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An Assessment of Storm Surge Risk in Coastal Communities in the Rio Grande Valley

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Abstract: (1) Background: Cameron County, which is located in the Rio Grande Valley, holds historical records for storm surges with noticeable property damage, fatalities, and injuries; (2) Methods: using storm surge hazard datasets from the National Oceanic and Atlantic Agency (NOAA), and American Community Survey (ACS) 2019 datasets and Geographic Information System (GIS), the study estimates at-risk population and their socio-demographic attributes; (4) Conclusions: Estimated water levels of a storm surge could be reached up to 5 feet in category 1 event, 9 feet in category 2, 17 feet in category 3, and above 20 feet in category 4 and 5. In the category 5 event, there is an estimated 37% (159,659) of the total county’s population (434,294) will be under flooded water. Suggestions are made to better prepare and successfully evaluate.

Keywords: storm surge, flood risk, costal region, Rio Grande Valley

1. Introduction

Hurricanes are associated with major hazards, namely storm surge and storm tide, heavy rainfall and inland flooding, high winds, rip currents, and tornadoes [1]. Among the hazards, the storm surge and storm tide pose great threats to the lives of people who reside in the coastal regions. According to the National Hurricane Center [1], storm surge is defined as an unusual rise of water, which is caused by a speedy wind during a storm, whereas storm tide is caused by a the storm surge coupling with the astronomical tide. The storm surge which could reach to a height of more than 20 feet, in fact, could take away lives of individuals, damage buildings, and wash away roads and beaches. For example, Hurricane Charley (Category 4), which made landfall in Florida in 2004, produced a storm surge of 6 to 8 feet; Hurricane Katrina (Category 3), at landfall in Louisiana in 2005, produced a 28-foot storm surge; Hurricane Ike (Category 2), in Texas in 2008, included a 20-foot storm surge; Hurricane Irene (Category 1) at landfall in North Carolina in 2011 had a storm surge of 8 to 11 feet [2]; and Hurricane Harvey (Category 4), which made landfall in Texas in 2017, caused a 12 feet storm surge [3]. The varying amount of surge is influenced by many factors which include central pressure of the impacting hurricane, storm intensity, size of the storm, storm forward speed, angle of approach to coast, shape of the coastline, wind and slope of the ocean bottom, and local features [2]. The total water level during a hurricane storm is contributed by a storm surge, tides, waves, and freshwater input [2]. Through the years, storm surges have demonstrated their destructive power with a record of many deaths and injuries [4]. According to a study which examines the number of deaths from coastal waters during tropical cyclones in the United States in a 50-year period, about half of the fatalities were caused by the storm surge [5].

In the U.S., the coastal regions, including the Atlantic Coast, the Gulf of Mexico, and the Hawaiian Islands have been hit hard by hurricanes and storm surges. It was estimated that there are about 52% (163.8 million) of the total US population (US Census 2010) who live in 769 Coastal Watershed Counties [6]. The states that host the coastal regions which include AL, CT, DE, DC, FL, GA, LA, ME, MD, MA, MS, NH, NJ, NY, NC, RI, SC, TX, and
VA are vulnerable to hurricanes [7]. The study’s findings also reveal that all the coastal states are vulnerable to storm surge inundation, while their exposure to storm surge risk increases with the level of severity of hurricane storm. According to the National Hurricane Center, the coastal communities which are located along the Gulf of Mexico are extremely vulnerable to storm surge. Their geographical locations with unique features of flat continental shelf and low-lying land elevations exposed the communities to potential storm surges with a greater height and a wide inland extent [7]. It was observed that there were at least one major hurricane making landfall in the Gulf Coast region every two years [2]. The level of vulnerability to storm surge could be amplified by increase in ocean temperature due to climate change. According to the Fourth National Climate Assessment Report, a rise in atmospheric temperature and an increase in ocean surface temperature could result in increased wind speeds from tropical storms [8, 9]. It is projected that more frequent and intense hurricanes in the U.S. Atlantic and Gulf Coast states are likely to increase the probability of extreme flooding and storm surge risk [8]. For example, by the end of the 2018 Atlantic hurricane season, there were 15 named storms, including eight hurricanes of which Florence and Michael were major category. These statistics exceed the seasonal average of 12 named storms, six hurricanes and three major hurricanes annually [10].

Among the counties that are situated in the Gulf Coast, Cameron and Willacy are the two out of four counties that constitutes the Rio Grande Valley (RGV), which hosts a population of around 1.3 million [11]. The valley consists of four counties, namely Hidalgo (61% of the valley’s total population), Cameron (32%), Willacy (5%), and Starr (2%) counties. The Cameron and Willacy counties are located adjacent to the Gulf of Mexico and prone to hurricanes and storm surges. In addition, the county that shares the border along the Rio Grande River with Mexico is exposed to risk of river flooding. Historically, the Cameron and Willacy counties have been significantly impacted by hurricanes and storm surges. On September 4th and 5th, 1933, Cameron county was inundated with a 13-foot storm surge; on September 20th to 22nd, 1967, Hurricane Beulah caused inundation in both Cameron and Willacy County with a 18 feet tides; on August 10th, 1980, Hurricane Allen (Category 5) made a landfall with one of the worst storms on record which inundated the Brownsville with 4-feet of storm surge; on September 16th and 17th, 1988, Hurricane Gilbert (Category 3), the strongest storm on record for the Atlantic basin at the time, flooded Cameron and Willacy coastal regions with a notable storm surge; on August 23rd, 1999, Hurricane Bret (Category 4) hit Brownsville are with a foot of rain fall; on July 23rd, 2008, Hurricane Dolly (Category 2) hit the residents of the Lower Texas coastline and 3 to 4 foot surge was observed in the Brownsville Ship Channel; on June 30th, 2010, Hurricane Alex caused heavy rains and severe flooding in the Lower and Middle Rio Grande Valley [12].

To better cope with the anticipated frequency and new level of intensity of hurricanes and their associated hazards including storm surge and tide, it is imperative to build disaster resiliency in the coastal communities which are at-risk of hurricanes and their repercussions. Disaster resiliency is defined as increasing the ability to understand risk and vulnerability and enhancing capability to mitigate from, prepare for, respond to and recover from natural disasters. This brings about a return to normal or better than normal conditions [13]. The current approach of relying much on response and recovery phases will not work for future disasters resulting from climate change [8]. Building disaster resiliency begins with understanding hazards, social vulnerability, and risk which is conceptualized as the intersection between storm hazards and social vulnerability. The study aims at empirically investigating spatial distribution of storm surge hazards associated with hurricanes in Cameron County, the largest coastal county in the Rio Grande Valley and assessing social vulnerability of the coastal community members who expose to the storm surge hazards.
2. Materials and Methods

The study utilizes a conceptual framework which consists of storm surge hazards, social vulnerability, and storm surge risk (Figure 1). Storm surge hazard is defined as a dangerous phenomenon that causes an unusual rise of water during a storm and the amount of water is caused by storm surges, tides, waves, and freshwater input. Storm surge vulnerability refers to the social characteristics of a community that are susceptible to the damage caused by a storm surge hazard. Storm surge risk or exposure to storm surge hazards refers to communities and their members that reside in storm surge hazard areas and they are subject to potential losses.

![Figure 1. Conceptual Framework of Storm Surge Hazards, Social Vulnerability, and Storm Surge Risk](image)

To examine storm surge risks, the study employs two types of datasets: storm surge hazards and social vulnerability. First, storm surge hazard datasets were obtained from the National Oceanic and Atlantic Agency (NOAA). The datasets included the National Storm Surge Hazard Maps (NSSHM) - Version 2 data from NOAA [7]. Second, socio-demographic datasets were obtained from the U.S. Census Bureau. The social datasets consisted of census block group American Community Survey (ACS) 2019 data. In addition, the county boundary shapefiles were obtained from the U.S. Census Bureau (Figure 2).

![Figure 2. Data Analytics for Computing Socio-demographic Attributes Associated by Block Group which are Exposed to Storm Surge Risk under Five Hurricane Categories](image)
The NSSHM data was downloaded from the NHC, the National Oceanic and Atmosphere Administration (NOAA), website [14]. The hydrodynamic Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model was utilized to project the storm surge map in the NSSHM data. The SLOSH model, which was developed by the National Weather Service (NWS), is a numerical model that could run on computers to project storm surge heights. The model could be used to estimate storm surge heights from past hurricanes or predicting future hurricanes [15]. Specifically, the model consists of physical equations which require input information of shoreline, bay and river configurations, water depths, bridges, roads, levees and other physical features [15]. The data is in GeoTIFF format which could be used in Geographic Information Systems (GIS) software.

The attribute data of ACS 2019 at block group level include (1) total population, (2) gender, (3) age, (4) race, (5) tenure of living in the same house, (6) language, (7) total number of families, (8) educational attainment, (9) households with public assistance, (10) medium household income, (11) employment, (12) average age of buildings, (13) median value of houses, (14) total population without insurance, (15) native born, and (16) total occupied houses.

The study utilizes the areal apportionment method, which is widely used in estimating population [16, 17]. The method recalculates area of each census block group area that exists within the projected storm surge area in the NSSHM layer. When a census block group is covered by a storm surge area, then the entire population is counted toward the number exposed to storm surge risk. Similarly, when only a fraction of a census block group is exposed to a projected storm surge area in the NSSHM layer, then the fraction of the population is counted as the portion exposed to the storm surge risk.

\[ P_s = P_t \times P_{cb} \]

Whereas:

\( P_s \) = the number of people potentially impacted by the storm surge,

\( P_t \) = the population type,

\( P_{cb} \) = the percentage of census block group area.

For example, 5,000 individuals live in a block group and only 10% of the block group exists in the projected storm surge area, then only 500 individuals are counted as population that is exposed to the storm surge risk. The other socio-economic variables are also recalculated using the apportionment method. One underlying assumption with this method is that the population and its socio-demographic attributes are evenly distributed in a block group, but, it is not always the case.

3. Results

Five storm surge maps for hypothetical hurricane events with category 1, 2, 3, 4, and 5 are depicted in the Figure 3.A, 3.B, 3.C, 3.D, and 3.E respectively (Figure 3). The findings indicate that estimated storm surge water could be as high as 21 feet or more during the hypothetical hurricane category 4 and 5 (Figure 3.D and 3.E). It is obvious that the area impacted by the storm surge water increases with the level of hurricane intensity.
Data Source: The National Storm Surge Hazard Maps (NSSHM)

First, estimated water levels of a storm surge could be up to 5 feet in category 1 event, 9 feet in category 2, 17 feet in category 3, and above 20 feet in category 4 and 5. The study’s
findings show that an estimated 36.7% (159,659) of the county’s total population (434,294) will likely be exposed to hurricane induced storm surges in a hypothetical hurricane category 5 event (Figure 4.A, Appendix A, Table A.5). Similarly, 14.39% (62,512), 3.48% (15,123), 1% (4,340), and 0.16% (711) of the county’s total could be exposed to storm surge in a hypothetical hurricane category 4, 3, 2, and 1 event (Appendix A, Table A.4, Table A.3, Table A.2, and Table A.1).

Second, 23.53% of individuals who are at-risk for flooding speak only Spanish in Category 5, 21.87% in Category 4, 19.02% in Category 3, 18.15% in Category 2, and 19.24% in Category 1 (Figure 4.B, Appendix A, Table A.5, Table A.4, Table A.3, Table A.2, and Table A.1).

Third, among the at-risk individuals, an estimated 32.48% of the total had no schooling or attained less than high school education in the hypothetical hurricane category 1, 29.57% in category 2, 28.81% in category 3, 33.28% in category 4 and 35.27% in category 5 (Figure 4.C, Appendix A, Table A.5, Table A.4, Table A.3, Table A.2, and Table A.1). Fourth, a trend of close association among the level of education attainment and median household income was observed. The higher the percentage of no schooling and less than high school education, the lower the income. The median household income was observed as $37276 among the at-risk population in hypothetical hurricane category 1, $36454 in category 2, $37875 in category 3, $40352 in category 4, and $41384 in category 5 (Figure 4.D, Appendix A, Table A.5, Table A.4, Table A.3, Table A.2, and Table A.1).

Fifth, about 14% and 38% of at-risk total households received public assistance in hypothetical hurricane category 4 and 5 respectively whereas lower percentage of them (0.22% in category 1, 1.31% in category 2, 4.16% in category 3) were observed as households receiving public assistance (Figure 4.E, Appendix A, Table A.5, Table A.4, Table A.3, Table A.2, and Table A.1).

Sixth, the findings indicated that there was an estimated 42% of total at-risk individuals observed to have no health insurance who were likely to be exposed to storm surges induced by a hypothetical hurricane category 5 (Figure 4.F). Similarly, about 17%, 4%, 1% and 0.22% of the total at-risk individuals were observed in the hypothetical hurricane category 4, 3, 2, and 1 respectively (Figure 4.F, Appendix A, Table A.5, Table A.4, Table A.3, Table A.2, and Table A.1).

Figure 4.A Projected total population exposed to hurricane induced storm surge under five hypothetical hurricane categories

Figure 4.B Projected percent speaking Spanish of total population exposed to hurricane induced storm surge under five hypothetical hurricane categories
4. Discussion and Conclusions

The study’s findings provide a better understanding of social vulnerability to storm surge hazards in Cameron County in the Rio Grande Valley, Texas, which is adjacent to the Gulf of Mexico and bordering with the Rio Grande River and Mexico. The county hosts a total population of 423,163 [18]. Using NOAA’s storm surge projection under each of five hypothetical hurricane categories, the study finds community members who reside in the storm surge hazard areas under projected varying water depth up to 21 feet. It was alarming to notice that in a hypothetical hurricane category five event, there is an estimated 37% (159,659) of the total population (434,294) in the country that will be under flooded water (Appendix A, Table 5). The estimated population could experience the flooding water level over 21 feet high. In the event of hurricane category 5, the most daunting task for local emergency managers is to encourage at-risk individuals to leave their residence under a mandatory evacuation. This challenge was evident with previous findings that during the deadliest hurricane category 5 event, there are people who will remain in their residences in the Rio Grande Valley [19]. This daunting task could be amplified with the existing condition of low level of disaster preparedness among the residents [20].

A successful implementation of a mandatory evacuation order begins with individual preparedness. It is vital to educate the at-risk population about potential risks associated with a storm surge, its impacts on property, and potential deaths. The need for the
educating program is justified by three reasons. First, the Saffir–Simpson scale of hurricanes does not explicitly carry the risk associated with a hurricane [21]. Second, the public does not pay sufficient attention the storm surge risk [22]. Third, the storm surge is an abstract phenomenon, and it is rare to have personal experience with during a sole lifetime [7]. Providing relevant and reliable information is associated with building trust in authorities recommendation which could in turn influence the positive evacuation-decision making among the valley residents [23].

In addition, the storm surge maps in this study were very helpful to visualize the spatial distribution of the flooding areas, but it also requires additional steps to provide an understanding on the location of individual households and impacts from the potential storm surge, including deaths [24]. Moreover, according to the findings, a larger percentage (about 23%) of the total at-risk population who speak Spanish indicates that communication in Spanish is a factor.

To respond effectively to the hurricane event, the at-risk population must be able to safely leave their residential areas to a designated location. To do so, it is essential to be familiar with the evacuation routes and estimated time to travel to their destination. There are only three primary evacuation routes from the coastal areas toward the mainland (Appendix B, Figure 1). The storm surge map shows that these primary routes originating from the coastal areas could be inundated (Figure 3). As a result, local emergency managers must make a prompt evacuation order, while evacuees must execute their evacuation plan in a timely manner. Moreover, the findings show that about 40% of the total at-risk population receive public assistance and about 42% of them do not have health insurance. These findings suggest that local authorities must prepare to provide shelters, necessities, and health care services during evacuation. Some studies suggest that those who are socially vulnerable are likely to face asset vulnerability [21]. This suggests that there is a need for better mitigation strategies for this at-risk population to mitigate potential loss of their property. Above all, the study’s evidence provides a wake-up call to all key stakeholders to prepare for a potential storm surge in Cameron County.

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### Table A.1 Socio-demographic characteristics of projected population who are exposed to storm surge under Hurricane Category 1

| Unflooded Flooded | Level     | Total | Flooded | Level     |
|-------------------|-----------|-------|---------|-----------|
|                   | 0-2’      | 2-3’  | 3-4’    | 4-5’      | 0-2’    | 2-3’  | 3-4’    | 4-5’      |
| Total population  | 433583    | 711   | 295     | 188       | 142     | 86    |         | 434294    |
| Male              | 211281    | 334   | 138     | 90        | 66      | 41    |         | 211615    |
| Female            | 222030    | 376   | 157     | 98        | 76      | 45    |         | 222679    |
| 65 or older (female) | 8121   | 30    | 12      | 8         | 5       | 4     | 8151    |
| 65 or older (male) | 4323   | 13    | 6       | 4         | 2       | 1     | 4336    |
| White             | 407064    | 694   | 289     | 183       | 139     | 84    | 407758  |
| Black             | 2440      | 1     | 0       | 0         | 0       | 0     | 2441    |
| Native            | 1069      | 1     | 0       | 0         | 0       | 0     | 1070    |
| Asian             | 2967      | 3     | 1       | 1         | 1       | 0     | 2970    |
| Other             | 20044     | 11    | 5       | 3         | 2       | 1     | 20055   |
| Same house 1 year ago | 389572   | 638   | 270     | 166       | 128     | 75    | 390210  |
| Different house 1 year ago | 32596  | 23    | 9       | 7         | 4       | 2     | 32619   |
| Spanish           | 96601     | 137   | 55      | 36        | 28      | 18    | 96738   |
| English Only      | 29524     | 110   | 48      | 32        | 19      | 11    | 29634   |
| Total families    | 100101    | 164   | 68      | 44        | 32      | 20    | 100265  |
| Families with no husband | 25342  | 35    | 15      | 9         | 7       | 4     | 25377   |
| Total population (age 25 or older) | 253292 | 476   | 199     | 129       | 92      | 56    | 253768  |
| No schooling      | 10732     | 33    | 14      | 7         | 7       | 4     | 10785   |
| Less than high school | 71328  | 122   | 52      | 29        | 26      | 15    | 71450   |
| Highschool diploma | 66747  | 164   | 67      | 44        | 32      | 20    | 66911   |
| Associate degree  | 18335     | 30    | 12      | 9         | 5       | 4     | 18365   |
| Bachelor degree   | 30218     | 46    | 19      | 14        | 8       | 5     | 30264   |
| Professional degree | 2067   | 2     | 1       | 1         | 0       | 0     | 2069    |
| Some college      | 42886     | 61    | 25      | 19        | 10      | 7     | 42947   |
| Graduate degree   | 10959     | 18    | 9       | 6         | 2       | 1     | 10977   |
| Medium household income ($) | 39568 | 37276 | 36633 | 36836 | 37112 | 38523 | 38422 |
|----------------------------|-------|-------|-------|-------|-------|-------|-------|
| Total household            | 127453| 248   | 104   | 69    | 47    | 29    | 127701|
| Households with public assistance | 2829 | 3     | 1     | 1     | 1     | 1     | 2832  |
| Household without public assistance | 124624 | 245   | 103   | 68    | 47    | 28    | 124869|
| Total population (labor force) | 315546 | 548   | 226   | 148   | 107   | 66    | 316094|
| In labor                   | 175675 | 275   | 114   | 74    | 54    | 33    | 175950|
| Unemployed                 | 10270  | 6     | 2     | 2     | 1     | 1     | 10276 |
| Average age of buildings   | 36     | 27    | 28    | 28    | 27    | 26    | 36    |
| Medium value of houses ($) | 84754  | 143899| 138527| 141529| 144387| 151155| 114326|
| Total population without health insurance | 123420 | 278   | 118   | 68    | 59    | 33    | 123698|
| Native                     | 333950 | 528   | 216   | 145   | 102   | 65    | 33478 |
| Foreign born               | 99634  | 182   | 80    | 42    | 40    | 21    | 99816 |
| Total houses               | 154553 | 505   | 221   | 148   | 84    | 51    | 155058|
| Total occupied houses      | 127453 | 248   | 104   | 69    | 47    | 29    | 127701|
| Total vacant houses        | 27100  | 257   | 118   | 80    | 37    | 23    | 27357 |

| Unflooded | Flooded Level | Total | Flooded Level |
|-----------|---------------|-------|---------------|
| 0-2'      | 2-4'          | 4-6'  | 6-9'          |

Table A.2 Socio-demographic characteristics of projected population who are exposed to storm surge under Hurricane Category 2
| Category                        | Total       | Male         | Female        | 65 or older (female) | 65 or older (male) | White         | Black | Native | Asian  | Other | Same house 1 year ago | Different house 1 year ago | Total families | Families with no husband | Total population (age 25 or older) | No schooling | Less than high school | Highschool diploma | Associate degree | Bachelor degree | Professional degree | Some college | Graduate degree | Medium household income ($) | Total household | Households with public assistance |
|--------------------------------|-------------|--------------|---------------|---------------------|--------------------|-------------------|-------|--------|--------|-------|------------------------|-----------------------------|----------------|-------------------------|-----------------------------|--------------|----------------------|---------------------|-------------------|------------------|-------------------|-------------|----------------|------------------------|----------------|----------------------|-------------------|
### Table A.3 Socio-demographic characteristics of projected population who are exposed to storm surge under Hurricane Category 3

| Unflooded | Flooded Level | Total | Flooded Level |
|-----------|---------------|-------|---------------|
|           | 0-2'          | 2-4'  | 4-6'          | 6-9' | 9-17' | 0-2' | 2-4' | 4-6' | 6-9' | 9-17' |
| Total population | 419171 | 15123 | 6082 | 3608 | 3337 | 1761 | 335 | 434294 |

- Household without public assistance
- Total population (labor force)
- In labor
- Unemployed
- Average age of buildings
- Medium value of houses ($)
- Total population without health insurance
- Native
- Foreign born
- Total houses
- Total occupied houses
- Total vacant houses

| Household without public assistance | 123363 | 1506 | 994 | 370 | 103 | 39 | 124869 |
|-------------------------------------|--------|------|-----|-----|-----|----|--------|
| Total population (labor force)     | 312713 | 3381 | 2225 | 829 | 232 | 95 | 316094 |
| In labor                           | 174328 | 1622 | 1038 | 418 | 116 | 49 | 175950 |
| Unemployed                         | 10245  | 31   | 22   | 7   | 2   | 1  | 10276  |
| Average age of buildings           | 36     | 27   | 27   | 28  | 27  | 27 | 36     |
| Medium value of houses ($)         | 84754  | 129126 | 132496 | 130894 | 124630 | 128482 | 106940 |
| Total population without health insurance | 122073 | 3251 | 2154 | 782 | 225 | 89 | 334478 |
| Native                              | 331227 | 3251 | 2154 | 782 | 225 | 89 | 334478 |
| Foreign born                        | 98727  | 1089 | 661  | 308 | 80  | 41 | 99816  |
| Total houses                        | 152743 | 2315 | 1427 | 648 | 182 | 58 | 155058 |
| Total occupied houses               | 126175 | 1526 | 1008 | 374 | 104 | 40 | 127701 |
| Total vacant houses                 | 26568  | 789  | 419  | 275 | 77  | 18 | 27357  |
| Category                        | Male       | Female     | 65 or older (female) | 65 or older (male) | White       | Black     | Native   | Asian      | Other      | Same house 1 year ago | Different house 1 year ago | Spanish | English Only | Total families | Families with no husband | Total population (age 25 or older) | No schooling | Less than high school | Highschool diploma | Associate degree | Bachelor degree | Professional degree | Some college | Graduate degree | Medium household income ($) | Total household | Households with public assistance | Household without public assistance |
|--------------------------------|------------|------------|----------------------|--------------------|-------------|-----------|----------|------------|------------|-----------|----------------------|--------------------------|----------|--------------|----------------|--------------------------|----------------------------------|-------------|-----------------------|-------------------|-----------------|-----------------|----------------------|-------------|----------------|--------------------------|----------------|--------------------------|--------------------------|
|                                | 204446     | 214725     | 7749                 | 4128               | 393262      | 2412      | 1050     | 2888       | 19559      | 375988               | 32053                   | 93861   | 27753       | 96655             | 24598                  | 244101              | 10302       | 69148                | 63861            | 17610          | 29296          | 2032              | 41372        | 10480          | 39568                   | 122889        | 2764                  | 120125                  |
|                                | 7169       | 7954       | 402                  | 208                | 14496       | 29        | 20       | 82         | 496        | 14222                 | 566                     | 2877    | 1881        | 3610              | 779                     | 9667                | 483         | 2302                | 3050             | 755             | 968             | 37               | 1575         | 497             | 37876                   | 4812          | 68                   | 4744                   |
|                                | 2884       | 3197       | 113                  | 60                 | 5804        | 7         | 7        | 34         | 228        | 5612                 | 338                    | 1255    | 547         | 1446              | 341                     | 3656                | 150        | 907                 | 1062             | 289             | 434             | 16              | 636           | 497             | 40880                   | 1819          | 30         | 1789                   | 42846          | 35225      |
|                                | 1745       | 1863       | 110                  | 60                 | 1583        | 7         | 4        | 18         | 125        | 1753                 | 99                     | 657     | 486         | 859               | 175                     | 115                 | 114        | 513                 | 760              | 204             | 222             | 11              | 636           | 197             | 37646                   | 1155          | 37       | 1142                   | 36946          | 38722      |
|                                | 1583       | 1754       | 112                  | 67                 | 803         | 10        | 5        | 20         | 89         | 1680                 | 82                     | 571     | 486         | 819               | 152                     | 89                  | 89         | 484                 | 767              | 69              | 213             | 8               | 410           | 297             | 3213                   | 715           | 1165      | 1144                   | 35025          | 38722      |
|                                | 803        | 958        | 56                   | 27                 | 154         | 2         | 3        | 9          | 45         | 297                  | 7                      | 326     | 448         | 417               | 32                      | 10                  | 10         | 328                 | 391              | 49              | 183             | 11              | 375           | 297             | 3213                   | 10            | 71450      | 1236                   | 32846         | 38722      |
|                                | 154        | 182        | 11                   | 3                  | 211615      | 0         | 1        | 1          | 45         | 325                  | 7                      | 68      | 326         | 414               | 74                      | 45                  | 45         | 70                  | 71               | 32              | 324             | 11              | 137           | 1236            | 211615                   | 10            | 71450      | 1236                   | 32846         | 38722      |
|                                | 211615     | 222679     | 8151                 | 4336               | 407758      | 2441      | 1070     | 2970       | 20555      | 390210               | 32619                  | 96738   | 29634       | 100265            | 25377                  | 390210             | 2441       | 2302                | 66911            | 3248           | 3064            | 9              | 497           | 2832            | 37646                   | 127701        | 287       | 124869                  | 20480          | 2032      |
|                                | 3.39       | 3.57       | 4.93                 | 4.79               | 3.56        | 1.18      | 1.90     | 2.75       | 2.47        | 3.64                  | 1.74                    | 2.97    | 6.35       | 3.60              | 3.07                     | 3.81                | 4.48       | 3.22                | 4.56             | 4.11             | 3.20             | 1.79            | 3.67           | 4.53           | 3.77                   | 122889        | 96       | 3.80                   | 1.43             | 0.91             | 0.92             | 0.46            |
| Total population (labor force) | 304745 | 11349 | 4456 | 2752 | 1304 | 242 | 316094 | 3.59 | 3.59 | 1.41 | 0.87 | 0.82 | 0.41 |
| In labor                      | 170177 | 5773  | 2373 | 1380 | 1247 | 647 | 175950 | 3.28 | 3.28 | 1.35 | 0.78 | 0.71 | 0.37 |
| Unemployed                    | 10051  | 225   | 128  | 50   | 34   | 9   | 10276  | 2.19 | 2.19 | 1.25 | 0.49 | 0.33 | 0.09 |
| Average age of buildings      | 36     | 26    | 25   | 26   | 27   | 27  | 36     | 2.19 | 2.19 | 1.25 | 0.49 | 0.33 | 0.09 |
| Medium value of houses ($)    | 84754  | 124511| 131761| 135497| 129572| 121421| 104306| 104632|
| Total population without health insurance | 118549 | 5149  | 2007 | 1177 | 1111 | 709 | 146 | 123698 | 4.16 | 4.16 | 1.62 | 0.95 | 0.90 | 0.57 |
| Native                        | 322995 | 11483 | 4623 | 2816 | 2571 | 1243 | 231 | 334478 | 3.43 | 3.43 | 1.38 | 0.84 | 0.77 | 0.37 |
| Foreign born                   | 96176  | 3640  | 1459 | 792  | 766  | 518 | 105 | 99816 | 3.65 | 3.65 | 1.46 | 0.79 | 0.77 | 0.52 |
| Total houses                   | 148373 | 6685  | 2314 | 1608 | 1721 | 900 | 142 | 155058 | 4.31 | 4.31 | 1.49 | 1.04 | 1.11 | 0.58 |
| Total occupied houses          | 122889 | 4812  | 1819 | 1155 | 1161 | 577 | 100 | 127701 | 3.77 | 3.77 | 1.42 | 0.90 | 0.91 | 0.45 |
| Total vacant houses            | 25484  | 1873  | 495  | 453  | 560  | 323 | 42  | 27357 | 6.84 | 6.84 | 1.81 | 1.65 | 2.05 | 1.18 |

Table A.4 Socio-demographic characteristics of projected population who are exposed to storm surge under Hurricane Category 4

| Unflooded Flooded Level | Flooded Level |
|-------------------------|---------------|
| 0-2' 2-4' 4-6' 6-9' 9-21' | Total         |
| Flooded Level           | 0-2' 2-4' 4-6' 6-9' 9-21' |
| Category                        | Total Population | Male          | Female         | 65 or Older (Female) | 65 or Older (Male) | White       | Black    | Native  | Asian  | Other  | Same House 1 Year Ago | Different House 1 Year Ago | Spanish | English Only | Total Families | Families with No Husband | Total Population (Age 25 or Older) | No Schooling | Less than High School | High School Diploma | Associate Degree | Bachelor Degree | Professional Degree | Some College | Graduate Degree | Medium Household Income ($) | Total Household | Households with Public Assistance |
|--------------------------------|-----------------|---------------|----------------|---------------------|---------------------|-------------|----------|---------|--------|--------|----------------------|---------------------------|---------|-------------|-----------------|------------------------|--------------------------|-------------|--------------------------|-----------------|---------------------|------------------------|----------------|------------------------|
|                                | 371782          | 181536        | 190245         | 7297                | 3882                | 347728      | 2245     | 943     | 2675   | 18190  | 332991                                           | 28605                                           | 83065   | 25966                                  | 85745          | 22004               | 217562                                           | 9125          | 61062                                | 57153          | 15745                            | 25768                                            | 1878         | 37337                             | 9404           | 39568                           | 110190                                            | 2442         | 95788                               |
### Table A.5 Socio-demographic characteristics of projected population who are exposed to storm surge under Hurricane Category 5

| Unflooded | Flooded Level | Flooded Level |
|-----------|---------------|---------------|
|           | 0-2’ | 2-4’ | 4-6’ | 6-9’ | 9-21’ | Total | 0-2’ | 2-4’ | 4-6’ | 6-9’ | 9-21’ |
| Total population | 274635 | 159659 | 45007 | 37197 | 28893 | 28947 | 19615 | 434294 | 36.76 | 36.76 | 10.36 | 8.36 | 6.65 | 6.67 |
| Category                          | Male    | Female    | 65 or older (Female) | 65 or older (Male) | White     | Black     | Native    | Asian     | Other     | Same house 1 year ago | Different house 1 year ago | Spanish      | English Only | Total families | Families with no husband | Total population (age 25 or older) |
|----------------------------------|---------|-----------|---------------------|-------------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------------|--------------|--------------|-----------------|-------------------------------|----------------------------------|
| Age                              | 133715  | 140919    | 5833                | 3126              | 255340   | 1551      | 684       | 2056      | 15004     | 246214                | 20799                      | 59165        | 23186        | 63524          | 16152                      | 162228                           |
| Race                             | 77900   | 81760     | 2318                | 1210              | 152418   | 890       | 386       | 914       | 5051      | 143996                | 11820                      | 37573        | 6448         | 36741          | 9225                        | 91540                           |
| Same family                      | 22105   | 22902     | 743                 | 368               | 42798    | 251       | 140       | 242       | 1577      | 39568                 | 3885                       | 10963        | 1406         | 10199          | 2832                        | 25346                           |
| Household income ($)             | 18319   | 18878     | 513                 | 267               | 35418    | 288       | 85        | 254       | 1151      | 26118                 | 2731                       | 9188         | 977          | 8544           | 2129                        | 21415                           |
| Education                        | 14197   | 14697     | 304                 | 172               | 27658    | 154       | 79        | 159       | 844       | 26342                 | 2198                       | 6855         | 866          | 6544           | 1632                        | 16368                           |
| Dropout                          | 13966   | 14982     | 346                 | 190               | 18783    | 121       | 59        | 161       | 845       | 18270                 | 2069                       | 6564         | 1355         | 6721           | 1603                        | 11869                           |
| Bachelor degree                  | 9313    | 10301     | 412                 | 213               | 407758   | 77        | 23        | 98        | 634       | 390210                | 936                        | 4003         | 1844         | 4587           | 1029                        | 11899                           |
| Associate degree                 | 21165   | 222679    | 8151                | 4336              | 470758   | 2441      | 1070      | 2970      | 20055     | 39210                 | 32619                      | 96738        | 29634        | 30265          | 25377                      | 253768                          |
| Medium household income ($)      | 36.81   | 36.72     | 28.44               | 27.90             | 37.38    | 36.46     | 36.10     | 30.76     | 25.19     | 36.90                 | 36.24                      | 38.84        | 21.76        | 36.64          | 36.35                      | 36.07                           |
| Total household                  | 36.81   | 36.72     | 28.44               | 27.90             | 37.38    | 36.46     | 36.10     | 30.76     | 25.19     | 36.90                 | 36.24                      | 38.84        | 21.76        | 36.64          | 36.35                      | 36.07                           |
| Household with public assistance | 36.81   | 36.72     | 28.44               | 27.90             | 37.38    | 36.46     | 36.10     | 30.76     | 25.19     | 36.90                 | 36.24                      | 38.84        | 21.76        | 36.64          | 36.35                      | 36.07                           |
| Household without public assistance| 36.81  | 36.72     | 28.44               | 27.90             | 37.38    | 36.46     | 36.10     | 30.76     | 25.19     | 36.90                 | 36.24                      | 38.84        | 21.76        | 36.64          | 36.35                      | 36.07                           |
|                                | 2009 | 2011 | 2013 | 2014 | 2015 | 2016 | 2017 | 2019 |
|--------------------------------|------|------|------|------|------|------|------|------|
| Total population (labor force)| 20097| 115157| 32376| 27052| 20749| 14352| 316094| 36.43|
| In labor                      | 111628| 64322| 17634| 15405| 11971| 11701| 7611| 175950| 36.56|
| Unemployed                    | 6467| 3809| 1080| 959| 750| 668| 351| 10276| 37.07|
| Average age of buildings      | 36| 27| 28| 27| 26| 27| 36|
| Medium value of houses ($)     | 84754| 113604| 102289| 108756| 117159| 121693| 118123| 99179| 41.56|
| Total population without health insurance | 72291| 51407| 14252| 11752| 9178| 9528| 6697| 123698| 34.92|
| Native                        | 217687| 116791| 32655| 27014| 21079| 21334| 14709| 334478| 42.95|
| Foreign born                   | 56947| 42869| 12352| 10183| 7814| 7614| 4906| 99816| 42.95|
| Total houses                   | 103548| 51510| 14111| 11610| 8795| 9295| 7699| 155058| 33.22|
| Total occupied houses          | 83194| 44507| 12486| 10292| 7818| 8008| 5902| 127701| 34.85|
| Total vacant houses            | 20354| 7003| 1624| 1317| 978| 1287| 1797| 27357| 25.60|

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Appendix B

Figure 1. Hurricane Evacuation Routes in Brownsville and Rio Grande Valley
Source: Texas Department of Transportation (TxDOT) [25]

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