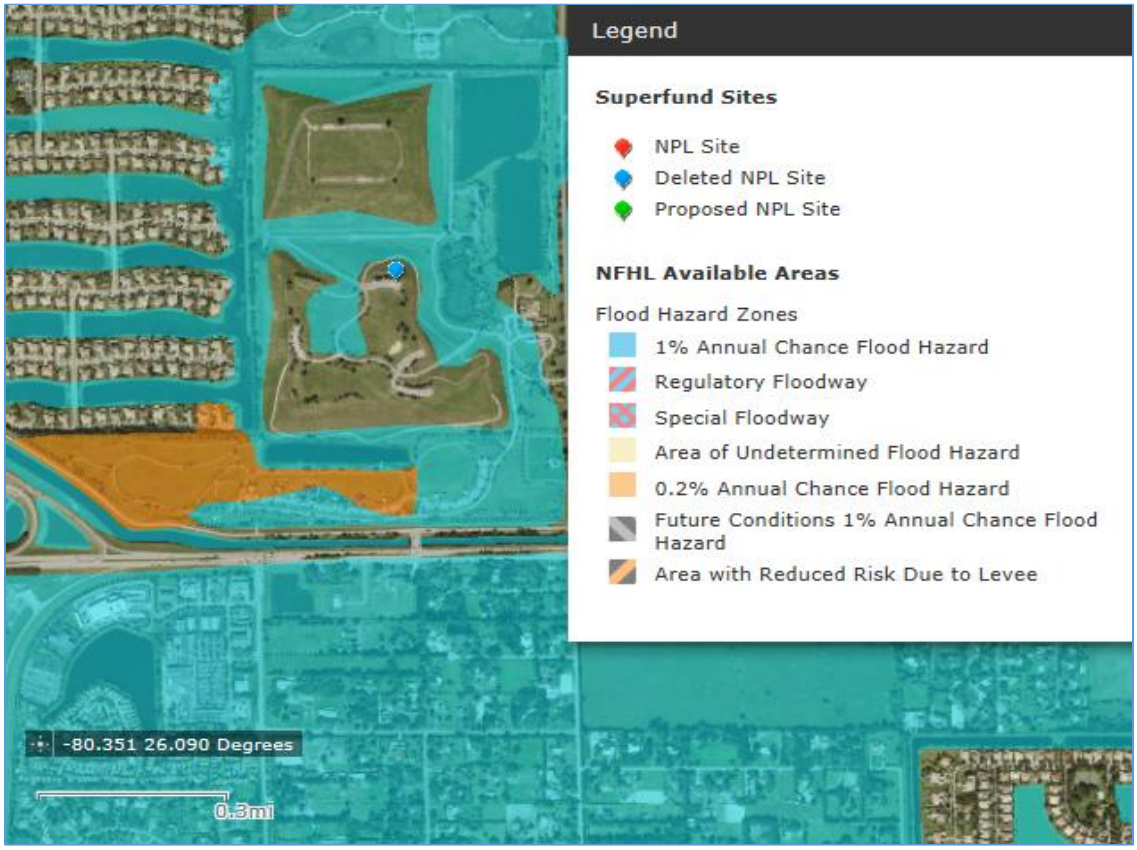
[4] https://fema.maps.arcgis.com/home/item.html?id=cbe088e7c8704464aa0fc34eb99e7f30 , accessed September 2017

Figure 2. FEMA National Flood Hazard Layer, 100 Year Flood Plain, Florida



Since the physical location of the sites was obtained using the single-point latitude and longitude coordinates, a portion of the site may lie in a floodplain even when the single coordinate did not. Figure 3 shows an example of a site where the site boundary is within a floodplain when the coordinate location is not. It was not necessary to "correct" the floodplain designation to the site boundary as no sites were eliminated from this study based on floodplain designation.

Figure 3. FEMA National Flood Hazard Layer, Davie Landfill, FL



The location of the single-point coordinate for Davie Landfill would suggest the site is not in a floodplain. However, plotting the site on 100 Year and 500 Year Floodplain Hazard Zones reveals a different situation. This is a known shortcoming of using single point coordinates and is addressed in the section on *Identifying Superfund NPL and SAA Sites that Experienced Flooding*, and in Figure 8.

Identifying Superfund NPL and SAA Sites that Experienced Wind

Wind data for all three hurricanes was obtained from the National Hurricane Center[5]. These datasets indicated spatial areas experiencing tropical-storm-force winds (39-57 mph), strong tropical-storm-force winds (58-73 mph), or hurricane-force winds (74 mph or greater) for each hurricane. As shown in Figures 4, 5, and 6, the wind data was compared to the site locations to categorize the severity of hurricane-generated winds at each remedial site for Hurricanes Harvey, Irma and Maria, respectively.

[5] https://www.nhc.noaa.gov/

Figure 4. National Hurricane Center Experience Wind Data for Hurricane Harvey

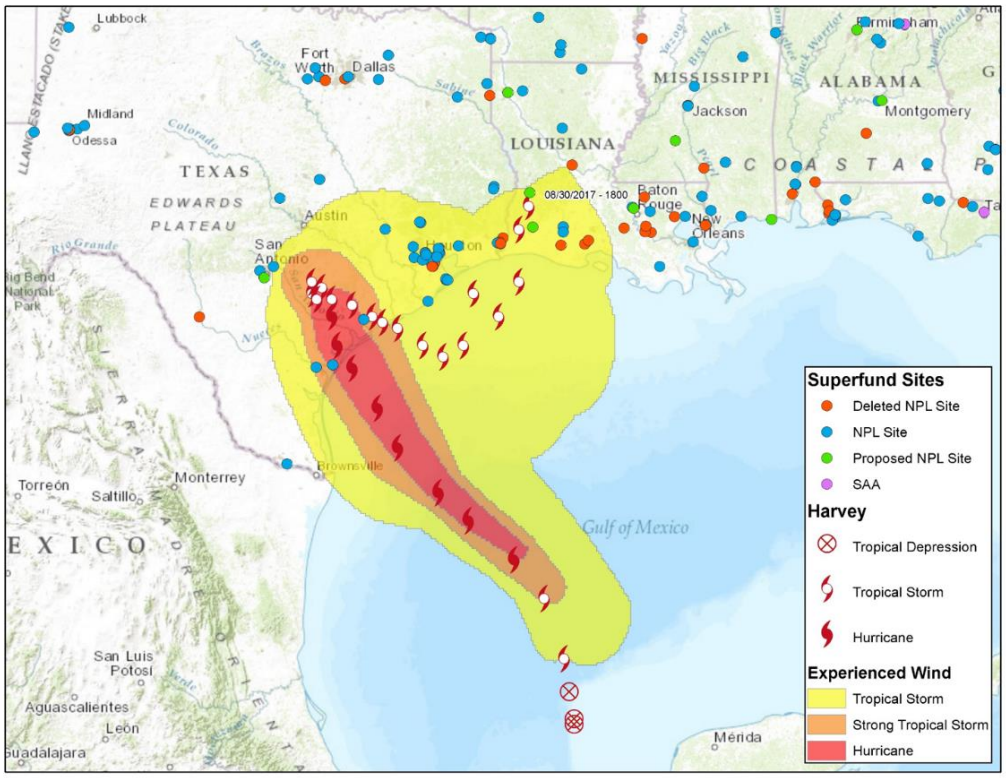


Figure 5. National Hurricane Center Experience Wind Data for Hurricane Irma

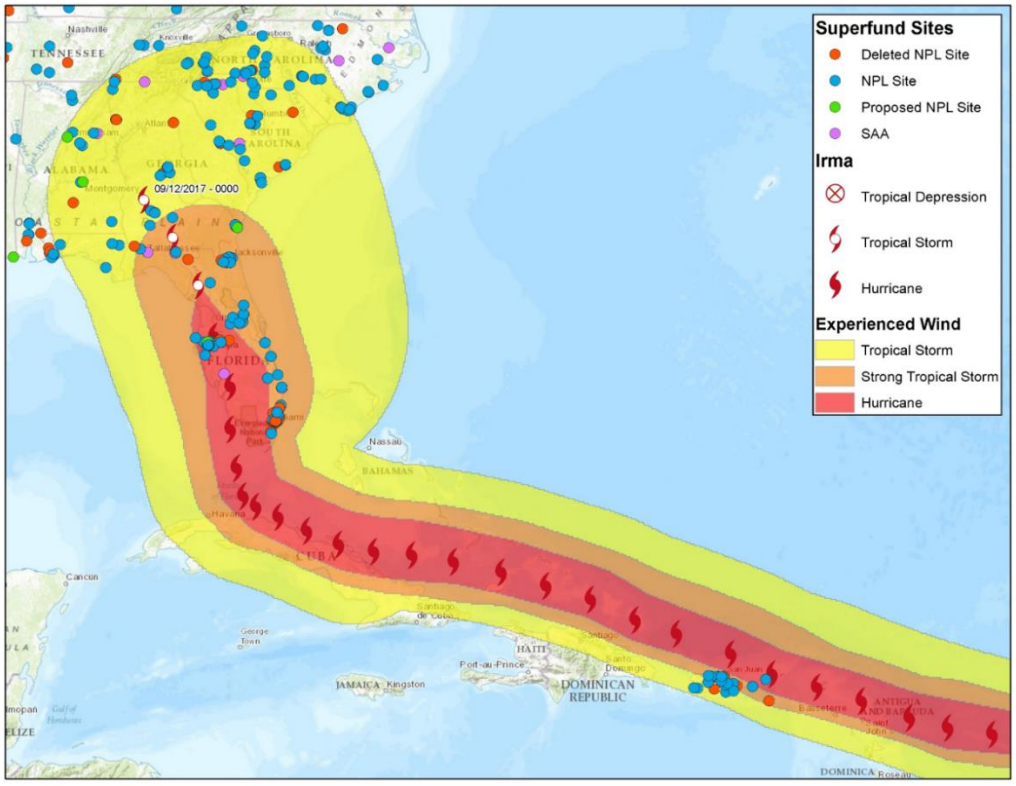
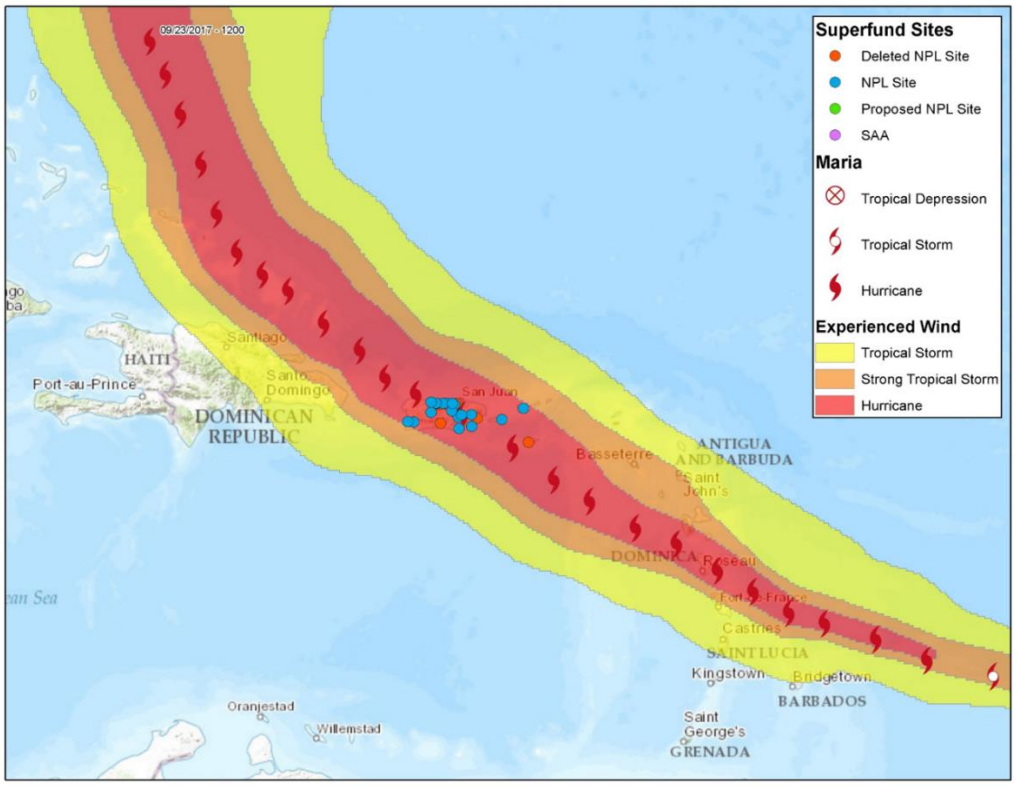


Figure 6. National Hurricane Center Experience Wind Data for Hurricane Maria

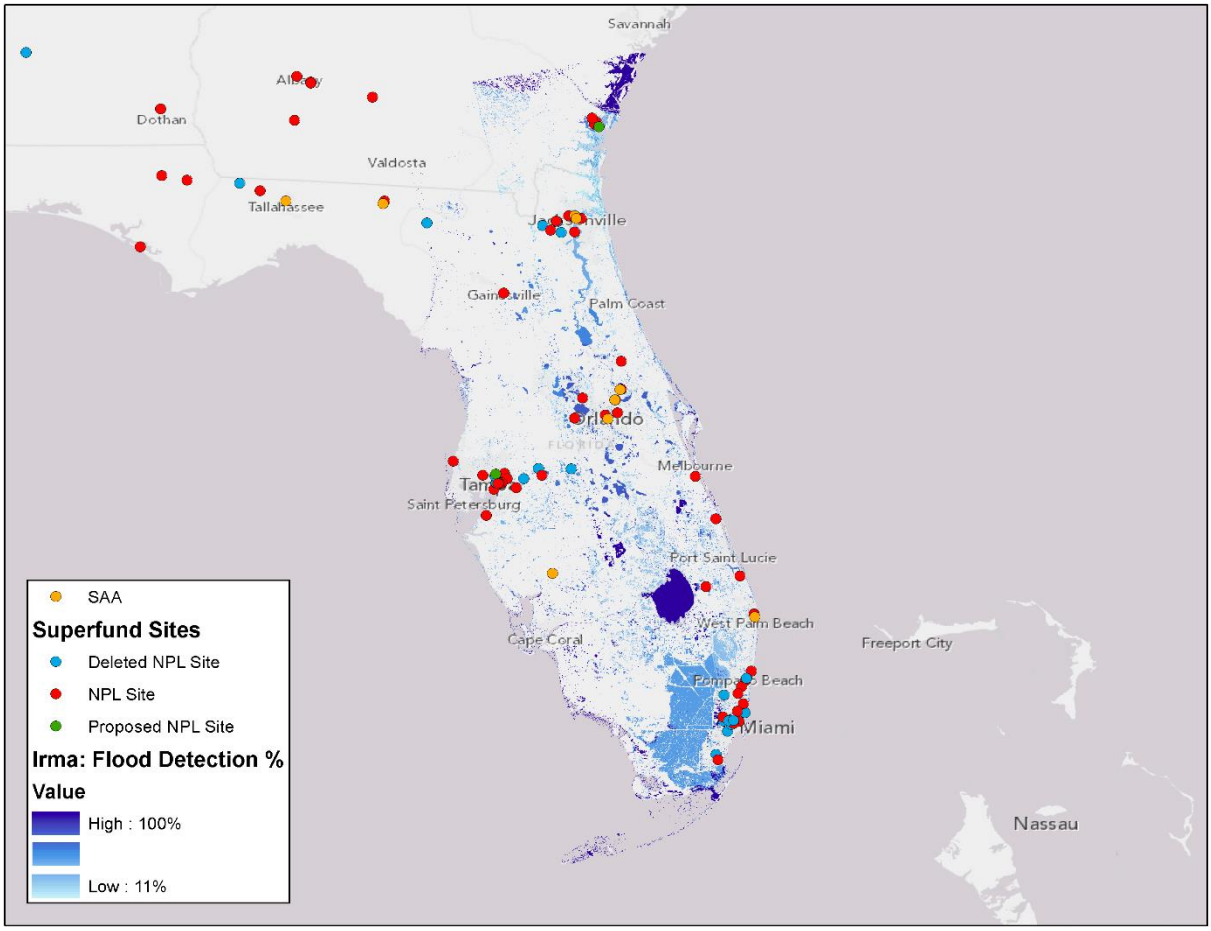


Identifying Superfund NPL and SAA Sites that Experienced Flooding

Superfund NPL and SAA site inundation was determined using FEMA Flood Detection Maps[6] for Hurricanes Harvey and Irma. For Hurricane Maria, EPA Region 2 reported that all Superfund NPL and SAA sites experienced inundation. The FEMA Flood Detection Maps were developed using data compiled from remote sensing imagery from multiple passes over the affected areas. The FEMA Flood Detection maps provide a Flood Detection Percent calculated by dividing the number of times a location was identified as flooded by the number of times a location was surveyed. Figure 7 shows the Flood Detection Map for Hurricane Irma, which includes the Flood Detection Percent calculated for impacted areas across Florida and Georgia.

[6] https://gis.fema.gov/arcgis/rest/services/FEMA/Flood_Detection_Map/MapServer , accessed October 2017

Figure 7. FEMA Flood Detection Percent Map for Hurricane Irma



The FEMA Flood Detection Maps were added as layers onto the site location map. Because the site locations are single-point latitude and longitude coordinates, a distance of 0.2 miles from that point was used as the estimated site boundary. A site was categorized as flooded if any flooding was identified within the estimated site boundary. If the site type and imagery suggested a larger or smaller site boundary, the site boundary was modified accordingly. The site boundary provided in a site decision document was used in a small number of cases. In this way, the frequency of flooding and the extent of flooding was taken into account. In Figure 8, the single point for Munisport Landfill is not shown as flooded, but within the site boundary there are areas where flooding was observed. Therefore, this site was categorized as flooded.

Figure 8. FEMA Flood Detection Percent Map for Munisport Landfill, FL

- Location of single-point coordinate and site boundary for Munisport Landfill in relation to FEMA Flood Detection Percent.

Findings

The 445 remedial sites identified in the regions where the hurricanes made landfall were compared against the observed wind data for the three hurricanes. This analysis identified 251 sites experiencing tropical-storm-force winds or above. The 445 sites were also compared against the flood data; the comparison determined that 63 sites experienced flooding. All but one of the flooded sites also experienced tropical-storm-force winds or above from a hurricane. Therefore 252 sites of the 445 sites were determined to be impacted by a hurricane either by wind or flooding. Table 1 shows the 252 sites that were flooded or experienced heavy winds from the hurricane, and where they were located in relation to FEMA floodplains. Table B-1 in Appendix B provides a list of the 252 sites impacted by flooding or wind from one or more of the hurricanes.

Table 1. Summary of Flooding and Hurricane Wind Impacts at 252 Superfund NPL and SAA Sites from Affected by Hurricanes Harvey, Irma and Maria.

				Wind Force			
FEMA Floodplain Designation	Total # of Sites	Flooded	Total (% by Floodplain)	Hurricane	Strong Tropical Storm	Tropical Storm	Below Tropical Storm
100 Year	42	No	23 (55%)	5	7	11	
		Yes	19 (45%)	6	6	7	
500 Year	8	No	5 (62%)		2	3	
		Yes	3 (38%)	1	2		
Floodway	7	No	2 (29%)			2	
		Yes	5 (71%)	2		3	
Minimal Flood Hazard	169	No	123 (73%)	14	22	87	
		Yes	46 (27%)	22	18	5	1
Designation Unavailable	26	No	17 (65%)		4	13	
		Yes	9 (35%)		1	8	
Total	**252**	**No**	**170 (67%)**	**19**	**35**	**116**	**0**
		Yes	**82 (33%)**	**31**	**27**	**23**	**1**

3. Identifying Resiliency Measures at Superfund NPL and SAA Sites

For purposes of this report, resiliency measures are measures that ensure the capacity of the remedy to retain protectiveness. Resiliency measures include system components built into the design of the remedial action or preparedness actions taken at the time the site is considered under threat of an impact such as a hurricane. Examples of resiliency design measures include hurricane proof structures designed with concrete walls and steel doors to house groundwater treatment system components or engineered dikes and berms for drainage and erosion control. Examples of preparedness actions include securing or removing drums from an outside storage area, sand bagging, or conducting controlled drawdowns of a surface impoundment.

In order to narrow down the number of sites EPA would review for resiliency measures, EPA applied the following criteria:

- Sites with remedies that EPA considers to be the most vulnerable to the direct effects of a hurricane.
- Sites with remedies that were likely to be in place in 2017.
- Sites that had recent five-year review reports (FYR) that may provide information about resiliency measures.

The remedies of interest are considered susceptible to the direct effects of a hurricane, because they have infrastructure that could be damaged by high winds and flooding and because they

remain in place long enough to have a higher likelihood of being impacted by a hurricane. The remedies examined include those discussed in EPA's report *Adaptation of Superfund Remediation to Climate Change*, (EPA, 2012). The remedies of interest include: (1) all groundwater in situ remedies, (2) pump and treat, (3) on-site containment of source, (4) soil vapor extraction, (5) multi-phase extraction, (6) wetland redevelopment and (7) phytoremediation. Remedy information was collected for all 252 impacted sites in Regions 2, 4, and 6 using EPA's *Superfund Remedy Report, 15th Edition*[7], (EPA, 2017a). A total of 174 impacted sites contained one or more remedies of interest.

These candidate sites were narrowed down to those likely to have a remedy in place during the 2017 hurricane season. EPA identified remedies selected between fiscal year (FY) 2005 and 2012, as a timeframe allowing for remedies to have been implemented and potentially still active in 2017. This narrowed the list of sites to 83. EPA then then identified which of the 83 sites had a FYR published between fiscal year (FY) 2012 and FY 2017, resulting in a total of 36 sites to analyze. The availability of a recent FYR provided the opportunity to review information on the implementation of the remedy and any subsequent modifications. Finally, six additional sites of interest were identified for remedy resilience assessment. Of these six additional sites, three were in Region 4 and had experienced damage and three were in Region 2 and were under consideration for additional assessment of site conditions. Although EPA had selected remedies for these six prior to FY 2005, each of these sites had remedies of interest in place and had been the subject of recent FYRs.

The FYRs were reviewed for the 42 sites to identify resilient remedies and relevant site histories. Potential resiliency measures were determined by comparing the selected remedy as described in the site's most recent FYR with the "Examples of Adaptation Measures" tables in each of the three EPA Climate Change Fact Sheets, *Climate Change Adaptation Technical Fact Sheet: Groundwater Remediation Systems;*[8] *Climate Change Adaptation Technical Fact Sheet: Landfills and Containment as an Element of Site Remediation*[9]; *Climate Change Adaptation Technical Fact Sheet: Contaminated Sediment Remedies*[10]; (EPA, 2013; EPA, 2014a; and EPA, 2015). The "Examples of Adaptation Measures" tables in the factsheets contain potential adaptation measures for various remedy components with a description of how such measures are implemented and how they can help to prevent against extreme weather events including temperature, precipitation, wind, sea level rise and wildfires. The FYRs were reviewed to determine if a site had implemented any remedies containing measures that closely resembled the adaptation measures found in the factsheets.

In addition to analyzing descriptions of the selected remedies, the site history in each FYR was reviewed to determine if previous natural disasters had affected the site. Information from the site decision documents was sometimes used to provide additional detail on previous natural disasters. Sites that have been impacted by previous storm events consisting of heavy rain,

[7] https://www.epa.gov/remedytech/superfund-remedy-report
[8] https://semspub.epa.gov/src/document/HQ/175851.pdf
[9] https://semspub.epa.gov/src/document/HQ/175853.pdf
[10] https://semspub.epa.gov/src/document/HQ/177110.pdf

flooding and strong winds, may have had remedies in place to mitigate against potential threats. In addition, sites that were previously damaged may have taken steps to prevent against similar storms in the future. Comprehending the manner in which a site responded to natural disasters in the past can help to understand how and why a site was either damaged or avoided damage during the 2017 hurricane season.

Findings

Based on the analysis of the 42 FYRs, 31 sites reported resiliency design measures or preparedness actions in the FYR. The Case Studies in Section 5 include the specific resiliency measures noted for the selected sites. Examples of resiliency design measures and preparedness actions included:

- Engineered caps (including asphalt and concrete caps) with drainage and erosion control components such as revegetation.
- Automated shut-off controls and system notifications that prevent tank overflows and provide information on operating systems when sites are not accessible.
- Use of berms, dikes, stormwater collection systems and other drainage and erosion control measures.
- Use of structures built with concrete walls and ceilings and steel doors to house groundwater treatment system components.
- Alternative forms of power including backup generators or renewable sources of energy.
- Hazard preparedness plans including moving drums to enclosed structures, strapping tanks, controlled drawdowns of surface impoundments, and controlled shutdowns of operating remedial systems.
- Time-critical removal actions and interim actions at sites where permanent remedies are not yet in place.

4. Identifying Superfund NPL and SAA Sites with Damage from Hurricanes Harvey, Irma and Maria

After determining the Superfund NPL and SAA sites impacted by Hurricanes Harvey, Irma and Maria, EPA examined how remedies at these affected sites fared under these extreme conditions. Potential damage to site remedies was determined by reviewing EPA publications on the site status following each hurricane, and by discussing sites with regional EPA personnel. EPA developed websites to provide the public with safety information and updates on the response to the three hurricanes[11].

Hurricane Harvey

Within a week of Hurricane Harvey's landfall, the Agency had conducted initial assessments of 41 Superfund remedial sites in Texas and Louisiana through use of aerial images and direct contact with parties responsible for ongoing cleanup. EPA found that 28 sites were not impacted but 13 sites appeared to be flooded or experienced damage. Immediate field inspections were

[11] https://www.epa.gov/newsreleases/status-superfund-sites-areas-affected-harvey

possible at two of the 13 sites and neither was found to require emergency cleanup actions. Teams were assembled to investigate possible damage and collect samples at the remaining 11 sites as soon as floodwaters receded. EPA Region 6 released a series of fact sheets for a list of 43 Superfund sites within federally declared counties in Texas and Louisiana impacted by Hurricane Harvey[12]. These sites were assessed by EPA in the aftermath of the hurricane, and any releases or issues were reported in the fact sheets. The fact sheets were released soon after the assessment was completed, with updates to the reports released if sampling results or any other new information was obtained. Additionally, RPMs compiled a list of observed inundation and impacts for the 43 sites, noting if there were any damage impacts. Region 6 identified seven sites with some damage from Hurricane Harvey.

Hurricane Irma

Region 4 took precautions before Hurricane Irma, identifying 22 current or former NPL sites within southern Florida. Activities included taking necessary actions to shore up these sites appropriately working with parties responsible for their ongoing cleanups, and ensuring that staff in the area were safe. Region 2 assessed 23 Superfund and oil sites in Puerto Rico and the U.S. Virgin Islands to evaluate their vulnerabilities prior to Hurricane Irma. After the hurricane struck, Region 4's Superfund Division deployed six rapid assessment teams to assess all regional NPL sites[13]. Within one week of Hurricane Irma's landfall, EPA Region 4 completed initial assessments at 168 sites including 93 in Florida, 22 in Georgia, 17 in Alabama, and 36 in South Carolina[14]. EPA teams also began assessing Superfund sites and regulated facilities in the U.S. Virgin Islands and Puerto Rico. However, these efforts stalled as Hurricane Maria threatened the islands. Information on Superfund sites in Region 4 affected by Hurricane Irma was released in a one-time press release, including information for three sites reporting post-hurricane damage. Issues were identified at only three NPL sites. At the Post and Lumber Preserving Co, Inc. site in Quincy, Florida, a tear in the geomembrane cap was identified. At the Fairfax Wood Treating site in Jacksonville, Florida, stormwater runoff concerns were identified at an onsite retention point, and a washout under site fencing. Sampling of surface water indicated no significant issues. The Terry Creek Dredge Spoil Areas/Hercules Outfall site in Brunswick, Georgia experienced minor damage to site fencing and an outfall ditch. The 2017 interim Record of Decision (ROD) includes replacing the outfall canal with a concrete-lined stormwater channel along a different route and armoring the slope of the backfilled canal.

Hurricane Maria

In Puerto Rico and the U.S. Virgin Islands, Hurricane Maria caused damage to the infrastructure of the islands including island-wide power and telecommunication outages. Remedy resilience relies in part on regional infrastructure and as a result, remedies at Superfund NPL sites were adversely affected by the regional infrastructure damage. For example, at Tutu Wellfield the active remedy for the pump-and-treat system addressing groundwater contamination could not be operated due to electrical grid outages. The environmental concerns at the 26 Superfund sites in

[12] https://response.epa.gov/site/site_profile.aspx?site_id=12353
[13] https://www.epa.gov/newsreleases/epa-prepares-hurricane-irma
[14] https://www.epa.gov/newsreleases/epa-hurricane-maria-preparation-irma-recovery-update-september-19-2017

Puerto Rico and the U.S. Virgin Islands also included potential damage to remedies. The 26 sites underwent a multi-phase evaluation including a post-storm assessment and determination if a follow up site inspection was warranted. Site inspections were recommended for 13 sites, and 11 of these site inspections were conducted in October 2017. The remaining two sites were addressed at a later date[15]. Region 2 identified five sites with some damage from Hurricane Maria.

Findings

All reports and fact sheets were reviewed and used to create a list of sites adversely affected by the hurricane, and whether there was mention of flooding, site damage, or potential environmental releases. Additional information was obtained through conference calls including Regional Project Managers from Regions 2, 4 and 6. This list grouped sites by similar observed damage and compared to the type of hurricane impacts observed at each site (wind, flooding, or both). The reported damage categories included ancillary damage, fencing and other access control damage, containment related damage, and active system component damage. EPA found 16 of the 252 sites that experienced hurricane related impacts reported at least minor damage. Table 2 provides a list of the 16 sites, the hurricane related wind or flooding impacts observed at the site, the reported damage and the related decision documents (RODs, ROD Amendments [ROD Amds], Explanation of Significant Differences [ESDs] and FYRs). The majority of observed damage is categorized as Fencing and Other Access Control Damage or Ancillary Damage (nine sites). Three sites are categorized as having active system component damage and four sites are categorized as experiencing containment related damage.

[15] https://response.epa.gov/site/site_profile.aspx?site_id=12403

Table 2. Observed Damage from Hurricanes Harvey, Irma and Maria at 16 Superfund NPL and SAA Sites

Site Name	State	Observed Damage	Category of Damage	Decision Documents (FY)	Observed Wind or Flooding	FYR
Bailey Waste Disposal	TX	Earthen ramp to bridge eroded	Fencing and Other Access Control Damage	ROD 1988; ESD 1996 (2); ROD Amd 1996	Both	2015
Falcon Refinery	TX	Empty tank caved in	Ancillary Damage	ROD 2017	Both	NA
French, Ltd.	TX	Fence caved outward due to water current	Fencing and Other Access Control Damage	ROD 1988	Both	2017
Malone Services Company, Inc.	TX	Erosion of topsoil on the 30-Acre RCRA cell; hydromulch placed on cell washed off	Containment Related Damage	ROD 2009	Both	NA
San Jacinto River Waste Pits	TX	Erosion of armor cap; site warning buoy washed downstream; site warning signs knocked down/damaged; extensive site fencing damage	Containment Related Damage	ROD 2018	Both	NA
Triangle Chemical Company	TX	Section of fence is to be repaired	Fencing and Other Access Control Damage	ROD 1985	Both	2016
US Oil Recovery	TX	Different containments in the former municipal wastewater treatment plant overflowed	Containment Related Damage	None	Both	NA
Fairfax St. Wood Treaters	FL	Minor damage fencing	Fencing and Other Access Control Damage	ROD 2017	Wind	NA
Post and Lumber Preserving Co. Inc.	FL	Geomembrane tear	Containment Related Damage	None	Wind	NA

Site Name	State	Observed Damage	Category of Damage	Decision Documents (FY)	Observed Wind or Flooding	FYR
U.S. Naval Air Station Cecil Field	FL	Compressor failure of the air sparging unit due to flooding	Active System Component Damage	ROD 1996, 1998, 2001; ROD Amd 1998, 2000	Both	2016
Terry Creek Dredge Spoil Area/Hercules Outfall	GA	Minor damage to security fencing and underflow weir in the outfall ditch	Fencing and Other Access Control Damage	None	Both	NA
Pesticide Warehouse I	PR	Fencing or physical safety damage	Fencing and Other Access Control Damage	None	Both	NA
Pesticide Warehouse III	PR	Fencing or physical safety damage	Fencing and Other Access Control Damage	ROD 2015	Both	NA
Scorpio Recycling, Inc.	PR	Fencing or physical safety damage	Fencing and Other Access Control Damage	ROD 2006, 2013	Both	NA
Upjohn Facility	PR	Active pump and treat system experienced sustained power outage; damage to aeration tower	Active System Component Damage	ROD 1988, ESD 1989	Both	2013
Tutu Wellfield	VI	Active pump and treat system experienced sustained power outage, resulting in oxidation and seizing of equipment and programmable logic controller components	Active System Component Damage	ROD 1996, ESD 2003	Both	2014

5. Case Studies of Impacted Sites

Case studies are provided for six sites that experienced a hurricane but were able to avoid damage to remedies. Case studies are also provided for six sites experiencing damage to a remedy. These sites were chosen for a case study because information was available on the site remedy components and resiliency measures that may have prevented damage to the remedies or mitigated further damage. Resiliency measures obtained from FYRs or decision documents are referenced at the end of each case study. The site background information was taken from the Superfund Site Profile page for each site[16].

Sites with Noted Resiliency Measures and No Damage

Summaries are provided for six sites in Region 2, Region 4 and Region 6 that experienced hurricane impacts yet did not report any damage. These sites all had a combination of resilient remedy components in place that may have played a role in preventing damage to site remedies.

Region 2

Fibers Public Supply Wells (PR) is located in Guayama, in southeast Puerto Rico. The Site encompasses about 540 acres, including a former fiber manufacturing plant, the Baxter facility, a former sugar cane field, and five closed public water supply wells owned by the Puerto Rico Aqueduct and Sewer Authority (PRASA). The contaminated groundwater plume is present in both the overburden and fractured bedrock and the primary COCs are chlorinated VOCs and haloethers. The chlorinated VOC impacts are generally limited to tetrachloroethene (PCE). Selected remedies include groundwater pump and treat and soil excavation. The site experienced tropical-storm-force winds from Hurricane Irma, and hurricane-force winds and flooding from Hurricane Maria. The treatment system was removed from service as a precaution in advance of Hurricane Irma making landfall in Puerto Rico. The system remained off until December 5, 2017 and was 70% operational during December and became 95% operational in January 2018. (EPA, 2014f)

Region 4

Anniston Army Depot (Southeast Industrial Area) (AL) is a 15,319-acre site and an active U.S. Army installation in Calhoun County, Alabama, 10 miles west of Anniston. The installation provides munitions storage and refurbishment, testing and decommissioning of combat vehicles and various types of ordnance. In the past, operations generated solid and liquid wastes that contaminated soil and groundwater. Selected remedies include groundwater pump and treat and in situ bioremediation, and capping of contaminated soil. The pump and treat remedy was still operating as of the most recent FYR and site profile update. The site experienced tropical-storm-force winds from Hurricane Irma, and had no reported damage. Portions of the site are in a 100-year floodplain. As resiliency measures the site utilizes riprap along ditches and is equipped with alarms that can automatically shutoff groundwater pumps to prevent overfilling of treatment tanks. The system can notify operators of faults occurring, thereby avoiding releases during

[16] https://cumulis.epa.gov/supercpad/cursites/srchsites.cfm

circumstances when operators are not on site such as during extreme weather events. (USACE, 2015)

Holtra Chem/Honeywell Inc. (NC) is a 24-acre, former chlor-alkali manufacturing plant located in Riegelwood, North Carolina, 20 miles west-northwest of Wilmington, North Carolina. The Cape Fear River borders one side of the plant. The other three sides are fenced and bounded by International Paper's Riegelwood Mill (IP). The plant was originally constructed to provide chlorine gas, caustic soda, and bleach to the adjacent IP facility, using a mercury cell process. Holtra Chem discharged process wastewater generated during chlorine production to IP's wastewater treatment system. Removal actions conducted in 2002 and 2008 included removing various hazardous chemicals, tanks, piping, asbestos, PCB contaminated soil and other miscellaneous debris from the site. The site experienced tropical-storm-force winds from Hurricane Irma, and reported no damage. The site has experienced damage from hurricanes in the past, including in 1999 when Hurricane Floyd caused flooding that resulted in a release of contaminated water. Prior to Hurricane Isabel in 2003, preparations were made to the site to mitigate damage. Activities included stabilization of tarps on roll-off boxes, movement of drums containing hazardous substance into warehouses, and strapping down loose items. Hurricane Isabel passed through the area on September 17, 2003. The PRP's contractor handled all water and reported that only minor damage occurred to the cell building metal sheeting. The 2017 Record of Decision[17] selected in-situ stabilization with Subtitle C cap of the treated area, a geosynthetic liner and cap with vegetative cover over contaminated soil, an onsite disposal unit that meets Toxic Substances Control Act (TSCA) chemical waste landfill requirements, closure of underground storm water conveyance system, and erosion control measures to control sedimentation from stormwater runoff (EPA, 2017d).

Jacksonville Naval Air Station (FL) is an active U.S. Navy Installation in Jacksonville, Florida. The installation currently provides facilities and support for the operation and maintenance of naval weapons and aircraft. EPA placed the site on the NPL in 1989 because of contaminated soil, sediment, groundwater and surface water. Selected remedies include in situ bioremediation of groundwater and caps for contaminated soil and sediment. The site experienced strong tropical-storm-force winds and flooding from Hurricane Irma, and had no reported damage. A portion of the site is located in a 100-year floodplain. Site documents note that hurricane-force winds are expected every 5 years, and historically heavy rains have led to contamination releases. Therefore, caps for contaminated soil include concrete caps or engineered caps with a 30-mm geomembrane layer to prevent water migration. (Dept. of the Navy, 2016)

Savannah River Site (SC) is a secured U.S. Department of Energy (DOE) facility. The facility produced tritium, plutonium and other special nuclear materials for national defense and the space program. A range of nuclear-related research and production operations are ongoing at the site. Past disposal practices caused site contamination. Selected remedies have been implemented in many areas of the site including groundwater pump and treat, capping of contaminated soil, soil vapor extraction, in situ stabilization, placement of soil covers with revegetation, and drainage and erosion control. The site experienced tropical-storm-force winds from Hurricane

[17] https://semspub.epa.gov/work/04/11070121.pdf

Irma, and had no reported damage. Historically, precipitation has resulted in the raising of the water table to come in contact with contaminated soils. To minimize infiltration of precipitation into contaminated soil, a low permeability soil and vegetative cover was installed over soils treated via in-situ stabilization. Furthermore, the site has used solar powered vacuums to assist in the removal of volatile organic compounds (VOCs), and has backup power for emergency situations. (EPA, 2013d; EPA, 2013e; EPA, 2015b)

***Region** 6*

North Cavalcade Street (TX) is a 21-acre site is located in Houston, Texas. Houston Creosoting Company established wood-preserving operations on site in 1946. These operations continued until 1961, contaminating the site with hazardous chemicals. Selected remedies have included recovery of dense non-aqueous phase liquid, groundwater pump and treat, in situ stabilization, in situ bioremediation and capping of contaminated soil. The site experienced tropical-storm-force winds and flooding from Hurricane Harvey, and had no reported damage. The site has experienced localized flooding in the past. To combat this, the site has three storm water drainage ditches which lead to a flood control ditch. The on-site containment cell uses a geo-composite drainage net, polyethylene geomembrane, and a geo-synthetic clay liner, with grasses planted and maintained for cover. Finally, leachate wells allow for monitoring of groundwater to ensure surface water has not entered the cell. (EPA, 2013c)

Sites with Damage

Summaries for sites with reported damage are provided for six sites from Region 2, Region 4 and Region 6. In addition to describing the damage sustained at the site, the summaries also detail resiliency measures that may have assisted in mitigating damage to the site remedies.

Region 2

Upjohn Facility (PR) is a 2-acres site located in Barceloneta, Puerto Rico. A pharmaceutical manufacturing plant operated at site. A leak in an underground storage tank contaminated wells on site. Soil and groundwater are contaminated with carbon tetrachloride. Selected remedies include groundwater pump and treat. The site experienced strong tropical-storm-force winds from Hurricane Irma and hurricane-force winds and flooding from Hurricane Maria, with sustained loss of grid power to the pump and treat system. In addition to damage to electrical equipment, the aeration tower, containing the groundwater treatment system, was substantially destroyed by wind and debris. Damage was also reported for the heat exchange unit of the soil vapor extraction (SVE) system (covered under the RCRA program) due to power surges, with the SVE system offline until May 2018.The site uses an automated computerized monitoring and data collection system with remote access and automated notification system for groundwater extraction and treatment, dedicated electrical feed, security camera system and solar powered lighting. These systems allow for site managers to monitor, control and suspend remedial activities during emergencies. (EPA, 2013a)

Tutu Wellfield (VI) is located in east-central St. Thomas in the U.S. Virgin Islands. The site consists of a plume of contaminated groundwater covering an area about 108 acres in size. VOCs were contaminating several public, institutional, commercial and private wells. Selected remedies include groundwater pump and treat and soil vapor extraction. The remedy was

constructed with the local weather conditions in mind. The systems are housed in hurricane proof structures with solid concrete walls and roofs and steel doors and the extraction wells are constructed in flood resistant vaults. The site experienced hurricane-force winds from Hurricanes Irma and Maria. The hurricane proof structures remained intact but sustained a five month long loss of power due to area wide utility damage. During this five month period in the tropical moist environment, equipment and programmable logic controller (PLC) components oxidized and seized requiring replacement. (EPA, 2014e with additional detail provided by Region 2)

Region 4

Fairfax St. Wood Treaters (FL) is a 12-acre site located in Jacksonville, Florida. The site includes an area operated as a chromium copper arsenate (CCA) wood-treating facility from 1980 to 2010. The site was proposed to the NPL in March 2012 and was finalized in September 2012 because of contaminated soil, sediment and surface water resulting from facility operations. Removal actions, or short-term cleanups, in 2010 and 2011, included removing contaminated soil on the Susie E. Tolbert Elementary School playground located near fence line with the site; removing contaminated water and sediment from the retention pond on the school property; removing contaminated soil from unpaved parts of the former wood-treating facility; treating and disposing of more than 150,000 gallons of contaminated water; cleaning and removing chemical storage tanks, containment area and piping; removing contaminated soil from three residential properties; covering exposed soils with gravel to prevent the spread of contamination through dust and stormwater runoff; transporting contaminated soil, sludge and debris off site for proper disposal; and repairing and placing a lock on site fencing. Although not in place at the time of the hurricane, the remedies selected in the 2017 ROD include soil, sediment, debris and residual waste excavation. The site experienced strong tropical-storm-force winds from Hurricane Irma, with minor damage to fencing. Located just outside a 500-year floodplain, the site employs a stormwater management system consisting of drainage ditches and a retention pond with an overflow pipe. (EPA, 2017b)

Region 6

Bailey Waste Disposal (TX) is 280-acre site located in Bridge City, Texas. The site owner constructed two ponds on site in the early 1950s as part of the Bailey Fish Camp. The fish camp operated at the site until 1961, when Hurricane Carla introduced saline waters into the ponds, killing the freshwater fish. Disposal of industrial and municipal waste took place near the ponds until 1971. Waste disposal activities contaminated groundwater, surface water and soil. Selected remedies include an engineered cap, in situ stabilization, and drainage and erosion control. The site experienced tropical-storm-force winds and flooding from Hurricane Harvey, with minor damage to an earthen ramp leading to the site. Portions of the site are located in a 100-year floodplain. Resiliency measures incorporated into its selected remedies included the use of geo-synthetic clay liner material, storm water management controls to divert runoff from active areas of the site, and a vegetative cover for the geotextile cap with riprap added to reinforce susceptible areas including cap perimeter. (EPA, 2013b)

French, Ltd. (TX) is a 55-acre site located in Crosby, Harris County, Texas. Site uses between 1950 and 1973 included sand mining and operation of an industrial waste storage and disposal

facility. Between 1966 and 1971, 90 million gallons of industrial wastes from petrochemical companies were disposed of on the property. Site activities and waste disposal practices contaminated groundwater, surface water, soil and sludge with hazardous chemicals and heavy metals. Selected remedies include groundwater pump and treat and in situ bioremediation of soil and sludge. The site experienced tropical-storm-force winds and flooding from Hurricane Harvey, with minor damage to fencing. Portions of the site are located in a floodway, with the site experiencing past flooding in 1969, 1973, 1979 and 1983 that resulted in releases from an on-site lagoon. To mitigate the effects of flooding, the site remedy includes a lagoon floodwall, planting of natural vegetation to control erosion and planting of trees to uptake groundwater. (EPA, 2017c)

San Jacinto River Waste Pits (TX) is located in Harris County Texas, east of the City of Houston, between two unincorporated areas known as Channelview and Highlands. The site consists of impoundments built in the mid-1960s for the disposal of solid and liquid pulp and paper mill wastes, and the surrounding areas containing sediments and soils impacted by waste materials disposed of in the impoundments. In 1965 and 1966, pulp and paper mill wastes (both solid and liquid) were transported by barge to the site and deposited in the impoundments. The northern set of impoundments, approximately 14 acres in size, are located on a partially submerged 20-acre parcel on the western bank of the San Jacinto River. The Southern Impoundment, less than 20 acres in size, is located on a small peninsula that extends south of I-10. The primary hazardous substances documented at the Site are polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans. A Time Critical Removal Action (TCRA) to address temporarily the hazardous substances associated with the northern impoundments was completed in July 2011. The TCRA included the installation of geotextile and geomembrane underlayments in certain areas and a temporary armored cap. The temporary cap constructed over the northern waste pits in 2010 and 2011 experienced repeated damage and repairs during the seven years since construction. The site experienced tropical-storm-force winds and flooding from Hurricane Harvey. The responsible parties hired a crew to temporarily repair sections of the cap armor above water. EPA deployed its Emergency Response Team divers to help Region 6 assess the submerged sections. The divers inspected the cap and confirmed the submerged northwest area of the cap had been damaged. Samples were collected in the damaged area, with one sample confirming high dioxin concentrations, above 70,000 nanograms per kilogram. The recent October 2017 San Jacinto ROD[18] considered the potential for the impacts of extreme weather, as demonstrated by text in the ROD in the Summary of the Rationale for the Selected Remedy on page 85:

> "The area has a high threat of repeated storm surges and flooding from hurricanes and tropical storms, which if the material was left in place, could result in a release of hazardous substances. Modeling by the U.S. Army Corps of Engineers projects a significant erosion of cap armor, even with the two most robust capping alternatives, as result of combined hurricane and flood conditions." (EPA, 2017e)

[18] https://semspub.epa.gov/work/06/100003945.pdf

6. Summary of Findings

The 2017 hurricane season provided an opportunity to gather data on the resiliency of Superfund remedies to extreme weather conditions. The data gathered, although not comprehensive, provide some general observations as well as some insight regarding the design measures that can help remedies remain protective during extreme wind and flooding.

General observations included:

- Damage was limited: only 16 of the 252 impacted Superfund NPL and SAA sites reported damage, and most damage reports were for auxiliary systems such as fencing.
- The analysis completed for this study indicates that resiliency measures are being implemented at Superfund NPL and SAA sites where remedies are in place.

Some of the noted design measures and actions included:

- Engineered caps (including asphalt and concrete caps) with drainage and erosion control components helped alleviate flooding and protected floodwater from contacting contaminated material when inundation did occur.
- Fencing, while noted as damaged at several sites, likely prevented debris from causing more significant damage to site infrastructure and clogging of drainage structures.
- Automated shut-off controls and system notifications prevented tank overflows and provided information on operating systems when sites were not accessible.
- Use of berms, dikes, and other drainage and erosion control measures prevented some sites from flooding and likely allowed quicker reduction of floodwaters where inundation occurred.
- Implementation of hazard preparedness plans including moving drums to enclosed structures, strapping tanks, controlled drawdowns of surface impoundments, controlled shutdowns of operating remedial systems and close communication with regulatory officials prevented infrastructure damage and allowed quick assessment of the sites impacted by the storms.
- Time-critical removal actions at sites where permanent remedies are not yet in place reduced the amount of contamination potentially vulnerable to release during extreme wind and flooding.

Some sites experienced unique challenges and yielded information that may assist development of future remedies. For example, the design of the temporary armored cap at San Jacinto River Waste Pits in Texas was not able to withstand the experienced flooding and scouring that resulted from the Hurricane Harvey. While this was only used as a temporary measure, it provides some information on the types of caps or site conditions that may be particularly susceptible during extreme weather events. EPA has selected excavation of the most highly contaminated material in the record of decision for the San Jacinto site, eliminating this vulnerability once the selected remedy is implemented.

Superfund NPL and SAA sites relying on the power grid also had vulnerabilities. Sites on the U.S. mainland were able to receive alternative power sources such as generators or have power

sources restored relatively quickly. However, sites in Puerto Rico and the U.S. Virgin Islands experienced sustained power outages and the extensive damage to roads, powerlines, and other infrastructure made restoring power or providing alternative power challenging. Research into solar power and other alternative power sources may help alleviate sustained shutdown of operating remedial systems such as groundwater pump and treat systems.

7. References

Department of the Navy, Naval Facilities Engineering Command Southeast. 2016. *Five-Year Review Operable Units 1, 2, 3, 4, 5, 6, 7, and 8, Jacksonville Naval Air Station*. March. https://semspub.epa.gov/src/document/04/11018513.pdf

Klotzbach, Philip J. and Michael M. Bell. 2017. *Summary of 2017 Atlantic Tropical Cyclone Activity and Verification of Authors' Seasonal and Two-Week Forecasts*. Department of Atmospheric Science, Colorado State University. November. https://webcms.colostate.edu/tropical/media/sites/111/2017/11/2017-11.pdf

Masters, Jeff. 2017. *2017 U.S. Hurricane Damage Estimate of $206.6 Billion: Highest on Record*, *Weather Underground*, November 28, 2017. https://www.wunderground.com/cat6/2017-us-hurricane-damages-206-billion-highest-record

National Oceanic and Atmospheric Administration. 2018a. *National Hurricane Center Tropical Cyclone Report, Hurricane Harvey*. AL092017. January 2018. https://www.nhc.noaa.gov/data/tcr/AL092017_Harvey.pdf

National Oceanic and Atmospheric Administration. 2018b. *National Hurricane Center Tropical Cyclone Report, Hurricane Irma*. AL112017. March 2018. https://www.nhc.noaa.gov/data/tcr/AL112017_Irma.pdf

National Oceanic and Atmospheric Administration. 2018c. *National Hurricane Center Tropical Cyclone Report, Hurricane Maria*. AL152017. April 2018. https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf

U.S. Army Corps of Engineers (USACE) for U.S. Environmental Protection Agency. 2015. *Fourth Five-Year Review Report for OU-1 Southeast Industrial Area Groundwater Interim Remedial Action; Second Five-Year Review Report for OU-2 Southeast Industrial Area Soil and OU-3 Ammunition Storage Area Soil and Groundwater, Anniston Army Depot (Southeast Industrial Area)*. September. https://semspub.epa.gov/src/document/04/11015219.pdf

U.S. Environmental Protection Agency. 2012. *Adaptation of Superfund Remediation to Climate Change*, February.

U.S. Environmental Protection Agency. 2013a. *Five-Year Review Report for Upjohn Manufacturing Company Superfund Site*. September. https://semspub.epa.gov/src/document/02/216159.pdf

U.S. Environmental Protection Agency. 2013b. *Fourth Five-Year Review Report for Bailey Waste Disposal Superfund Site*. September.

U.S. Environmental Protection Agency. 2013c. *Fourth Five-Year Review Report North Cavalcade Street Superfund Site*. September. https://semspub.epa.gov/src/document/06/693083.pdf

U.S. Environmental Protection Agency. 2013d. *Fourth Five-Year Remedy Review Report for the Savannah River Site, Volume I*. November.

U.S. Environmental Protection Agency. 2013e. *Fourth Five-Year Remedy Review Report for the Savannah River Site, Volume II*. November.

U.S. Environmental Protection Agency. 2013f. *Climate Change Adaptation Technical Fact Sheet: Groundwater Remediation Systems*. EPA 542-F-13-004. December. https://semspub.epa.gov/work/HQ/175851.pdf

U.S. Environmental Protection Agency. 2014a. *Climate Change Adaptation Technical Fact Sheet: Landfills and Containment as an Element of Site Remediation*. EPA 542-F-14-001. May. https://semspub.epa.gov/work/HQ/175853.pdf

U.S. Environmental Protection Agency. 2014b. *Climate Change Adaptation Plan.* EPA 100-K-14-001. June. https://www.epa.gov/sites/production/files/2015-08/documents/adaptationplans2014_508.pdf

U.S. Environmental Protection Agency. 2014c. *Office of Solid Waste and Emergency Response Climate Change Adaptation Implementation Plan.* June. https://www3.epa.gov/climatechange/Downloads/OSWER-climate-change-adaptation-plan.pdf

U.S. Environmental Protection Agency. 2014d. *Policy Statement on Climate Change Adaptation*. June. https://archive.epa.gov/epa/sites/production/files/2016-08/documents/adaptation-statement-2014.pdf

U.S. Environmental Protection Agency. 2014e. *Second Five-Year Review Report Tutu Wellfield Superfund Site*. September. https://semspub.epa.gov/src/document/02/282490.pdf

U.S. Environmental Protection Agency. 2014f. *Third Five-Year Review Report Fibers Public Supply Wells Superfund Site.* September. https://semspub.epa.gov/src/document/02/265538

U.S. Environmental Protection Agency. 2015a. *Climate Change Adaptation Technical Fact Sheet: Contaminated Sediment Remedies*. EPA 542-F-14-009. April. https://semspub.epa.gov/work/HQ/177110.pdf

U.S. Environmental Protection Agency. 2015b. *Fifth Five-Year Remedy Review Report for Savannah River Site Operable Units with Native Soil Covers and/or Land Use Controls (U).* October.

U.S. Environmental Protection Agency. 2017a. *Superfund Remedy Report, 15th Edition*. July. EPA-542-R-17-001. https://www.epa.gov/remedytech/superfund-remedy-report

U.S. Environmental Protection Agency. 2017b. *Record of Decision Summary of Remedial Alternative Selection Fairfax Street Wood Treaters Superfund Site*. August.

U.S. Environmental Protection Agency. 2017c. *Fifth Five-Year Review Report for French Limited Superfund Site*. September. https://semspub.epa.gov/src/document/06/100003584.pdf

U.S. Environmental Protection Agency. 2017d. *Record of Decision, Holtra Chem/Honeywell Inc*. September. https://semspub.epa.gov/work/04/11070121.pdf

U.S. Environmental Protection Agency. 2017e. *Record of Decision, San Jacinto River Waste Pits.* October. https://semspub.epa.gov/work/06/100003945.pdf

Appendix A. Background Data for Hurricanes Harvey, Irma and Maria

The 2017 Atlantic hurricane season was a hyperactive hurricane season that produced three hurricanes, Harvey, Irma and Maria that struck the United States (U.S.) mainland and the U.S. Virgin Islands and Puerto Rico. Hurricanes Harvey and Irma were category 4[19] hurricanes when they struck the U.S. mainland. Hurricanes Irma and Maria were category 5[20] hurricanes, when they struck the Caribbean. Preliminary estimates suggests the U.S. damage from these three storms exceeded $200 billion, making it the costliest hurricane season on record (Masters, 2017). Each hurricane resulted in unique cleanup challenges, with EPA's emergency response program coordinating closely with local state, tribal and federal partners to provide support to people and communities affected by the storm. The National Hurricane Center issued a series of Tropical Cyclone Reports for each of the three hurricanes: *National Hurricane Center Tropical Cyclone Report, Hurricane Harvey* (NOAA 2018a)[21]; *National Hurricane Center Tropical Cyclone Report, Hurricane Irma* (NOAA 2018b)[22]*;* and *National Hurricane Center Tropical Cyclone Report, Hurricane Maria* (NOAA 2018c)[23]. Background data on each of the hurricanes was obtained from these reports except where otherwise noted.

Hurricane Harvey was the first major hurricane to make landfall on the continental U.S. since 2005, arriving at the Texas coast as a category 4 hurricane on August 25, 2017, with peak winds of 130 mph. Harvey lasted a record 117 hours as a named storm after making landfall in Texas (Klotzbach and Bell, 2017). The longevity of the storm produced a record amount of rainfall generated from a tropical cyclone in the United States, with Nederland, TX, receiving over 60 inches of rain, exceeding initial maximum rainfall forecasts of 20 inches. The precipitation led to catastrophic flooding, with portions of southeastern Texas experiencing 1000-year or greater flooding. Intentional releases from two reservoirs lengthened the duration of flooding in and around Houston. Over 300,000 structures in southeastern Texas were flooded, with 336,000 customers losing power. Harvey was responsible for at least 68 direct deaths and an additional 35 indirect deaths in the United States, the most attributed to a hurricane since Hurricane Sandy in 2012 and the deadliest in Texas since 1919. The National Oceanic and Atmospheric Administration (NOAA) damage estimate for the hurricane is $125 billion, second only to Hurricane Katrina (2005). Harvey also produced 57 preliminary reported tornadoes to Texas, Louisiana, Mississippi, Alabama and Tennessee.

Hurricane Irma made landfall in the northern Caribbean four times as a category 5 hurricane, passing 50 nautical miles north of Puerto Rico on September 6, 2017 bringing gusts of over 70 mph and 10 to 15 inches of rainfall to the island. Significant storm surge likely occurred on the U.S. Virgin Islands, however actual inundation amounts are not available. Four days later on September 10, the hurricane reached the Florida Keys as a category 4 hurricane, and made landfall in southwestern Florida as a category 3 hurricane later that day. With Irma's arrival in Florida occurring roughly two weeks after Harvey hit Texas, 2017 marked the first time two Category 4 hurricanes made landfall on the continental United States in the same year. While

[19] Category 4 on the Saffir-Simpson Hurricane Wind Scale is 130-156 mph.
[20] Category 5 on the Saffir-Simpson Hurricane Wind Scale is 157 mph or higher.
[21] https://www.nhc.noaa.gov/data/tcr/AL092017_Harvey.pdf
[22] https://www.nhc.noaa.gov/data/tcr/AL112017_Irma.pdf
[23] https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf

reaching a maximum intensity of 185 mph as it strengthened in the Atlantic (a record for an Atlantic Hurricane), the hurricane brought 130 mph winds when it reached Florida's coast (Klotzbach and Bell, 2017). Portions of the Florida Keys experienced floods of five to eight feet above ground level due to the storm surge and tide, while areas of southwestern Florida experienced six to ten feet maximum inundation levels. Along Florida's southeast coast, maximum inundation levels of four to six feet were observed, with areas of downtown Miami receiving significant flooding. Farther north, three to five feet of inundation brought flooding to areas near the Florida-Georgia border. Irma then tracked across north central Florida and into Georgia on September 11, 2017, resulting in tropical storm conditions across much of northern Florida and parts of Georgia and South Carolina. Rainfall totals of 10 to 15 inches were common throughout Florida, with Ft. Pierce, FL, receiving over 21 inches. The heavy rain caused streets and low lying areas to flood throughout the state. Georgia and South Carolina received rainfall totals between 3 and 10 inches, also leading to some flash flooding. Finally, 25 confirmed tornadoes touched down in Florida and South Carolina. Irma caused seven direct deaths and an additional 85 indirect deaths in the Unites States, with 6 million Florida residents evacuated from coastal areas. In Puerto Rico, there was widespread loss of electricity and water supply for several days. The total damage to the Unites States was estimated at $50 billion, which placed the storm as the fourth costliest hurricane to affect the Unites States at the time of landfall, dropping to fifth after Maria struck.

Hurricane Maria hit Puerto Rico as a high-end category 4 hurricane, the strongest hurricane to hit the island since 1928. Only the fourth Atlantic basin hurricane to intensify 70 mph in 18 hours, Maria caused significant damage to multiple Caribbean islands and was a category 5 hurricane with winds above 165 mph when it hit the island of Dominica (Klotzbach and Bell, 2017 and NOAA, 2018c). When the hurricane crossed Puerto Rico's southeast coast on September 20, 2017, the maximum winds were at 155 mph, just below the threshold for a category 5 storm. The hurricane took just under 10 hours to cross the island from the southeast to northwest. St. Croix of the U.S. Virgin Islands reported sustained winds of 107 mph with gusts reaching 137 mph. The storm surge and tide produced maximum inundation levels of six to nine feet above ground along part of Puerto Rico's coast, with simulations suggesting inundation levels of three to five feet occurred on the islands of Vieques and St. Croix. Puerto Rico also experienced significant rainfall, reaching 38 inches in one location, which caused severe flooding and mud slides throughout much of the island. Significant flooding and mud slides were reported across the U.S. Virgin Islands as well. The hurricane resulted in 65 official deaths, however the number of casualties is highly uncertain, with the potential for hundreds of additional indirect deaths that may be attributed to Maria's aftermath pending an official government review. The NOAA estimate of damage due to Hurricane Maria in Puerto Rico and the U.S. Virgin Islands is $90 billion, making it the third costliest hurricane in U.S. history, and the most destructive to hit Puerto Rico in modern times. Between Hurricanes Irma and Maria, the U.S. Virgin Islands experienced the longest power outage in U.S. history, with the 104,000 residents of the islands losing power on September 6, 2017, with more than half without power as of November 30, 2017. Hurricane Maria also caused an island-wide blackout in Puerto Rico, with 35 percent of the 1.5 million customers on the island still without power as of November 30, 2017 (Masters, 2017).

Appendix B. Master Summary Tables