



Coastal Bend Hurricane Evacuation Study: Evacuation Zone Development Report

Prepared by the
Texas A&M Transportation Institute
and the
Texas A&M Hazard Reduction & Recovery Center
The Texas A&M University System

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Background

This report summarizes the process to develop updated hurricane evacuation zones for the Coastal Bend Study Area (CBSA) and the outcomes of that process for each county in the Hurricane Evacuation Study (HES) area. The critical first step of the HES was evaluating and deciding whether current evacuation zones needed to be updated or modified. A major driver in that evaluation and decision was a comparison of existing zones against new hurricane surge hazard data based on the latest available (2017) storm surge modeling. Other factors shaped updates such as changes in and knowledge about local communities, including land use patterns, population growth and distribution patterns, and modifications related to local evacuation planning such as instituting or improving phased evacuation. Assessments and decisions to update evacuation zones were in consultation with and incorporating input from local emergency management and other officials and stakeholders from the eight counties—Aransas, Calhoun, Kenedy, Kleberg, Nueces, Refugio, San Patricio, and Victoria—and municipalities in the CBSA.

The updated evacuation zones that emerged from the HES process are designed to enable households and individuals to readily understand their residential locations relative to potential hurricane storm surge hazards. The zones are also designed to enhance the ability of local emergency management to both plan for and mobilize their local populations to evacuate when facing hurricane threats. The revised evacuation zones that emerged from the HES process are an important component of evacuation planning for local governments, emergency managers, businesses, and households. Additionally, the updated zones set the framework for the transportation and vulnerability analyses also conducted by the study, the results of which are presented in separate reports. This report documents the processes undertaken to develop the updated evacuation zones for Coastal Bend counties, and presents the information and data used in the development of these zones, as well as the final zones created.

This report also introduces the Coastal Bend Hurricane Evacuation Study (CBHES) *Planning Atlas*, a web-based mapping tool. The *Atlas* presents information about where hurricane storm surge might impact coastal areas, what critical and residential infrastructures might be affected, the types and locations of vulnerable populations who could be impacted, and where the updated evacuation zones are located. Data in the *Atlas*, which are discussed here and used in the development of the updated evacuation zones, and additional data layers included in the *Atlas* can be used to facilitate additional planning activities that local emergency managers, community planners, and other agencies should undertake to refine their evacuation planning. These other datasets and layers are discussed in the companion vulnerability analysis report.

Evacuation Zone Development

There are no recognized or established guidelines for the development of evacuation zones although many examples from the host of hurricane studies that have been performed can provide some guidance (i.e., Wilmot and Meduri 2005; Lindell et al. 2019). Fundamentally, the establishment of evacuation zones must be based on the best scientific modeling evidence for likely surge inundation because it has been well established that hurricane surge is the greatest immediate risk to life safety generated by hurricanes.¹

Other factors could be considered as well. Some of these include local features of the natural and built environment, transportation road networks, bridges, high population concentrations that may necessitate the development of phased evacuations, and consideration of additional hazards such as inland flooding, wind, etc. While these and other factors can be important, an additional set of critical factors, next to the inundation data, is directly related to effective emergency communication.

Specifically, evacuation zones must be readily identifiable by both the public and authorities. The public must be able to easily identify their location, particularly residential, school, and work locations, relative to evacuation zones. If zones help the public understand their hurricane risk, then emergency management should be able to use these zones to effectively plan and call for public evacuation.

Hence, both with respect to local conditions and development of effective emergency management communications, it is critical that evacuation zone development be undertaken with and driven by local community involvement. To facilitate local input, the HES project team members from the Texas Transportation Institute (TTI) and the Texas A&M Hazard Reduction & Recovery Center (HRRC), along with project partners from the Federal Emergency Management Agency (FEMA), U.S. Army Corps of Engineers (USACE), and Texas Division of Emergency Management, held a series of meetings and workshops with local officials, stakeholders, and community members to guide the development of updated evacuation zones.

Meetings and Consultation with Stakeholders

As part of the overall HES, 11 meetings were held with various stakeholder groups. These meetings included an initial kickoff meeting, a webinar meeting addressing vulnerability analyses and instruction on using the *Planning Atlas* website, and nine workshops. All of the workshops were held in communities located in Coastal Bend counties. In total, more than 80 different individuals attended these meetings, not including the project team or the partner agency personnel, representing over 45 local county and city governments and local, state, and federal agency offices or divisions.

The kickoff meeting and five subsequent workshops addressed issues related to the development of the evacuation zones, with four later workshops to present findings from other aspects of the project. Specifically, an initial kickoff meeting was held in Portland, Texas, on May 23, 2018, to address the data that would be used, identify criteria for zone development, and develop general goals and principles. Following the initial meeting, a series of workshops were held in communities throughout the Coastal Bend area: Refugio (August 29, 2018), Sinton (October 29, 2018), Robstown (October 29, 2018), Port Lavaca (November 26, 2018), Corpus Christi (November 27, 2018), Sinton (March 27,

¹ Globally, coastal surge related to tropical cyclones is the greatest immediate threat to life. If people and households fail to evacuate from surge hazard areas and surge does impact those areas, there is a high probability of death. However, in the United States, in part because of effective evacuations and the unique features of shorelines, more deaths occur from inland flooding related to hurricanes than surge (Lindell et al. 2019).

2019), Corpus Christi (September 12, 2019), Port Lavaca (November 18, 2019), and Corpus Christi (February 20, 2020). An online meeting was held on July 25, 2019, to brief local officials about the *Atlas*.

These workshops enabled the team to work very closely with local officials and agencies to make final decisions on specific boundary locations within counties, local communities, and places. When just considering the five meetings and workshops that focused primarily on evacuation zone development, 52 different individuals (not counting project staff and team leaders) attended at least one of these meetings. In total, these attendees represented 41 different organizations from Coastal Bend counties and cities, state and federal agencies that had offices within the Coastal Bend counties, and state and federal agencies located elsewhere in the state.

Data and Web-Based Geographic Information System Platform

A variety of data were gathered and integrated into a comprehensive database to facilitate the assessment of existing zones relative to new hurricane hazard data and when necessary update and generate new evacuation zone boundaries. To enhance this process, an interactive web-based geographic information system (GIS) platform called the [CBHES Planning Atlas](#) was created to assist and facilitate the development of the evacuation zones.² This report includes images taken from the *Planning Atlas*, which will remain available on Texas A&M's [Hazard Reduction & Recovery Center's website](#).

This section provides a brief description of the primary data gathered and used in the development of the new updated evacuation zones. This section also includes examples and images of how these data were used. The *CBHES Planning Atlas* includes many other data fields and data layers that can be used to enhance local evacuation and general community planning activities. These additional data are discussed in further detail in the vulnerability analysis report.

U.S. Army Corps of Engineers SLOSH-Based Storm Surge Inundation Risk Area Data

USACE has made available storm surge data for use in HESs. More specifically, USACE has collaborated with the National Oceanic and Atmospheric Administration (NOAA) to develop a process of combining NOAA's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) data with other data sources to generate storm surge inundation risk area maps. Essentially, USACE processes SLOSH modeled output for the maximum of maximums for each storm category at high tide, digital elevation data from a variety of sources, 12-digit hydrological unit data, and coastal water feature data to produce a surge risk inundation mapping layer for use in GIS mapping tools. The processing emphasizes the hydrology of the modeled coastal area, and then various smoothing and elimination processes are undertaken, yielding a final result of inundation estimates. The modeling for the CBSA was completed during the summer of 2017. Figure 1 displays an example of these data layers for the CBSA as it appears on the CBHES website developed for this project.

² In addition to the website, the team also brought the data on laptops to the meetings, and actual GIS analysis was performed during the meeting to make fine-resolution changes to evacuation zone boundaries suggested by meeting participants.

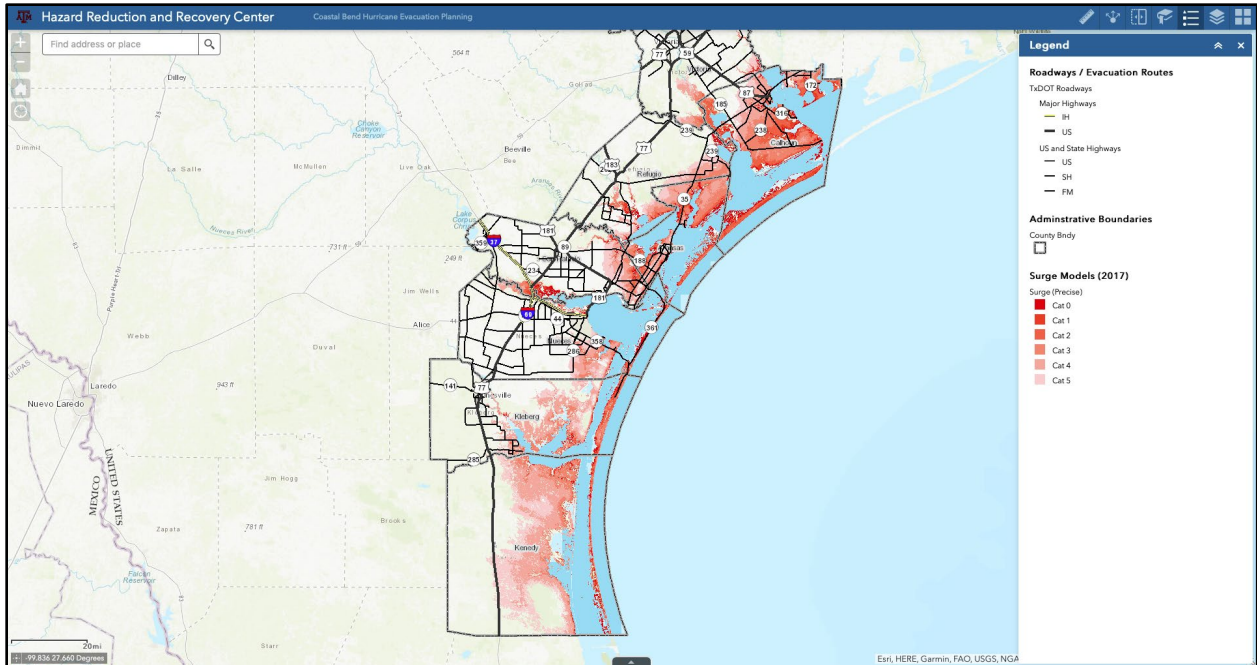


Figure 1. USACE’s SLOSH-Based Storm Surge Inundation Risk Area Data.

Generalized Surge Inundation Risk Data

As the TTI/HRRC team worked with the surge inundation data provided by USACE, it became evident that it would be difficult to make a determination of where a potential evacuation zone boundary might be placed due to the ragged edges of the inundation areas and the presence of orphaned or lost pockets of inundation that extend well beyond more continuous inundation areas.

Figure 2, for example, displays the inundation levels (blue in color) for a Category 5 storm in and around the Aransas Bay areas of San Patricio, Aransas, and Refugio Counties. This figure is taken directly from the web-based GIS platform created as part of the CBHES project. In overland areas, the degree of saturation of blue indicates the potential depth of inundation. Darker blue indicates greater depth. Moving from the shoreline inland, lighter blue indicates decreasing depth. Surge can extend well past the coast in many areas, due to relatively low elevations. In many cases, surge extends deeply inland into smaller bays, streams, canals, and other waterways throughout the area.

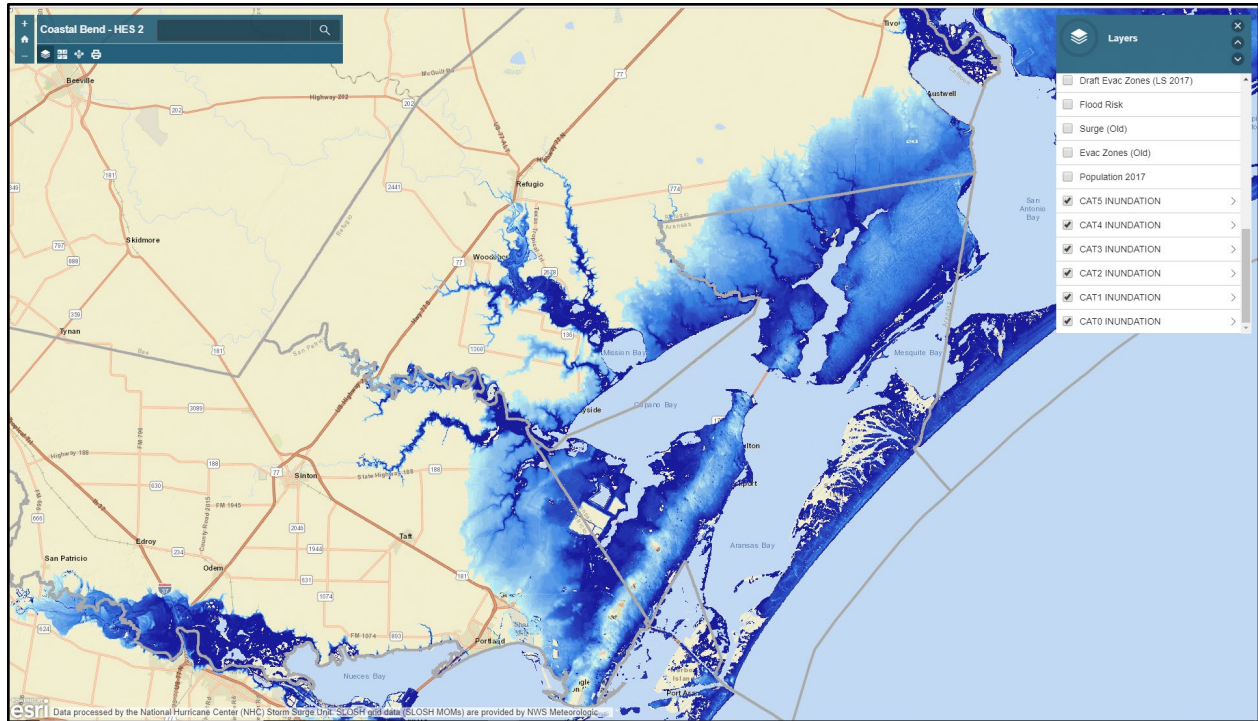


Figure 2. Category 5 USACE Inundation Data for Aransas Bay Area.

Figure 3 shows an enlarged view of the Gregory, Ingleside, and Port Aransas communities of San Patricio and Aransas Counties. Once again, inundation levels are displayed in shades of blue with darker shades representing deeper inundation. In this case, depths represent that which might be experienced for a Category 3 hurricane impacting these areas. While Figure 3 is from a GIS image, these inundation levels are based on modeled data, not actual storm data. The model represents an attempt to capture the maximum levels of water overlaying the ground given many hypothetical storms with varying forward speeds and directions for each category of storm, from tropical storms through Category 5 storms. In both cases, but particularly in Figure 3, evidence of ragged edges, pockets of no inundation, and orphaned areas of inundation completely surrounded by uninundated land are apparent.

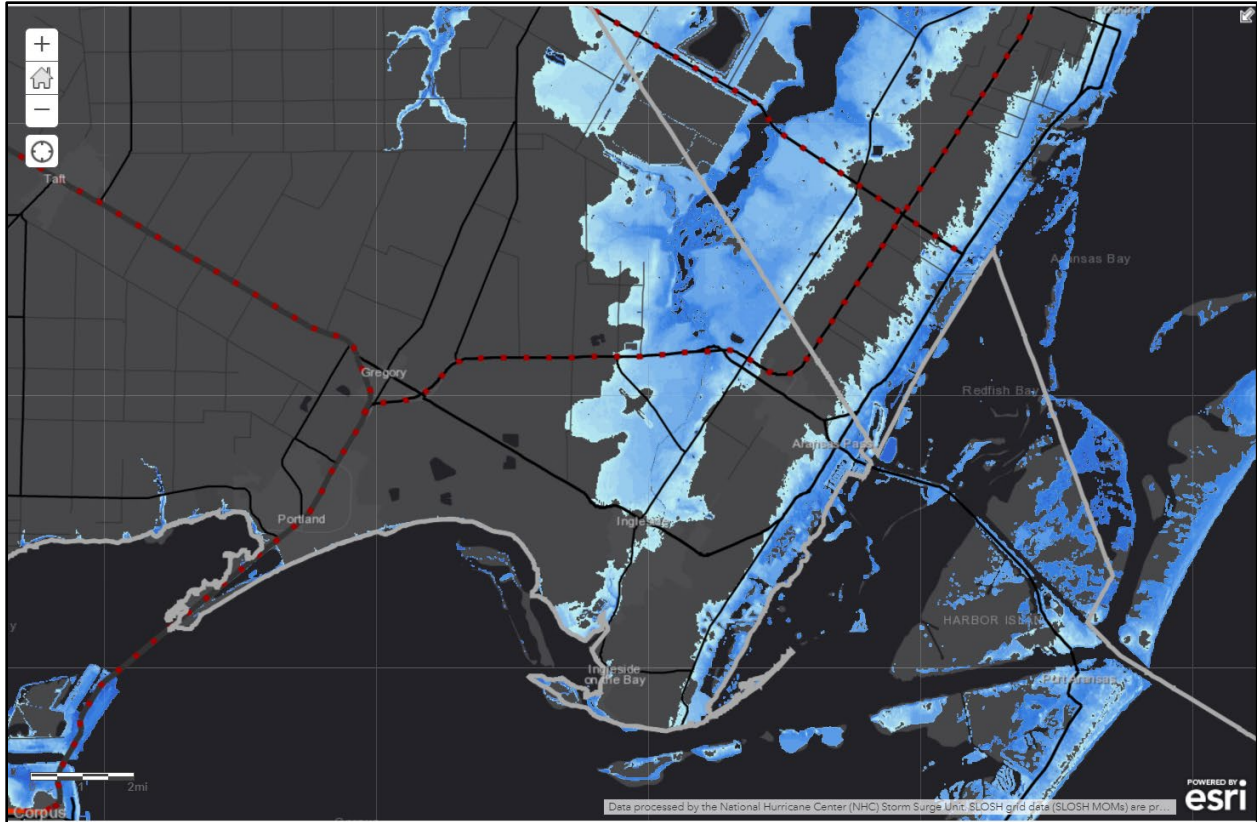


Figure 3. Category 3 USACE Inundation Data near Gregory, Ingleside, and Aransas Pass Area.

The ragged appearance of these inundation data on map images does not necessarily denote errors. These data are simply a function of combining the rather coarse SLOSH output with finer-resolution digital terrain data. In an attempt to simplify interpretation of the USACE inundation data, a generalized version of these data was created.³ Essentially, the generalized version of these data aggregates or clusters inundation areas that were relatively close to each other, adds a 100-meter buffer around these aggregated areas, and smooths the inundation contours so that they are more easily recognizable. The buffer also improves the visibility of waterways and channels that may be subject to surge according to the USACE inundation data. Each category polygon, beginning with Category 1, aggregates with lesser category areas to create a cumulative surge zone for each. For example, the Category 3 extent aggregates with Categories 2, 1, and tropical storm.

Figure 4 displays the same area as Figure 3 in and around Gregory, Ingleside, and Port Aransas with the new generalized version of the USACE inundation data. These generalized data layers aggregate areas that may not be subject to surge with those that are (based on the SLOSH and digital elevation data). These data layers have the advantage of forming smoother boundaries and making more visible streams and channels that may be subject to surge. In a very real sense, these data layers are perhaps even more conservative representations of risk, which may provide planning benefits given the importance of life safety issues.

³ First, inundation models for each category were simplified to individual binary models to indicate the extent of areas impacted by surge 1 foot or greater in depth. Next, each of these models was vectorized and buffered by 100 meters to create contiguous boundary layers. These buffered layers were smoothed by aggregating any orphaned areas within 500 meters of the main body of surge and by eliminating holes within the main body. Finally, the six layers representing storm intensity from tropical storm to category 5 were merged into one layer holding the six category extent polygons.

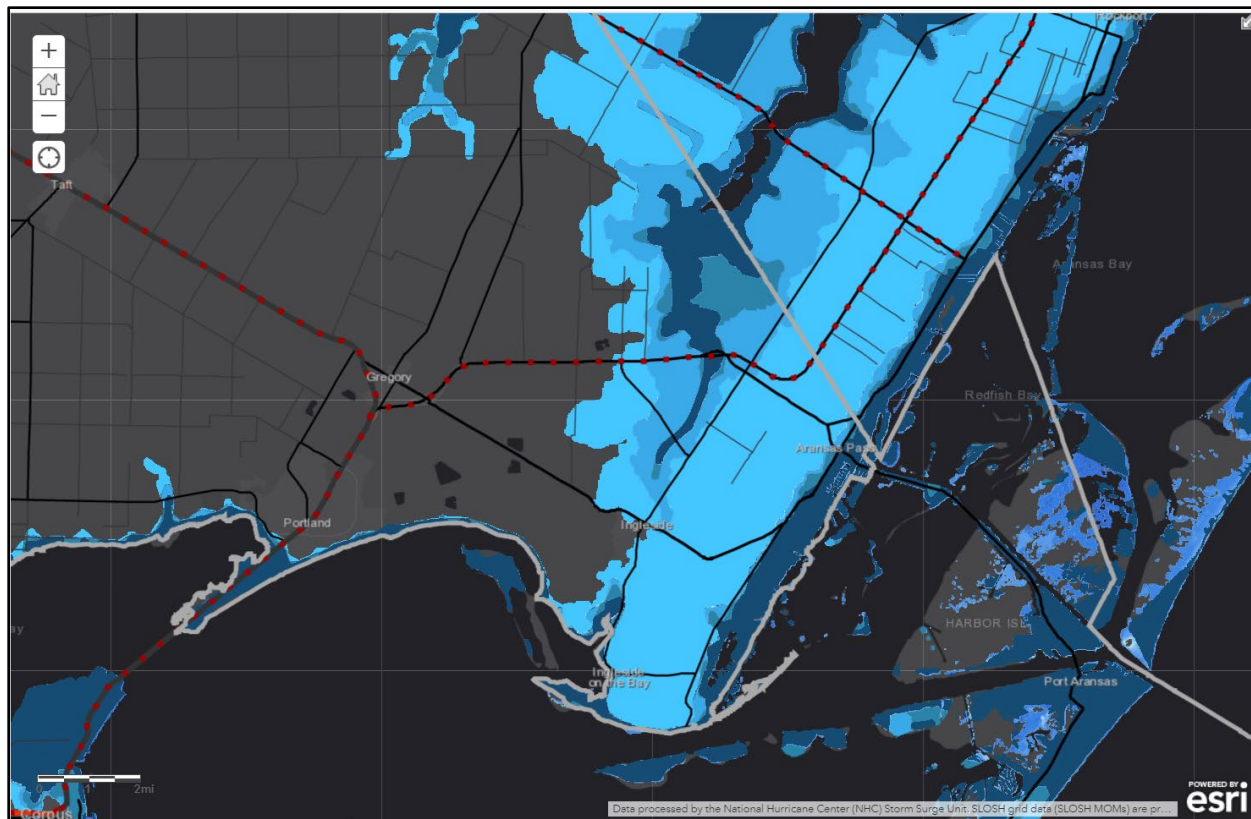


Figure 4. Generalized Category 3 USACE Inundation Data for the Same Area in Figure 3.

Additional Hazard Data

In addition to the surge inundation data, the HES team, in part as a response to local stakeholders, also gathered wind and flood hazard data and incorporated them into the integrated GIS platform. Specifically, FEMA flood zone data for the area along with high-wind-hazard data layers were also incorporated into the HES GIS website.

Historical High-Wind-Risk Hazard Data

The wind risk data (wind fields) are based on historical wind hazard modeling data created by Dr. Steven Quiring⁴ for the Texas Division of Emergency Management. Dr. Quiring's model is based on wind speed estimates for recorded historical storms that have crossed coastal Texas, including the study area. However, these data do not include Hurricane Harvey. Figure 5 displays the wind fields for just the coastal counties in and around the Coastal Bend area. The wind fields are displayed in ever darker grey shading from Category 1 through Category 5 storms (the legend on the right side of the image). The counties in the Coastal Bend area are predominantly covered by Category 2–4 wind speeds, with the higher speeds at the northern- and southern-most counties. Figure 5 also displays historical storm track data.

⁴ Dr. Quiring was with the Department of Geography at Texas A&M University in College Station when these data were generated. He is now at Ohio State University.

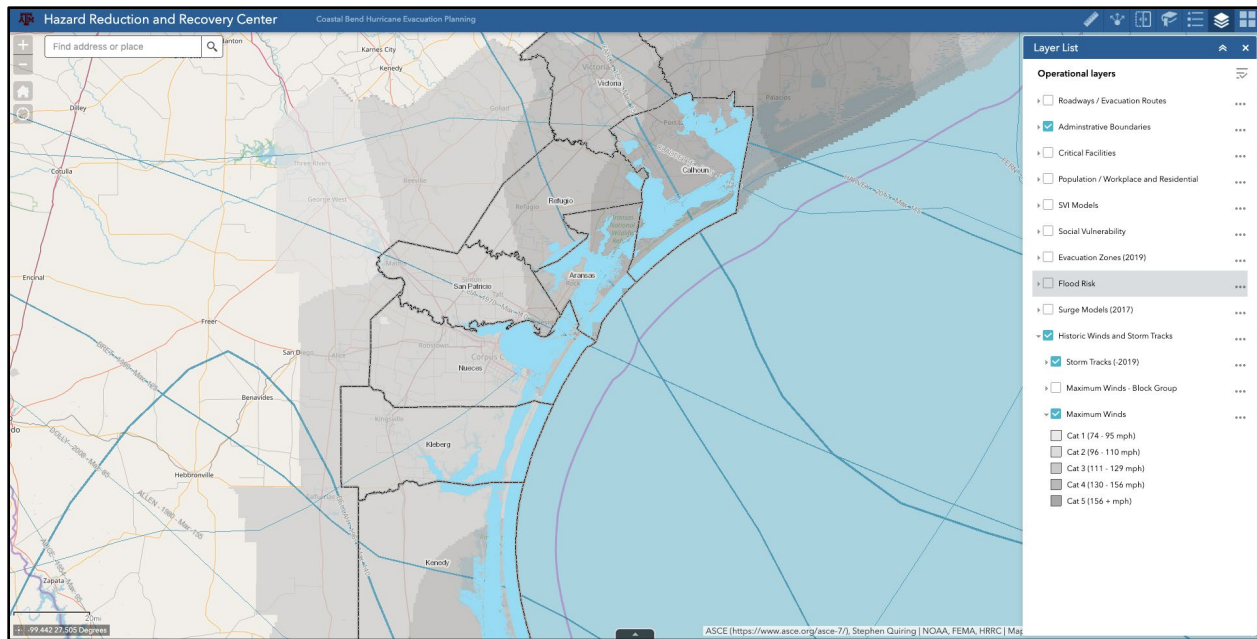


Figure 5. Dr. Quiring's Hurricane Wind Fields for the Coastal Bend Study Area.

The high-wind-hazard data are only approximate risk data and do not necessarily reflect the precise high-wind-hazard risk that an area might experience for a specific storm. Rather, the data reflect the tendencies, based on recorded historical storms, providing some indication of the potential wind risks for areas within the Coastal Bend. However, and importantly, the historical data used to generate these wind fields *did not include Hurricane Harvey*, which was a Category 4 storm when it hit the area. As a consequence, if the focus is on the most northern section of the Coastal Bend, shown in Figure 6, the area just northeast of the Coastal Bend does include a Category 5 wind field (the darkest grey shading), and the bold blue hurricane track line of Hurricane Harvey does touch that wind field area. Nevertheless, the Coastal Bend counties, according to these data, do not show historically based storm winds above a Category 4 storm. This discrepancy should clearly drive home the point that these data, as with all hazard data, are approximate and often based on relatively recent history.

Looking more closely at these high-wind-hazard data, it is quite clear that Coastal Bend counties are substantially covered by wind fields for major hurricanes (Category 3 or higher). Just as is the case with hurricane evacuation decision making, which is generally based on the possibility of at least one category higher storm surge impacting an area, the hurricane evacuation planning team recommends that all planning in the Coastal Bend should generally anticipate that experiencing Category 5 storm force winds is not only possible but has occurred in the past. This is particularly germane to structures that are inherently unsafe in even *tropical storm force winds* such as high-profile vehicles (i.e., recreational vehicles or commercial trucks) and mobile homes (manufactured housing) and trailers. The TTI/HRRRC team recommends that, regardless of location, *all residents or occupants of mobile homes, recreational vehicles, and travel trailers throughout the Coastal Bend (including those outside evacuation zones) evacuate and seek safer shelters outside evacuation zones for all tropical storms and hurricanes*. These types of homes and vehicles are not safe locations when the area is under a hurricane threat.

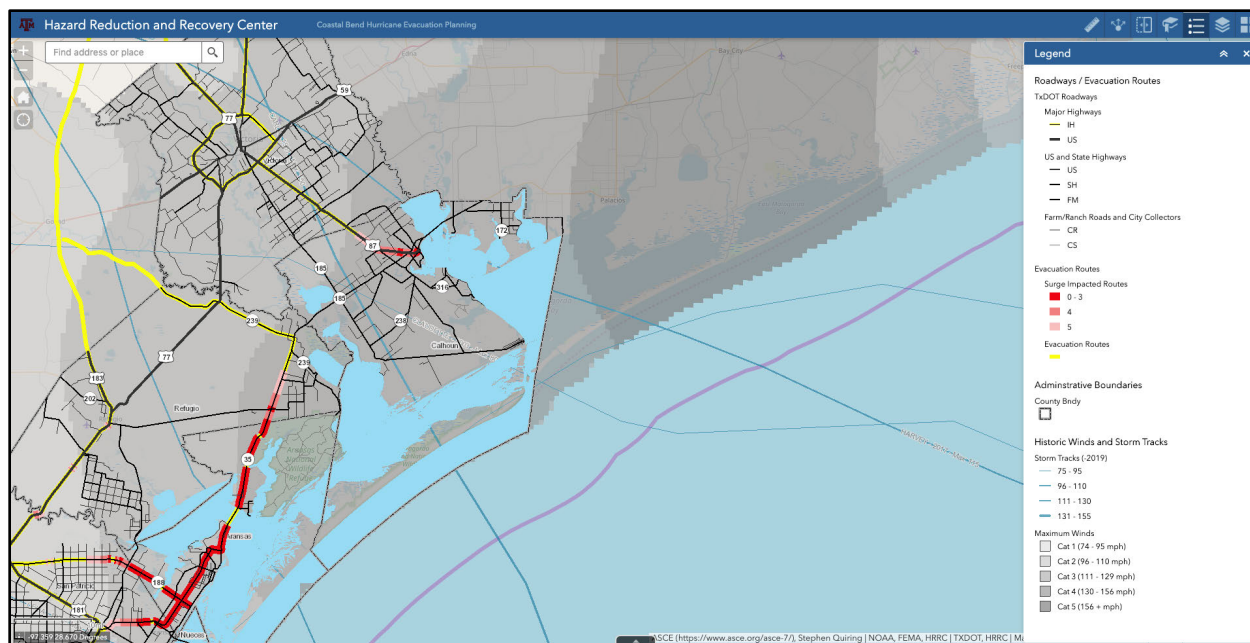


Figure 6. Northern Section of the CBSA with Dr. Quiring's Hurricane Wind Fields.

FEMA Flood Hazard Zones

Figure 7 displays an example of the 100- and 500-year FEMA flood hazard data for the areas around Refugio and extending into Aransas County. There are, of course, many types of flood hazard data included with FEMA mapping data. These data will, for example, identify likely and unlikely flood areas based on the modeling methods or analysis undertaken to identify their likelihood to flood. For the purposes of the evacuation zone planning atlas, the project team has simplified these data by collapsing them into areas that fall within either the 100- or 500-year floodplain areas. In Figure 7, the 100-year floodplain is indicated by the grey-blue shading, and the 500-year zones are in darker blue. The latter generally extend from the edges of the 100-year floodplain because floodplains expand from riverine or coastal areas in more extreme flooding events. To help visualize these areas, they are identified in the figure using arrows pointing southwest of Refugio. While these flood zones are not as pronounced as in some areas of Texas, many counties in the Coastal Bend have major problems within low-lying areas, such as in Calhoun County.

Population Density Data

The final significant data sets used for developing the new evacuation zones captured population location, dispersion, and density. A variety of data might be used to capture population density. One likely source is U.S. Census data, and the ideal population data resolution would be at their lowest areal unit, the census block level. Unfortunately, these data are only available every 10 years from the Decennial Census, and the most recent year for which block-level data are available is 2010. For key areas of the Coastal Bend, these data would not accurately reflect current population/household figures. Additionally, even if these data were current, they can be problematic when trying to capture a population's spatial distribution in more rural areas. In highly urbanized areas, such as major cities, census blocks tend to be spatially small, capturing high concentrations of people. In more rural areas, census blocks can be rather large, which means they are less likely to capture where people are actually located. This becomes a major problem when trying to determine where people are likely to be residing for evacuation zone development.

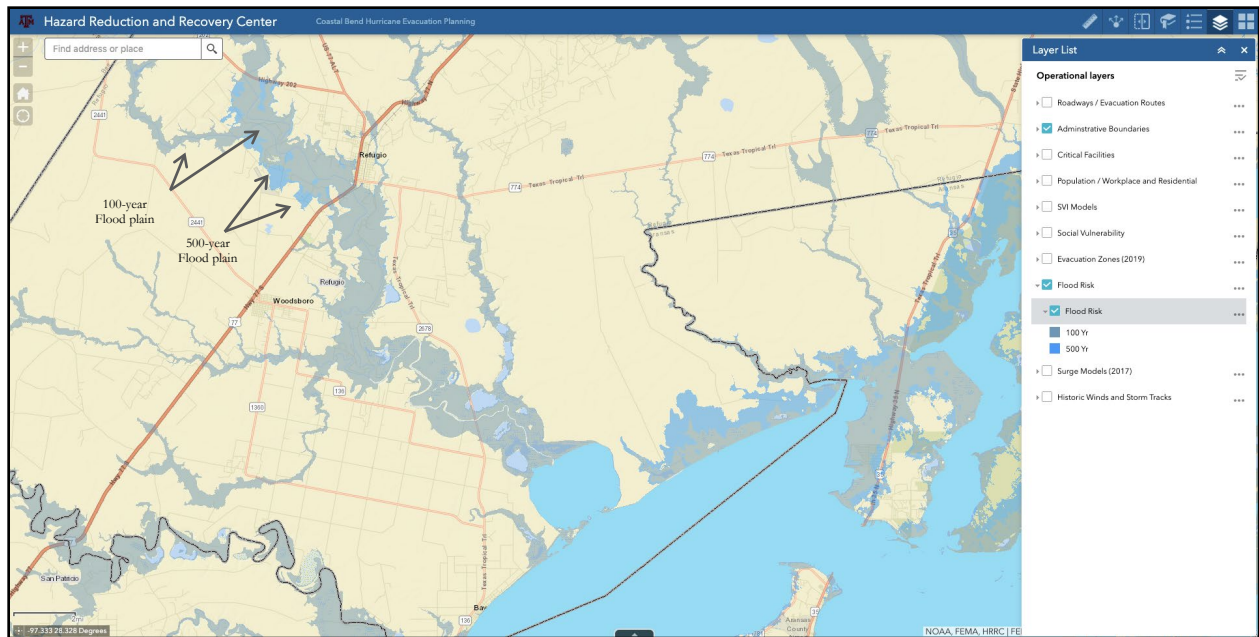


Figure 7. Examples of 100- and 500-Year FEMA Flood Zones around Refugio.

Fortunately, the U.S. Department of Energy (DOE) Oak Ridge National Laboratory produces population density data that capture an estimated number of people in very small areas and were made available for this project. These data are called *Landscan* population density data, with a spatial resolution of 90 meters by 90 meters.⁵ Figure 8 displays the *Landscan* population density data for the area in and around Corpus Christi. These data are displayed using brownish-tan shading. The darker the color, the greater the numbers of individuals that are likely to be residing in that area. What is most important is that these concentrations are captured not only in the urban areas, but also in more isolated areas outside the city, such as areas to the west of the city. These data better allowed estimating population locations in more rural areas. Although the data were used to identify evacuation zone options for this project, they are not included in the *Atlas* data layers because DOE has not released these data for general public use.

⁵ The population density for these areas is reported in the number of people per square kilometer. Even though the areas for each *Landscan* spatial unit of analysis is small, the density can be reported in terms of the number of individuals per square kilometer, square mile, or some other measure.

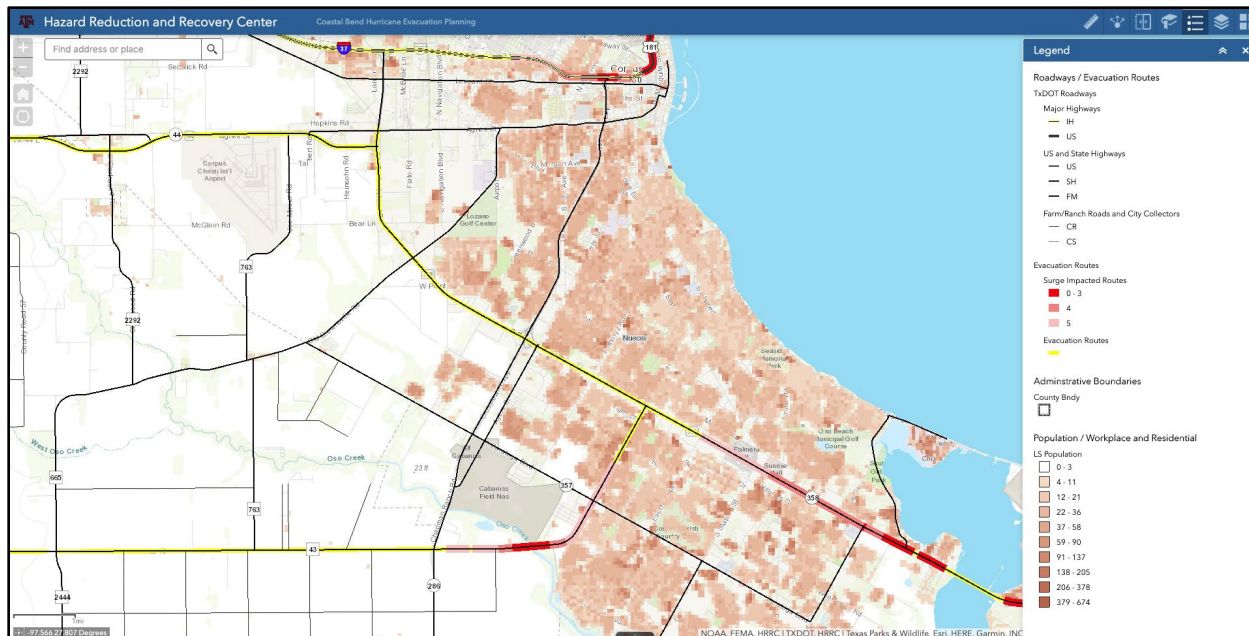


Figure 8. Example of *Landscan* Population Density Data.

In addition to the *Landscan* data, the project team also utilized another U.S. Census data product that is publicly available through the U.S. Census's Economic Research Service. These data identify employee job locations and employee residential locations at a very fine resolution, the census block level. Collectively, these data are known as Longitudinal Employer-Household Dynamics Program's Origin-Destination Employment Statistical (LODES) data. These data are available for download from a website created and maintained by the U.S. Census known as *OnTheMap* (<http://onthemap.ces.census.gov/>).

These data are not without their problems but have the potential for helping locate residential population locations that are more current than the Decennial Census. Figure 9 displays the LODES employee residential data for census block groups in and around Corpus Christi. The legend shows that the size of the block provides information on the number of employees that reside within a specific census block. Very small blue dots range from one to five employees, while larger dots represent hundreds of employees. Again, these data display the number of employees per census block, which means these data do not overcome the issue of census blocks being less spatially refined in more rural areas. Additionally, a fuzzing factor is added as the map scale becomes larger (at a finer, more zoomed-in resolution). For example, at the finest resolution (fully zoomed-in to the map), an employee's location may not actually be displayed correctly for a specific Census block but might be randomly aligned to the adjacent block.

The major advantage of these data is that they are more current than the Decennial Census data. These data are available for most states for the years 2002–2016, and the data displayed on the *CBHES Atlas* are for 2015. For purposes of evacuation zone development, the project team focused on employee residences and assumed that each employee represented a household composed of multiple individuals.

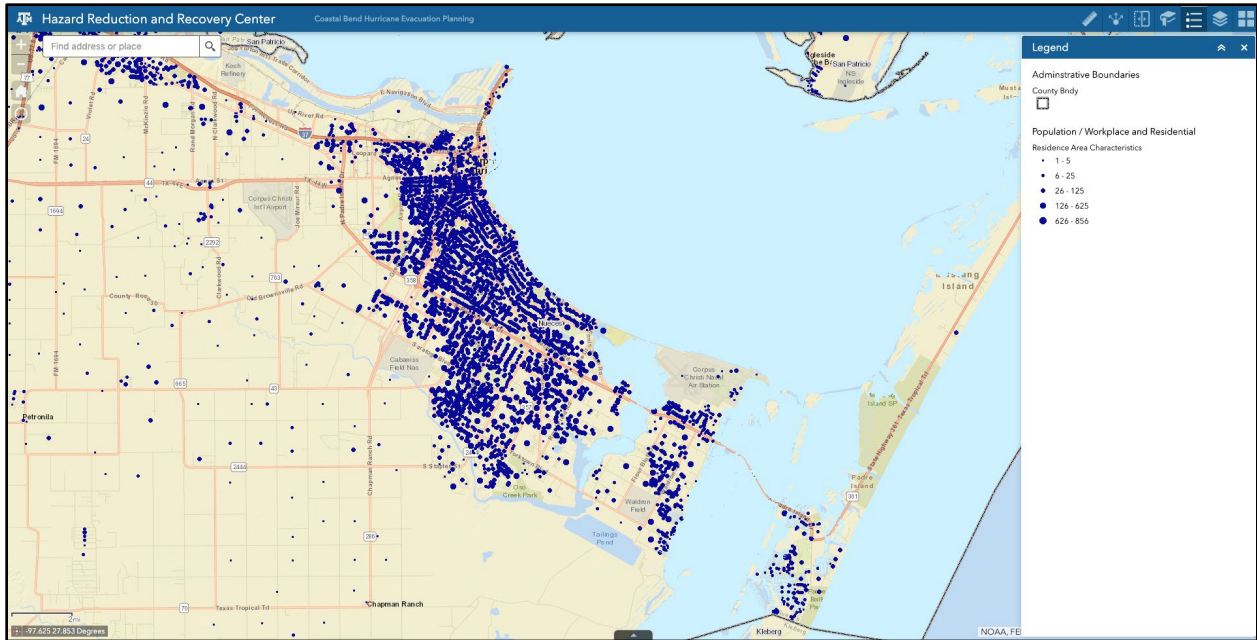


Figure 9. Example of LODES Employee Residential Density Data.

In addition to the layers, other data were employed periodically during the development of the evacuation zones. Most of these data were available via ESRI default background layers that were incorporated into the [CBHES Atlas](#) to facilitate evacuation zone development. These background layers included OpenStreetMap, Imagery layers, National Geographic, the U.S. Geological Survey National Topo Map, and the U.S. Topo Map. Finally, the project team also made available previous Hurricane Risk (Evacuation) Zone and Hurricane Surge Zone layers.

Figure 10 and Figure 11 offer examples of multiple data layers in use to help better understand potential hazard risk and help establish undated boundaries. Figure 10, for example, displays the current—and soon to be outdated—hurricane evacuation/risk zones overlaid with the new smoothed version of the USACE/NOAA surge hazard data in Kenedy and Kleberg Counties. In both counties, the new hurricane surge hazard data extend well beyond current evacuation zones. Hence, in both cases, adjustments were necessary. Figure 11 provides yet another example, only in this case multiple hazard layers—surge hazard and flood zone data—along with population *Landscan* data are displayed for the areas around Aransas Bay. These data were often combined with road network data to help determine updated evacuation zone boundaries.

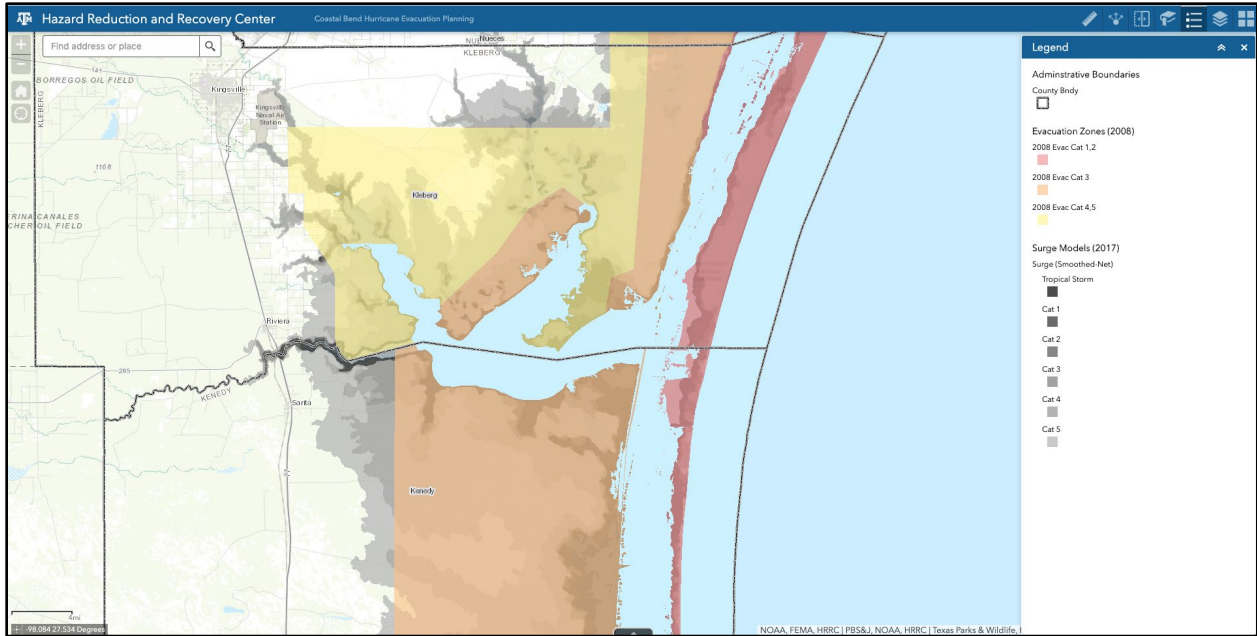


Figure 10. Old Hurricane Evacuation/Risk Zones and New Surge Data.

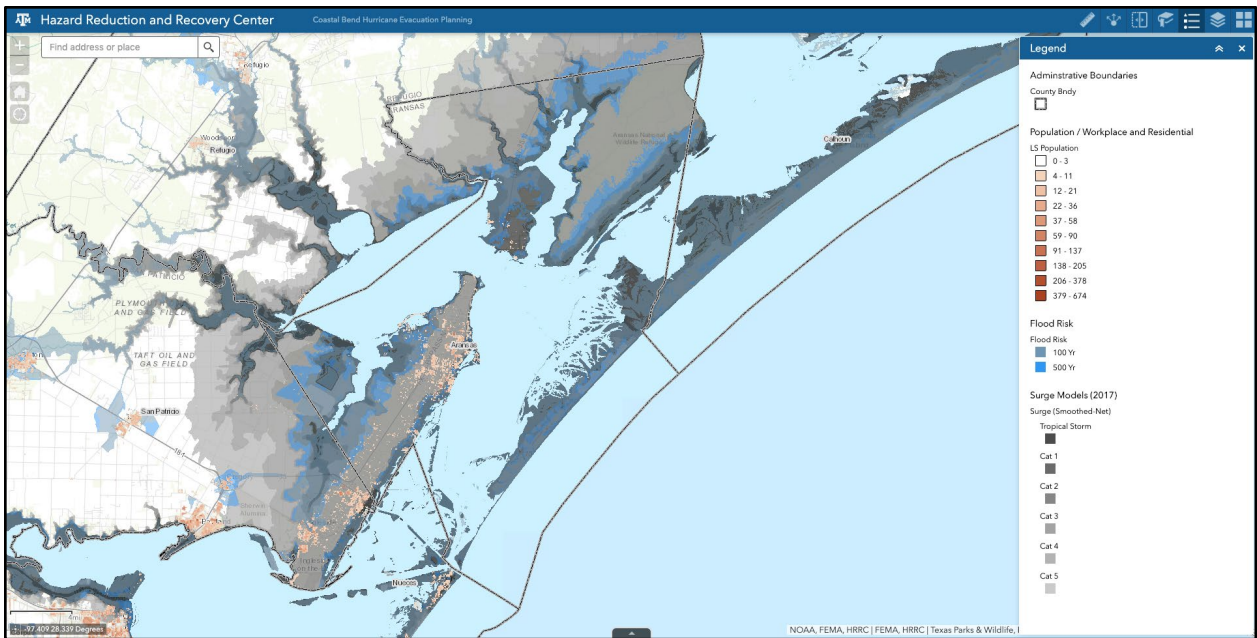


Figure 11. Example of Surge and Flood Hazard with *Landscan* Layers.

General Guidelines and Principles for Zone Development

As part of the initial workshops with local stakeholders, a set of guidelines and principles for establishing the new evacuation zones was developed after reviewing potential data inputs and general discussion. The guidelines were as follows:

1. Life safety will be of paramount concern when developing new evacuation zones.
2. Storm surge will be the key hazard risk driving evacuation zone development. Other hazard data should be considered such as the generally high flooding potential for the area and wind issues, particularly for mobile home residents. In addition to the modeled data, local knowledge of hazards will also be considered.
3. Evacuation zone development should facilitate risk/warning communication such that the zones and their boundaries are easily communicable and interpretable by the public.
4. Evacuation zones should make sense for emergency management decision making when calling for evacuations.
5. Storm categories *should not* be used as a basis for evacuation zones.⁶ Rather, there should be three zones—A, B, and C—capturing surge risks ranging from tropical storms through Category 5 hurricanes. However, some counties in the study area also desired flexibility to consider sub-areas in the high-risk zone—Zone A—that would capture highest risk areas or areas where staged evacuation could be implemented.

After work with local stakeholders and study participants to introduce the data and develop the general guidelines and principles to be followed in updating evacuation zones, the next critical tasks were incorporating the new surge modeling data and other data as necessary to evaluate and analyze how each county's current hurricane evacuation/risk zones might be modified to better capture potential surge risks. The TTI/HRRC team accomplished this by creating detailed maps of problematic areas from the most recent surge hazard data that indicate highest priority for modification of current evacuation zone boundaries. USACE surge data were supplemented by image data, topographic data/maps, population data, road/highway network data, and other data as necessary.

Alternative evacuation zone boundary configurations were generated and presented on printed maps and on the CBHES *Planning Atlas* website, which were used in discussions with local community officials and stakeholders at multiple workshops. Given the complexity of the decision making for some areas within the Coastal Bend, laptop computers were brought to workshops so that data layers could be manipulated, boundaries iteratively adjusted, analyses performed, and results projected on large screens in real time using GIS applications, until final decisions could be agreed upon. The goal in each workshop was to reach consensus on boundary decisions. In all cases, consensus was reached, and local representatives gave final approvals for updated evacuation zone boundaries.

⁶ This is because relying simply on a storm category as indicated by maximum sustained wind strength does not fully explain surge risk. For example, Hurricanes Katrina and Ike were very large storms in area and had substantial surges that caused extensive damage but made landfall as Category 3 and Category 2 hurricanes, respectively.

2020 Coastal Bend Hurricane Evacuation/Risk Zones

Figure 12 displays the new hurricane evacuation/risk zones for the Coastal Bend and the Appendix contains individual evacuation zone map sheets for each CBHES county (in alphabetical order). In general, following the guidelines established for the development of the zones, there are three zones—A, B, and C⁷. The highest risk zone, Zone A, is shaded in pink and represents areas of these counties most likely to experience coastal surge for even tropical storms and weaker hurricanes.

Calhoun and Nueces Counties have sub-zones within Zone A that local officials may use in early calls for evacuation. Calhoun County has a single higher-risk subzone, Zone A1. Nueces County has three Zone A subzones: Zones A1, A2, and A3, corresponding with maximum, highest, and higher risk levels. These even higher-risk zones within A are shaded with magenta and are discussed more completely. The second evacuation zone, Zone B, is shaded in orange, and the final zone, Zone C, is portrayed in yellow. All of these evacuation zones are at some risk of experiencing life-threatening levels of hurricane surge.⁸

It is critical that residents and visitors to the Coastal Bend understand their locations relative to these hurricane risk zones so that they can follow calls for evacuation made by local emergency directors (the lead local elected official for a jurisdiction, typically a county judge or mayor) and communicated by emergency management and emergency response officials. *To facilitate residents' and visitors' ability to recognize their residential or work locations relative to these hurricane evacuation zones, a location tool is available on the CBHES Planning Atlas* and identified in Figure 12. [CBHES Atlas website](#) users can type in an address (such as their home address) in the text box and click on the search icon to identify which hurricane evacuation zone the address is located in.

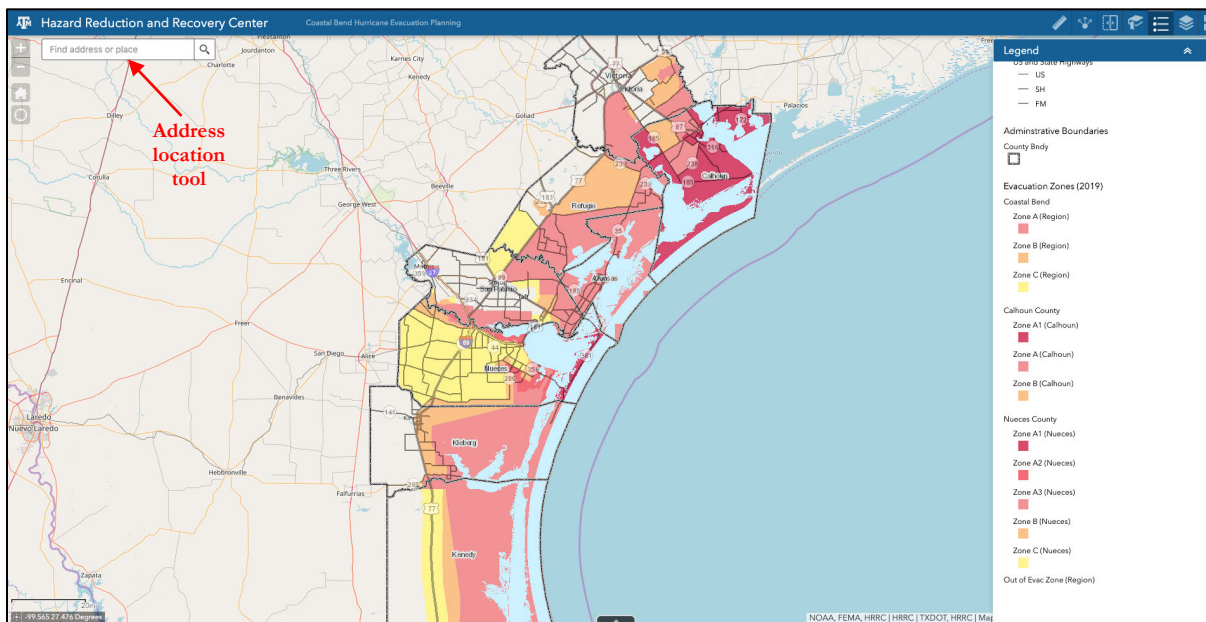


Figure 12. Updated Hurricane Evacuation/Risk Zones for the Texas Coastal Bend Area.

⁷ Evacuation zones are used instead of storm categories because simply relying on storm category as indicated by maximum sustained wind strength does not fully explain surge risk. For example, Hurricanes Katrina and Ike had substantial surges that caused extensive damage but made landfall as Category 3 and Category 2 hurricanes, respectively.

⁸ Zone C in Nueces County extends beyond surge risk areas to cover the entire county area, as desired by local officials.

This section displays the 2020 updated hurricane evacuation/risk zones for each of the Coastal Bend counties using images from the CBHES Planning Atlas, and provides a brief discussion of the risk areas. At times, the shaded layers for the hurricane evacuation/risk layers have been made partially transparent (an option available on the Atlas website) to allow road and other features to be visible. Additional mapping templates with much more vivid colors will be provided to each county for public distribution. The discussion begins with the northern-most coastal county within the Coastal Bend and continues south.

Victoria County Hurricane Evacuation/Risk Zones

Figure 13 displays the evacuation zones for Victory County, which are created by the low areas associated with the Guadalupe River’s floodplains as the river moves south out of Victoria City toward the Green and Mission Lakes and ultimately into the San Antonio Bay, and by Garcitas Creek, between Victoria and Jackson Counties, as it flows into Lavaca Bay.

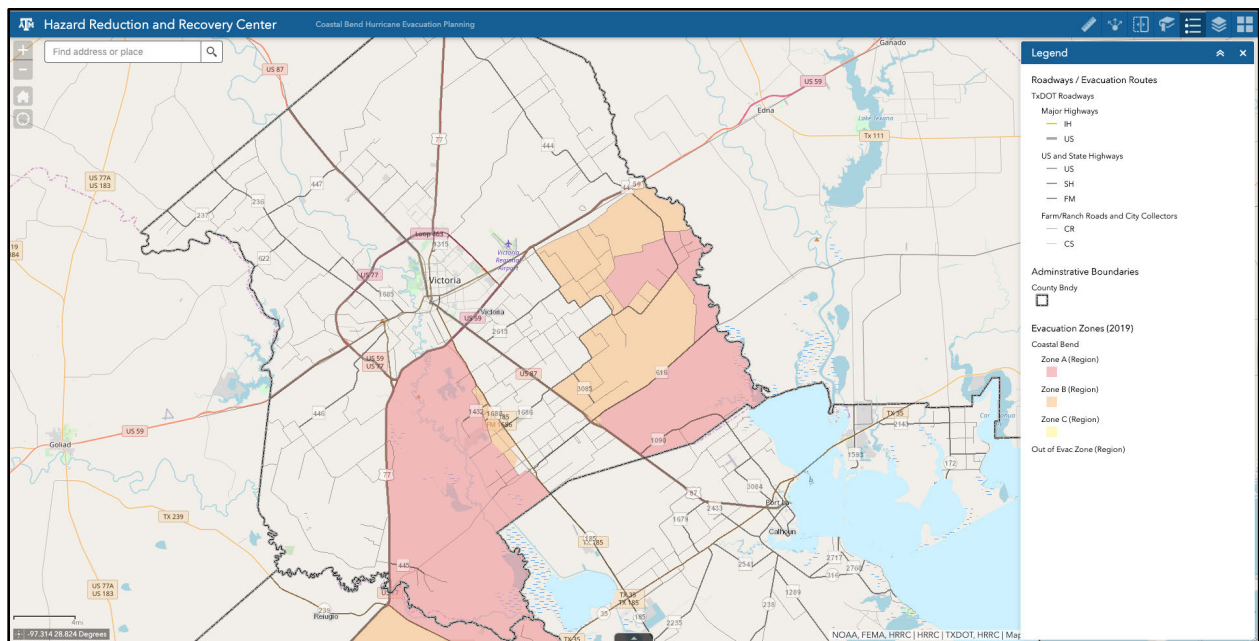


Figure 13. Hurricane Evacuation/Risk Zones for Victoria County.

Figure 14 provides a more detailed map of the hurricane evacuation/risk areas, associated with Garcitas Creek. Much of the area bordered by Garcitas Creek, south of US 59, east of US 87, and north of the Calhoun County line, is in either Zone A or B. The highest-risk area, Zone A, is the southern sections of this area, south of FM 661, but also includes a strip extending north along Garcitas Creek north of FM 616 with a significant appendage extending well into Victoria County north of FM 444. Zone B extends beyond Zone A to FM 1686 as it winds northeast from US 87 and then eventually north to US 59.

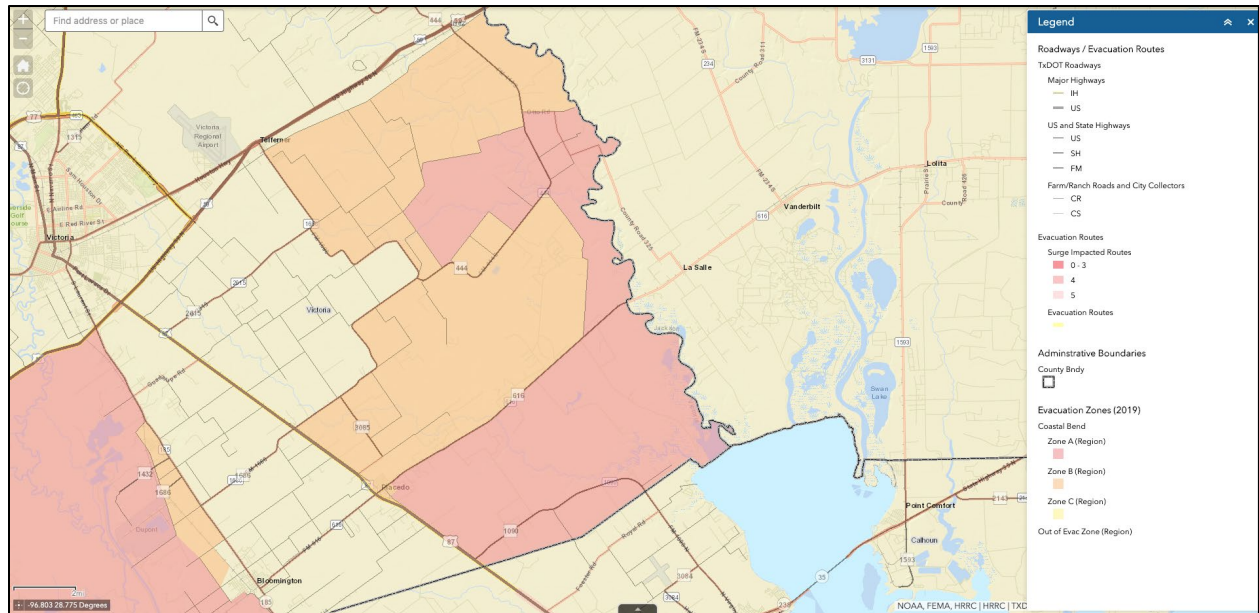


Figure 14. Evacuation Zone Boundaries for Southeastern Victoria County.

Figure 15 presents a closeup map of the southern sections of Victoria County’s hurricane evacuation/risk zones. Most of the area falling within the area south of US 59, east of US 77, west of TX 185, and north of county boundaries with Refugio and Calhoun Counties are in Zone A. A small section of this area is classified as Zone B, which falls between TX 185 and Old Bloomington Road northwest of Bloomington. While much of Bloomington’s downtown is not in either Zone A or B, some areas southwest of the rail lines do fall into Zone A. Residents of this area need to study their locations relative to these zones, perhaps using the location tool.

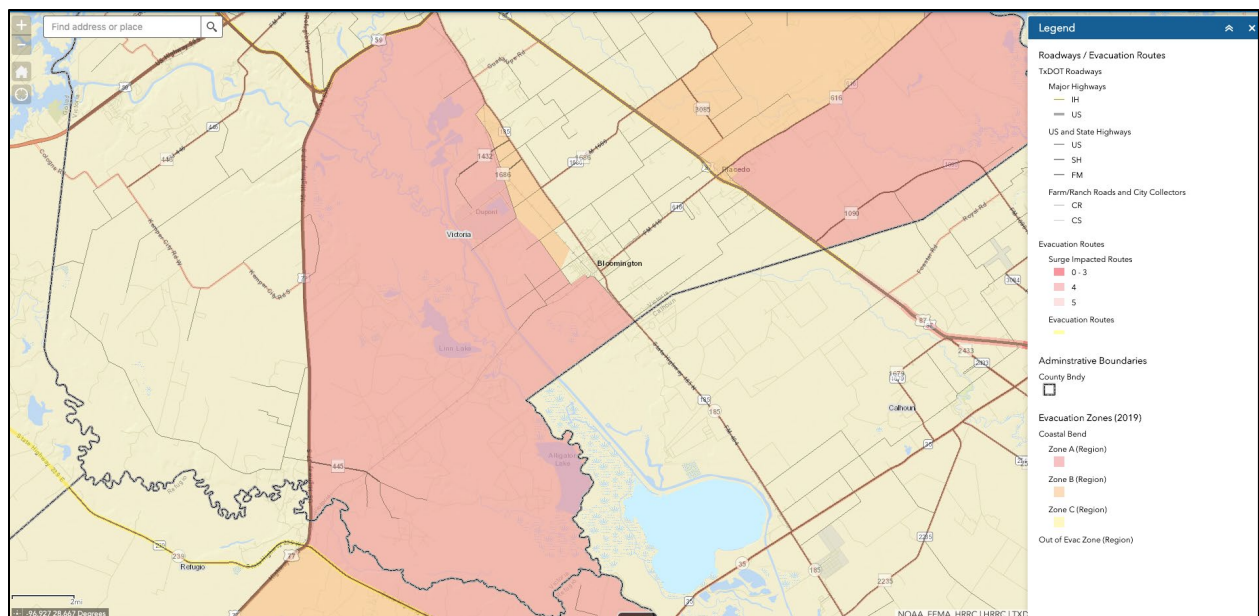


Figure 15. Evacuation Zone Boundaries for Southern Victoria County.

Calhoun County Hurricane Evacuation/Risk Zones

Figure 16 displays the evacuation zones for Calhoun County. Given that the county is essentially bounded on three sides by water and its extremely low topography, the entire county is in an evacuation zone. Indeed, given the extremely low elevation and extensive flood zones, Calhoun County has a very high-risk surge hazard area, Zone A1, indicated by the magenta shaded areas, and a high-risk area, Zone A, with lighter pink shading. The remaining part of the county is designated Zone B and is shaded in orange. As is evident in Figure 16, all Calhoun County areas adjacent to the coast and barrier islands are in the highest-risk Zone A1.

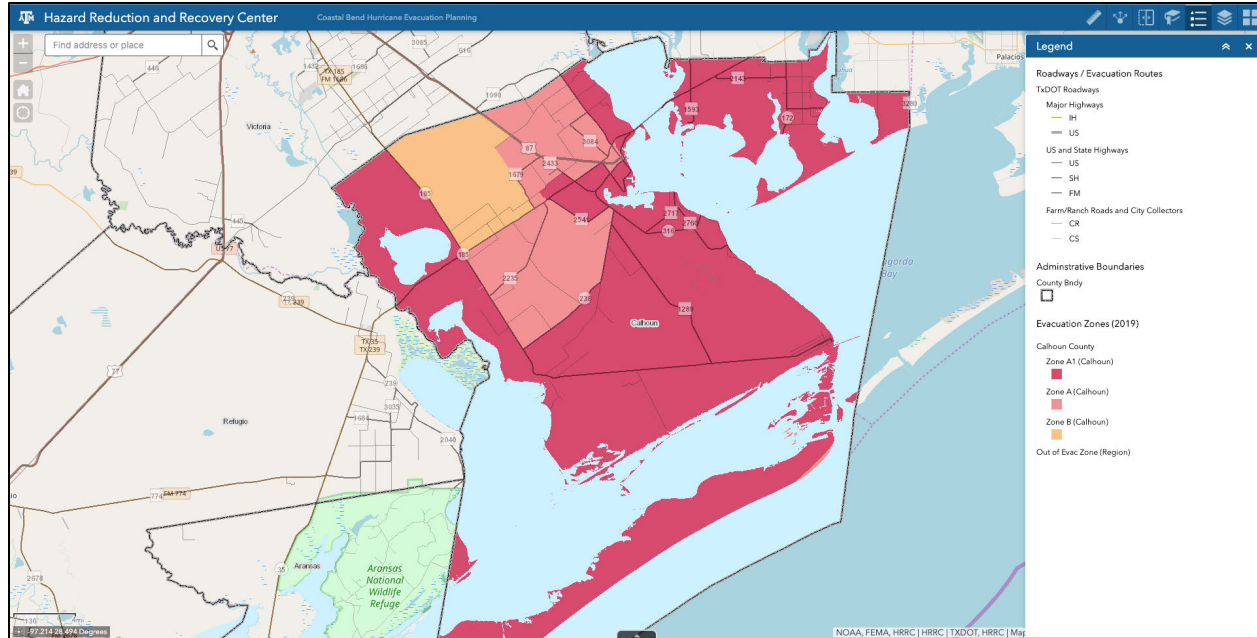


Figure 16. Hurricane Evacuation/Risk Zones for Calhoun County.

Figure 17 shows a smaller-scale map of Central Calhoun County where evacuation zone designations vary. South of TX 35, Zone A falls into the area south of TX 35, east of TX 185, north of TX 238, and west of FM 2547. A section of Zone A is north of TX 35, southwest of FM 1090, and east and south of FM 1679. However, a section of Zone A1 does extend into this area north of TX 35 as well. Zone B includes areas south of the county line with Victoria County, east of TX 185, north of TX 35, and west of FM 1097 and US 87. The entire area of Calhoun County is highly vulnerable to hurricane storm surge.

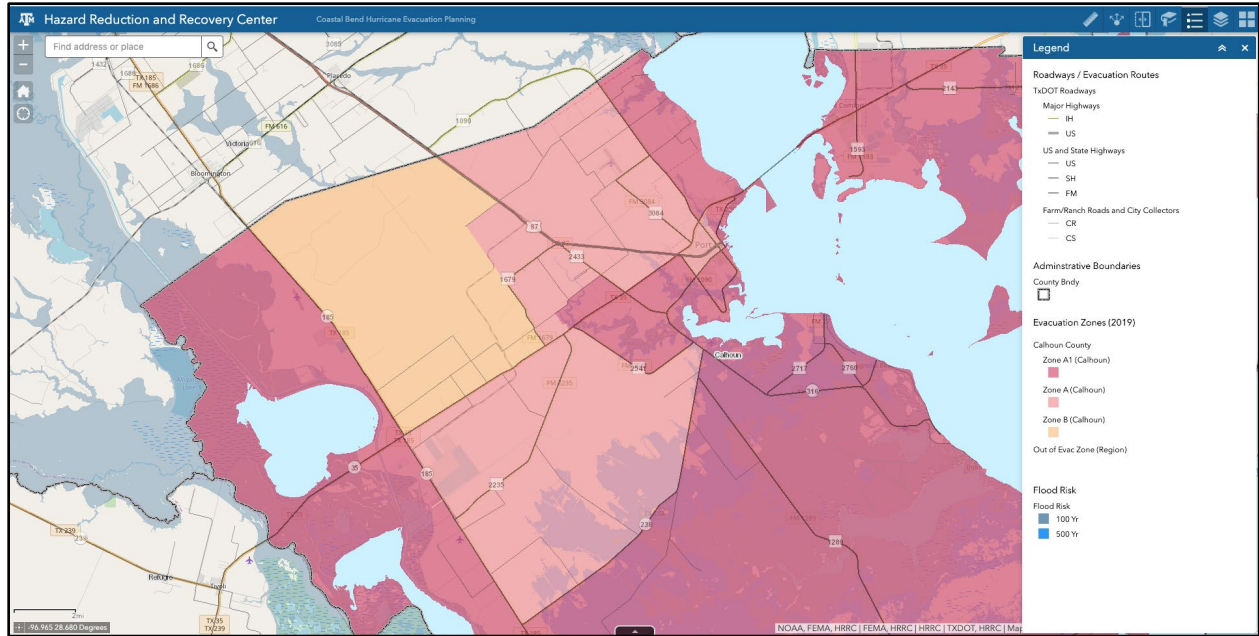


Figure 17. Hurricane Evacuation/Risk Zone Boundaries for Central Calhoun County.

Refugio County Hurricane Evacuation/Risk Zones

Figure 18 displays the evacuation zones for Refugio County, which are attributed to both the low topography within the county and its natural floodplains. Those areas bordered by coastal waters are at a higher risk of flooding, while those located further inland are less susceptible to coastal waters but still at risk from the inland water channels. Those areas at the highest risk of flooding, Zone A, are primarily located north of TX 239, east of TX 35, south of FM 774, and east/southeast of US 77. These flood zones extend out toward the waterways surrounding Refugio County. The next flood zone, Zone B, indicated in Figure 18 as the orange shaded area, is primarily enclosed to the south of TX 239, west of TX 35, and north/northwest of US 77. A small area of Zone B is located to the west of the larger Zone B area and south of TX 202 in the city of Refugio, which is vulnerable to inland flooding. The third zone, Zone C, indicated in yellow in Figure 18, is primarily located west/northwest of US 77, south/southwest of FM 2441, and north/northeast of the Aransas River and US 181 in San Patricio County.

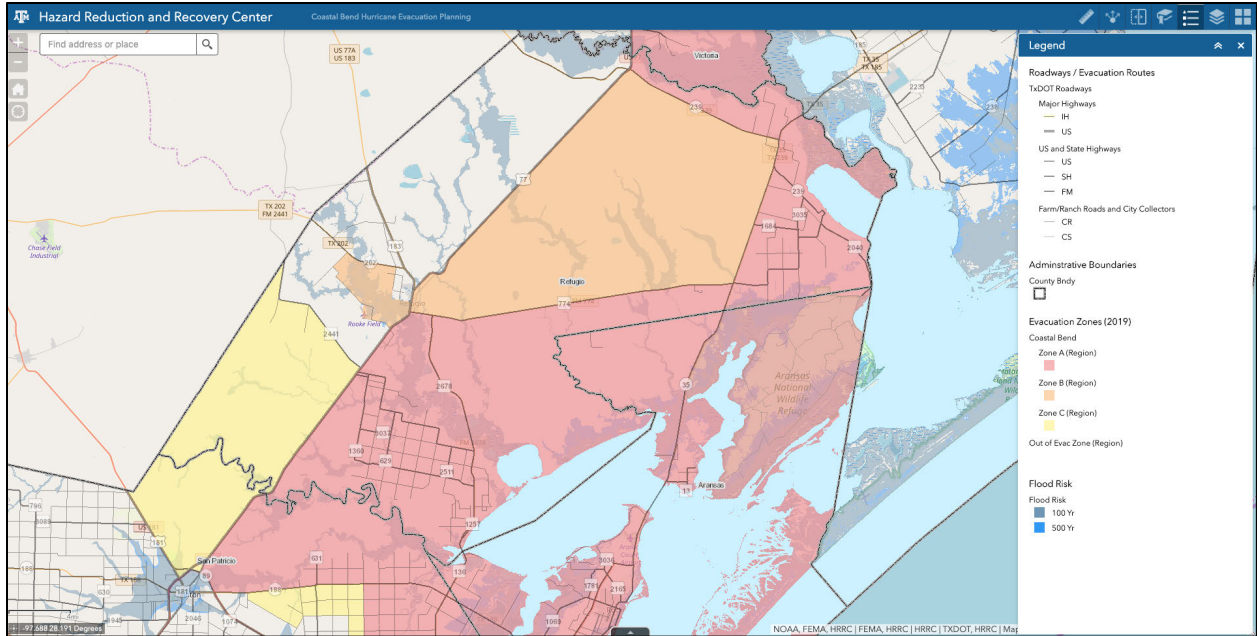


Figure 18. Hurricane Evacuation/Risk Zones Refugio County.

Aransas County Hurricane Evacuation/Risk Zones

Figure 19 shows the evacuation zones for Aransas County. Given that the county is highly exposed to coastal waters and is low in topography, the entire county is included in an evacuation zone. Due to Aransas County being primarily comprised of peninsulas, the entire county is in a high-risk surge hazard area, Zone A, indicated by the light-pink shading.

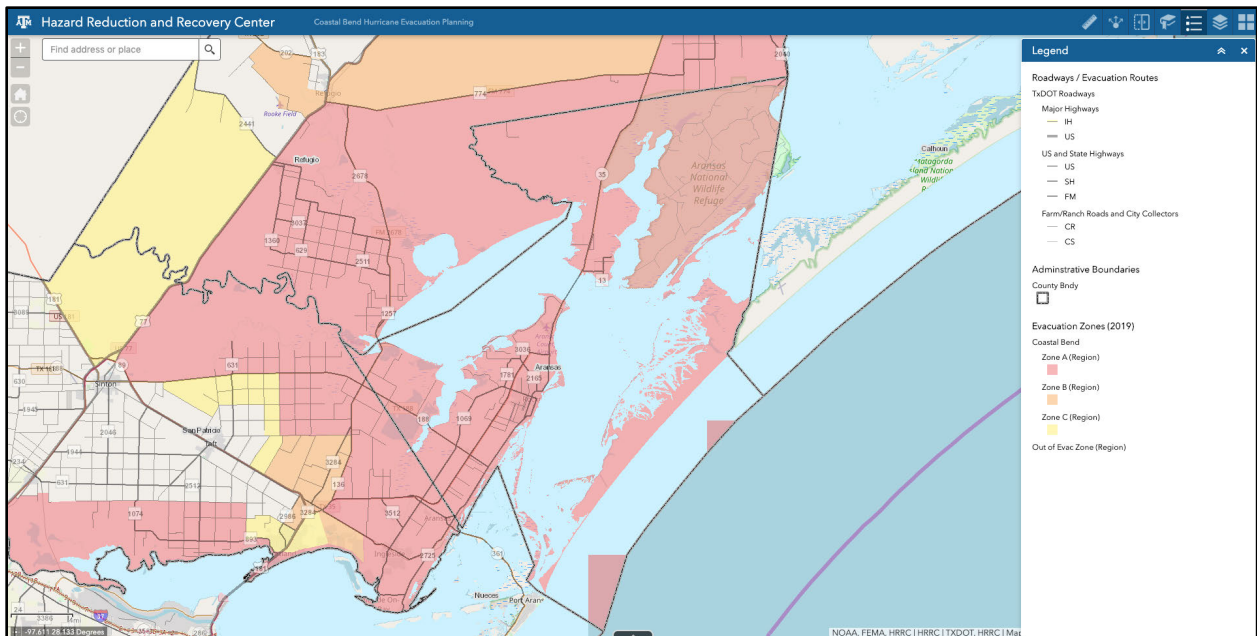


Figure 19. Hurricane Evacuation/Risk Zones for Aransas County.

San Patricio County Hurricane Evacuation/Risk Zones

Figure 20 shows the evacuation zones for San Patricio County. While the county is not entirely included in a flood zone, a large portion of the outer edge of the county is susceptible to varying levels of hurricane storm surge. Those portions closest to coastal waters have a high-risk surge hazard area, Zone A, indicated by the light-pink shading. In the north part of San Patricio County, this area is located north and east of the area bounded by US 77, north of TX 188, east to CR 81, south to CR 102, east to FM 136, south to TX 361 until the railroad tracks on the east side of the Air Liquide terminal near McCampbell Road, and due south to roughly parallel to the end of the rail line, from which point east and south in San Patricio County is all within Zone A.

In the south part of San Patricio County (Figure 21), the Zone A area extends to a few hundred yards inland near the Ingleside petrochemical industrial area at the north end of Ingleside Cove/Channel to the west along the coast to Country Club Boulevard, and then west to Moore Avenue. Zone A follows along the coast to the south of Moore Avenue/FM 893 until CR 79, north to CR 1906, and west, past the end of CR 1906 to the south of Odem to where CR 56 intersects US 77. From there, Zone A follows to the south/west of CR 201 north to CR 54 and past the end of CR 54 through farmland to the intersection of CR 62 with FM 666 in San Patricio.

Those areas set marginally more inland and/or encompassing a higher topography have a medium-risk surge hazard area, Zone B, indicated by the orange shading. These areas are spaced throughout the county with one area being located west of FM 136, another south of TX 361, and another on opposite sides of FM 666 surrounding the city of San Patricio. Areas extending farther inland beyond these two zones and/or having a higher topography have a lower-risk surge hazard area, Zone C, indicated by the yellow shading. The largest designation for Zone C within San Patricio County is located in the north of the county just south of the Bee-Refugio-San Patricio County lines between US 77 and US 181. Smaller designations of Zone C can be found throughout the county near FM 666 surrounding the city of San Patricio, south of US 181/TX 361, and south of TX 188.

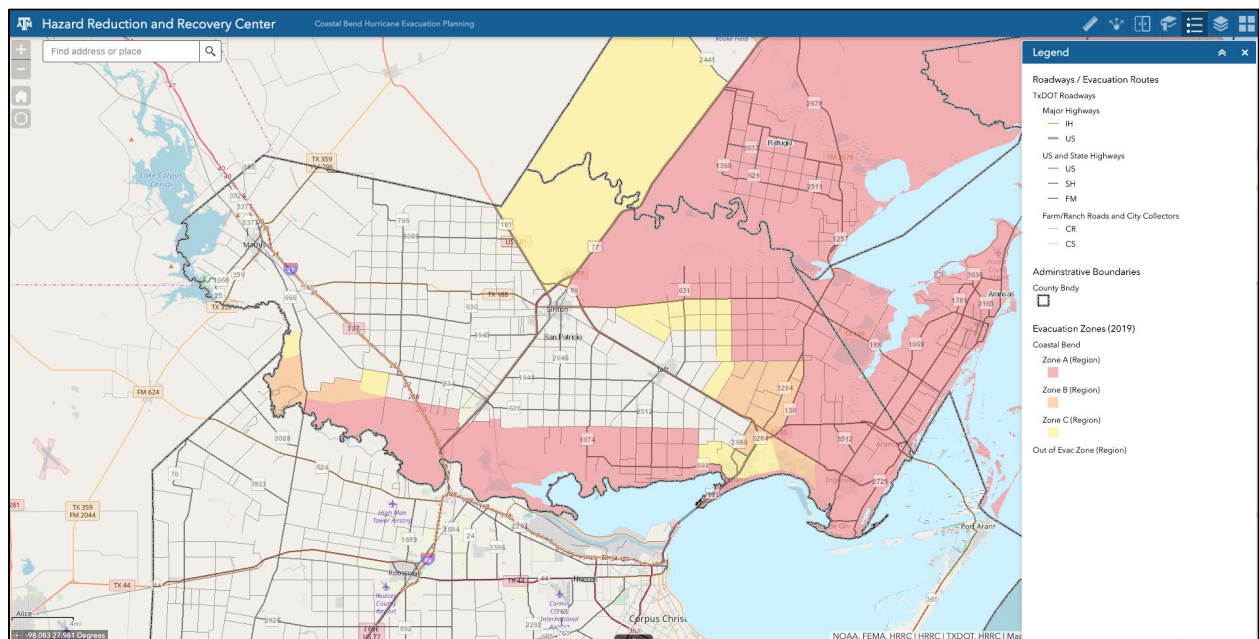


Figure 20. Hurricane Evacuation/Risk Zones for San Patricio County.

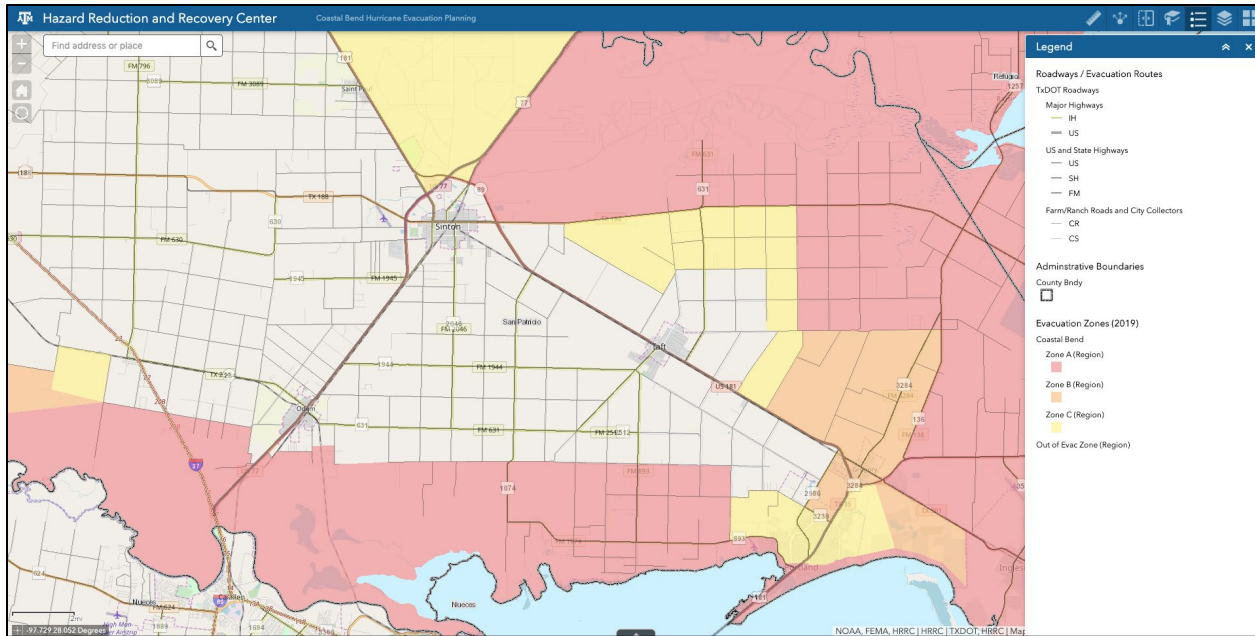


Figure 21. Evacuation Zone Boundaries around Sinton in San Patricio County.

Nueces County Hurricane Evacuation/Risk Zones

Figure 22 shows the evacuation zones for Nueces County. Figure 23, Figure 24, and Figure 25 show closeups of the Flour Bluff, Oso Creek, and downtown areas of Corpus Christi in Nueces County, respectively. Due to the county’s low coastal topography and its high exposure to coastal waters, the entire county is included in a flood zone ranging from a very high-risk surge hazard area, Zone A1, which is indicated by the magenta shaded areas, to a low-risk surge hazard area, Zone C, indicated by the yellow shaded areas. Areas included in Zones A1, A2, and A3 primarily include the barrier islands, those directly adjacent to coastal waters and those that make up the low-lying coastal zones. These flood zones extend from the north almost entirely to IH 37. These zones are most likely to be inundated by storm surge during a Category 1, 2, or 3 event.

Zone A1 is comprised by the North Padre Island and Mustang Island areas of Nueces County. Zone A2 is more complex. In the Flour Bluff areas, it includes the seaward areas bounded by Waldron Road and Flour Bluff Drive. West of Oso Bay, it includes the seaward areas generally along Redd Field Road south to Yorktown Boulevard. Along Oso Creek, the residential areas between the creek and a boundary comprised of Yorktown Blvd., west to Everhart Road, north to Saratoga Boulevard, and west to CR 35 are also in Zone A2. Sparsely populated farmland areas to the south of Oso Creek are also included in Zone A2. Along the Corpus Christi Ship Channel, Zone A2 also includes residential areas that are seaward from a boundary comprised of I-37 and Nueces Bay Boulevard, and much of the ship channel industrial area. In the Calallen Area, Zone A2 follows the Nueces River to to Up River Road, and then extends to I-37 at Renfeld Road to the west to the railroad tracks near Sharpsburg Road to Leopard Street. West of US 77, Zone A2 follows along the Nueces River at various distances inland generally within a few hundred yards.

In the Flour Bluff/Oso Creek area, Zone A3 includes all areas east of CR 43 south and east of Oso Creek that are not otherwise in Zones A1 and A2. West of Oso Bay, Zone A3 includes areas east of Airline Boulevard not otherwise in Zone A2, as well as a small residential area to the south of the intersection of Lipes Boulevard with Airline Road. There is also an area of Zone A3 toward the West end of Oso Creek bounded by CR 33 and CR 763 that includes a few residential buildings and mostly

farmland area. East of US 77 along the Corpus Christi Ship Channel, Zone A3 comprises almost all areas seaward from I-37 that are not otherwise in Zone A2. West of US 77, Zone A3 extends farther inland another several hundred yards in places from Zone A2.

In southeast Nueces County, Zone B comprises the area between the southern county boundary and CR 70, and areas east of CR 47 not otherwise in Zone A. There is also an area of Zone B at the west end of Oso Creek bounded by Old Brownville Road to the northwest side. West of Oso Bay, Zone B includes areas east of Everhart Road not otherwise included in Zone A, and then seaward toward Corpus Christi Bay north of Santa Fe Street. In the Downtown Corpus Christi area Zone B includes the area between Old Robstown Road to the west, I-37 to the north, Tanchua Street to the east, and Agnes Street to the south. East of US 77, Zone B comprises all areas between Hearn Road and I-37, while west of US 77 Zone B includes all areas north of CR 624 that are not in Zone A. Zone C consists of all areas of Nueces County that are not in Zones A or B.

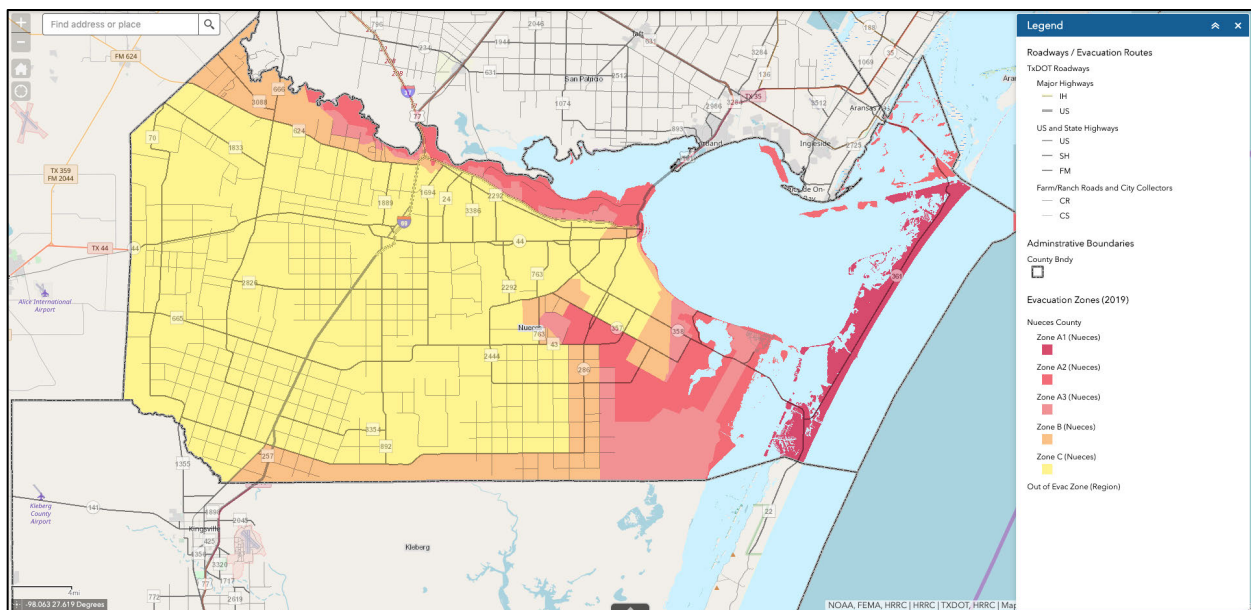


Figure 22. Hurricane Evacuation/Risk Zones for Nueces County.

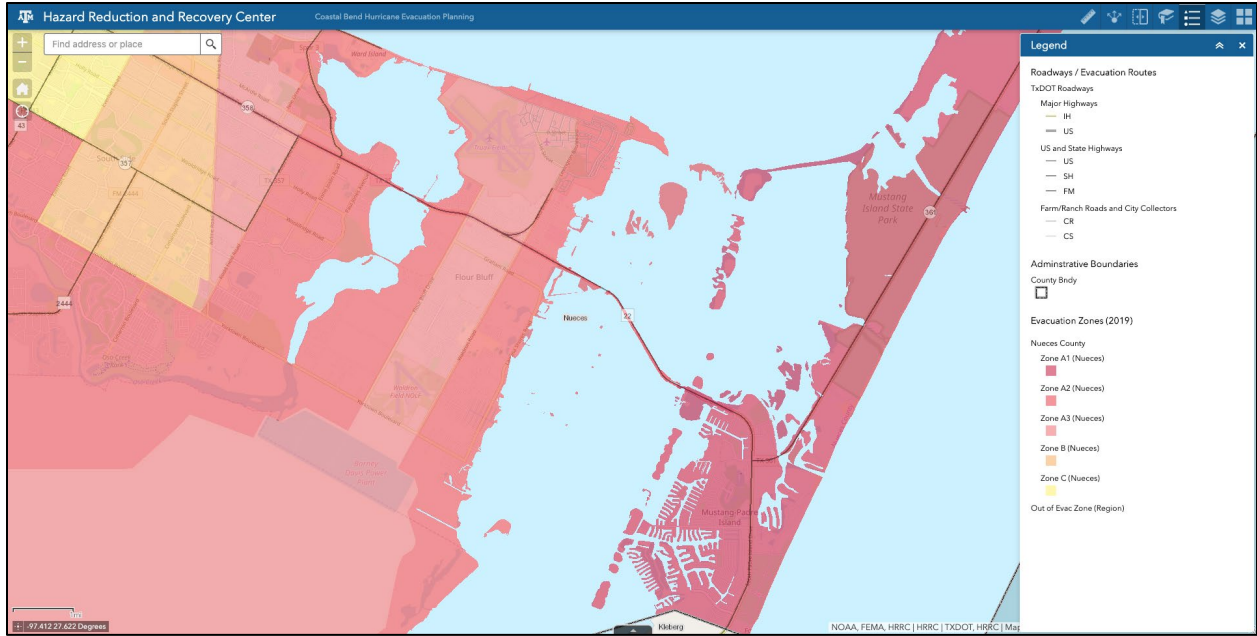


Figure 23. Flour Bluff Area in Corpus Christi in Nueces County.

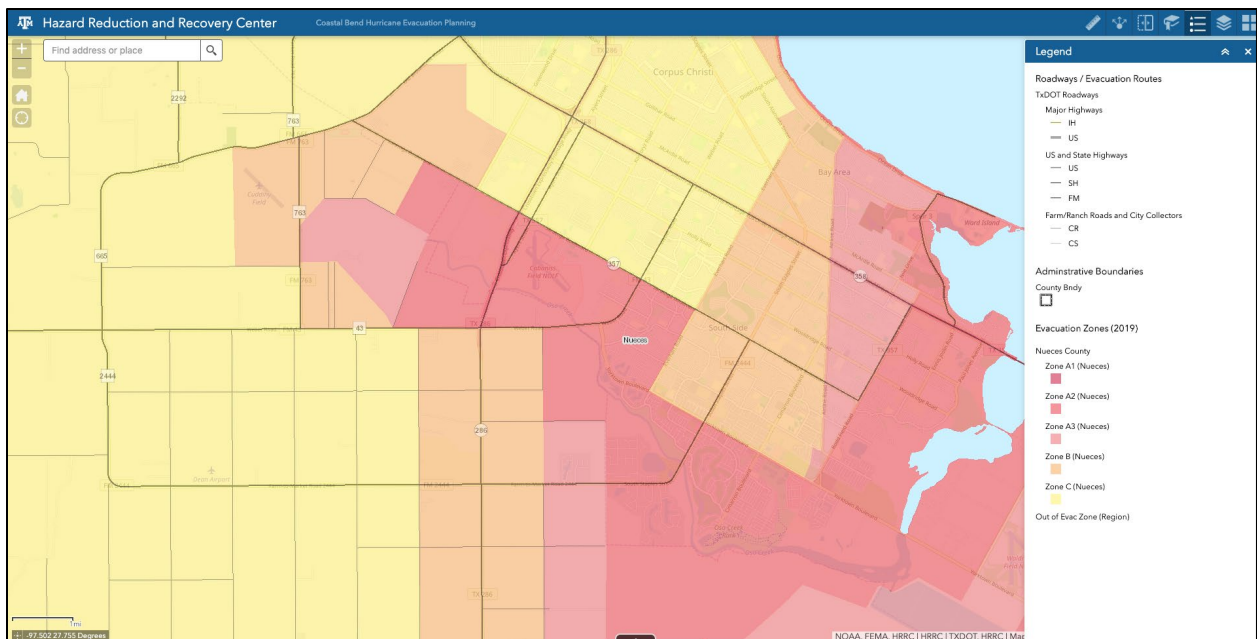


Figure 24. Oso Creek Area in Corpus Christi in Nueces County.

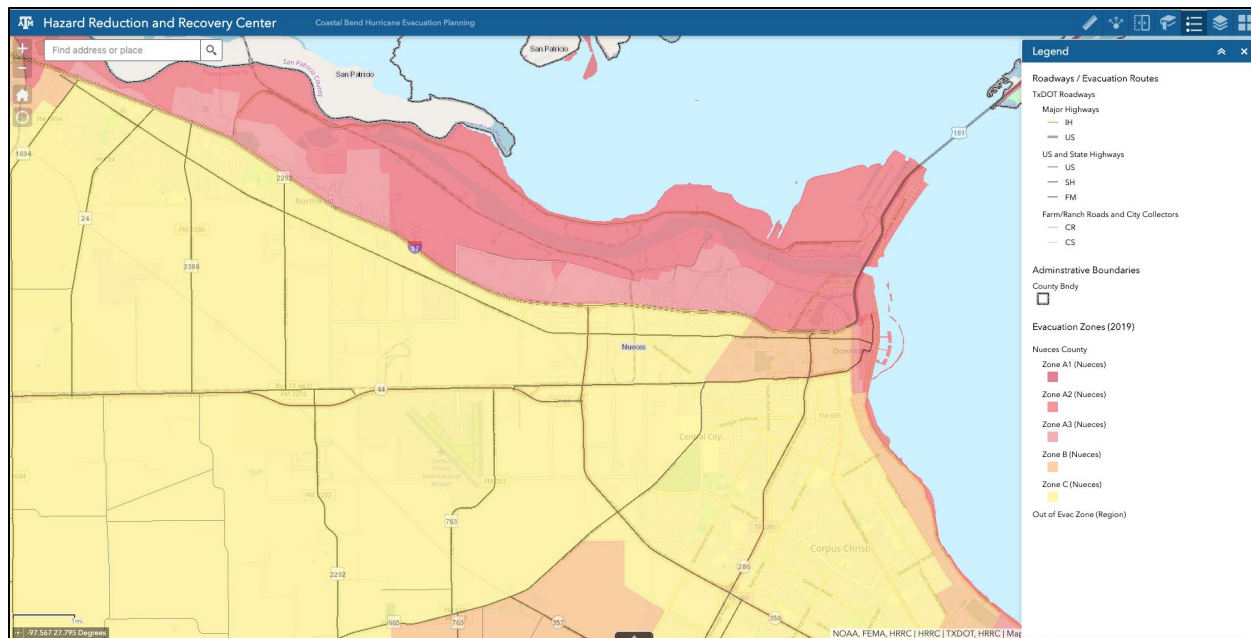


Figure 25. Downtown Corpus Christi in Nueces County.

Kleberg County Hurricane Evacuation/Risk Zones

Figure 26 shows the evacuation zones for Kleberg County, and Figure 27 shows a closeup of west Kleberg County. While the majority of the county area is sparsely populated, a large portion of it has a high-risk surge hazard area, Zone A, indicated by the light-pink shading. This is attributed to the coastal waters that cut inland as well as the county’s low topography. These areas are primarily located east of CR 1080, east of FM 772, east of FM 2510, and south of FM 771. Between these roads and US 77/US BUS running through Kingsville is Zone B. This zone designation is the medium-risk surge hazard area indicated by the orange shading. This evacuation zone primarily includes those areas most developed and those adjacent to the inland water channels. The smallest portion and one that has the lowest-risk surge hazard area, Zone C, indicated by the yellow shading, is located in the southwestern most part of the evacuation zones near the Kleberg-Kenedy County border. This small portion of Zone C is an extension of a larger designation located in Kenedy County. It lies between TX 285 and the county boundary west of US 77.

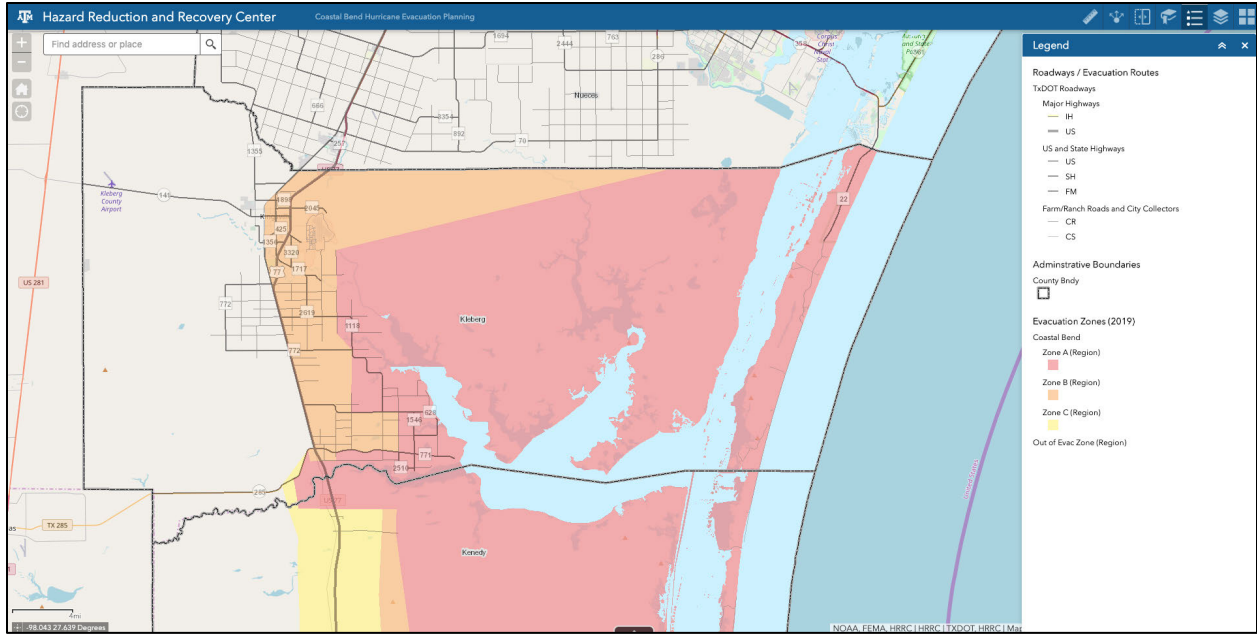


Figure 26. Hurricane Evacuation/Risk Zones for Kleberg County.

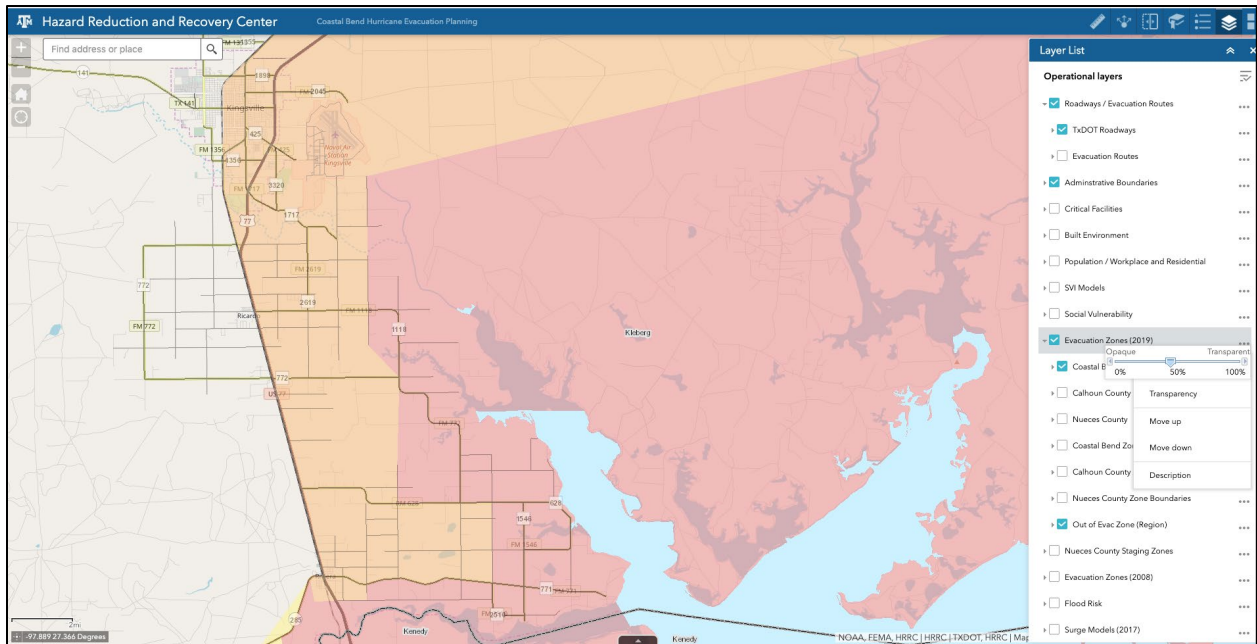


Figure 27. West Kleberg County.

Kenedy County Hurricane Evacuation/Risk Zones

Figure 28 shows the evacuation zones for Kenedy County, which are created by the natural topographic changes of this coastal county as its height increases moving inland. The coastal portion of the county has a high-risk surge hazard area, Zone A, indicated by the light-pink shading. This designation starts from the inland water channel to the north of Kenedy County, extends out toward the Laguna Madre, and covers the barrier islands extending into the Gulf of Mexico. Extending beyond this zone is Zone B, which is the medium-risk surge hazard area, indicated by the orange shading. This zoning designation is the smallest within Kenedy County and lies in between Zone A and Zone C. The farthest extent of surge zoning is Zone C, the low-risk surge hazard area indicated by the yellow shading. This flood zone designation surrounds nearly the entirety of US 77 that runs through Kenedy County.

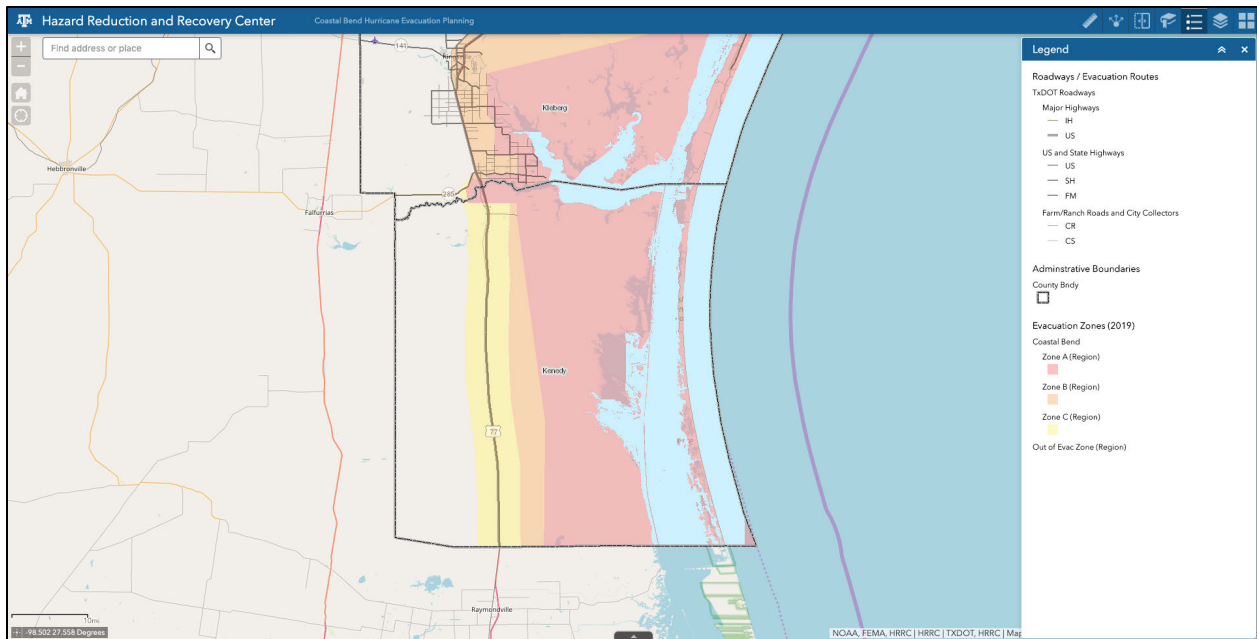


Figure 28. Hurricane Evacuation/Risk Zones for Kenedy County.

Conclusions

This project updated hurricane evacuation zone designated areas in an eight-county region of the Texas Coastal Bend region. The process incorporated the most recent available data on hurricane storm surge risk and population vulnerabilities, tools to facilitate planning decisions such as printed maps and the web-based GIS [CBHES Atlas](#), and engagement with local, state, and federal representatives through collaborative, consensus-building meetings and workshops. In all cases, consensus was reached, and local officials gave final approvals for updated evacuation zone boundaries.

Evacuation zones must accomplish two primary goals. First, they must be based on accurate data of where storm surge and wind damage are likely to occur. Second, zones must be drawn in a way that is readily understood by both the public and local authorities. It is critical that the local population be able to easily and readily identify their residential location relative to evacuation zones.

The project team assembled data from a variety of official sources and processed the data to be more comprehensible and interpretable. Using the [CBHES Atlas](#), the team worked with over 80 stakeholders and officials representing over 40 local, state, and federal organizations, governments, and agencies to visualize threatened areas to identify three primary evacuation zones that were understandable to both residents and local authorities. These zones also form the basis for modeling different storm evacuation clearance time scenarios in the subsequent traffic study and vulnerability analysis reports undertaken by the TTI/HRRC team, documented separately.

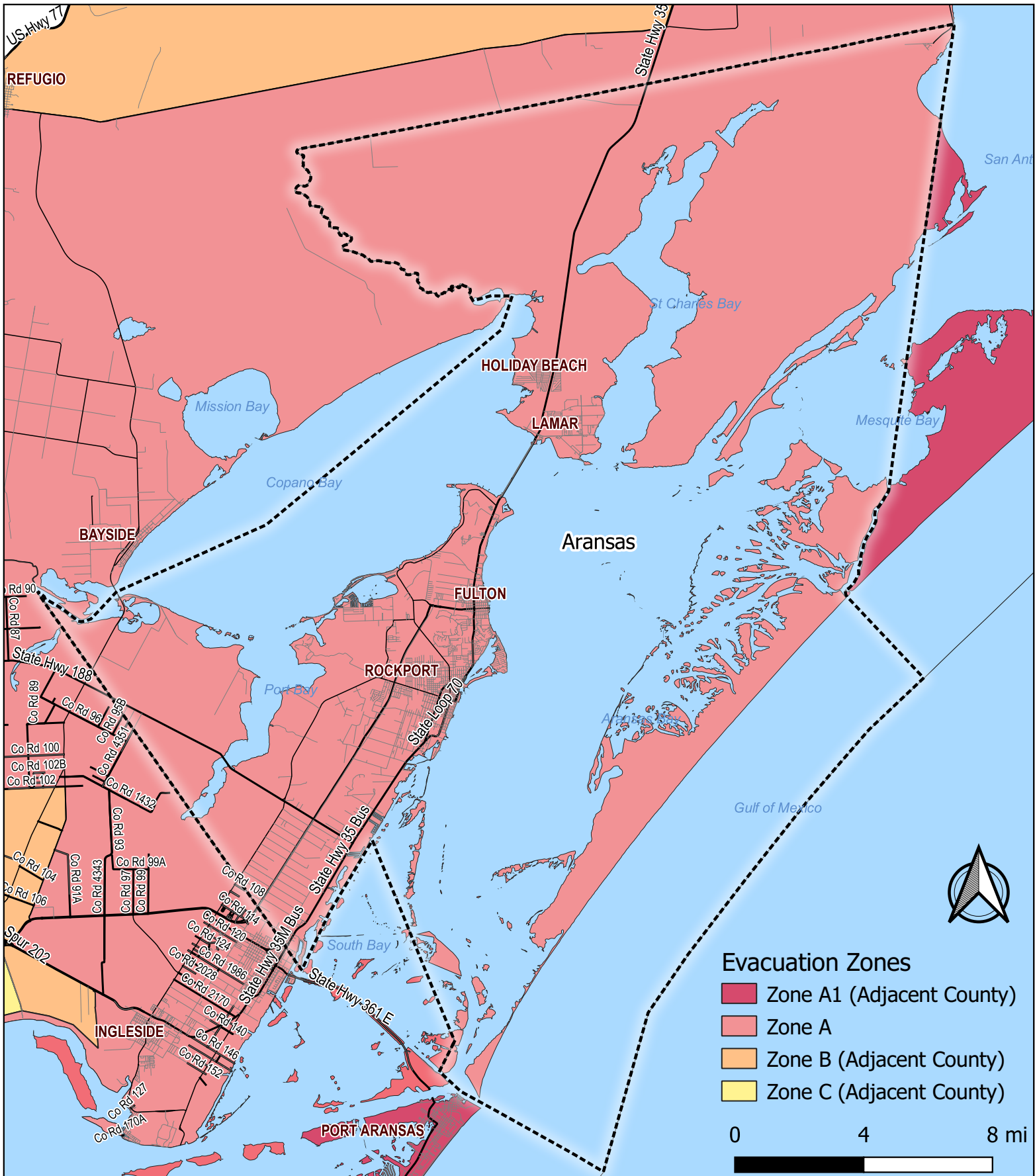
This report describes the data and decision-making process, and the designated evacuation zones for each county using example map images from the [CBHES Atlas](#). The updated evacuation zones cover large portions of most counties in the Coastal Bend area. Stand-alone evacuation zone maps have also been developed in PDF format for each county and were provided to each county's emergency management office. These maps are usable in a variety of printed and online communications formats and can be used in both public preparedness and emergency warning applications.

Disaster planning, preparedness, and initial response are ultimately most impactful at local levels for both residents and the elected and agency officials who serve their communities. Local communities can use these maps and the [CBHES Atlas](#) to identify applicable hurricane evacuation risk zones before disaster strikes. The *Atlas* is accessible to the general public and includes an address lookup tool that can help users identify where a location such as their residence is situated relative to updated evacuation zones and major transportation routes. Local and state officials can also use data layers included in the *Atlas* for other emergency and community planning applications.

References

- Lindell, M. K., Murray-Tuite, P., Wolshon, B., and Baker, E. J. (2019) *Large-Scale Evacuation: The Analysis, Modeling, and Management of Emergency Relocation for Hazardous Areas*. New York, NY: Routledge.
- Wilmot, C. G., and Meduri, N. (2005) Methodology to Establish Hurricane Evacuation Zones. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1922, Transportation Research Board of the National Academies, Washington, DC, 2005, pp. 29–137.

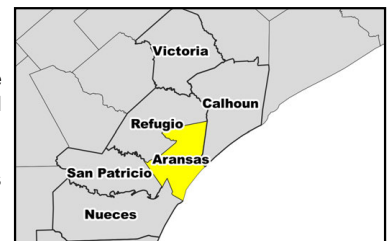
Appendix

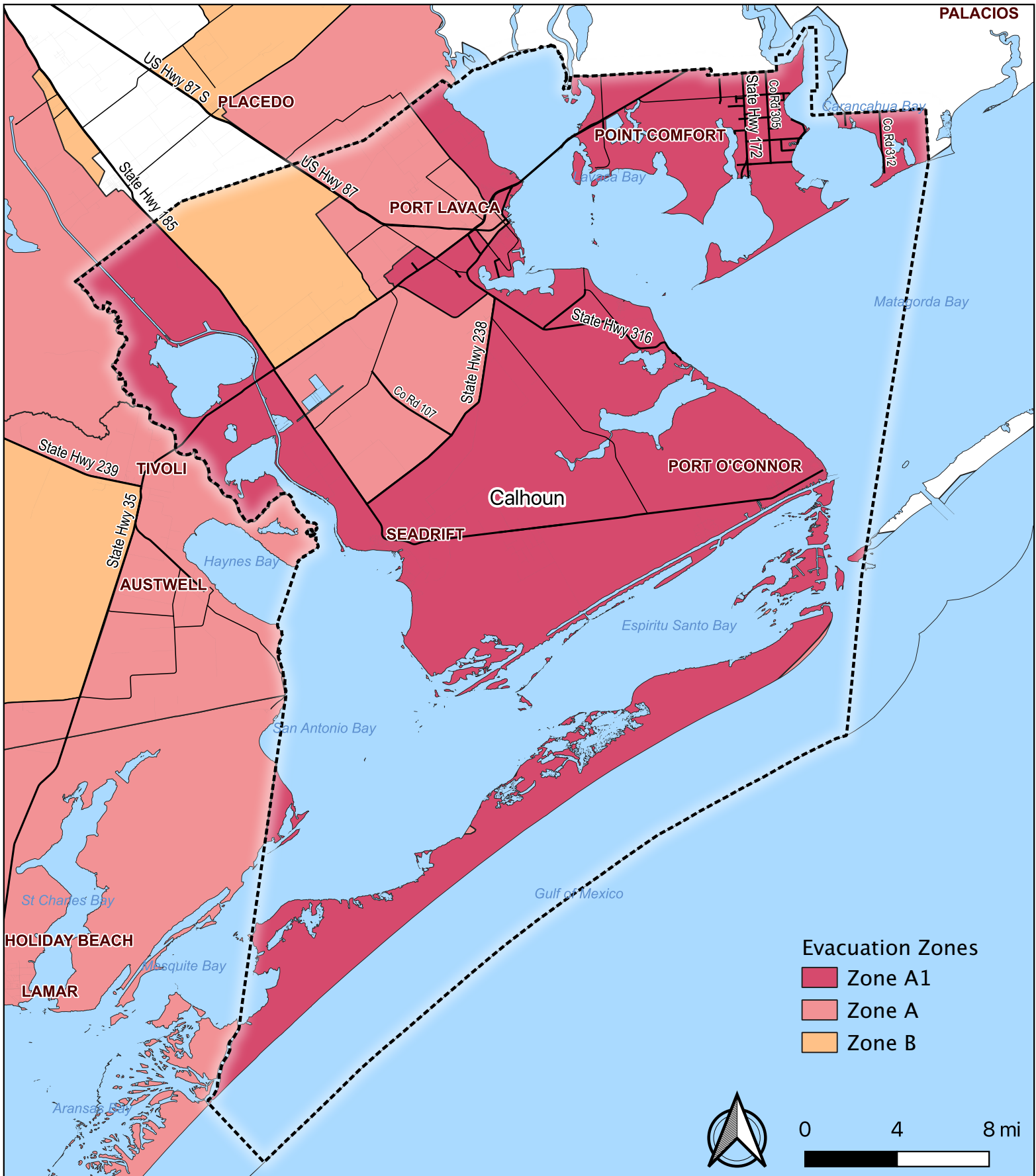


Evacuation Zones in Aransas County

The evacuation map for Aransas County was developed by Emergency Management and Public Safety officials as part of the Coastal Bend Hurricane Evacuation Study with the assistance of the Texas A&M Transportation Institute and Texas A&M Hazard Reduction & Recovery Center. January, 2020. This map is available at: <http://hrrc.arch.tamu.edu/research/HES/>

IMPORTANT: Considering the vulnerable nature of manufactured homes (such as mobile homes, RVs, & trailers) for all levels of hurricane winds, it is strongly recommended that all residents of manufactured homes in Aransas County evacuate and seek safer shelters regardless of their locations whenever voluntary or mandatory evacuations are declared for these counties.

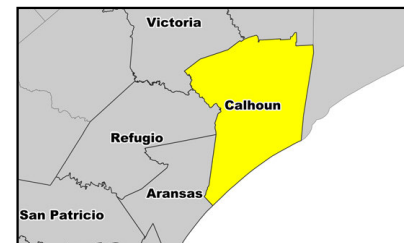


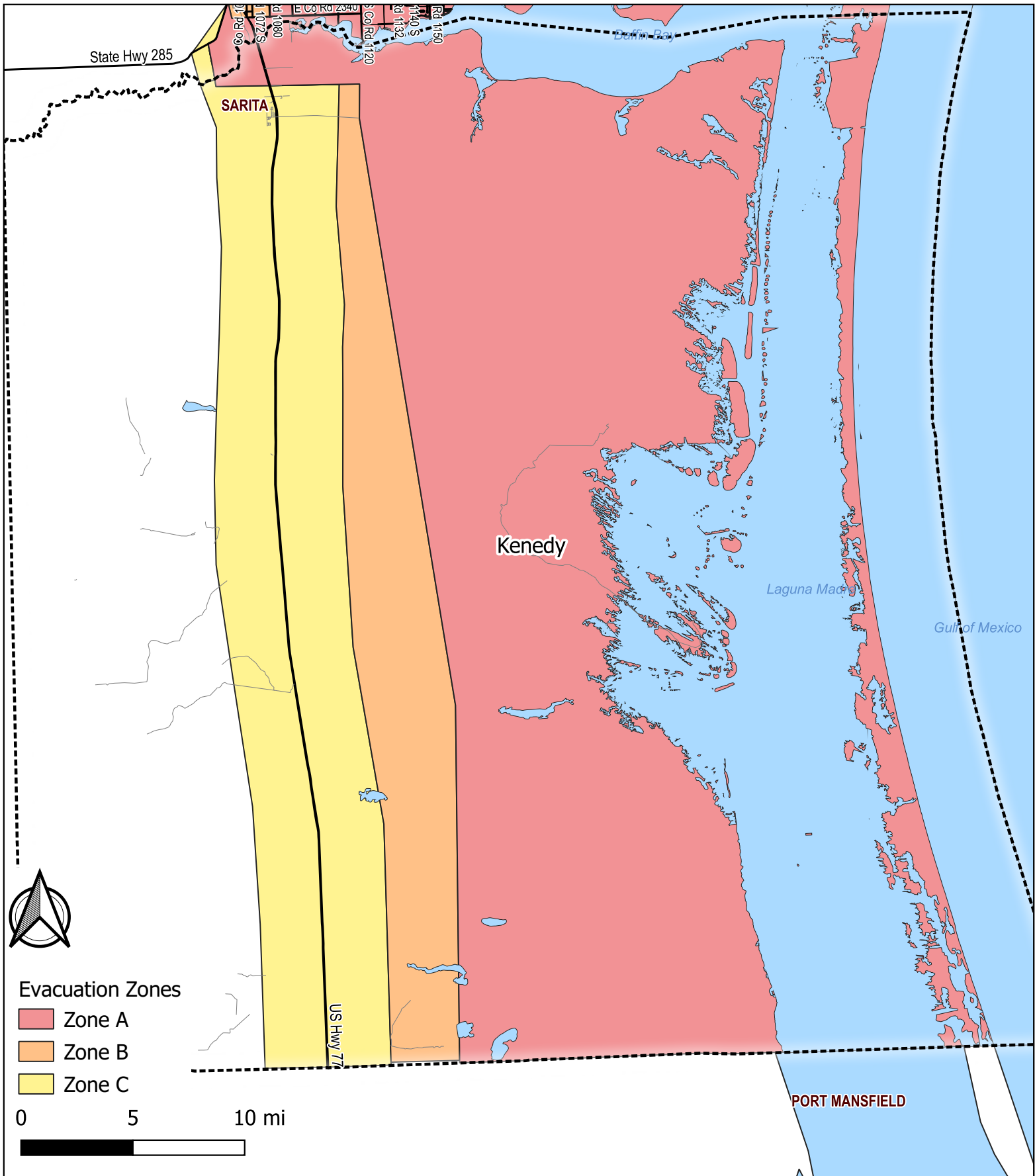


Evacuation Zones in Calhoun County

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IMPORTANT: Considering the vulnerable nature of manufactured homes (such as mobile homes, RVs, & trailers) for all levels of hurricane winds, it is strongly recommended that all residents of manufactured homes in Calhoun County evacuate and seek safer shelters regardless of their locations whenever voluntary or mandatory evacuations are declared.

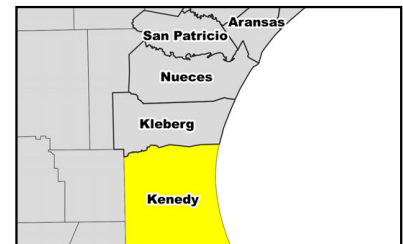


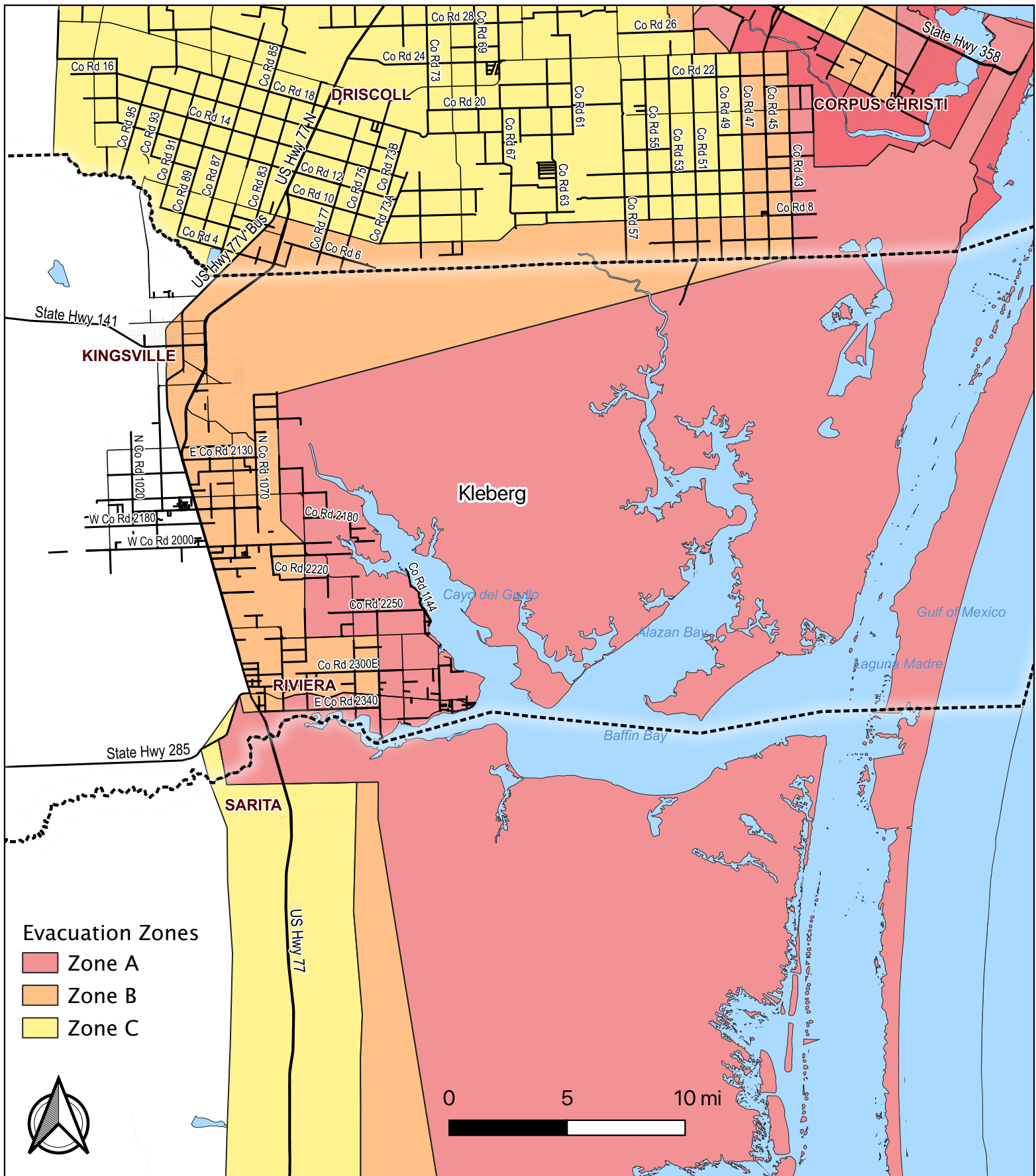


Evacuation Zones in Kenedy County

The evacuation map for Kenedy County was developed by Emergency Management and Public Safety officials as part of the Coastal Bend Hurricane Evacuation Study with the assistance of the Texas A&M Transportation Institute and Texas A&M Hazard Reduction & Recovery Center. January, 2020. This map is available at: <http://hrc.arch.tamu.edu/research/HES/>

IMPORTANT: Considering the vulnerable nature of manufactured homes (such as mobile homes, RVs, & trailers) for all levels of hurricane winds, it is strongly recommended that all residents of manufactured homes in Kenedy County evacuate and seek safer shelters regardless of their locations whenever voluntary or mandatory evacuations are declared for these counties.



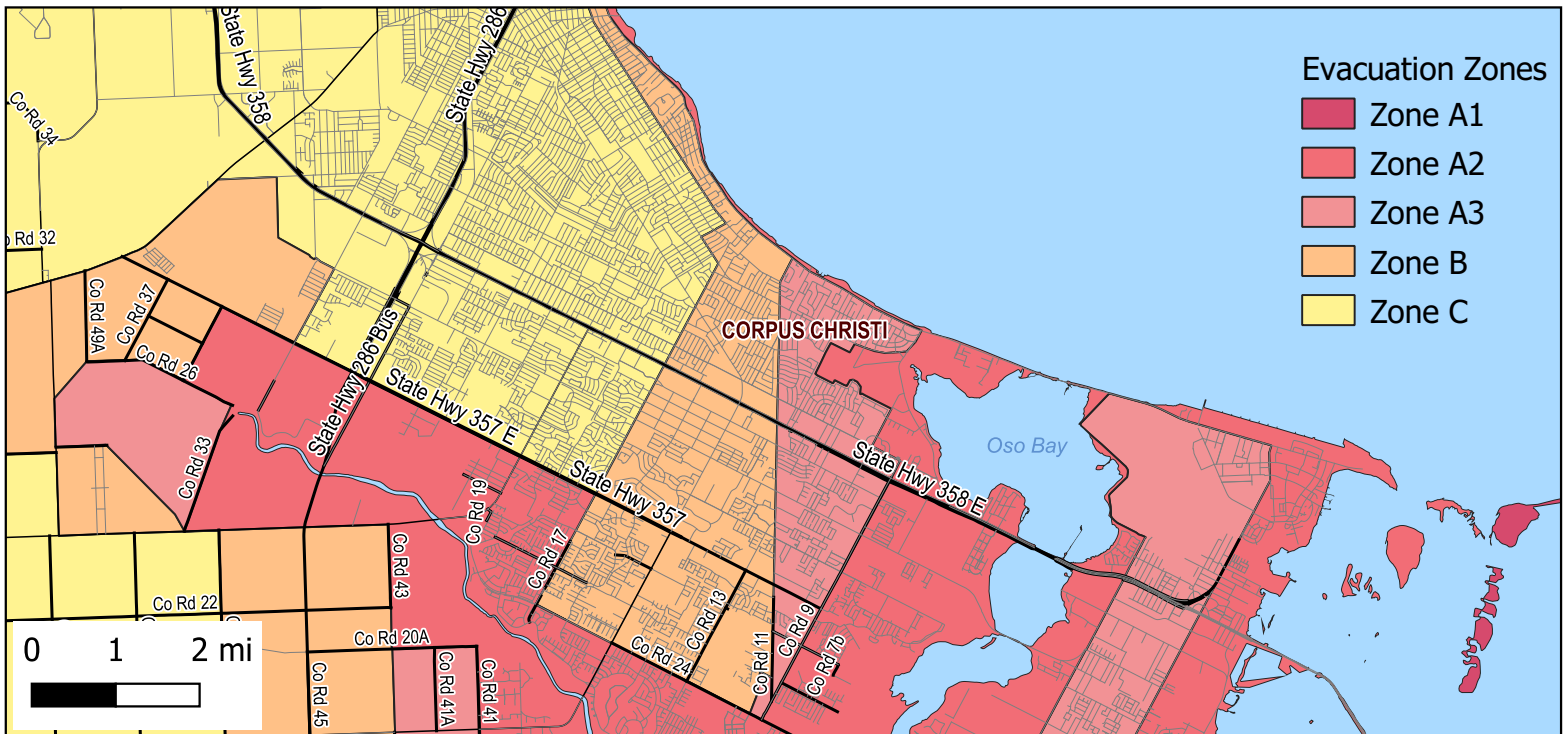
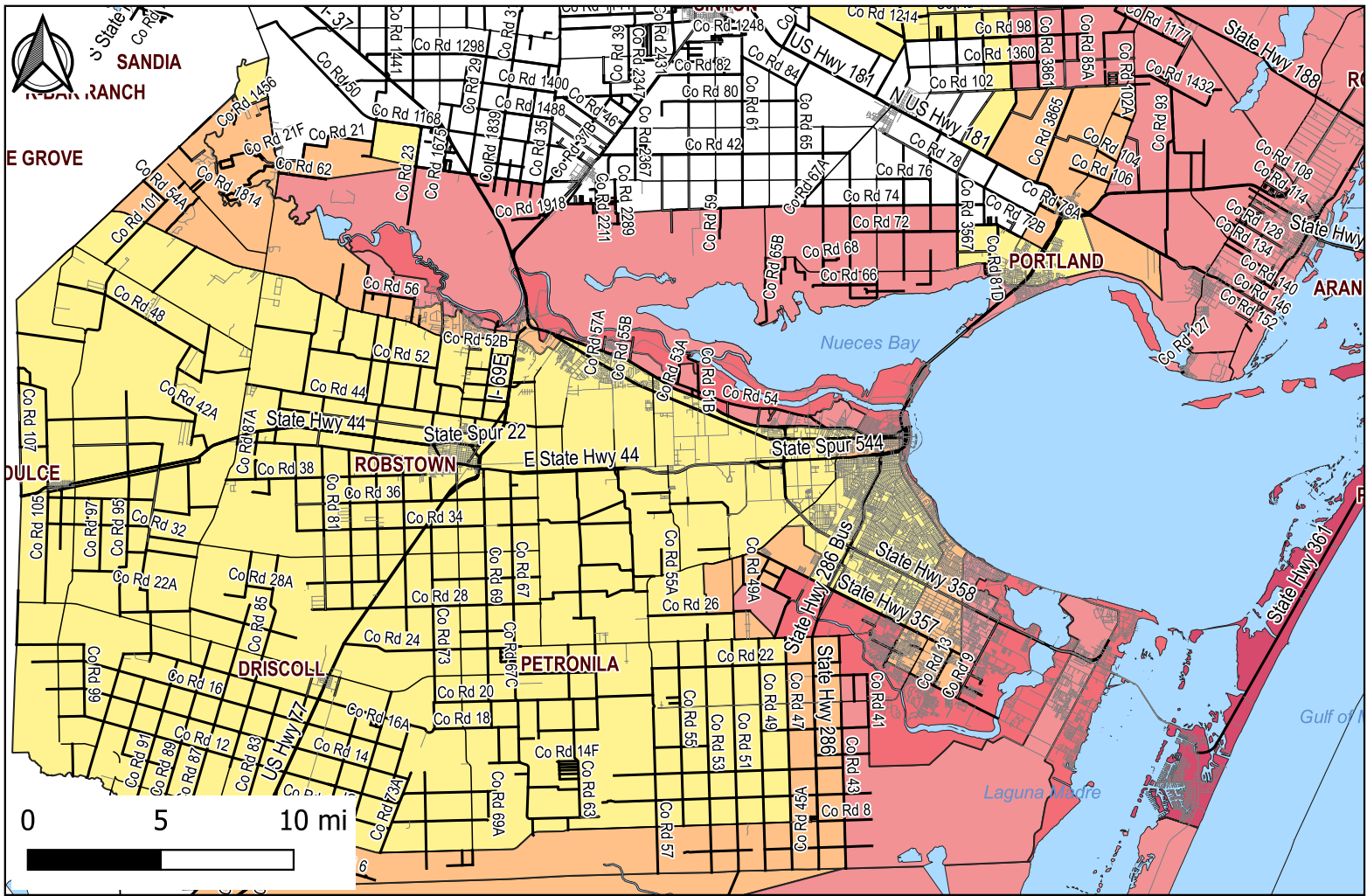


Evacuation Zones in Kleberg County

The evacuation map for Kleberg County was developed by Emergency Management and Public Safety officials as part of the Coastal Bend Hurricane Evacuation Study with the assistance of the Texas A&M Transportation Institute and Texas A&M Hazard Reduction & Recovery Center. January, 2020. This map is available at: <http://hrrc.arch.tamu.edu/research/HES/>

IMPORTANT: Considering the vulnerable nature of manufactured homes (such as mobile homes, RVs, & trailers) for all levels of hurricane winds, it is strongly recommended that all residents of manufactured homes in Kleberg County evacuate and seek safer shelters regardless of their locations whenever voluntary or mandatory evacuations are declared for these



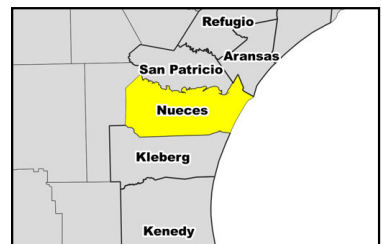


- Evacuation Zones**
- Zone A1
 - Zone A2
 - Zone A3
 - Zone B
 - Zone C

Evacuation Zones in Nueces County

The evacuation zone for Nueces County was developed by Emergency Management and Public Safety officials as part of the Coastal Bend Hurricane Evacuation Study with the assistance of the Texas A&M Transportation Institute and Texas A&M Hazard Reduction & Recovery Center. January, 2020. This map is available at: <http://hrrc.arch.tamu.edu/research/HES/>

IMPORTANT: Considering the vulnerable nature of manufactured homes (such as mobile homes, RVs, & trailers) for all levels of hurricane winds, it is strongly recommended that all residents of manufactured homes in Nueces County evacuate and seek safer shelters regardless of their locations whenever voluntary or mandatory evacuations are declared for these counties.



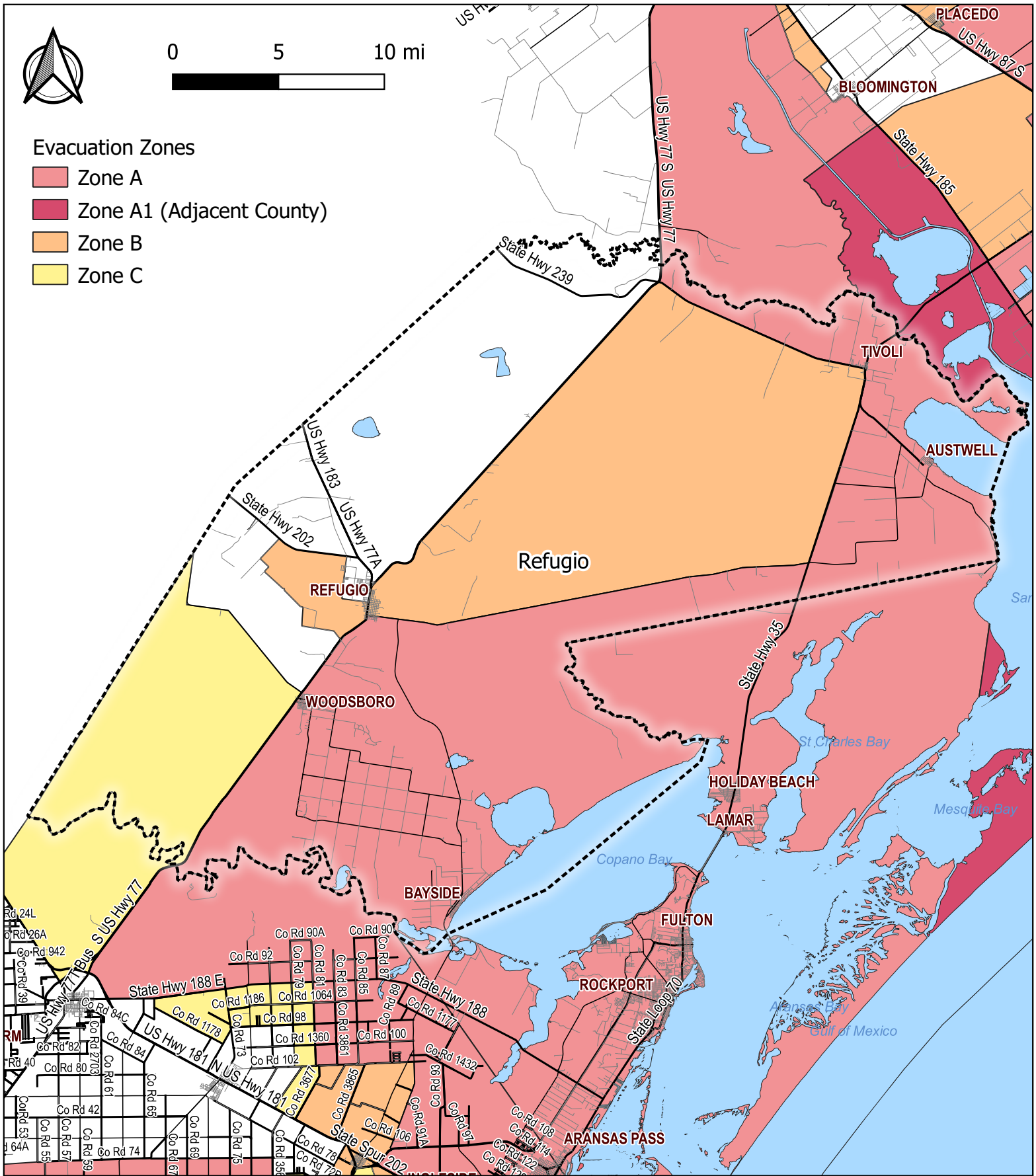


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Evacuation Zones

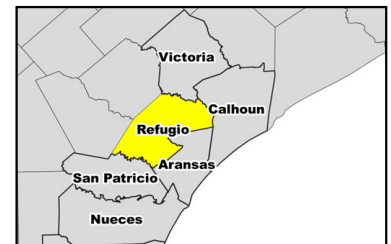
- Zone A
- Zone A1 (Adjacent County)
- Zone B
- Zone C

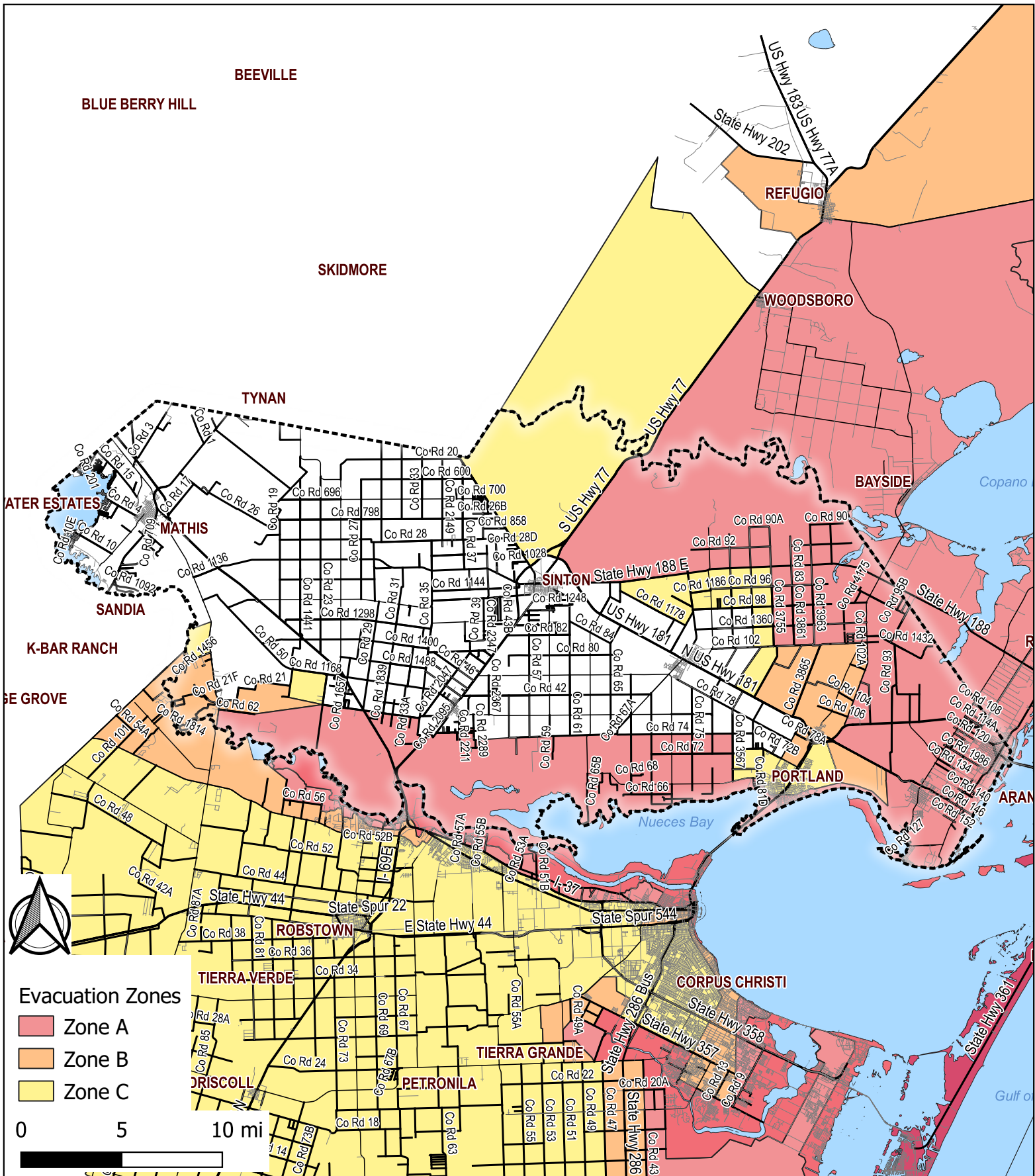


Evacuation Zones in Refugio County

The evacuation map for Refugio County was developed by Emergency Management and Public Safety officials as part of the Coastal Bend Hurricane Evacuation Study with the assistance of the Texas A&M Transportation Institute and Texas A&M Hazard Reduction & Recovery Center. January, 2020. This map is available at: <http://hrc.arch.tamu.edu/research/HES/>

IMPORTANT: Considering the vulnerable nature of manufactured homes (such as mobile homes, RVs, & trailers) for all levels of hurricane winds, it is strongly recommended that all residents of manufactured homes in Refugio County evacuate and seek safer shelters regardless of their locations whenever voluntary or mandatory evacuations are declared for these counties.

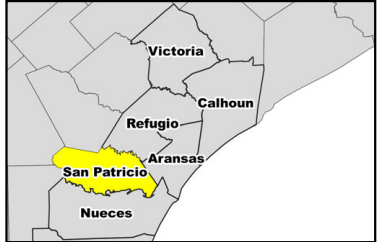


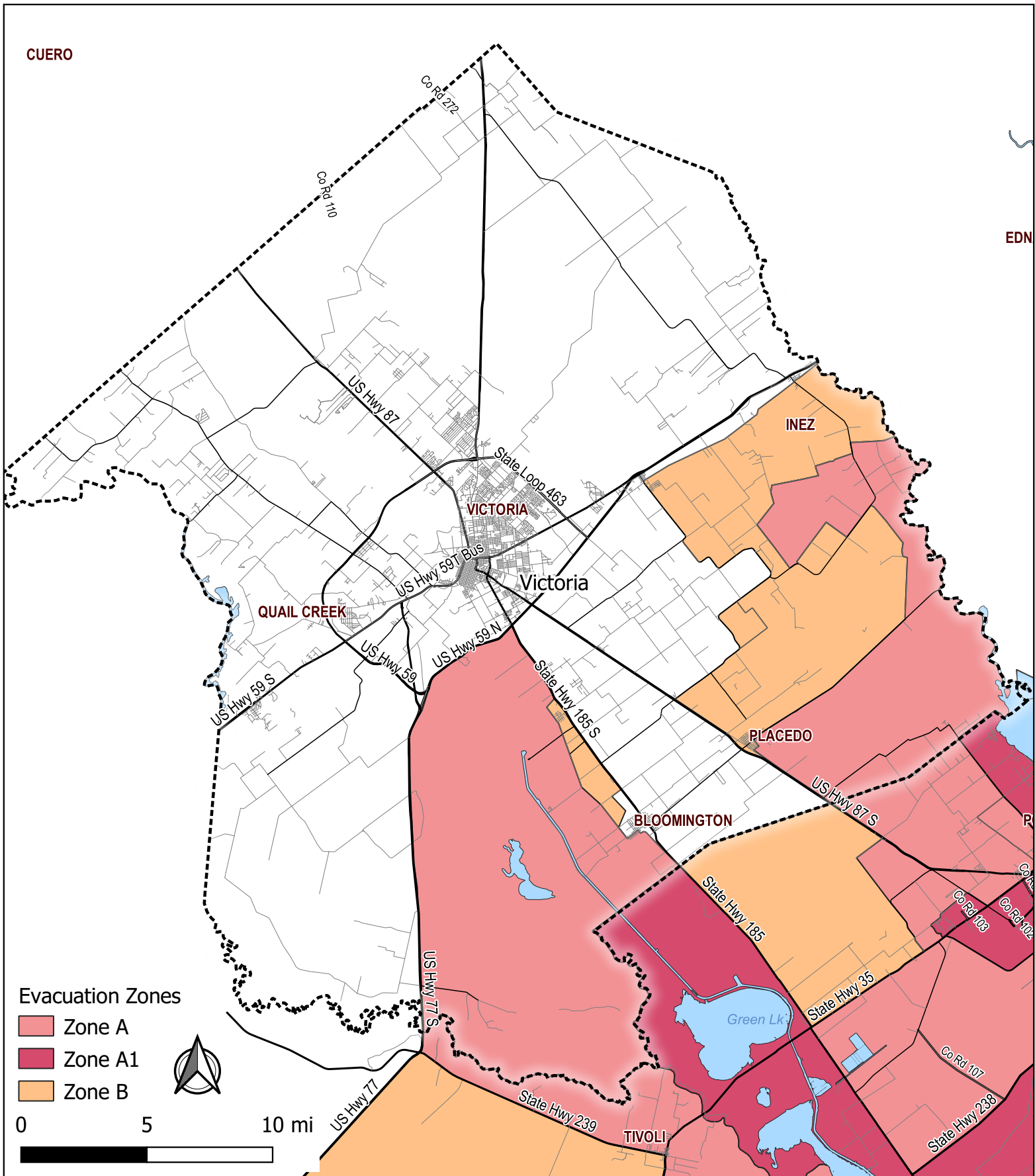


Evacuation Zones in San Patricio County

The evacuation map for San Patricio County was developed by Emergency Management and Public Safety officials as part of the Coastal Bend Hurricane Evacuation Study with the assistance of the Texas A&M Transportation Institute and Texas A&M Hazard Reduction & Recovery Center. January, 2020. This map is available at: <http://hrrc.arch.tamu.edu/research/HES/>

IMPORTANT: Considering the vulnerable nature of manufactured homes (such as mobile homes, RVs, & trailers) for all levels of hurricane winds, it is strongly recommended that all residents of manufactured homes in San Patricio County evacuate and seek safer shelters regardless of their locations whenever voluntary or mandatory evacuations are declared for these counties.





Evacuation Zones in Victoria County

The evacuation map for Victoria County was developed by Emergency Management and Public Safety officials as part of the Coastal Bend Hurricane Evacuation Study with the assistance of the Texas A&M Transportation Institute and Texas A&M Hazard Reduction & Recovery Center. January, 2020. This map is available at: <http://hrrc.arch.tamu.edu/research/HES/>

IMPORTANT: Considering the vulnerable nature of manufactured homes (such as mobile homes, RVs, & trailers) for all levels of hurricane winds, it is strongly recommended that all residents of manufactured homes in Victoria County evacuate and seek safer shelters regardless of their locations whenever voluntary or mandatory evacuations are declared for these counties.

