ISSN 2348-1218 (print)
International Journal of Interdisciplinary Research and Innovations ISSN 2348-1226 (online)
Vol. 6, Issue 3, pp: (522-527), Month: July - September 2018, Available at: www.researchpublish.com

Development of Hurricane Storm Surge Model to Predict Coastal Highway Inundation for South Texas

Sara Esther Davila[1], Adan Garza[2], Jungseok Ho[3]

[13]Civil Engineering, University of Texas Rio Grande Valley, Edinburg, Texas, U.S.A.
[2]Jacobs Engineering, Central Texas Transportation, Austin, Texas, U.S.A.

Abstract: **Forecasting areas prone to flooding will allow us to send off our information gathered to departments such as TxDOT and the United States Department of Transportation. This would then enable these departments to create appropriate evacuation routes, depicting which roads are clear and which cannot be used in the event of a storm. Simulating hurricanes that have passed through this area such as Dolly in 2008, Beulah in 1967, and Bret in 1999 will display the roads and federal highways that frequently tend to get flooded. Identifying the "danger roads" and which federal highways will ultimately be useful for various engineering purposes, such as show the information produced. Since roads act as not only a means for transportation, but a very important drainage system as well. In the Willacy County and Cameron County, there is about 14 major highways (four of them which are US highways). A research study is being proposed over the course of the year that would project the overflow of storm surge onto USDOT and TXDOT major highways. The project entailment is to simulate about 3 historical hurricanes that have passed through the Laguna Madre and focusing on about five of the nearest highways along the coast. This would give the project outcome of receiving the adequate information to identify how much of each highway would get flooded from each Hurricane, as well as the duration of the surge submerging the areas of each specific highway.**

Keywords: **Hurricane, storm surge, highways, roads.**

I. INTRODUCTION

The Laguna Madre is a hypersaline lagoon which separates the Padre Island and the Texas inland. The Lower Laguna Madre stretches around 95 kilometers and has a width ranging from 3 to 12 kilometers. [1] The average depth is of about one meter, according to Texas Parks and Wildlife. It is most famous for it being the longest barrier island in the world, as well as for it being one of the six hypersaline lagoons in the world. [1] It is also a unique and a key setting in the world since it is the birth home of many flora and fauna that thrive on hypersaline environments and cannot be found anywhere else. Because of these special attributes, it has obtained its name ("Mother Lagoon" in English). Hurricanes are the most frequent natural hazards that the residents of South Texas must prepare and protect themselves from. Hurricanes are tropical disturbances that are formed due to warm waters and low-pressure systems [1]. Hurricanes bring about tides, rainfall, strong winds and storm surge that can cause major damage. Hurricane storm surge is the abnormal rise in sea level caused by a passing storm that destroys coastal lands due to the extensive eroding caused by the rapid flow circulation of a hurricane. Overland floods are also caused by storm surge. This, along with rainfall can cause severe floods in many locations along the south Texas coast and it is essential to be aware of the potential damages hurricanes can reciprocate.

Figure 2 depicts the Gulf of Mexico bathymetry as well as several historical hurricane tracks that have passed through and made impact along the Lower Rio Grande Valley, specifically the Lower Laguna Madre, which is boxed in red. The SMS is a program that can withhold many numerical models and provides tools for every phase of a hydraulic simulation including site characterization, model development, post-processing, calibration, and visualization. SMS provides an integrated graphical environment for performing surface flow, contaminant fate/transport, and project design evaluations. [3] ADCIRC (ADvanced CIRCulation) model is a system of computer programs that uses finite element method to create mesh, which can then be used to determine occurrences such as: storm and flood prediction and modelling, tidal and wind effects on circulation, and even dredging feasibility and material disposal studies. [11]. The project goal of this research project is to simulate several historical hurricanes that have passed through the Lower Laguna Madre/South Texas area. The Hurricanes will be simulated using ADCIRC modelling, and then an approximated peak storm surge height of each will be determined. Once this is obtained, implementation of the data onto a geographic information system (GIS) map will be done to determine what highways and roads will be unavailable during the event of those specific hurricanes. With this forecasting information, flood maps and evacuation routes can be proposed to Emergency Evacuation planners along South Texas. This would increase preparedness and benefit specifically the residents of areas prone to damage caused by hurricanes. Another way the results of this study can be used for is for mitigation purposes: if a levy needs to be implemented in a certain area to prevent development loss. It can be planned and designed as per the results. This study presents a numerical development of coastal storm surge maps due to historical hurricanes that have passed through and using GIS application to identify affected roads and highways.

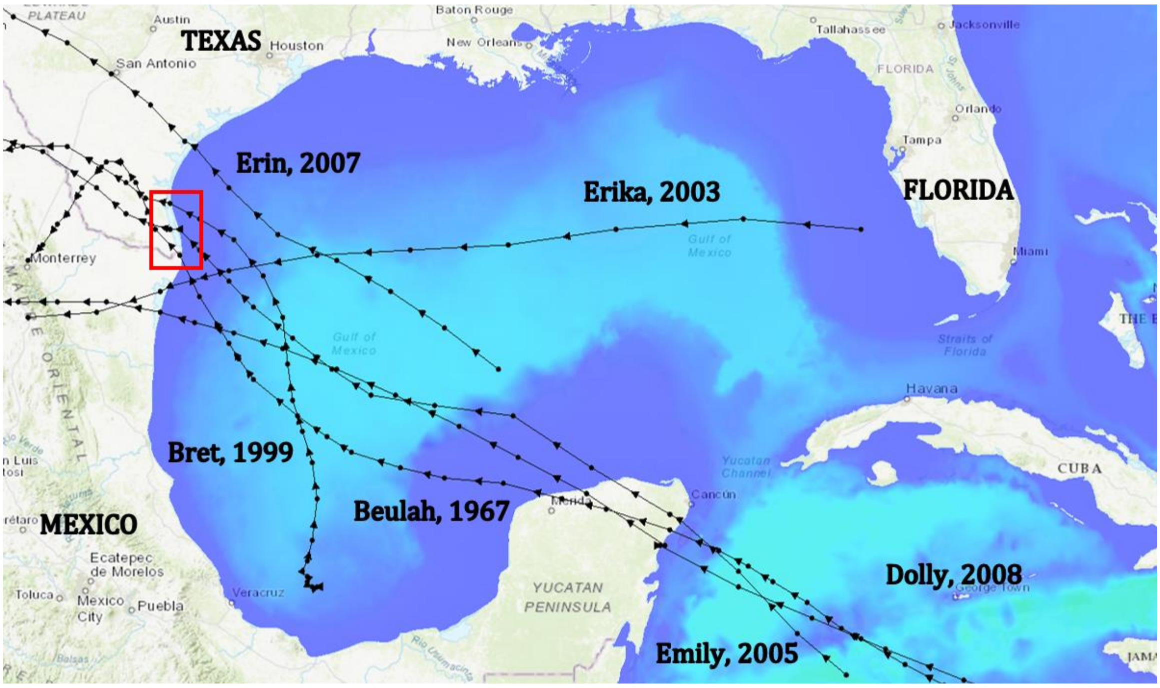


Figure 1: The Lower Rio Grande Valley location map along with Historical Hurricane Storm Events

II. METHODOLOGY AND MODEL IMPLEMENTATION

The 2D mesh shown in Figure 1 above entails the Gulf of Mexico in its entirety. This automated mesh was downloaded from Aquaveo website; however, NOAA is the actual creator of this mesh and it was created for research purposes. The SMS is a computer program that is known to be the most sophisticated riverine, wetland, coastal, and estuarine modelling environment available today. [3] The ADCIRC model that has been developed by the U.S Army Corps of Engineers was used for the flow circulations. The SMS was adopted for the model for processing of the numerical domain finite element mesh creations, model control, the editing of properties, and computational result visualization. The model provides an integrated graphical environment for performing surface flow, contaminant fate and transport, and project design evaluations [3]. Node strings are created within SMS to create and to build a geographic boundary of the domain that will dictate the computation areas of water and land to assign numerical boundary conditions by enclosing meshes. Along the Laguna Madre and Padre Island coasts, the node strings will be tighter together; furthermore, the node strings along the Gulf of Mexico coast will be more relaxed. The togetherness of node strings will bring about finer 2-dimensional mesh, while the more relaxed node strings would bring about coarser mesh. It is important to obtain the finer mesh along the Laguna Madre area since it is our area of focus and finer mesh would accord less error in the simulation results. After building boundary condition node strings and setting up a geometric mesh the model takes bathymetry data. Bathymetry used for this research study was obtained from two sources and then merged into a single raster file for modelling purposes. Using the SMS software, DEM (Digital Elevation Model) data and Gulf of Mexico Scatter data obtained by NOAA are merged to make one large scatter data set. A 1/3 arc-second raster (Lower Laguna Madre raster) was obtained from the National Oceanic and Atmospheric Administrations' National Center for Environmental Information Converting from raster to scatter data was necessary since the raster file was in a GIS format. It must be converted into a scatter set format for SMS to read the bathymetric data and interpolate nodal elevations. A Gulf of Mexico 2-dimensional mesh was used; however, this data file did not need much manipulation. Since it was already in 2-dimensional mesh format, the only thing needed is to convert from mesh to scatter data. Merging the two entities was required due to the large scale of the model's domain, and it was done using a tool on SMS. This newly created scatter data set can now operate to generate 2-dimensional mesh on ADCIRC using the automatic meshing tool. The grid in Figure 2 is the finite element grid that has been modified to include South Texas and the Gulf of Mexico. The Gulf of Mexico is implemented for effective computations of the south Texas coast tropical cyclone tracking.

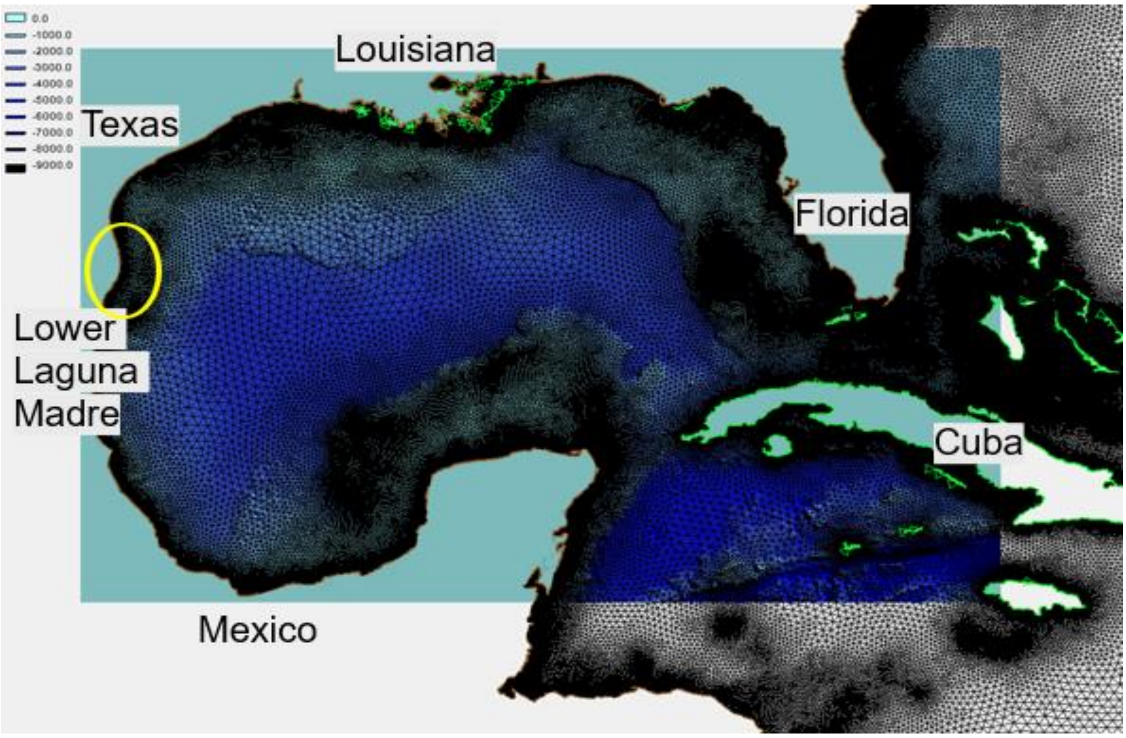


Figure 2: ADCIRC 2-dimensional finite element mesh

There are several input files needed from the symmetric cyclone for it to be considered for simulation by ADCIRC. The National Hurricane Center (NHC) from NOAA provides within the Historical Hurricane Archive a northeast and north central pacific database text file with all recorded hurricanes from the year 1949-2017 [8]. Downloading this file and opening it as a "hurdat.2" file on SMS would allow us to implement any hurricane within that database file. ADCIRC model input are specific as to what information is needed by the user. The HURDAT2 file has the information needed to successfully implement a symmetric cyclone to the ADCIRC model. Several Historical Hurricanes that have passed through the Laguna Madre will be implemented into our ADCIRC model, as well as some other input files necessary for successful simulation. The HURDAT2 file includes parameters such as: the date/time of each recorded hurricane, the coordinate location, the direction the hurricane is going, wind speed, atmospheric pressure, radius of last isobar, speed of hurricane, and the pressure of the hurricane [2]. Because Hurricanes are symmetric cyclones, many of the input files will have a constant number throughout, like the radii of the hurricane. This simplifies and shortens the simulation time. The model will be simulated with the hurricane included and obtain the output files ADCIRC provides us with. Simulation time will vary depending on computer configuration, how refined the model is, and the duration of the hurricane. The table below depicts the Historical hurricanes used throughout the research study as well as some important information regarding these storms.

TABLE 1: HISTORICAL HURRICANE DATA [5].

Hurricane	Year	Category	Maximum Wind Speed (knots)	Atmospheric Pressure (mbar)
Beulah	1967	5	233.4	923
Bret	1999	4	125	944
Dolly	2008	2	144.5	963

The output data ADCIRC computer model gives out after simulation has been completed come in text files, and each file holds different parameter information. The output files are: fort.61 (Water Surface Elevation data at a recorded observation point), fort.63 (elevation/bathymetry time series), fort.64 (velocity time series), fort.73 (atmospheric pressure time), and fort.74 (wind velocity). With the fort.61 file, we can compare the ADCIRC simulation storm surge to the actual real-life water surface elevation data obtained from one of the NOAA Buoy stations stationed in the Laguna Madre. The NOAA Buoy station ID: 8779770 is used for this research study and it is located in Port Isabel, Texas. [4.] Once the maximum-peak storm surge has been accurately calculated, it will then be placed on QGIS to create a storm surge map of Hurricanes: Dolly 2008, Bret 1999 and Beulah 1967.

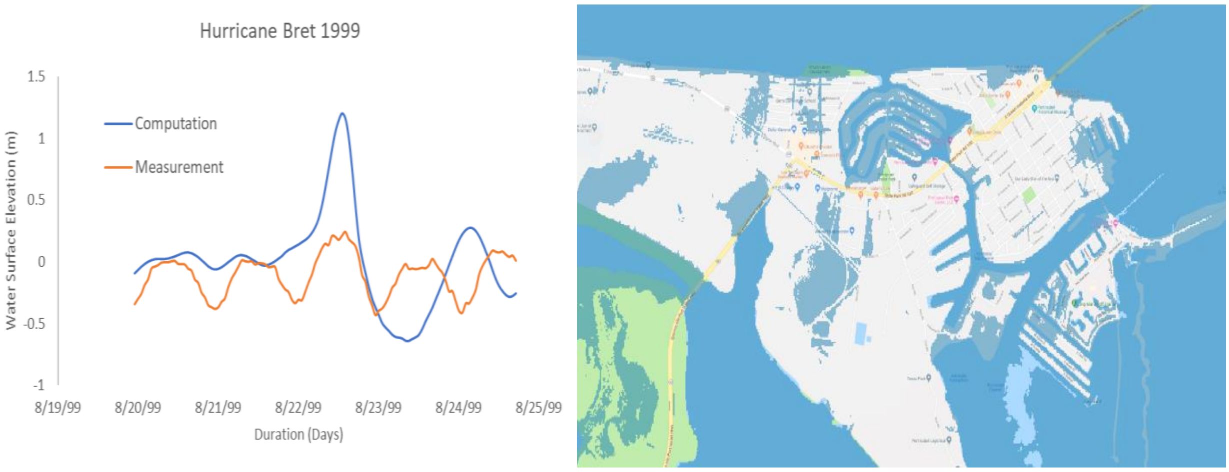
III. RESULTS AND ANALYSIS

The Hurricane Dolly 2008 event was used for the LRGV model validation. The model's computation of water surface level was compared with the measurements from NOAA buoy station (Port Isabel, ID: 8779880) [4] by adjusting the tidal constituents (K1, O1, P1, and Q1) and coastal floor bottom roughness. One second of computational time step was assigned for a total of seven days of runtime. The HURDAT2 fed the Hurricane Dolly 2008 tracking data starting July 20, 2008. The computed water surface levels (blue colour line) in Figure 3(a) show a very good agreement with the NOAA buoy station measurements in orange colour line. The maximum storm surge was over estimated slightly as 1.21 m than 0.78 m of measurements. However, the LRGV model predicted promising storm surge trend and timing of the Hurricane Dolly.

(a) (b)

Figure 3: Water Surface Elevation fluctuation comparisons of the Lower Laguna Madre model computations and NOAA buoy measurements of hurricane Dolly July 22-27, 2008.

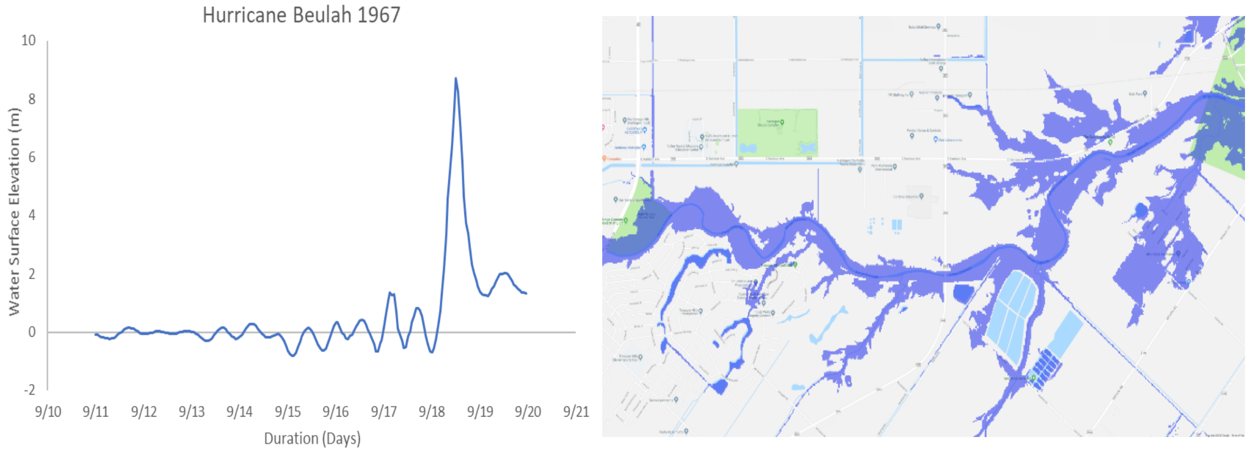
The Lower Rio Grande Valley flow circulation model simulated the coastal hurricane storm surge reasonably, as shown in Figure 3. The counter clockwise cyclone pushes the shallow water of the Lower Laguna Madre from the east side (South Padre Island) as shown in red contoured area, when the cyclone is approaching to the coast. The computed maximum storm surge height was about 3.8 m at the west shoreline. Hurricane Dolly, as shown on the GIS map Figure 3(b), closes off the Brownsville-Port Isabel Highway 48, and as well floods many surrounding structures.



(a) **(b)**

Figure 4: (a) Water Surface Elevation fluctuation comparisons of the Lower Laguna Madre model computations and NOAA buoy measurements of hurricane Bret August 20, 1999 to August 25, 1999 and (b) coastal storm surge map of Port Isabel area

Hurricane Bret, as it is shown in Figure 5 (a), had an approximate computational storm surge height of 1.2 meters (3.9 ft.) according to the Lower Laguna Madre model. The computational time step implemented for Hurricane Bret was of 5 days. Overlaying the surge map on a street map image of the Port Isabel, Texas, area, as shown in Figure 4 (b), moderate flooding is occurring. Some neighbourhood roads will inundate, and some docks would be submerged. According to Figure 4, parts of the Brownsville/Port Isabel Highway 48 will be submerged during the peak-storm surge time.



(a) **(b)**

Figure 5: The Lower Rio Grande Valley model predictions of Hurricane Beulah – (a) water surface elevation changes and (b) the coastal storm surge map of the Arroyo Colorado in Harlingen, Texas area

Because Hurricane Beulah occurred during a time when Buoy Station ID: 8779770 was unavailable for recording, we are depending on the ADCIRC computational model results only and assuming the prediction is accurate. Figure 7 depicts the approximate peak-storm surge Beulah caused was approximately 8.37 meters (27.5 ft.). The massive surge completely submerged the cities of Port Isabel and Laguna Vista. Figure 6 shows the part of the Arroyo Colorado channel that passes through the city of Harlingen, which is about 31 miles from the Laguna Madre. Arroyo Colorado drain canal passing the City of Harlingen, which is one of the major flood control channels (approximately 145 km long, [7]) of the Lower Rio Grande Valley watershed. Highways like 499 and Business 77 in the Harlingen area will be underwater since they cross pass to the Arroyo Colorado. Since it drains into the Lower Laguna Madre, the water surface level at the estuary is a critical factor of the channel flow, e.g., backwater from the Lower Laguna Madre.

IV. CONCLUSION

After extensive research and analysis, it can be concluded that ADCIRC computational modelling is a useful tool for weather forecasting and for hurricane studies. Historical hurricane data information provided by NOAA, as well as a fine grained, 2-dimensional finite element model can produce accurate results. The model computes fundamental information of hurricane storm surge analysis, with the insertion of hurricane tracks over the modelling domain, 2-dimensional velocity vectors of wind and water flow, and dynamic water surface level during any hurricane period. From the data obtained with regards to this study, it is with forthright to adopt the theory that any category 5 hurricane, such as Beulah 1967, will cause catastrophic damage and close off a large portion of South Texas roads and highways, especially to the cities by the bay, such as Port Isabel and Laguna Vista. This will prevent any automobile evacuation during and after the storm. A total of three major highways will always have areas submerged with any category hurricane, whereas a total of five major highways will be severely affected if a category five hurricane makes landfall in South Texas. This research study focused primarily on storm surge outputs created by symmetric cyclones. Other parameters caused by hurricanes, such as rainfall, were not taken into consideration. In this study, the modelling performance was promising; however, to fill the information gap regarding the impact of a hurricane storm surge on coastal inundation, the Lower Rio Grande Valley Model needs to be substantially improved by model parameter calibrations. Implementing multiple parameter calibrations would greatly improve the model and thus the research study. Nonetheless, it is important to prepare for any type of tropical storm or hurricane event. Storm surge is an important parameter to observe when planning evacuation routes.

REFERENCES

[1] Nationalgeographic.com. (2018). *How Hurricanes Form and What Makes Them So Destructive*. [online] Available at: https://www.nationalgeographic.com/environment/natural-disasters/hurricanes/ [Accessed 1 Aug. 2018].

[2] Nationalgeographic.com. (2018). *How Hurricanes Form and What Makes Them So Destructive*. [online] Available at: https://www.nationalgeographic.com/environment/natural-disasters/hurricanes/ [Accessed 1 Aug. 2018].

[3] "SMS – Surface-water Modeling System", Engineer Research and Development Center, U.S. Army Corps of Engineers, https://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/919656/sms-surface-water-modeling-system/, Retrieved August 1, 2018.

[4] "Tides and Currents", Center for Operational Oceanographic Products and Services, National Oceanic and Atmospheric Administration, https://tidesandcurrents.noaa.gov/stationhome.html?id=8779770, Retrieved August 1, 2018.

[5] Wunderground.com. (2018). *Hurricane Archive | Weather Underground*. [online] Available at: https://www.wunderground.com/hurricane/hurrarchive.asp [Accessed 1 Aug. 2018].

[6] Dietrich, J.C., S. Tanaka, J.J. Westerink, C.N. Dawson, R.A. Luettich Jr, M. Zijlema, L.H. Holthuijsen, J.M. Smith, L.G. Westerink, H.J. Westerink (2011). "Performance of the unstructed-mesh, SWAN+ADCIRC model in Computing hurricane waves and surge" J Sci. Comput., http://dx.doi.org/10.1007/ s10915-011-9555-6.

[7] Mukai A.Y., J.J., Westerink, R.A. Luettich, and D. Mark, (2002), "Eastcoast 2001, A tidal constituent database for Western North Atlantic, Gulf of Mexico, and Caribbean Sea", Engineering Research and Development Center, U.S. Army Corps of Engineers, Vicksburg, MS.

[8] "NHC Data Archive", National Oceanic and Atmospheric Administration, https://www.nhc.noaa.gov/data/#hurdat, Retrieved May 20, 2018.

[9] "Arroyo Colorado about the Watershed", Arroyo Colorado Organization, http://arroyocolorado.org/about-the-watershed/, Retrieved August 11, 2018.

[10] "U.S. Billion-Dollar Weather and Climate Disasters (2018), NOAA National Centers for Environmental Information (NCEI), https://www.ncdc.noaa.gov/billions/, Retrieved April 9, 2018.

[11] Adcirc.org. (2018). [online] Available at: http://adcirc.org/ [Accessed 1 Aug. 2018].