SOUTHEAST TEXAS HURRICANE EVACUATION STUDY HAZARD ANALYSIS – 2023

Final Report

NATIONAL HURRICANE PROGRAM

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EXECUTIVE SUMMARY – HAZARD ANALYSIS

The updated Hazard Analysis for the Texas coastal counties of Brazoria, Chambers, Galveston, Hardin, Harris, Jackson, Jasper, Jefferson, Liberty, Matagorda, Newton, and Orange includes the following enhancements and updates:

- A new methodology utilizing directional Maximum Envelope of Water (MEOW) output data was developed for this updated Hazard Analysis. Previous hazard mapping of Maximums of the Maximums (MOMs) was only according to storm intensity. The new analysis included effects from intensity and directional approach. Directional MEOW maps show the influence that approach direction has on storm surge. Equivalent inundation extent maps were developed from directional MEOWs of different intensities which produced similar maximum surge inundation extents. Only the maximum of “worst case” forward speed was utilized for this Hazard Analysis Update, and specifically for modeling equivalent inundation.-The forward speed that caused the maximum or "worst case" inundation per MEOW was utilized for this Hazard Analysis Update, and specifically for modeling equivalent inundation.
- National Hurricane Center (NHC) 2017 Texas SLOSH Super Basin (TX3) Model was used for the updated Hazard Analysis.
- Freshwater flood risk was also determined using the latest Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) mapping.
    - Mapping of modeled surge from directional MEOWs and MOMs also includes FEMA FIRM floodplain extents for freshwater flooding.
- Wind Extent Maps (WEMs) have been produced from directional Maximum Envelopes of Wind (MEOW)s that were developed for 5 forward speeds (8, 12, 16, 20, and 24 knots) using the 2021 National Oceanic and Atmospheric Administration (NOAA) Wind Speed Decay Modeling polygons based on the Saffir-Simpson Hurricane Wind Scale. They depict the estimated furthest inland wind extents for sustained wind speeds for representative tropical cyclones making landfall from the Gulf of Mexico.
- A Geographic Information System (GIS) database containing all data from this analysis will be provided to the user at: https://texasatlas.arch.tamu.edu/

1 HAZARDS ANALYSIS

1.1 INTRODUCTION

1.1.1 OVERVIEW

The purpose of this updated Hazard Analysis is to determine storm surge, freshwater flooding, and wind threats that can be anticipated from tropical cyclones of various categories and tracks for the Texas counties of Brazoria, Chambers, Galveston, Hardin, Harris, Jackson, Jasper, Jefferson, Liberty, Matagorda, Newton, and Orange.

Three major hazards associated with tropical cyclones are the following:

1. **Storm Surge** - Still-water modeled storm surge heights from tropical cyclones of various categories, approach directions, and forward speeds are estimated and provide the basis of Evacuation Zones developed within the updated Vulnerability Analysis.
2. **Freshwater Flooding** - Freshwater flooding (including riverine with contributing creeks and streams) estimates from heavy rainfall runoff associated with tropical cyclones are considered in FEMA FIRMs products.
3. **Winds** - Wind speed decay modeling estimates the maximum sustained surface wind as a storm moves inland.

1.2 BACKGROUND

1.2.1 SAFFIR-SIMPSON HURRICANE WIND SCALE

The Saffir-Simpson Hurricane Wind Scale, developed by Herbert Saffir, a civil engineer, and Dr. Robert H. Simpson, a meteorologist, and former Director of the National Hurricane Center (NHC), is a 1 to 5 rating scale used by the National Weather Service (NWS) and NHC to quantify a hurricane's strength based on peak sustained wind speed (using the U.S. 1-minute average at the observation height of 10 meters or 33 feet over unobstructed exposure). Hurricanes with a Category 3 or higher are considered major hurricanes due to their potential for significant damage and loss of life.

Earlier versions of the scale, formerly the Saffir-Simpson Hurricane Scale, incorporated storm surge and central pressure as components of the categories. The central pressure was used as a proxy for the winds since accurate wind speed intensity measurements from aircraft reconnaissance were not routinely available until 1990. Actual storm surge values were sometimes substantially outside of ranges suggested in original scale since hurricane size, local bathymetry (or depth of near-shore waters), topography, and hurricane's forward speed and approach direction affect the surge produced. Therefore, to reduce public confusion about impacts associated with hurricane categories and to provide a more scientifically defensible scale, the flooding impact, storm surge ranges, and central pressure statements were removed from the scale.[1] An abbreviated version of the wind related damage potential of each hurricane category is described in Table 1-1. An extended table can be found at https://www.nhc.noaa.gov/pdf/sshws_table.pdf.

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[1] Source: https://www.nhc.noaa.gov/pdf/sshws.pdf

Table 1-1: Saffir-Simpson Hurricane Damage Scale[2]

Category	Damage
1	Winds 74 to 95 miles per hour (64 to 82 knots). **Very dangerous winds will produce some damage**: Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	Winds 96 to 110 miles per hour (83 to 95 knots). **Extremely dangerous winds will cause extensive damage**: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3	Winds 111 to 129 miles per hour (96 to 112 knots). **Devastating damage will occur**. Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4	Winds 130 to 156 miles per hour (113 to 136 knots). **Catastrophic damage will occur**. Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5	Winds greater than 157 miles per hour (137 knots or higher). **Catastrophic damage will occur.** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

1.2.2 HURRICANE FORECASTING INACCURACIES

The worst-case approach is used in the hazards analysis because of inaccuracies in forecasting the precise tracks and other parameters of approaching hurricanes. The NHC conducts an annual analysis of tropical cyclone forecasts to determine the normal magnitude of error. According to the "NHC Forecast Verification Report 2022 Hurricane Season" (May 8, 2023) by John P. Cangialosi, the NHC issued 255 Atlantic basin tropical cyclone forecasts in 2022, which is below long-term averages making 2022 Atlantic hurricane season the least active since 2015. Mean track errors ranged from 21 nautical miles at 12 hours to 126 nautical miles at 120 hours. The mean official track forecast errors in 2022 were below the 5-year mean at all times, and up to 27% smaller at 120 hours. Over the past 30 years, there has been a reduction of the 24-72 hour track forecast error by 70-75% as shown in Figure 1-1. Over the past 15 to 20 years, track forecast

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[2] Source: https://www.nhc.noaa.gov/aboutsshws.php

errors have been reduced by about 60% for the 96 hours and 120 hours forecast periods. On average, the NHC track errors decrease as the initial intensity of a cyclone increases.

In 2022, the mean forecast errors for intensity ranged from 5 knots at 12 hours to 21 knots at 120 hours. The errors were 11-24% lower than the previous 5-year means from 12 to 72 hours, setting records for accuracy, specifically for the 12 to 60 hour forecast periods. Errors were considerably higher than the 5-year means at 96 and 120 hours as shown in Figure 1-2. However, over the long-term, despite year-to-year variability, there has been a notable decrease in intensity error that began around 2010. Although forecasting techniques are improving, the risk from storm surge flooding cannot be determined alone from the forecasted intensity on the Saffir-Simpson Hurricane Wind Scale.

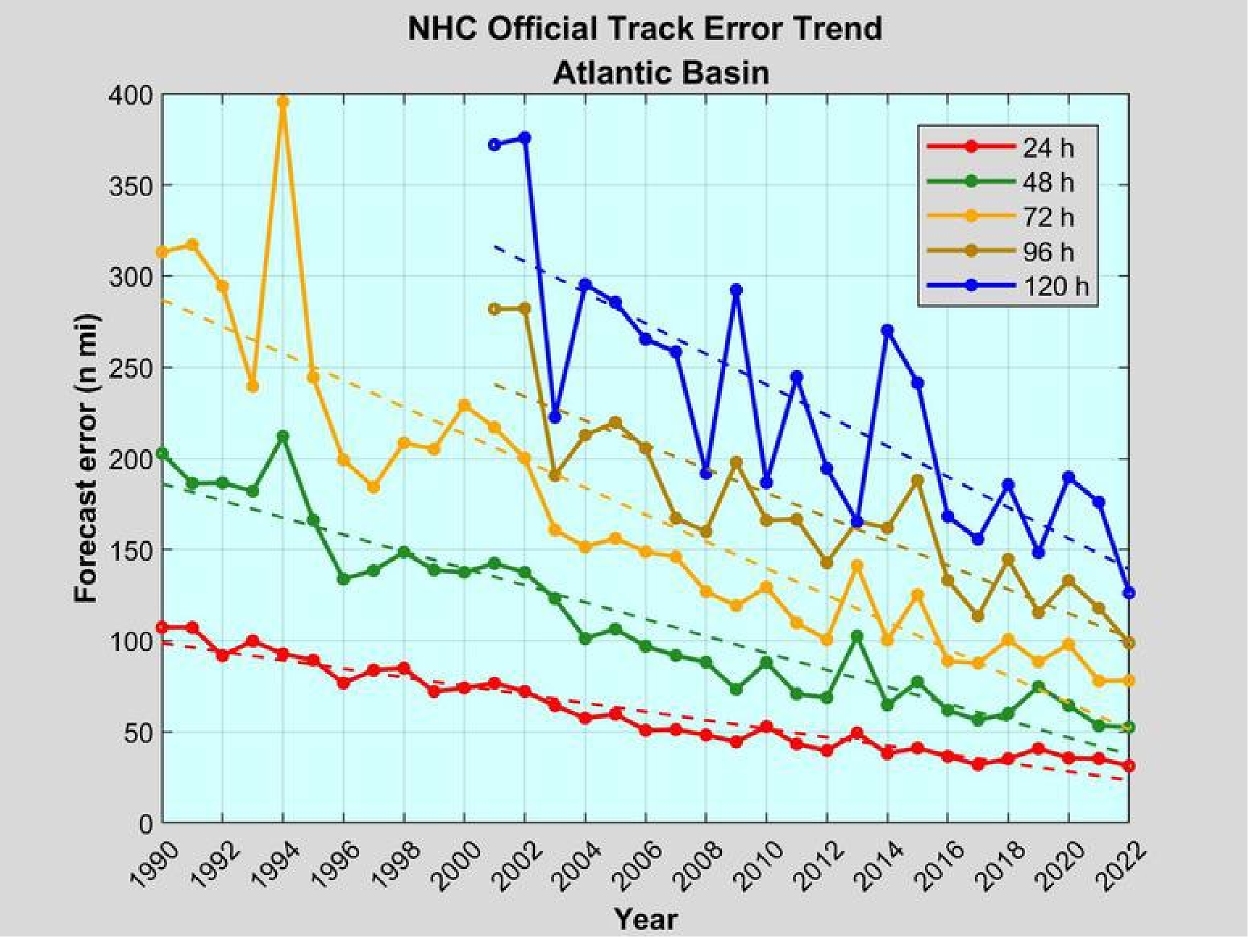

Figure 1-1 NHC Official Track Error Trend (1990 - 2022)[3]

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[3] Source: https://www.nhc.noaa.gov/verification/pdfs/Verification_2022.pdf

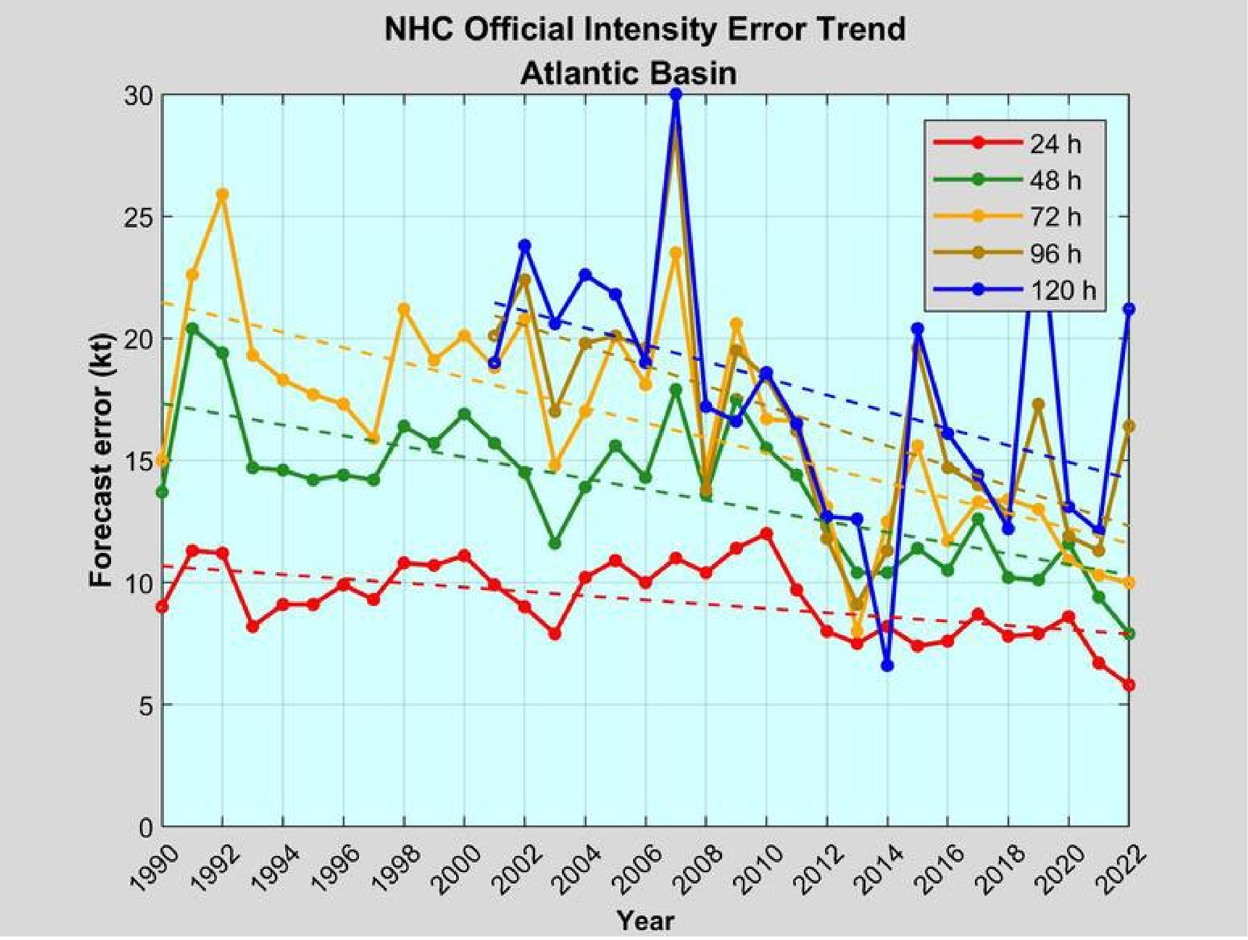

Figure 1-2 NHC Official Intensity Error Trend (1990 – 2022) [4]

1.3 STORM SURGE

1.3.1 INTRODUCTION

Storm surge is the abnormal rise in water level, over and above the predicted astronomical tides, caused by extreme wind and pressure forces. Storm surge along the coast is often the greatest threat to life and property from a hurricane. Various storm events can cause storm surge, but it is generally the result of a very large-scale meteorological disturbance with wind being the primary cause.

1.3.2 TOTAL FLOOD ELEVATION

Factors that contribute to the total flood elevation, or total water level, are storm tide and wave effects. The storm tide consists of the initial water level (e.g., normal astronomical tide) within the basin plus storm surge at the time the hurricane strikes. Since storm surge increases the water level above the normal astronomical tide, a low tide event is the best possible timing for landfall, while a high tide event is the worst. Figure 1-3 illustrates the relationship of the normal high tide, storm surge, storm tide, and wave setup. Normal astronomical tide and storm tide are both considered stillwater conditions.

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[4] Source: https://www.nhc.noaa.gov/verification/pdfs/Verification_2022.pdf

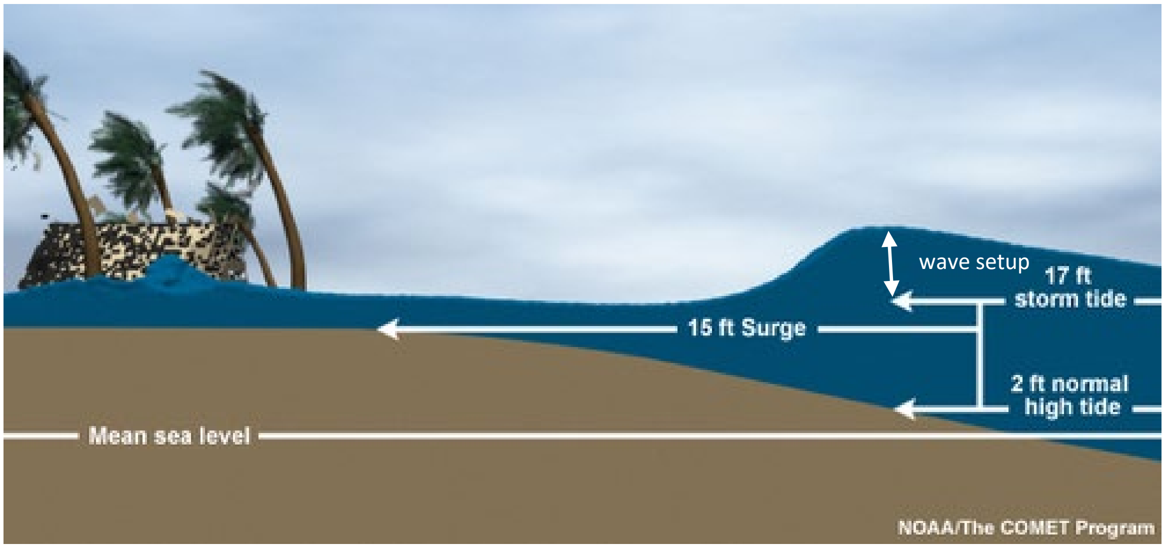

Figure 1-3 Relationship of Storm Surge to Mean Sea Level and Tides[5]

One factor that increases storm surge beyond storm tide is a localized phenomenon known as wave setup. Energy of the waves breaking near the shore forces water further landward. During severe storms, there is a significant increase in wave height and volume, and water cannot flow back to the sea as rapidly as it comes ashore. This increases the water level along the beachfront. Since waves break and dissipate their energy in shallow water, wave setup allows the waves to move further landward than under normal conditions. Also, a relatively steep offshore beach slope allows large ocean waves to get closer to the shore before breaking, resulting in greater wave setup than on a gradually sloping beach. Since large waves are generally not transmitted inland of the coastline, even if the beach has been overtopped, wave setup is primarily a concern near the beachfront. Progress has been made recently to capture wave set-up in the SLOSH model by coupling it with the Simulating Waves Nearshore (SWAN) model to include the wave set-up component.

It is assumed that for the open coast, maximum theoretical wave heights occur near the time of landfall. Immediately along the coastline or the shorelines of very large sounds and estuaries, wave crests can increase the expected still-water depth above the terrain by one-third, thus greatly increasing the hazard. Due to the presence of barriers such as structures, dunes, or vegetation, the waves break and dissipate a tremendous amount of energy within a few hundred yards of the coastline. Buildings within that zone that are not specifically designed to withstand the forces of wave action are often heavily damaged or destroyed. Also, currents created by tides combined with wave action severely erode beaches and coastal highways.

1.3.3 FACTORS AFFECTING STORM SURGE HEIGHT

The elevation reached by the storm surge depends upon the meteorological parameters of the hurricane and the physical characteristics along the coastline. The meteorological parameters affecting the height of the storm surge include the intensity of the hurricane (measured by the

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

storm center sea level pressure), track (path) of the storm, forward speed, and radius of maximum winds. This radius, which is measured from the center of the hurricane eye to the location of the highest wind speeds within the storm, can vary from as little as 4 miles to greater than 50 miles. Due to the complementary effects of forward motion and the counterclockwise rotation of the wind field (in the northern hemisphere), highest surges from a hurricane usually occur on the right side of the storm's track in the region of the radius of maximum winds. As shown in Figure 1-4, the impact of surge from the storm's low pressure is minimal in comparison to the water being forced towards the shore by wind. Peak storm surge may vary drastically within a relatively short distance along the coastline, depending on the radius of maximum winds and the point of hurricane eye landfall. The geophysical characteristics that influence the surge heights include the basin bathymetry (e.g., water depths), roughness and slope of the continental shelf, configuration of the coastline (such as bays and estuaries), and natural or manmade barriers. A wide, gently sloping continental shelf or a large bay may produce particularly large storm surges, as compared to a continental shelf that drops off very quickly which may produce a smaller storm surge. Table 1-2 summarizes generalized storm surge impacts from meteorological and geophysical parameters mentioned above.

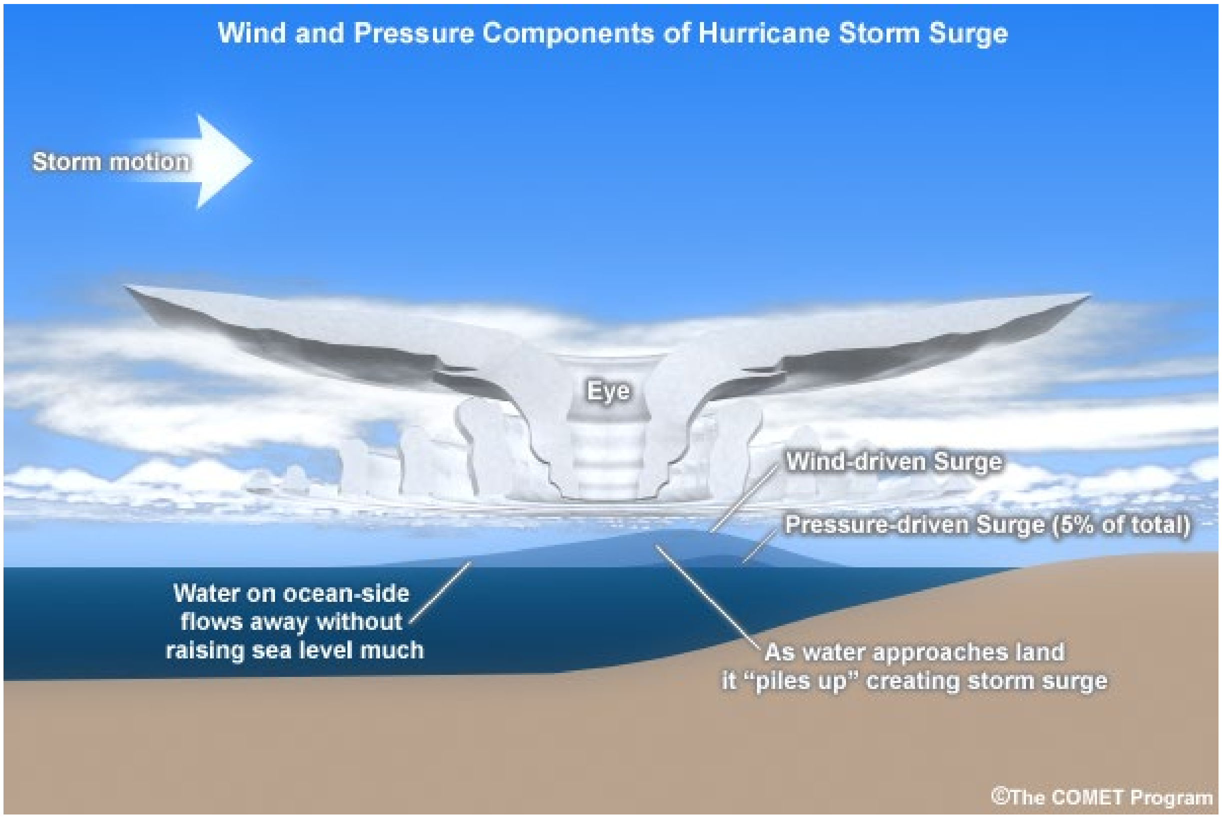

Figure 1-4 Wind and Pressure Components of Hurricane Storm Surge[6]

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[6] Source: https://www.nhc.noaa.gov/surge/

Table 1-2 Generalized Storm Surge Impacts from Factors[7]

Impact Factor	Generalized Impacts
Hurricane Intensity	Higher wind speeds = increased storm surge
Central Pressure	Little impact
Forward Speed	• Slower storms = higher and broader storm surge inland including bays and estuaries • Faster storms = more storm surge along the open coast
Size	• Storm with large wind field = more storm surge • Storm with small wind field = less storm surge
Angle of approach	• Perpendicular to coastline = more storm surge • Parallel to coastline = less storm surge
Width and slope of continental shelf	• Wide shelf/gentle slope = more storm surge with relatively small waves • Narrow shelf/sharp slope = less storm surge with relatively big waves
Local features	• Concavity of coastlines, bays, rivers, headlands, islands, etc. = greater storm surge impact

The waters offshore of Texas can be characterized by gently sloping depths typically associated with the continental shelf. Depths gradually increase from the shore to approximately 15 fathoms (90 feet) in 90 miles.

1.4 STORM SURGE FORECASTING

1.4.1 SLOSH MODEL

The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) computerized numerical model is used by NOAA and NWS for coastal inundation risk assessment and the operational prediction of potential storm surge from hurricanes. The SLOSH model was first conceived for real-time forecasting of surges from approaching hurricanes. The SLOSH model is now also the basis of establishing the extents of worst-case storm surge hazards by modeling multiple storm scenarios of different intensity, approach directions, and forward speeds. The SLOSH model computes storm surge for open coast and overland locations, as well as routes storm surge into sounds, bays, estuaries, and coastal river basins, but it does not account for localized wave setup.

Geophysical characteristics of an area covered by a SLOSH model are constructed as input data within the model. These characteristics include the topography of inland areas; river basins and waterways; bathymetry of near-shore areas, sounds, bays, and large inland waterbodies; significant natural and manmade barriers such as barrier islands, dunes, roads, levees, etc.; and a segment of the continental shelf.

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[7] Source: https://www.nhc.noaa.gov/surge/faq.php

The SLOSH model uses time-dependent meteorological data to determine the driving forces of a simulated storm. Input data includes the following:

1. Central pressure deficit at 6-hour intervals (approximated by subtracting the central pressure of the storm from 1013 mb).
2. Latitude and longitude of storm positions at 6-hour intervals.
3. Storm size measured by the radius of maximum winds. Wind speed is not an input parameter, since the model calculates a wind-field for the modeled storm based on the central pressure deficit using an internal symmetric wind model.
4. Height of the water surface before the storm directly affects the area of interest. This initial height is the observed water surface elevation occurring about 2 days before storm arrival.

Previous modeling for the Texas Hazard Analysis was conducted in 2004 for the Houston-Galveston study area and 2011 for the Sabine-Lake Study area using the Matagorda Bay (PS2), Galveston Bay (GL3), and Sabine Lake (BP3) SLOSH Basins (Figure 1-5). This updated Hazard Analysis utilizes data from the 2017 Texas SLOSH Super Basin (TX3) model which has a more detailed grid and greater inland extents than the previous basin versions. Figure 1-6 illustrates the area covered by the model grid (called a "basin") for the 2017 Texas SLOSH Super Basin (TX3) model.

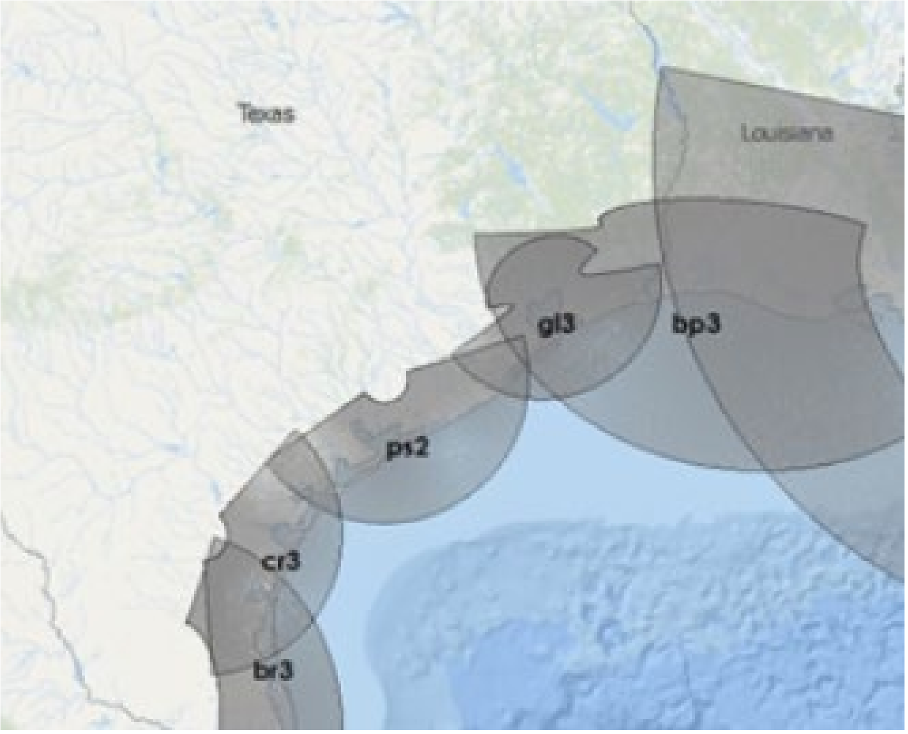


Figure 1-5 Historic Texas SLOSH Basins Matagorda Bay (PS2), Galveston Bay GL3, and Sabine Lake (BP3)

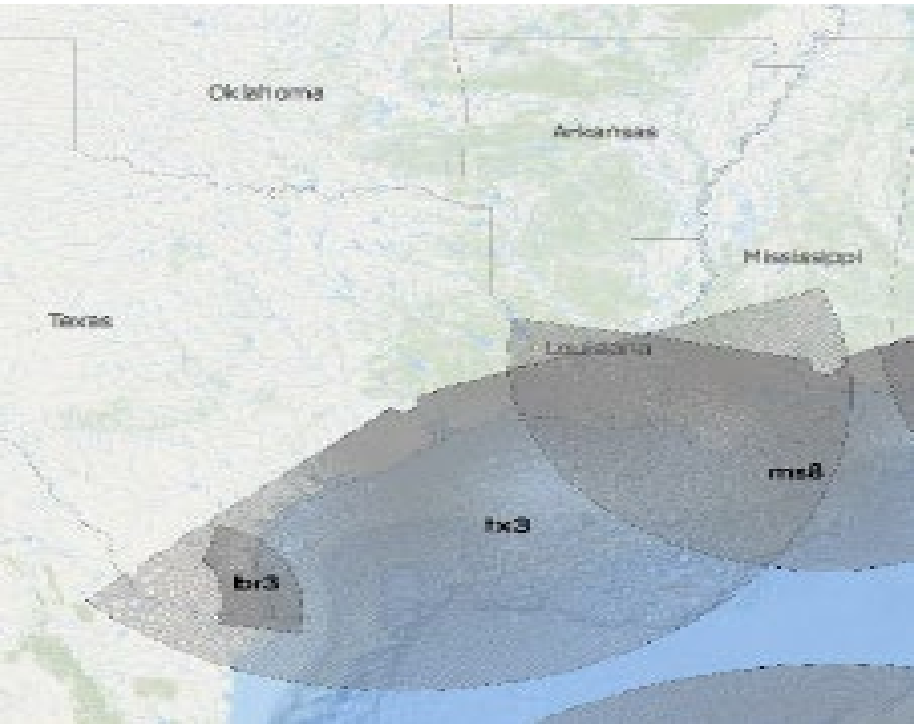


Figure 1-6 Texas SLOSH Super Basin (TX3)

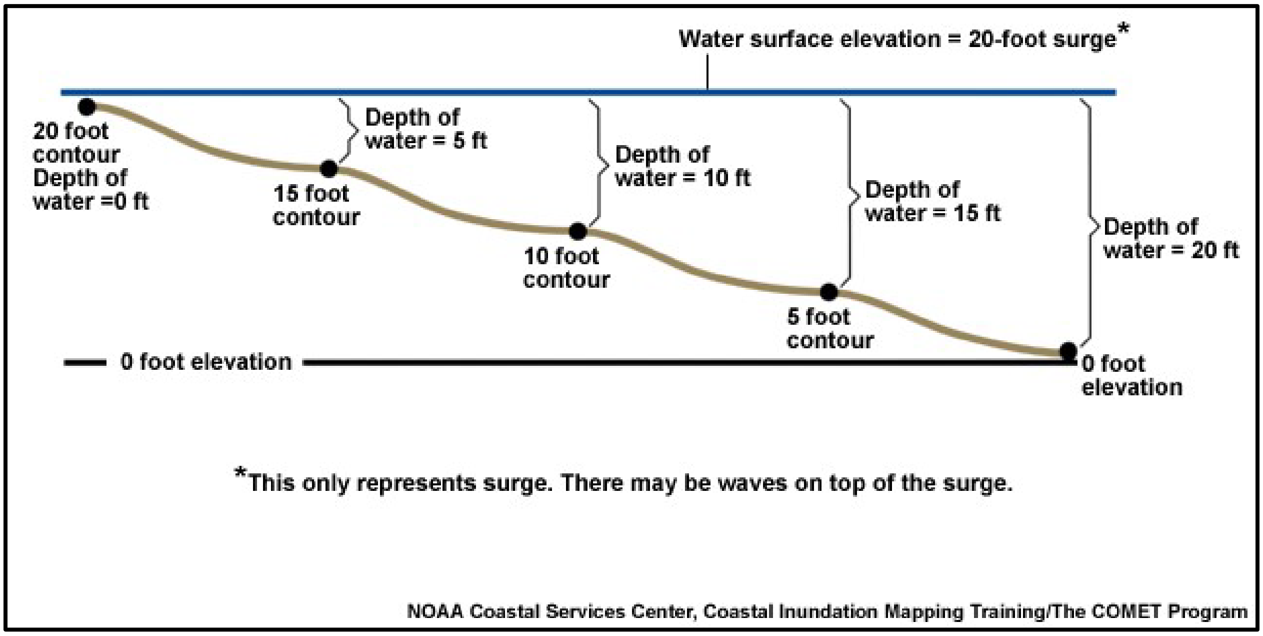
The characteristics of the simulated hurricanes were determined from an analysis of historical hurricanes that have occurred within the study area. The parameters selected for the modeled storms were the intensities (Tropical Storm and Categories 1-5), forward speeds, approach directions, landfall location, initial water level, and radii of maximum winds that are considered to have the highest meteorological probability of occurrence within Texas SLOSH Basin. For this Hazard Analysis, only the high tide events were considered.

1.4.2 VERIFICATION OF SLOSH MODEL

After a SLOSH model has been constructed for a coastal basin, verification is conducted as real-time operational runs in which available meteorological data from historical storms are input into the model. The computed surge heights are compared with those measured from the historical storms and, if necessary, adjustments are made to the input or basin data. These adjustments are not made to force agreements between computed and measured surge heights from historical storms, but to represent the basin characteristics or historical storm parameters more accurately. In instances where the model has given realistic results in one area of a basin but not in another, closer examination has often revealed inaccuracies in the representation of barrier heights or missing values in bathymetric or topographic data.

1.4.3 MODEL OUTPUT

The SLOSH model output for a modeled storm consists of envelopes of high water above ground datum and contains the maximum surge height values calculated for each grid point in the model. Maximum surges along the coastline do not necessarily occur at the same time. The time of the maximum surge for one location may differ by several hours from the maximum surge that occurs at another location. Therefore, at each grid point, the water height value shown is the maximum that was computed at that point during the 72 hours of model time, irrespective of the time during the simulation that the maximum surge height occurred. An example of this computation is shown in Figure 1-7 below. Output of the Texas (TX3) model was produced for mean and high tide conditions using the North American Vertical Datum of 1988 (NAVD88). However, only high tide conditions were used for purposes of this Hazard Analysis update since high tide conditions represent the worst case.



*This only represents surge. There may be waves on top of the surge.

NOAA Coastal Services Center, Coastal Inundation Mapping Training/The COMET Program

Figure 1-7 Storm Surge Inundation Shown as Height Above Ground Level[8]

1.4.3.1 DIRECTIONAL MAXIMUM ENVELOPES OF WATER

The highest surges reached at all locations within the affected area of the coastline during the passage of a hurricane are called the maximum or peak surges for those locations. The location of the peak surge depends on where the eye of a hurricane crosses the coastline, hurricane intensity, basin bathymetry, configuration of the coastline, approach direction, and radius of maximum winds. As discussed previously, the peak surge from a hurricane usually occurs to the right of the storm path and within a few miles of the radius of maximum winds.

The NHC's Storm Surge Unit developed MEOWs to determine the potential peak surge at every location within the SLOSH basin. For example, if there were two storms, identical in every respect and they followed parallel tracks separated by 50 miles, then very likely there would be locations having markedly different surge values resulting from the two storms. This dependency of surge height on storm track can be troublesome in evacuation planning. Accordingly, MEOWs were produced by running the SLOSH model to create a group of storms, all having the same characteristics, but with parallel tracks 5 to 10 miles apart. At each grid square, the maximum surge value that was calculated was saved. The result was a "maximum envelope of water." Thus, the MEOW is the "worst-case" surge that is likely to be produced at a modeled location from a storm with a particular combination of approach direction, forward speed, and intensity, regardless of where landfall may have occurred. Since the MEOW is the "worst case" at all grid square locations, no one storm can duplicate the flooding depicted by a MEOW.

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[8] Source: https://www.nhc.noaa.gov/surge/faq.php

Table 1-3 summarizes the model runs related to MEOWs for the TX3 SLOSH basin. The 54 MEOWs were generated for various hurricane approach directions and various intensities for Tropical Storm (Category 0) and Categories 1 through 5 events which are initialized at a high tide.

Table 1-3 Texas SLOSH Super Basin Model Data for TX3 at High Tide Conditions

Direction	Intensities	MEOWs
N	TS, Cat. 1-5	6
NE	TS, Cat. 1-5	6
NNE	TS, Cat. 1-5	6
NNW	TS, Cat. 1-5	6
NW	TS, Cat. 1-5	6
PAR	TS, Cat. 1-5	6
W	TS, Cat. 1-5	6
WNW	TS, Cat. 1-5	6
WSW	TS, Cat. 1-5	6
	TOTALS	**54**

Note: 9 storm track directions x 6 intensities = 54 MEOWs

1.4.3.2 MAXIMUM OF THE MAXIMUMS

In addition to MEOWs the NHC produced MOMs data which are ensemble products of maximum storm surge heights representing the near worst-case scenario of flooding under worst-case storm conditions. The MOMs are created for each SLOSH basin by compositing all the MEOWs, separated by category, and selecting maximum storm surge values for each grid cell regardless of the forward approach speed, storm direction, or landfall location. It was from those MOMs that storm surge inundation maps were developed for high tide conditions in each of the counties within the Southeast Texas HES study area.

1.4.4 DIRECTIONAL MEOW ANALYSIS

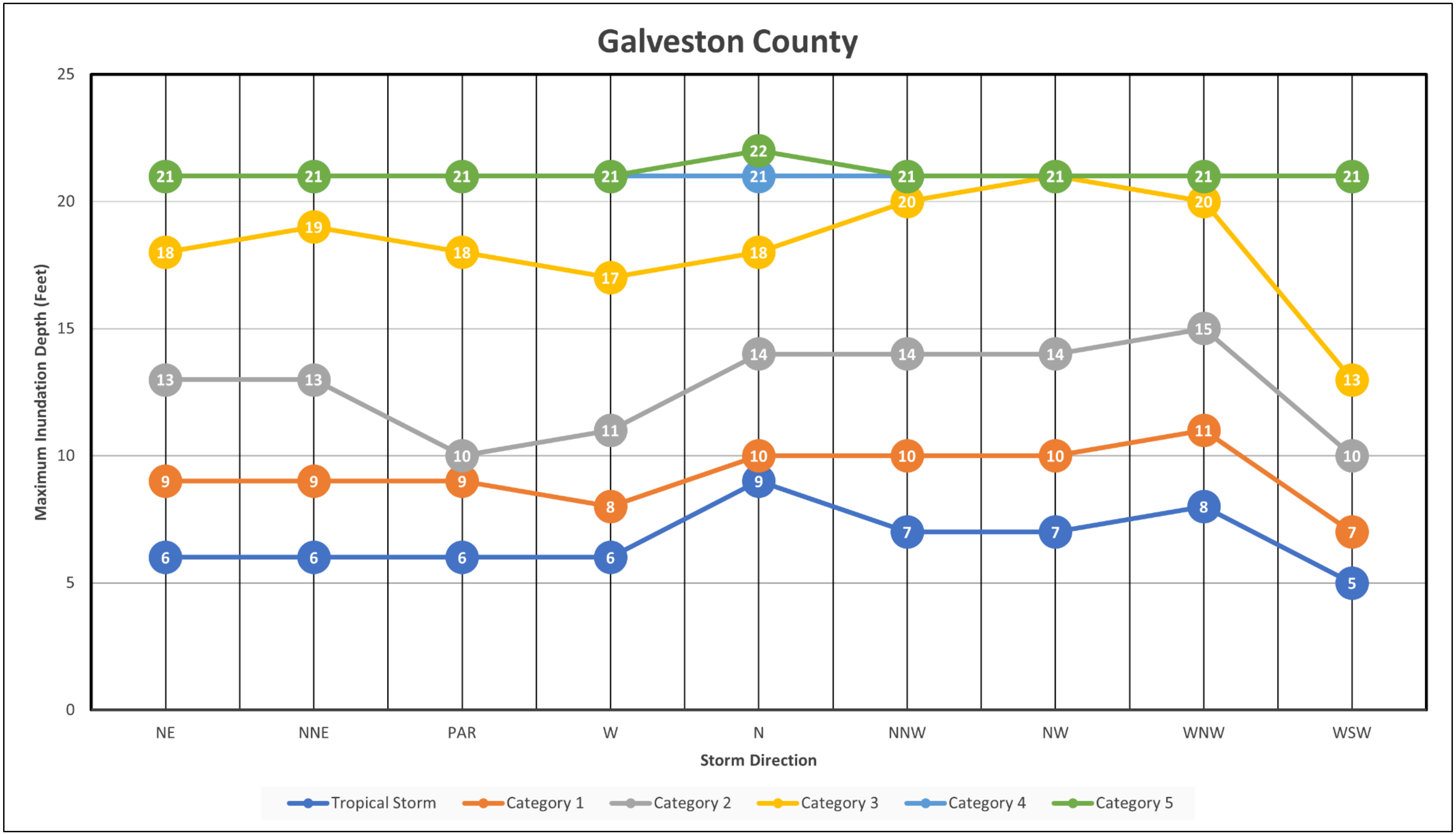
A new methodology for analyzing the MEOWs output data was developed to evaluate and determine areas of equivalent storm surge risk from various storm scenarios for each coastal county. The intent of this new methodology is to provide emergency planners with a more detailed look into the effects of storm intensity, direction, and forward speed to enhance emergency planning.

The MEOWs maximum depth data were first organized using an Excel pivot chart. Figure 1-8 graphically depicts the maximum modeled inundation depths for 54 directional MEOWs for Galveston County. The 54 MEOWs were generated by taking the 6 different intensity storms (e.g., Tropical Storm through Category 5 Hurricane) multiplied by the 9 different approach directions for the Southeast Texas area. The Max Inundation Depths of the Category 4 and Category 5 Storms are shown as they were modeled in SLOSH. Note that all the data has been included for these figures, including outliers of maximum depths that may have very small areas associated with them. Although the inundation depth appears to be the same for Category 4 and Category

5 in Figure 1-8, further analysis of the pivot table data for Galveston County (Table 1-4) indicates the flood elevation causing an increase in acreage extents is greater for a Category 5 and could potentially impact more population.

For somewhat protected areas, it was noted the storm intensity (i.e., storm category) and the approach direction typically have the most influence on surge height. The higher the intensity, generally the larger the storm size and the wider the wind field, which pushes more water further inland. However, when there is a wide-open fetch in the direction of the hurricane approach to land, the inundation depths produced are more sensitive to the forward speed. In addition, storms that are moving parallel to the coast, east to west, also exhibit a larger influence from forward speed than storms moving west to east, due to the additive relative velocity forces produced from forward speed and counterclockwise rotation of the winds in the upper right quadrant of the storm.

Maximum Inundation Depth graphs for each county are found in Appendix E. Pivot data tables for each county are found in Appendix F.



Note: There is overlap of data points for maximum inundation depths greater than 20 feet.

Figure 1-8 Galveston County, TX Maximum Inundation Depths for Directional MEOWs

Table 1-4 Galveston County, TX Grouping Based on Acreage of Inundation Extent

Storm/Direction	Min. Depth (ft.)	Avg. Depth (ft.)	Max. Depth (ft.)	Population Impacts	Acres
MEOW N0	1	5	9	93343	71318.93148
MEOW N1	1	5.5	10	113555	93590.19398
MEOW N2	1	7.5	14	165160	113962.4217
MEOW N3	1	9.5	18	250835	149030.9715
MEOW N4	1	11	21	321829	193866.7952
MEOW N5	1	11.5	22	349179	222427.4061
MEOW NE0	1	3.5	6	91131	66842.50702
MEOW NE1	1	5	9	109401	87683.61539
MEOW NE2	1	7	13	155055	110102.6284
MEOW NE3	1	9.5	18	234269	139784.0851
MEOW NE4	1	11	21	311545	184072.3459
MEOW NE5	1	11	21	347021	218568.2955
MEOW NNE0	1	3.5	6	91225	68216.97168
MEOW NNE1	1	5	9	110448	90040.36979
MEOW NNE2	1	7	13	159250	111188.8177
MEOW NNE3	1	10	19	240657	142548.9637
MEOW NNE4	1	11	21	314496	186195.3775
MEOW NNE5	1	11	21	348567	219074.8323
MEOW NNW0	1	4	7	94834	74672.73405
MEOW NNW1	1	5.5	10	115348	96973.59429
MEOW NNW2	1	7.5	14	174667	119090.4132
MEOW NNW3	1	10.5	20	261469	156720.1264
MEOW NNW4	1	11	21	333347	204425.6521
MEOW NNW5	1	11	21	350135	225994.6424
MEOW NW0	1	4	7	98007	77520.67443
MEOW NW1	1	5.5	10	119100	99279.79082
MEOW NW2	1	7.5	14	181454	123186.3876
MEOW NW3	1	11	21	269775	163198.7327
MEOW NW4	1	11	21	341763	213068.565
MEOW NW5	1	11	21	350682	227593.1994
MEOW PAR0	1	3.5	6	91502	66979.06975
MEOW PAR1	1	5	9	110194	86606.74996
MEOW PAR2	1	5.5	10	155880	110410.0705
MEOW PAR3	1	9.5	18	237773	140638.5251
MEOW PAR4	1	11	21	314827	186395.0272
MEOW PAR5	1	11	21	346657	219638.4284
MEOW W0	1	3.5	6	91207	71558.7024
MEOW W1	1	4.5	8	107426	90231.52496
MEOW W2	1	6	11	149077	109154.4869
MEOW W3	1	9	17	229205	142245.4034
MEOW W4	1	11	21	308620	188319.8254
MEOW W5	1	11	21	348550	221950.1759
MEOW WNW0	1	4.5	8	98023	78019.27324
MEOW WNW1	1	6	11	120152	98992.62912
MEOW WNW2	1	8	15	180424	122504.2451
MEOW WNW3	1	10.5	20	266945	162445.4173
MEOW WNW4	1	11	21	342813	214361.0767
MEOW WNW5	1	11	21	350682	227648.4131
MEOW WSW0	1	3	5	85677	62483.33079
MEOW WSW1	1	4	7	98883	81915.50736
MEOW WSW2	1	5.5	10	130457	101861.3175
MEOW WSW3	1	7	13	199052	129323.0712
MEOW WSW4	1	11	21	283613	174133.7145
MEOW WSW5	1	11	21	340847	211867.095
MOM1	1	11.5	22	141175	98705.05359
MOM2	1	8	15	193632	123755.5096
MOM3	1	11.5	22	278857	167674.0075
MOM4	1	11.5	22	343973	218961.6485
MOM5	1	11.5	22	350682	230904.1845

Considering all storm categories (e.g., Tropical Storm through Category 5 Hurricane) and storm direction, the maximum inundation depths were plotted for all 9 storm approach directions to determine the worst and best cases. Figure 1-9 and Figure 1-10 are the composited directional MEOW maps showing the worst case (e.g., highest maximum inundation) and best case (e.g., lowest maximum inundation) related to storm approach directions for the study area counties. The northwest approach direction (Figure 1-9) produced the most areas inundated with the highest surge heights due to water pushing across Southeast Texas and into its waterways. The West Southwest approach direction (Figure 1-9) produced the least areas inundated with the lowest surge heights due to the storm moving in an opposite direction to the coastline and not pushing as much water into Southeast Texas and into its waterways. Figures B-1 through B-7 in Appendix B depict the remainder of the composited directional MEOW maps related to storm approach directions for the maximum inundation depths associated with all storms and approach speeds for Southeast Texas.

1.4.5 EQUIVALENT EXTENTS OF STORM SURGE INUNDATION

The inundation extents for composited directional MEOWs for Southeast Texas were sorted into 6 groups (TS, Group I through V) according to maximum surge depths. This new approach enabled comparison of similar surge impacts from 6 different intensity storms (e.g., Categories 0 through 5) and 9 approach directions resulting in 54 scenarios. Figure 1-11 1-16 depict the equivalent inundation extents for each maximum surge depth group for directional MEOWs for the coastal counties. The associated tables in the figures show which storm intensities and directions produce equivalent maximum surge depths within groups. For instance, in -14, Southeast Texas Group III shows extents of surge inundation flooding over 20 feet (annotated as >20 feet) in depth for various Category 3 and 4 storms of varying approach directions that produce maximum depths of 18 to over 20 feet, whereas Figure 1-16 provides a good representation of a greater inundation area for Group V compared to Group IV in Figure 1-15. As indicated earlier, although inundation depth appears to be relatively similar when comparing category storms, it is also similar when comparing the different groupings. However, there are also differences in the inundation acreage numbers.

Additional inundation data analysis addressing impacts to critical facilities and identifying specific vulnerabilities across a given county's population and infrastructure will be performed during upcoming components of the Southeast Texas HES. Also, please note that Figures 1-9 to 1-16 illustrate levee locations **only** and **does not** represent overtopping at specific inundation depths.

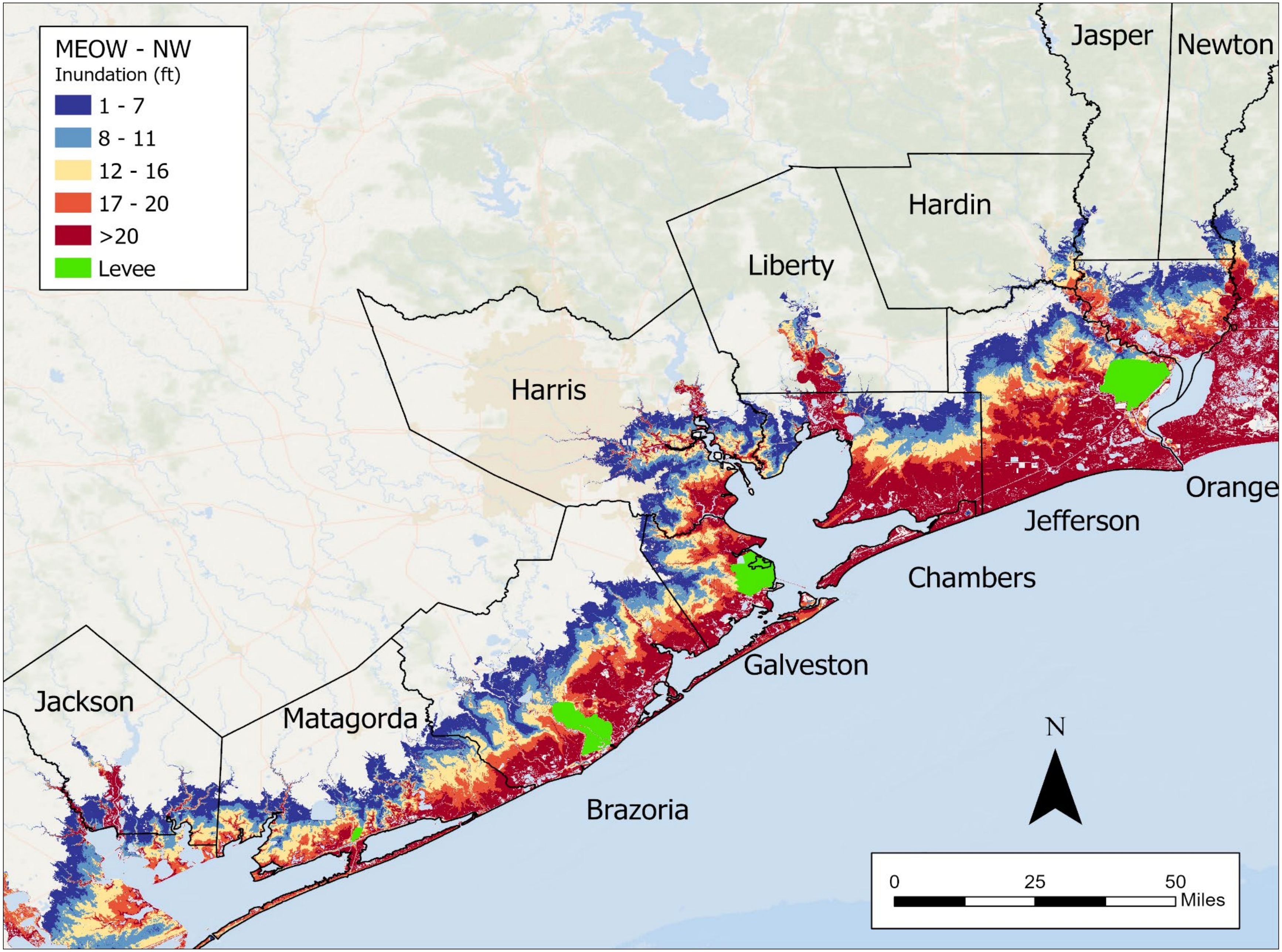


Figure 1-9 Northwest Directional MEOW Map (Worst Case Approach Direction – Highest Maximum Inundation)

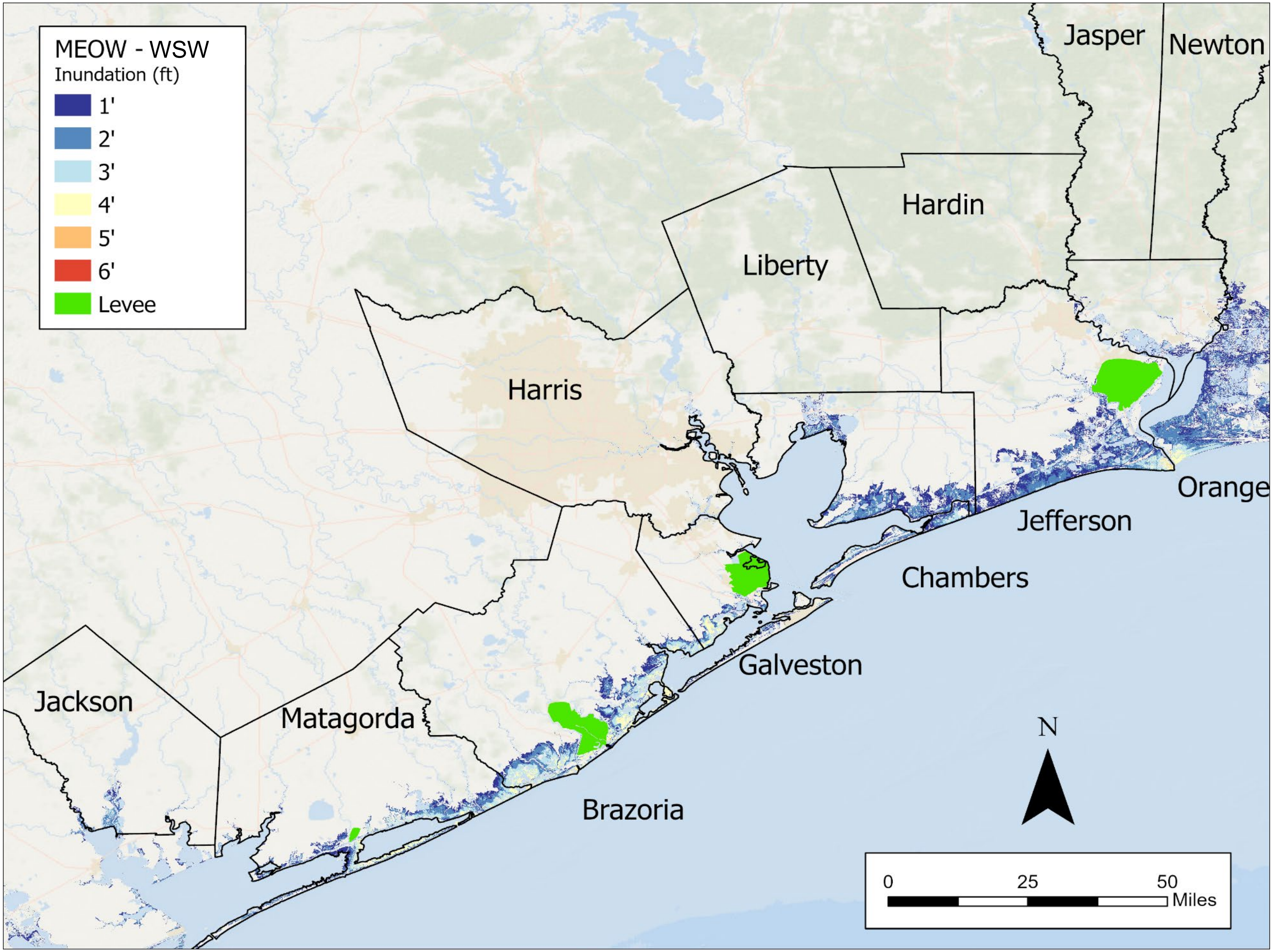
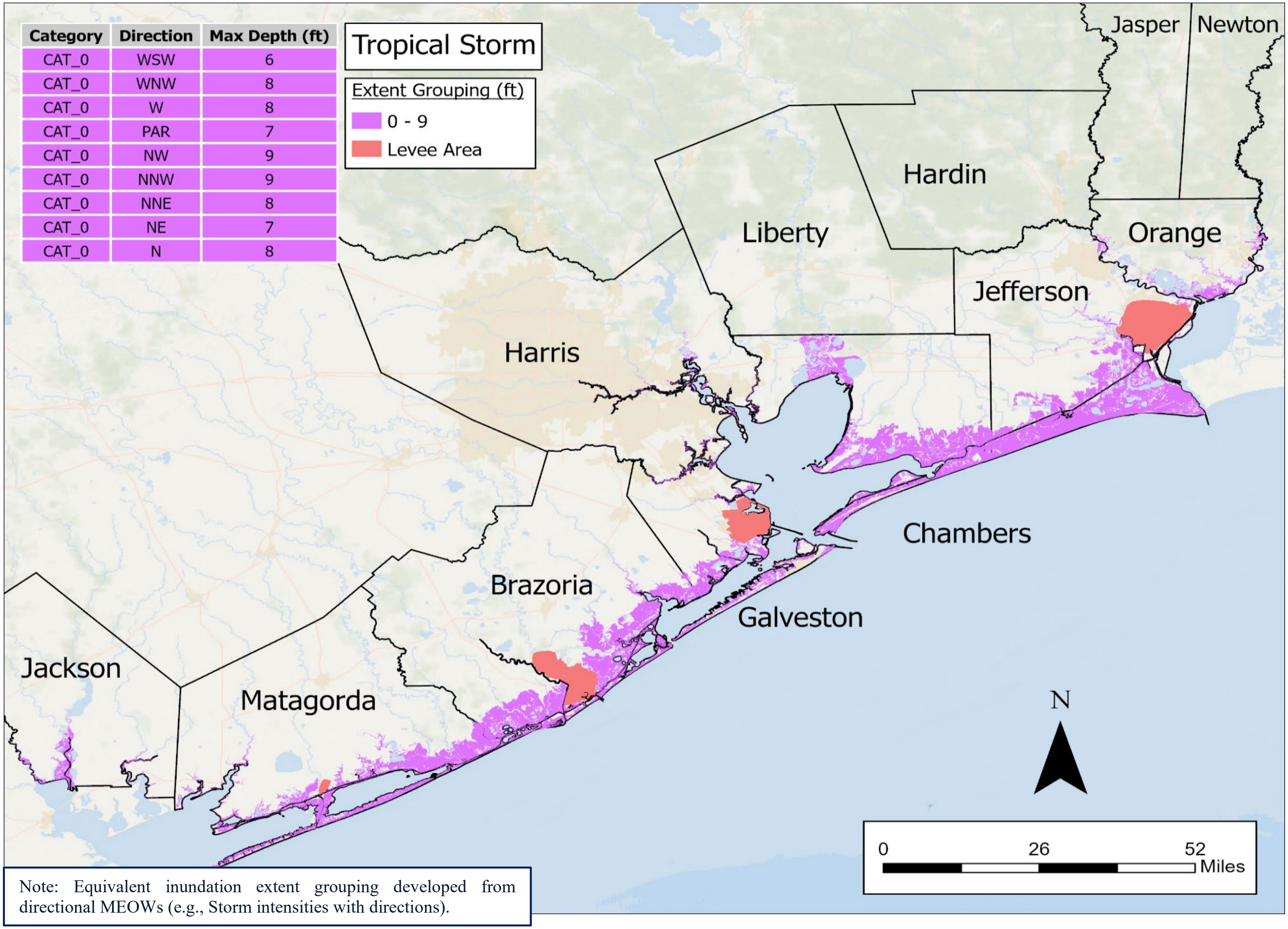


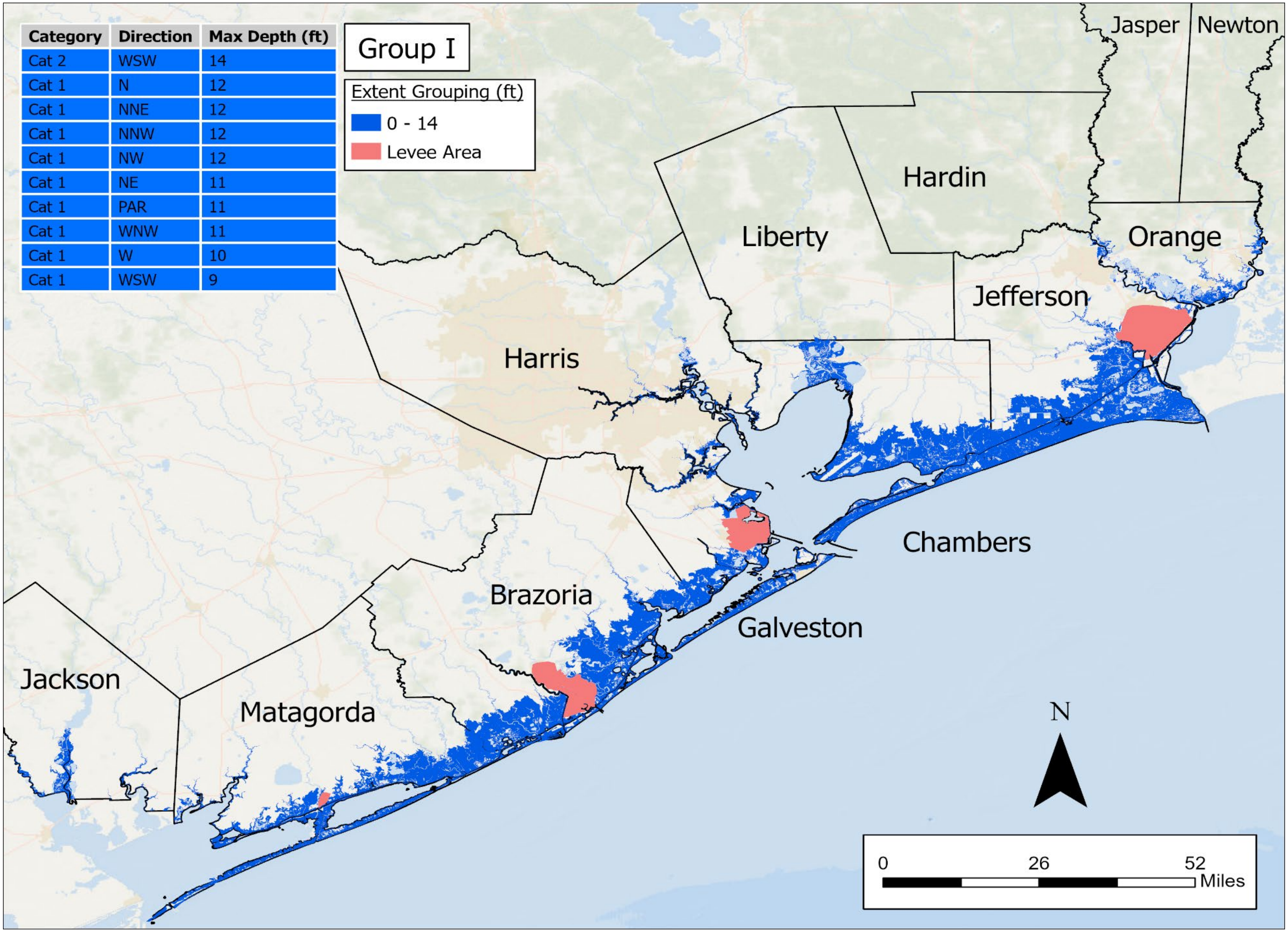
Figure 1-10 West Southwest Directional MEOW Map (Best Case Approach Direction – Lowest Maximum Inundation)



Category	Direction	Max Depth (ft)
CAT_0	WSW	6
CAT_0	WNW	8
CAT_0	W	8
CAT_0	PAR	7
CAT_0	NW	9
CAT_0	NNW	9
CAT_0	NNE	8
CAT_0	NE	7
CAT_0	N	8

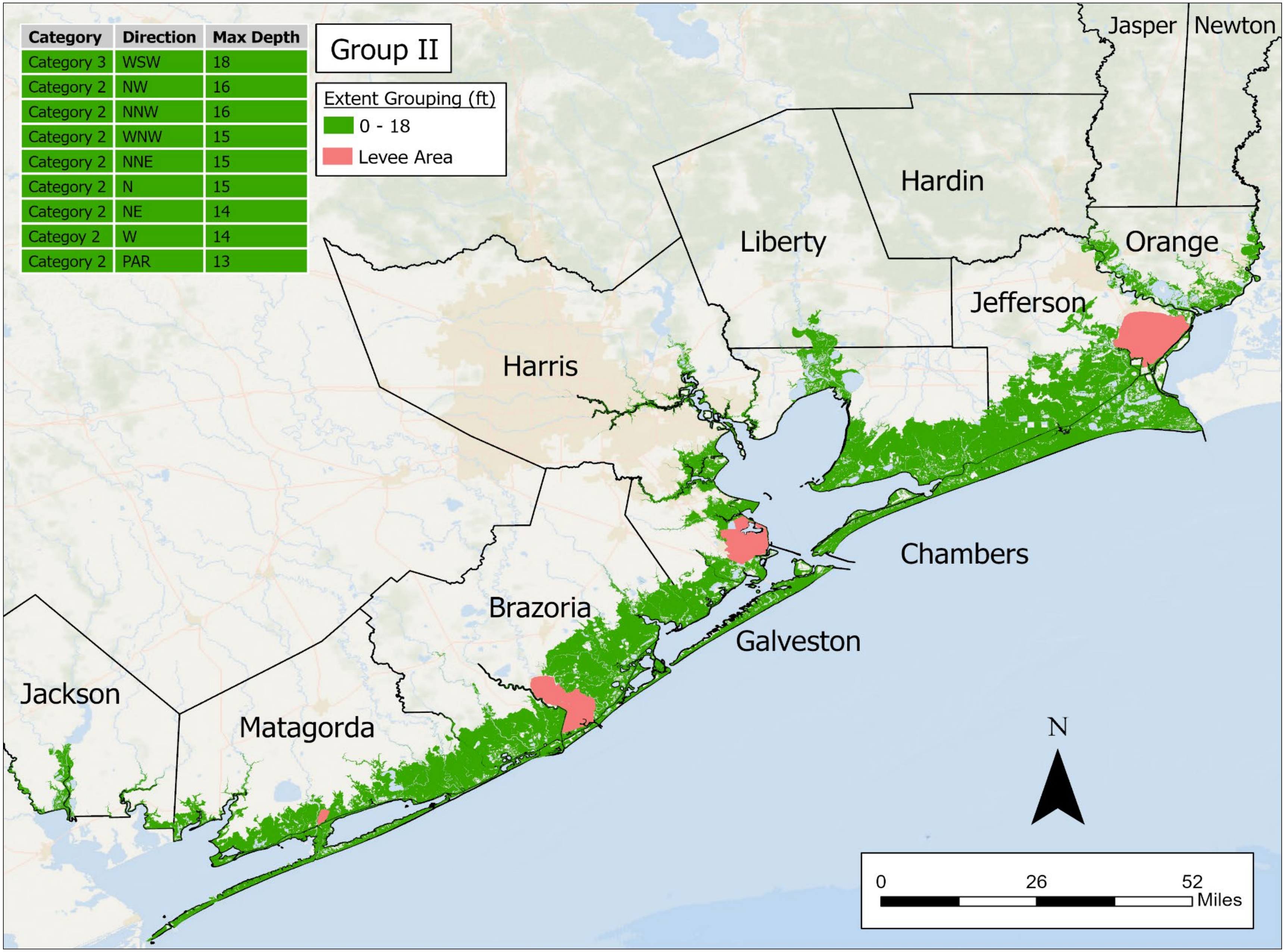
Note: Equivalent inundation extent grouping developed from directional MEOWs (e.g., Storm intensities with directions).

Figure 1-11 Equivalent Inundation Extent Map: Group TS



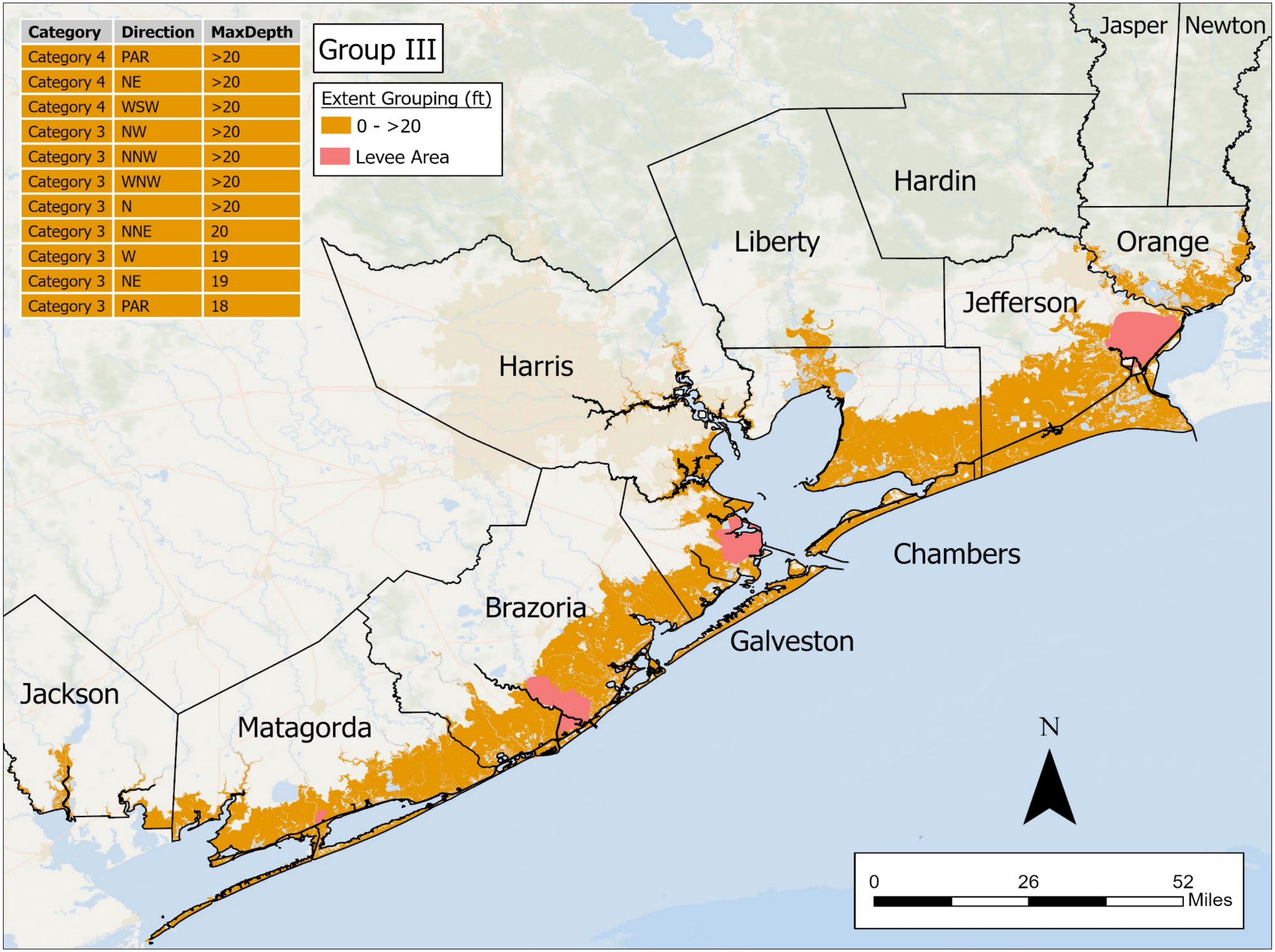
Category	Direction	Max Depth (ft)
Cat 2	WSW	14
Cat 1	N	12
Cat 1	NNE	12
Cat 1	NNW	12
Cat 1	NW	12
Cat 1	NE	11
Cat 1	PAR	11
Cat 1	WNW	11
Cat 1	W	10
Cat 1	WSW	9

Figure 1-12 Equivalent Inundation Extent Map: Group II



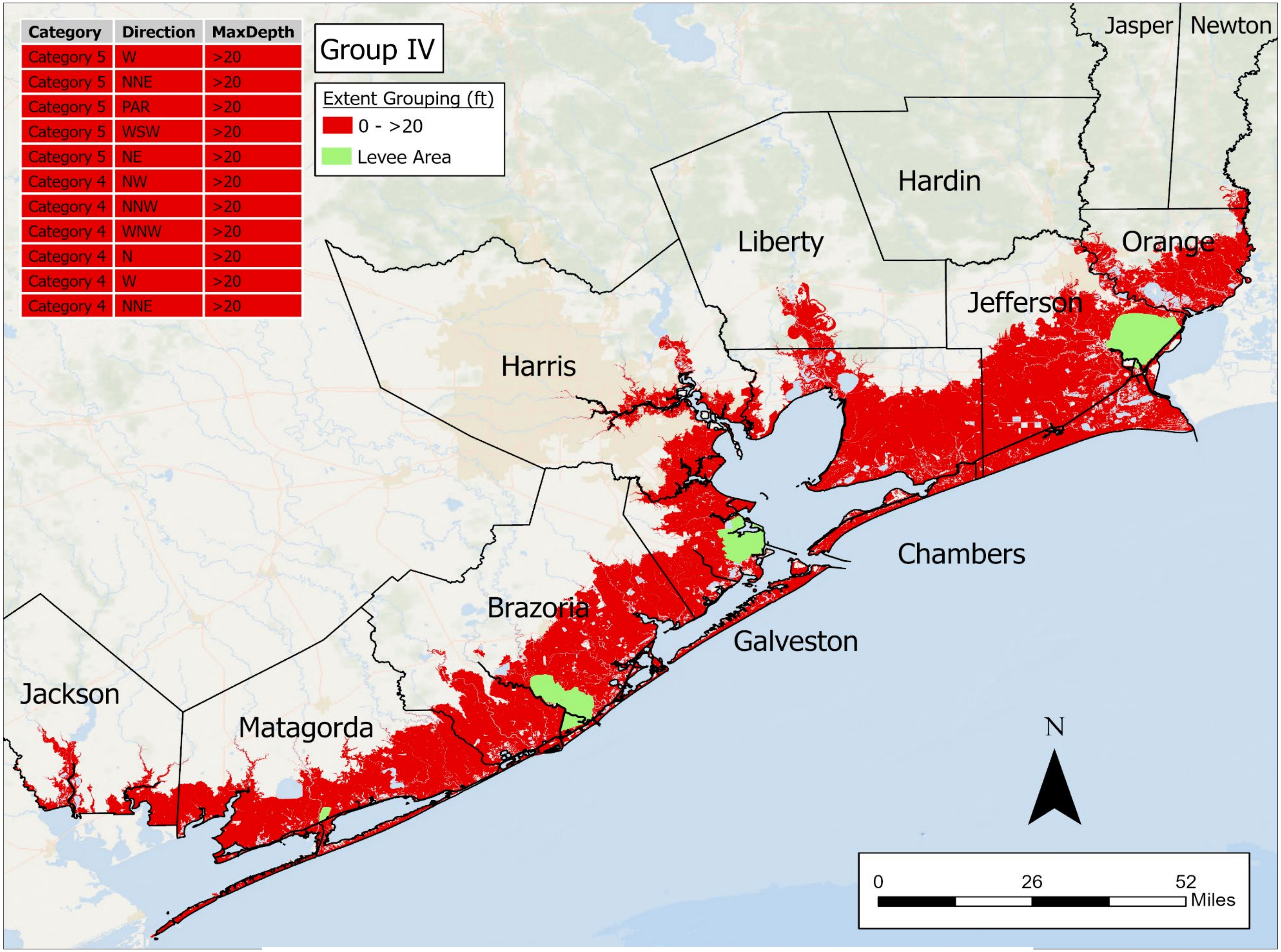
Category	Direction	Max Depth
Category 3	WSW	18
Category 2	NW	16
Category 2	NNW	16
Category 2	WNW	15
Category 2	NNE	15
Category 2	N	15
Category 2	NE	14
Categoy 2	W	14
Category 2	PAR	13

Figure 1-13 Equivalent Inundation Extent Map: Group II



Category	Direction	MaxDepth
Category 4	PAR	>20
Category 4	NE	>20
Category 4	WSW	>20
Category 3	NW	>20
Category 3	NNW	>20
Category 3	WNW	>20
Category 3	N	>20
Category 3	NNE	20
Category 3	W	19
Category 3	NE	19
Category 3	PAR	18

Figure 1-14 Equivalent Inundation Extent Map: Group III



Category	Direction	MaxDepth
Category 5	W	>20
Category 5	NNE	>20
Category 5	PAR	>20
Category 5	WSW	>20
Category 5	NE	>20
Category 4	NW	>20
Category 4	NNW	>20
Category 4	WNW	>20
Category 4	N	>20
Category 4	W	>20
Category 4	NNE	>20

Figure 1-15 Equivalent Inundation Extent Map: Group IV

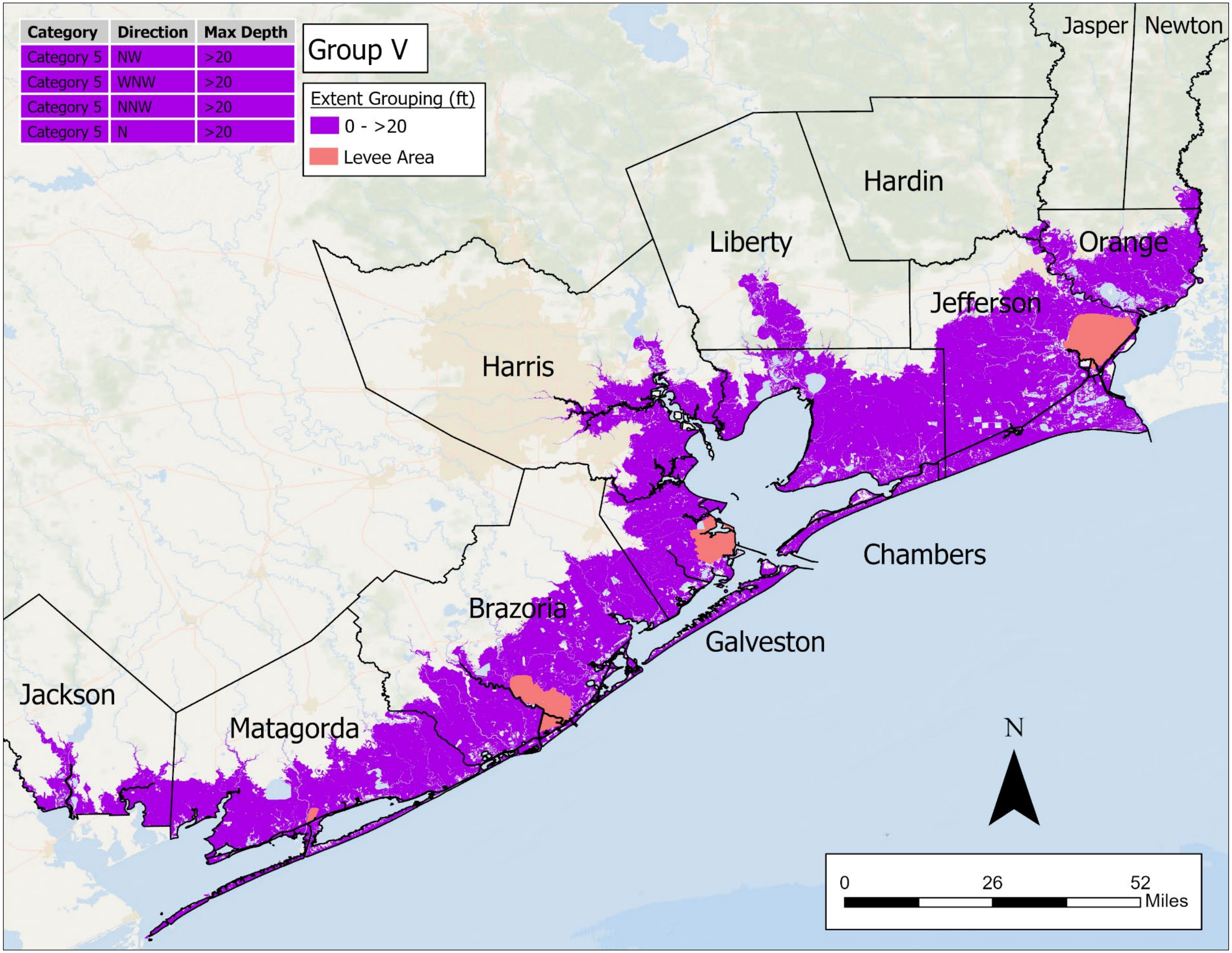


Figure 1-16 Equivalent Inundation Extent Map: Group V

The equivalent inundation extents for all groups are presented as a cumulative map in Figure 1-17, which show all the groups I through V in an overlapping fashion. For example, Group V is drawn underneath Groups I through IV so that the other groups can be seen. Modeled MEOWs inundation impacts extend far inland of the estuaries and tributaries of the Southeast Texas study area with more inundation anticipated along low-lying coastal areas due to topographical differences.

1.4.6 ADJUSTMENTS TO SLOSH MODEL VALUES / STATISICAL ANALYSIS

Hurricane evacuation decision-makers should keep in mind that the SLOSH model is a mathematical model and does not always produce perfect results, nor is it expected to. Based on the results of statistical analysis reviews and comparison of actual storm tides vs. SLOSH model results conducted by the NWS in past tropical cyclone storm events, an average variance of +/- 20 % has been observed. However, errors in wind input provided to SLOSH model may cause storm surge errors which are much larger than 20%. One limitation of the MEOWs that are simulated for theoretical storms is that they lack timing information of an actual storm which contains tidal water levels (highly dependent on time), abnormal water levels (e.g., sea level rise, disruptions of currents), and external wind fields.[9] However, the MEOWs used for hazard mapping are a conservative estimate to be used for planning purposes. Evacuation planners should remain cognizant of the potential for approximately 20 % over or underestimate of some predicted SLOSH surge values.

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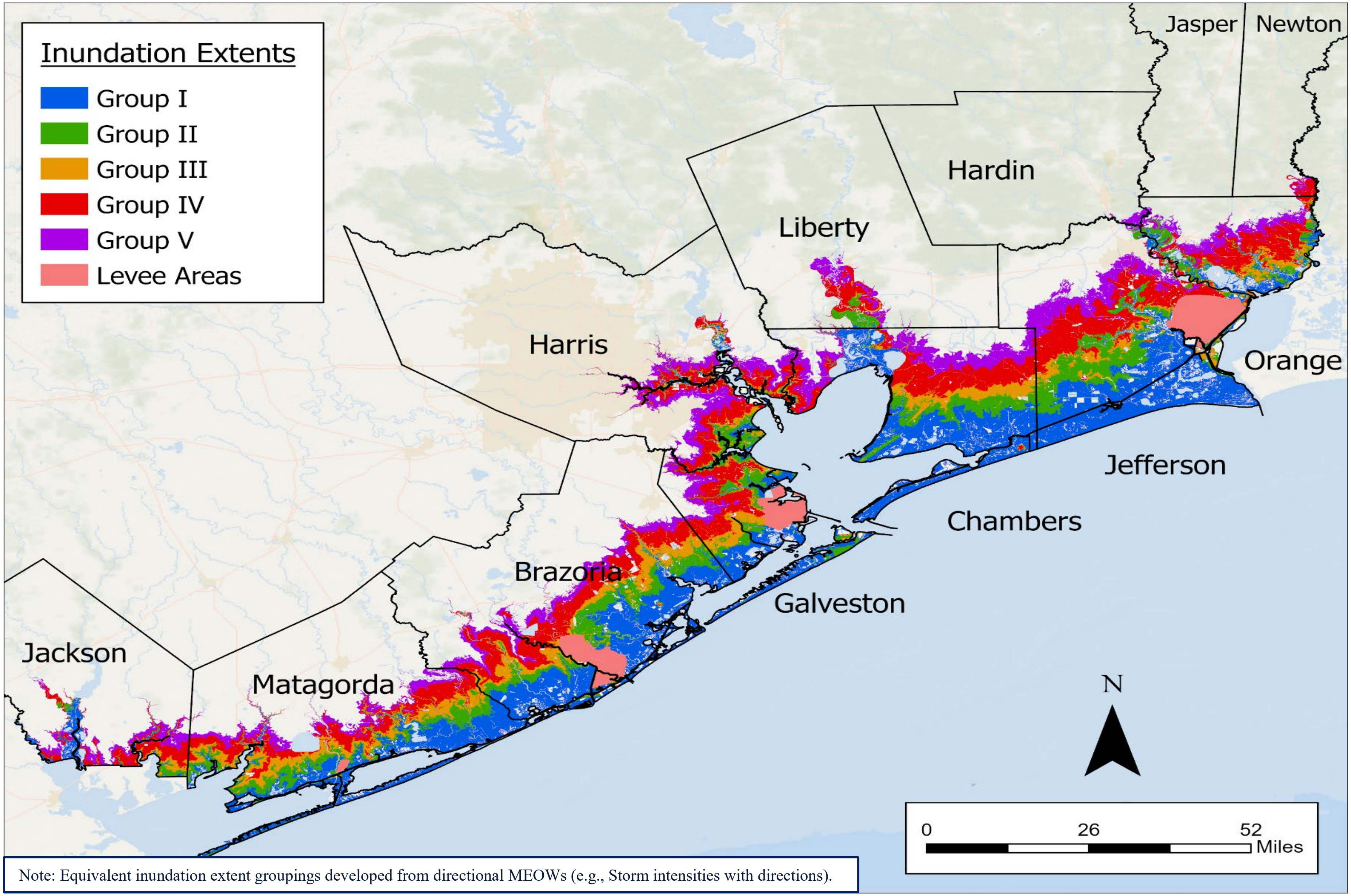
[9] Source: "Latest Developments in the NWS' Sea Lake and Overland Surges from Hurricanes Model," Arthur Taylor and Huiqing Liu, 1. NOAA/NWS/STI/Meteorological Development Laboratory, 2. Ace Info. Solutions, Inc., Presented at the 100th AMS Annual Meeting, Boston, MA, January 14, 2020.



Note: Equivalent inundation extent groupings developed from directional MEOWs (e.g., Storm intensities with directions).

Figure 1-17 Southeast Texas Summary – Equivalent Inundation Extent Map: Groups I through V

1.4.7 POTENTIAL STORM SURGE FLOODING MAPS[10]

The NHC also uses the SLOSH models to depict the risk associated with coastal flooding from storm surge related to real tropical cyclones in real time. The Potential Storm Surge Flooding Map is based on probabilistic storm surge guidance developed by the NWS Meteorological Development Laboratory in cooperation with NHC, which is called Probabilistic Hurricane Storm Surge (P-Surge 2.8)[11]. The map shows a reasonable worst-case scenario of the flooding of normally dry land at particular locations due to storm surge. Storm surge values that have a 1-in-10 chance of being exceeded at each location are included in the Potential Storm Surge Flooding Map. Roadways are only included as a reference point on the map since flooding of roadways from fresh or salt water in a hurricane situation are not indicated.

On the Potential Storm Surge Flooding Map, it is possible to either choose potential storm surge flooding or the intertidal zone. Potential storm surge flooding is not depicted in the intertidal zone, that is the area that is above water at low tide and under water at high tide. The intertidal zone is displayed in a masked layer along with estuarine wetlands, or lands that are saturated with water either permanently or seasonally.

A storm surge watch / warning graphic is available with the Potential Storm Surge Flooding Map and highlights areas along the coast that have a significant risk of life-threatening storm inundation from a tropical storm or hurricane. Areas are displayed that would qualify for inclusion under a storm surge watch / warning by the NWS. More details can be found at https://www.nhc.noaa.gov/surge/warning/#:~:text=Storm%20Surge%20Warning%3A,%2C%20or%20post%2Dtropical%20cyclone.

The initial Potential Storm Surge Flooding Map is issued by the NHC with the first issuance of a hurricane watch or warning or in some cases a tropical storm watch or warning (anytime within 48 hours of the anticipated onset of tropical storm force winds). The issued map will change every six hours in association with every new NHC full advisory package. Due to the processing time required to produce the map, it is not available until approximately 60 to 90 minutes following the advisory release. When active, the mapping is available in HURREVAC and on the NHC website with an interactive viewer at: https://www.nhc.noaa.gov/surge/inundation/. An interactive example of the Potential Storm Surge Flooding Map is located at: https://www.nhc.noaa.gov/surge/inundation/interactive_example/

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[10] Source: https://www.nhc.noaa.gov/surge/inundation/

[11] Source: https://slosh.nws.noaa.gov/psurge/

1.5 FRESHWATER FLOODING

1.5.1 BACKGROUND

In addition to the storm surge and high winds, tropical cyclones threaten the United States with torrential rains and flooding. Even after the wind and storm surge has diminished, the flooding potential of these storms remains for several days. Unfortunately, the SLOSH model, discussed in Section 1.4.1 of the Hazard Analysis, does not model rainfall, freshwater flooding, and normal river flow.

Approximately 25 % of deaths in U.S. from tropical cyclones from 1963 to 2012 occurred in inland counties, with more than half of deaths related to freshwater flooding.[12] From 1963 to 2012, 88% of fatalities from tropical cyclones were from either storm surge (49%), rainfall flooding (27%), high surf (6%), or occurred offshore within 50 nautical miles of the coast (6%).[13] Historically, over three-fourths (78%) of deaths among children in tropical cyclones were the result of drowning in freshwater floods.[14] In fact, more people are killed by floods than any other weather related cause. Most of these fatalities occur because people underestimate the power of moving water.

It is common to think the stronger and faster the storm the greater the potential for flooding. However, this is not always the case. A weak, slow moving tropical storms can cause more damage due to flooding than a more powerful fast moving tropical storm. This was evident with Hurricane Harvey in August 25-30, 2017 and Tropical Storm Imelda in September 16-19, 2019

Although Hurricane Harvey made landfall near Rockport, Texas as a Category 4 Hurricane on August 25, 2017, it weakened to a Tropical Storm within the following days as it stalled along the Southeast Texas coastline. As Harvey stalled over south and Southeast Texas for days, it produced catastrophic and deadly flash and river flooding. Southeast Texas bared the brunt of the heavy rainfall, with some areas receiving more than 40 inches of rain in less than 48 hours. Cedar Bayou in Houston received a storm total of 51.88 inches of rainfall which is a new North American record. Figure 1-18 shows a map of the radar derived rainfall estimates through September 1, 2017 associated with Hurricane Harvey.[15]

After making landfall near Freeport, Texas on September 17, 2019, Tropical Storm Imelda weakened to a Tropical Depression and stalled between Houston and Lufkin, Texas for 2 days. The surrounding area accumulated 30 to 44 inches of rainfall during the storm, with the greatest total of 44.29 inches recorded 2 miles south-southwest of Fannett, Texas. During the height of the flooding, numerous vehicles were either stuck or flooded on I-10 between Beaumont and Winnie for 2.5 days.[16]

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[12] Source: https://www.noaa.gov/stories/inland-flooding-hidden-danger-of-tropical-cyclones
[13] Source: https://weather.com/safety/hurricane/news/hurricanes-tropical-storms-us-deaths-surge-flooding
[14] Source: https://www.chicagotribune.com/sns-cane-inlandfloods-story.html
[15] Source: https://www.weather.gov/crp/hurricane_harvey
[16] Source: https://www.weather.gov/lch/2019Imelda.

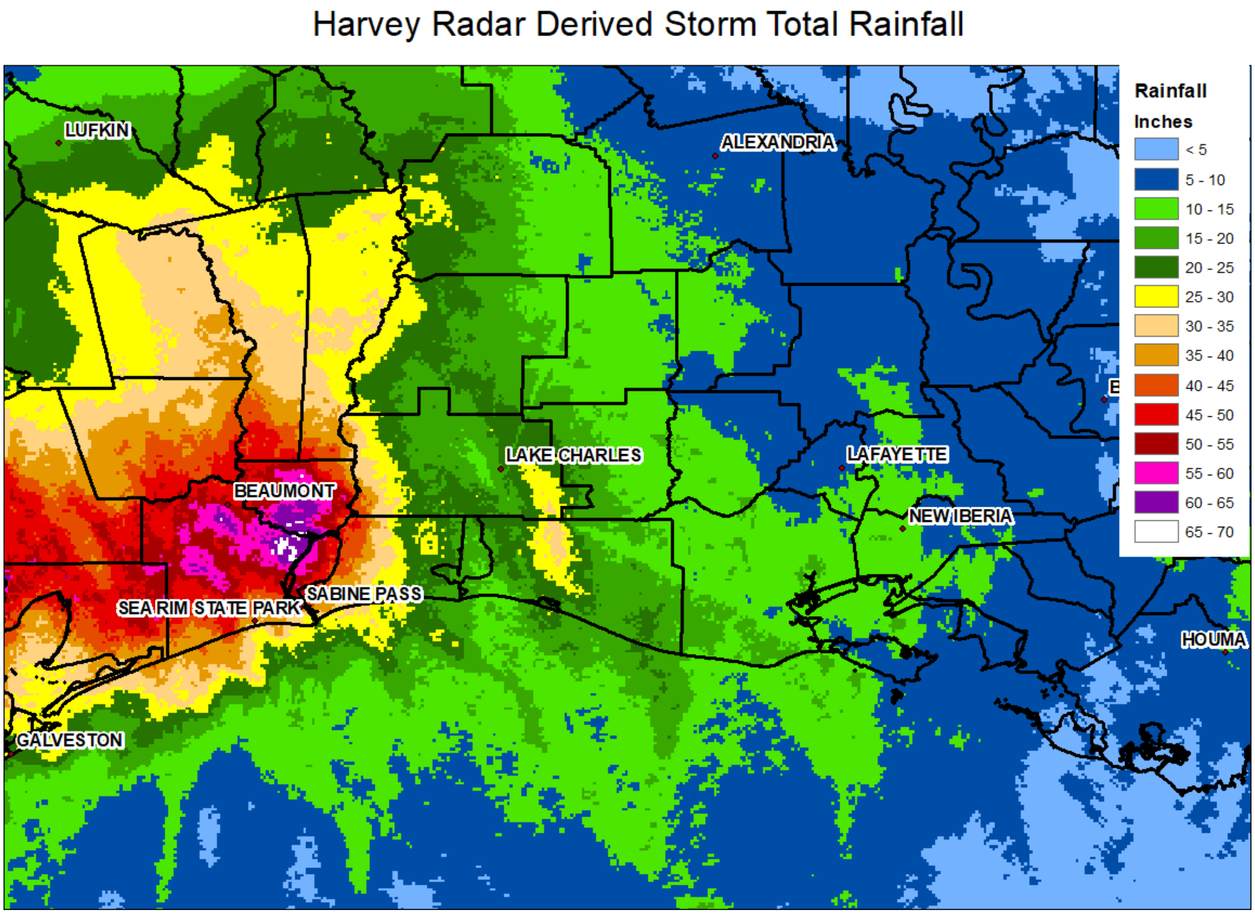

Figure 1-18 Raw NOAA Multi-radar multi-sensor quantitative precipitation estimation (inches) for Harvey in southeastern Texas from August 25-September 1, 2017[17]

1.5.2 FLASH FLOODING

Flash floods are rapid occurring events. This type of flood can begin within a few minutes or hours of excessive rainfall, but generally within 6 hours of the immediate cause. The rapidly rising water can potentially roll boulders, rip trees from the ground, and destroy buildings and bridges. Urban areas are especially prone to flash floods due to large amount of asphalt and concrete surfaces that are impervious, or do not easily allow water to penetrate into the soil.[18] Water that would have naturally infiltrated into the ground now runs into storm drains and sewers, which may be old and inadequate to handle floodwaters.

1.5.3 RIVER FLOODING

River floods occur when river levels rise and overflow their banks or edges of their main channel and inundate areas that are normally dry. They are longer term events and occur when the runoff from torrential rains, often brought on by decaying hurricanes or tropical storms, reach the rivers. A great deal of the excessive water in river floods may have begun as flash floods. River floods can occur in just a few hours and also last a week or longer. For designated river forecast points,

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[17] Source: https://www.weather.gov/lch/2017harvey

[18] Source: https://www.weather.gov/safety/flood-hazards

the NWS issues Flood Warnings where a flood stage has been established.[19] The NWS's Southeast River Forecast Center (RFC) provides hydrologic information to local NWS forecast offices which then issue the critical warning information to the emergency management community, public, and media.[20] The website for the Southeast River Forecast Center is located at: https://www.weather.gov/wgrfc//.

The National Weather Service Advanced Hydrologic Prediction Service (AFPS) is a web-based tool available for river stage forecasts out through several days. The NWS AFPS website associated with the NOAA Mobile, Alabama forecast office is located at: https://water.weather.gov/ahps2/index.php?wfo=mob .

Amounts and arrival times of rainfall associated with hurricanes are highly unpredictable. For most hurricanes, the heaviest rainfall begins near the time of arrival of sustained tropical storm winds; however, heavy rains in amounts exceeding 20 inches can precede an approaching hurricane by as much as 24 hours. Unrelated weather systems can also contribute significant rainfall amounts within a basin in advance of a hurricane.

No detailed modeling and analysis were conducted to quantify the effects of rainfall from hurricanes in this study. However, it should be assumed that locations and facilities which have historically flooded during periods of heavy rainfall are vulnerable to freshwater flooding from hurricane conditions. Additionally, other factors such as increased development and changes in land use, especially in urban areas, can also cause flooding in areas which have not historically been susceptible to excessive runoff or freshwater inundation.

1.5.4 FEMA FLOOD INSURANCE STUDY FLOOD INSURANCE RATE MAPS

Useful products of the FEMA Flood Insurance Study (FIS) are Flood Insurance Rate Maps (FIRMs) which are a mapping source that identify flood hazard areas. These products are produced to determine general overall risks to property and used by development officials and insurance professionals. These products are not intended to predict effects of different types of tropical cyclone events but are useful to hurricane evacuation studies in defining areas of inland flooding that may impact evacuation planning decisions and recovery staging.

FEMA FIS include separate analyses for coastal and riverine areas. In some areas, coastal analyses include complex localized model calculations for wave hindcasting, wave setup, storm surge, effects of dunes, overland and wave propagation, wave runup for wave setup, beach erosion, and wave heights. Riverine and stream analyses consider flooding from rainfall runoff. The statuses of the FIS studies for this project are provided in Table 1-5 below. Data is available in PDF and GIS formats on the following FEMA website: https://msc.fema.gov/portal/advanceSearch#searchresultsanchor.

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[19] Source: https://www.weather.gov/safety/flood-hazards

[20] Source: https://www.noaa.gov/stories/inland-flooding-hidden-danger-of-tropical-cyclones

Table 1-5 Status of FEMA Flood Insurance Study and FIRM Products

County	Effective Date	Preliminary/Pending
Brazoria, Texas	01/06/2017, 05/02/2019, 11/15/2019, 12/30/2020, 01/29/2021	
Chambers, Texas	06/15/1983, 12/02/1992, 05/18/1999, 05/04/2015, 01/06/2017, 01/19/2018, 11/15/2019	
Galveston, Texas	01/06/2017, 05/02/2019, 08/15/2019, 11/15/2019	
Hardin, Texas	10/06/2010	
Harris, Texas	08/18/2014, 01/06/2017, 01/19/2018 05/16/2019, 08/15/2019, 11/15/2019, 12/30/2020, 01/29/2021	
Jackson, Texas	9/17/2014	
Jasper, Texas	12/17/2010	
Jefferson, Texas	07/06/1982, 08/02/1982, 10/17/1983, 09/04/1987, 08/06/2002	08/30/2012 (1 FIRM Panel)
Liberty, Texas	01/19/2018	
Matagorda, Texas	01/15/2021	
Newton, Texas	11/16/2018	
Orange, Texas	12/16/2021	

FIRMs are produced from FIS and are the official map of a community on which FEMA has delineated both the Special Flood Hazard Areas (SFHAs) subject to inundation by the 1% annual chance flood and the risk premium flood zones applicable to the community. FIRMs are based on statistical occurrence rather than a hypothetical storm. On the FIRM, SFHAs are shown as shaded areas and are divided into different flood hazard zones depending upon the severity and type of flood hazard.

Flood hazard areas identified on FIRMs are based on two levels of probability of flooding events: flooding that has a 1% probability of being equaled or exceeded in any given year (e.g., 1% annual chance flood or 100-year flood) and flooding that has a 0.2% probability of being equaled or exceeded in any given year (e.g., 0.2% annual chance flood or 500-year flood). Digital FIRM data is shown for Southeast Texas in Figure 1-19. Note, the method for mapping floodways causes floodplains to be mapped over portions of freshwater and open water. There is also a lack of data within Jefferson County, which shows it as if it was without flooding, when it would experience similar flooding as its neighboring counties. A floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights. The floodways are included in the 1% annual chance flood. Although the recurrence interval represents the long term, average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year.

As shown in Figure 1-20, when the summary of equivalent surge inundation groups are plotted with the FEMA floodplain map, it is clear that the 1% annual chance flood coincides closely with the inundation extents for directional MEOWs. However, the floodways are not always included as experiencing surge.

The 1% and 0.2% annual change flood plains from the latest FEMA Floodplain maps for Southeast Texas are shown along with the Category 5 MOM inundation in Figure 1-21. The extent of MOMs and FEMA floodplains coincide closely.

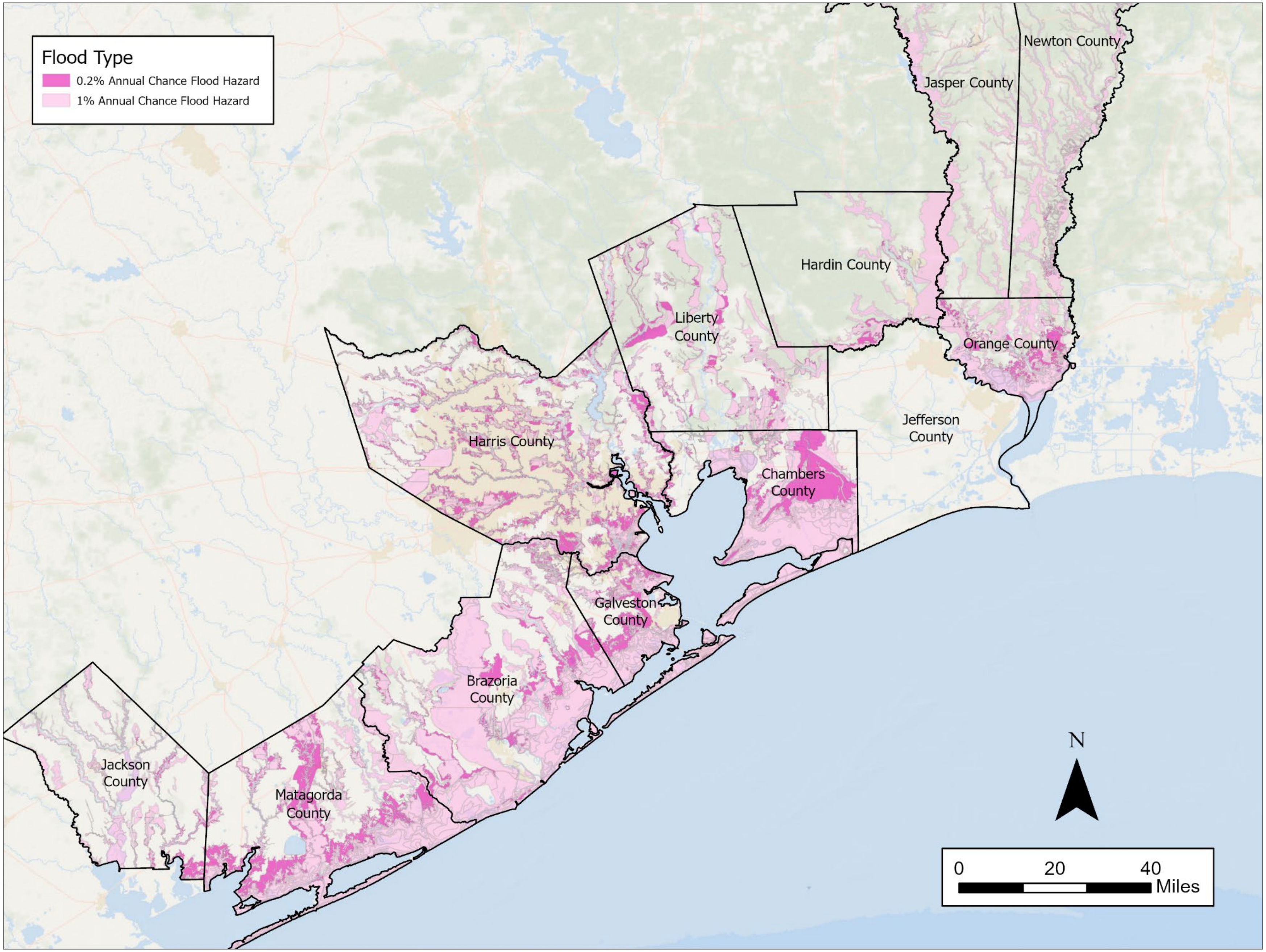
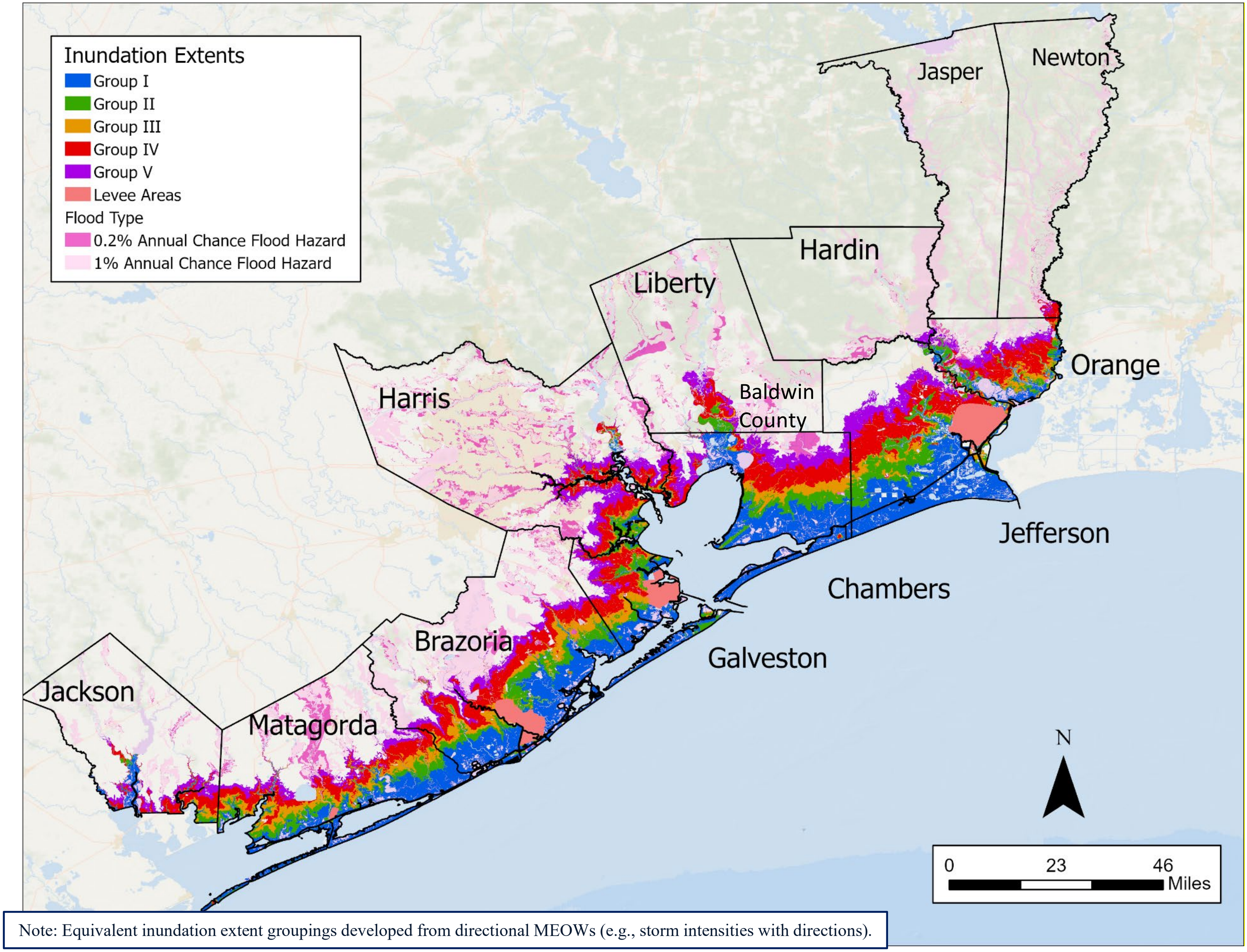


Figure 1-19 FEMA FIRM Floodplains for 1% and 0.2% Annual Probability Flooding



Note: Equivalent inundation extent groupings developed from directional MEOWs (e.g., storm intensities with directions).

Figure 1-20 Southeast Texas Summary – Equivalent Inundation Extent Map (Groups I through V) with FEMA FIRM Floodplain

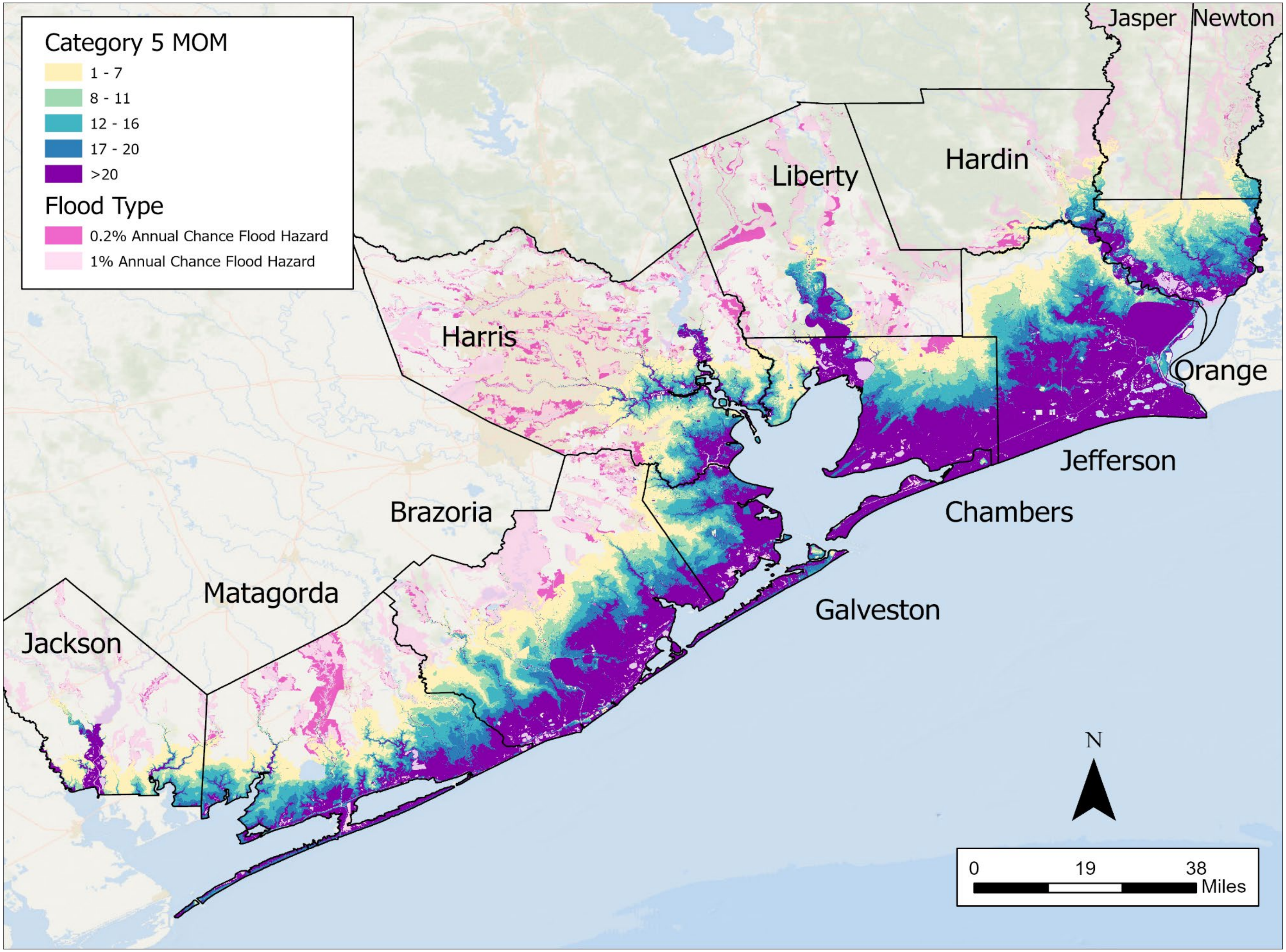


Figure 1-21 Category 5 MOM Map for all Southeast Texas Study Area Counties with Inundation Groupings with FEMA FIRM Floodplains

The rainfall depths for FEMA FIS modeling were based on 24-hour point precipitation frequency estimates from NOAA at https://hdsc.nws.noaa.gov/hdsc/pfds/. A summary of Partial Duration Series point precipitation frequency estimates for a 24-hour 1% annual chance storm and a 24-hour 0.2% annual chance storm at NOAA stations in Harris and Orange Counties is included in Table 1-6 below. These are provided for perspective as to the quantity of rainfall that is associated with the modeled 24-hour 1% annual chance and 24-hour 0.2% annual chance flood plains.

Table 1-6 PDS Based Precipitation Frequency Estimates with 90% Confidence Intervals[1]

NOAA Station Name	Location	24-hr. 1% Annual Chance Storm (inches)	24-hr. 0.2% Annual Chance Storm (inches)
Harris COUNTY			
Clear CK at Bay Area Blvd	League City, TX	17.9 (12.6-25.5)	26.9 (17.7-40.7)
Goose Creek	Baytown, TX	18.1 (12.7-25.7)	27.5 (18.1-41.8)
Houston WB City	Houston, TX	17.0 (12.0-23.9)	25.5 (16.8-38.2)
Cypress CK at Kuykendahl Rd	Houston, TX	16.7 (11.8-23.9)	24.9 (16.4-37.7)
Katy City	Katy, TX	16.0 (11.2-22.7)	23.4 (15.4-35.4)
Armand BYU at Genoared BLF RD	Pasadena, TX	17.9 (12.6-25.6)	26.9 (17.7-40.8)
Houston ALIEF	Houston, TX	16.5 (11.6-23.5)	24.3 (16.0-36.9)
Houston Hobby AP	Houston, TX	17.6 (12.4-25.0)	26.4 (17.4-40.1)
Orange COUNTY			
Orange	Orange, TX	17.1 (12.1-23.9)	25.1 (16.6-37.3)
Orange 9 N	Orange, TX	17.1 (12.0-24.1)	25.3 (16.7-37.8)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of (PDS). Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

The coastal analysis for FEMA FIS includes complex model calculations for wave hindcasting, wave setup, storm surge, effects of dunes, overland and wave propagation, wave runup for wave setup, beach erosion, and wave heights. On the FIRM maps, the 1% annual chance flood plain (e.g., 100-year flood plain) is split into flood hazard zones AE, VE, and VO with the following descriptions:

- Zones V are closest to the shoreline and subject to wave action, high velocity flow, and erosion during the 1% annual chance flood.
- Zones A are areas subject to flooding during the 1% annual chance flood, but where flood conditions are less severe than those in V zones.
- VE and AE zones have Base Flood Elevations (BFE), which are used for new construction, shown at selected intervals which is the expected elevation of flood water and wave effects during the 1% annual chance flood. Usually these are whole foot elevations derived from detailed hydraulic modeling.
- Zones AO are areas subject to shallow flooding or sheet flow during the 1% annual chance flood. They are likely on the landward slopes of coastal dunes.

Coastal hydrologic analyses modeled individual storms with different tracks and various combinations of storm parameters for synthetic hurricane simulations. Coastal high hazard zones are areas of coastline subject to significant wave attack. A 3 foot breaking wave is the criterion established by United States Army Corps of Engineers (USACE) for identifying the limit of coastal high hazard zones since it has been determined as the minimum size wave that can cause major damage to conventional brick veneer and wood frame structures. However, wave heights as little as 1.5 feet can cause damage and failure to construction in a Zone AE area. Therefore, for advisory purposes a limit of Moderate Wave Action (LiMWA) boundary, which represents the approximate landward limit of the 1.5 foot breaking wave, has been added in coastal areas subject to wave action. Where wave runup elevations dominate, the LiMWA is shown immediately landward of the VE/AE boundary. [21]

Figure 1-22 from the latest Southeast Texas Study Area county FIS reports shows what a typical transect (or cross-section for modeling) schematic and the relationship to energy dissipation or regeneration of waves as they move inland. Wave crest elevations are decreased by obstructions such as vegetation, buildings, and rising ground elevations, but wave crest elevations are increased by open, unobstructed areas with large wind fetches. The transects used for modeling were located to consider physical and cultural characteristics of the land so that they represent local conditions. In areas of dense development and complex topography, the transects were spaced closer together.

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[21] Source: Flood Insurance Study Orange County, Texas, Federal Emergency Management Agency, Revised December 16, 2021 (Flood Insurance Study Number 48361CV001A).

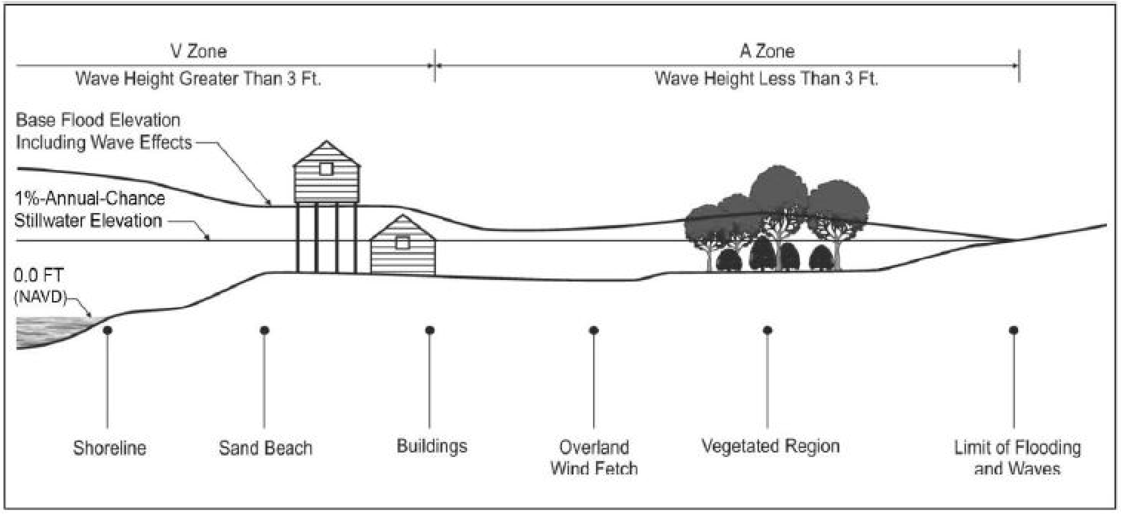

Figure 1-22 FEMA FIRM Example Transect Schematic for Coastal Hydraulic Modeling[22]

1.6 WINDS

Extreme winds can be a life-threatening feature of tropical cyclones. To some degree, all structures exposed to hurricane-force winds are vulnerable to wind-related hazards (see Table 1-17). This is especially true of intense storms, generally considered Category 3 and greater hurricanes. However, high-rise buildings merit special consideration. Wind pressures on upper portions of tall structures can be much greater than those at ground level. These pressures can cause significant problems during even a moderate hurricane. Within the transportation network, high-rise bridges are particularly vulnerable to the hazards of extreme winds and could experience wind-related structural problems. Several major high-rise bridges in the study area have been closed during past storms after gale-force winds caused high profile vehicles to overturn.

Destructive hurricane force winds and tornadoes can also affect many inland counties. NOAA's Hurricane Research Division has developed a model, the Wind Speed Decay Model, for predicting inland winds associated with landfalling hurricanes. The model accounts for wind speed decay as hurricanes move over land from water. The decay process is due to the interaction with land, where terrain roughness provides the friction needed to slow the wind, and the storm is cut off from the heat and moisture sources that sustain it. Wind gusts, rather than sustained speed, may actually increase because the greater turbulence over land mixes faster air to the surface in short bursts. Studies have shown that the sustained winds in a hurricane will decrease at a relatively constant rate, approximately half the wind speed in the first 24 hours. Therefore, the faster the forward speed of a landfalling hurricane, the further the inland penetration of hurricane force winds.

The model applies a decay equation to the hurricane wind field at landfall to estimate the maximum sustained surface wind as a storm moves inland. This model can be used for operational forecasting of the maximum winds of landfalling tropical cyclones. It can also be used

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[22] Source: Flood Insurance Study Orange County, Texas, Federal Emergency Management Agency, Revised December 16, 2021 (Flood Insurance Study Number 48361CV001A).

to estimate the maximum inland penetration of hurricane force winds (or any wind threshold) for a given initial storm intensity and forward storm motion.

NOAA provided 2021 Wind Speed Decay Modeling results of MEOWs as geodatabase polygons based on the Saffir-Simpson Hurricane Wind Scale. They depict the estimated most inland wind extents for sustained wind speeds for representative tropical cyclones making landfall from the Gulf of Mexico. Wind Extent Maps (WEMs) have been produced from directional MEOWs that were developed for 5 forward speeds (8, 12, 16, 20, and 24 knots) and sustained storm intensity wind speed of 60 knots (Tropical Storm), 75 knots (Category 1), 90 knots (Category 2), 105 knots (Category 3), 120 knots (Category 4), 135 knots (Category 4), and 140 knots (Category 5). Table 1-6 is provided as a reference of wind speeds in knots and mph for the different category storms.

Table 1-7 Wind Speeds for Category Storms in knots and mph

Category Storm	Wind Speed (knots)	Wind Speed (mph)
Tropical Storm	34 – 63	39 - 73
Category 1	64 - 82	74 – 95
Category 2	83 - 95	96 – 110
Category 3	96 - 112	111 – 129
Category 4	113 - 136	130 – 156
Category 5	137 +	157 +

Figure 1-233 depicts the extents of minimum tropical storm strength winds (34 knots) from the NOAA Wind Speed Decay Model for a Tropical Storm having 60 knots sustained winds with forward speeds ranging from 8 to 24 knots. It is evident that the forward speed of a tropical cyclone has great influence on how far inland the maximum sustained winds extend. Figure 1-24 depicts the modeled wind extents for a Tropical Storm having 60 knots sustained winds with the worst case forward speed of 24 knots. Note, tropical storm force winds extend inland and well beyond the study area counties for this modeled case.

Figure 1-25, Figure 1-26and Figure 1-27 depict the wind extents for a Category 4 storm having 135 knots sustained winds with forward speeds of 8, 16, and 24 knots respectively. The comparison of the three figures shows that increasing forward speed of a tropical cyclone causes higher wind speeds to extend further inland, thus increasing the area that is affected by higher sustained winds. Appendix D includes maps for storms with sustained winds of 74 knots (Category 1), 90 knots (Category 2), 105 knots (Category 3), 120 knots (Category 4), and 140 knots (Category 5) with forward speeds of 24 knots. All of the Wind Extent Maps are included in the GIS database included in the online ArcGIS Mapping Portal associated with this Hazard Analysis.

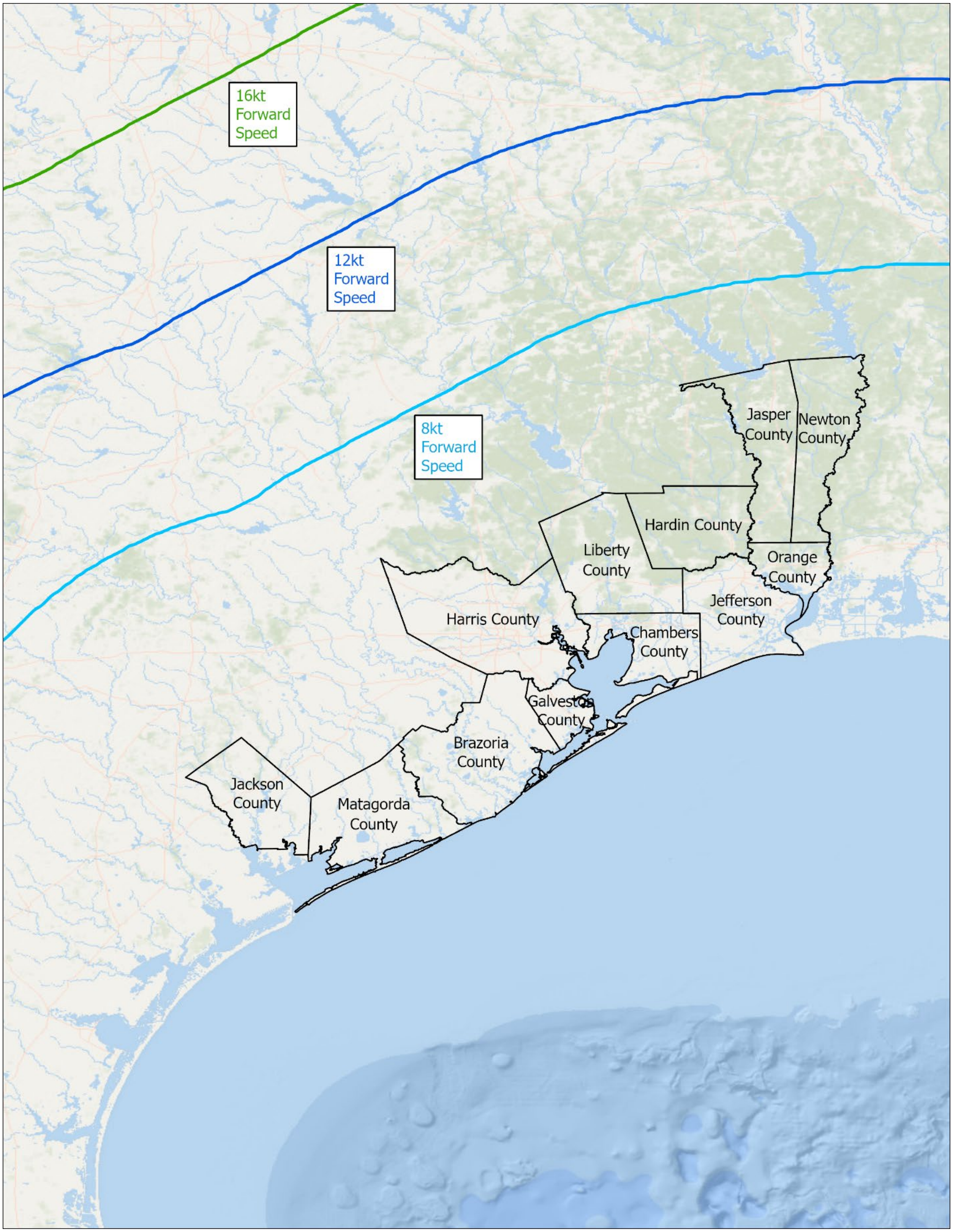


Figure 1-23 Wind Extent Map for Tropical Storm Strength Winds (34 kt) for Tropical Storm (60 kt) with 8 to 24 kt Forward Speed (Line Map)

Figure 1-24 Wind Extent Map for Tropical Storm (60 kt) with 24 kt Forward Speed (Shaded Map)

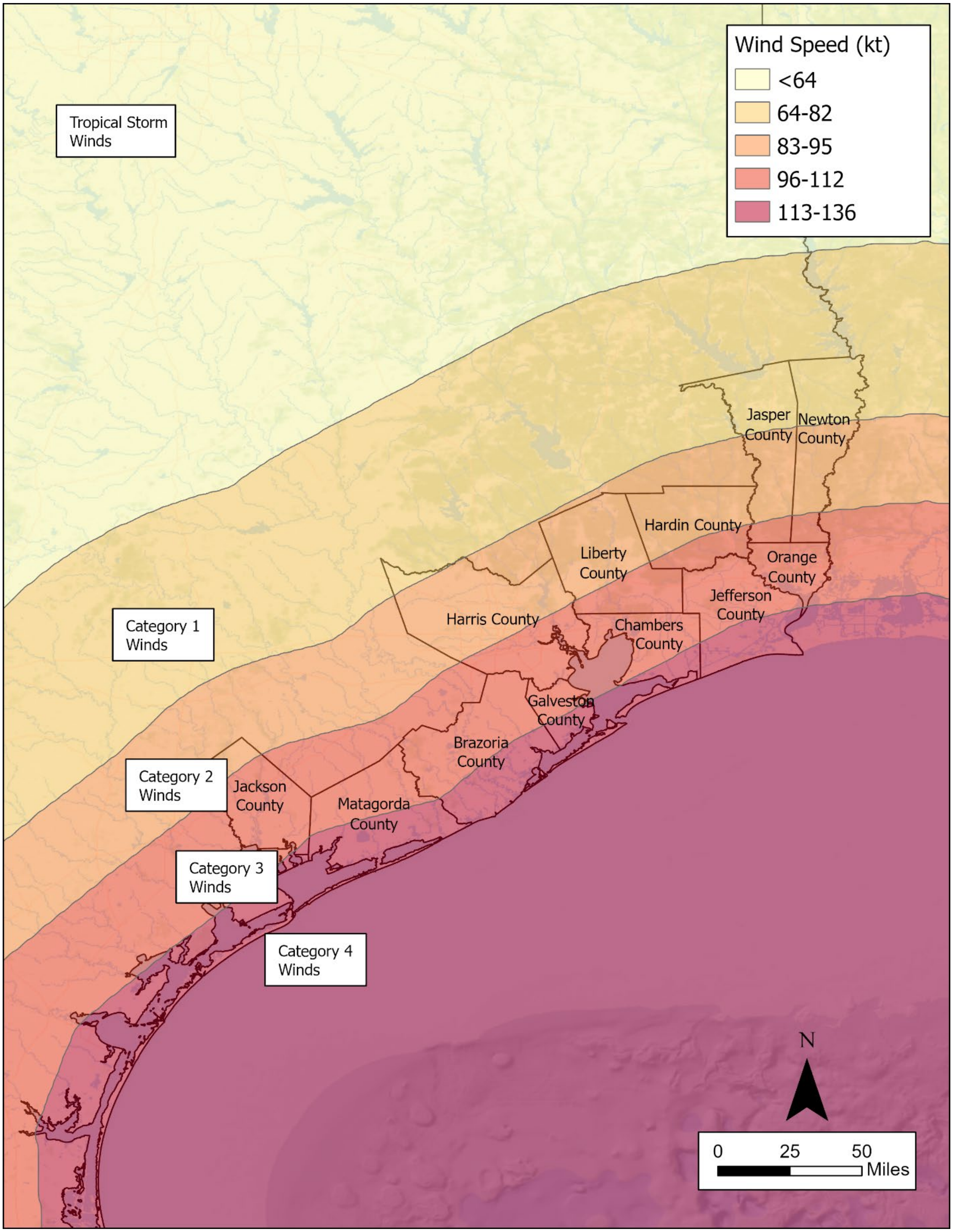


Figure 1-2510 Wind Extent Map for Category 4 Storm (135 kt) with 8 kt Forward Speed (Shaded Map)

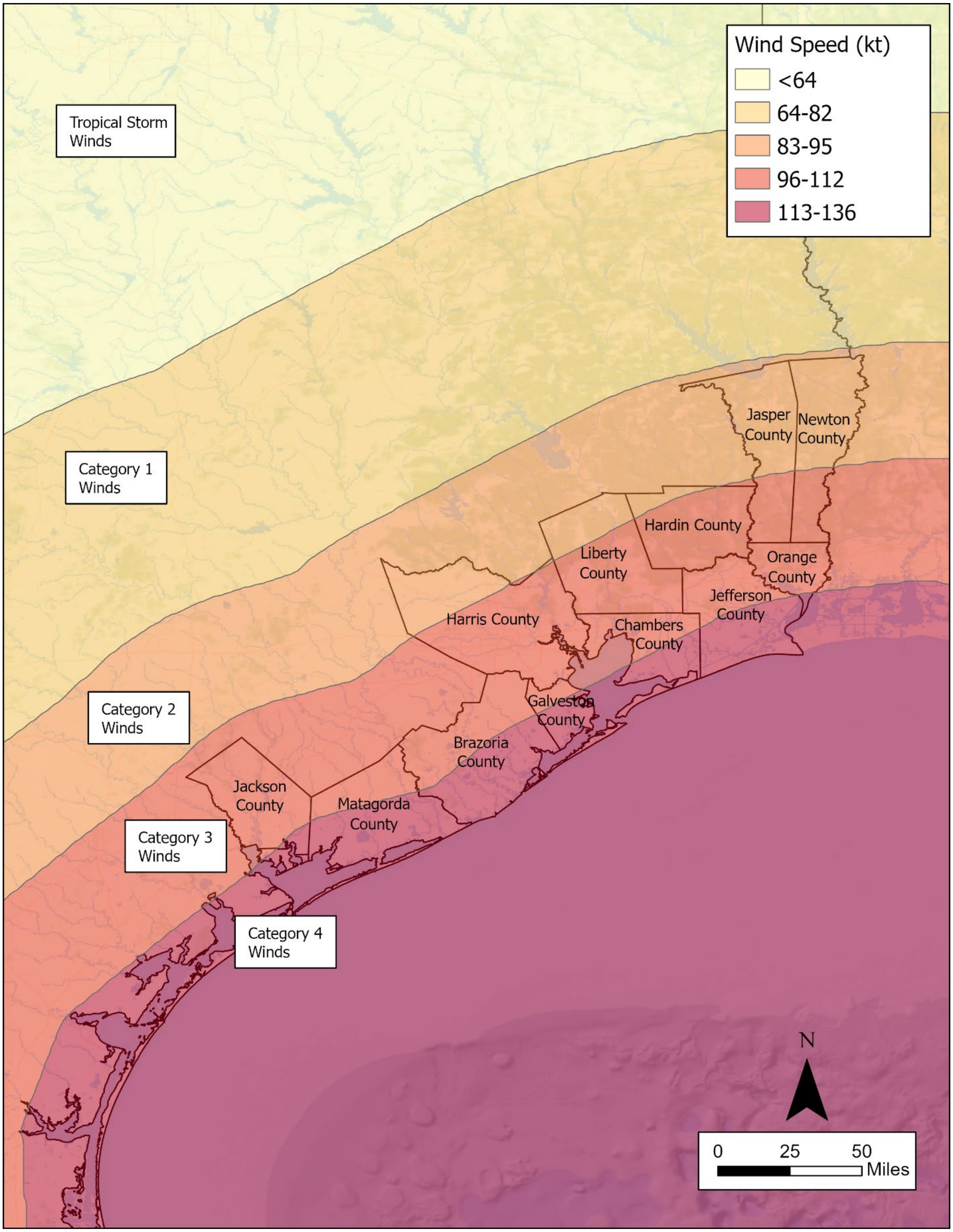


Figure 1-26 Wind Extent Map for Category 4 Storm (135 kt) with 16 kt Forward Speed (Shaded Map)

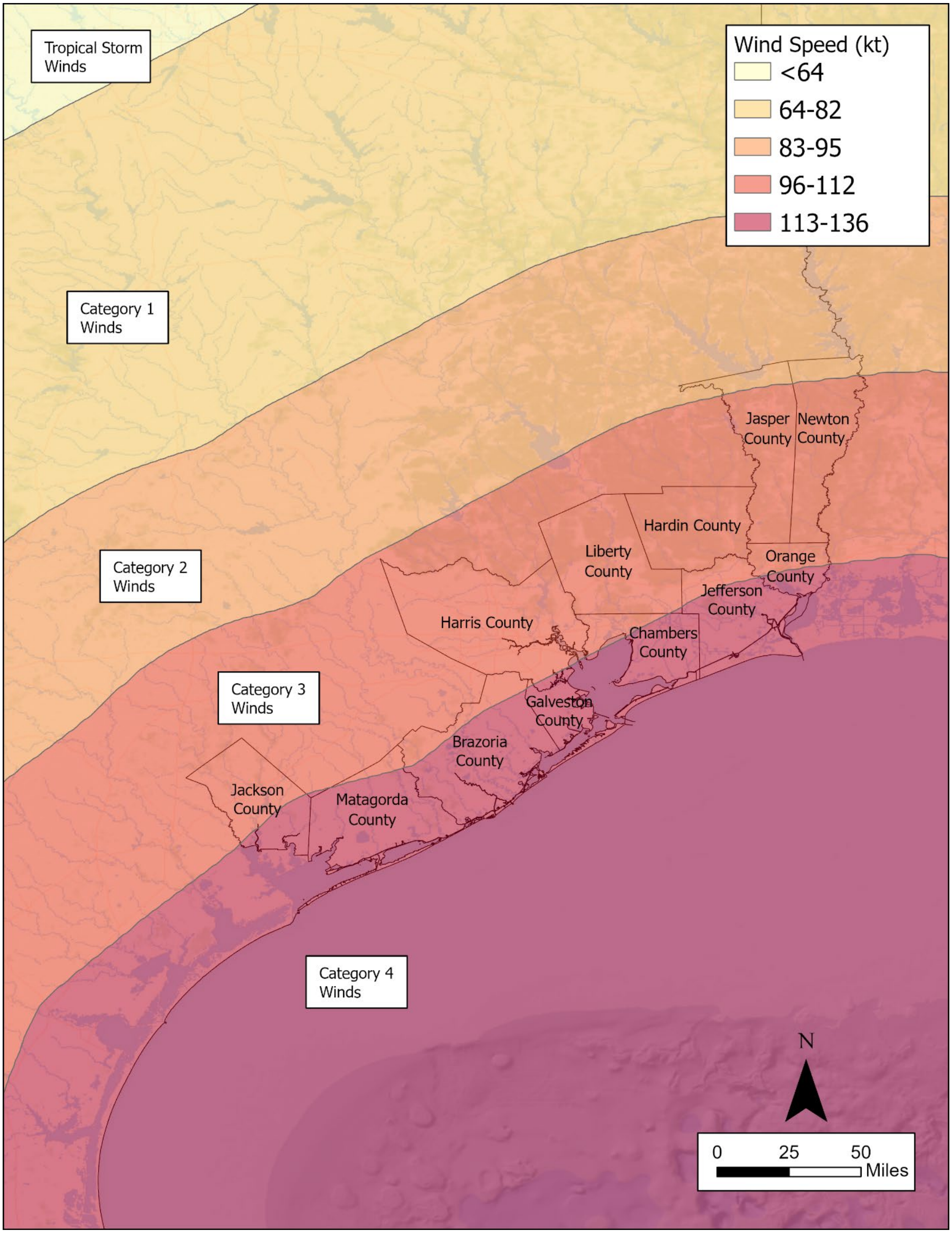
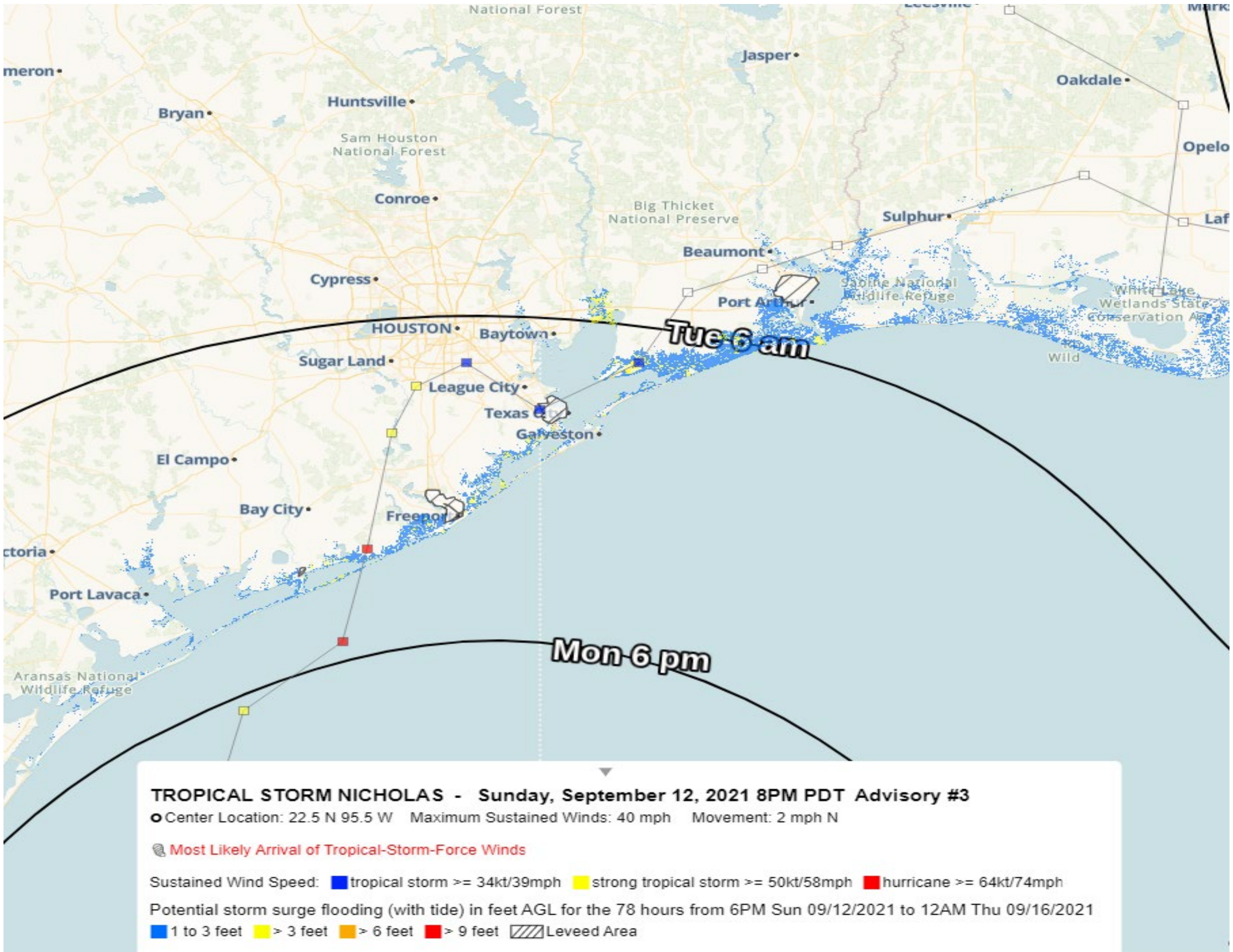


Figure 1-27 Wind Extent Map for Category 4 Storm (135 kt) with 24 kt Forward Speed (Shaded Map)

1.7 HURREVAC TOOL

HURREVAC (an abbreviation for HURRicane EVACuation) is a web browser-based decision support tool that assists local and state emergency managers in hurricane evacuation planning, training, and timely decision making. This real-time data analysis tool combines official NHC and NWS forecasts with Hurricane Evacuation Studies identifying vulnerable coastal populations and their evacuation clearance times under various storm scenarios. Information available within the program includes forecast track, timing, and wind speed; storm surge scenarios; evacuation timing; evacuation zones, and more. HURREVAC is developed and maintained by the National Hurricane Program, which is administered by FEMA, in partnership with the USACE, and the NOAA National Hurricane Center. HURREVAC is available free of charge to government emergency managers. Visit https://www.hurrevac.com/ for more information and link to registration page to apply for program access.

HURREVAC is also a useful tool for debriefing discussions and implementing recovery after real-time events such as Hurricane Nicholas in mid-September 2021, which made landfall as a Category 1 hurricane and then degraded to a tropical depression as it traveled along coastal Texas and into Louisiana, accompanied by extensive rain. Figure 1-28 below shows most likely arrival of tropical-storm-force winds and the track of the storm center.



TROPICAL STORM NICHOLAS - Sunday, September 12, 2021 8PM PDT Advisory #3
○ Center Location: 22.5 N 95.5 W Maximum Sustained Winds: 40 mph Movement: 2 mph N

Most Likely Arrival of Tropical-Storm-Force Winds

Sustained Wind Speed: 🟦 tropical storm >= 34kt/39mph 🟨 strong tropical storm >= 50kt/58mph 🟥 hurricane >= 64kt/74mph

Potential storm surge flooding (with tide) in feet AGL for the 78 hours from 6PM Sun 09/12/2021 to 12AM Thu 09/16/2021
🟦 1 to 3 feet 🟨 > 3 feet 🟧 > 6 feet 🟥 > 9 feet ▨ Leveed Area

Figure 1-28 Arrival of tropical-force-winds vs. Track for Nicholas Sept. 2021, Source: HURREVAC 9/12/21

APPENDIX A: GLOSSARY

A

Advanced Hydrologic Prediction Service: service improves flood warnings and water resource forecasts to meet diverse and changing customer needs.

Astronomical Tide: Tidal levels which result from gravitational effects from the earth, sun, and moon, without any atmospheric influences.

B

Bathymetry: The measurement of the depth of large bodies of water, for example, lakes, oceans, and seas.

C

Critical Facilities: Facilities that may need assistance of special consideration and planning if they are to be evacuated.

E

Evacuation: People leaving their residence to go from a perceived dangerous place to a perceived safer place.

Evacuation Timing: Appropriate start and end times of an evacuation based on storm and traffic conditions.

Evacuation Zone: Designated by local officials and based on the surge inundation maps used in the transportation model. Surge inundation areas are divided up into zones for modeling purposes and evacuation notice dissemination.

F

Fathom: A unit of length equal to 1.83 m (6 ft), used mainly in nautical contexts for measuring the depth of water.

FEMA: Federal Emergency Management Agency

FIRM: Flood Insurance Rate Map

Flood Insurance Study: A compilation and presentation of flood risk data for specific watercourses, lakes, and coastal flood hazard areas within a community. When a flood study is completed for the NFIP, the information and maps are assembled into an FIS. The FIS report contains detailed flood elevation data in flood profiles and data tables.

G

GIS: Geographic Information Systems

H

HES: Hurricane Evacuation Study

HURREVAC: HURRicane EVACuation Tracking and Analysis Software

I

Inland Wind Model: Applies a simple two parameter decay equation to the hurricane wind field at landfall to estimate the maximum sustained surface wind as a storm moves inland. This model can be used for operational forecasting of the maximum winds of land falling tropical cyclones. It can also be used to estimate the maximum inland penetration of hurricane force winds (or any wind threshold) for a given initial storm intensity and forward storm motion.

M

MEOW: Maximum Envelope of Water; stores the maximum water surface elevation in each SLOSH grid cell for all the hurricane tracks in one direction for a particular forward speed, and storm intensity.

MOMs: Maximums of MEOWs; represents the maximum water surface elevation for each SLOSH grid cell regardless of approach direction, forward speed or track.

N

NAVD: North American Vertical Datum

NFIP: National Flood Insurance Program

NHC: National Hurricane Center

NOAA: National Oceanographic and Atmospheric Administration

NWS: National Weather Service

S

Saffir/Simpson Hurricane Scale: Scale developed to describe the potential storm surge generated by hurricanes: Category 1. Winds of 74 to 95 miles per hour Category 2. Winds of 96 to 110 miles per hour Category 3. Winds of 111 to 129 miles per hour Category 4. Winds of 130 to 156 miles per hour Category 5. Winds greater than 157 miles per hour.

Simulating Waves Nearshore (SWAN): numerical wave model to obtain realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions.

SLOSH Model: Acronym meaning Sea, Lake and Overland Surges (SLOSH) from **H**urricanes. SLOSH provides heights of storm surge for various combinations of hurricane strength, forward speed of storm, and direction of storm. SLOSH model is used for real-time forecasting of surges from approaching hurricanes within selected Gulf and Atlantic coastal basins.

Storm Category:
Category 0, Tropical Storm, winds 35-73 miles per hour
Category 1. Winds of 74 to 95 miles per hour
Category 2. Winds of 96 to 110 miles per hour
Category 3. Winds of 111 to 129 miles per hour
Category 4. Winds of 130 to 156 miles per hour
Category 5. Winds greater than 157 miles per hour.

Storm Surge: The abnormal rise in water level caused by wind and pressure forces of a hurricane, over and above the predicted astronomical tide. Storm surge produces most of the flood damage and drowning associated with tropical systems; highest surges from a hurricane usually occur on the northeast quadrant of the storm’s track.

Storm Tide: The water level rise during a storm due to the combination of storm surge and the astronomical tide.

T

Topography/ Topographic Features: Features on the surface of land, including natural features such as mountains and rivers and constructed features such as highways and railroads.

Tropical Cyclones: Defined by the National Weather Service as a non-frontal, low-pressure synoptic scale (large-scale) systems that develop over tropical or subtropical waters and have a definite organized circulation. Tropical depressions are < 33 knots (38 mph). Tropical storms are 34 to 63 knots (39-73 mph). Hurricanes are >64 knots. Geographical areas affected by tropical cyclones are referred to as tropical cyclone basins knots (74 mph). Atlantic tropical cyclone basin is one of six in the world and includes much of the North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. Official Atlantic hurricane season begins on June 1 and extends through November 30 of each year.

U

USACE: United States Army Corps of Engineers

V

Vulnerability Analysis: Identifies those areas, populations, and facilities that are vulnerable to specific hazards under a variety of hurricane threats.

W

Wave Setup: An increase in the mean water level on a beach due to the effects of waves running up the beach and breaking. Under some conditions the set- up can be large enough to contribute to local flooding and over- topping of sea defenses.

WEM: Wind Extent Map

APPENDIX B: DIRECTIONAL MEOWS MAPS WITH MAXIMUM DEPTHS OF INNUNDATION BASED ON DIRECTION

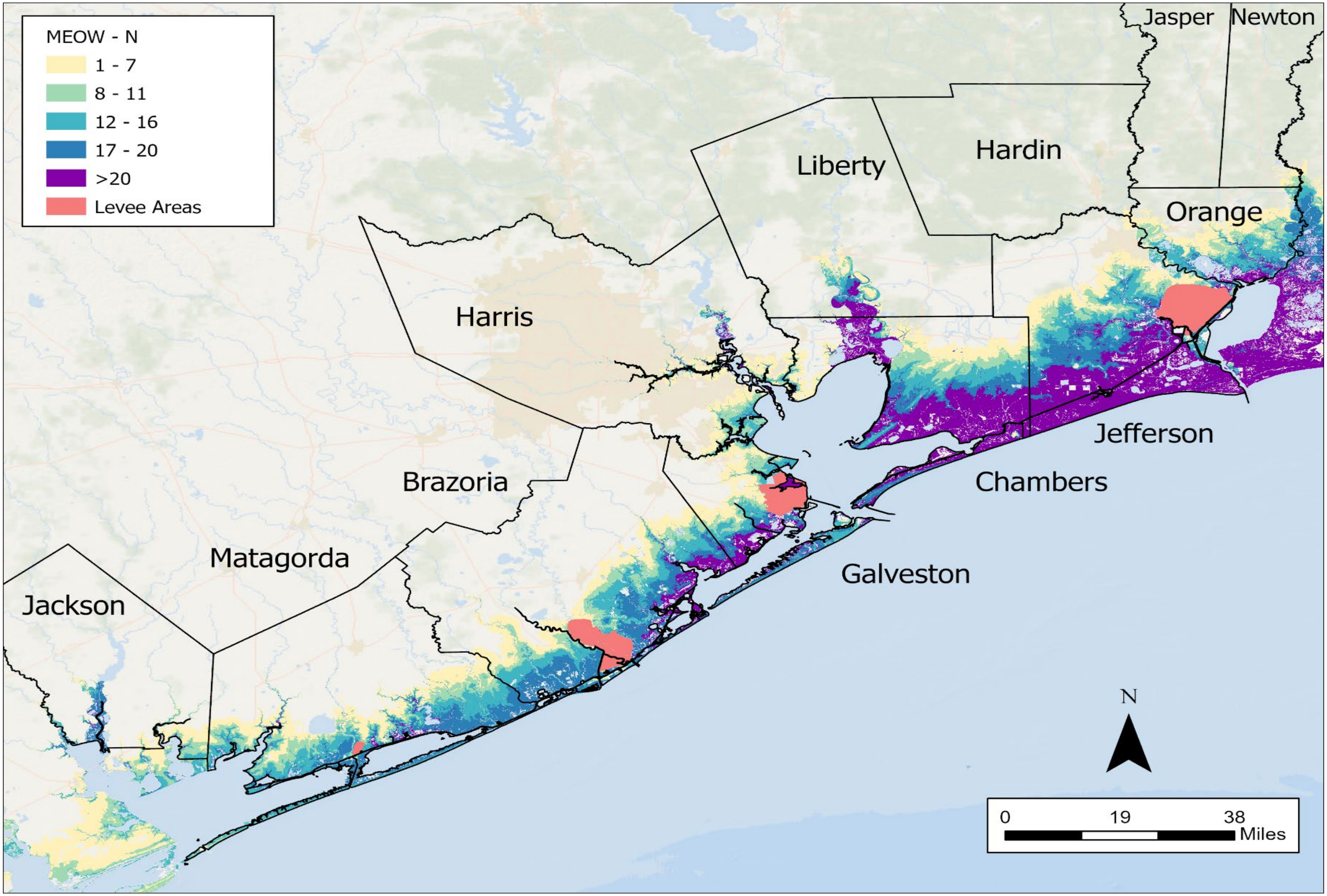


Figure B-1 North Directional MEOW Map (With Maximum Inundation for All Storm and Forward Speeds)

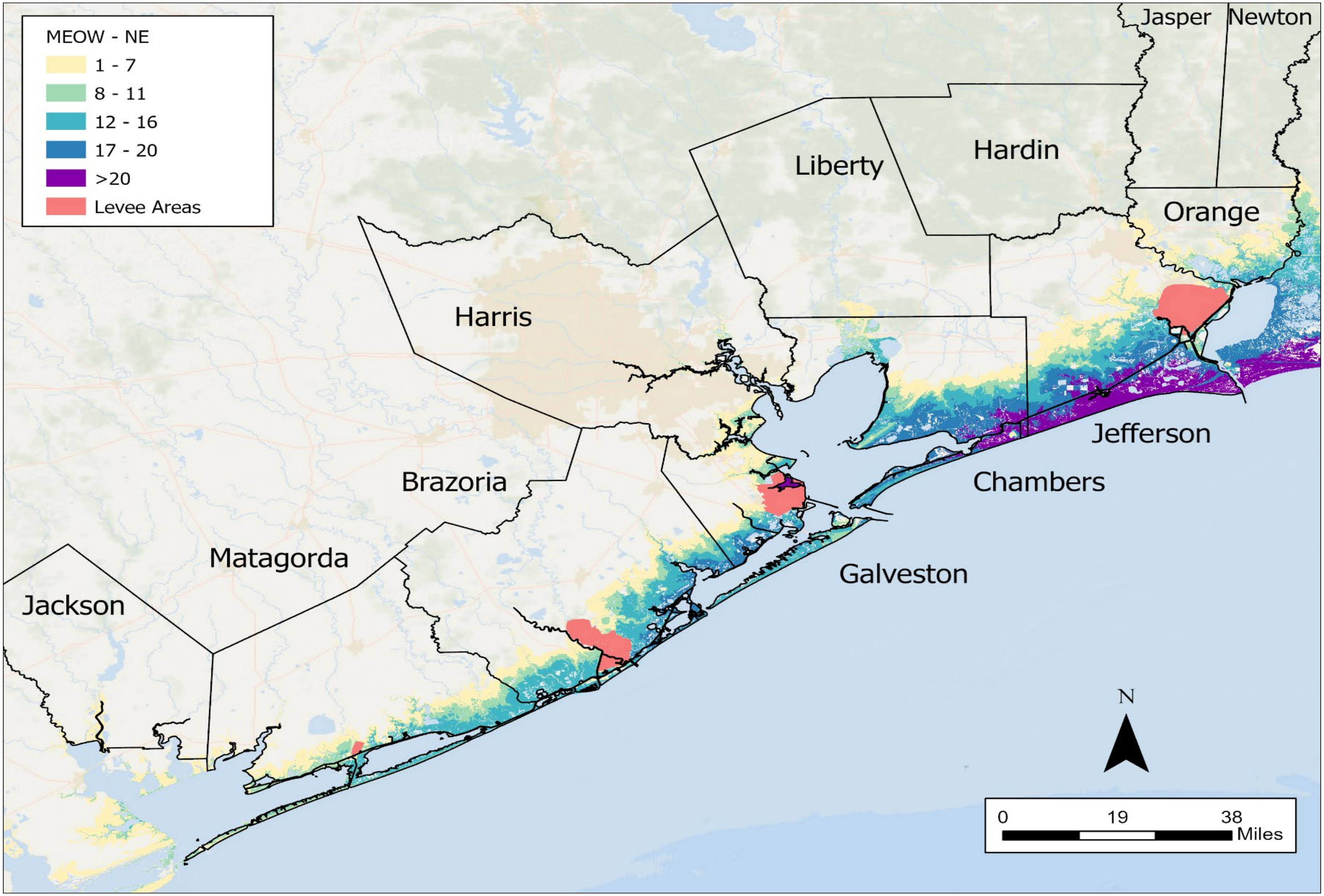


Figure B-2 Northeast Directional MEOW Map (With Maximum Inundation for All Storm and Forward Speeds)

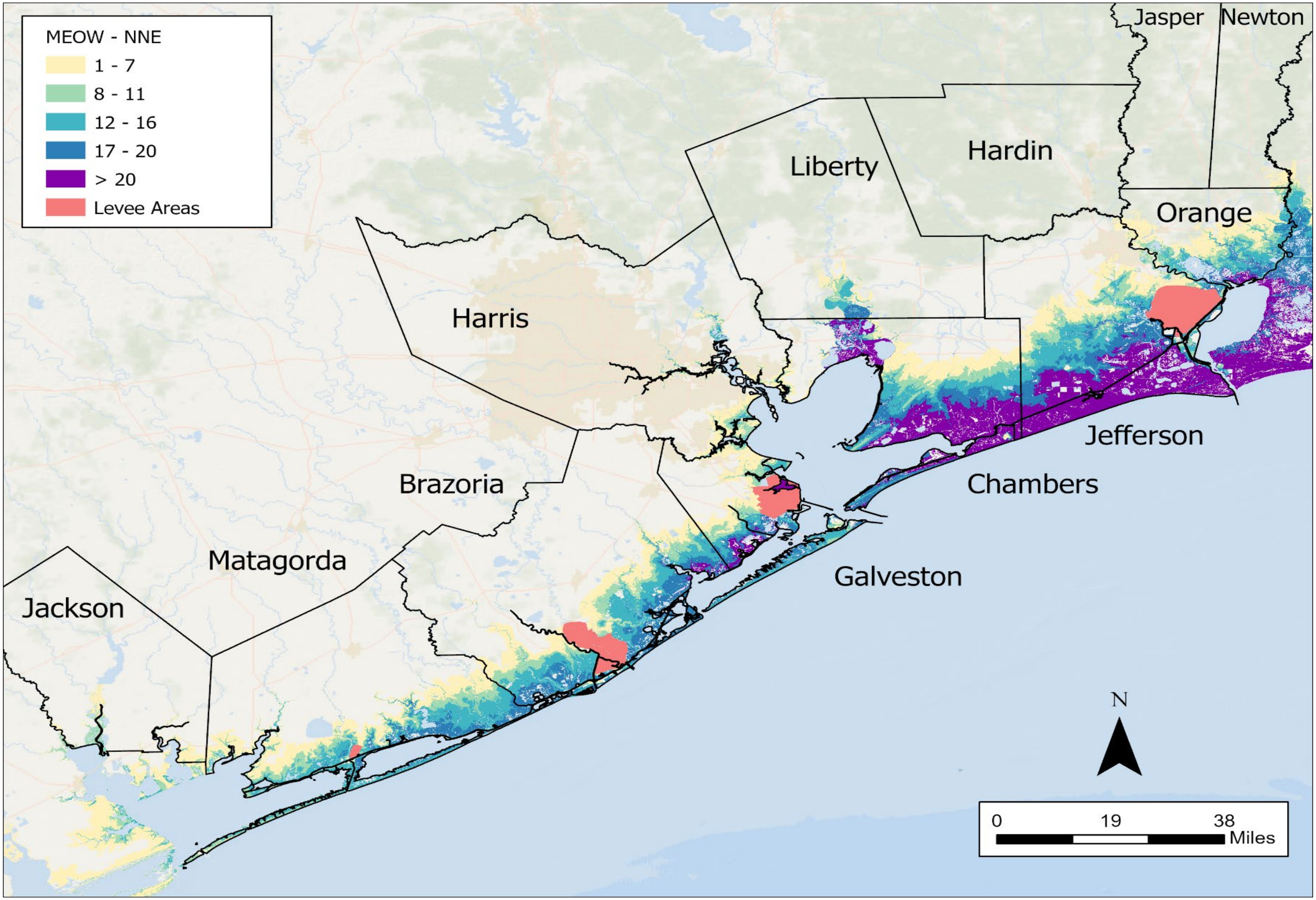


Figure B-3 North Northeast Directional MEOW Map (With Maximum Inundation for All Storm and Forward Speeds)

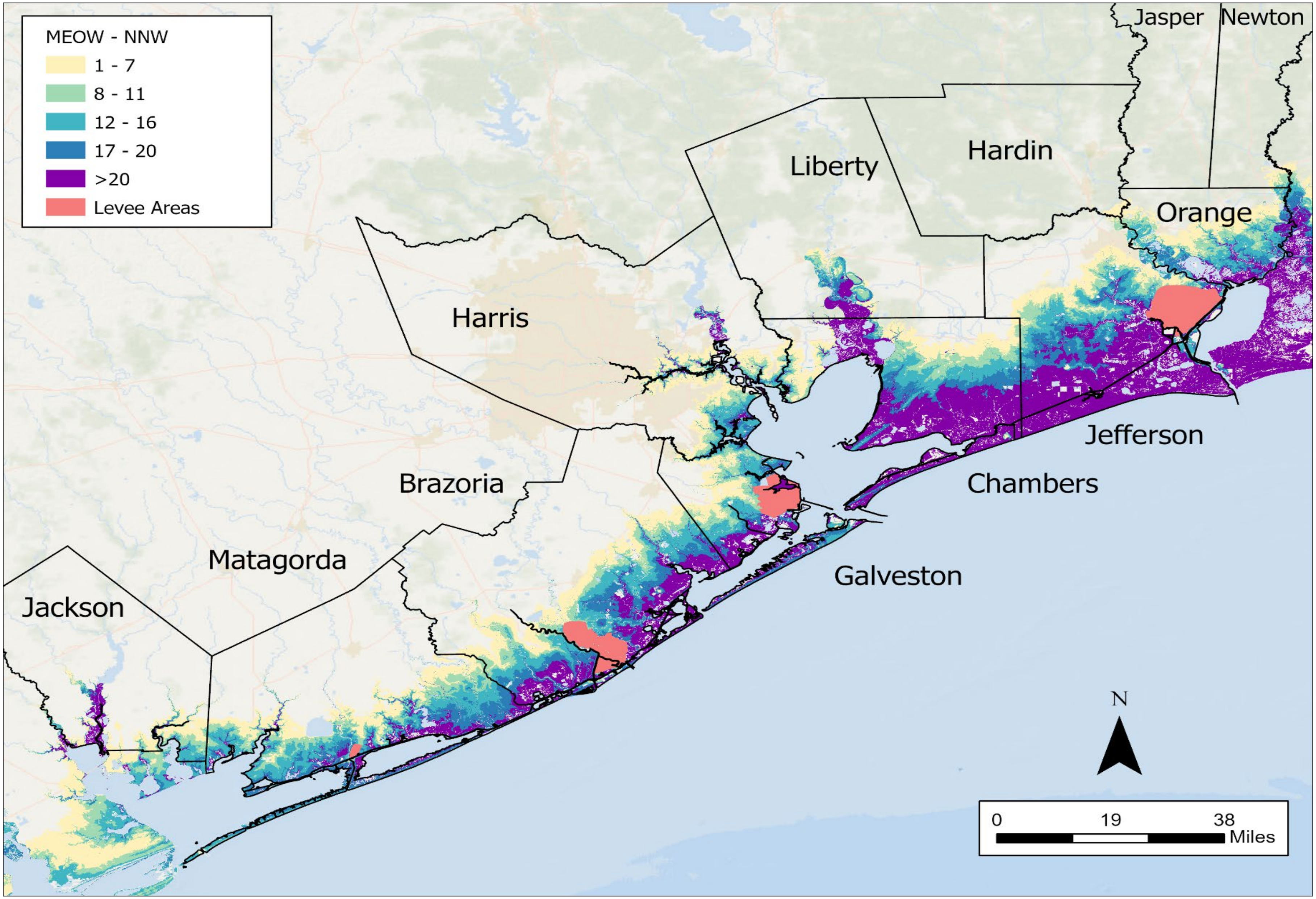


Figure B-4 North Northwest Directional MEOW Map (With Maximum Inundation for All Storm and Forward Speeds)

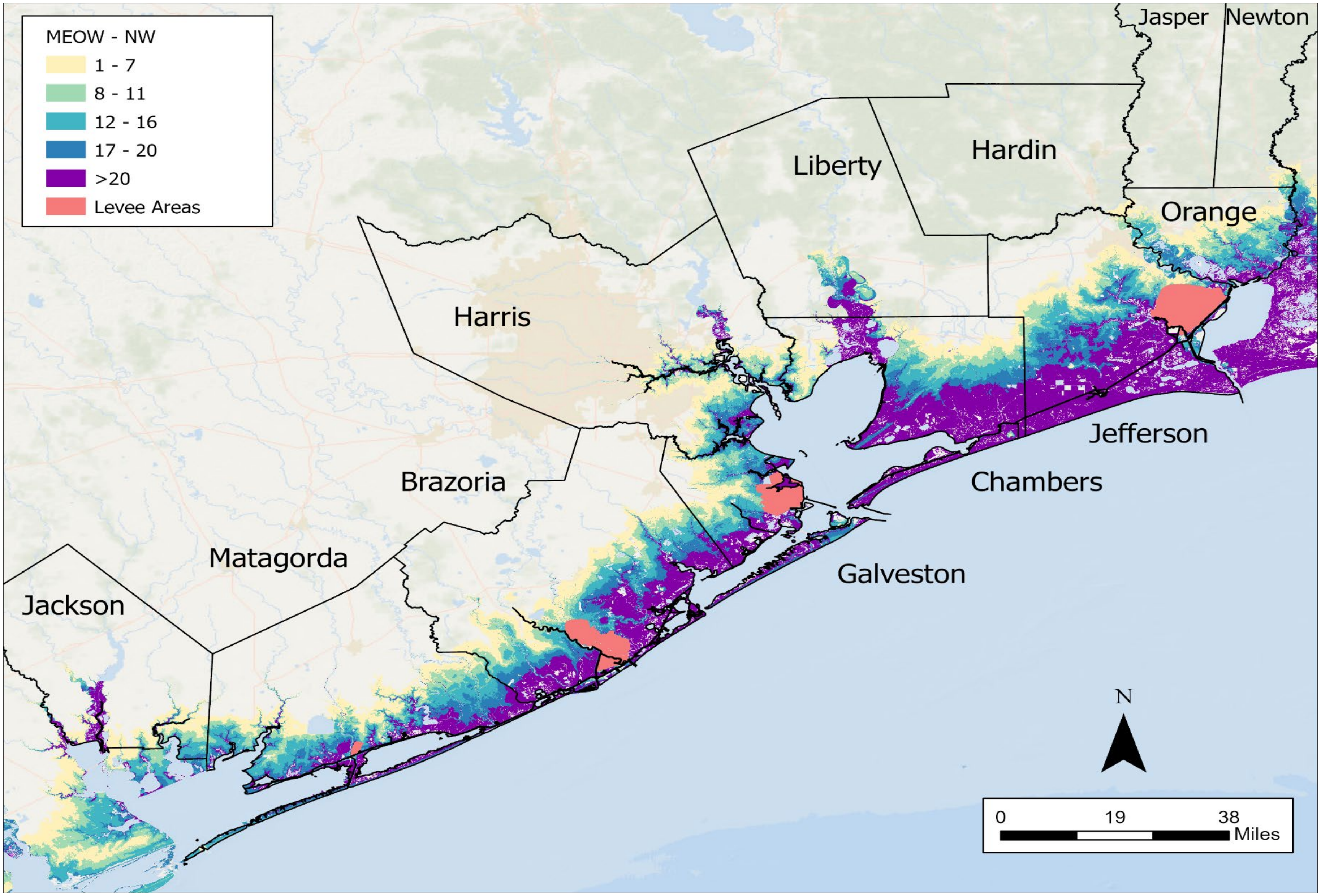


Figure B-5 Northwest Directional MEOW Map (With Maximum Inundation for All Storm and Forward Speeds)

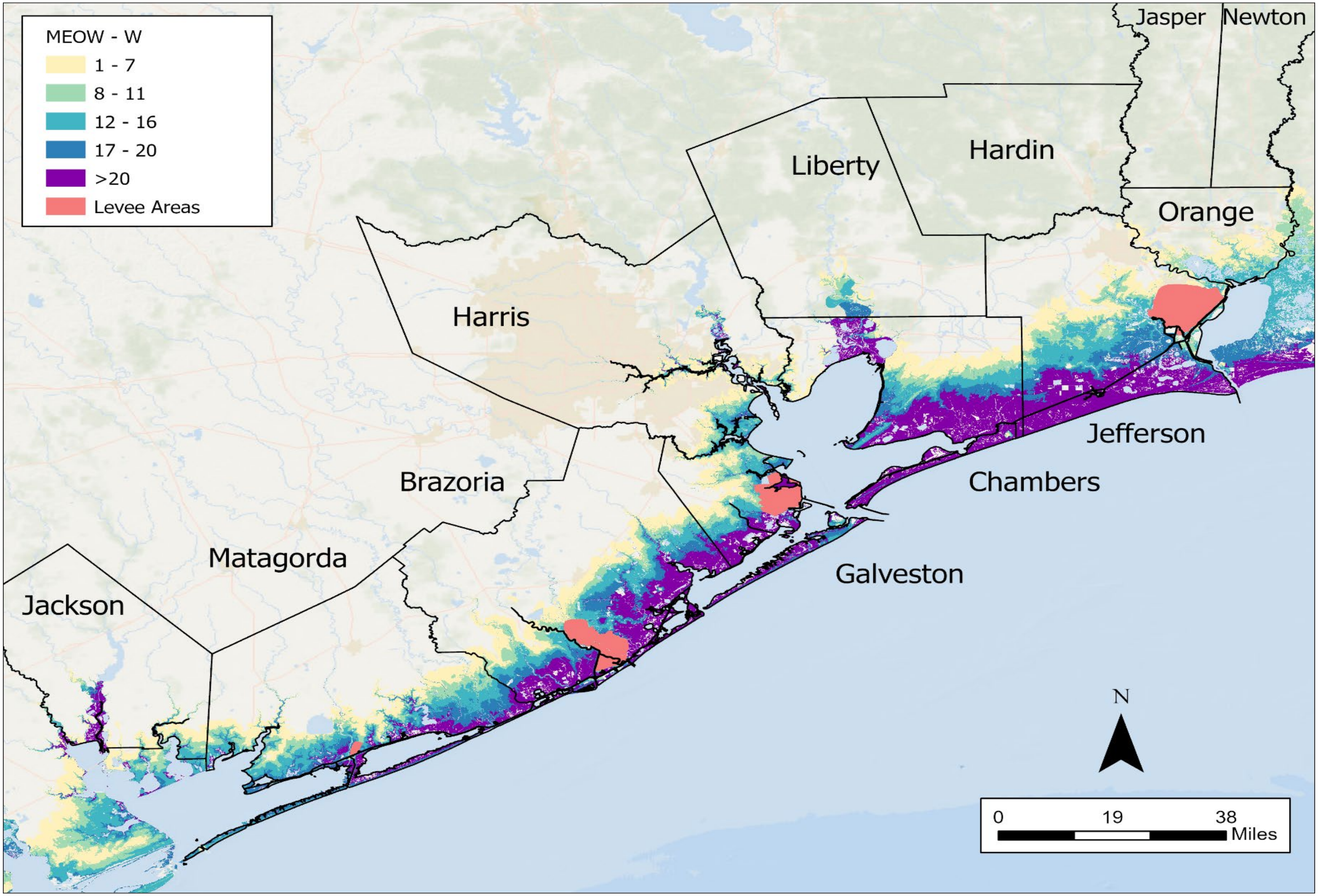


Figure B-6 West Directional MEOW Map (With Maximum Inundation for All Storm and Forward Speeds)

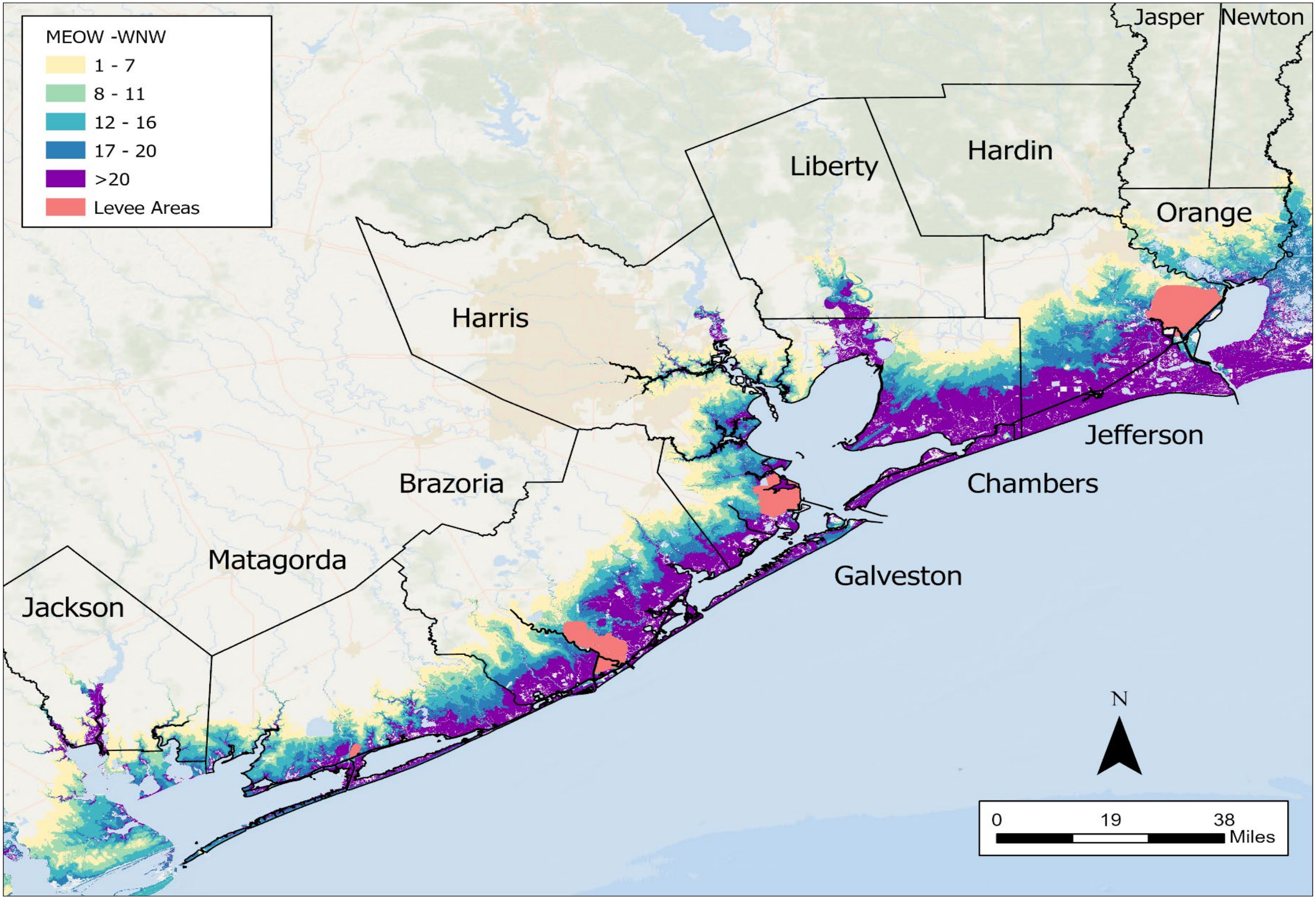


Figure B-7 West Northwest Directional MEOW Map (With Maximum Inundation for All Storm and Forward Speeds)

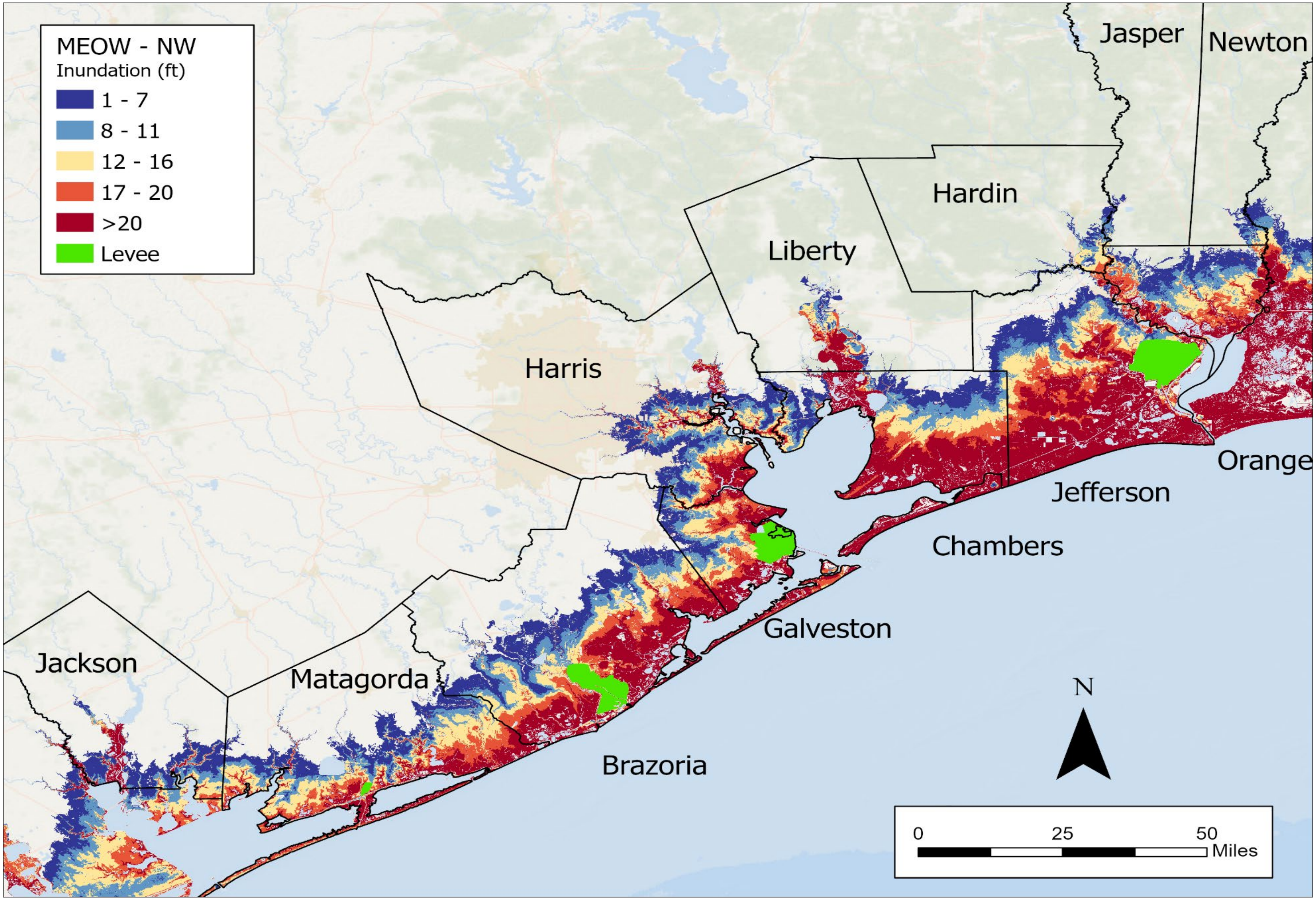


Figure B-8 Northwest Directional MEOW Map (Worst Case Approach Direction – Highest Maximum Inundation)

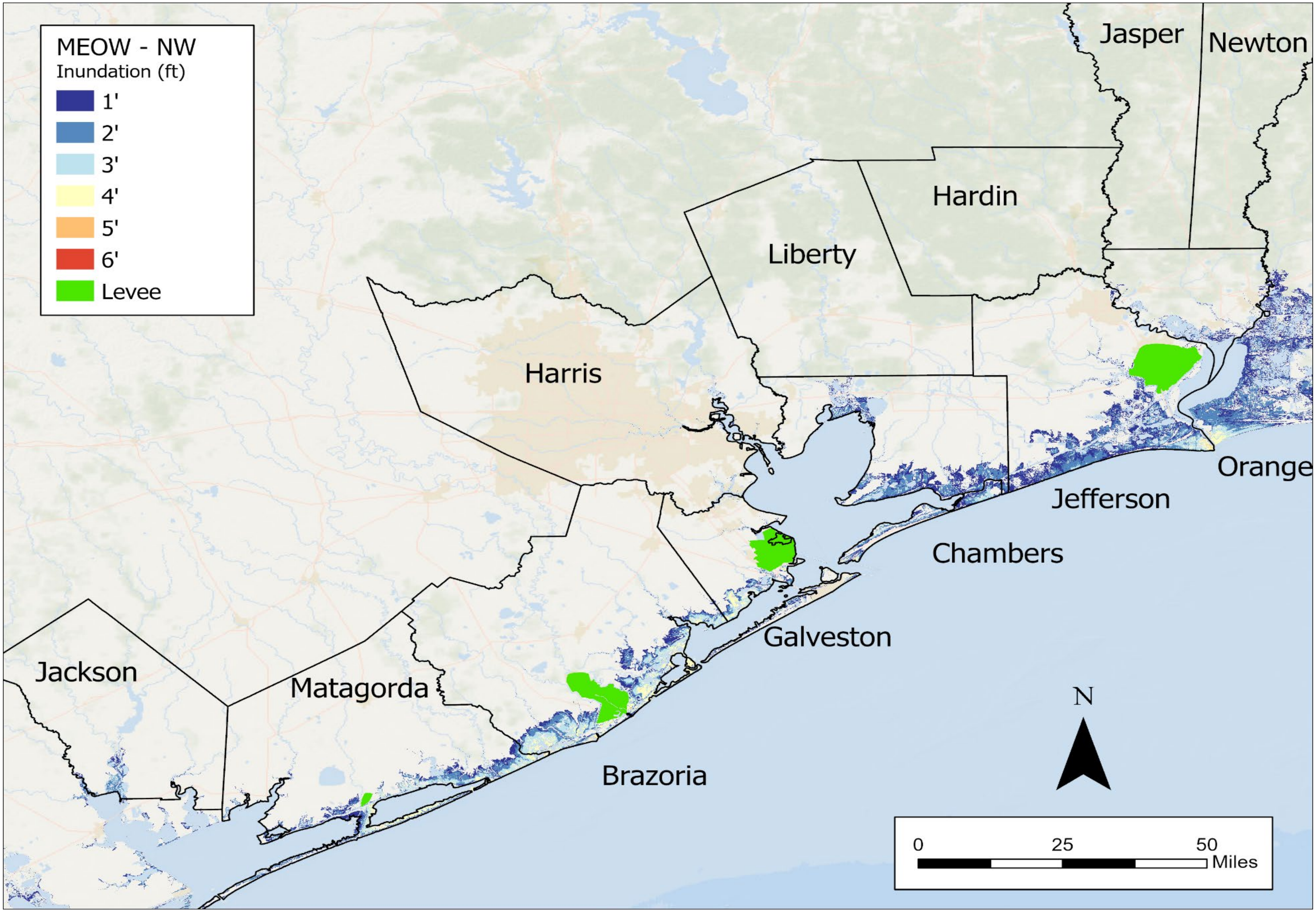


Figure B-119 West Southwest Directional MEOW Map (Best Case Approach Direction – Lowest Maximum Inundation)

APPENDIX C: CATEGORY STORM MOMS MAPS

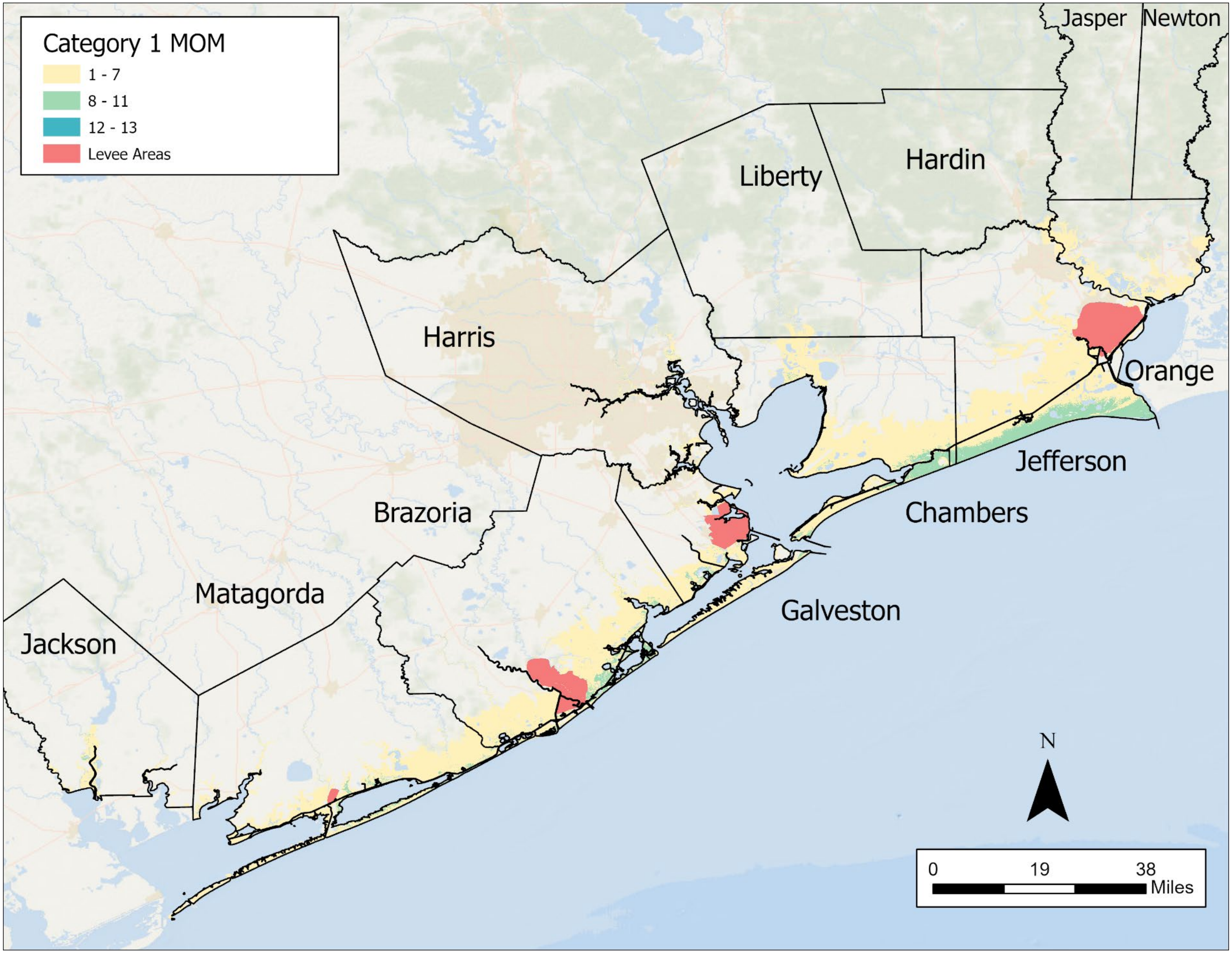


Figure C-1 Category 1 MOM map for all counties

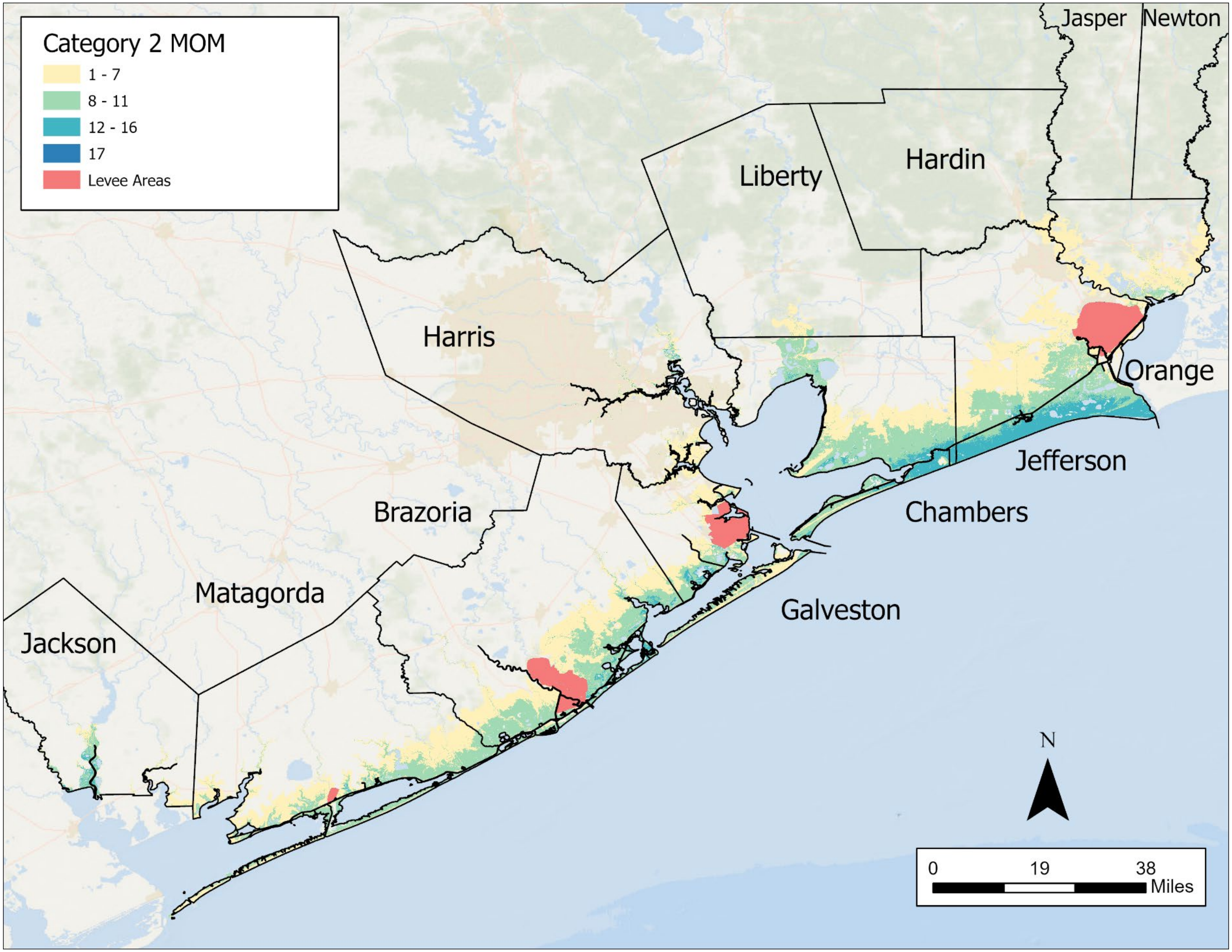


Figure C-2 Category 2 MOM map for all counties

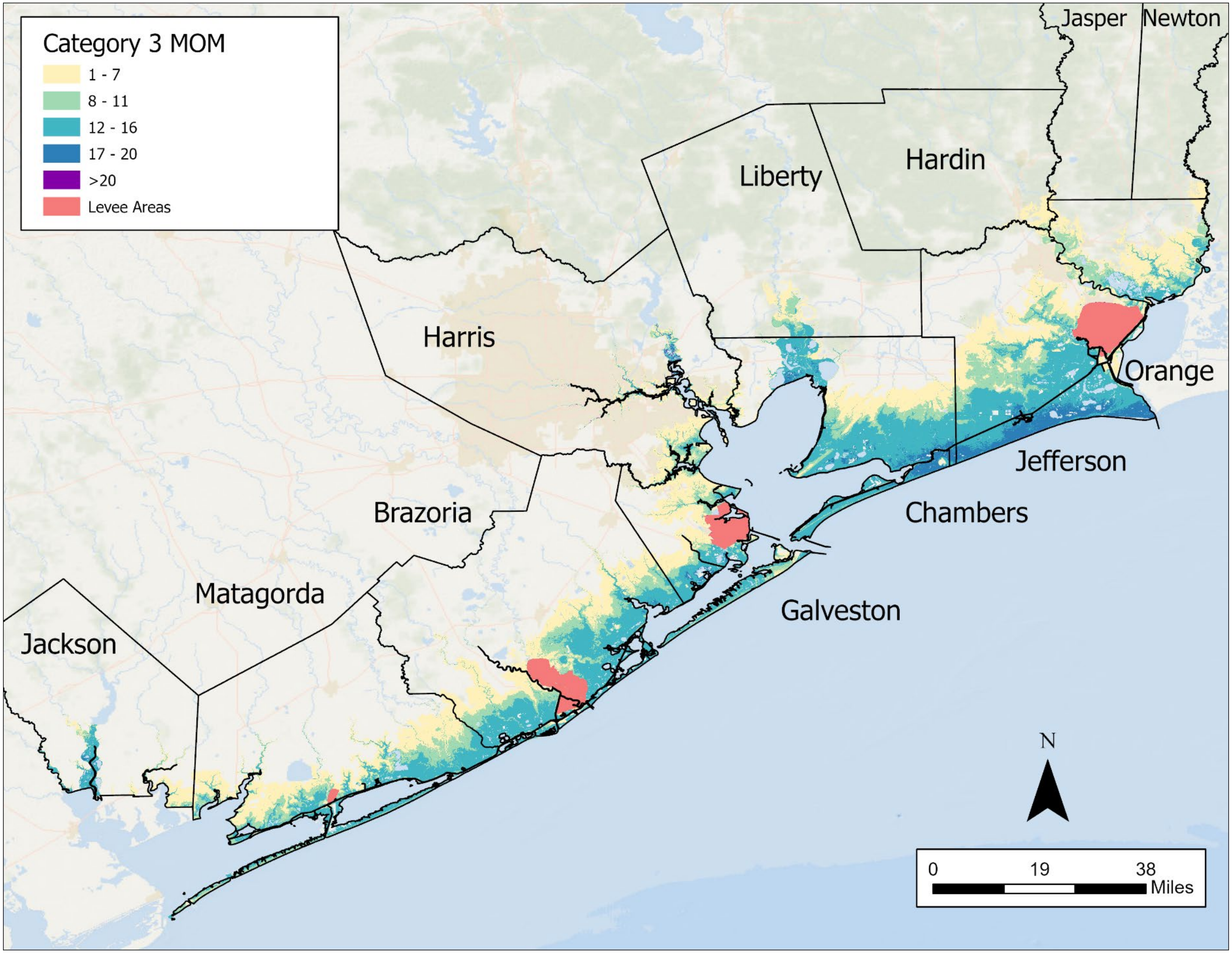


Figure C-3 Category 3 MOM map for all counties

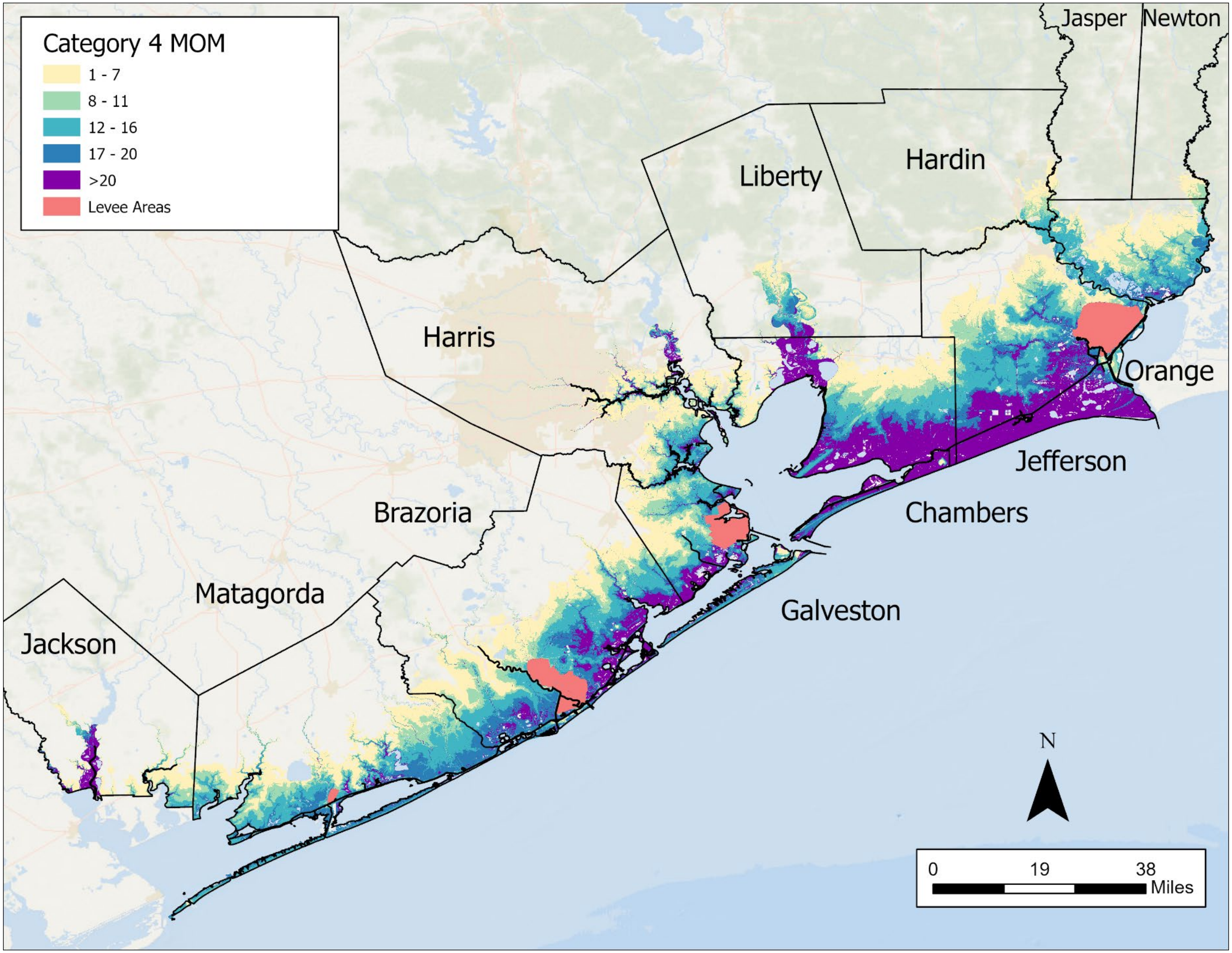


Figure C-4 Category 4 MOM map for all counties

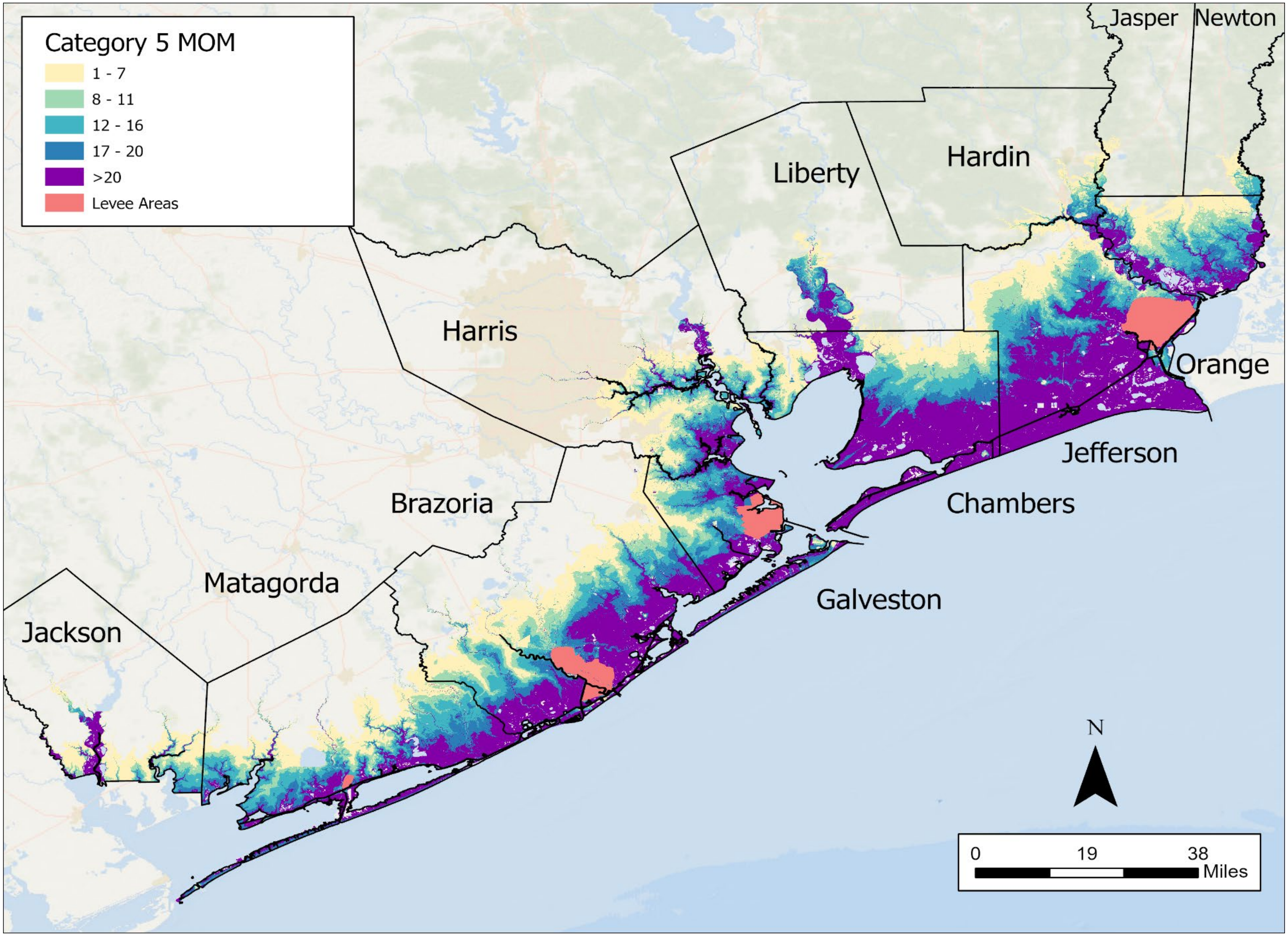


Figure C-5 Category 5 MOM map for all counties

APPENDIX D: WIND EXTENT MAPS (WEM) CATEGORIES 1, 2, 3, 4, AND 5 STORMS (WITH 24 KTS FORWARD SPEED)

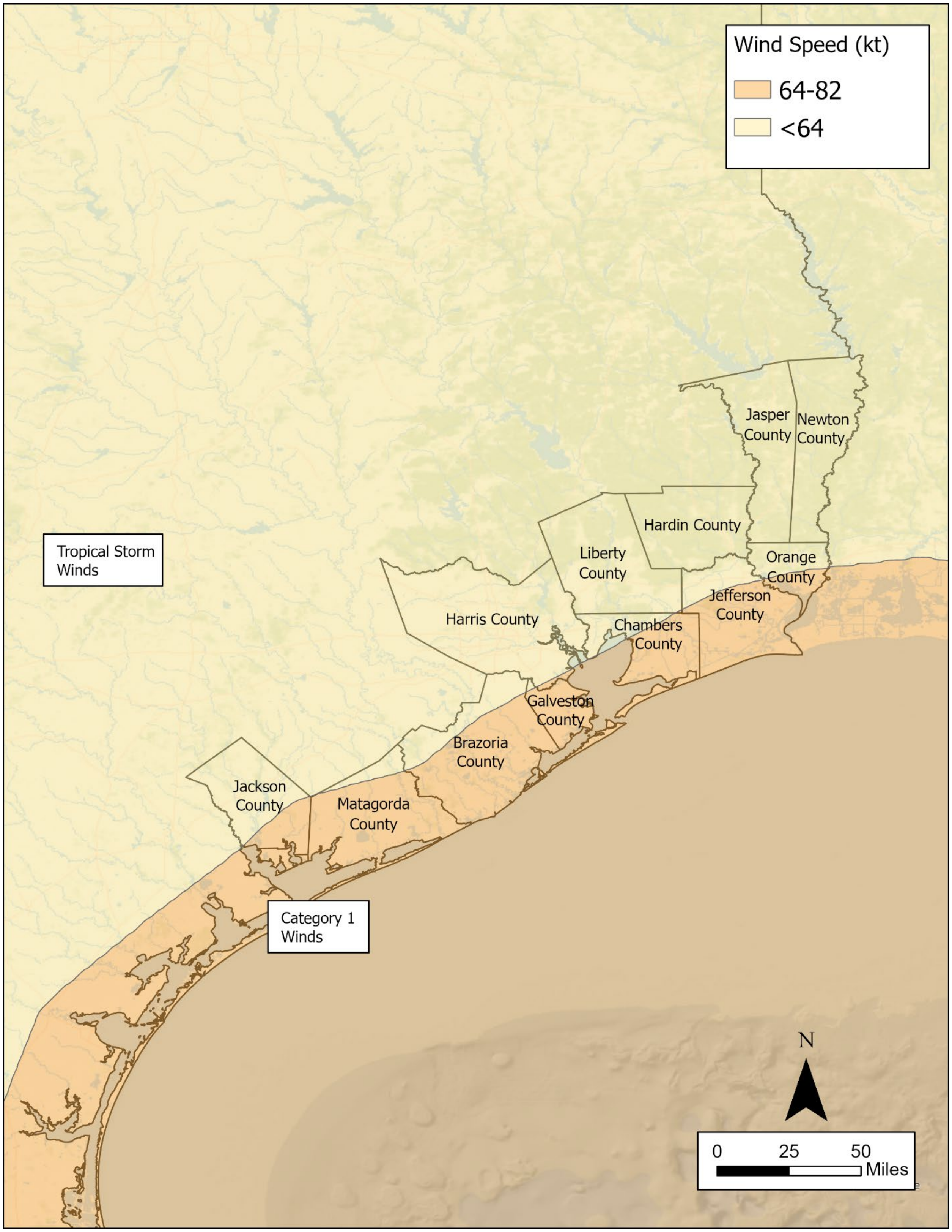


Figure D-1 Wind Extent Map for Category 1 Storm (75 kt) with 24 kt Forward Speed (Shaded Map)

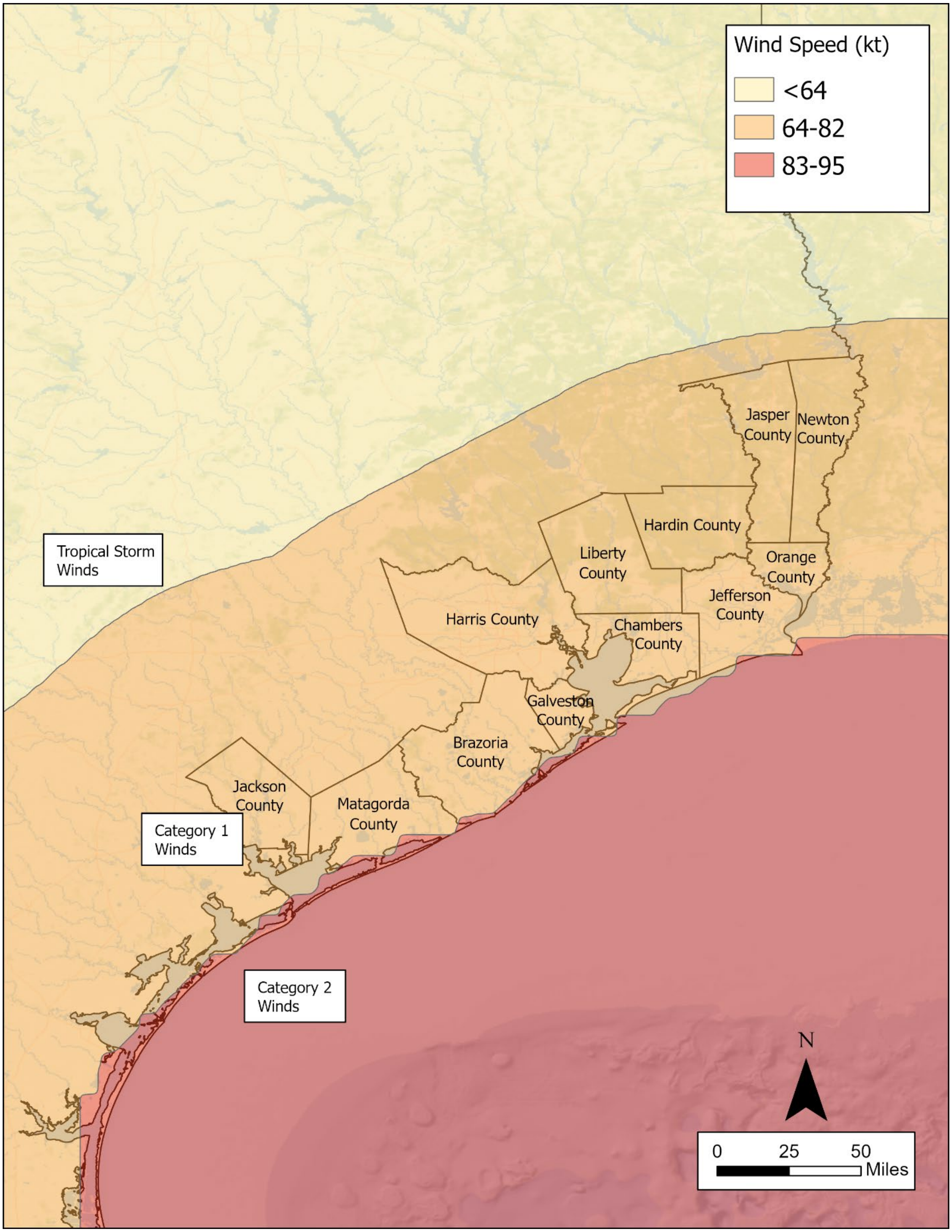


Figure D-2 Wind Extent Map for Category 2 Storm (90 kt) with 24 kt Forward Speed (Shaded Map)

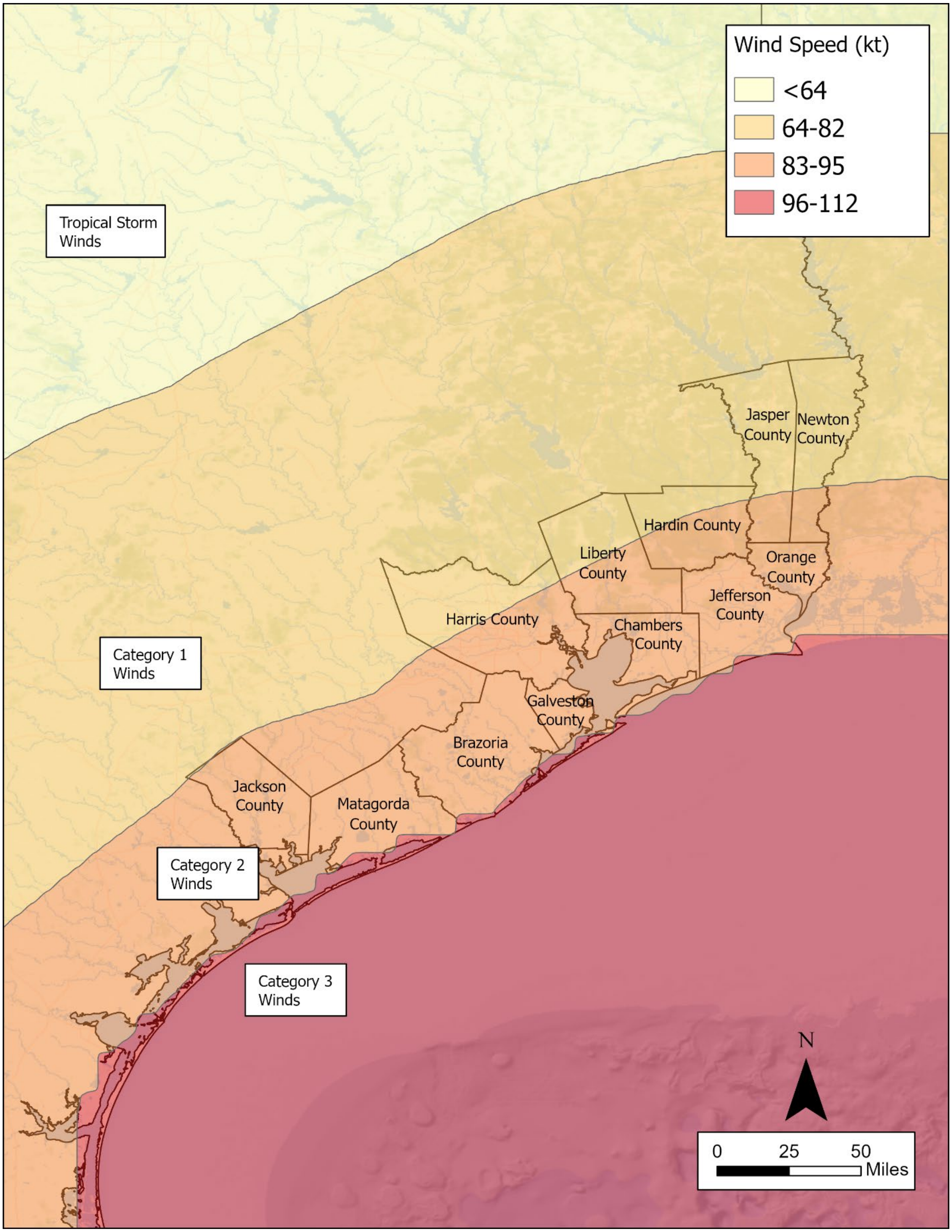


Figure D-3 Wind Extent Map for Category 3 Storm (105 kt) with 24 kt Forward Speed (Shaded Map)

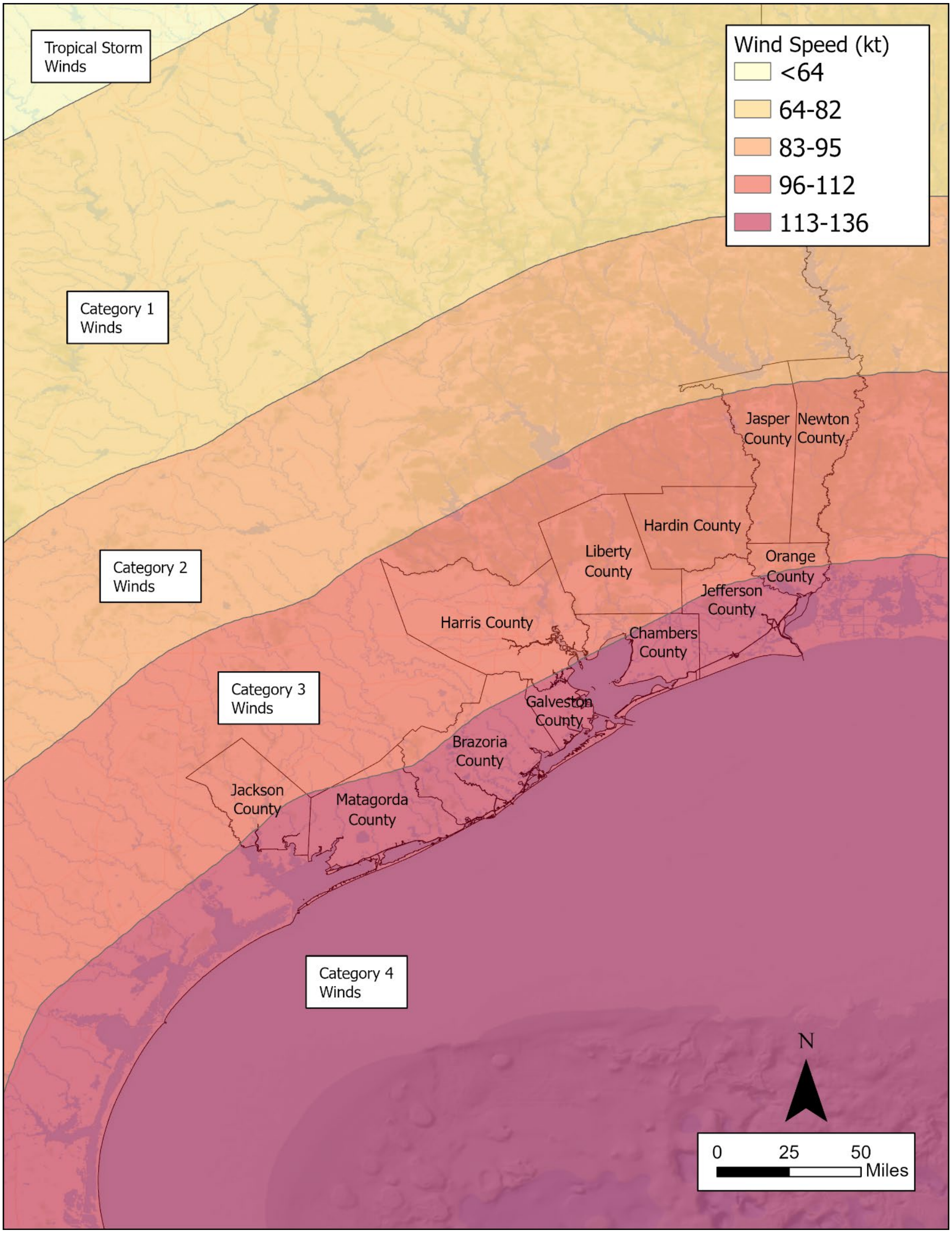


Figure D-4 Wind Extent Map for Category 4 Storm (120 kt) with 24 kt Forward Speed (Shaded Map)

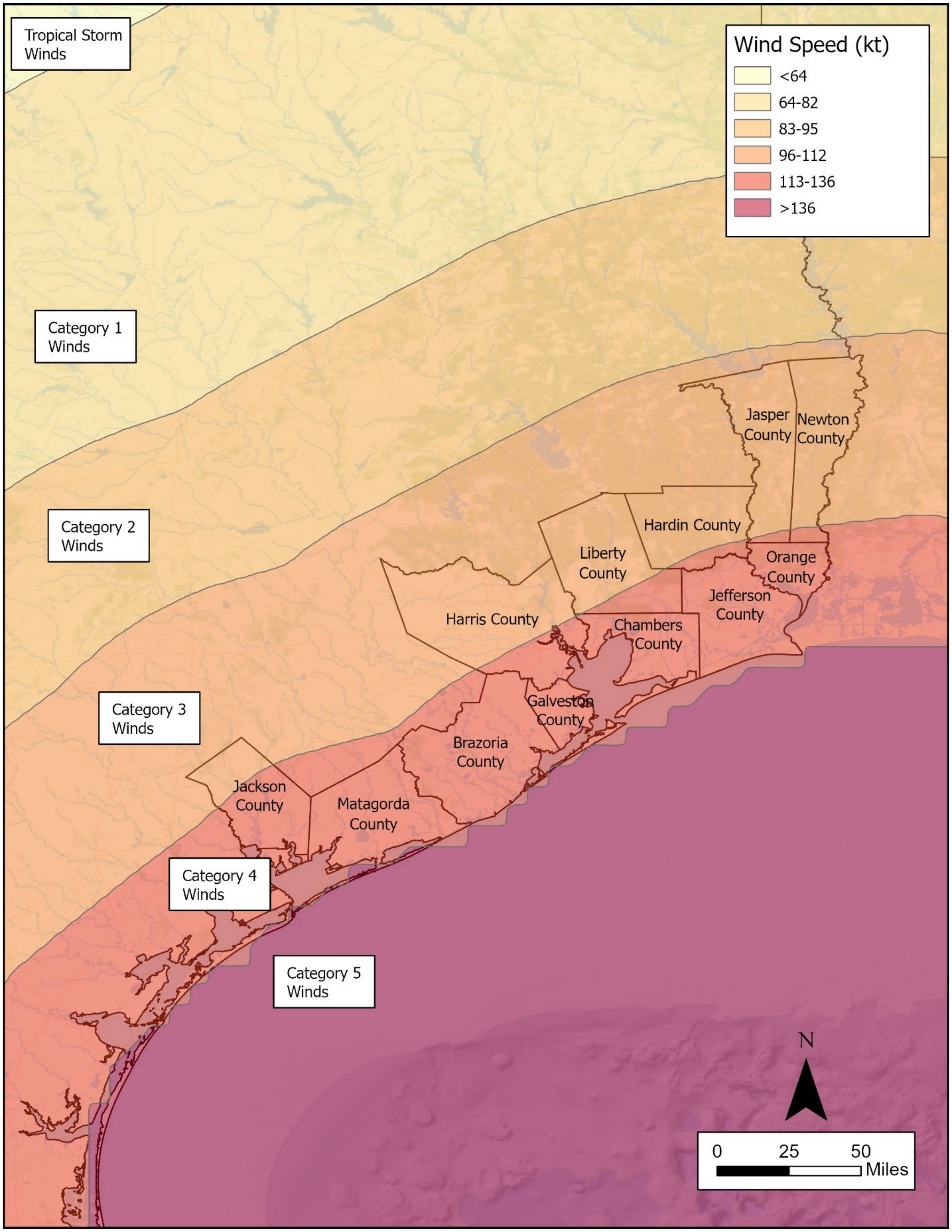


Figure D-5 Wind Extent Map for Category 5 Storm (140 kt) with 24 kt Forward Speed (Shaded Map)

APPENDIX E: MAXIMUM INUNDATION DEPTHS FOR DIRECTIONAL MEOW GRAPHS

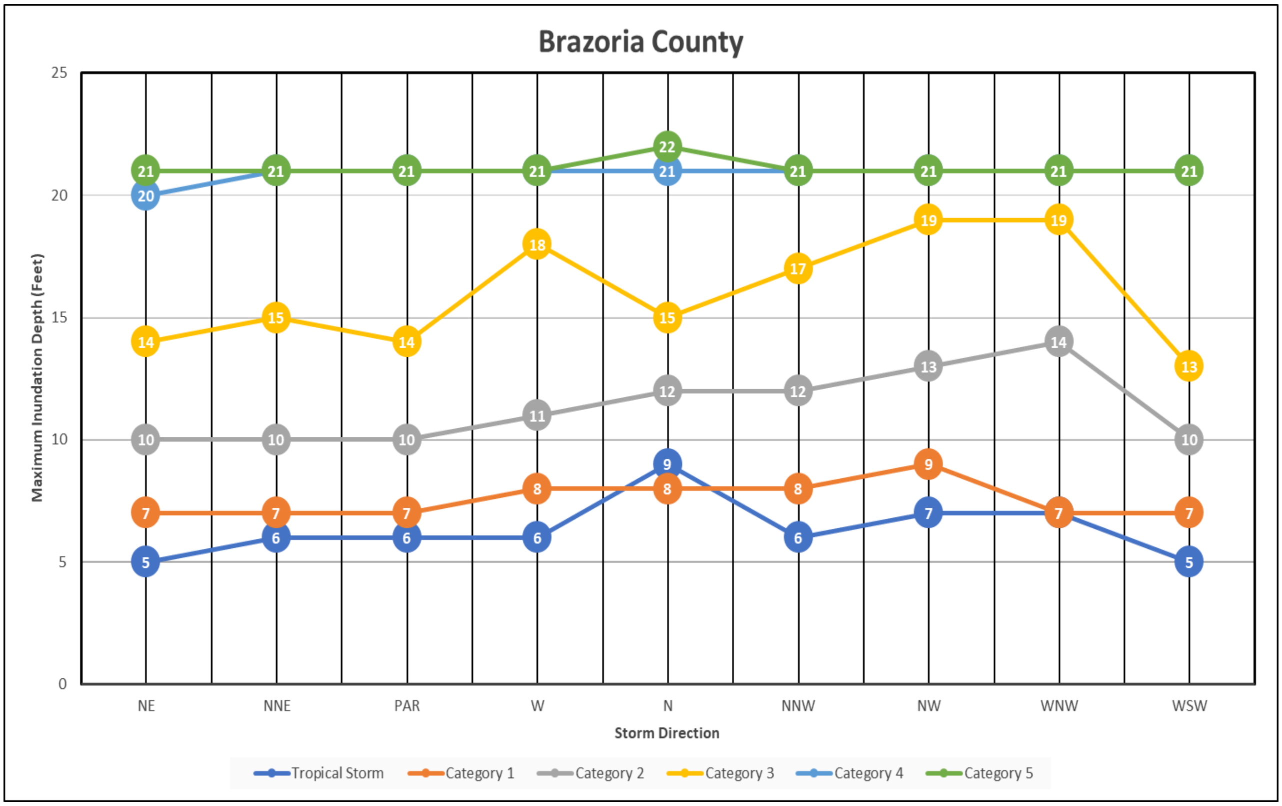


Figure E-1 Brazoria County, TX Maximum Inundation Depths for Directional MEOWs

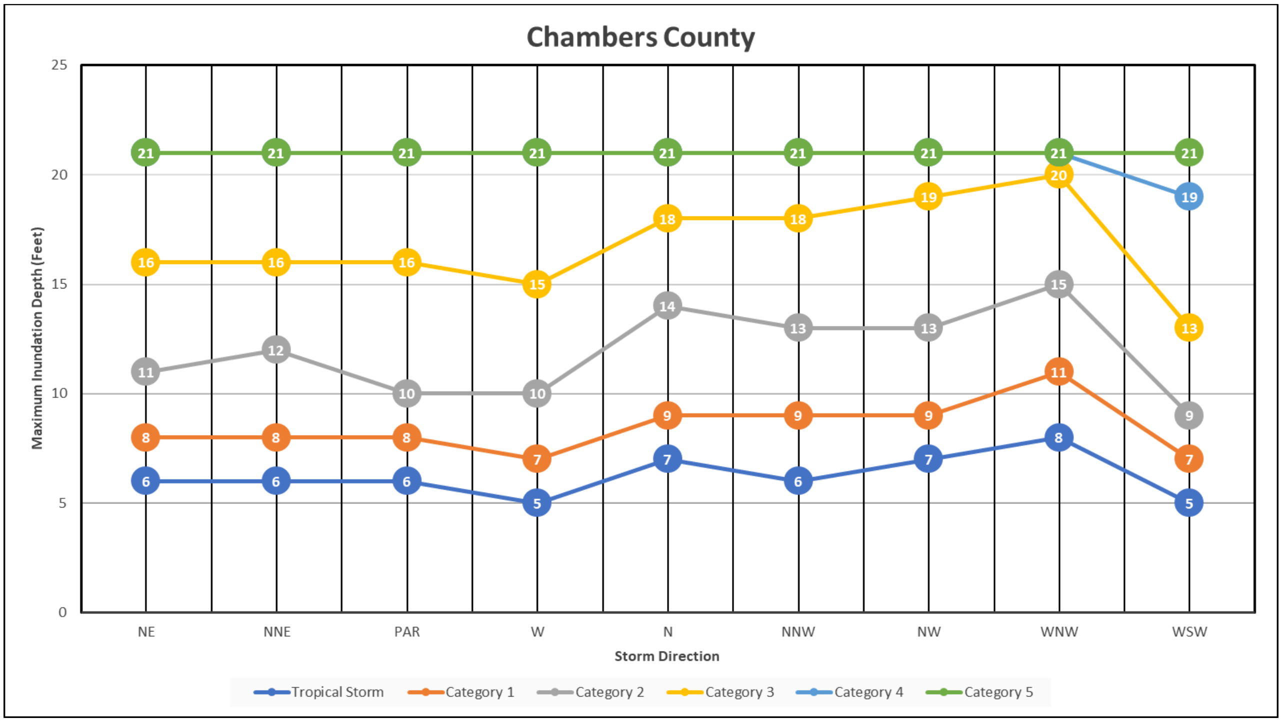


Figure E-2 Chambers County, TX Maximum Inundation Depths for Directional MEOWs

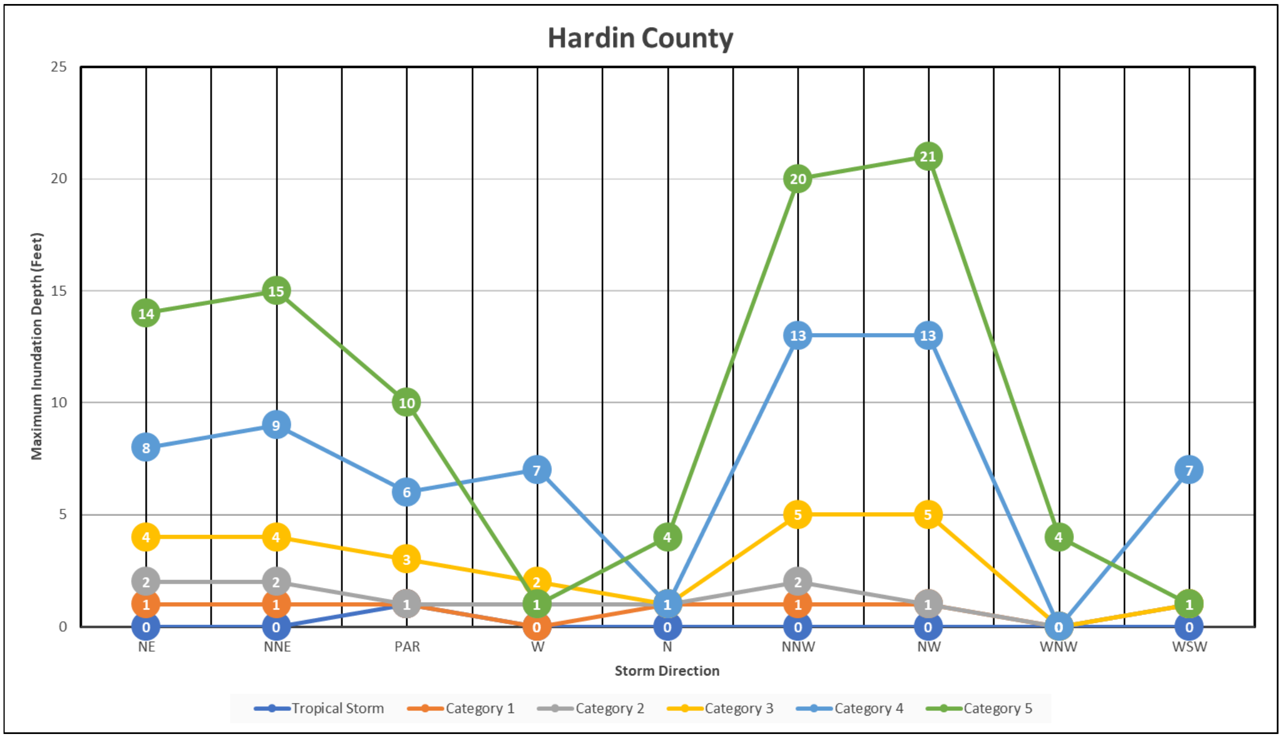


Figure E-3 Hardin County, TX Maximum Inundation Depths for Directional MEOWs

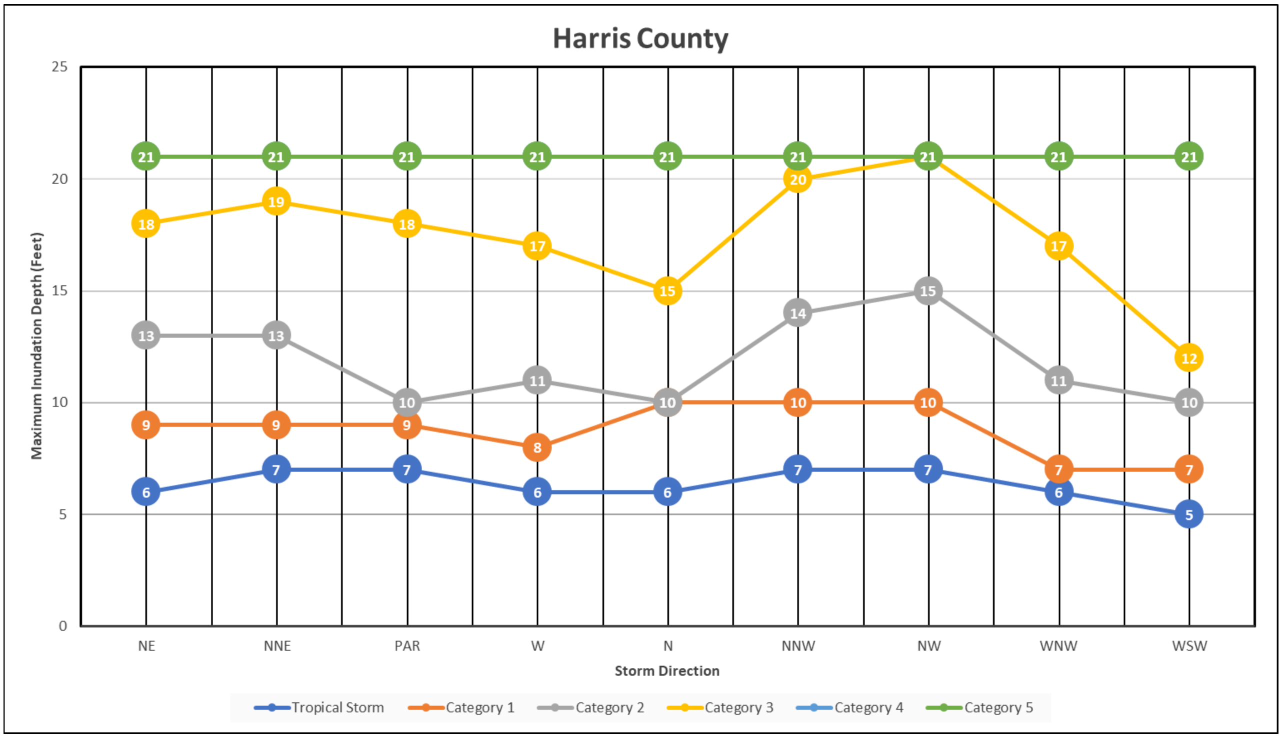


Figure E-4 Harris County, TX Maximum Inundation Depths for Directional MEOWs

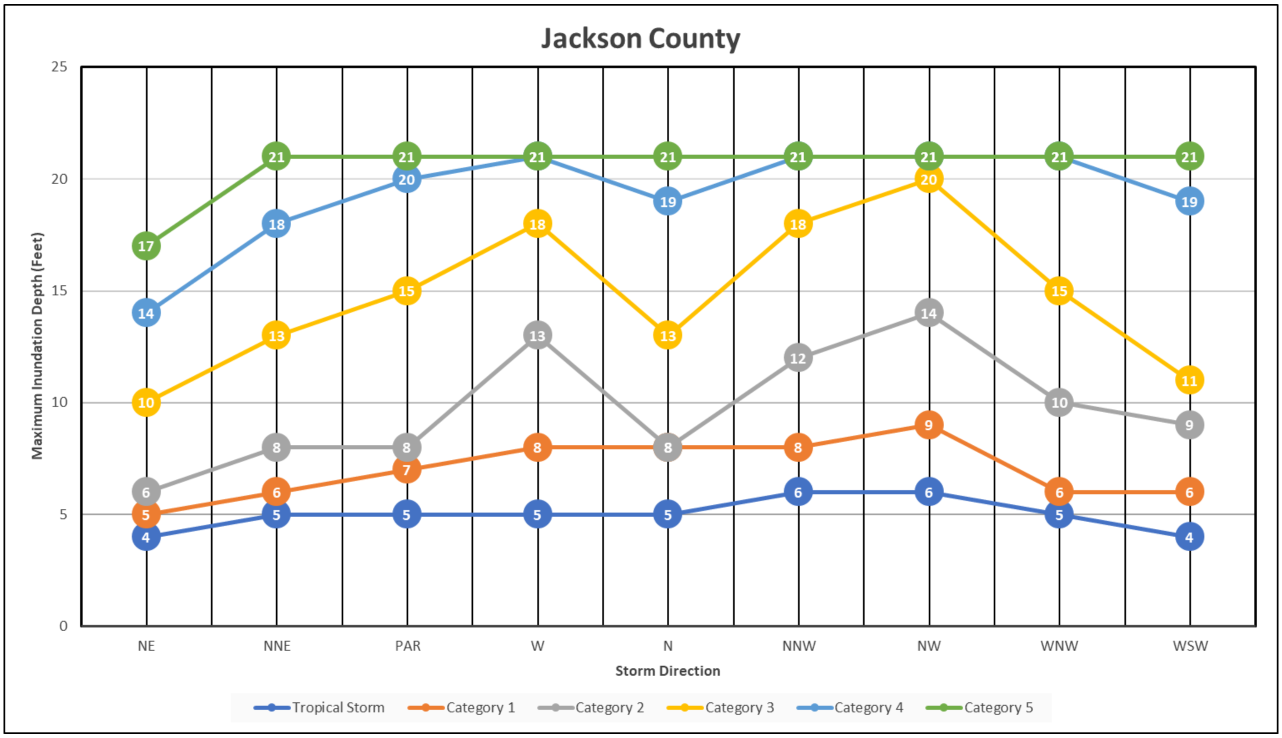


Figure E-5 Jackson County, TX Maximum Inundation Depths for Directional MEOWs

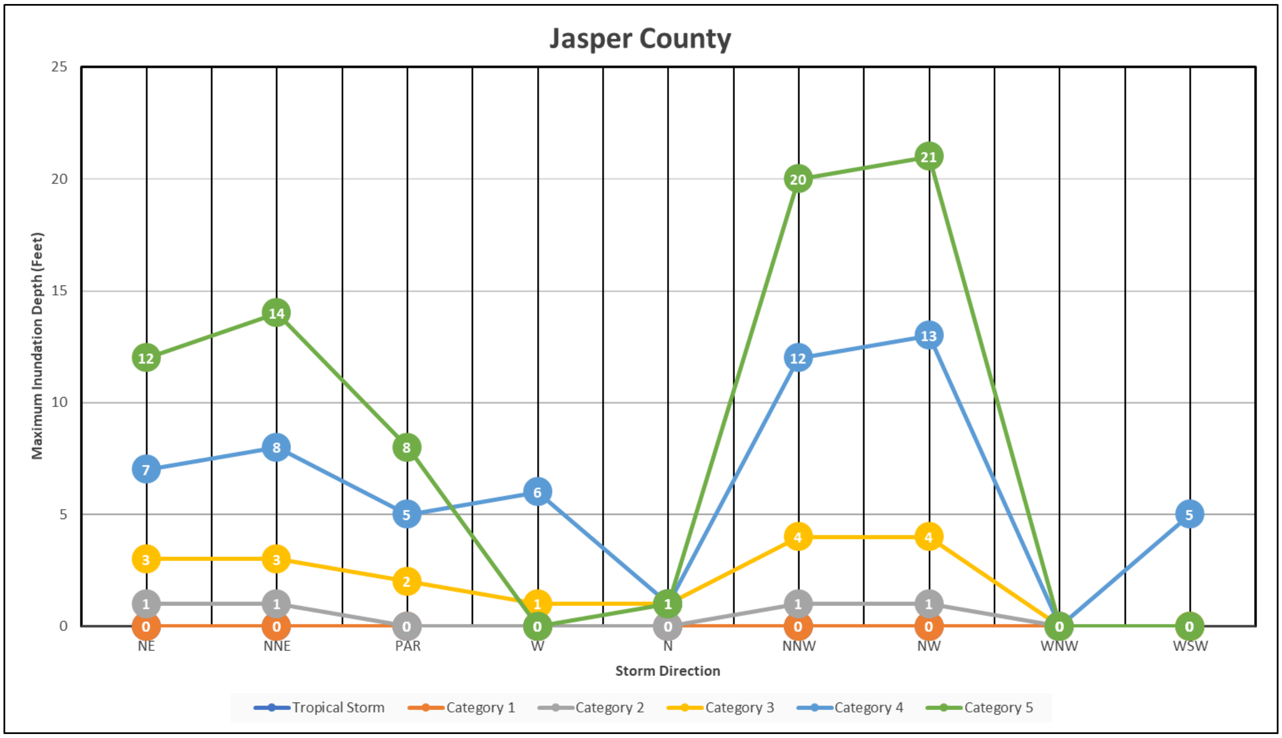


Figure E-6 Jasper County, TX Maximum Inundation Depths for Directional MEOWs

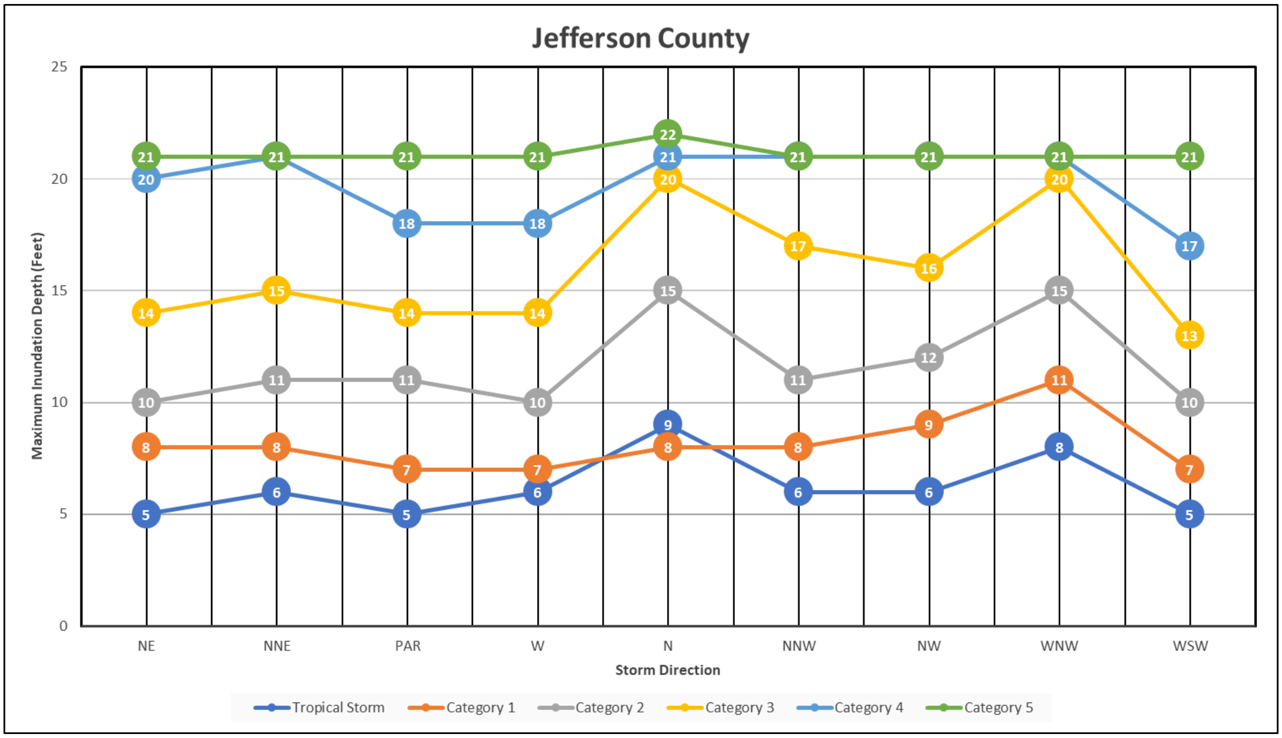


Figure E-7 Jefferson County, TX Maximum Inundation Depths for Directional MEOWs

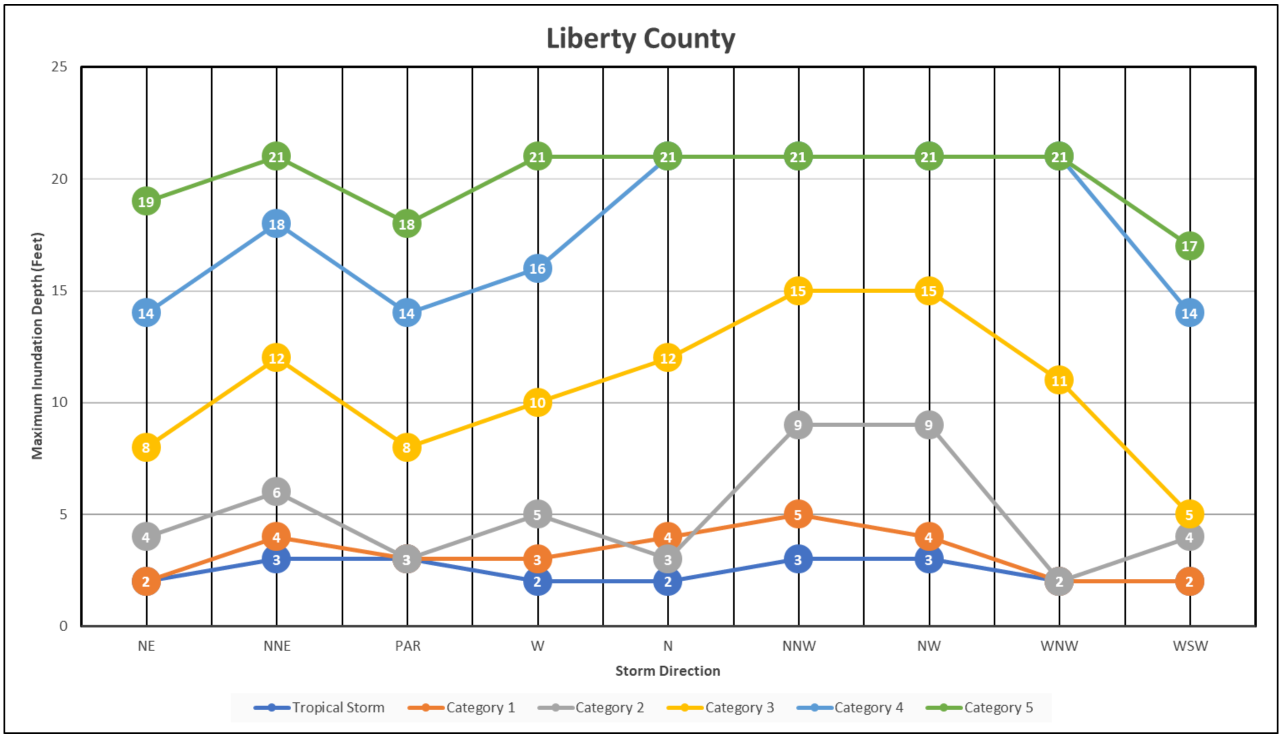


Figure E-8 Liberty County, TX Maximum Inundation Depths for Directional MEOWs

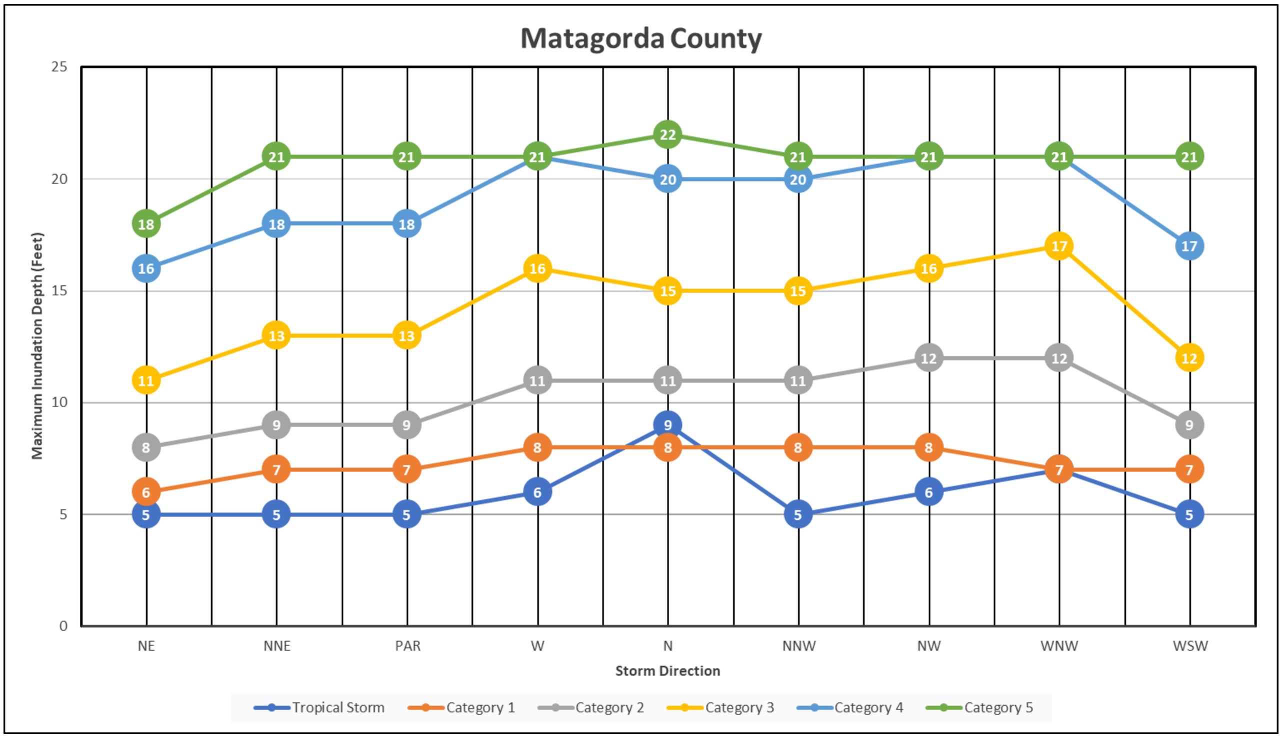


Figure E-9 Matagorda County, TX Maximum Inundation Depths for Directional MEOWs

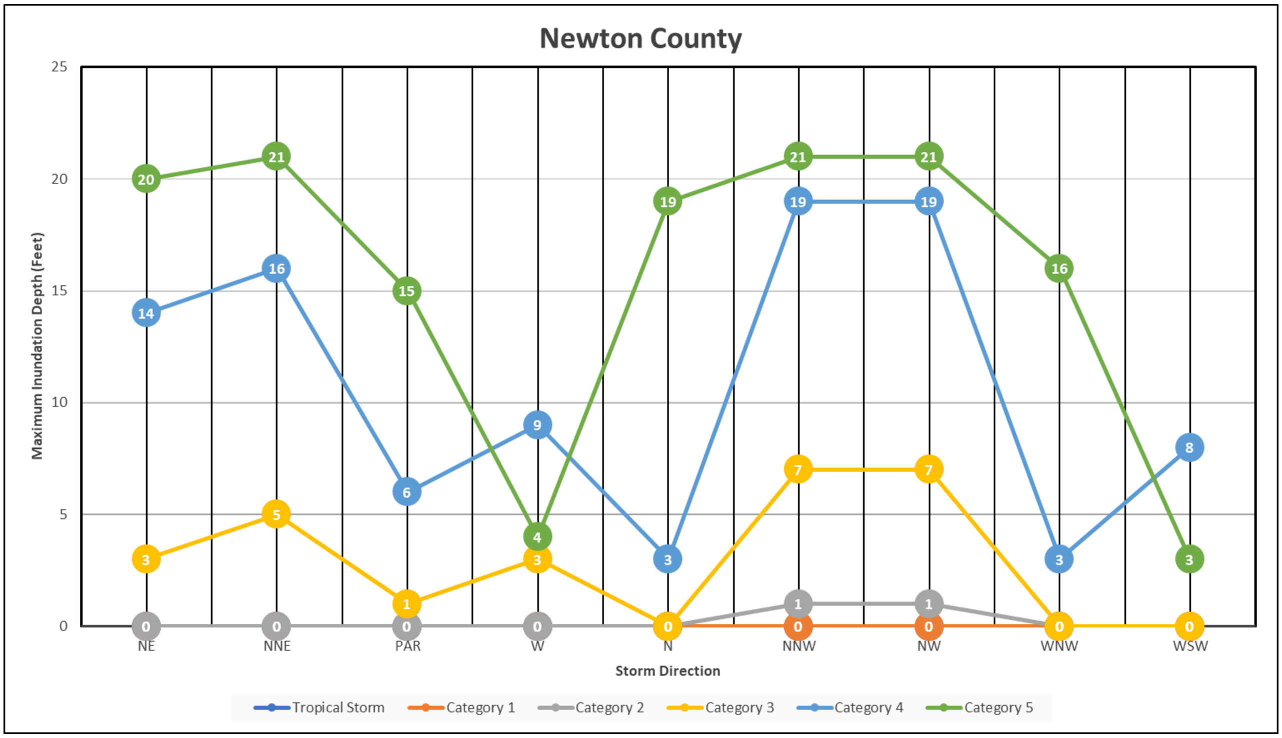


Figure E-10 Newton County, TX Maximum Inundation Depths for Directional MEOWs

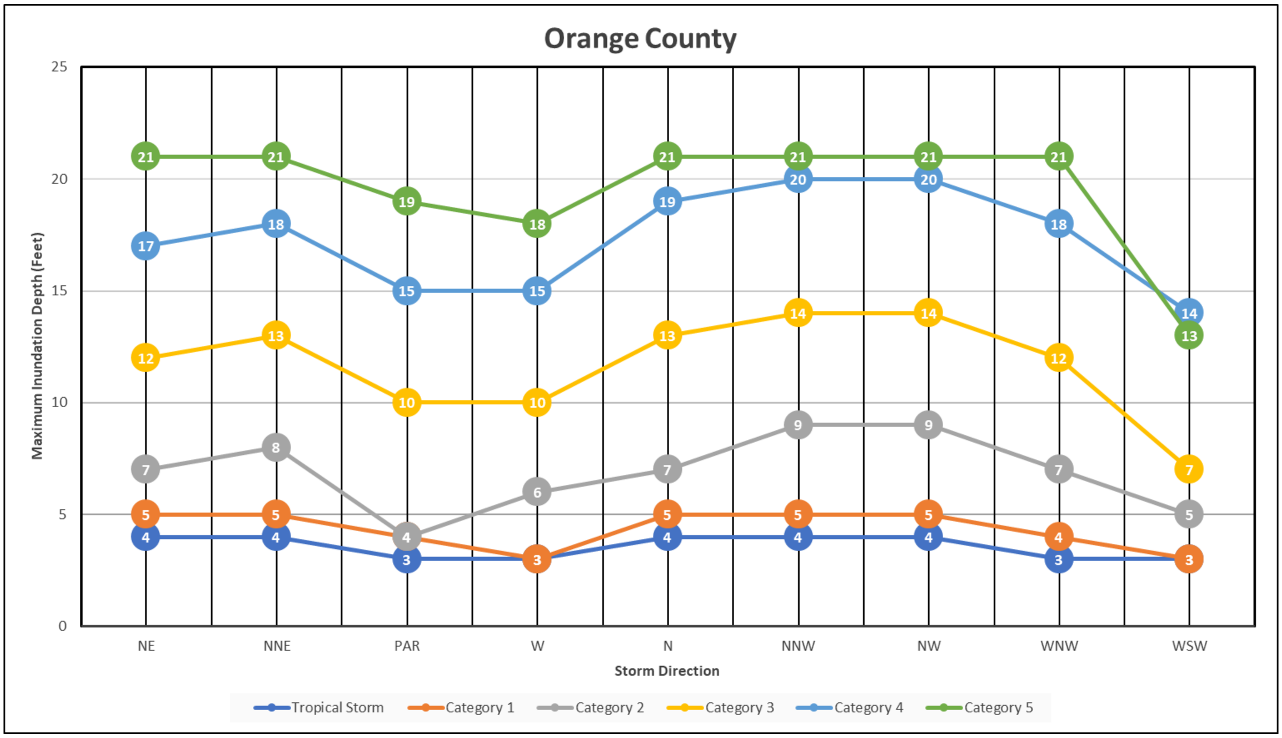


Figure E-11 Orange County, TX Maximum Inundation Depths for Directional MEOWs

APPENDIX F: COUNTY GROUPINGS BASED ON ACREAGE OF INUNDATION EXTENT

Brazoria					
Storm/Direction	**Min. Depth (ft.)**	**Avg. Depth (ft.)**	**Max. Depth (ft.)**	**Population Impacts**	**Acres**
MEOW N0	1	5	9	56870	116254.3659
MEOW N1	1	4.5	8	58923	143436.6728
MEOW N2	1	6.5	12	62533	189024.1418
MEOW N3	1	8	15	72864	250506.8974
MEOW N4	1	11	21	90074	325979.9179
MEOW N5	1	11.5	22	119464	397322.9962
MEOW NE0	1	3	5	56601	109180.6847
MEOW NE1	1	4	7	57366	130925.2382
MEOW NE2	1	5.5	10	60297	168265.0102
MEOW NE3	1	7.5	14	67148	221286.8621
MEOW NE4	1	10.5	20	80205	280280.9655
MEOW NE5	1	11	21	93408	334214.1074
MEOW NNE0	1	3.5	6	56811	112125.3131
MEOW NNE1	1	4	7	57545	135808.8072
MEOW NNE2	1	5.5	10	60825	177169.1474
MEOW NNE3	1	8	15	69905	235347.2609
MEOW NNE4	1	11	21	84842	299728.7123
MEOW NNE5	1	11	21	105418	365900.9194
MEOW NNW0	1	3.5	6	56916	122018.6858
MEOW NNW1	1	4.5	8	59576	151599.8215
MEOW NNW2	1	6.5	12	64033	203388.2542
MEOW NNW3	1	9	17	74782	269694.9749
MEOW NNW4	1	11	21	99979	361846.5174
MEOW NNW5	1	11	21	133118	443616.595
MEOW NW0	1	4	7	57380	127734.2102
MEOW NW1	1	5	9	59752	161384.7868
MEOW NW2	1	7	13	66262	216335.7968
MEOW NW3	1	10	19	79521	285863.1432
MEOW NW4	1	11	21	113987	394505.4563
MEOW NW5	1	11	21	148406	486799.6747
MEOW PAR0	1	3.5	6	56808	111128.7115
MEOW PAR1	1	4	7	57599	133737.5133
MEOW PAR2	1	5.5	10	61508	173780.9598
MEOW PAR3	1	7.5	14	69514	229640.832
MEOW PAR4	1	11	21	83721	292310.603
MEOW PAR5	1	11	21	99634	353422.7615
MEOW W0	1	3.5	6	56911	122109.9387
MEOW W1	1	4.5	8	58982	150528.5869
MEOW W2	1	6	11	64164	198691.0946
MEOW W3	1	9.5	18	74480	259452.1433
MEOW W4	1	11	21	93815	344140.0982
MEOW W5	1	11	21	123623	420394.6516
MEOW WNW0	1	4	7	57465	130233.3802
MEOW WNW1	1	5.5	10	60445	165804.5493
MEOW WNW2	1	7.5	14	67898	221386.0679
MEOW WNW3	1	10	19	83234	292619.4358
MEOW WNW4	1	11	21	114817	400091.8794
MEOW WNW5	1	11	21	149153	496940.3229
MEOW WSW0	1	3	5	56597	110867.2511
MEOW WSW1	1	4	7	57231	131549.3829
MEOW WSW2	1	5.5	10	61055	169451.9791
MEOW WSW3	1	7	13	67755	223831.8349
MEOW WSW4	1	11	21	82360	290593.8357
MEOW WSW5	1	11	21	100624	355947.6185
MOM1	1	11.5	22	64212	165508.1529
MOM2	1	8	15	72177	221447.2573
MOM3	1	11.5	22	84984	295093.4711
MOM4	1	11.5	22	118437	409398.3898
MOM5	1	11.5	22	155156	508025.4241

Table F-1 Brazoria County, TX Grouping Based on Acreage of Inundation Extent

Table F-2 Chambers County, TX Grouping Based on Acreage of Inundation Extent

Chambers

Storm/Direction	Min. Depth (ft.)	Avg. Depth (ft.)	Max. Depth (ft.)	Population Impacts	Acres
MEOW N0	1	4	7	10177	77288.84489
MEOW N1	1	5	9	11584	101387.8334
MEOW N2	1	7.5	14	13021	138261.5424
MEOW N3	1	9.5	18	19778	185298.0639
MEOW N4	1	11	21	31061	256058.6408
MEOW N5	1	11	21	41838	312341.6673
MEOW NE0	1	3.5	6	9077	62705.84554
MEOW NE1	1	4.5	8	9581	81845.15083
MEOW NE2	1	6	11	11758	114835.787
MEOW NE3	1	8.5	16	14619	150870.6979
MEOW NE4	1	11	21	22391	191977.8086
MEOW NE5	1	11	21	28683	230664.9913
MEOW NNE0	1	3.5	6	10095	74124.53568
MEOW NNE1	1	4.5	8	10314	94701.29594
MEOW NNE2	1	6.5	12	12210	126672.2925
MEOW NNE3	1	8.5	16	16812	165185.2643
MEOW NNE4	1	11	21	26020	217886.9489
MEOW NNE5	1	11	21	34268	263845.9309
MEOW NNW0	1	3.5	6	9872	78048.50745
MEOW NNW1	1	5	9	11685	104910.8359
MEOW NNW2	1	7	13	14012	143400.9444
MEOW NNW3	1	9.5	18	21687	194112.2734
MEOW NNW4	1	11	21	35242	271480.3912
MEOW NNW5	1	11	21	44234	330328.6253
MEOW NW0	1	4	7	9839	77079.89119
MEOW NW1	1	5	9	11772	104955.4944
MEOW NW2	1	7	13	14012	143086.3737
MEOW NW3	1	10	19	21880	191238.2507
MEOW NW4	1	11	21	36991	267848.7315
MEOW NW5	1	11	21	44098	323821.5609
MEOW PAR0	1	3.5	6	9926	64521.16916
MEOW PAR1	1	4.5	8	10238	81502.49451
MEOW PAR2	1	5.5	10	11788	109519.5446
MEOW PAR3	1	8.5	16	14030	144699.9697
MEOW PAR4	1	11	21	19564	182660.7456
MEOW PAR5	1	11	21	27010	218406.3677
MEOW W0	1	3	5	9285	63516.37894
MEOW W1	1	4	7	9742	85943.49897
MEOW W2	1	5.5	10	11907	113835.4837
MEOW W3	1	8	15	14941	148658.8907
MEOW W4	1	11	21	23057	196244.4388
MEOW W5	1	11	21	32158	248010.764
MEOW WNW0	1	4.5	8	9630	72359.13828
MEOW WNW1	1	6	11	10610	99288.76423
MEOW WNW2	1	8	15	12615	134874.2733
MEOW WNW3	1	10.5	20	20339	175603.8907
MEOW WNW4	1	11	21	32280	244016.6475
MEOW WNW5	1	11	21	42754	301572.4718
MEOW WSW0	1	3	5	8951	53555.96746
MEOW WSW1	1	4	7	9515	75506.82168
MEOW WSW2	1	5	9	11614	104905.4807
MEOW WSW3	1	7	13	13170	139364.4935
MEOW WSW4	1	10	19	18825	179231.4546
MEOW WSW5	1	11	21	26981	220900.0778
MOM1	1	11.5	22	13347	109003.5371
MOM2	1	8	15	14721	145972.2262
MOM3	1	10.5	20	22194	197563.9073
MOM4	1	11	21	38507	276327.715
MOM5	1	11	21	44323	333307.703

Harris

Storm/Direction	Min. Depth (ft.)	Avg. Depth (ft.)	Max. Depth (ft.)	Population Impacts	Acres
MEOW N0	1	3.5	6	51143	5370.726114
MEOW N1	1	5.5	10	70705	9991.478276
MEOW N2	1	5.5	10	103850	22595.65777
MEOW N3	1	8	15	166462	48673.30017
MEOW N4	1	11	21	356895	97172.67398
MEOW N5	1	11	21	611591	154216.2105
MEOW NE0	1	3.5	6	49952	4712.07468
MEOW NE1	1	5	9	67576	8258.690308
MEOW NE2	1	7	13	92254	18334.34134
MEOW NE3	1	9.5	18	138852	39394.51386
MEOW NE4	1	11	21	254586	70351.67618
MEOW NE5	1	11	21	441183	114155.5461
MEOW NNE0	1	4	7	50092	4982.571854
MEOW NNE1	1	5	9	69263	9200.046867
MEOW NNE2	1	7	13	96736	20474.34125
MEOW NNE3	1	10	19	152606	44058.85658
MEOW NNE4	1	11	21	301547	83088.82489
MEOW NNE5	1	11	21	521154	132947.1513
MEOW NNW0	1	4	7	59944	5748.890711
MEOW NNW1	1	5.5	10	73464	11225.69294
MEOW NNW2	1	7.5	14	109285	25837.11515
MEOW NNW3	1	10.5	20	195749	58131.2802
MEOW NNW4	1	11	21	486007	127612.2808
MEOW NNW5	1	11	21	792188	192449.1054
MEOW NW0	1	4	7	60284	5935.547271
MEOW NW1	1	5.5	10	76880	12109.77291
MEOW NW2	1	8	15	117688	28985.17113
MEOW NW3	1	11	21	229978	65768.54858
MEOW NW4	1	11	21	580225	147976.1364
MEOW NW5	1	11	21	929821	217447.4821
MEOW PAR0	1	4	7	49967	4779.399004
MEOW PAR1	1	5	9	67685	8259.408032
MEOW PAR2	1	5.5	10	92021	18284.46135
MEOW PAR3	1	9.5	18	137037	38795.81864
MEOW PAR4	1	11	21	247975	68748.19178
MEOW PAR5	1	11	21	423076	110549.9109
MEOW W0	1	3.5	6	47968	4262.270428
MEOW W1	1	4.5	8	64798	6820.140855
MEOW W2	1	6	11	86377	15607.38452
MEOW W3	1	9	17	134712	38030.80341
MEOW W4	1	11	21	269931	73961.55439
MEOW W5	1	11	21	476039	123027.7112
MEOW WNW0	1	3.5	6	59460	5646.636952
MEOW WNW1	1	4	7	73003	10853.11725
MEOW WNW2	1	6	11	110742	26192.77941
MEOW WNW3	1	8	17	197414	56922.23099
MEOW WNW4	1	11	21	506597	129294.8742
MEOW WNW5	1	11	21	859852	199421.8405
MEOW WSW0	1	3	5	44843	3266.893648
MEOW WSW1	1	4	7	58851	5163.734663
MEOW WSW2	1	5.5	10	75114	11566.9604
MEOW WSW3	1	6.5	12	117665	30342.46638
MEOW WSW4	1	11	21	215425	61672.24504
MEOW WSW5	1	11	21	380187	102325.9561
MOM1	1	5.5	10	94030	10945.47499
MOM2	1	8	15	129682	26860.7259
MOM3	1	11	21	245793	63005.10823
MOM4	1	11	21	589994	144628.5557
MOM5	1	11	21	945882	216091.9262

Hardin

Storm/Direction	Min. Depth (ft.)	Avg. Depth (ft.)	Max. Depth (ft.)	Population Impacts	Acres
MEOW N0	0	0	0	0	1.523428346
MEOW N1	1	1	1	0	14.50227546
MEOW N2	1	1	1	0	37.10606338
MEOW N3	1	1	1	1401	2156.926053
MEOW N4	1	1	1	3022	11874.83133
MEOW N5	1	2.5	4	4608	22590.2128
MEOW NE0	0	0	0	0	0.028220342
MEOW NE1	1	1	1	0	7.388820479
MEOW NE2	1	1.5	2	0	55.23306428
MEOW NE3	1	2.5	4	1401	2039.830316
MEOW NE4	1	4.5	8	2339	5011.417802
MEOW NE5	1	7.5	14	3901	13647.08653
MEOW NNE0	0	0	0	[illegible]	0.028220342
MEOW NNE1	1	1	1	0	11.29710756
MEOW NNE2	1	1.5	2	0	25.56395439
MEOW NNE3	1	2.5	4	1390	1894.318241
MEOW NNE4	1	5	9	2398	10292.16426
MEOW NNE5	1	8	15	3948	18280.6229
MEOW NNW0	0	0	0	0	0.028220342
MEOW NNW1	1	1	1	0	13.06382217
MEOW NNW2	1	1.5	2	0	35.28532431
MEOW NNW3	1	3	5	1882	2733.404008
MEOW NNW4	1	7	13	3901	13784.67587
MEOW NNW5	1	10.5	20	5558	28605.92644
MEOW NW0	0	0	0	0	0.028220342
MEOW NW1	1	1	1	0	4.958900207
MEOW NW2	1	1	1	0	20.44742783
MEOW NW3	1	3	5	2048	2924.434492
MEOW NW4	1	7	13	3913	16139.84705
MEOW NW5	1	11	21	5981	29786.52039
MEOW PAR0	1	1	1	0	0.223995022
MEOW PAR1	1	1	1	0	0.363311865
MEOW PAR2	1	1	1	0	11.43595714
MEOW PAR3	1	2	3	0	109.520295
MEOW PAR4	1	3.5	6	2048	3156.121314
MEOW PAR5	1	5.5	10	2610	10311.66517
MEOW W0	0	0	0	0	0
MEOW W1	0	0	0	0	0
MEOW W2	1	1	1	0	11.29710756
MEOW W3	1	1.5	2	0	85.19082774
MEOW W4	1	4	7	2066	4020.166466
MEOW W5	1	1	1	3901	13312.13175
MEOW WNW0	0	0	0	0	0
MEOW WNW1	0	0	0	0	0.028220342
MEOW WNW2	0	0	0	0	15.48151808
MEOW WNW3	0	0	0	1000	1781.812861
MEOW WNW4	0	0	0	3684	12548.67178
MEOW WNW5	1	2.5	4	5543	27161.86873
MEOW WSW0	0	0	0	0	0
MEOW WSW1	0	0	0	0	0
MEOW WSW2	1	1	1	0	11.29710756
MEOW WSW3	1	1	1	0	122.1049104
MEOW WSW4	1	4	7	2066	3880.689388
MEOW WSW5	1	1	1	3042	11841.00361

Table F-3 Hardin County, TX Grouping Based on Acreage of Inundation Extent

Jackson

Storm/Direction	Min. Depth (ft.)	Avg. Depth (ft.)	Max. Depth (ft.)	Population Impacts	Acres
MEOW N0	1	3	5	585	10307.29021
MEOW N1	1	4.5	8	600	12751.73614
MEOW N2	1	4.5	8	743	16886.70473
MEOW N3	1	7	13	1243	26251.66628
MEOW N4	1	10	19	1763	42353.26956
MEOW N5	1	11	21	1925	60926.76611
MEOW NE0	1	2.5	4	552	7448.408164
MEOW NE1	1	3	5	552	8177.577009
MEOW NE2	1	3.5	6	585	10103.70612
MEOW NE3	1	5.5	10	684	14530.70323
MEOW NE4	1	7.5	14	978	20226.77216
MEOW NE5	1	9	17	1189	24766.07287
MEOW NNE0	1	3	5	571	8183.495541
MEOW NNE1	1	3.5	6	585	9715.970405
MEOW NNE2	1	4.5	8	654	12883.28572
MEOW NNE3	1	7	13	866	19435.93352
MEOW NNE4	1	9.5	18	1299	27560.85379
MEOW NNE5	1	11	21	1490	35758.65142
MEOW NNW0	1	3.5	6	589	10719.78508
MEOW NNW1	1	4.5	8	606	13549.59491
MEOW NNW2	1	6.5	12	942	19137.88545
MEOW NNW3	1	9.5	18	1535	30419.12932
MEOW NNW4	1	11	21	1897	50407.86359
MEOW NNW5	1	11	21	2080	83167.53803
MEOW NW0	1	3.5	6	589	10739.9575
MEOW NW1	1	5	9	654	14364.86721
MEOW NW2	1	7.5	14	1100	21411.20143
MEOW NW3	1	10.5	20	1709	33686.49447
MEOW NW4	1	11	21	1985	59963.94331
MEOW NW5	1	11	21	2322	98419.41197
MEOW PAR0	1	3	5	574	9438.136061
MEOW PAR1	1	4	7	600	11514.74066
MEOW PAR2	1	4.5	8	672	14651.42439
MEOW PAR3	1	8	15	1154	22845.81458
MEOW PAR4	1	10.5	20	1626	35873.82519
MEOW PAR5	1	11	21	1763	48843.83478
MEOW W0	1	3	5	585	10150.33961
MEOW W1	1	4.5	8	641	13778.19413
MEOW W2	1	7	13	1000	19350.59033
MEOW W3	1	9.5	18	1342	28689.65924
MEOW W4	1	11	21	1763	48494.86241
MEOW W5	1	11	21	2059	80226.93128
MEOW WNW0	1	3	5	589	10742.82827
MEOW WNW1	1	3.5	6	657	14503.08159
MEOW WNW2	1	5.5	10	1107	21599.09199
MEOW WNW3	1	8	15	1705	33413.2339
MEOW WNW4	1	11	21	1919	59939.73679
MEOW WNW5	1	11	21	2226	97914.44676
MEOW WSW0	1	2.5	4	552	7806.893953
MEOW WSW1	1	3.5	6	585	10554.17455
MEOW WSW2	1	5	9	657	14552.42742
MEOW WSW3	1	6	11	1020	20144.24544
MEOW WSW4	1	10	19	1415	29782.85276
MEOW WSW5	1	11	21	1739	41625.9876
MOM1	1	5	9	649	13677.52468
MOM2	1	8	15	1092	20698.51189
MOM3	1	10.5	20	1603	33481.60477
MOM4	1	11	21	1940	60897.16852
MOM5	1	11	21	2322	99152.3473

Table F-4 Harris County, TX Grouping Based on Acreage of Inundation Extent

Table F-5 Jackson County, TX Grouping Based on Acreage of Inundation Extent

Jasper

Storm/Direction	Min. Depth (ft.)	Avg. Depth (ft.)	Max. Depth (ft.)	Population Impacts	Acres
MEOW N0	0	0	0	0	0
MEOW N1	0	0	0	0	0
MEOW N2	0	0	0	3	93
MEOW N3	1	1	1	25	145
MEOW N4	1	1	1	578	970
MEOW N5	1	1	1	786	3335
MEOW NE0	0	0	0	0	0
MEOW NE1	0	0	0	0	0
MEOW NE2	1	1	1	145	3.933836
MEOW NE3	1	2	3	145	22.371501
MEOW NE4	1	4	7	145	139.580458
MEOW NE5	1	6.5	12	578	1319.428248
MEOW NNE0	0	0	0	0	0
MEOW NNE1	0	0	0	0	0
MEOW NNE2	1	1	1	0	0.698293
MEOW NNE3	1	2	3	145	20.781305
MEOW NNE4	1	4.5	8	145	600.919197
MEOW NNE5	1	7.5	14	641	2656.242318
MEOW NNW0	0	0	0	0	0
MEOW NNW1	0	0	0	0	0
MEOW NNW2	1	1	1	0	1.253878
MEOW NNW3	1	2.5	4	145	35.552487
MEOW NNW4	1	6.5	12	578	1393.951656
MEOW NNW5	1	10.5	20	1148	5248.800457
MEOW NW0	0	0	0	0	0
MEOW NW1	0	0	0	0	0
MEOW NW2	1	1	1	0	0.278417
MEOW NW3	1	2.5	4	145	39.312548
MEOW NW4	1	7	13	641	1974.906335
MEOW NW5	1	11	21	1048	5148.377244
MEOW PAR0	0	0	0	0	0
MEOW PAR1	0	0	0	0	0
MEOW PAR2	0	0	0	0	0
MEOW PAR3	1	1.5	2	145	8.950363
MEOW PAR4	1	3	5	145	55.443848
MEOW PAR5	1	4.5	8	145	569.805547
MEOW W0	0	0	0	0	0
MEOW W1	0	0	0	0	0
MEOW W2	0	0	0	0	0
MEOW W3	1	1	1	145	6.34276
MEOW W4	1	3.5	6	145	85.799773
MEOW W5	0	0	0	578	1295.733747
MEOW WNW0	0	0	0	0	0
MEOW WNW1	0	0	0	0	0
MEOW WNW2	0	0	0	0	0
MEOW WNW3	0	0	0	145	18.30694
MEOW WNW4	0	0	0	578	1005.068616
MEOW WNW5	0	0	0	1048	4634.09763
MEOW WSW0	0	0	0	0	0
MEOW WSW1	0	0	0	0	0
MEOW WSW2	0	0	0	0	0
MEOW WSW3	0	0	0	145	10.890057
MEOW WSW4	1	3	5	145	77.193042
MEOW WSW5	0	0	0	204	912.145562
MOM1	0	0	0	0	0
MOM2	1	1	1	93	5.123907
MOM3	1	3.5	6	145	236.860338
MOM4	1	6.5	12	641	2594.401789
MOM5	1	10	19	1193	5009.415815

Table F-6 Jasper County, TX Grouping Based on Acreage of Inundation Extent

Jefferson

Storm/Direction	Min. Depth (ft.)	Avg. Depth (ft.)	Max. Depth (ft.)	Population Impacts	Acres
MEOW N0	1	5	9	98744	151371.4605
MEOW N1	1	4.5	8	98979	187860.617
MEOW N2	1	8	15	100330	245121.7414
MEOW N3	1	10.5	20	111574	327769.7969
MEOW N4	1	11	21	172098	416614.9893
MEOW N5	1	11.5	22	228268	476654.5249
MEOW NE0	1	3	5	98744	138020.1351
MEOW NE1	1	4.5	8	98968	178178.9494
MEOW NE2	1	5.5	10	100172	227824.349
MEOW NE3	1	7.5	14	105234	289260.4982
MEOW NE4	1	10.5	20	125156	364514.4098
MEOW NE5	1	11	21	173204	419815.5157
MEOW NNE0	1	3.5	6	98744	145836.2764
MEOW NNE1	1	4.5	8	98968	180809.7405
MEOW NNE2	1	6	11	100185	231326.6816
MEOW NNE3	1	8	15	108938	307220.258
MEOW NNE4	1	11	21	143997	387224.1008
MEOW NNE5	1	11	21	202455	444902.0381
MEOW NNW0	1	3.5	6	98955	155323.2438
MEOW NNW1	1	4.5	8	98983	195684.8856
MEOW NNW2	1	6	11	101364	260305.8012
MEOW NNW3	1	9	17	113055	339330.5817
MEOW NNW4	1	11	21	187421	433277.5828
MEOW NNW5	1	11	21	234247	491186.8241
MEOW NW0	1	3.5	6	98744	156345.6089
MEOW NW1	1	5	9	98968	195113.6506
MEOW NW2	1	6.5	12	101229	252814.5726
MEOW NW3	1	8.5	16	111946	331652.478
MEOW NW4	1	11	21	182543	425152.959
MEOW NW5	1	11	21	231469	481702.101
MEOW PAR0	1	3	5	98530	139296.2043
MEOW PAR1	1	4	7	98968	173197.7622
MEOW PAR2	1	6	11	99552	214401.2187
MEOW PAR3	1	7.5	14	101433	273420.5301
MEOW PAR4	1	9.5	18	113731	337412.6546
MEOW PAR5	1	11	21	143923	389067.4406
MEOW W0	1	3.5	6	98450	140141.7509
MEOW W1	1	4	7	98968	169816.3248
MEOW W2	1	5.5	10	99298	212660.6671
MEOW W3	1	7.5	14	104380	277682.0387
MEOW W4	1	9.5	18	118754	350994.6902
MEOW W5	1	11	21	172223	417325.8918
MEOW WNW0	1	4.5	8	98744	152542.1354
MEOW WNW1	1	6	11	98968	187754.5023
MEOW WNW2	1	8	15	100341	240649.1215
MEOW WNW3	1	10.5	20	109491	316162.2732
MEOW WNW4	1	11	21	165061	409800.2161
MEOW WNW5	1	11	21	226624	477394.5043
MEOW WSW0	1	3	5	98436	129415.5523
MEOW WSW1	1	4	7	98968	159196.6135
MEOW WSW2	1	5.5	10	99266	206598.7022
MEOW WSW3	1	7	13	104114	268348.0627
MEOW WSW4	1	9	17	113733	336127.8342
MEOW WSW5	1	11	21	152523	399396.1771
MOM1	1	11.5	22	103593	220614.269
MOM2	1	8.5	16	105341	286029.9407
MOM3	1	11.5	22	120321	358529.5918
MOM4	1	11.5	22	201361	447867.4418
MOM5	1	11.5	22	243282	506126.5944

Table F-7 Jefferson County, TX Grouping Based on Acreage of Inundation Extent

Liberty					
Storm/Direction	**Min. Depth (ft.)**	**Avg. Depth (ft.)**	**Max. Depth (ft.)**	**Population Impacts**	**Acres**
MEOW N0	1	1.5	2	1667	107.1191268
MEOW N1	1	2.5	4	1678	306.8711772
MEOW N2	1	2	3	2891	7462.676862
MEOW N3	1	6.5	12	4043	18142.52939
MEOW N4	1	11	21	5231	34305.03468
MEOW N5	1	11	21	7904	44917.84526
MEOW NE0	1	1.5	2	1667	48.29764195
MEOW NE1	1	1.5	2	1667	62.9288047
MEOW NE2	1	2.5	4	1667	228.21066
MEOW NE3	1	4.5	8	2891	6555.444278
MEOW NE4	1	7.5	14	3005	13684.50694
MEOW NE5	1	10	19	4451	21598.52001
MEOW NNE0	1	2	3	1667	104.8160707
MEOW NNE1	1	2.5	4	1667	208.7976706
MEOW NNE2	1	3.5	6	2489	6071.993879
MEOW NNE3	1	6.5	12	2994	12252.27315
MEOW NNE4	1	9.5	18	4594	23146.08421
MEOW NNE5	1	11	21	5416	33450.41858
MEOW NNW0	1	2	3	1667	94.92744486
MEOW NNW1	1	3	5	2319	644.0324987
MEOW NNW2	1	5	9	2942	9567.876666
MEOW NNW3	1	8	15	4333	21759.83544
MEOW NNW4	1	11	21	5836	39239.88711
MEOW NNW5	1	11	21	11999	54669.19979
MEOW NW0	1	2	3	1667	81.94156428
MEOW NW1	1	2.5	4	1678	383.4634982
MEOW NW2	1	5	9	2942	9393.782733
MEOW NW3	1	8	15	4333	20848.5078
MEOW NW4	1	11	21	5851	38682.98638
MEOW NW5	1	11	21	11252	52303.21686
MEOW PAR0	1	2	3	1667	69.9112126
MEOW PAR1	1	2	3	1667	109.2268953
MEOW PAR2	1	2	3	1667	287.7992261
MEOW PAR3	1	4.5	8	2942	8140.692011
MEOW PAR4	1	7.5	14	3005	13201.25869
MEOW PAR5	1	9.5	18	4382	20862.04507
MEOW W0	1	1.5	2	1667	34.37611589
MEOW W1	1	2	3	1667	95.98679431
MEOW W2	1	3	5	2329	2685.177092
MEOW W3	1	5.5	10	2942	10673.34313
MEOW W4	1	8.5	16	4190	20065.80907
MEOW W5	1	11	21	5026	28034.36387
MEOW WNW0	1	1.5	2	1667	50.56231523
MEOW WNW1	1	1.5	2	1667	253.1304726
MEOW WNW2	1	1.5	2	2942	8393.188125
MEOW WNW3	1	6	11	3653	16298.24911
MEOW WNW4	1	11	21	5218	31837.77804
MEOW WNW5	1	11	21	7706	43414.99279
MEOW WSW0	1	1.5	2	1667	29.27688095
MEOW WSW1	1	1.5	2	1667	45.1499923
MEOW WSW2	1	2.5	4	1667	300.9199635
MEOW WSW3	1	3	5	2942	9364.290932
MEOW WSW4	1	7.5	14	4010	17105.2725
MEOW WSW5	1	9	17	4636	24035.25655
MOM1	1	3.5	6	2402	3197.196554
MOM2	1	5.5	10	2964	8376.377795
MOM3	1	9.5	18	4394	20601.34193
MOM4	1	11	21	8961	40071.03128
MOM5	1	11	21	14536	52958.21433

Table F-8 Liberty County, TX Grouping Based on Acreage of Inundation Extent

Matagorda					
Storm/Direction	**Min. Depth (ft.)**	**Avg. Depth (ft.)**	**Max. Depth (ft.)**	**Population Impacts**	**Acres**
MEOW N0	1	5	9	3130	66966.72682
MEOW N1	1	4.5	8	3662	94143.16175
MEOW N2	1	6	11	4653	134434.3183
MEOW N3	1	8	15	8025	193462.5298
MEOW N4	1	10.5	20	9374	259324.0782
MEOW N5	1	11.5	22	9720	303547.9284
MEOW NE0	1	3	5	2792	54828.73401
MEOW NE1	1	3.5	6	2930	73985.27281
MEOW NE2	1	4.5	8	3248	100263.8797
MEOW NE3	1	6	11	3668	135927.2142
MEOW NE4	1	8.5	16	4665	182103.9603
MEOW NE5	1	9.5	18	5624	215039.1688
MEOW NNE0	1	3	5	2998	60682.58933
MEOW NNE1	1	4	7	3329	86765.81023
MEOW NNE2	1	5	9	3926	119133.7704
MEOW NNE3	1	7	13	5210	167312.6407
MEOW NNE4	1	9.5	18	7768	225499.0719
MEOW NNE5	1	11	21	9145	265019.7092
MEOW NNW0	1	3	5	3169	71637.24701
MEOW NNW1	1	4.5	8	3735	102086.441
MEOW NNW2	1	6	11	5074	146387.5355
MEOW NNW3	1	8	15	8441	210223.5159
MEOW NNW4	1	10.5	20	9459	276600.8145
MEOW NNW5	1	11	21	9962	323550.8759
MEOW NW0	1	3.5	6	3202	75985.8147
MEOW NW1	1	4.5	8	3745	107959.7486
MEOW NW2	1	6.5	12	5243	158152.2647
MEOW NW3	1	8.5	16	8811	223661.9642
MEOW NW4	1	11	21	9564	289465.7052
MEOW NW5	1	11	21	10173	342147.7856
MEOW PAR0	1	3	5	3016	59877.9072
MEOW PAR1	1	4	7	3581	86212.34073
MEOW PAR2	1	5	9	4287	120071.8314
MEOW PAR3	1	7	13	6530	174139.0765
MEOW PAR4	1	9.5	18	9259	236756.3968
MEOW PAR5	1	11	21	9503	279421.2479
MEOW W0	1	3.5	6	3071	73913.46385
MEOW W1	1	4.5	8	3638	103736.1623
MEOW W2	1	6	11	4750	149839.2889
MEOW W3	1	8.5	16	7694	207383.4292
MEOW W4	1	11	21	9378	269410.9679
MEOW W5	1	11	21	9918	312917.8602
MEOW WNW0	1	4	7	3175	77359.5881
MEOW WNW1	1	5	9	3712	109449.0112
MEOW WNW2	1	6.5	12	5227	161488.6048
MEOW WNW3	1	9	17	8695	227295.1452
MEOW WNW4	1	11	21	9628	294031.1409
MEOW WNW5	1	11	21	10487	348012.196
MEOW WSW0	1	3	5	2919	62281.57895
MEOW WSW1	1	4	7	3147	84843.60959
MEOW WSW2	1	5	9	3757	118073.72
MEOW WSW3	1	6.5	12	4851	162744.7924
MEOW WSW4	1	9	17	8166	220628.3975
MEOW WSW5	1	11	21	9137	265695.8807
MOM1	1	11.5	22	3782	108369.0291
MOM2	1	7	13	5180	161226.8805
MOM3	1	11.5	22	8633	227224.8154
MOM4	1	11.5	22	9873	296171.3706
MOM5	1	11.5	22	10468	351158.3853

Table F-9 Matagorda County, TX Grouping Based on Acreage of Inundation Extent

Newton					
Storm/Direction	**Min. Depth (ft.)**	**Avg. Depth (ft.)**	**Max. Depth (ft.)**	**Population Impacts**	**Acres**
MEOW N0	0	0	0	0	0
MEOW N1	0	0	0	0	0
MEOW N2	0	0	0	0	0
MEOW N3	0	0	0	260	835.3490937
MEOW N4	1	2	3	912	6163.627034
MEOW N5	1	10	19	1374	10458.12264
MEOW NE0	0	0	0	0	0
MEOW NE1	0	0	0	0	0
MEOW NE2	0	0	0	0	0
MEOW NE3	1	2	3	26	6.285071305
MEOW NE4	1	7.5	14	523	3230.903507
MEOW NE5	1	10.5	20	912	7531.494536
MEOW NNE0	0	0	0	0	0
MEOW NNE1	0	0	0	0	0
MEOW NNE2	0	0	0	0	0
MEOW NNE3	1	3	5	233	313.5912198
MEOW NNE4	1	8.5	16	832	5006.029606
MEOW NNE5	1	11	21	1199	9162.626071
MEOW NNW0	0	0	0	0	0
MEOW NNW1	0	0	0	0	0
MEOW NNW2	1	1	1	26	0.139212446
MEOW NNW3	1	4	7	260	1044.879033
MEOW NNW4	1	10	19	912	6964.778125
MEOW NNW5	1	11	21	1816	14161.25287
MEOW NW0	0	0	0	0	0
MEOW NW1	0	0	0	0	0
MEOW NW2	1	1	1	26	0.139212446
MEOW NW3	1	4	7	260	1000.008753
MEOW NW4	1	10	19	912	6635.992151
MEOW NW5	1	11	21	1621	11846.50973
MEOW PAR0	0	0	0	0	0
MEOW PAR1	0	0	0	0	0
MEOW PAR2	0	0	0	0	0
MEOW PAR3	1	1	1	26	0.705845814
MEOW PAR4	1	3.5	6	233	549.5427792
MEOW PAR5	1	8	15	540	3655.632353
MEOW W0	0	0	0	0	0
MEOW W1	0	0	0	0	0
MEOW W2	0	0	0	0	0
MEOW W3	1	2	3	26	4.325086856
MEOW W4	1	5	9	346	2248.774651
MEOW W5	1	2.5	4	912	6069.392453
MEOW WNW0	0	0	0	0	0
MEOW WNW1	0	0	0	0	0
MEOW WNW2	0	0	0	0	0
MEOW WNW3	0	0	0	233	408.2482829
MEOW WNW4	1	2	3	802	5193.882922
MEOW WNW5	1	8.5	16	1236	9625.484259
MEOW WSW0	0	0	0	0	0
MEOW WSW1	0	0	0	0	0
MEOW WSW2	0	0	0	0	0
MEOW WSW3	0	0	0	26	2.397655796
MEOW WSW4	1	4.5	8	260	1266.757524
MEOW WSW5	1	2	3	733	4527.241619
MOM1	0	0	0	0	0
MOM2	0	0	0	0	0
MOM3	1	3.5	6	777	3219.988538
MOM4	1	6.5	12	1166	8179.004542
MOM5	1	9.5	18	2000	15759.98912

Table F-10 Newton County, TX Grouping Based on Acreage of Inundation Extent

Orange					
Storm/Direction	**Min. Depth (ft.)**	**Avg. Depth (ft.)**	**Max. Depth (ft.)**	**Population Impacts**	**Acres**
MEOW N0	1	2.5	4	8340	12613.32019
MEOW N1	1	3	5	10243	18121.4491
MEOW N2	1	4	7	16775	35305.40875
MEOW N3	1	7	13	41252	71584.06318
MEOW N4	1	10	19	60741	126371.8136
MEOW N5	1	11	21	80004	169287.0694
MEOW NE0	1	2.5	4	7989	10956.01164
MEOW NE1	1	3	5	8967	15908.23581
MEOW NE2	1	4	7	13456	31907.46586
MEOW NE3	1	6.5	12	32579	58411.05763
MEOW NE4	1	9	17	54477	100012.0563
MEOW NE5	1	11	21	66930	141659.1309
MEOW NNE0	1	2.5	4	8331	12872.23988
MEOW NNE1	1	3	5	9996	17852.57963
MEOW NNE2	1	4.5	8	14528	32882.85023
MEOW NNE3	1	7	13	36025	64841.46444
MEOW NNE4	1	9.5	18	57237	110794.6621
MEOW NNE5	1	11	21	72757	153248.8338
MEOW NNW0	1	2.5	4	8336	11811.94517
MEOW NNW1	1	3	5	10261	18134.33968
MEOW NNW2	1	5	9	19899	37357.48265
MEOW NNW3	1	7.5	14	46529	76564.66242
MEOW NNW4	1	10.5	20	65650	139409.9283
MEOW NNW5	1	11	21	83376	186202.8833
MEOW NW0	1	2.5	4	7989	10107.20205
MEOW NW1	1	3	5	9884	17330.77606
MEOW NW2	1	5	9	19866	36929.96999
MEOW NW3	1	7.5	14	46481	75974.82552
MEOW NW4	1	10.5	20	66027	138370.3524
MEOW NW5	1	11	21	82658	180522.4896
MEOW PAR0	1	2	3	7774	9900.877472
MEOW PAR1	1	2.5	4	8298	12462.52177
MEOW PAR2	1	2.5	4	10636	22486.85431
MEOW PAR3	1	5.5	10	21734	42337.93486
MEOW PAR4	1	8	15	49181	79320.69631
MEOW PAR5	1	10	19	55702	109564.9953
MEOW W0	1	2	3	7662	7009.769005
MEOW W1	1	2	3	7824	9326.385239
MEOW W2	1	3.5	6	10587	19915.18782
MEOW W3	1	5.5	10	25538	45363.22193
MEOW W4	1	8	15	52645	88751.78424
MEOW W5	1	9.5	18	63534	132215.4978
MEOW WNW0	1	2	3	7700	8510.75218
MEOW WNW1	1	2.5	4	8938	13879.08827
MEOW WNW2	1	4	7	14521	31310.40468
MEOW WNW3	1	6.5	12	38296	66769.58487
MEOW WNW4	1	9.5	18	59776	121956.7717
MEOW WNW5	1	11	21	80052	165949.3284
MEOW WSW0	1	2	3	7656	6306.988357
MEOW WSW1	1	2	3	7662	7988.342873
MEOW WSW2	1	3	5	10402	20904.93517
MEOW WSW3	1	4	7	21995	42229.37425
MEOW WSW4	1	7.5	14	49196	79604.56197
MEOW WSW5	1	7	13	58896	116735.7133
MOM1	1	3.5	6	14716	33196.68326
MOM2	1	5	9	34204	53124.59218
MOM3	1	8	15	58106	97283.09343
MOM4	1	11	21	75939	151986.8411
MOM5	1	11	21	84193	192523.4258

Table F-11 Orange County, TX Grouping Based on Acreage of Inundation Extent