Hurricane Harvey Hospital Flood Impacts: Accuracy of Federal Emergency Management Agency Flood Hazard Areas in Harris County, Texas

ABSTRACT

Objective: To compare the flood impacts experienced by Harris County's hospitals with Federal Emergency Management Agency (FEMA) flood hazard areas and Hurricane Harvey's inundation boundary.

Methods: One year following Hurricane Harvey, we created a novel dataset of Hurricane Harvey's flood impacts within Harris County hospitals. The hospital flood impact data was then mapped in ArcGIS alongside FEMA flood hazard areas and Hurricane Harvey's inundation boundary to classify each hospital's location in high flood risk areas and in areas purportedly impacted by Hurricane Harvey.

Results: Out of the 66 hospitals for which flood impact information was ascertained, 16 hospitals (24%) experienced flood impacts during Hurricane Harvey. Out of these 16 hospitals, five (31%) were located outside of a FEMA flood hazard area and eight (50%) were located outside of Hurricane Harvey's inundation boundary.

Conclusions: FEMA flood hazard areas did not accurately predict all areas of Harris County, Texas that flooded during Hurricane Harvey, nor which hospitals experienced flood impacts.

INTRODUCTION

Hurricane Harvey made landfall in Texas as a Category 4 hurricane on August 26th, 2017. Areas of Harris County received between 40-60 inches of rain, surpassing the previous single-storm rainfall record in the continental U.S.[1] The ensuing flooding, influenced by a variety

of factors, left an estimated 25% of Harris County underwater, with 50% of total flooding occurring outside of Federal Emergency Management Agency (FEMA) flood hazard areas.[2–4]

Initial reports indicated hospitals across Harris County scrambled to evacuate patients amidst basement flooding and damage to kitchens, pharmacies, and supplies.[5] Although many of these hospitals had previous experience with flooding and recently fortified buildings to increase their preparedness, many also experienced difficulty withstanding Harvey's flooding impacts: hospital access roads were blocked, winds prevented helicopter landings, and food supplies ran low.[5,6]

Hospitals are critical infrastructure that should be capable of delivering both day-to-day and emergency services at surge capacity during extreme weather events, like flooding. Aside from providing care to currently-admitted patients, hospitals must also manage new patients with flood-related health concerns, necessitating efforts to minimize hospitals' flood-related complications related to power generation, clean water provision, patient safety, communication, and access.[7–9]

Planning for extreme flooding events and reducing hospital vulnerabilities requires understanding where flood impacts are most likely. The FEMA National Flood Hazard Layer (NFHL) is a geospatial database used to map high flood risk areas (100-year and 500-year flood hazard areas), but several recent studies have expressed concerns about its reliability for planning and policy purposes.[18,19] For hospitals, decisions on matters like evacuation procedures and flood insurance can be based primarily on FEMA flood hazard areas. Therefore, it is important to determine this data source's validity in predicting where water inundation and impacts occurred from an extreme flooding event.

Harris County is located in southeastern Texas and is highly susceptible to heavy rainfall and storm surge events due to its proximity to the Gulf of Mexico.[10,11] Harris County's dams and bayous, which are intended to hold and channel water toward the Gulf, are at risk of failing and are often overwhelmed by flood waters.[11] This physical vulnerability, paired with the explosive growth in Harris County from around 2 million to 6.5 million people since 1970, is putting an unprecedented number of people at risk during extreme flooding events.[11] Unchecked urban sprawl since the 1990s has resulted in the loss of almost 30% of the county's wetlands, which were largely responsible for retaining stormwater.[12,13] Although the Texas coast has experienced several extreme flooding events in the past two decades, including Tropical Storm Allison (2001), Hurricane Ike (2008), the Memorial Day Flood (2015), and the Tax Day Flood (2016), many questioned whether Harris County had adequately prepared for Hurricane Harvey's arrival in 2017.[13–15]

Hurricane Harvey provided an opportunity to use geospatial analysis to validate FEMA flood hazard area data against the flood impacts experienced in Harris County's hospitals and the hurricane's inundation boundary, informing the reliability of these data for future extreme flooding planning in coastal Texas and elsewhere.

METHODS

Study Area

This study focused on the 80 non-psychiatric hospitals located within Harris County, Texas. Psychiatric hospitals were excluded from this analysis because they do not serve the general public or address physical health concerns during a hurricane.

Data Sources

A) Hospital Flooding Impacts in Harris County, Texas

We first created a novel dataset of Hurricane Harvey's flood impacts experienced within Harris County hospitals, through secondary data searches and phone calls with hospitals. The "flood impacts" definition used encompassed any case of water entering a hospital building. Two methods were used to obtain information for as many hospitals as possible while also cross-validating our findings. First, we searched for secondary data from news reports and documents from government agencies and local organizations. These secondary sources were identified through Google searches using hospital names and keywords like "Hurricane Harvey" and "flood". The secondary sources used in this analysis are categorized as follows: news reports (n=31), peer-reviewed journal articles (n=1), government agency documents (n=2), local organization documents (n=3), and hospital websites (n=10). Next, we called each of the 80 hospitals during business hours and asked to speak with staff from facilities or emergency management to determine whether the hospital experienced any flooding during Hurricane Harvey. Using the combined results of the secondary source search and phone calls with hospitals, we were able to ascertain flood impacts for 66 of the 80 hospitals in Harris County, leaving 14 hospitals with no data on flood impacts. No disagreements were found between the two methods used for obtaining hospital flood impacts.

B) Geospatial Datasets

The shapefiles used for the Geographic Information System (GIS) analysis of flooding impacts from Hurricane Harvey on hospital infrastructure are summarized below.

The Homeland Infrastructure Foundation-Level Data (HIFLD) hospitals shapefile contains all U.S. hospitals' location information and descriptive characteristics acquired from various state or federal sources (https://hifld-geoplatform.opendata.arcgis.com/datasets/hospitals). We extracted HIFLD information for all hospital types except for psychiatric hospitals in Harris County, Texas from April 2017. To map the novel hospital flood impact dataset described earlier, we spatially linked them to the HIFLD hospitals shapefile.

We acquired Harris County's FEMA flood hazard areas from the National Flood Hazard Layer (NFHL) (https://msc.fema.gov/portal/advanceSearch). This geospatial database contains polygons delineating high flood risk areas (100- and 500-year flood hazard areas) which are based on current hydrology, infrastructure, and land use. The 100-year flood hazard areas delineate land with a 1% chance of flooding in any given year, whereas the 500-year flood hazard areas delineate land with a 0.2% chance of flooding in any given year. The FEMA NFHL is updated through several processes, including Letters of Map Revision/Amendment (LOMRs/LOMAs) and a cost-benefit approach, where communities are chosen for updates based on criteria such as development levels and date of last update. Our analysis was done retrospectively, and because the FEMA NFHL's historic versions are not archived online, we used the January 2018 version.

We acquired two versions of Hurricane Harvey's inundation boundary, one from Harris County Flood Control District (HCFCD) (https://www.hcfcd.org/hurricane-harvey/countywide-impacts/) and another from FEMA's Natural Hazard Risk Assessment Program (NHRAP) (https://data.femadata.com/FIMA/NHRAP/Harvey/). Both versions estimate the maximum area of water inundation over during the hurricane. The HCFCD inundation boundary used high water

marks to identify where the bayous and tributaries overflowed their banks during Hurricane Harvey.[16] High water marks were assessed using water monitoring sites and manual surveying. The FEMA NHRAP created another version of the inundation boundary by supplementing the initial HCFCD high water marks with United States Geological Survey (USGS) high water marks. For each dataset, the high water marks were interpolated into a continuous water surface elevation using the inverse distance weighting (IDW) method, and then compared to Harris County's digital elevation model (DEM), to delineate the inundation's estimated boundary. Both versions of Hurricane Harvey's inundation boundary were created in 2017 following Hurricane Harvey. To capture the full potential inundation extent of Hurricane Harvey, we merged the HCFCD and FEMA inundation extent shapefiles using a geometric union, which allowed all areas assessed as inundated in either dataset to be considered inundated in the merged data. It is important to note neither of these inundation boundary estimates necessarily shows all flooding impacts throughout Harris County nor necessarily indicates where structural flooding occurred, since water levels, as well as structure elevations and flood resistant design, varied widely throughout the inundated areas.

GIS Analysis

Our first goal was to identify the areas of overlap and non-overlap between Harris County's FEMA flood hazard areas and Hurricane Harvey's inundation boundary, allowing for an assessment of whether the FEMA flood hazard areas accurately predicted the areas of Harris County that would flood during an extreme flooding event like Hurricane Harvey.

Our second goal was to assess whether Harris County hospital flood impacts from Hurricane Harvey were accurately predicted (1) by the hospitals' flood risk due to their locations

within FEMA flood hazard areas and/or (2) by their locations within Hurricane Harvey's inundation boundary. To do this, each hospitals' location was first classified as either inside or outside a FEMA flood hazard area, because the likelihood of hospital flood impacts should be higher for hospitals located within a FEMA flood hazard area. Next, each hospitals' location was classified as either inside or outside Hurricane Harvey's inundation boundary. These two flood risk classifications were then compared to whether hospitals reported (either verbally from a phone call or through secondary data) flood-related impacts during Hurricane Harvey, based on the flood impacts dataset we created as outlined above.

All GIS analyses described were completed in ESRI ArcMap version 10.6.1.[17]

RESULTS

Using both primary and secondary data sources, information about Hurricane Harvey's flood impacts was ascertained for 66 of the 80 non-psychiatric hospitals in Harris County included in this study. Out of the 66 hospitals for which flood impact information was ascertained, 16 hospitals (24% of those ascertained) experienced flood impacts during Hurricane Harvey and 50 hospitals (76% of those ascertained) did not experience flood impacts during Hurricane Harvey. Table 1 presents the flood impacts by hospital, as well as their locations inside or outside the FEMA flood hazard areas and Hurricane Harvey's inundation boundary.

The GIS analyses revealed considerable disagreement between the FEMA flood hazard areas and Hurricane Harvey's inundation boundary. The areas of overlap between the FEMA flood hazard areas and Hurricane Harvey's inundation boundary, such as within the Addicks and Barker Reservoirs and around Lake Houston and other major waterways, are shown in beige in Figure 1, totaling 382 mi^2. However, two types of non-overlap were observed. Approximately

37% (227 mi^2) of the FEMA flood hazard areas did not experience inundation from Hurricane Harvey according to Hurricane Harvey's inundation boundary (red representing both 100- and 500-year FEMA flood hazard areas in Figure 1). Approximately 18% (83 mi^2) of the areas that experienced inundation were located outside FEMA flood hazard areas (blue in Figure 1).

The 80 non-psychiatric hospitals in Harris County included in this study are also mapped in Figure 1. The 16 hospitals that experienced flood impacts during Hurricane Harvey are shown as green dots whereas the 50 hospitals that did not experience flood impacts during Hurricane Harvey are shown as black dots. Hospitals for which Hurricane Harvey flood impacts were not ascertained (n=14) are represented as black Xs.

Next, we sought to understand whether the hospital flood impacts were predicted well by the FEMA flood hazard areas and Hurricane Harvey's inundation boundary. From top to bottom, the flowchart in Figure 2 displays whether hospitals in Harris County were located inside or outside a FEMA flood hazard area, followed by whether they were located inside or outside Hurricane Harvey's inundation boundary, followed by whether or not they experienced flood impacts during Hurricane Harvey. The results presented in the bottom row are categorized into three themes: expected results, unpredicted results with potential explanations, and unexpected flooding.

Out of the 66 hospitals whose flooding impacts were ascertained, 40 (60%) fell into the "expected results" theme (shown with a solid outline in Figure 2). These hospitals' flood impacts (or lack thereof) were largely expected based on the hospitals' flood risk. For example, six hospitals in this category experienced flood impacts, but this should have been expected since they had a high flood risk due to their locations within a FEMA flood hazard area and Hurricane Harvey's inundation boundary. Similarly, 34 hospitals did not experience flood impacts, but this

was likely expected because their locations were outside FEMA flood hazard areas and Hurricane Harvey's inundation boundary.

Out of the 66 hospitals whose flooding impacts were ascertained, 21 (32%) fell into the "unpredicted results with potential explanations" theme (shown with a dotted outline in Figure 2). These hospitals' flood impacts were largely unpredicted but have potential explanations worth exploring. For example, 16 hospitals did not experience flood impacts despite high flood risk due to their locations inside both the FEMA flood hazard area and Hurricane Harvey's inundation boundary (n=3) or locations inside a FEMA flood hazard area only (n=13). Five other hospitals in this category did experience flood impacts but this was unpredicted because they were located outside Hurricane Harvey's inundation boundary (despite being inside the FEMA flood hazard area). We explore the potential explanations for these unpredicted results in the Discussion.

Out of the 66 hospitals whose flooding impacts were ascertained, five (8%) fell into the "unexpected flooding" theme (shown with a dashed outline in Figure 2). These hospitals' flood impacts were unexpected based on the low flood risk due to their locations outside of a FEMA flood hazard area (two hospitals were located inside Hurricane Harvey's inundation boundary while the remaining three were located outside the inundation boundary). Considering their lower flood risk, it is possible these hospitals were perhaps less prepared for the flood impacts.

DISCUSSION

Our study is the first to document Hurricane Harvey's flooding impacts on Harris County hospitals and compare these impacts to FEMA flood hazard areas through geospatial analysis. FEMA flood hazard areas are heavily considered in hospital emergency preparedness planning;

therefore, it is imperative to establish whether the FEMA flood hazard areas are reliable in predicting hospital flood impacts.

Our analysis first revealed the FEMA flood hazard areas did not accurately predict the areas of Harris County, Texas that flooded during Hurricane Harvey in August 2017. The analysis also indicated that out of the 16 hospitals that experienced Hurricane Harvey flood impacts, only 11 (69%) were located within a FEMA flood hazard area. Thus, the remaining five hospitals that experienced flood impacts were located outside of a FEMA flood hazard area—a particularly concerning finding considering these hospitals were likely less prepared due to their lower perceived risk.

Despite being used by hospitals to identify flood risk, plan emergency procedures, and inform policy decisions, the FEMA flood hazard area data had not previously been validated against the impacts of flooding on Harris County's hospital infrastructure. Our study demonstrates FEMA flood hazard areas did not fully capture hospital flood impacts, with severe implications for healthcare service continuity and patient safety. Our concerns about the data's validity support several other studies' findings documenting disagreement between FEMA's flood risk estimates and actual flood losses, particularly in coastal Texas.[18,19]

Although our results primarily indicate reliability concerns with the FEMA flood hazard areas, two other potential explanations exist for the unpredicted flood impacts found. First, some hospitals (n=8) located outside Hurricane Harvey's inundation boundary still experienced flood impacts, potentially implying problems with the inundation boundary's accuracy. Alternatively, since our "flood impacts" definition was broad (encompassing any case of water entering a hospital building), it is possible the reported hospital flood impacts were not due to ground-level water inundation, but instead structural problems that led to falling water getting into the

hospital. Our study, however, was not able to confirm each hospitals' flooding source(s). Second, some hospitals (n=3) located inside Hurricane Harvey's inundation boundary did not experience flood impacts, suggesting these hospitals may have prevented flooding by implementing flood adaptation strategies in advance. Our study was unable to confirm either of these potential explanations, but it is crucial both are further explored in future studies to inform hospital preparations for future extreme flooding in Harris County and elsewhere.

Limitations and Future Directions

Some study limitations are worth noting, as well as suggestions for forthcoming studies. First, since no historic versions of the FEMA flood hazard area data exist, this analysis only considered the January 2018 version available during analysis. Considering FEMA flood hazard area re-evaluations take time, it is unlikely the updated version already incorporated Hurricane Harvey's impact, and therefore, we do not anticipate any drastic differences in the FEMA flood hazard area data between August 2017 and January 2018. Additionally, this analysis only considered two versions of Hurricane Harvey's inundation boundary, created by FEMA and HCFCD, neither of which considered floodwater depth. Future studies would benefit from comparing a larger number of inundation boundaries, including floodwater depth estimates, to understand the full extent of flooding related to a hurricane or other extreme rainfall event.

Second, our broad flood impacts definition may have unintentionally included impacts unrelated to ground-level water inundation, thus inflating the category of hospitals with unexpected flood impacts. However, these other flooding impacts are important and should be further investigated. Additionally, hospitals with more severe flooding impacts may be more likely to disclose, meaning our findings could underestimate Hurricane Harvey's true impacts on

Harris County's hospitals. Future studies should use different flooding impacts categories with specific definitions to separate out the causes of flooding and help inform how hospitals prepare for future flooding events.

Additionally, even though we used two methods to ascertain hospital flood impacts, we were unable to ascertain flooding impacts for all 80 hospitals. We also limited our analysis to non-psychiatric hospitals. Future studies on healthcare service flood impacts should include all facilities to determine if the impacts uncovered in this study apply more widely.

Recommendations

Based on our findings, we recommend the following for flood-prone hospitals and their partner organizations in academia, private industry, and government. First, since our study's results are only applicable to Harris County, Texas, we advise that future studies validate FEMA flood hazard area data against flood extents and impacts in other U.S. case studies. Second, since FEMA flood hazard areas are the traditional source of flood risk estimates, we suggest exploring avenues to improve the FEMA flood hazard area data's reliability in predicting flood extents and impacts. Third, researchers should test whether alternative data sources could potentially complement, or even replace, FEMA flood hazard area data to inform emergency preparedness plans and policy decisions.

PUBLIC HEALTH IMPLICATIONS

Hospitals are a critical component of our country's healthcare infrastructure and are tasked with delivering both day-to-day and emergency services at surge capacity during extreme flooding events. Results from this study document a concerning inconsistency between FEMA

flood hazard areas and hospitals' flood impacts following Hurricane Harvey in Harris County, Texas, strengthening the evidence base that FEMA flood hazard areas deserve further scrutiny in informing hospital emergency preparedness plans and policy. In the interest of healthcare service continuity and patient safety during extreme flooding events, hospitals nationwide must be provided with reliable flood risk estimates.

Overall, this study contributes to efforts aimed at improving U.S. hospitals' ability to better prepare for, respond to, and recover from future catastrophic flooding events like Hurricane Harvey. With extreme flooding events predicted to become more frequent and intense in many regions across the U.S. over the next decade,[20] it is crucial to fully understand the risks and impacts of flooding on healthcare infrastructure to ensure healthcare availability and accessibility during future extreme flooding events.[7,9]

Production Requests

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Contributor Statement

EH conceived of the presented idea, under the supervision of CER. EH and CER contributed to the design of the research. EH collected the data and conducted the analyses, under the supervision of CER. EH wrote the article, with critical revisions from CER. Both authors discussed the results and contributed to the final manuscript.

Conflict of Interest Statement

Emmanuelle Hines does not have conflicts of interest to declare.

Colleen E. Reid does not have conflicts of interest to declare.

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Human Participant Protection

This study was deemed "exempt" by the University of Colorado Boulder Institutional Review Board.

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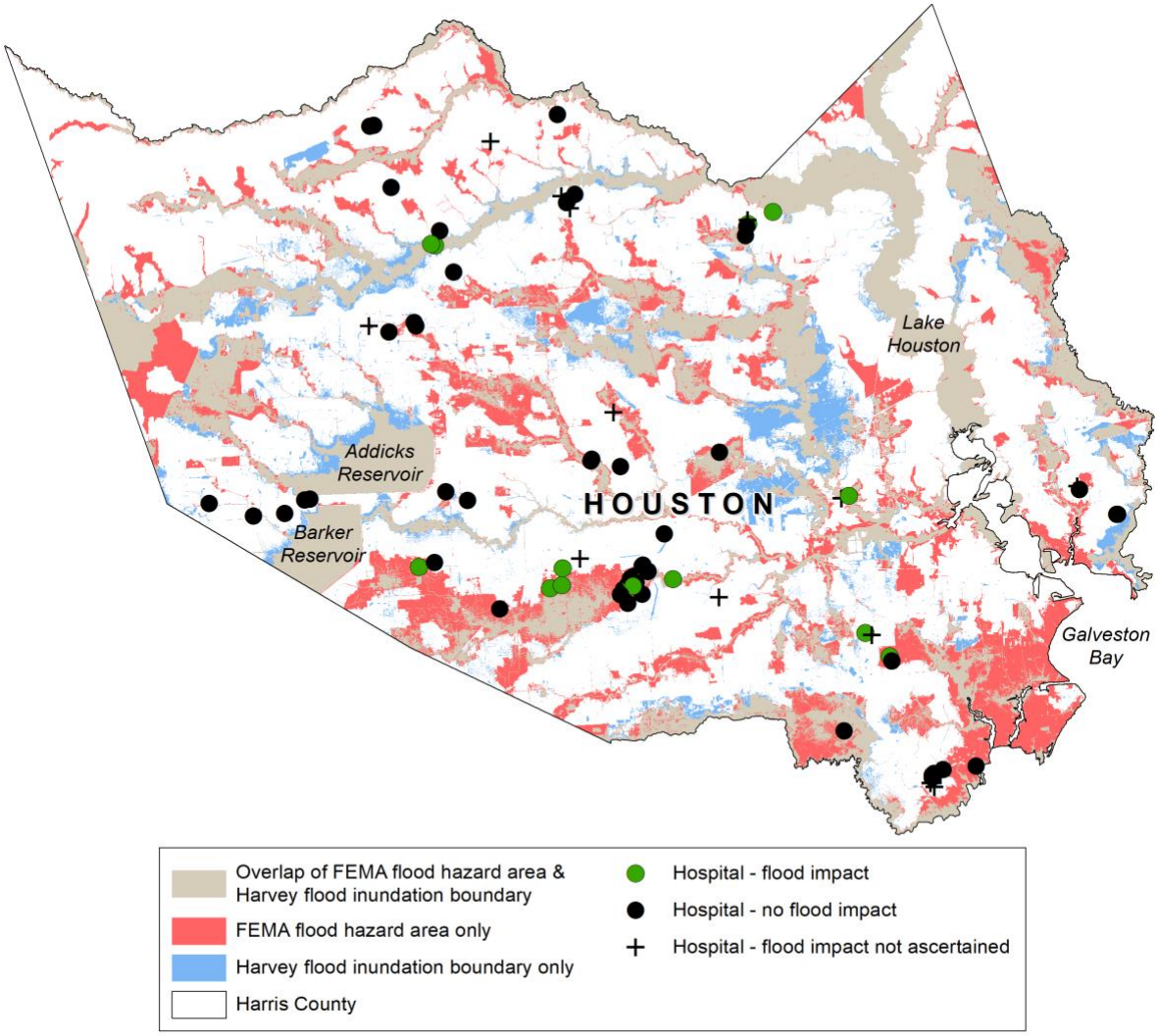
393 Figure and Table Captions



394

395 **Figure 1:** Overlap and non-overlap between FEMA flood hazard areas and Hurricane Harvey's

396 inundation boundary, and hospital locations and flood impacts related to Hurricane Harvey.

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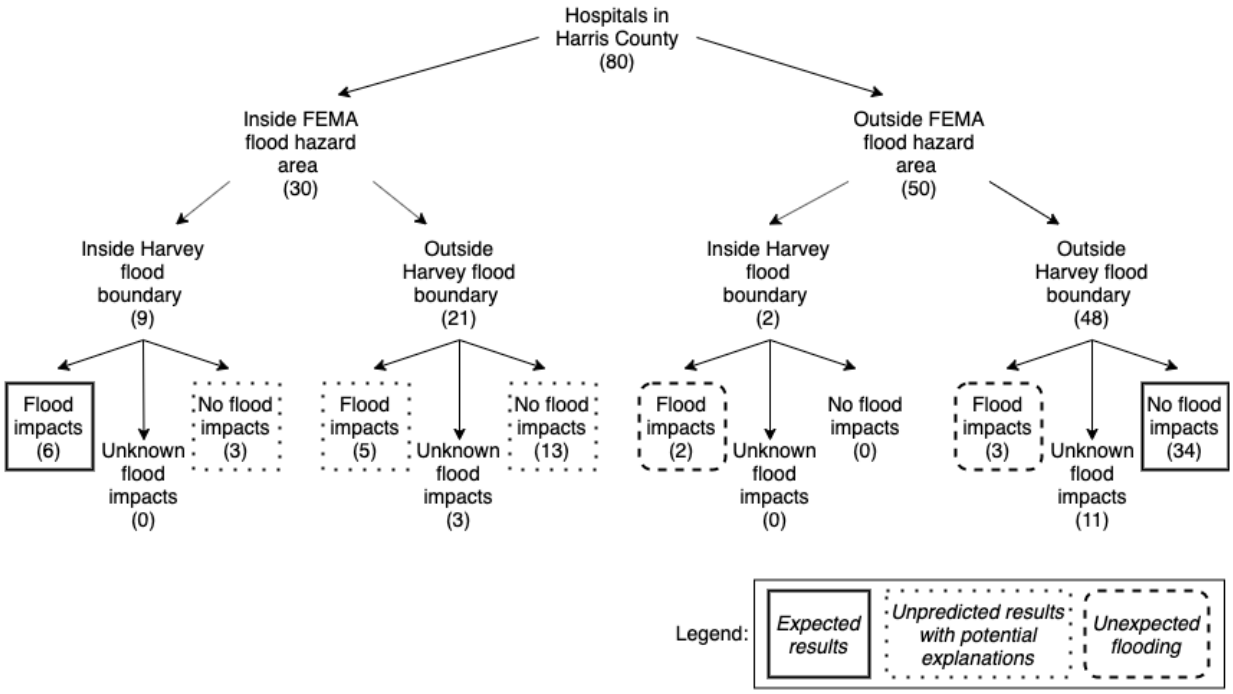

Figure 2: GIS Analysis Results Flowchart.

Table 1. Dataset of Hurricane Harvey's Flood Impacts in Harris County Hospitals.

403 **Table 1.** Dataset of Hurricane Harvey's Flood Impacts in Harris County Hospitals

Hospital Name	City	Type	Inside FEMA Flood Hazard Area?	Inside Harvey Inundation Boundary?	Harvey Flood Impacts?	Harvey Flood Impacts Description	Harvey Flood Impacts Confirmed By
Advanced Diagnostics Hospital East LLC	Houston	General Acute Care	500-year	No	Not ascertained		
Altus Baytown Hospital	Baytown	Special	500-year	No	Not ascertained		
Bay Area Regional Medical Center	Webster	General Acute Care	No	No	No	remained operational with no structural damage	Bay Area Regional Medical Center, 2017; Ismail, 2018
Bayshore Medical Center	Pasadena	General Acute Care	No	Yes	Yes	had flooding, evacuated patients	phone call; Christensen and Edwards, 2017
CHI St Lukes Health - Springwoods Village	Spring	General Acute Care	No	No	No	remained operational	Feigen and Sixel, 2017
CHI St Lukes Health Baylor College Of Medicine Medical Center	Houston	General Acute Care	500-year	Yes	No	no flooding, evacuated some patients, remained operational	phone call; Christensen and Edwards, 2017; Feigen and Sixel, 2017
Clear Lake Regional Medical Center	Webster	General Acute Care	No	No	No	remained operational	Feigen and Sixel, 2017
Cornerstone Speciality Hospitals Bellaire	Houston	Long Term Care	100-year	Yes	Yes	had flooding, closed temporarily	phone call; Ackerman, 2017
Cornerstone Speciality Hospitals Clear Lake	Webster	Long Term Care	No	No	Not ascertained		
Cornerstone Speciality Hospitals Medical Center	Houston	Long Term Care	No	No	Yes	had flooding	phone call
Cypress Fairbanks Medical Center	Houston	General Acute Care	100-year	No	No	no flooding	phone call
East Houston Regional Medical Center	Houston	General Acute Care	100-year	Yes	Yes	closing due to damage from Hurricane Harvey	Deam and Ackerman, 2017
Encompass Health Rehabilitation Hospital of Cypress	Houston	Rehabilitation	No	No	No	remained operational	Ackerman, 2017; Encompass Health Corp, 2017
Encompass Health Rehabilitation Hospital of Humble	Humble	Rehabilitation	No	No	No	remained operational	Encompass Health Corp, 2017
Encompass Health Rehabilitation Hospital The Vintage	Houston	Rehabilitation	No	Yes	Yes	closed temporarily, evacuated patients	Encompass Health Corp, 2017
First Street Surgical Center	Bellaire	Special	100	Yes	Yes	had flooding, cases moved elsewhere	Nobilis Health Corp, 2017

First Texas Hospital CyFair	Houston	General Acute Care	No	No	No	remained open	First Choice Emergency Room, 2017
Harris Health System Ben Taub General Hospital	Houston	General Acute Care	500-year	No	Yes	had flooding	Fink and Blinder, 2017; Goldstein and McGinley, 2017; Blau, 2018; Christensen and Edwards, 2018
Harris Health System Lyndon B. Johnson General Hospital	Houston	General Acute Care	No	No	No	maintained operations, took in evacuees, surrounded by water	Harris Health System, 2017; Vartorella, 2018
Harris Health System Quentin Mease Hospital	Houston	General Acute Care	No	No	Yes	closed during harvey	Vartorella, 2017
Hermann Drive Surgical Hospital	Houston	General Acute Care	No	No	No	remained operational	Nobilis Health Corp, 2017
Houston Methodist Hospital	Houston	General Acute Care	500-year	No	Yes	had flooding, remained operational, elective surgeries cancelled	phone call; Marshall, 2017
Houston Methodist San Jacinto Hospital	Baytown	General Acute Care	No	No	No	remained operational, elective surgeries cancelled	Marshall, 2017
Houston Methodist San Jacinto Hospital Alexander Campus	Baytown	General Acute Care	No	No	No	remained operational, elective surgeries cancelled	Marshall, 2017
Houston Methodist St. Catherine Hospital	Katy	Long Term Care	No	No	No	remained operational, elective surgeries cancelled	Marshall, 2017
Houston Methodist St. John Hospital	Nassau Bay	General Acute Care	100-year	No	No	remained operational, elective surgeries cancelled	Marshall, 2017
Houston Methodist West Hospital	Houston	General Acute Care	No	No	No	remained operational, elective surgeries cancelled	Marshall, 2017
Houston Methodist Willowbrook Hospital	Houston	General Acute Care	No	No	No	remained operational, elective surgeries cancelled	Marshall, 2017
Houston Northwest Medical Center	Houston	General Acute Care	No	No	No	remained operational, elective surgeries cancelled	Marshall, 2017
Houston Physicians' Hospital	Webster	General Acute Care	No	No	Not ascertained		
Icon Hospital	Humble	Long Term Care	No	No	Not ascertained		
Kindred Hospital Bay Area	Pasadena	Long Term Care	500-year	No	No	remained operational	Kindred Healthcare, 2017
Kindred Hospital Baytown	Baytown	Long Term Care	No	No	No	remained operational	Kindred Healthcare, 2017
Kindred Hospital Clear	Webster	Long	No	No	No	remained operational	Kindred Healthcare,

Lake		Term Care					2017
Kindred Hospital Houston Medical Center	Houston	Long Term Care	500-year	No	No	remained operational	Kindred Healthcare, 2017
Kindred Hospital Houston Northwest	Houston	Long Term Care	100-year	No	No	remained operational	Kindred Healthcare, 2017
Kindred Hospital Spring	Houston	Long Term Care	No	No	No	remained operational	Kindred Healthcare, 2017
Kindred Hospital The Heights	Houston	Long Term Care	100-year	No	No	remained operational	Kindred Healthcare, 2017
Kindred Hospital Tomball	Tomball	Long Term Care	No	No	No	remained operational	Cruz, 2017
Kindred Hospital Town & Country	Houston	Long Term Care	No	No	No	remained operational	Kindred Healthcare, 2017
Kindred Rehabilitation Hospital Clear Lake	Webster	Rehabilitation	No	No	No	remained operational	Kindred Healthcare, 2017
Kindred Rehabilitation Hospital Northeast Houston	Humble	Rehabilitation	500-year	Yes	No	remained operational	Kindred Healthcare, 2017
Memorial Hermann Greater Heights Hospital	Houston	General Acute Care	500-year	No	No	remained operational	Feigen and Sixel, 2017
Memorial Hermann Hospital	Houston	General Acute Care	500-year	No	No	closed submarine doors to prevent flooding	Gooch, 2017; Park, 2017
Memorial Hermann Katy Hospital	Katy	General Acute Care	No	No	No	no flooding, but had leaks from rainfall, remained operational	Brust, 2017; Feigen and Sixel, 2017
Memorial Hermann Memorial City Medical Center	Gonzales	General Acute Care	No	No	No	remained operational	Feigen and Sixel, 2017
Memorial Hermann Northeast Hospital	Humble	General Acute Care	No	No	Yes	had flooding, remained operational	Feigen and Sixel, 2017; Feuk, 2018
Memorial Hermann Orthopedic and Spine Hospital	Bellaire	General Acute Care	500-year	No	Yes	temporarily closed	Ellison, 2017
Memorial Hermann Rehabilitation Hospital Katy	Katy	Rehabilitation	No	No	No	remained operational	Feigen and Sixel, 2017
Memorial Hermann Southeast Hospital	Houston	General Acute Care	500-year	No	No	declared weather emergency, remained operational	Feigen and Sixel, 2017; Memorial Hermann, 2017
Memorial Hermann Southwest Hospital	Houston	General Acute Care	No	No	No	no flooding, took on patients from other hospitals	Slabodkin, 2017
Memorial Hermann Tomball Hospital	Tomball	General Acute Care	No	No	No	remained operational	Feigen and Sixel, 2017

Michael E. Debakey VA Medical Center	Houston	Military	No	No	No	no flooding, remained operational	Wentling, 2017
New Life Hospital	Houston	General Acute Care	No	No	Not ascertained		
Nexus Children's Hospital	Houston	Children	No	No	No	no flooding, took on patients from other hospitals	Nexus Health Systems, 2017
North Cypress Medical Center	Cypress	General Acute Care	500-year	No	Not ascertained		
Pam Rehabilitation Hospital Of Clear Lake	Webster	Rehabilitation	No	No	Not ascertained		
Park Plaza Hospital	Houston	General Acute Care	No	No	No	remained operational	Feigen and Sixel, 2017
Pine Valley Specialty Hospital	Houston	Long Term Care	No	No	Not ascertained		
Plaza Specialty Hospital	Houston	Long Term Care	No	No	No	remained operational	Feigen and Sixel, 2017
Providence Hospital of North Houston LLC	Houston	General Acute Care	No	No	Not ascertained		
Shriners Hospitals For Children	Houston	General Acute Care	500-year	No	No	no flooding	phone call
Spring Excellence Surgical Hospital LLC	Spring	General Acute Care	No	No	Not ascertained		
St. Joseph Medical Center	Houston	General Acute Care	No	No	No	closed floodgates to prevent flooding, declared weather emergency, remained operational	phone call; Evans 2017
St. Joseph Medical Center In The Heights	Houston	General Acute Care	No	No	No	remained operational	Feigen and Sixel, 2017
St. Luke's Hospital At The Vintage	Houston	General Acute Care	100-year	Yes	Yes	had flooding, evacuated patients	Fink and Blinder, 2017
St. Luke's Patients Medical Center	Pasadena	General Acute Care	100-year	No	Yes	closed temporarily	Feigen and Sixel, 2017
Surgery Specialty Hospitals of America Southeast Houston	Pasadena	General Acute Care	No	No	Not ascertained		
Texas Children's Hospital	Houston	General Acute Care	500-year	No	No	closed floodgates to prevent flooding, cancelled outpatient services but continued inpatient services	phone call; Christensen and Edwards, 2017; Park, 2017; Sullivan and Wootson, 2017; Vartorella, 2017
Texas Children's Hospital	Houston	Children	No	No	No	no flooding, cancelled	phone call;

West Campus						outpatient services but continued inpatient services	Vartorella, 2017
Texas Orthopedic Hospital	Houston	Special	500-year	No	No	remained operational	Feigen and Sixel, 2017
The Woman's Hospital of Texas	Houston	General Acute Care	500-year	No	No	remained operational	Feigen and Sixel, 2017
TIRR Memorial Hermann	Houston	Rehabilitation	500-year	Yes	No	closed submarine doors to prevent flooding, declared disaster, remained operational	phone call; Feigen and Sixel, 2017; Toppo, 2017; Verduzco-Gutierrez, 2018
Tomball Regional Medical Center	Tomball	General Acute Care	No	No	No	remained operational	Feigen and Sixel, 2017
TOPS Surgical Specialty Hospital	Houston	Special	No	No	No	no flooding, remained operational, cancelled elective surgeries, issues with access	phone call
Townsen Memorial Hospital	Humble	General Acute Care	500-year	Yes	Yes	had flooding, closed for nearly a year due to Harvey damage	Shelton, 2018
United Memorial Medical Center	Houston	General Acute Care	No	No	Not ascertained		
University Of Texas M.D. Anderson Cancer Center	Houston	Special	100-year	Yes	Yes	flooding in lobby, cancelled outpatient services but continued inpatient services	phone call; Christensen and Edwards, 2017; Goldstein and McGinley, 2017
West Houston Medical Center	Houston	General Acute Care	100-year	No	Yes	evacuated patients and suspended services	Slabodkin, 2017
Westside Surgical Hospital	Houston	General Acute Care	No	No	Not ascertained		

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