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Hydrologic Modeling Study to Determine Hydrologic Impact of Resacas on the Lower Laguna Madre Watershed

Antonio L. Reyna
The University of Texas Rio Grande Valley

HYDROLOGIC MODELING STUDY TO DETERMINE HYDROLOGIC IMPACT OF RESACAS ON THE LOWER LAGUNA MADRE WATERSHED

A Thesis

by

ANTONIO L. REYNA

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COMMITTEE MEMBERS

Dr. Jungseok Ho

Chair of Committee

Dr. Andrew Ernest

Committee Member

Dr. Abdoul A. Oubeidillah

Committee Member

May 2022

ABSTRACT

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During a high intensity storm events, a series of catastrophic events occur. These catastrophic events include flooding and destruction of infrastructure. Engineers have determined a method to design for high intensity storms based off hydrologic analysis of previous storms. With this data engineers can determine the outflow of major rivers and streams that may impact infrastructure. By determining the watershed engineers can predict the flow of the water and as well as the location of the outfall. In the Rio Grande Valley, water quality is very important because after rain events stormwater from cities is carried out towards the Laguna Madre, which is home to an array on environmental habitats and wildlife. With the determination of the watershed boundaries of this region, engineers and environmentalists can use this data to determine where pollution source points that can affect the environment are located.

This project will simulate the watershed boundaries for the region of the Lower Laguna Madre using ArcGIS in conjunction with the extension HEC-GeoHMS, a tool developed by the Hydrologic Engineering Core. With the use of a Digital Elevation Model (DEM) provided by the United States Geologic Survey, the watershed boundaries were delineated using both ArcGIS and the HEC-GeoHMS extension. These watershed boundaries were then compared to existing watershed boundaries in the region to check the validity. The Rio Grande Valley is considered a

flat region that does not have a very erratic change in slope, it is also covered by a series of canals and streams; because of these factors found in the terrain, an exact delineation is hard to determine. With the completion of the watershed delineation and the development of the hydrologic model in the area will developed to simulate the impact of the resacas in the region

DEDICATION

This thesis could not have been completed without the continued support from my family. Their unwavering support from both my parents and siblings was greatly appreciated during the time it took to reach this point. This chapter of my academic career could not have been completed with the relentless support of my mother, Maria Barrgan, and my father, Antonio Reyna. Time and time again I am grateful to have them both as my parents, as I know that with their support and wisdom, anything is achievable. My younger siblings Nixie and Jesus were a always a great help in providing a needed break or distraction from this long journey. Special thanks to my extended family and friends who without their knowing also greatly helped reach this point in my life.

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CHAPTER I

INTRODUCTION

Chapter 1.1 History of the Study Region

The Rio Grande Valley (RGV) is a region located in the southernmost region of the state of Texas. The RGV consist of four counties which include Cameron, Hidalgo, Willacy, and Starr. The focus of this study will be the two eastern coastal counties, Cameron County and Willacy County. These two counties are prone to coastal storms, such as hurricanes and tropical storms, during the hurricane season. These storms create high intensity rain events, that in turn can create this region into a flood prone area if the drainage infrastructure is not up to date, well maintained or well designed. In the RGV the drainage infrastructure consists of a series of drainage ditches that flow from the west end of the region to the east end. Each drainage ditch outfalls into another larger drainage ditch that will convey stormwater runoff into one of three main drainage channels depending on the location of the drainage infrastructures. The Arroyo Colorado (located in Cameron and southern Hidalgo County), the Brownsville Ship Channel (located in Cameron County), or the Main Floodway (located in Hidalgo and Willacy County). These three channels then outfall into the Laguna Madre Bay which will outfall into the Gulf of Mexico. Most rainfall that falls near the Rio Grande River will flows into the river; this storm water runoff will also outfall into the Gulf of Mexico.

For this study the region that will be specifically looked at is the Lower Laguna Madre watershed (LLMW), which is found within HUC 12110208 within Cameron County. Currently this watershed is currently in line to become a protected watershed with approval from the United States Environmental Protection Agency (EPA). One of the requirements is to create a hydrologic model for the watershed to determine the response of waterflow in the watershed.

The geologic attribute of a valley consists of a land mass surrounded by various mountains or hills. The RGV is not this type of geological feature, the RGV is a coastal plain. The terrain in this region is very flat averaging a land slope of 0 to 1 percent. A hydrologic characteristic that can cause flooding in areas due to the waterflow not being able to quickly and freely move down stream. The land use is typically seen mixed as both agricultural and urbanized. The climate is arid with occasional droughts seen in some years to semi-arid. The spring is warm with moderate to high winds with a small amount of rain in the month of April. The summer is hot and dry with the possibility of hurricanes during the summer hurricane season and rain during the latter part of June or early part of July. The fall is slightly cooler than the summer, but the temperature change is no more than a 10 to 15-degree Fahrenheit difference with occasional cold fronts passing through the region. The winter is like the fall, however there are small possible chances of rain.

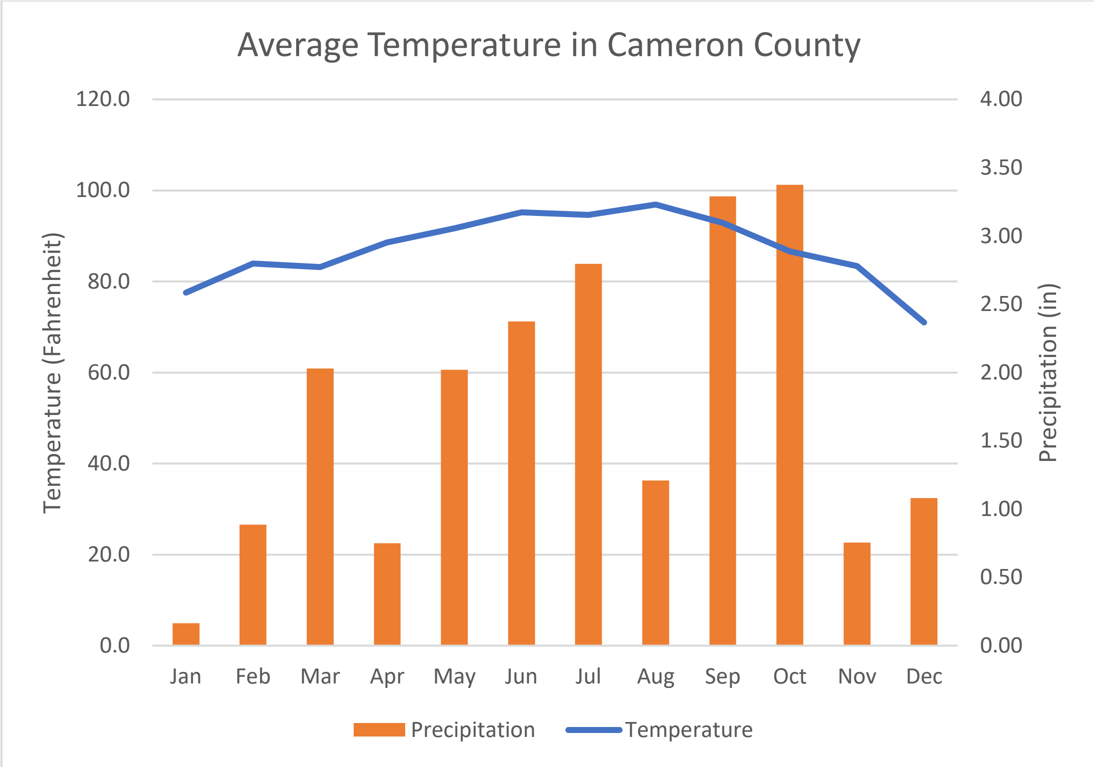

Figure 1: Average Monthly Temperature and Precipitation in Cameron County

Recently storm events have been increasing in intensity, causing risk for flooding events as well as flash flood events. In late June of 2018, the RGV experienced heavy rainfall that equated the intensity of a 500-year storm event. This rainfall created flooding in many urbanized subdivisions, forcing residents to evacuate their homes. Cause for this flooding was attributed to oversaturation of the soils form a previous small rain event a few days before the larger one, as well as poor drainage infrastructure. Reactive measures have taken place by studying the current drainage infrastructure via modeling or hydrologic calculations. In late June of 2019 a similar high intensity storm event affected the region again. Localized high intensity storms caused flooding events particularly in the Harlingen area within Cameron County.

Chapter 1.2 Drainage Districts in the Region

In the RGV each county has their own drainage district the manages the maintenance of the drainage infrastructure. Hidalgo County has the county drainage district which manages the rural infrastructure of the county, while the city manages their infrastructure internally with aid from the county whenever necessary. Willacy County has two drainages districts, one funded by the county and another that is privately owned. The Willacy County Drainage District #1 (county funded) is aided in times by the Hidalgo County Drainage District, as they have allowed access to a main floodway the conveys water from Hidalgo County to Willacy County, which will outfall into the Lower Laguna Madre. Cameron County is divided into five drainage districts, each district manages the drainage infrastructure in the rural areas of the county. Other drainage conveyance systems such as irrigation canals are managed by Irrigation Districts within the county. The rural drainage infrastructure is maintained and managed by the main Cameron County offices. Each district has a main floodway or channel that conveys stormwater runoff into the Lower Laguna Madre, *Figure 2* depicts each main drainage channel.

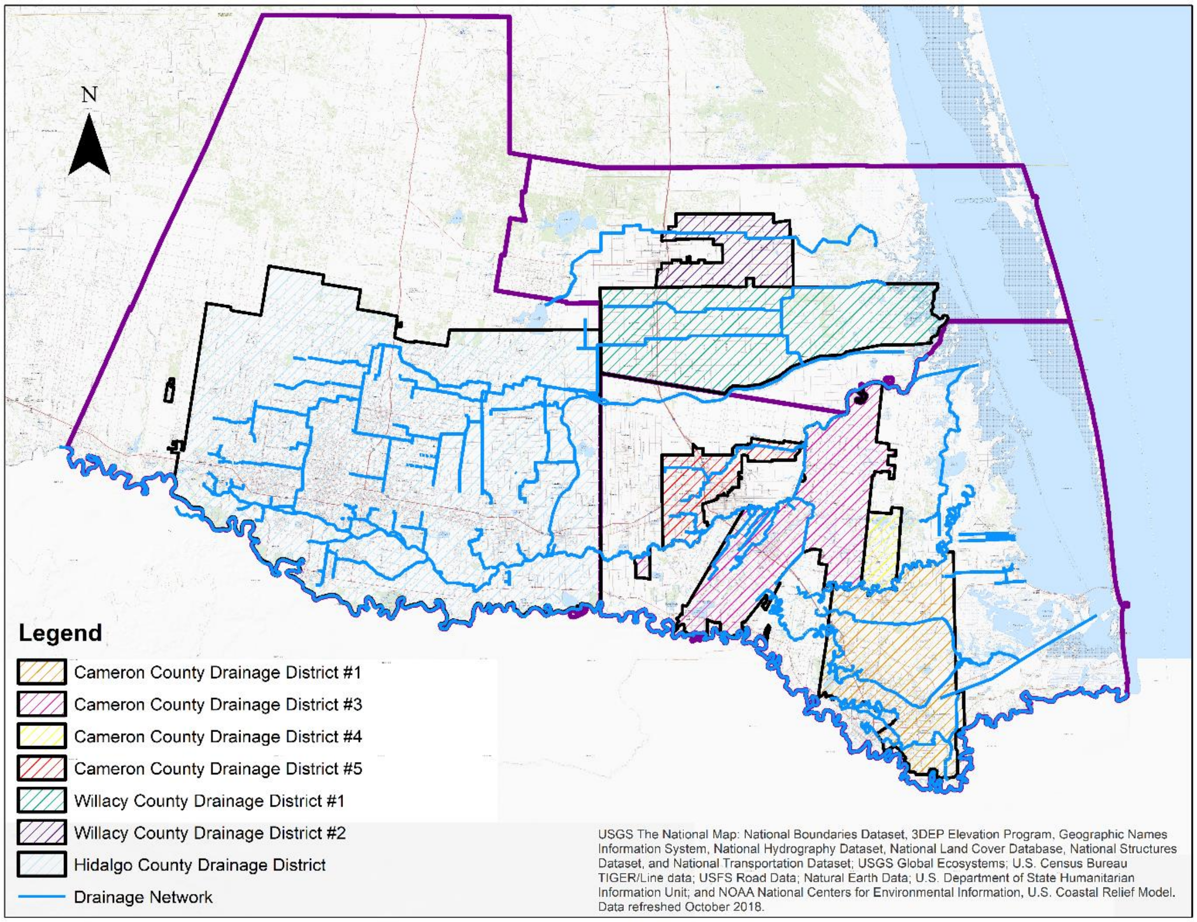

Figure 2: Drainage Districts and Main Drainage Channels

To mitigate flooding in the region, various cities and drainage districts developed either Flood Mitigation Plans, Flood Protection Plans, or Master Drainage Plans. Each of these plans includes an assessment of the state of the current drainage infrastructure, the assessment also includes a resolution or alternatives to avoid flood damages or improve the infrastructure. The National Flood Insurance Program (NFIP) awards cities that are creating flood mitigation plans and are bringing awareness of flooding into the communities by giving a reduced premium on flood insurance. Most of these documents include a hydrologic or hydraulic model that shows the response of waterflow within the watershed the city is located in.

Chapter 1.3 History of Hydrologic & Hydraulic Studies Found Within the Region

An engineering report was developed to help Cameron County Drainage District #3 (CCDD3) assess their drainage infrastructure as well as create contingency plans for future flood events using hydrologic and hydraulic modeling. The area and jurisdiction of CCDD3 contains the city of San Benito as well as parts of Los Indios and Rio Hondo. The engineering firm Espey Consultants, Inc. oversaw the development of the models as well aid in the infrastructure's assessment. The engineering firm developed the models and then developed flood event scenarios. With the results from the model a series of plans were created to alleviate flooding, by either structural repair to the infrastructure or by nonstructural repair. This study was completed in 2010. (Espey Consultants, Inc.)

Another flood protection study was done by Espey Consultants, Inc. for Cameron County Drainage District #5 (CCDD5). Similarly, this study was also to assess the drainage infrastructure for the drainage district with the use of hydrologic and hydraulic models. This study included the City of Harlingen as well as the smaller cities of Palm Valley, Combes, and Primera. The same process and procedures were used from the previous study have adapted to this area. HEC-HMS and HEC-RAS were the two models used in the CCDD3 and CCDD5 study. This study occurred before the study in CCDD3, which was completed in 2010, two years after the study in CCDD5 which was completed in 2008. (Espey Consultants, Inc.)

Cameron County Drainage District #5 has updated their 2008 model in September 2019. For this model CCDD5 employed the services of Scheibe Consulting, LLC to develop an updated hydrologic and hydraulic model, improving on the original model developed in 2008. For the 2019 the consulting firm used updated modeling techniques; implementing 2-dimensional hydraulic analysis to model overland flow in the region. With the use of 2-dimensional overbanks of the channel could be modeled more accurately improving the overall results of the analysis. (Scheibe Consulting, LLC)

In 2006 a Flood Protection Plan was developed for the City of Brownsville by Ambiotec Group in conjunction with Rice University. The document details the current conditions of the city as well as any existing flooding issues that occurred mainly near the local resacas and drainage ditches. The development of three different type of models were used to characterize the watershed, understand the hydrologic and hydraulic response of the watershed, and a third model was used to understand the hydraulics of the reach systems (ditches and resacas). With the use of the models, different options were developed to alleviate the current conditions when flooding would occur.

In 2008 the City of Harlingen tasked the engineer firm Civil Systems Engineering, Inc. to prepare a Master Drainage Plan for the city. Civil Systems analyzed the current drainage infrastructure of Harlingen using a variety of hydrologic and hydraulic model. Within their study they also recommended areas that could be improved to help the drainage system by utilizing their models. Funding recommendations were also giving in their report to help the City decided on alternative financial possibilities to help fund the proposed improvements. (Civil Systems Engineering, Inc.)

In 2014 the City of Edinburg tasked the engineering firm Civil Systems Engineering, Inc. to prepare a Master Drainage Plan for the city. The purpose of the plan was to help the city to develop a plan to prioritize where city funding should be spent for its drainage infrastructure. The document details an evaluation of the current drainage infrastructure using hydrologic and hydraulic models. With the evaluation of the infrastructure with the use of computer models a cost analysis is then created to prioritize where future funding should ideally be spent to properly improve the drainage infrastructure of the city in a beneficial cost-effective manner. (Civil Systems Engineering Inc. & TEDSI Infrastructure Group)

The City of San Juan had a Master Drainage Plan prepared for them by Cruz-Hogan Consultant, Inc. with the intent to help aid the city in understanding its current drainage infrastructure. This study was also used as a basis to determine how new development and new road construction would hydrologically impact the city. With the use of the rational method, the waterflow and drainage patterns were determined to understand the current capacity of the drainage canals and other drainage structures within the city. (Cruz-Hogan Consultants, Inc.)

Each of these studies conducted an analysis of the current infrastructure with the uses of hydrologic and hydraulic models, and in some instances the use of hydrologic computations using Rational Method. This study occurred in 2006 nearly 12 years ago and the city of Brownsville is only one of other communities that can be found inside the watershed that are also growing and urbanizing. With the development of a new updated model, new and update scenarios can be developed to predict high frequency storm events, such as the one that was seen in June 2018.

Cameron County Drainage District #1 in conjunction with the city of Brownsville is creating a flood protection plan. The goal of this plan is to develop or update any gauge stations found within the main drainage canals or drainage laterals. The plan of this study is to predict possible flooding events with the use of predictive measurement based on the behavior of flow within the reaches.

Hidalgo County Drainage District #1 (HCDD1) is looking to create models for any areas that currently see high flood waters during any storm event, with an emphasis in the areas affected by the June 2019 Flood. HCDD1 is also in charge of some of the drainage in Willacy County due to Hidalgo county's main floodway drains out towards Willacy County. The two counties developed an agreement that Hidalgo, being the larger drainage district, will help Willacy County maintain their drainage infrastructure for Willacy County Drainage District #1 (WCDD1). There is currently a bond in place to help develop a new drainage canal (Raymondville Drain) that will help alleviate the high amounts of water flow enter Willacy county's Main Floodway.

In 2014 the Texas Water Development Board developed a Stormwater Drainage Plan to mitigate flooding in small communities located on the Texas-Mexico Border called Colonias. These small residential communities are defined as areas near the Texas-Mexican border that do not have communal necessities such as potable water, sewer systems, paved roads, and safe and sanitary housing. These Colonias can be seen in areas in Hidalgo, Cameron, and Willacy County. This plan was developed as a reactive major to the flooding seen during the 2008 hurricane Dolly, which affected all three counties with its destructive flooding. The plan details the goal to identify the state of the drainage infrastructure and determine a resolution if any problems arise. The current state of this plan is to determine which Colonias issues or have inadequate drainage systems, compile necessary data to make these assessments, and to determine if any hydrologic or hydraulic modeling will be required to improve the assessment.

In 2014, Cameron County developed a document entailing details for flood plain management and regulations. The purpose of this document is to develop rules and regulations that protect the life, property, health, and safety of the citizens of Cameron County during any flooding events in the county caused by tidal waters from the Gulf of Mexico, obstruction effecting the floodplains causing an increase in flood heights, or the occupancy in possible flood hazard areas. This document also states methods for reducing flood loss. These methods include establishing and understanding flood zones that are established by the Federal Emergency

Management Agency (FEMA) flood insurance studies or flood insurance rate maps. These studies and maps that are developed by FEMA require a comprehensive hydrologic analysis of the region which is usually done by hydrologic and hydraulic modeling.

A Flood Mitigation Plan (FMP) for the City of Raymondville was developed in 2004 by MGM Engineering Group, LLC. The FMP purpose was a document to help aid the city inform the residents of what possible actions it would take in flood events as well as inform the residents on the potential risks and dangers of flooding in the city. With the development of the FMP the National Flood Insurance Program awards the city discounted flood insurance premiums to the residents of the city. The document then details the current flood hazards and problems found in the city and then establishes and action plan to improve on the current situation. One of the problems stated in the document is the lack of a flood plan in place for a city that is deemed in a 100-year flood zone by FEMA; one of the resolutions given is to develop and utilize modeling and predictive techniques in the development of a drainage masterplan.

The Hidalgo County Drainage District tasked TurnerCollie&Braden Inc. to develop a Flood Protection Plan for Hidalgo County. This flood protection plan was developed in September of 1997. This document details the previous drainage studies done for the drainage district, current layout and conditions of the drainage infrastructure, and a capital improvement plan which details the cost of possible improvements to the drainage system of the time. One of the purposes of this study is to evaluate the current drainage criteria and recommend modifications to the drainage policy, identify any watersheds associated with the drainage system, and develop a basic mapping system.

Table 1: Current Hydrologic and Hydraulic models found in Cameron and Hidalgo County

Type of Model	Location of Model	Model Creator	Year of Model
EPA SWMM	Harlingen, TX	Civil Systems Engineering	2008
HEC-HMS	Harlingen, TX	Civil Systems Engineering	2008
HEC-HMS	Harlingen; Combes; Primera; Palm Valley, TX	ESPEY Consultants	2008
HEC-HMS	Harlingen; Combes; Primera; Palm Valley, TX	Scheibe Consulting	2019
HEC-HMS	San Benito; Los Indios, TX	ESPEY Consultants	2010
HEC-RAS	Harlingen, TX	Civil Engineering Systems	2008
HEC-RAS	Harlingen; Combes; Primera; Palm Valley, TX	ESPEY Consultants	2008

Table 1, cont.

HEC-RAS	Harlingen; Combes; Primera; Palm Valley, TX	Scheibe Consulting	2019
HEC-RAS	San Benito; Los Indios, TX	ESPEY Consultants	2010
HEC-HMS	Brownsville	Ambiotec Group	2006
HEC-RAS	Brownsville	Ambiotec Group	2006
Vflo	Brownsville	Ambiotec Group	2006
HEC-HMS	Edinburg	Civil Engineering Systems	2014
HEC-RAS	Edinburg	Civil Engineering Systems	2014
Rational Method Calc.	San Juan	Cruz-Hogan Consultants	-

Each of these documents details the use of hydrologic and hydraulic modeling to determine the adequacy of the current design of the drainage infrastructure. These same models are then used to determine alternatives to improve the current design. With changes in the climate and weather, certain models and design criteria must be altered or updated to coincide with the changes. The models developed (*Table 1*) are attributed to being centralized in one small city or town. With a model at too small of a scale, accuracy of determining the waterflow could be inaccurate. This is because some of the models may not consider the inflow of waterflow coming from surrounding watersheds that are outside the project area, thus they are not modeled. Thus, the development of a large scale hydrologic and hydraulic watershed model could be used to better understand the behavior of the watershed and improve the accuracy of the model results.

Chapter 1.4 Summary of Available Hydrologic & Hydraulic Models

The table below details various models that can be used to calculate both hydrologic and hydraulic calculations. Each model may be able to achieve the same results. The difference between each model is mainly accessibility to the user as well as what information is readily available. Some areas may not have LiDAR or terrain data readily available which would make the V flo model harder to use, as it requires geospatial data to provide any type of results. V flo is also not a very common program unlike Hydrologic Engineering Center (HEC) programs which are commonly used in most hydrologic/hydraulic projects. Resource material for V flo may not be easily accessible which can prove to be necessary to help aid in the development of any type of model.

Table 2: Different Hydrologic/Hydraulic models available.

Modeling Software	**Model Description**	**Model Type**
HEC-HMS	Most common hydrologic modeling software. Uses various hydrologic calculation to determine the hydrologic response of study areas. Uses a system of subbasins and junctions to determine subbasin water runoff.	Hydrologic

Table 2, cont.

HEC-RAS	Most common hydraulic modeling software for open channel hydraulics. Uses Manning's Formula to determine water surface elevation and other hydraulic parameters for open channel flow.	Hydraulic
EPA SWMM (Storm Water Management Model)	SWMM is both a hydrologic and hydraulic modeling software. This model is best used for urban areas where pipe systems are used as the main form of storm water conveyance. Hydraulic calculations in this model can be coupled with closed channel systems and open channel systems. Normal hydraulic calculations used are Hazen-Williams and Manning's Formula	Hydrologic/Hydraulic

Table 2, cont.

V flo	V flo is a hydrologic watershed modeling software. Using geospatial data for both rainfall and terrain input, V flow can determine the hydrologic response of a watershed with these inputs. Unlike HEC-HMS, V flow uses a grided system to calculate the hydrologic parameters of the watershed. V flow can give floodplain mapping as well as stage data.	Hydrologic

Every land mass has a defining watershed that determines the direction of stormwater runoff and outfall of the runoff. This is crucial to determine the drainage pattern in the watershed, which is important for the urbanization of the watershed. By determining the drainage pattern of the watershed, localized flooding can be avoided during high intensity storm events, an event that can cripple the development of urbanized areas. By understanding the drainage pattern of the watershed; drainage improvements can be designed and constructed that will help improve the drainage in the area. This could help prevent flooding issues that can be created by rapid urbanization and poor understanding of watershed.

Chapter 1.5 Previous Watershed Delineation Study Developed for the Study Region

A previous study done by the National Water Center Innovators Program Summer Institute in 2016, developed a watershed delineation of the LLMW. This study complied datasets of high resolution lidar data and stream network data (streamline data). With the compilation of this data a watershed delineation was derived by automatic computation of a GIS super computer as well as manual editing of the watershed wherever it was deemed necessary, based off topographic elevation changes found on the lidar data. (Brenda Elisa Bazan) The results of this delineation can be seen on Figure 2. This similar approach was taken to create the watershed delineation in this study, without the use of high resolution lidar data and a GIS super computer.

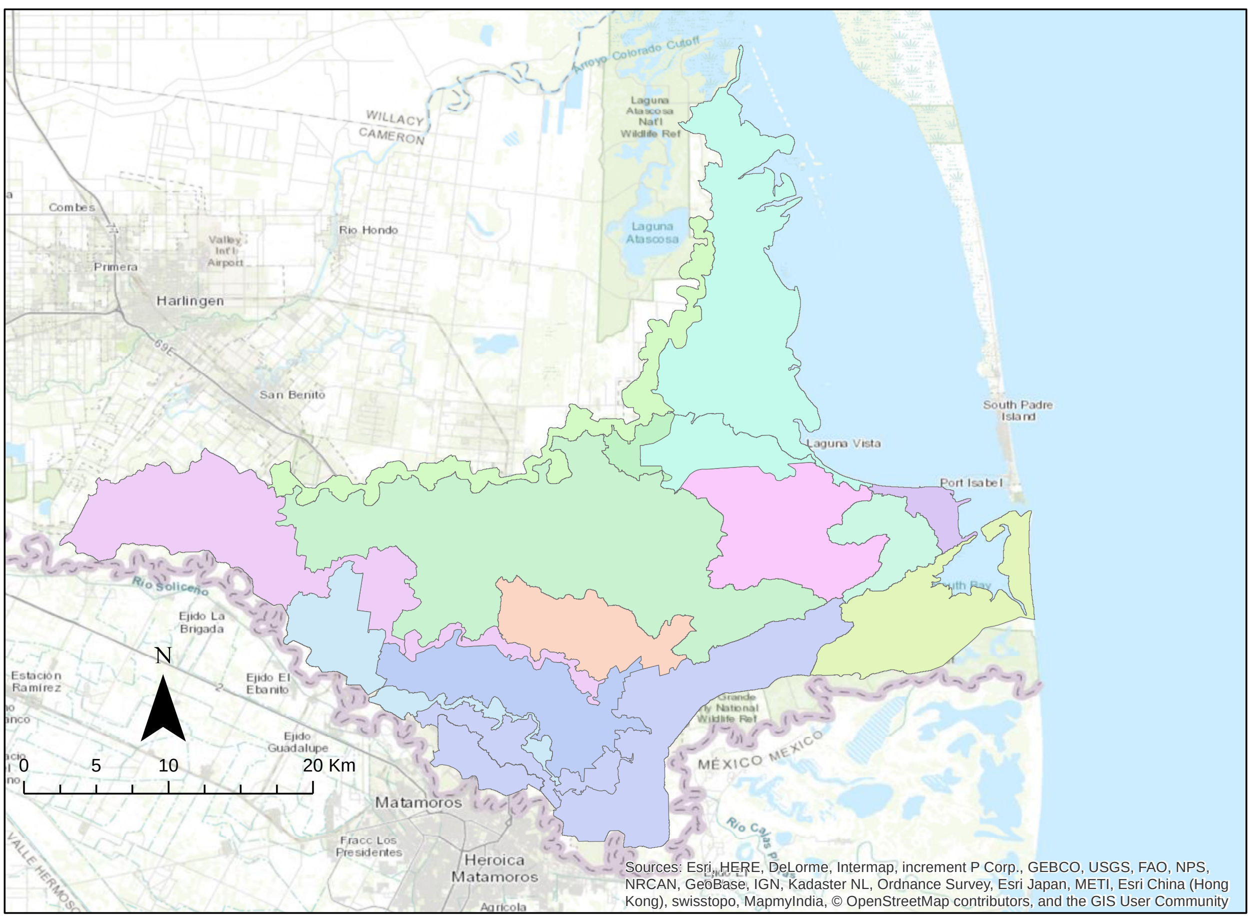

Figure 3: Existing Representation of the Lower Laguna Madre Coastal Watershed

For this project the watershed for the Lower Laguna Madre will be delineated. Once the delineation of the watershed is complete a hydrologic model will be created. To create the watershed delineation, GIS tools will be used to determine the necessary inputs to create the sub-basins for the watershed. A digital elevation model (DEM) as well as the existing stream network for the region will be needed to create the watershed delineation. The DEM and the stream network are merged together to highlight the existing streams and drainage channels in the watershed, creating a burned DEM. This burned DEM will help determine the flow direction as well as the flow accumulation of the watershed.

With the completion of the watershed delineation, a hydrologic model will be created. Using GIS computations, hydrologic parameters such as the basin area, flow length, curve number, percent imperviousness, lag time, and basin slope will be determined. The computation of the curve number and the percent of impervious areas, additional data, soil type and land use, will be required. The hydrologic model will be used in an analysis in determining

Chapter 1.6 Resacas in the Lower Laguna Madre Watershed

In the lower Rio Grande Valley, there are a systems of segmented lakes or streams, locally called Resacas. Resacas are formed from the Rio Grande River during times of high flooding in the region. Prior to the urbanization of the region and flow control structures on the Rio Grande River, the river was free to overbank and flood the region causing smaller river streams that would stem off the main river. Over time these smaller streams would lose their connection to the Rio Grande and would form the Resacas we see today. The figure below shows the network of Resacas that are within the Lower Laguna Madre Watershed.

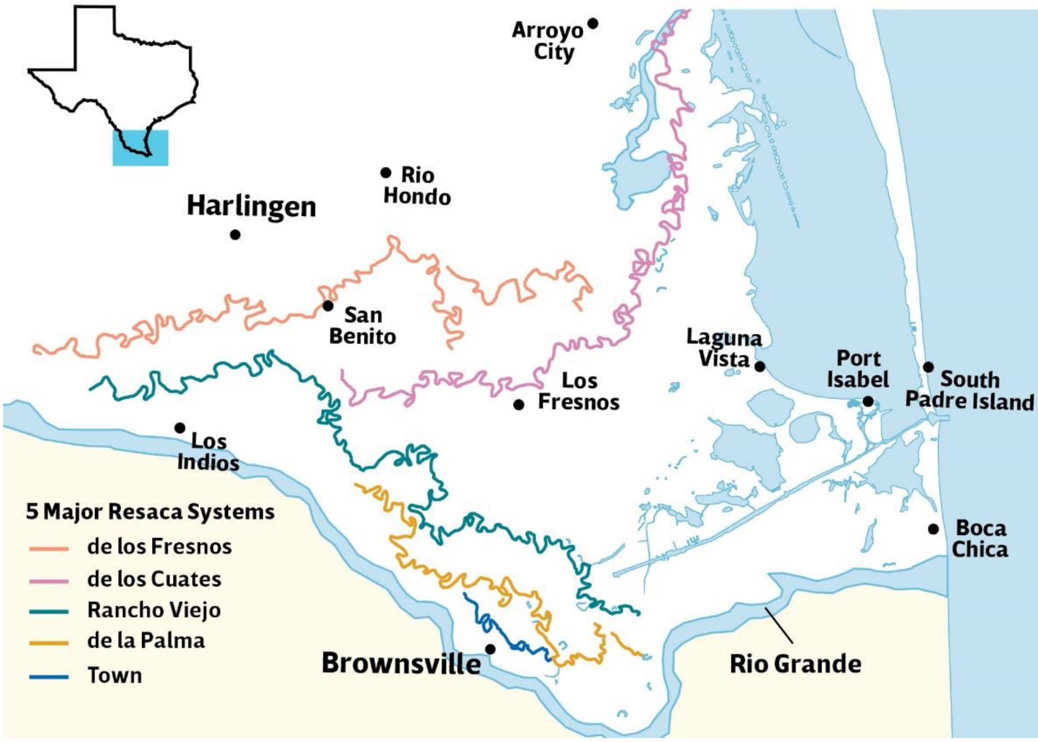

Figure 4: Resacas in the Lower Laguna Madre Watershed. Map created by Julie Straton, map data gathered by Dr. Jude Benavides. (Saldaña)

These Resacas lost their connection because urbanization and flood control features, dams and gates were constructed in the Rio Grande allowing the flooding of the Rio Grande to be controlled. With the lost connection Resacas still provided the people of the region areas where water could be gathered and stored for agricultural purposes. Today these Resacas are used to either store raw water to be used for agricultural use or as detention ponds storing stormwater during rain fall events. Resacas have pumps and gate structures to allow water to enter or leave the water body depending on it’s need. For this study there will be a focus on the drainage aspect of the waterbodies and determine what their hydrologic impact is to the Lower Laguna Madre Watershed with the use of hydrologic and hydraulic modeling.

CHAPTER II

METHODOLOGY

Chapter 2.1 Watershed Delineation

To develop the hydrologic model, first the delineation of the watershed needs to be created to determine the boundaries of the sub-basins. With this the hydrologic parameters can be determined for each sub-basin. These hydrologic parameters will be the input data for the hydrologic model. The development of the sub-basins is done by using the DEM data. The DEM Data is using the terrain data to determine the flow direction and flow accumulation of the landscape, which in turn delineates the boundary of each sub-basin within the watershed. This also helps in determining each watersheds' outlet point.

Light Detection and Ranging (LiDAR) is a type of remote sensing used for the use of land surveying, which in turn is used to develop elevation models of different terrains. LiDAR data is collected when an aircraft mounted with a series of lasers passes through a desired location in which an elevation model is to be created of the specified location. The lasers on the aircraft hit surfaces of the area and returns, the travel time of the laser is then used to justify the coordinates of the region. When collecting the points from the lasers they are grouped in to two sets of points. The first points to return are dubbed "Non-Ground" points since they have a high possibility to hit an elevated object such as a buildings, trees, or other obstructions to the ground. The second points that are returned are dubbed “Ground”. With these two grouping the creation of the model will be more precise with less error. The LiDAR points are then recorded in a text file with values found in the x, y, and z-direction. This text document is then converted into a digital elevation model using any applicable GIS program.

For the watershed delineation for the region, high resolution LiDAR data is preferred in order to properly analyze the terrain. In this study area where the average slope varies from 0.5 to 1 percent, by having a higher resolution LiDAR dataset, each small slope change can be defined, thus increasing the accuracy of watershed delineation. The International Boundary and Water Commission (IBWC) have conducted two LiDAR based surveys in the region, one in 2006 and another in 2011. The resolution of each survey is a 1-meter by 1-meter, which is the ideal resolution needed for this project. These datasets can be found on the Texas Natural Resource Information System database (TNRIS). When first analyzing the dataset for the 2006 LiDAR, the projection of the data was not correct as it placed the dataset away from the study region. To correct this, GIS reprojection software was used to place the dataset in the correct area.

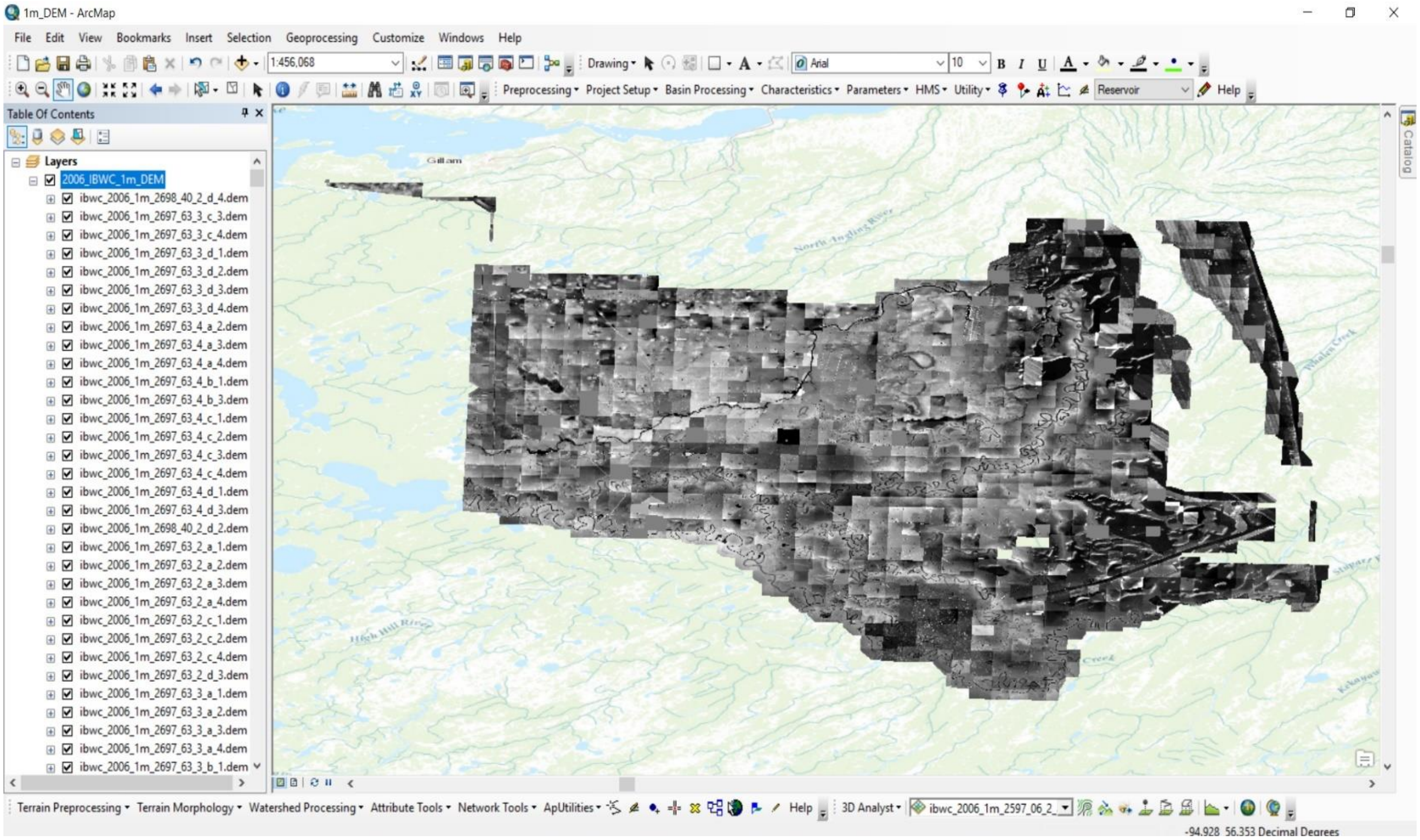

Figure 5: 2006 IBWC LiDAR dataset acquired from TNRIS. Reprojection is needed.

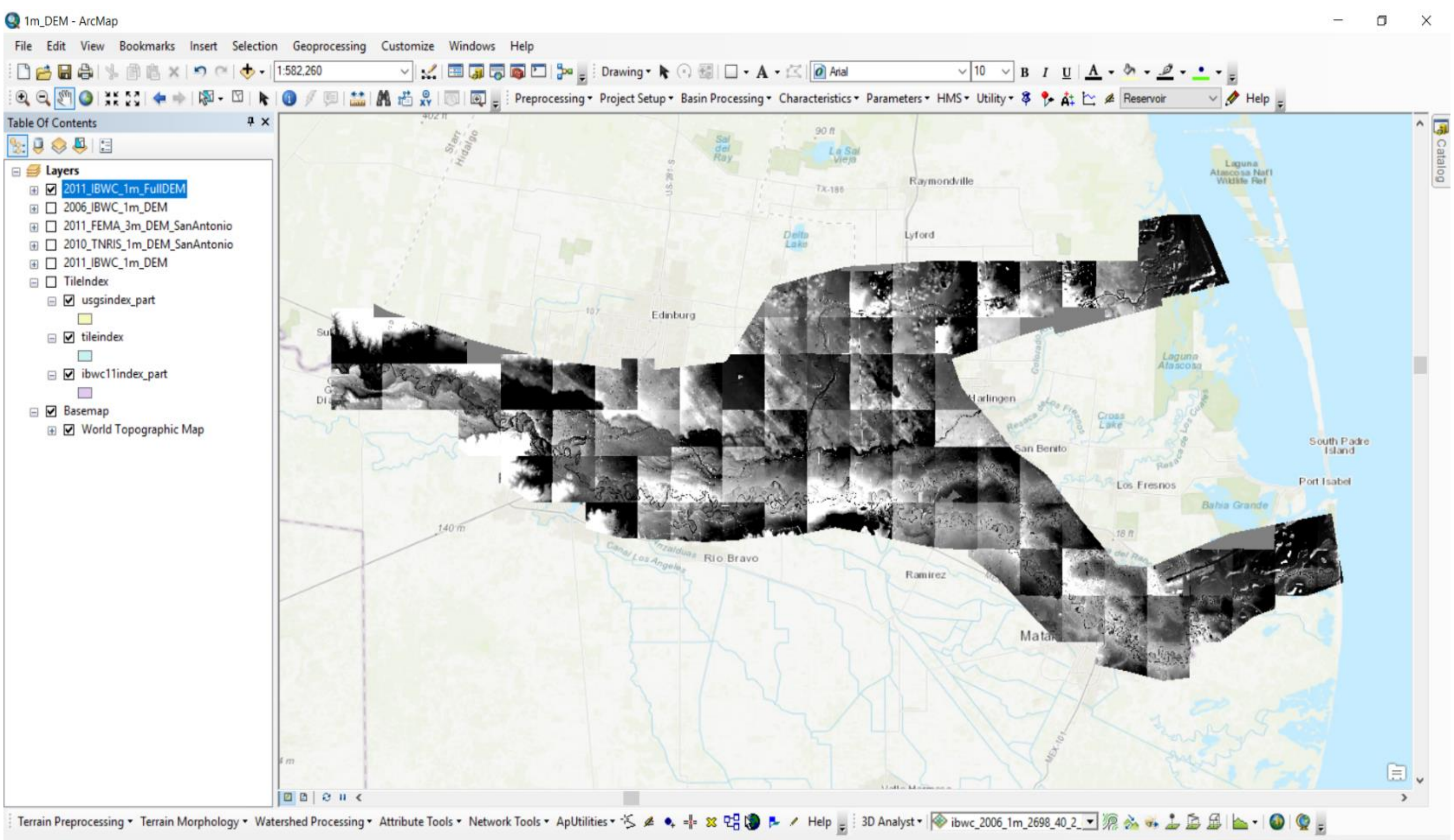

Figure 6: 2011 IBWC LiDAR dataset acquired from TNRIS.

When using the 1-meter DEM data, there were errors when delineating the watershed. An issue found with working with 1-meter DEM is computation time. This LiDAR dataset was approximately 82 gigabytes worth of data. While trying to determine the delineation, errors were also caused due to the small processing power of a home computer. The solution to fix these was by clipping the extent of the dataset that would not attribute to the watershed delineation. The dataset was still large in data, approximately 24 gigabytes of data. The dataset was clipped again into two datasets. Each dataset was 14 gigabytes and 10 gigabytes, with these new reduced datasets the home computer was able to process the data and develop watershed delineations. The delineation was very defined in some areas, but in other areas it was not able to define the watershed. This can be attributed to the processing power of the computer not being able to render all the watersheds. I was also informed that the dataset for the 2006 study had some errors. Typically, some LiDAR errors can be repaired, however an attempt was already made to fix these errors without any success.

Table 3: DEM Databases available during this study

LiDAR Dataset	**Dataset Resolution**	**Database**
2006 IBWC LiDAR	1-meter resolution	TNRIS Database
2011 IBWC LiDAR	1-meter resolution	TNRIS Database
USGS LiDAR Dataset	10-meter resolution	USGS National Map Database
USGS LiDAR Dataset	30-meter resolution	USGS National Map Database

The errors found in the 2006 dataset were “streaks” along certain tiles of the dataset. These “streaks” created inaccurate elevations causing the delineation of the watershed boundary to follow these “streaks” as their elevation created a line of high points. These “streaks” can be seen in the image below.

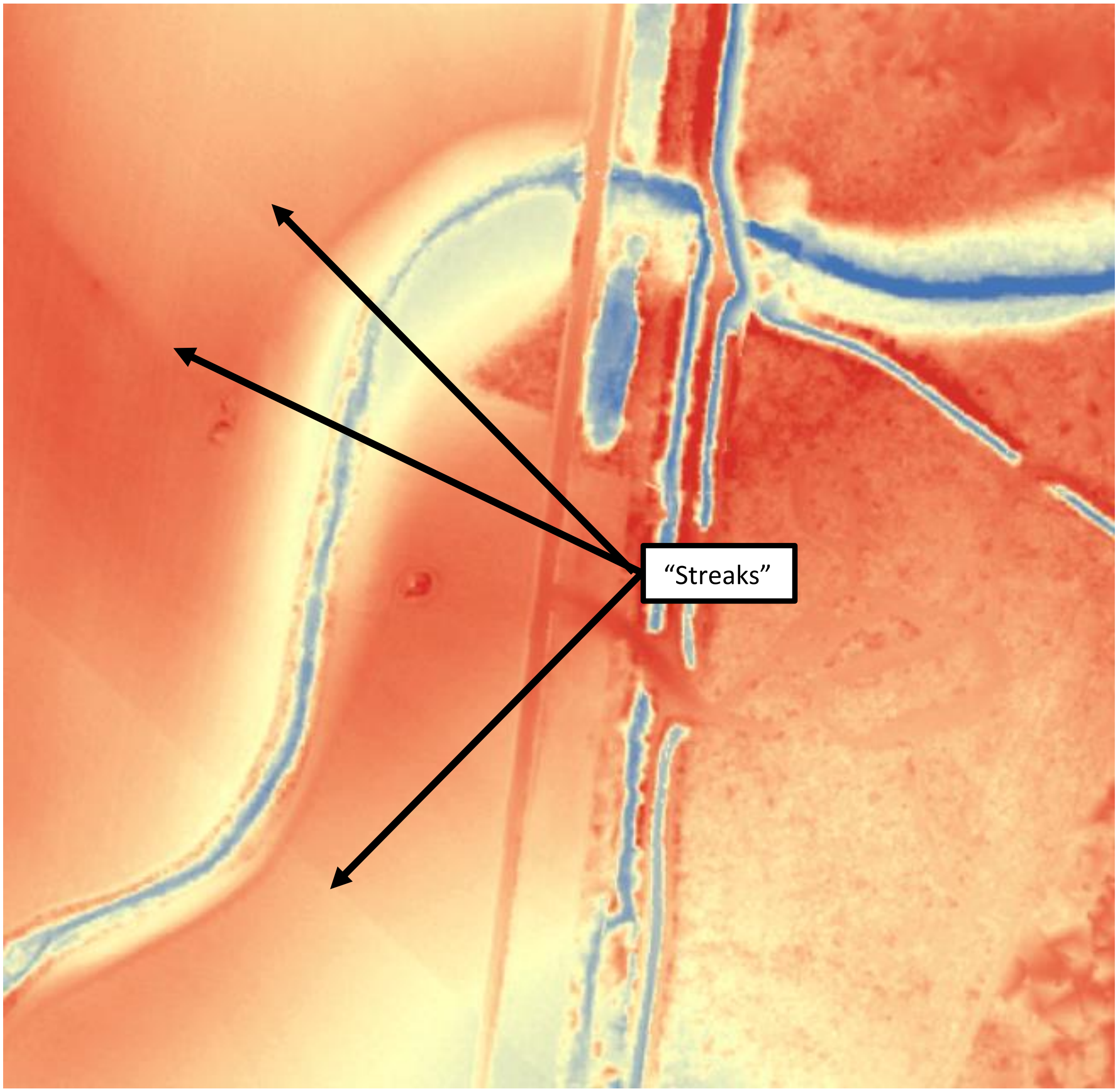

Figure 7: 2011 IBWC LiDAR dataset acquired from TNRIS.

To fix these definition errors and help with computer processing issues, the 10-meter DEM data was used instead. The 10-meter DEM is smaller in data size, approximately 257 megabytes, which will help with any computer processing issues. The data used was collected by the United States Geological Survey National Elevation Database (USGS NED). This database can be accessed from the USGS's National Map website. With the use of lower resolution DEM the delineation was of a higher density, which in this study it will be suitable, since the hydrologic model being created will cover approximately 1, 056 square kilometers. The processes of how the watershed delineation was created will be mentioned below, as well as some alterations that were made in order to improve the accuracy of the delineation.

With the acquisition of both the stream shapefile and the DEM the terrain preprocessing using HEC-GeoHMS will be used to determine the watershed basins for the region. The DEM and the stream shapefile will be reconditioned to ensure the stream network within the DEM matches and aligns properly. With the "DEM Reconditioning" tool, the user inputs the DEM and stream shapefile, with this the cells are lowered in the areas where the stream shapefile is present. After the DEM has been reconditioned, the next steps prepare the DEM data to determine the watershed boundaries as well as the outlets of each sub-basin. The "Fill Sinks" Tool fills any gaps found in the DEM data that can cause sinks or low areas. This step ensures that no sinks are present that could affect the direction of flow, thus creating an improper watershed delineation. The DEM is then used to determine the flow direction within the terrain using the "Flow Direction" tool. HEC-GeoHMS uses the "D8" method, which assign a number to the grid that corresponds with one of the eight directions of flow. The D8 method is the most common form of determining the direction of flow within a DEM. Flow accumulation is then processed from the DEM by using the "Flow Accumulation" tool. Flow accumulations gives the cells a value depending on how much accumulation is found within the cell. This is critical in determining the outlet point as well as determining the location of stream networks.

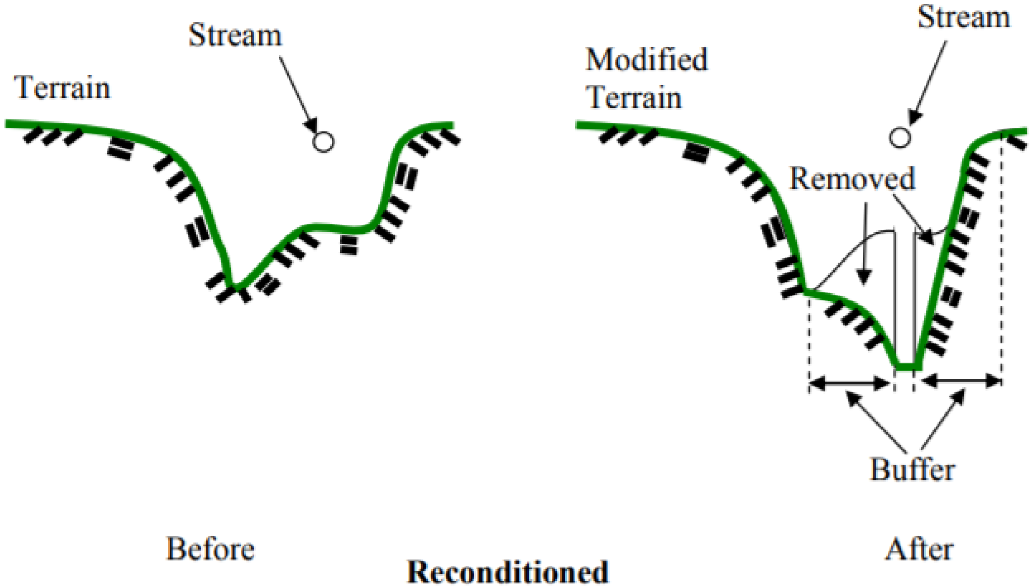

Figure 8: Reconditioning of DEM dataset to prepare for watershed delineation. (Fleming and Donan)

With these parameters completed the stream network can be developed to properly determine the boundaries of the watershed. The "Stream Definition" tool is used to define the stream network within the DEM. This tool uses the "Flow Accumulation" tool to define areas that accumulate enough water to create a stream. Here a cell size definition is necessary to establish. If left at the default accumulation, areas in your streams will have breaks. These breaks will cause a series of errors when defining the watershed boundary. The most commonly used cell size is 5000, but a smaller cell size will offer a concise stream network, which will be able to give smaller sub-basin boundary. The "Stream Segmentation" tool is used to determine junction connections, junction to outlet connections, or a junction to a drainage divide. The “Flow Direction” grid as well as the “Stream Definition” grid to create a stream link grid.

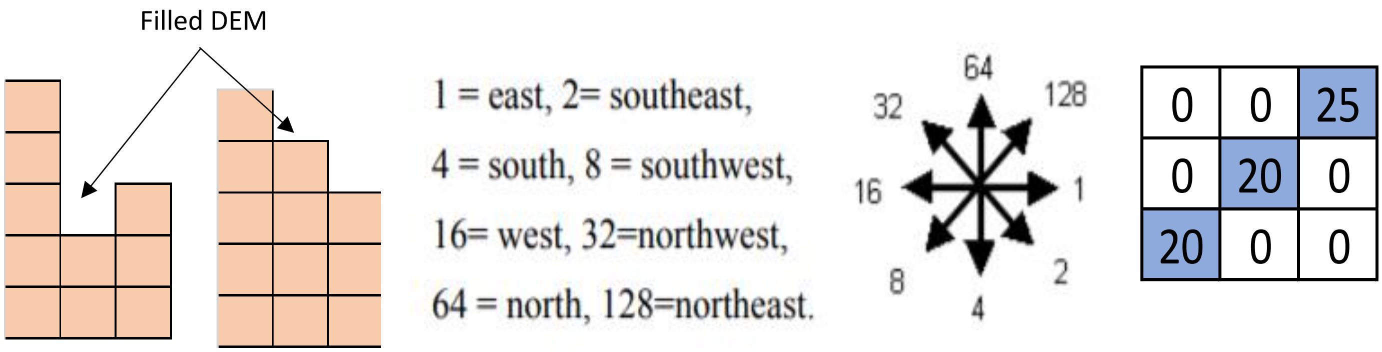

Figure 9: Graphical representation of filling sinks in DEM dataset and determine flow direction (Fleming and Donan)

The figure above shows a graphical representation of how a DEM dataset is filled in to fill any erratic dips or change in slopes between small cell areas. The second Image shows how the GIS program simulates the cumulation of water in each individual cell of the DEM dataset. The value will increase in areas where larger amounts of water would accumulate. With each cell having a unique value, a flow path pattern can be drawn showing the path of water being highlighted by values with a high accumulation value.

With the previous series of steps complete, the sub-basins can be delineated using the data generated from the previous process. The “Catchment Grid Delineation” tool is used with the input parameters of the “Flow Direction” and the “Stream Definition” required to create the sub-basin delineation. A raster dataset of the sub-basins is created. The “Catchment Polygon Processing” tool is used to convert the raster set of sub-basins into a vector format, which will allow for easier processing. Now with the development of the sub-basins the drainage network for the terrain can be created. This is necessary to see how each sub-basin is connected to one another, as well as to see where the outlet of each sub-basin is located.

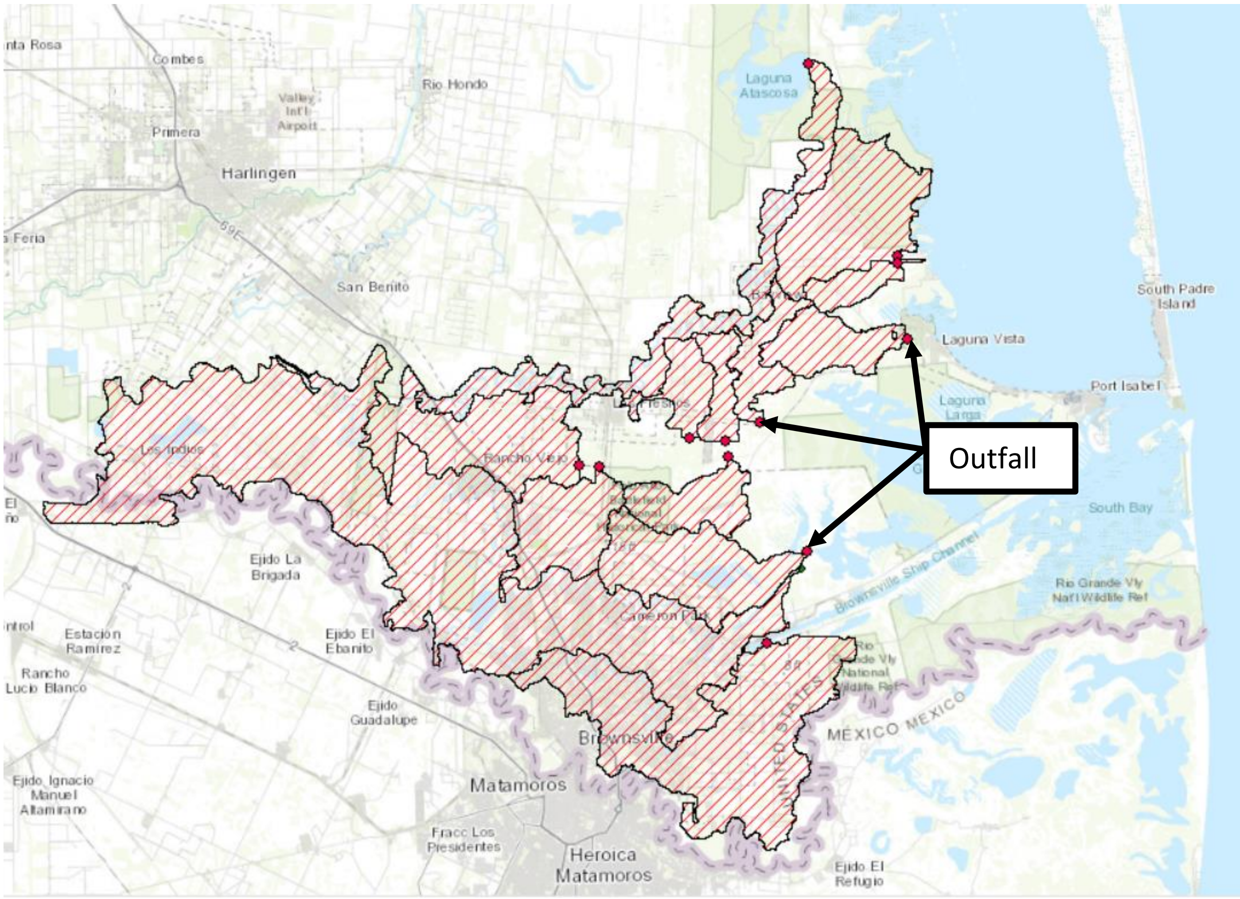

Figure 10: Watershed delineation showing each subbasin outfall

The “Drainage Line Processing” tool requires the same inputs required for the “Catchment Grid Delineation”. The output of the tool creates a vector dataset outlining the drainage path for each sub-basin. Now with the drainage network mapped out the sub-basins are then aggregated together at certain upstream points near confluences, using the “Adjoint Catchment Processing” tool. This step does not affect the hydrologic significance of the model, this will be later created by the HEC-HMS model, but does help during the data extraction when creating a HEC-GeoHMS project in Phase 2. Before continuing into Phase 2 for the development of the model, the “Drainage Point Processing” is used to create the outlets for each sub-basin. The final output of the delineation can be seen in Figure 10.

HEC-GeoHMS can convert the watershed delineation into a HEC-HMS model. During the delineation process, there are some connections issues with the sub-basins due to approximately 25% of the delineation not being defined, mainly in the portion near the coast of the watershed. To avert this issue, the sub-basin and river networks were converted into shapefiles, which were then uploaded into HEC-HMS. The missing sub-basins that were not delineated were manually drawn using the DEM terrain data as a reference to predict the flow patterns of the terrain in order delineate the boundary of the missing watersheds. The drawn sub-basins are also converted into a shapefile and imported into HEC-HMS. With the use of HEC-GeoHMS, developing an HMS model is relatively easy, as GeoHMS has all the necessary tools to determine hydrologic parameters and automatically adding them to the model. Creating a file ready to export into HEC-HMS. With manually drawn sub-basins being added, GeoHMS will not recognize the manually drawn sub-basins, hence making it difficult to utilize the automatic creation of a HEC-HMS model; the HEC-HMS model would need to be developed manually. The final watershed delineation for the LLMWS can be seen in Figure 13.

Chapter 2.2 Development of Hydrologic Model in the Lower Laguna Madre Watershed

The sub-basin shapefile was imported into HEC-HMS as a template to determine where each sub-basin component will be placed in reference to the delineation of the watershed. With the sub-basin placed, the hydrologic parameters are then determined. The hydrologic parameters include the sub-basin area, and the determination of the loss method, transform method, and baseflow method; each of these methods also have their own parameters that need to be determined. The loss method used was the "SCS Curve Number" method which include determining the curve number and percent of imperviousness area in the sub-basin. The transform method used was the "SCS Unit Hydrograph" method which includes the determination of the lag time using the SCS method. The baseflow method was not used in this instance due to the lack of available data used to determine the parameters for this method.

The basin area was determined by using GIS analysis of the sub-basin. With the sub-basin boundary being represented by a shapefile on GIS, the area of the shape can be determined. The area of shape in this instance will be equal to the area of the basin area.

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area 2/	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) 3/:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) 4/		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96

Figure 11: USDA CN Hydrologic Parameter Table as seen in USDA TR-55 Table 2-2a

The curve number (CN) is a hydrologic parameter that is used to determine the direct runoff of the watershed. The USDA has a table for determining the CN by establishing the soil type (A, B, C, or D) and the land use of the watershed. Shapefiles containing the land use and the soil types in the watershed were gather and imported into GIS. The attribute table for each shapefile should be reviewed so that each value, soil type and land use, is present in the attribute table. It is easy to determine the soil type since they are identified as alphabetical characters. Land use is determined in numerical codes (11, 12, 21, 22, 23 24, 31, 41, 42, 43, 52, 71, 81, 82, 90, and 95) which represent a land use. For example, numerical land use code 11 represents “open water: areas of open water, generally with less than 25% cover of vegetation or soil”. These codes are predetermined by USGS National Land Cover database, the developer of the shapefile. These two shapefiles were merged into one shapefile, this is done for convenience. With the newly merged shapefiles the two attributes are merged into one attribute table. This is important for the next step. With both soil type and land use in one attribute table the "Tabulate Area" tool can be used to determine the area covering each parameter. This will help us get a weighted value for each soil type and land use, since sub-basins typically have multiple land uses and soil types within its area. With this weighted value for both the soil type and land use, the accuracy of determining the CN will increase. A CN table is created to determine the weighted CN values based on the weighted soil types and land use values. The land use shapefile had the values for percent of imperviousness for each type of land use. The "Tabulate Area" tool was used to determine the percent of imperviousness area as well. As stated earlier each sub-basin has multiple land uses, so a weighted value was used to improve accuracy.

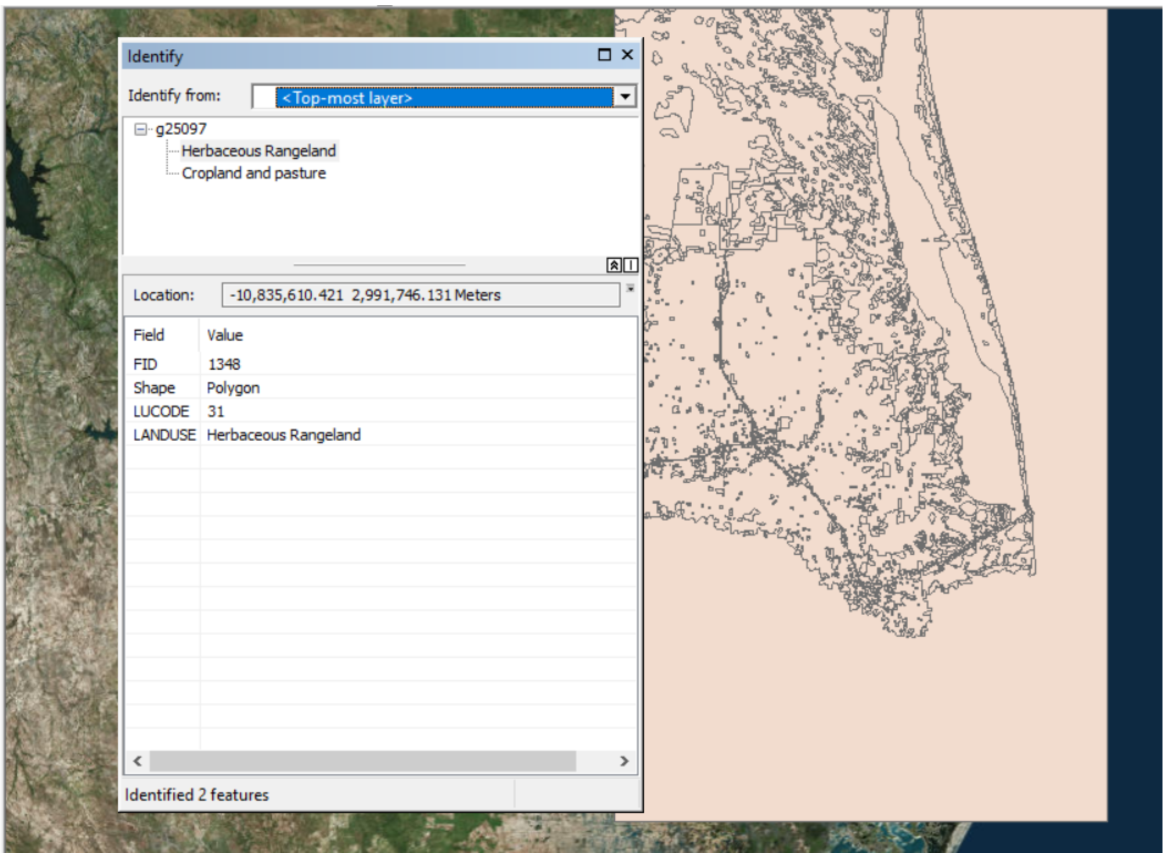

Figure 12: Land Use shapefile from the USGS Land Cover database.

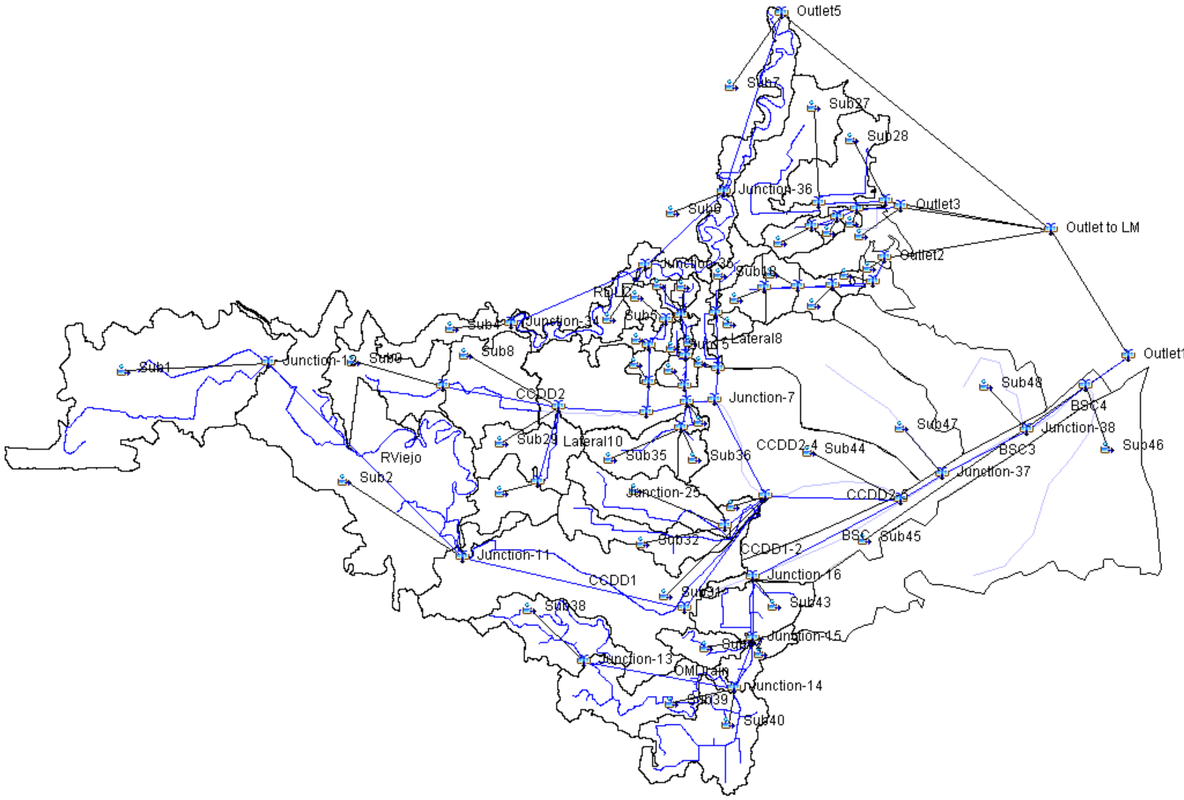

Figure 13: HEC-HMS watershed model for the Lower Laguna Madre Watershed

The lag time is a parameter that is determined for the Transform Method. This parameter is the time from when the excess rainfall event ends and the to the time the watershed reaches its peak outflow. This value is calculated using the following equation:

$$L = \frac{\ell^{0.8}(S+1)^{0.7}}{1{,}900Y^{0.5}}$$

where:

L = lag time in hours

ℓ = flow length in feet

Y = average basin slope in percent

S = Storage which is calculate using:

$$S = \frac{1{,}000}{curve\ number} - 10$$

The flow length in this equation is the length of the longest flow path of the watershed. This can be quickly determined by using the GIS tool "LongestFlowLength" which will compute the flow length for each watershed that was delineated automatically by GeoHMS. For the watersheds that were manually delineated, the flow length was also manually determined. The "Measure" tool in this GIS application has a snap feature. This tool is used and snapped to the outlet of the watershed. From there the measure tool is then used to measure various paths that appear to be the farthest away from the outlet. Once the length for each of these flow paths is determined, the largest value will be used. This process is repeated for each manually delineated sub-basin. The basin slope was determined using the GIS tool "BasinSlope". By using the DEM data along with the sub-basin shapefile, the slope of the basin is determined in percent. This value is found in the attribute table of the sub-basin shapefile, after the "BasinSlope" tool is used.

With the completion of the sub-basin component the reaches within the watershed were established. Each reach used in the model required a routing method to determine the flow entering and exiting the reach. The Muskingum method was originally used as the routing method. After reviewing the Cameron County Drainage District #3 and #5 Flood Protection Reports, the Muskingum-Cunge method was used in its place. The parameters needed for this method are the geometric components of the reach. This was determined by creating a cross-section of the reaches on the DEM data using the 3-D analyst function on the GIS application.

With the necessary parameters set for the basin models complete, the next step to complete the hydrologic model is to develop the meteorologic model. In HEC-HMS the meteorologic model is responsible for simulating various types of rain events. As mentioned earlier a hydrologic model is used to determine what the runoff flow value will be experienced by a sub-basin in a watershed. When reviewing FEMA flood studies, the typical design storm that is used to predict flooding is a design 100-year frequency storm. Trying to stay consistent with present design standards I simulated this HEC-HMS model with a 100-year design frequency storm. Frequency storms are simulated storms that are either developed as a synthetic storm or a storm developed from historical data. The return period is determined by the probability of the storm event occurring each year. For example, for the return period of a 100-year storm, the frequency this storm can occur each year is one percent. This is determined by the following equation:

$$P = \frac{1}{F}$$

where:

P = Probability in decimal form of a storm frequency occurring in any one year

A = Frequency in years

For this study perception data was used from NOAA's ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATE. NOAA collects precipitation data in different regions through out the country. Through there analysis they determine the precipitation values for frequency storm that include 1, 2, 5, 10, 25, 50, 100, 200, 500, 1,000-year return periods. The table below shows the precipitation values for a 100-year storm, which was included in the precipitation model in HEC-HMS.

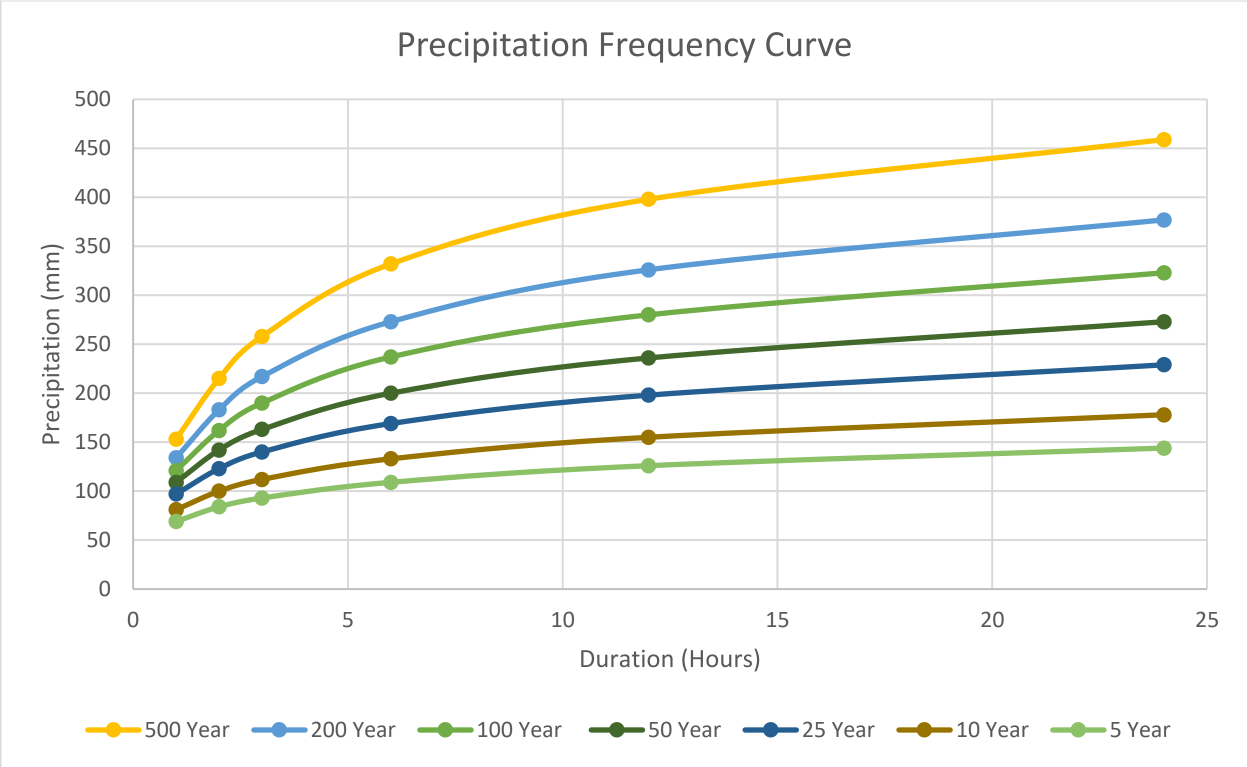

Figure 14: Precipitation Frequency Values for Brownsville, Cameron County, TX, NOAA ATLAS 14

With the precipitation now complete, the last remaining component of the hydrologic model is the control specification. In this component the user will need to determine for how long the design storm will be simulated for. This will help create the hydrographs, which are the outputs for hydrologic models. A hydrograph shows the relationship of stormwater runoff to the time of the storm. For this study a 24-hour storm period was used as the control. The results that will be developed by this model will show the stormwater runoff of various subbasins within the LLMWS during a 24-hour, 100-year storm. The results of this model will be further reviewed in the Results portion of this paper.

With the completion of the hydrologic model a hydraulic model of the region will be created in order to understand the hydraulics of the drainage channels. Understanding the drainage models will be crucial in order to determine which areas will be affected by flooding, the duration to how long these areas will be affected, and at what depth flood waters will reach in the area. Development of the hydraulic model will be created using the Hydrologic Engineering Center – River Analysis System (HEC-RAS) software.

HEC-RAS is a hydraulic modeling software developed by the Army Corp of Engineers as a tool to analyze the hydraulic properties of river systems. This tool is commonly used in many aspects of civil engineering such as for design and analysis of any hydraulic structure involving a river system. Over time HEC-RAS has evolved and gained other features such as water quality modeling and sediment transportation. Similar to the HEC-GeoHMS featured used to delineate the watershed, the counterpart, HEC-GeoRAS, can be used to analyze GIS data to develop a hydraulic model of the river system. This is the normal approach to developing the river systems geometry for a HEC-RAS model with GIS data. In HEC-RAS, a “RAS Mapper” tool was used to view the output of HEC-GeoRAS and to allow for the streamline import of the geometric data created in Geo-RAS.

Recently in 2016, the Hydrologic Engineering Center updated HEC-RAS to version 5.0. In this version “RAS Mapper” is able to analyze GIS data and develop the geometric data needed to run the hydraulic model. In this study HEC-RAS version 5.0.4 was used instead HEC-GeoRAS. One of the biggest benefits of using HEC-RAS over GeoRAS, and the main reason why it was chosen over GeoRAS, was its ease of access. “RAS Mapper” is already part of HEC-RAS while with GeoRAS the user will need a copy of ArcGIS with a valid spatial analyst license. The main benefit with GeoRAS is that it is a common program in the hydraulic studies world and there is an infinite amount of information in regard to trouble shooting and error analysis (which is a very helpful tool to have in a high degree of difficulty model).

There are three main phases to developing a hydraulic model. The first phase is determining the geometry of the river or reach that is going to be analyzed. As is seen with many hydraulic analysis equations, the geometry of the reach is needed to develop any type of output. For example, if one wants to determine the flow for an open channel, a commonly used hydraulic equation would be Manning's equation:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S_0^{\frac{1}{2}}$$

where:

n = Manning's roughness coefficient

A = cross-sectional area of the channel (ft^2)

R = hydraulic radius (ft)

S = channel slope

In this equation you will need to have the cross-sectional area, hydraulic radius, and channel slope to determine the flow of the open channel, three geometric properties of a reach.

Chapter 2.3 Proposed Hydraulic Model to Determine the Hydraulic Response Within the Watershed

To determine the geometric properties of the ditches, it is common practice to use survey data or use existing elevations models to extract the geometric properties of the drainage ditch. Survey data is the more preferable option because surveyors and their crews will be able to survey drainage ditches bottoms that are normally filled with water, such as Resacas. Some digital elevations models, such as the one used to delineate the watershed, use LiDAR to develop the models. As mentioned earlier, LiDAR uses light beams that reflects to a data reader to determine an elevation. This becomes a problem with channels that have water in them during the LiDAR survey. Water refracts light and may not give an accurate reading when it is returning to the data reader. Survey data for the ditches, resacas and other drainage channels that would be modeled for this study are not readily available, so some assumptions were made from field observations.

The “RAS Mapper” tool was used to extract the geometric data from a digital elevation model. To begin the development of the geometric data for the model a couple parameters must first be set. To begin a HEC-RAS project file needs to be created (.prj). This can be easily done by saving a HEC-RAS file and giving it a file name.

Next the projection for the project needs to be set. This a common procedure for all GIS works or geolocation work. It is important to setup a coordinate system and datum for this project. This will help with making sure your DEM data will line up with your research area. This in the future will be helpful when wanting to create a presentation map, which you will see below. For this project the projection used was North American Datum 1983, StatePlane Texas South, FIPS 4205 Feet. To set the projection the user will need to access the “RAS Mapper” tool and open the “Set Projection for Project” in the tools tab. Here you are prompted to add a projection file under a .prj format. Online there is an open-source spatial coordinate system database which contains many projections set in different file formats (Spatial Reference). With this database I was able to find my projection of choice and download it in a prj program that HEC-RAS is capable of reading. With my projection now set I can begin to add my DEM data into “RAS Mapper”.

Similarly, when developing the watershed delineation for this project, the DEM data will be used to extract the cross section of the reach. Like in the analysis of the watershed delineation the higher the resolution of DEM data is used, the more accurate the results. With a more defined resolution the user can easily determine the features of the reach. The two main features that need to be seen on the DEM data is the centerline of the reach and the bank lines. Figure 5 and 6shows the comparison between two sets of DEM datasets, one in which the reach is well defined and not as well defined. To do this I will need to first determine the centerline of my reach.

It is important to start drawing the centerline of the reach from the upstream point working downstream, as this will dictate your flow when you transfer it from “RAS Mapper” back into HEC-RAS. Next the user will define the banks of the reach. This will help HEC-RAS differentiate the reach into three portions, the right bank, center, and left bank. This is done to allow the user to define a manning’s roughness coefficient to each section. This is helpful when the user may have a high permeable area on the right bank, with a concrete lined center, and an impermeable area on the left bank. These roughness coefficients will be determined for this study when the geometric process is complete.

When the centerline and canal banks are defined for each of the reaches then cross section can be determined for the reach. By using “RAS Mapper” the user can draw and define the length and orientation of the cross section. The main thing that needs to be considered when developing the cross section is the spacing between the cross section. The spacing of the cross section can have a major implication when it comes time to running a complete model. If there are not enough cross sections in the model, then there will be an error during the computation. There is common equation used to determine the cross section spacing of a model using either Samuel's equation of Fread's equation.

Samuels Equation:

$$\Delta x \ \leq \frac{0.15D}{S_0}$$

where:

Δx = cross section spacing (ft)

D = average channel depth (ft)

S_0 = channel slope (ft/ft)

Fread's Equation:

$$\Delta x \ \leq \frac{cT_r}{20}$$

Where:

Δx = cross section spacing (ft)

c = the wave speed (ft/s)

T_r = time of rise (from low flow to peak) of the hydrograph (seconds)

Both equations can be used to determine the cross section spacing for a model. However, depending on the situation, it might be best to include more cross sections. For example, in the Resaca portion of this model there was plenty of meandering sections whereas the model developer, the need for more cross sections was necessary as to properly model this portion of the reach system. Cross sections are also important when running an unsteady state hydraulic model as it gives it more of an opportunity to solve the analytical hydraulic problem. If the reach system being study has non uniformed cross section, it would also be best to use multiple cross sections in those portions. In the image below, the layout of the HEC-RAS model can be seen.

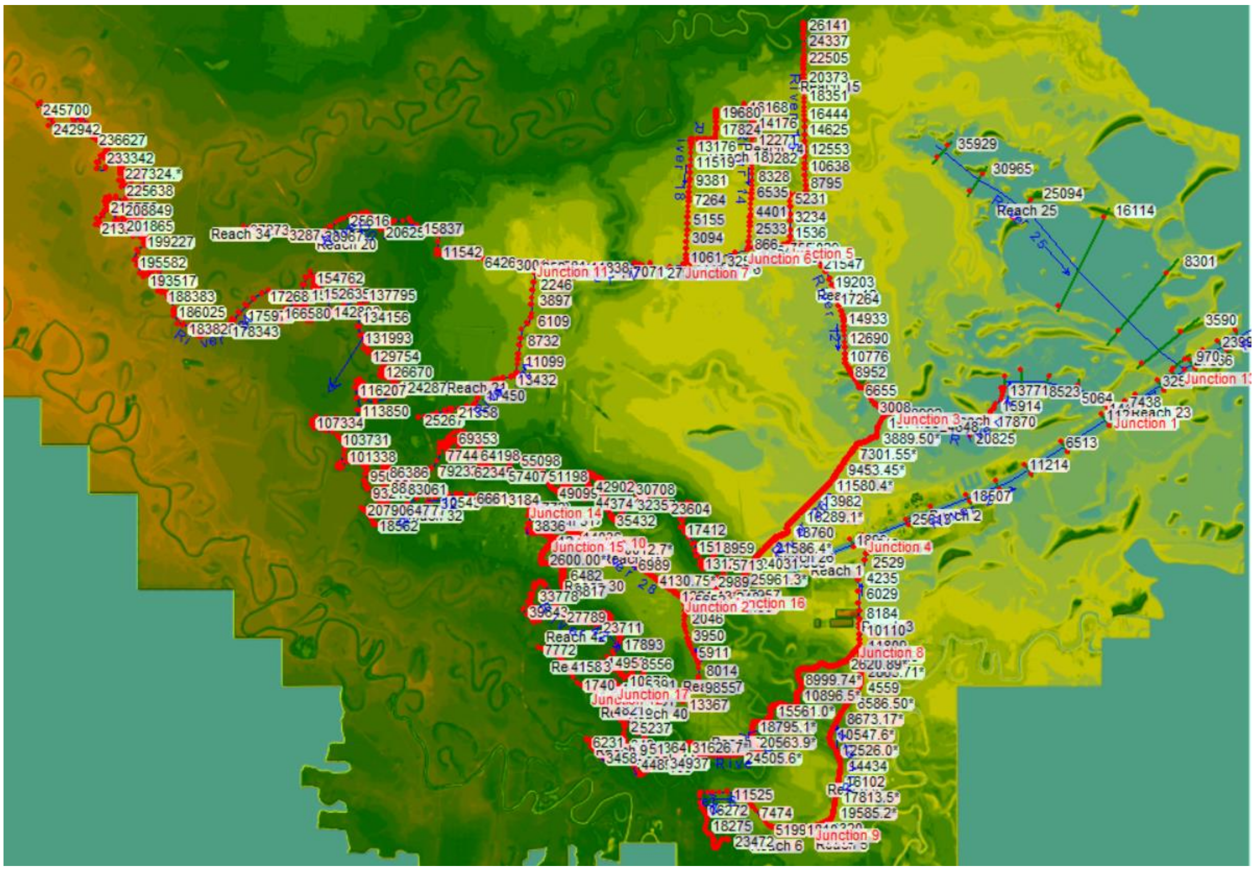

Figure 15: HEC-RAS model layout for the Lower Laguna Madre Watershed

Like in any model or computational analysis for every output the user is striving to obtain an input is needed. In HEC-RAS there a few methods of input data that can utilized to develop an output. Before going into further detail on the input used for this model, first the user needs to determine what type of model analysis will be run to acquire the output. In HEC-RAS there are two main types of computational analysis used for open channel hydraulics. These computations are steady state and unsteady state.

Steady state models are used when an open channel is even and depth and experiences uniform flow throughout the system. Unsteady state models are used when depths vary in the open channel and the flows vary throughout the system. Most of the channels in this system are either man made drainage ditches or naturally developed Resacas. The drain ditches are typically uniform when first constructed, however over time sediment build up and bank erosion will cause variations in depth. The Resacas in the region are also uniform in some areas, but like the drainage ditches, sediment build up and bank erosion will cause some changes in depth. With these conditions seen in the study, the best option would be to utilize an unsteady state model.

Now that we have determined to use an unsteady state model, boundary condition data is needed to compute the hydraulic model. The output of the hydrologic model (HMS) can be used as the input for the HEC-RAS model.

When developing a HEC-RAS model, both a downstream and upstream boundary condition must be determined. When doing an unsteady state analysis, the boundary conditions that can be used include Stage Hydrograph, Flow Hydrograph, Stage/Flow Hydrograph, Rating Curve and Normal Depth. Additional boundary conditions are available for lateral inflow, gates, dams, and precipitation. If baseflows or normal flows are present in the drainage channel, an initial condition with an initial flow can be included in the model. With the outputs from the HEC-HMS model, each subbasin that has a reach has a hydrograph that was created by the hydrologic model. The upstream hydrograph data is added to the upstream river station of the reach, likewise the downstream hydrograph is added to the downstream reach.

In this study, due to the lack of time the hydraulic model was not fully completed. However, during this study various errors did occur when developing the model. While trying to run a preliminary run of the model, with the now added geometric data and boundary condition, various errors occurred. As all models are, must errors that are found are typically user error. The first error that was given was that HEC-RAS needed to extend the end points of the cross-section vertically up to help compute the water surface. Originally when establishing my cross section, the limits to it included the main channel and 10 feet on either side of the bank lines. For the amount of flow that was being simulated in the model the current cross section was too small and was forced to extend the outer limits outwards. Because of this the water surface was unrealistically too high. In this region the normal terrain elevation varies from 0 to 20 feet above sea level. With the first iteration of the hydraulic model, the output water surface elevation was nearing 40+ feet about sea level.

CHAPTER III

RESULTS

Chapter 3.1 Final Watershed Delineation for the LLMWS

Once the watershed basins are delineated the final output can be seen. In the figure below you can see the auto generated watershed delineation. As mentioned in the methodology section, the low-resolution DEM could not delineate low lying areas. This is because the study region is located near sea where elevation is near or close to elevation 0 feet. This causes some discrepancies in the delineation the closer you get to the coastline.

To improve these results the use of higher resolution DEM would be ideal. In this region the slopes are very mild and typically average less than 1%. A higher resolution DEM would allow for a tighter network of data points, allowing for more detailed contours. This will give slopes more definition and help better define the boundaries of the watersheds. This will help in more accurately determining the boundaries in each watershed. Smaller subbasins can also be developed which can help with localized watershed analysis and developing smaller urban watershed models. In a flood prone region this tool can be used to help alleviate flooding as well as improve drainage infrastructure in developed areas. Engineers can also use these small local urban hydrologic models to see how developments impact the watershed. This will give engineers and designers a better understanding of the watershed and allow them to make the necessary adjustments to their design to reduce the effects of improvement in the watershed and reduce possible flooding.

The delineation output for this study was also not fully complete as it can be seen in Figure 10. During the delineation process the lower resolution DEM had flat areas that the program could not differentiate the edge of the watershed boundary, so the boundaries were not drawn as it assumed it was a flat area (ei. water body or sink). The program however was incorrect, and the user needed to manually determine the watershed boundary based off contours and aerial photography. The figure below shows the manually generated watershed basins. The output can be furthered improved and forgo the need for manually drawing watersheds that have extremely flat slopes.

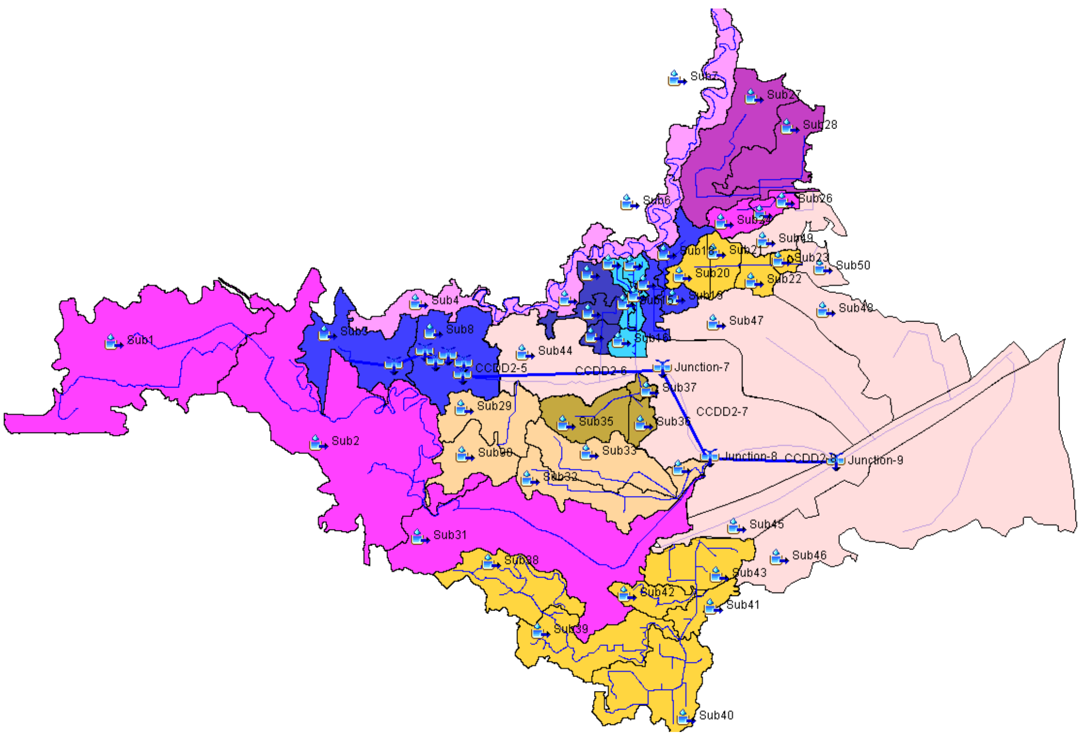

Figure 16: Final Watershed Delineation Including Manually Drawn Watersheds

Chapter 3.2 Hydrologic Model Output for LLMWS

With the completion of the hydrologic model, hydrographs were created for each of the subbasins with in the LLMWS. In the figure below the HMS output result for “Subbasin 2” can be seen. In the figure both the hyetograph and hydrograph. Both these graphs show how the subbasins functions during a 24-hour storm event. The response for this subbasin is as follows: flow is still at its baseflow for the 12 hours of the storm event. After 12 hours have elapsed, the flow begins to rise. This is in line with the peak rainfall intensity of the storm event. The flow in the watershed continues to increase 12 hours after the rain event. At this point the subbasin has reached its peak flow at the 36 hour mark of the hydrograph, 36 hours after the rain event began.

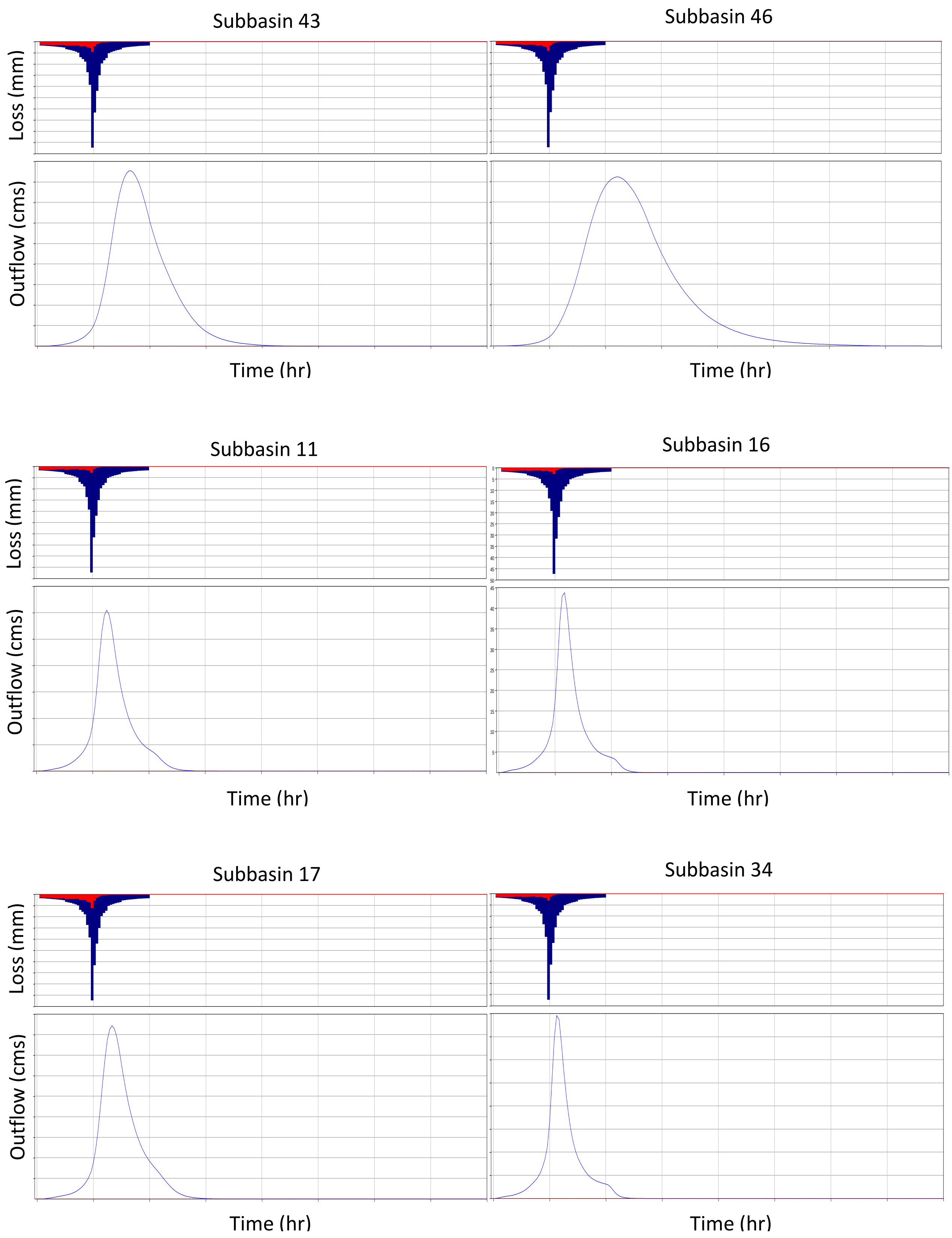

Figure 17: Series of Hydrographs Outputted from Watershed Hydrologic Model

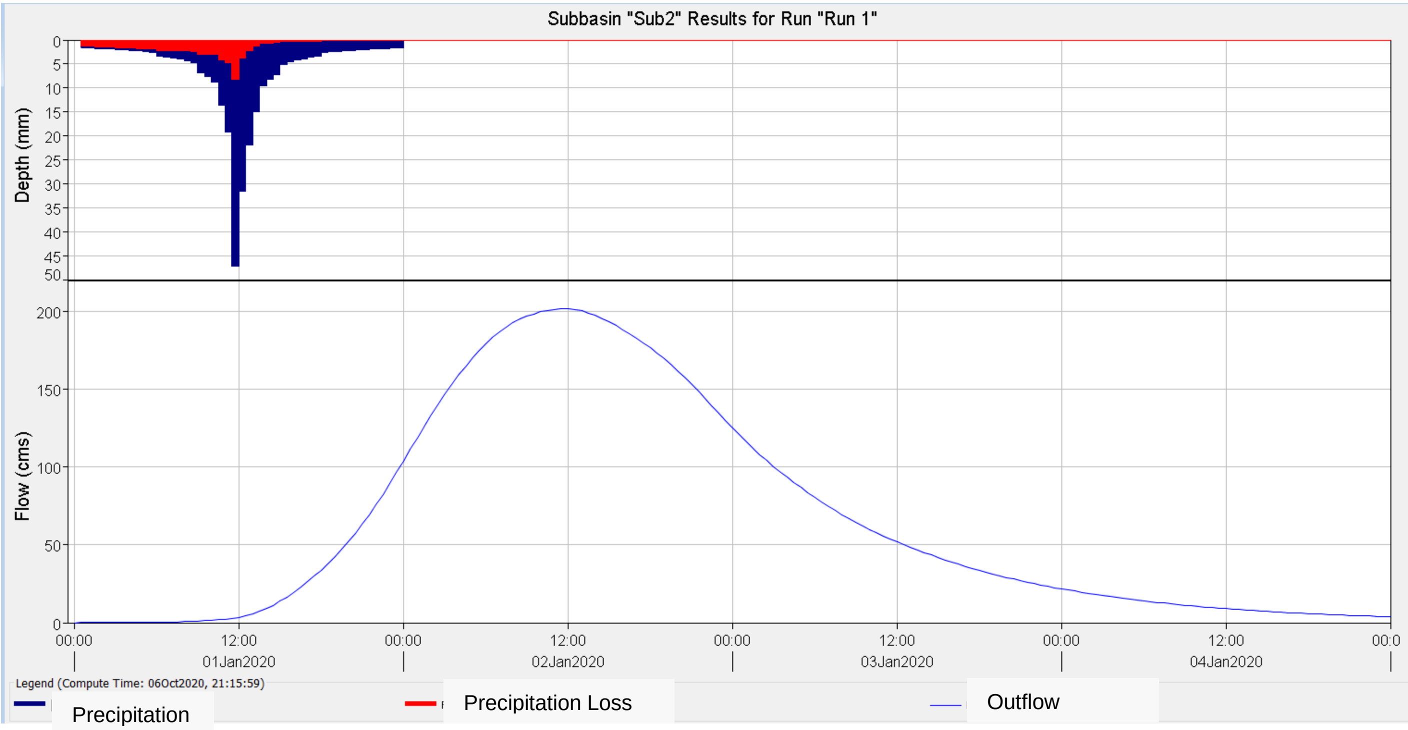

Figure 18: Hydrograph output from HEC-HMS for Subbasin 2

With information gathered from this hydrograph preventive action plans can be created to help not only alleviate potential drainage problems but also help emergency officials determine areas that may need to be evacuated as well as how long it will take for the watersheds to drain stormwater runoff. By increasing the frequency storm, users will be able to determine the peak flow as well as at what point the peak flow will be reached in the watershed. This is especially useful for determining the watershed response during high level storm events. Just recently in 2017, the state of Texas was devasted by Hurricane Harvey. This hurricane was categorized as a category 4 hurricane that caused severe flooding the Houston region. With historical rainfall data from previous hurricanes such as Harvey, Katrina and others, hydrologic modelers can now determine the response of the watershed. This can help save lives as the model could be ran with these historic storms creating hydrographs that can help determine areas of high risk that may need to be evacuated prior to a storm reaching land fall.

In the figure above, the peak outflow for each hydrologic feature can be seen. As it to be expected, flows were greater in areas that had urbanized land uses and lower in areas that had a denser rural community.

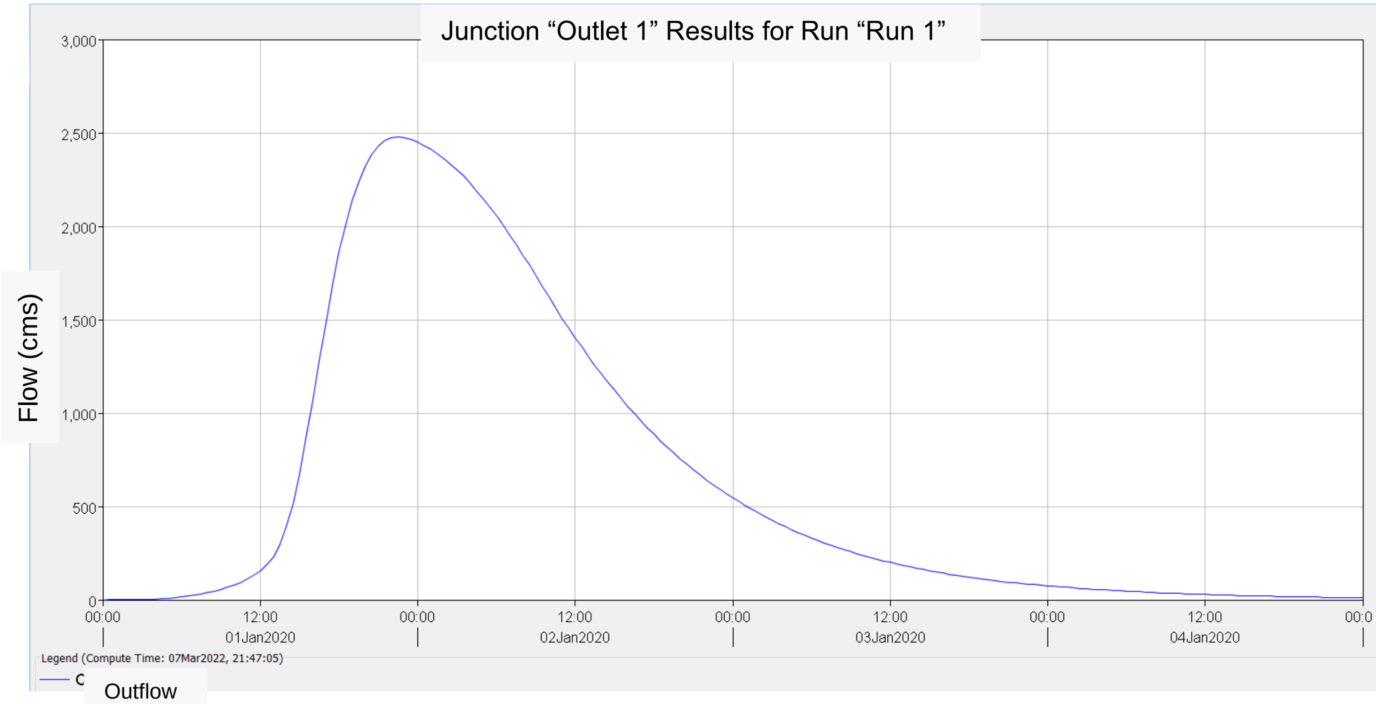

Figure 19: Final Flow Hydrograph for final outfall of the LLMWS

With these available results, areas in the watershed that are commonly known to be impacted by flooding can be corrected. The areas in question can be determined if drainage infrastructures can be added to improve any existing flooding issues. Furthermore, stormwater storage analysis can easily be calculated using this model, by inputting a lower frequency storm, the two hydrographs can be analyzed, and the necessary storage can be computed.

The final outfall has a flow rate of approximately 2,500 cubic meters per second. This simulation results shows the collective storm water runoff from a 100 year, 24-hour event for the entirety of the Lower Laguna Madre Watershed. This value is very useful during the development of the hydraulic model. When developing a hydraulic model one of the inputs that is required to run the model is a flow hydrograph of the watershed. The 2,500 cubic meter per second can be used as a downstream boundary condition in the HEC-RAS model.

Like all models they are only tools used to describe various scenarios and situations and are nowhere near perfect. Models are typically calibrated with historical data from monitoring equipment in a watershed. Typical watershed monitoring equipment can include but not limited to stream gauges, rain gauges and flow gauges.

CHAPTER IV

CONCLUSION & DISCUSSION

This study looked at using digital terrain data to determine watershed boundaries in a region that is prone to flooding that has low lying and flat terrain. With the development of a delineated watershed, a hydrologic model was used to determine the hydrologic response of the watershed during a 24-hour, 100-year storm event. Future studies can include adding a hydraulic model to further study the hydraulic impact of various reaches within the watershed.

During the development of the hydrologic model, further calibration could not be accomplished. In this LLMWS region the drainage channels do not have flow data because of lack of monitoring equipment. With out the use of monitoring equipment in the reaches, it is extremely difficult to calibrate a model without preexisting information from real time storms or scenarios. To improve modeling results it is always best to calibrate a model with real time data and scenarios. For example, the flood protection plan done in 2019 for Cameron County Drainage District Number 5, the paper states that model calibration was done to improve these results. As mentioned previously, there were several rain events that occurred in this region. Cameron County Drainage District Number 5 has monitoring equipment in some of their drainage channels. This monitoring equipment can measure the water surface elevation of the reach as well as measure the rainfall. With this data they can determine how high the water surface elevation during any event, as well as the rainfall amount in the surrounding area.

For the 2019 study, they used the information from this telemetry data to help calibrate their hydrologic model using the rainfall data. Here they were to improve the meteorologic model for the hydraulic model they used which was HEC-HMS as they had several stations around their project area to help get accurate results. They could also simulate the results for the 2008 storm event of Hurricane Dolly. Similarly, they were able to use the water surface elevation data to possibly create stage hydrographs for each of their drainage channels within their study area. By having real time data, they can check the output of the hydraulic model and determine any possibly discrepancies that can be corrected. To this point it is quite helpful to have some source of telemetry data for drainage channels. Especially drainage channels in areas that are extremely prone to flooding. This region to date does not have telemetry data available to the public to date. This may change in the future. Most telemetry equipment can be quite expensive, however there are various grants that area available to be used for the used for flood mitigation. The figure below shows the existing equipment used by Cameron County Drainage District Number 5.

Figure 20: Monitoring equipment used by Cameron County Drainage District No. 5 *(Scheibe Consulting, LLC)*

The Texas Water Development Board (TWDB) currently has a Flood Infrastructure Fund (FIF) that helps regions with flooding issues apply for a combination of grant funding or low interest rate loans. The 2019 Flood Protection Plan done by the drainage district is a result of using this funding. Municipal entities could take advantage of these funds to help create monitoring stations in major drainage channels. They could also re apply for a TWDB FIF grant/loan in the future to help get funding for the development of a similar flood protection plan done by Cameron County Drainage District No. 5.

The hydraulic model that was developed for this study was not fully completed. As mentioned in Chapter 2.3 the hydraulic model was constructed for the main reaches of the Lower Laguna Madre Watershed. With the current iteration of the existing model, it is setup to be expanded in future projects. Setting basic objectives for the development of a model, it can achieve the following objective. The first objective of developing this hydraulic model is the ability to properly convey water through the model as well as convey it in the right direction. This model is able to process input data and shows the water being conveyed in the right direction.

When developing the hydraulic model there are some challenges that are presented, especially in this region. The large area of study, which is approximately 1,056 square kilometers in area, created some difficulties in producing accurate geometric features. To improve on the accuracy of the cross section in the reaches, field visits to different areas along the reaches were visited to make field observations of the reach’s dimensions. As mentioned in Chapter 2.3 it is difficult to determine the geometry of a reach’s cross-section when there is water present in the channel. With field observations and measurements assumptions can be made for the dimensions of the channel flow line, improving the accuracy of the cross-section’s geometry. The difficulty to improve the cross-sections accuracy becomes difficult when you take in to account the large area that needs to be covered as well as the amount of reaches that need to be visited. A variable that was not implemented during the development of the model was its hydraulic structures that are found within the reaches. This includes weirs, culvert crossings, gates, and pump stations that can be found along the Resacas and drainage channels.

Figure 21: Drainage structure at a Resaca in Brownsville, TX

Another aspect that can be added on to the existing model and something that needs to be considered for this model is the addition of lateral inflows that the reaches will experience during a storm event. With the two-dimensional component of HEC-RAS, lateral inflows can be determined and added to the model, increasing the reality and accuracy of the model. This also increases the complexity of the model.

In conclusion this study used a combination of GIS and Hydrologic software to develop a watershed delineation of the LLMWS. With this watershed delineation a hydrologic model in the region was created. With the existing hydrologic model, a complimentary hydraulic model can be created to better understand the hydraulic response within the watershed. To help improve the accuracy of the results for the models, real time data from the watershed should be monitored during various events.

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BIOGRAPHICAL SKETCH

Antonio L. Reyna graduated with a B.S. in Civil Engineering from the University of Texas Rio Grande Valley in Fall 2017. He has worked as an intern for a local engineering firm as well as a participant for the UTRGV UTCRS in 2016 internship program at Texas A&M. Currently he works for a local engineering firm, Ferris, Flinn & Medina, LLC as an Engineer in Training. In April 2021 he passed his Professional Engineering Exam and has completed his MS in Civil Engineering in May 2022. He can be contacted at reynaat@gmail.com.