FLOOD RISK AND MITIGATION ANALYSIS OF THE BRAYS BAYOU

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ABSTRACT

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Flooding has been a problem of Houston since it was established in 1837. However, over the past 60 years Houston has gone from a city of about a 900,000 people in 1960, to over four million today. This dramatic increase in population has greatly changed the landscape of Houston. The city has been and continues to expand outwards in all directions. The Brays Bayou Watershed is currently home to over 700,000 people in Houston. This study will examine the implications due to the recent updated annual exceedance probability (AEP) values on the Brays Bayou watershed. ESRI ArcGIS has been utilized to conduct a hydrological analysis of the watershed. A new model of HEC-HMS has been built using 2018 Lidar data to study the hydrology of the rainfall-runoff in the watershed. A new model of HEC-RAS has been built to analyze the changes the new AEP values on the depth and extent of flooding. The results from HEC-HMS show that the median AEP values will cause the discharge to rise by 29% for the 100-Year 24-Hour event and 33% for the 500 year 24-rainfall event at the outlet. The model showed that the

peak discharges from Hurricane Harvey could have been reduced by at least 3.5% and volume reduction of 15% with the addition on the proposed detention ponds. The analysis for the 2040 projections shows that the peak discharge could increase in the range from 3.4% to 5.1% depending on the rainfall event. The HEC-RAS model shows three areas of increased water depth at the stream. The three areas coincided with areas of significant elevation change, and adjacent to highways crossing the streams. The lack of space left in the watershed will cause many challenges on the mitigation projects in the future.

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CHAPTER I:

INTRODUCTION

1.1 Context of Problem

The Brays Bayou Watershed is in the southwest corner of Harris County in Houston, TX as seen in Figure 1.1. Flooding is something Houstonians have always had to deal with. Significant flooding in the Houston area dates to 1843 (Project Brays 2018). Over the past few decades Brays Bayou has flooded repeatedly. In 1983 Brays Bayou flooded from Hurricane Alicia but did not flood again until Hurricane Allison in June of 2001. Hurricane Allison affected over 70,000 structures and caused about 5 billion dollars in damages and 22 deaths from the flooding that occurred (HCFCD 2018). After Hurricane Allison the Brays Bayou area did not receive any significant flooding until the Memorial Day floods.

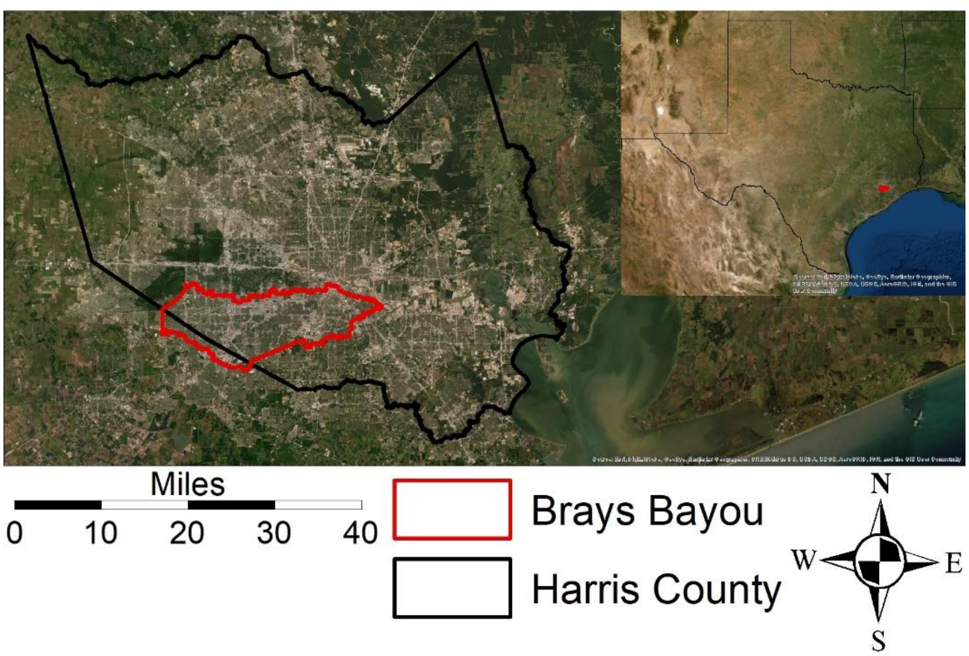

Figure 1.1 Location of the Brays Bayou Watershed

The Memorial Day floods occurred from May 25 to May 27, 2015 and destroyed more than 6,000 structures and took the lives of seven people. Brays Bayou received about 11 inches of rain in 3 hours from this rainfall event (HCFCD 2018).

The Tax Day Flood went from April 17 to April 18, 2016 dropping 12 to 16 inches of rain in 12 hours throughout Harris County (HCFCD 2018). The Tax Day floods flooded 9,840 homes in the Houston area (Linder & Fitzgerald 2018).

Hurricane Harvey is the latest major flooding event to occur in the Houston area. A couple of gauges located within Brays Bayou recorded about 35 inches of rain within a 5-day period during Hurricane Harvey. An estimated 154,170 houses were flooded in Houston which is over twice the amount of 73,000 houses that flooded during Hurricane Allison in June of 2001. The Brays Bayou Watershed suffered the greatest amount of flooded homes with 26,750 losses during Hurricane Harvey (Lindler & Fitzgerald 2018). In the Meyerland subdivision, water levels exceeded those from September 1983, Memorial Day 2015, and Tax Day 2016 by an average of 1.0-2.0 feet (Linder & Fitzgerald 2018). Despite this loss about 10,000 homes are estimated to have been saved from damage due to the construction work from Project Brays. Hurricane Harvey, Memorial Day, and Tax Day Floods prove there is still more work to be done to attempt to reduce the flooding of Houston.

1.2 Thesis Outline

The main objective of this research project is to determine the connection between increased streamflow/flooding and rapid urban land development. A relevant model of flooding risks assessment has been created to estimate future damage based on historical and current data of stream flow and land development. One of the objectives of this research is to examine the changes of the hydrology from the previous NOAA frequency numbers to the new updated rainfall events. The second objective of this investigation is relevant to the feasibility of adding additional detention ponds in the Brays Bayou Watershed. The third objective is to examine the future hydrology for 2040 based off projected land use data. The fourth objective is to examine the changes to the hydraulics in the watershed with the new rainfall events.

CHAPTER II:

REVIEW OF LITERATURE

2.1 Introduction

This chapter will first cover the main research that has been conducted within the Brays Bayou Watershed over the past 40 years.

2.2 Research Conducted Within the Area

A lot of the research done in the Brays Bayou area has been focused on the Texas Medical Center (TMC) (Hoblit, et al., 1999) discuss the beginning of the Rice University-Texas Medical Center Flood Alert System (FAS). This system started off using advances in geographic information systems (GIS), improvements of weather radar and the internet to create the FAS. (Bedient, et al., 2000) conducted a study to see how the next generation weather radar (NEXRAD) radar system could be used to create a flood warning system for the Brays Bayou Watershed. The results are being used to create the flood warning system using real-time NEXRAD radar. In 2003 (Bedient, et al., 2003) mentioned that the FAS used during Tropical Storm Allison was instrumental in Texas Children's Hospital's decision to make the call to close the parking garages and flood gates. These actions resulted in the hospital's loss totaling 300-400 million dollars less than some of the other facilities at the TMC. The report also discussed the ongoing improvements to the FAS and the developments of the FAS2 to yield more accurate hydrologic predictions. One of the papers analyzing the flood warning system for the Texas Medical Center provides details about the FAS2 system during three rainfall events in 2006 (Fang et al., 2008). Fang's (2008) thesis conducted an evaluation of the most up to date FAS2 developments at the time. Additionally, another objective of the study was to develop a real-time hydraulic prediction tool known as the Floodplain Map Library System. In a later article, (Fang et al., 2011) discussed the radar-based warning system for the TMC, focusing on improvements of the flood alert system and concluded with a summary of the flood alert system's performance over the past few years. A 2004 study was conducted on the Brays Bayou Watershed that examined the hydrologic prediction uncertainty for a system in relation to rainfall errors (Bedient & Vieux, 2004). In 1980 the (Bedient et al., 1980) report of the results from a stormwater monitoring program in Houston, TX, found a significant correlation between total storm load and total runoff volume of all sites examined. (Howlider 2018) conducted a study that examined the changes in soil characteristics in the Brays Bayou Watershed. (Smith & Bedient 1981) modeled the hydrologic response of Brays Bayou using HEC-1and demonstrated that full scale development of the upper part of the Brays Bayou Watershed would threaten to overload the flood control system, which was designed to handle a 100-year storm. (Bennett & Mays 1985) used Brays Bayou to propose a new methodology that could provide solutions to regional or watershed level evaluation of detention facilities compared to on-site detention. (Grout et al., 1999) investigations of Brays Bayou examined the composition and morphology of colloidal materials as they enter the bayou during a storm. Another study looked at variations in tropical cyclone related discharge in the Houston area (Zhu et al., 2015). Bhandari's (2016) dissertation on Brays Bayou and Sims Bayou focused on chemical and microbial analysis, and GIS. She conducted a multi-temporal geospatial analysis of the two bayous and used landsat images to compare vegetation and impervious surface differences from 1984 to 2010.

Much of the research on Brays Bayou has emphasized the impact of the flood alert system to help protect the TMC. The article from (Bedient et al., 2017) focused on the effects of the Memorial Day flood. Currently there have been no articles which present predictions past 2021. In addition, to date there have been no forecasts using the rainfall data from Hurricane Harvey. Research in needed to analyze present flooding data in order to investigate flood remedies for future conditions. Within the flood planning community there is a generally accepted view that Brays Bayou still needs more storage but there are no current plans to locate additional detention ponds.

2.3 Hydrologic Modeling

Hydrologic modeling is the examination of precipitation runoff events. The result from hydrologic modeling are hydrographs. There are many different software's for hydrologic modeling, the software used in this project was HEC-HMS.

The software chosen for the hydrologic modeling in this study is HEC-HMS version 4.3. There have been versions of HEC-HMS dating back over 30 years. HEC-HMS is the successor and replacement to HEC-1. This program improves upon and provides more capabilities than HEC-1 (HMS technical manual). HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic watersheds (HEC user manual). The primary output from this program is hydrographs. HEC-HMS can be used directly or with other software for the study of urban drainage, future urbanization impact, reservoir spillway design, and flood damage reduction (HMS User manual). Other options included in HEC-HMS include diversions, multiple-flood and multiple-plan analysis and snowfall and snowmelt (Hoggan, 1997). HEC-HMS is described mainly as an event, lumped, deterministic model.

2.3.1 NOAA atlas 14

In 2018 the National Oceanic Atmospheric Administration (NOAA) released a new a new precipitation-frequency atlas for Texas. This is known as NOAA Atlas 14 Volume 11. This document discusses the frequency estimates along with how they determined the new numbers. This document now supersedes the estimates from NOAA and the Weather Bureau. All the new updated point precipitation frequency (PF) estimates with 90% confidence intervals can be found on the NOAA website. The two scenarios that will be examined in this paper are the 100 year 24-hour and 500 year 24-hour events. These were chosen since these are the two main rainfall events that insurance companies use when looking at flooding events. The result of the paper greatly increased the 100 year and 500-year 24-hour events as seen in table 1.

2.3.2 Discuss curve number

The curve number loss model was used to model for the loss parameter of HEC-HMS. The Soil Conservation Service (SCS) Curve Number (CN) method is one of many ways to compute loss in HEC-HMS. The CN method is a function of accumulated rainfall, precipitation, soil cover, land use, and antecedent moisture. This method uses the equation:

$$Q = \frac{(P - I_a)^2}{P - I_a + S}$$

$$S = \frac{1000}{CN} - 10$$

Where Q = accumulated runoff

P = accumulated rainfall

I_a= initial abstraction

S= potential maximum retention after runoff begins

CN= curve number, percent of runoff

Through various studies of small watersheds, I_a can be approximated with the following equation:

$$I_a = .2S$$

This gives the excess at time t is:

$$Q = \frac{(P-0.2S)^2}{P+0.8S}$$

The CN values range from about 30 for a meadow, woods, or brush with a class A hydrologic soil group, to 100 for waterbodies. In general, the higher the CN the more direct runoff will occur from rainfall. Table 2.1 shows the numbers curve numbers that were used to set up the curve number model.

Table 2.1

Curve Numbers for different Land Uses in Brays Bayou Watershed

DESCRIPTION	A	B	C	D
Developed Low Intensity	61	75	83	87
Developed Med Intensity	69	80	87	90
Developed High Intensity	89	92	94	95
Greenspace	49	69	79	84
Barren Land	68	79	86	89
Woody Land	43	65	76	82
Water	100	100	100	100

2.3.3 Reservoir Routing

HEC-HMS has three methods for reservoir routing which includes, outflow curve, outflow structures, and specified release. The main concept of all of them is that outflow and storage are directed related to water level elevation. Different types of information are required for all three methods. Within the Outflow Curve method, there are three storage methods which include: storage-discharge, elevation-area-discharge, elevation-storage-discharge.

Studies that researched the effects of detention ponds/ reservoirs have concluded that these types of storage can effectively reduce the peak discharges and on the downstream side of the river, which can result in reduced flood inundation area and flood depth (Zope et al., 2015). One such study focused on the addition of detention ponds near the Poisar River basin in Mumbai (Zope et al., 2017). The results determined that adding detention ponds helped reduce peak discharge, flood extent and water depth. Therefore, these findings demonstrate that detention ponds help to reduce the flood hazard area and can act as an important flood control measure. These studies agree with (Smith & Bedient 1980) who concluded that detention reduces flood exposure and attenuates peak flows downstream.

Despite the benefits of detention ponds, one drawback is that they are designed on site to site basis. This can be problematic because they are not designed to operate in a coordinated fashion. The results from a study by (Emerson et al., 2005) showed mathematically that detention basins can increase watershed peak flow rates. The results agree with a study that proposed that only looking into stormwater detention in a localized area can result in increased flooding (McCuen 1974). Other research concluded that watersheds with an elongated shape are less effective at detention than watersheds that have a more rounded shape (Geoff, K.; Gentry, R., 2006). This could be one of the potential problems with Brays Bayou because of the elongated shape of the Brays Bayou Watershed. They also concluded that a watershed that is more developed will have less effective detention than less developed watersheds.

2.3.4 Muskingum method

Hydrologic and hydraulic are two types of routing techniques used to model channel flow. Hydrologic routing uses the continuity equation and the relationship between storage and discharge. Within HEC-HMS there are five routing techniques which include, lag, Muskingum, Modifed Puls, Kinematic-Wave and Muskingum Cunge.

For the study we chose the Muskingum method. There are two equations that the Muskingum channel routing method is based on. One equation is the continuity equation, which uses a simple finite approximation.

$$\frac{(I_1+I_2}{2}\Delta t - \frac{(O_1+O_2)}{2}\Delta t = S_2 - S_1$$

Where I is the inflow rate, O is the flow rate, and S is the change of storage. The amount of storage that is related to the inflow and outflow discharge is an assumption of the Muskingum method. Storage can be modeled as the sum of prism and wedge storage (HEC-HMS). Storage can be defined as:

S=K{XI+(1-X)O}

Where S is the reach storage, K is the travel time of the flood wave through routing reach, X is the weighting factor (0<X<0.5), I is inflow discharge, and O is outflow discharge.

2.3.5 Calibration

The purpose of calibration is to help ensure the model is as accurate as possible. One way to conduct the calibration for a model is to manually change the variables to try to make it look as close to the observed hydrograph. This is usually not feasible when there are too many variables to account for. That is why there is an auto-calibration processes built into HEC-HMS. This is conducted by a trial and error process.

2.4 Hydraulic Routing

In conjunction with HEC-HMS, HEC-RAS will also be used. HEC-RAS replaced HEC-2 in the late 1990s. Some of the capabilities of this software include one-dimensional steady flow and one- and two-dimensional unsteady flow hydraulics. Another capability of HEC-RAS is the ability to create water surface profiles. Potential floods of various sizes can be outlined with water surface profiles. HEC-RAS can also be used to analyze the hydraulic effects of bridges on streams. This software can also conduct floodway and channel improvement analysis as well as determine the effects from dams, weirs, and other structures in the flood plain. In HEC-RAS also can examine the sediment transport potential of a stream. Some of the outputs from HEC-RAS include X-Y plots of the river system schematic, hydrographs, cross sections, and inundation mapping.

2.5 Photogrammetry mapping

Unmanned aerial vehicles (UAVS), also known as drones, are aerial vehicles that can operate with human input. The main use of UAVs for most of their history has been for military use. The first use of an UAV dates to 1849, when Austria used incendiary balloons to attack Venice. Progress was made during both world wars on drone technology. During the cold war and Vietnam War there was a focus on reconnaissance drones. Drones such as the MQ-9 Reaper introduced in 2001, have gotten powerful to conduct missions that it has been able to replace F-16 fighter jets with them. Since the early 2000s there has begun a public demand for personal use drones with the increase in technology and reduction of cost (CITE). Over the past 10 years more military drone technology has been made available for the public. Companies such as DJI, which was founded in 2006, have been producing drones focused on the consumer. In 2015 about 300,000 people registered their UAVs for recreational use when the FAA put up an online registration form for drones. The purpose of the registration is to ensure all UAV operators are educated in the FAA laws regards UAVs. These numbers have continued to rise every year since then.

Today there are many types of small UAVs available to the public. The three main types are fixed wing, vertical takeoff and landing (VTOL) and rotorcraft. Each type has its advantages and disadvantages. VTOLs are the least popular currently because there are not many models on the market due to many in research and development.

For this paper, the focus will be primarily on rotorcraft because the model used in this research was a rotorcraft. The rotorcraft category can be broken up into smaller categories such as helicopter and multirotor. Helicopters are mainly used by hobbyist because they are more difficult to use and learn. Multirotor has quickly become the most popular type due to the maneuverability and the ease of learning. Multirotor can be broken up 4 categories: trirotor, quadrotor, hexacopter, and octocopter. Hexacopter and Octocopters prices can range from about 500 US dollars to 250,000 US dollars. These drones are usually designed to carry more equipment to accomplish different tasks. Because of these factors, these two are more marketed towards professionals instead of hobbyists. Quadrotors have gained a lot of popularity due to their price range and versatility. Quadcopters with cameras can be as found on Amazon.com for as low as 70 US dollars up to 20,000 US dollars.

There are many types of sensors available for use on UAVs. The most popular are red greed blue (RGB) cameras. The other most prevalent used UAV for 3D mapping is Lidar. There have been many studies that have compared the two. One of the reasons for the prevalent use of the RGB camera is the price. This is the type of camera used for this research on the Mavic Air. Other UAV based sensors include LiDAR, gas detection, biosensor, magnetometer, temperature, thermal imaging, multispectral, and hyperspectral imaging.

Photogrammetry has been around for over a century. It is the process of putting together a map from aerial imagery. Today that is done many ways including using cameras attached to drones. The most common way to derive 3D imagery from photographs is structure from motion (SfM). It does this by flying the camera over a determined area. During this time the camera takes many overlapping photographs of the area. For this a DGI Mavic air was used to collect the images.

The software used was the Pix4D app. From there it turns the images into orthomosaic, digital surface model (DSM), for 2D imagery and point cloud, Mesh OBJ, and Mesh FBX for 3D imagery.

CHAPTER III:

CURRENT CONDTIONS OF THE BRAYS BAYOU WATERSHED

3.1 Introduction

The Brays Bayou Watershed is one of the most important watersheds in Houston. This chapter will discuss go into detail of why Houston is extremely prone to flooding. These factors include: the hydrology, climate, geology and soils, and topography of the watershed. Project Brays will be discussed to show what has been done in order to mitigate flooding.

3.2 Description of Brays Bayou

Brays Bayou is located within Harris County, Texas. According to the Harris County Flood Control District, the county is divided into 22 watersheds. Most of the watersheds within Harris County have relatively small geographic areas. All of watersheds drain south and east towards Galveston Bay to the Gulf of Mexico. Harris County covers 1,777 square miles and is home to over 4,500,000 people.

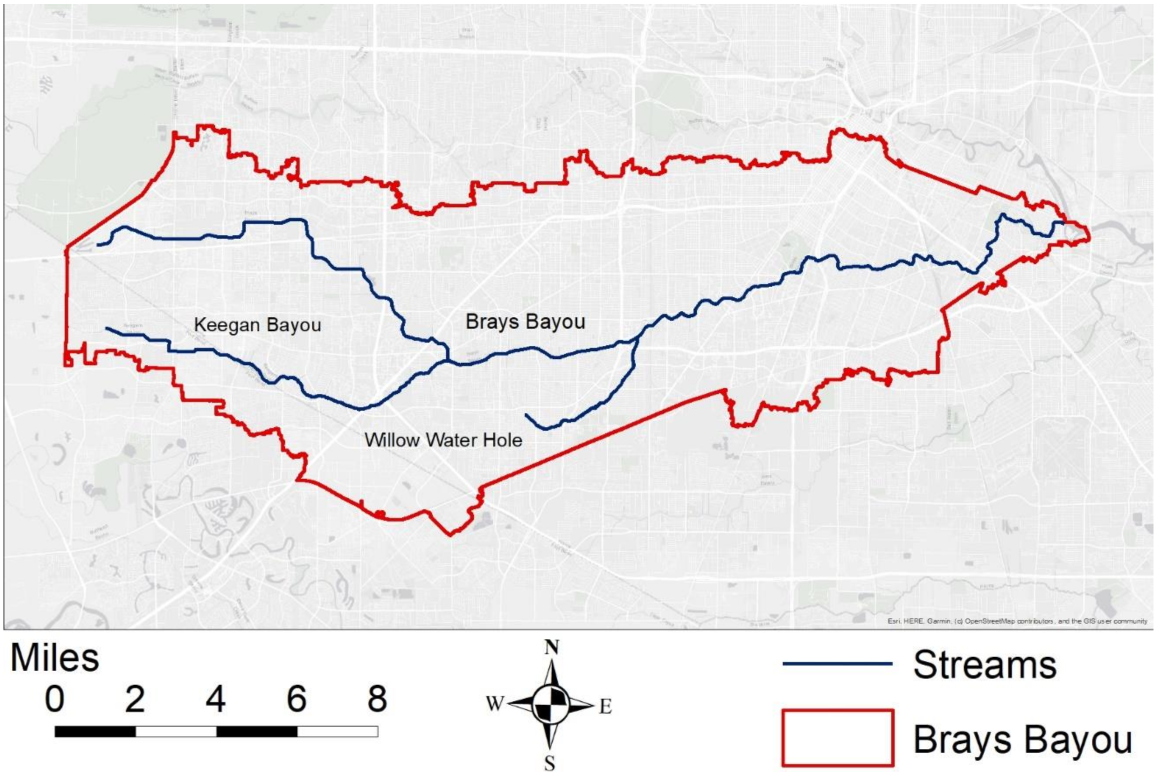

Figure 3.1 Location of Major Streams Located within the Brays Bayou Watershed

Brays Bayou covers a large area of southwest Houston. Although the starting point is in Fort Bend County, the majority flows through Harris County. Flood containment of Brays Bayou is of critical importance to the City of Houston. The Brays Bayou Watershed encompasses a population of about 717,198 based on the 2010 census. Additionally, Brays Bayou traverses an area that is home to several major universities, including Rice University and University of Houston; The Texas Medical Center, largest medical center in the United States; as well as NRG Stadium, Museum District and the Houston Zoo. Brays Bayou spans an area of 127 square miles (HCFCD), has a length of 31 miles and includes 121 miles of open streams. The Brays Bayou watershed consists of Brays Bayou, Keegans Bayou, and Willow Waterhole as the primary streams. In the 1960s the lower 26 miles of Brays Bayou was lined with concrete by the US Army Corps of Engineers (Vieux & Bedient 2004). The area is characterized by having very flat terrain and tight clay soils (Bedient et al., 2003). These clay soils make the terrain impervious to infiltration of surface waters. Over the years the peak flows increased, and the response time shortened due to increased urban developments. When Brays Bayou was first lined, it was considered one of the most protected watersheds in Houston. The urbanization in the upper part of the bayou increased the flow rates for smaller storms. The increase in urbanization caused stream flows to grow to a point that a 10-year storm would bring the channel to its design capacity in 1983 (Bedient et al., 2003).

Urbanization has surged along Brays Bayou from east to west over past 40 years. Around 28.35% (9,463 acres) of vegetated lands have disappeared over the period of 1984 to 2010. This development has resulted in an increase of 1,376 acres of impervious land added during this time period (Brandihar & Sridhar 2017). In 1980, more than 37% of the Brays Bayou Watershed was urbanized (Bedient et al., 1980). Since 1993, the Watershed has been over 90% developed thereby significantly lowering the design capacity of the bayou (Bedient et al., 2000). As a result of the loss in vegetative areas, there has been a significant increase in the amount of impervious surface areas. As seen in figure 3.2, most of the watershed is currently residential.

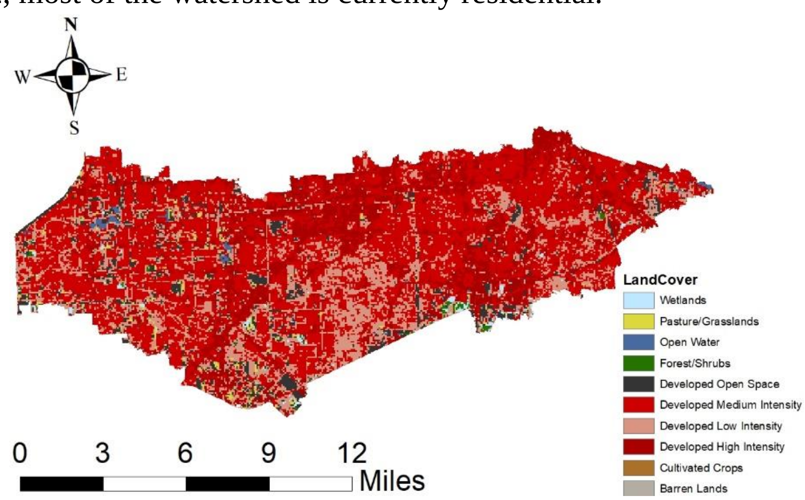

Figure 3.2 Land Cover from the Houston Galveston Area Council of the Brays Bayou Watershed

Historically subsidence has also been a major issue for Houston. Subsidence is primarily caused by pumping of the Gulf Coast Aquifer. Subsidence has caused some Houston neighborhoods to be condemned and others turned into parks near Galveston Bay. Another consequence of subsidence is that flat slopes can become flatter which increases flood levels and helps explain repeated flooding in this watershed (Bedient & Vieux 2004). One study used satellites to attempt to get a correlation between flooding and subsidence. The study showed that the correlation between localized land subsidence and flooding was robust. They confirmed that subsidence affects flood severity my modifying bas flood elevations and topographic gradients (Millier& Shirzaei 2019).

3.3 Hydrology

The Brays Bayou Watershed is located within the San Jacinto River Basin. The San Jacinto River Basin is then divided into 15 watersheds, including Brays Bayou. Brays Bayou is located within the Southwest corner of San Jacinto River Basin as seen in figure 1. The Brays Bayou Watershed spans an area of 143 square miles, has a length of 31 miles and includes 121 miles of open streams. The watershed consists of Brays Bayou, Keegan Bayou, and Willow Waterhole as primary streams. In the 1960s the lower 26 miles of Brays Bayou was lined with concrete by the US Army Corps of Engineers (Vieux & Bedient 2004). The streams flow west to east. Ultimately Brays Bayou flows into Buffalo Bayou, which flows into Trinity Bayou, then into the Gulf of Mexico.

Detention basins have been a tool for flood control in the Brays Bayou area for the past 15 years. There are four detention basins located within the Brays Bayou Watershed: the Arthur Story Park Stormwater Detention Basin, Eldridge Detention Basin, Old Westheimer Road Stormwater Detention Basin, and Willow Waterhole Detention Basin. The Eldridge detention basin can store up to 4,500 acre-ft (5.6 million m^3) on 340 acres of land. Westheimer Road detention basin provides 900 acre-ft (1.1 million m^3) of storage on 47 acres. Arthur Story Park can provide up to 3500 acre-ft (4.3 million m^3) of storage on 211 acres. The newest detention basin is Willow Waterhole which can provide up to 1,865 acre-ft (2.3 million m^3) on 280 acres (Landers 2004). Collectively the basins can hold over 3.5 billion gallons of water and cover over 800 acres (HCFCD 2016). The overall goal of these detention basins has been to reduce the flooding caused by the urbanization of the bayou.

3.4 Climate of Houston

The climate in Houston makes it very susceptible to flooding. With Houston being located near the Gulf of Mexico, this makes it very susceptible to tropical storms and hurricanes. Houston gets an average of about 50 inches of rainfall each year. The record for rainfall in the continental United States in a 24-hour period is 43.0 inches, which was recorded near Alvin, Texas on July 25-26, 1979 during Tropical Storm Claudette (Hill 2005). Alvin is a town located about 30 miles southeast of the Brays Bayou Watershed. This is just one example of how bad the rainfall can be in Houston. The rainfall is one of the main factors that affect the flooding of Houston.

3.5 Geology and Soils

The Brays Bayou Watershed is located within the Gulf Coast Basin. All the formations within the Gulf Coast Basin in Texas are from the late Oligocene and later. Bray Bayou is mainly located on the Beaumont Formation. The Beaumont Formation is one of the youngest formations within Texas with being from the middle of the late Pleistocene/ early Holocene epoch. The main lithologic constituents of this formation are unconsolidated fine detrital clay and silt particles. These properties make this formation very impermeable to water infiltration.

With Houston being located on a passive shelf, there are many passive growth faults found throughout the city. These faults move creep very slowly. These faults can have major implications on the hydrology and structures found throughout the area. However, at this time there are no major faults that run through the Brays Bayou Watershed.

The main type of soils in the Houston are vertisols. These are clay soils that shrink when they are dehydrated and swell with moisture. Within the Brays Bayou watershed there are over 20 soil units. 93.5% of the soil units within the watershed have a soil hydrologic group of class D as seen in figure 3.3. Only .5% of the watershed has class B soils, which are soils that have moderate rates of infiltration. With the majority of the watershed having the worst hydrologic group, this helps to show that this area even under the best of circumstances would be prone to flooding.

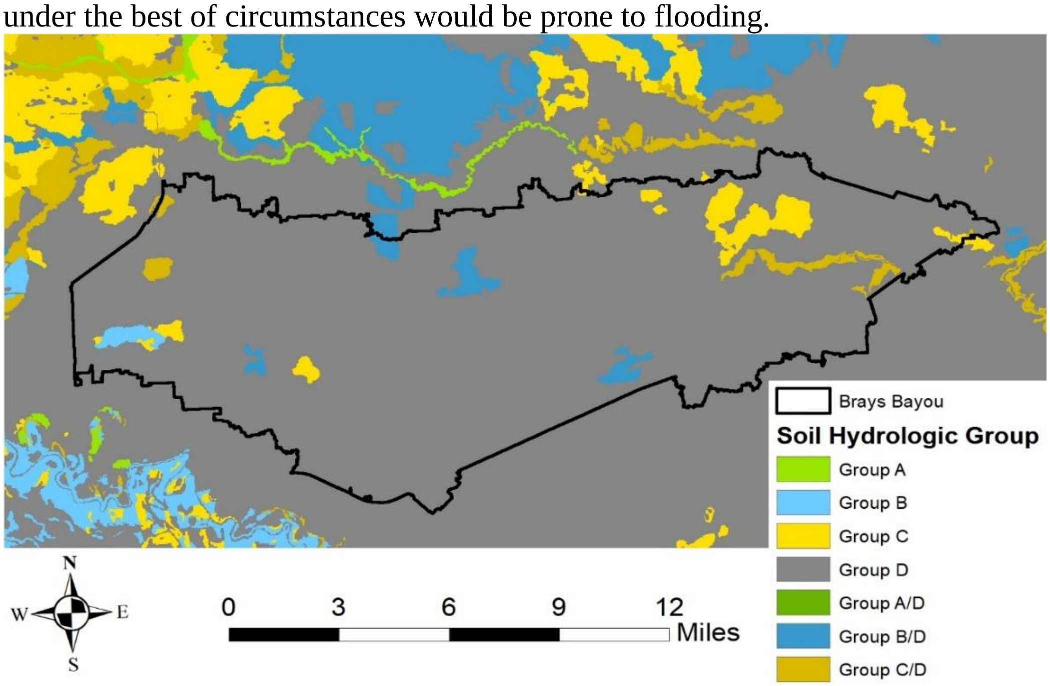

Figure 3.3 Soil Hydrologic Groups of the Brays Bayou Watershed

3.6 Topography

The Houston area is on the Gulf Coast Plain. The Brays Bayou channel drops 84 feet over the course of the 31 miles length where it meets up with Buffalo Bayou. As seen in figure 3.3, the Brays Bayou Watershed does not have much topography change. Figure

3.3 shows that most of the watershed has under a 4-degree change in slope. This is one of the many factors that affect the runoff of rainfall within the watershed. When the rain is dropped, the city is depended on the streets and sewer to drain the watershed into the bayous.

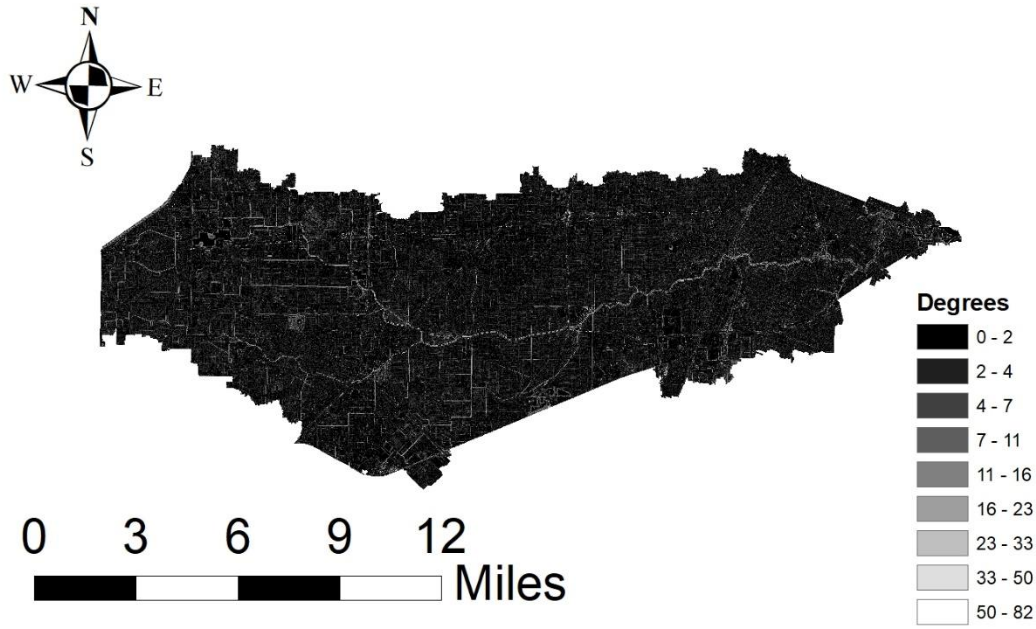

Figure 3.4 Slope Map of the Brays Bayou Watershed in Degrees

3.7 Project Brays

Project Brays has been a series of projects along Brays Bayou to reduce the peak flows and flooding throughout the area. Project Brays developments have focused on water detention dating back to 1994. In 2005 the HCFCD began a series of projects to expand the bayou (Project Brays 2018). The final phase of Project Brays has begun in 2018 and will last through 2021. The area of focus for the final part of Project Brays is to widen the bayou between South Rice Avenue and Fondren Road (Schneider 2017). In 2016 a case study was conducted on the effectiveness of Project Brays. It looked at pre-conditions (prior to 2001) current (2015), and future (2021). Their results showed that Project Brays reduced the amount of flooding from the Memorial Day 2015 flood.

However, the results also showed that there would still have been a significant number of houses flooded in the Meyerland area after the completion of Project Brays in 2021 (Bass et al., 2016). At the time of writing only 2.8 miles of channel excavation are left from the 16.4-mile project. The last phase needed to complete the project is the replacement of 12 bridges crossing Brays Bayou. When Project Brays is complete it will remove 1 percent (100-year) floodplain from about 15,000 homes and businesses. It will also reduce the number of homes at risk of flooding during a 25-year flood event by 3,470 (HCFCD 2016).

3.8 Chapter Summary

This chapter provided a detailed description of the Brays Bayou Watershed. It helped to explain the importance of why this watershed needs to be protected. The climate of Houston provides on average of 50 inches of rainfall each year. The main soils in area are clay vertisols, which are class D hydrologic group. These soils sit on top of the Beaumont Formation which is a clay formation. The urbanization has been at over 90% since 1993. The slope of the area has a slope of on average less than 4 degrees. All of these factors come together to help show why Houston has such horrible flooding problem, and why there needs to be as much research as possible of how to mitigate the flooding.

CHAPTER IV:

HYDROLOGIC MODEL DEVELOPMENT OF BRAYS BAYOU WATERSHED

4.1 Introduction

This chapter summarizes the development of the hydrologic model used in the hydrologic assessment of the Brays Bayou watershed. To process the Lidar DEM, we used Esri ArcGIS ArcMap 10.5 For hydrologic modeling we used the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) Version 4.3 to perform the modeling. The process for preparing the digital elevation model (DEM) data from the Texas Natural Resources Information Systems (TNRIS) website can be seen in Figure 4.1.

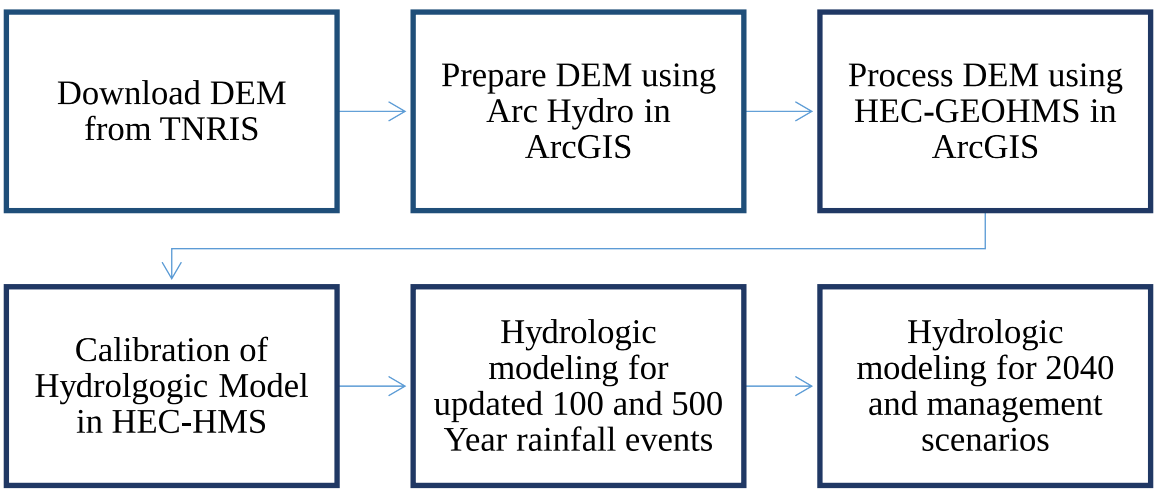

Figure 4.1 Overview of HEC-HMS modeling process

4.2 HEC-HMS Model Pre-Development

Before the HEC-HMS model could be built in ArcGIS using the ArcHydro and HEC-GEOHMS addons, a few steps had to occur first. Figure 4.2 shows the steps that were conducted.

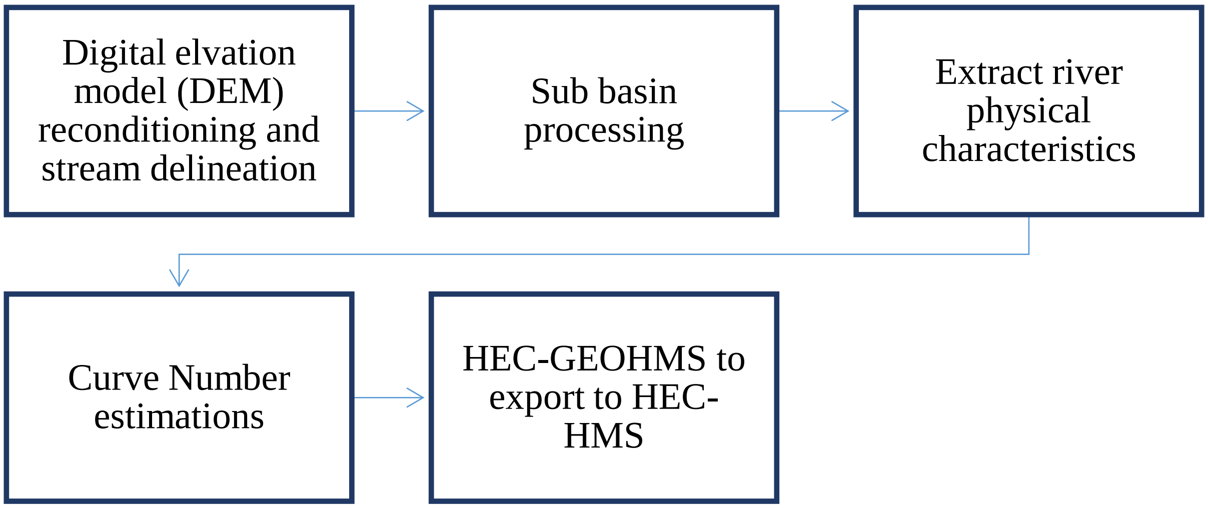

Figure 4.2 Overview of preprocessing steps in ArcGIS

4.2.1 Downloading and GIS data from TNRIS and merging data together

The digital elevation model (DEM) data was download the latest Light Detection and Ranging (LiDAR) data of Harris County. In spring of 2018 Fugro ran planes over Harris County to gather the data. In spring of 2019 the data was released to the public on the Texas Natural Resources Information System (TNRIS) website. The area of Brays Bayou Watershed was downloaded with extra area to help ensure proper delineation of the watershed. Once the data was loaded into ArcMap the tiles were merged using "Mosaic to New Raster" tool. The spatial resolution of the DEM data was 1 meter. The XY coordinate system used was NAD 1983 2011 UTM Zone 15N

Once all the digital elevation model (DEM) files were loaded into ARC Map and put together, the next step was to make the appropriate dataset to be able to run the steps for HEC-GEOHMS. This was accomplished by following the steps as seen in figure A.1 Once this was done the curve number grid has to be made to be put into HEC-GEOHMS.

4.2.2 Curve Number

One more step before the extension HEC-GEOHMS could be ran was to be a Curve Number Grid map. This was done by using land use data from the Houston-

Galveston Area Council and the hydrologic soils groups map. The land cover map shown in figure 4.2 shows that most of the watershed is either medium or highly developed space. The soils groups range from A to D. With A being very sandy and porous soils, while D being very clay soils and impervious to water infiltration. The two maps where prepared and merged as seen in figure a.1. Figure 4.1 shows the curve number map of Brays Bayou. The map shows that most of the watershed has a curve number of over 85. This shows that most of the rainfall is going to runoff instead of getting infiltrated into the soils. Once this was complete it could be put into HEC-HMS under the Loss method in for the sub basins.

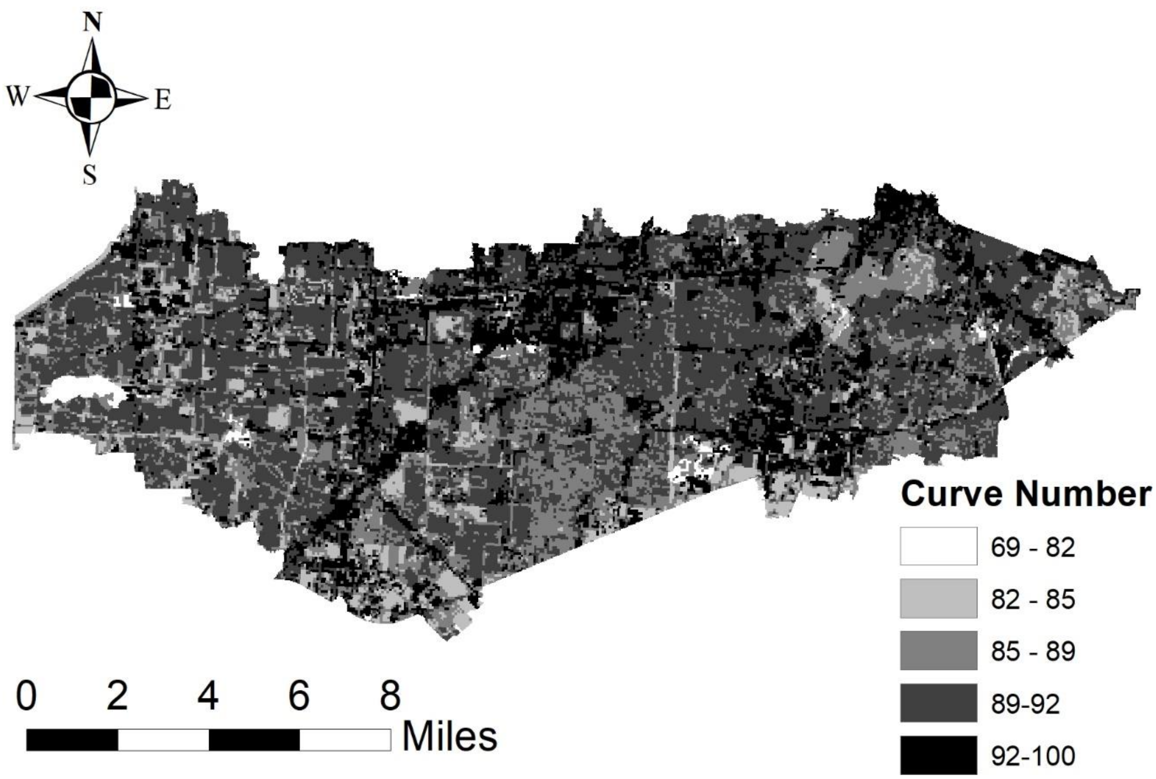

Figure 4.3 Curve number map of the Brays Bayou Watershed

4.3 Building HEC-HMS model in ArcGIS

The last step of the hydrologic modeling was to build the HEC-HMS model in ArcGIS using the extension HEC-GEOHMS. This was done using the files created in the previous steps. This was done by following the steps as seen figures A.3 and A.4. The number of sub-basins had to be reduced to 31. This is because there was an error running the Longest Flow Path.

Once this was completed, the model was exported to HEC-HMS. Figure 4.4 shows the completed model in HEC-HMS. This is a blank model that must had more steps done to it before it can be a fully working accurate model.

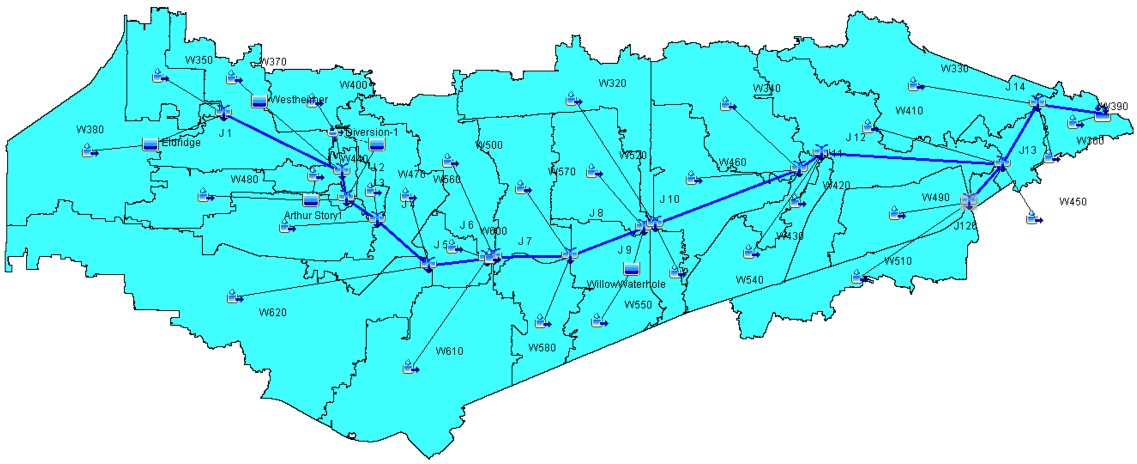

Figure 4.4 Completed Brays Bayou Watershed basin in HEC-HMS

4.4 Meteorological Model

Once the model was loaded into HEC-HMS, the steps as seen in figure 4.5 had to be conducted. Every simulation ran in HEC-HMS must have a meteorological model attached to it. The purpose is to input how much rain falls into each sub-basin in each event. Two types of meteorological models were built for simulation, the frequency storm and the specified hyetograph.

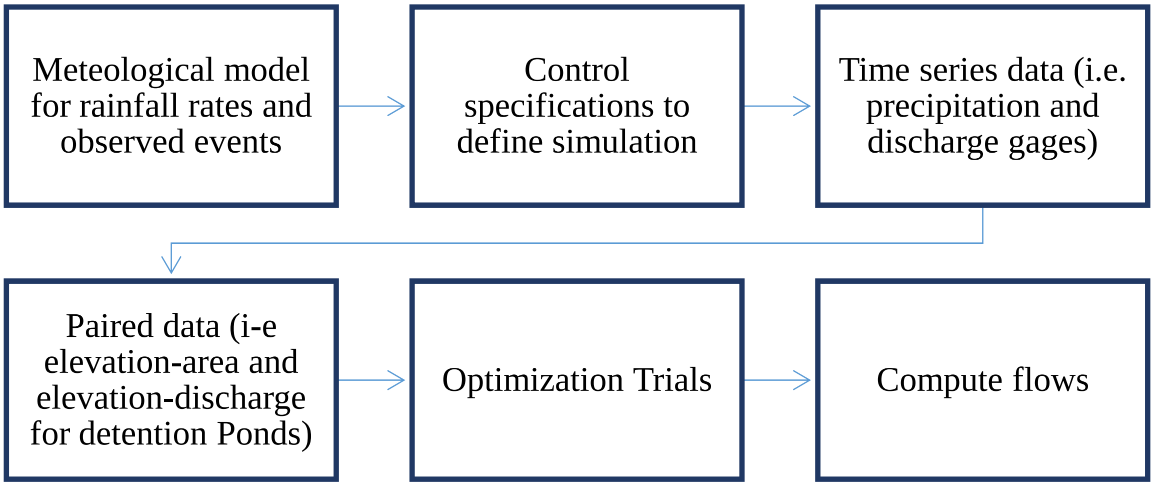

Figure 4.5 Overview of HEC-HMS model development

To build the meteorological model for this calibration purposes the Harris County Flood Control Warning System website was used. Their system provides real time and historical rainfall data from all over Harris County. There were 12 rainfall gauges from the Brays Bayou Watershed area was used. The event that was chosen for calibration was Hurricane Harvey, from August 25, 2017 at 00:00 to August 30, 2017 at 00:00. The reason for this is because it occurred only about 6 months before the Lidar data. The time is important because the longer the time period between calibration event and Lidar taken, the greater the differences will be in the watershed. This is of great importance in this watershed where there is always construction going on either within the channels or on the detention ponds.

In total there had to be six frequency storm models built for the simulation. They included the old and new 100-year storm events and the old and new 500-year storm events. The rainfall numbers can be seen in tables B.1 through B.6 in appendix B. The previous numbers were taken from (Hershfield, 1963) (TP40rainfall frequency atlas of the US 1961). The new rainfall numbers were taken from the NOAA website NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES.

(https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html). This provides the rainfall event numbers for the entire United States.

4.5 Using a Drone to Capture Measurements

In order to figure out the elevation-discharge levels required for the input for the reservoirs in HEC-HMS, detailed measurements were required for the outlets of the detention ponds within the Brays Bayou Watershed. In order to accomplish this small personal use drone was used. The drone selected was the DJI Mavic Air. It was selected due to its small size, but powerful camera.

In order to get the measurements, the PIX4D Capture app was used. To gather a map to put together a 3D image, the Double Grid Mission was selected from the home screen. Then the area was to be measured was selected as seen in the example in figure 4.5. The time and number of pictures required is automatically selected and determined by the size of the area to be surveyed. Once the drone is done it returns to the home position. This process was repeated for each of the detention pond outlets.

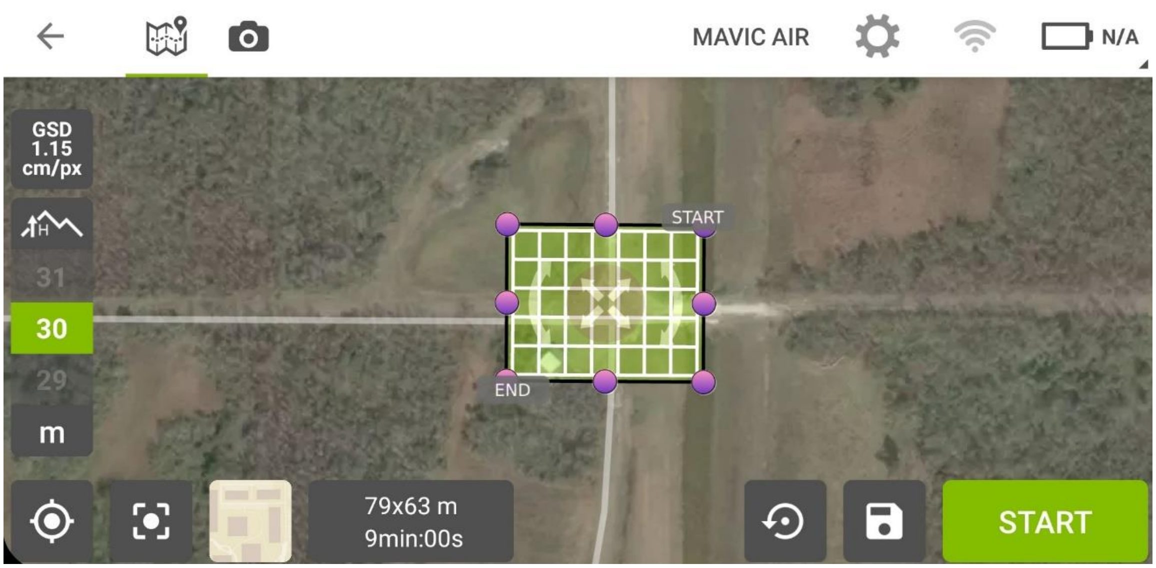

Figure 4.6 Selecting Area to be measured in using PIX4D app

4.6 Determining Discharge

Once the maps where made in Arc Scene it was time to figure out the discharge to put into the area discharge for the reservoirs in HEC-HMS. In order to get discharge (Q) equation 1 was used to get the weir discharge as seen in figure 4.6. Equation 2 was used to get the orifice discharge.

Figure 4.7 Spillway calculations for height and length.

1. $Q = CLh^{3/2}$
2. $Q = CA(2gh)^{1/2}$

Q = discharge cubic feet per second

L = Length of spillway

h= height of water above weir crest or distance from center of pipe to top of spillway

4.7 Determining Elevation and Area of Detention Ponds

To determine the elevation and area the 2018 DEM was used. Once loaded into ArcMap the Contour tool was used to produce a line shape file. Before the next tool was used, extra contour lines were cleaned up using the Edit tool to reduce the amount of noise. Then the Feature to Polygon tool was used to convert the elevation into a polygon file to produce the area. Once these two tools were running was the elevation and areas were exported from the attribute tables to excel by converting them to CSV files.

Junction 9 as seen in figure 4.7, shows the location to determine the effectiveness of the proposed detention ponds. The elevation and area numbers were then exported to HEC-HMS for the Elevation-Area

A= area of pipe

G=gravitational constant = 32.2 ft/sec^2

C= coefficient (3.1 in equation 1 and 0.6 in equation 2)

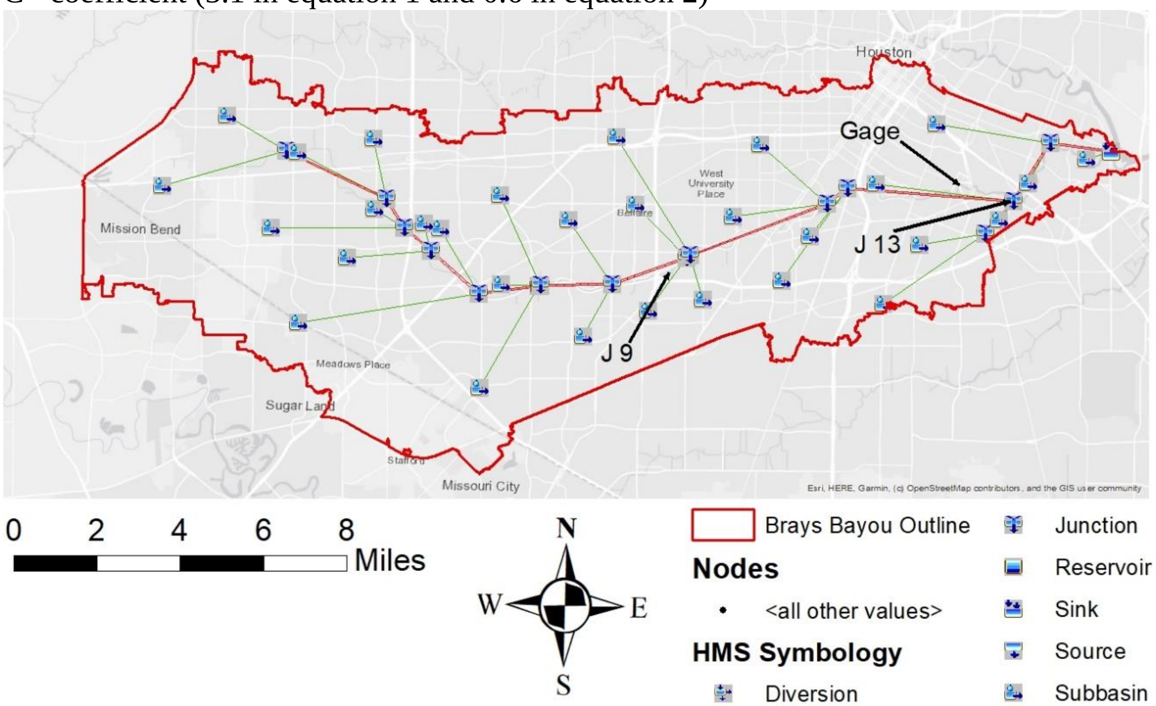

Figure 4.8 Location of J 9 which was used for determining discharge reduction for mitigation measures, and location of J13 which used for calibration.

4.8 Calibration

Once the model was exported into HEC-HMS and the detention ponds were accounted for, it needed to be calibrated in order to be as accurate as possible. Figure The overview of the calibration process can be seen in figure 4.8. First a new optimization trail had to be set up. For the optimization a discharge gauge from Hurricane Harvey was used. The discharge gauge data was downloaded from the USGS water data viewer. The gauge used was USGS 05075110 Brays Bayou at MLK Jr Boulevard. The reason for this gauge being chosen was because it was the closest to the end of Brays Bayou. The location of the gauge is located near the end of the watershed. The gauge was then set to Junction 113 as seen in figure 4.7.

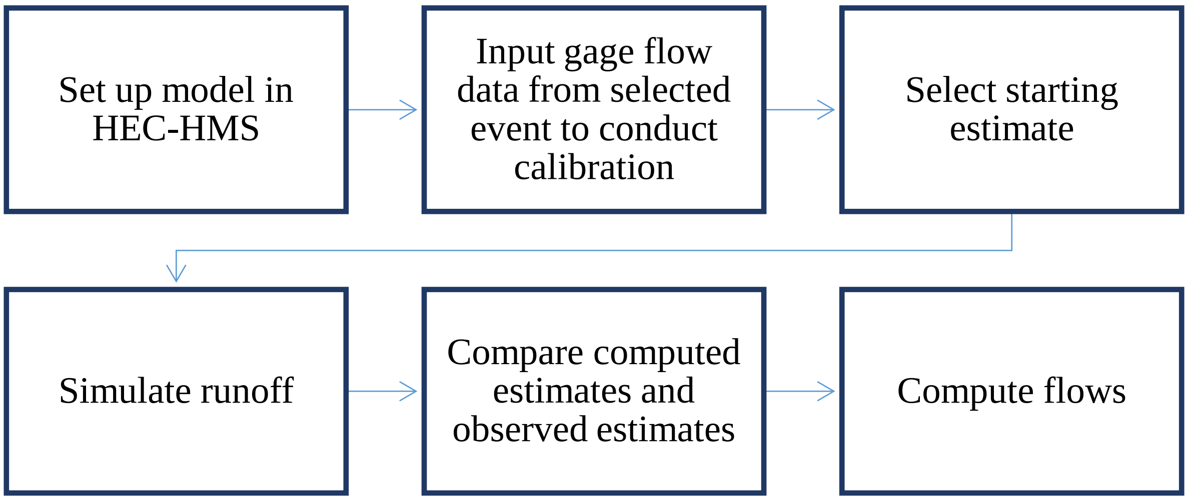

Figure 4.9 Overview of the calibration process

Simplex method was ran with the statistic sum of squared residuals for 5000 iterations. The time interval was set to 15 minutes to ensure consistency throughout the model. First the Muskingum parameters K, X, and sub reaches were running in optimization trail 1. Next the sub basin parameters curve number and lag time were running with the same values as trail 1.

Figure 4.9 shows the trends of calibration process. Although the peak discharge has a difference of 18.4%, other statics show that the calibration process was successful. The volume of water deposited over the watershed was off only by .35 inches. The peak discharge was off by one hour.

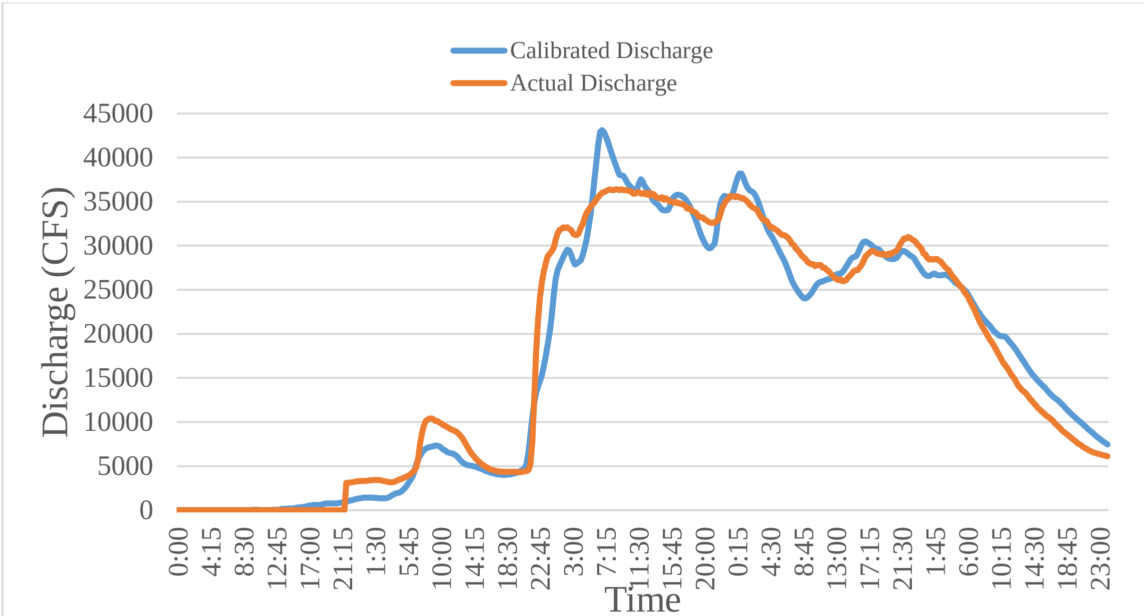

Figure 4.10 Calibration versus actual discharge of Hurricane Harvey at Junction 9

The root mean square error (RMSE) standard deviation from for the calibration at J141 and Gage 1 was 0.2. The range for RMSE is from 0-1 with 0 being the most accurate. The result of 0.2 shows that there is a high probability of the predicted values being true.

The percent bias between the calibrated model and actual discharge was -1.37%. Percent bias is the average tendency of calibrated values to be larger or smaller than values from the actual gage data. This small negative number shows that there is a small chance for the calibrated model to slightly underestimate the actual values.

The Nash-Sutcliffe model efficiency coefficient (NSE) can be used to evaluate the ability of a hydrologic model to predict the results. The range on the NSE can range from -∞ to 1. An efficiency of 1 is a perfect match. The results from the optimization show the NSE with a value of 0.970. The value of 0.970 helps the show that the calibration process for this HEC-HMS model was a success.

4.9 Comparison of Rainfall Events

The rainfall events that were compared are the old rainfall estimates from the Weather Bureaus Technical Paper No. 40 (TP-40) and the mid and upper bounds rainfall events from the new NOAA Atlas 14 Volume 2. These were first compared by examining the hydrograph at the outlet. The second way the rainfall events were compared was from taking the maximum discharge from the junctions in Brays Bayou as seen in figure C.1. The purpose of this was to examine the changes of discharge along the stream.

4.10 Mitigation Measures

The main mitigation measures proposed is making detention ponds in the areas of Westwood and Braeburn Country Clubs as seen in Figure 4.11. The areas of the country clubs were measures in ArcGIS. Both areas are about 130 acres. The proposed depth of these detention ponds will be 11.5 feet. This is to match one of the Arthur Story detention pond depths, which is closest in size. The proposed storage area for both will end up being 3000 Cubic Arce feet. This would add up to be a 30% increase in storage capacity for the watershed.

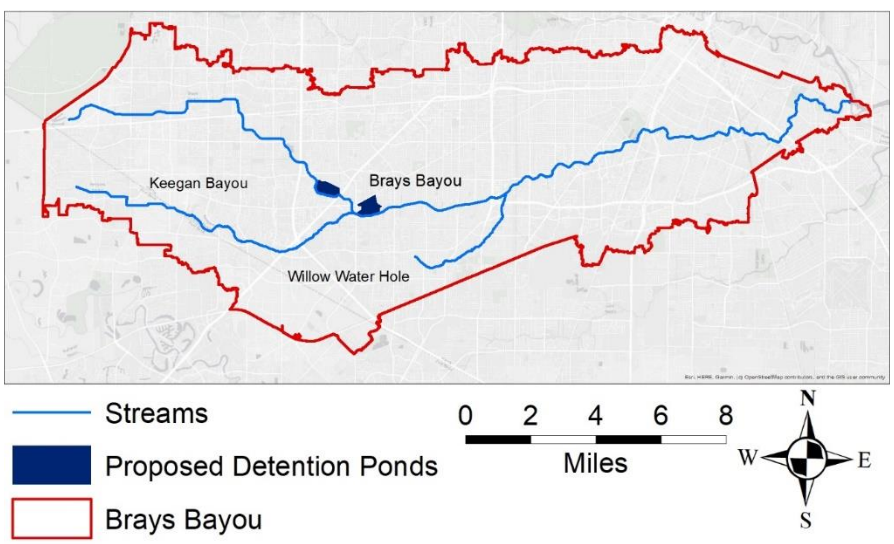

Figure 4.11 Location of Proposed Detention Ponds

4.11 2040 Analysis

To conduct the prediction analysis of the 2040 scenario the curve numbers were adjusted to reflect the changes in land use. All the curve numbers lower than 87 were brought up to 87. This is to reflect that the entire watershed will have curve numbers equal to residential areas with ¼ acre lot sizes on class D hydrologic soils or greater. This resulted in the increased curve numbers in 12 of the 31 sub-basins within the watershed.

4.12 Problems encountered

One of the major problems encountered while making the HEC-HMS model was processing the large dataset. Because the dataset was set to 1-meter resolution and the area was so large this made some of the smaller steps more difficult in ARC Map. Some of the other problems came with the compatibility between ARC-MAP and the add-on s ARC Hydro, and HEC-GEOHMS. The largest problem encountered was when trying to run the “Longest Flow Path” tool in HEC-GEOHMS. This was solved by reducing the number of sub-basins. This was done by reducing the area size in the “Stream Definition” tool. The calibration process presented problems with trying to figure out exactly where to place the gage. It was determined by trial and error that the gage should be placed on the nearest junction instead of reach.

CHAPTER V:

HYDRAULIC MODEL DEVELOPMENT OF BRAYS BAYOU

5.1 Introduction

This chapter summarizes the development of the hydrologic model used in the hydraulic assessment of the Brays Bayou watershed. We used the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center's River Analyst System (HEC-RAS) Version 5.0.7 to perform the 2-D modeling. The 2018 Lidar used for the hydrologic modeling in Chapter 4 was used for these procedures.

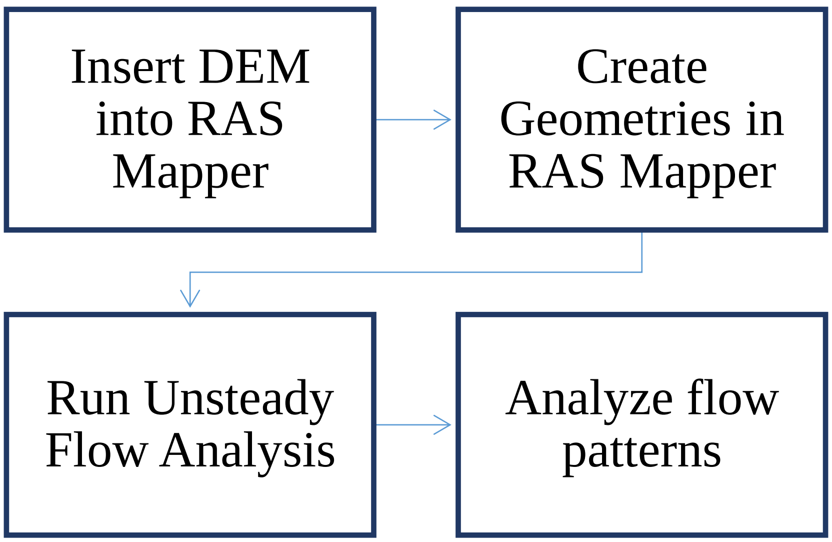

Figure 5.1 Overview of HEC-RAS computations

5.2 Creating HEC-RAS 2-D model

First the 2018 Lidar DEM had to loaded into RAS Mapper. Figure 5.2 shows the process for 2-D geometry in RAS mapper. This newer feature is where all the processing of 1-D and 2-D data is conducted. RAS Mapper is meant to be the replacement for the GIS addon HEC-GEORAS. First a projection file had to be loaded into RAS Mapper. The projection file was downloaded from "spatialreference.org". This had to be the same coordinate system as the DEM. Once the DEM was loaded into the terrain it was time to work on the geometry section. The first step in the geometry section was to make a perimeter of the area to be studied.

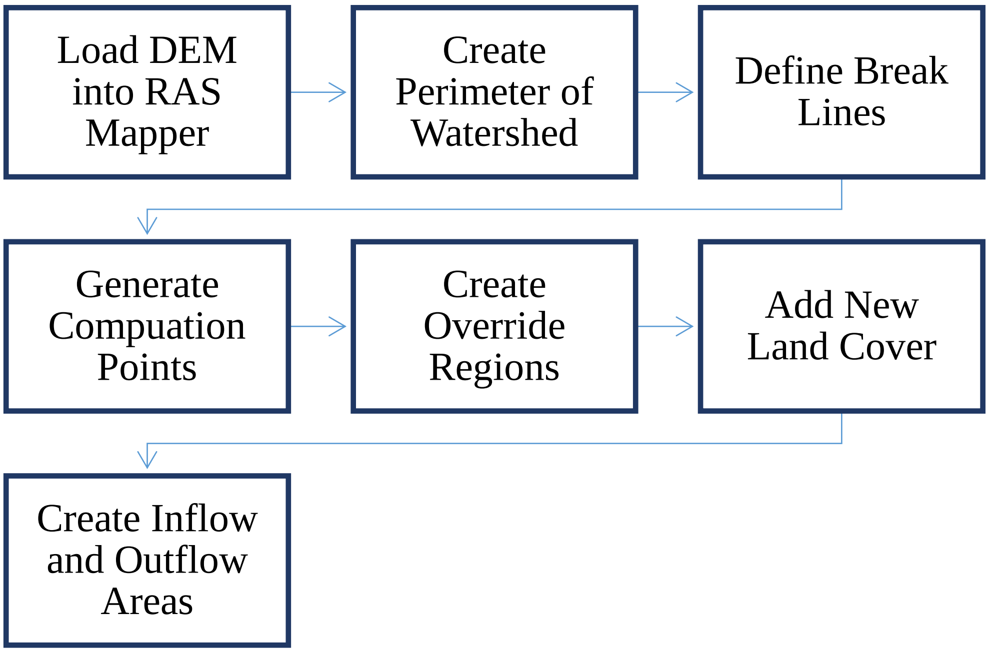

Figure 5.2 Process of processing 2-D flow area in RAS Mapper

The outline for Brays Bayou was loaded into RAS Mapper, then a new perimeter was traced. As seen in figure 5.3 the perimeter extends slightly beyond the original boundaries. The real outline of the watershed was extended to reduce hard corners to reduce errors when creating the 2-D mesh. As seen in figure C.3, the large areas undefined, a Manning's N Value of 0.05 was chosen. This value was chosen because most of this area is urban. A cell size of 20 feet was chosen for the 2-D area. Finer resolutions were tested; however, the computational power of our computer could not handle finer resolution. Override regions were chosen to lower the Manning's' N values in the streams. 0.025 was chosen for unlined portions of the watershed and 0.015 was chosen for lined portions of the watershed.

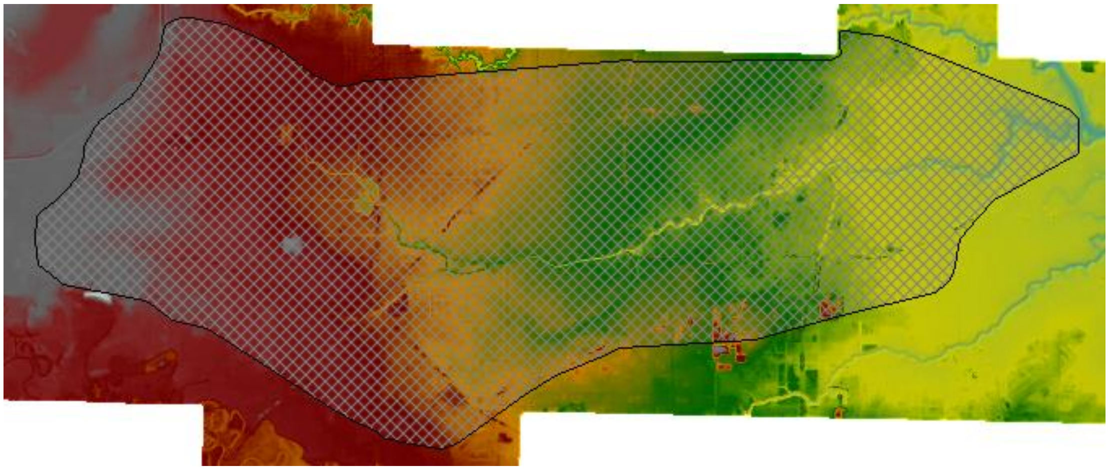

Figure 5.3 2-D flow area of the Brays Bayou Watershed

The discharge determined from HEC-HMS was then put into HEC-RAS. This was done in the Unsteady Flow window. The discharges from sub basins 380, 620, and 550 as seen in figure 5.4 were used for all the simulations. In total six simulations where ran. The old TP-40 100 year and 500-year 24 Hour events were computed for a base to compare. Then the 100 year and 500 year 24-hour mid and upper rainfall events were computed. Two days were modeled to account for the flow after the rainfall occurs.

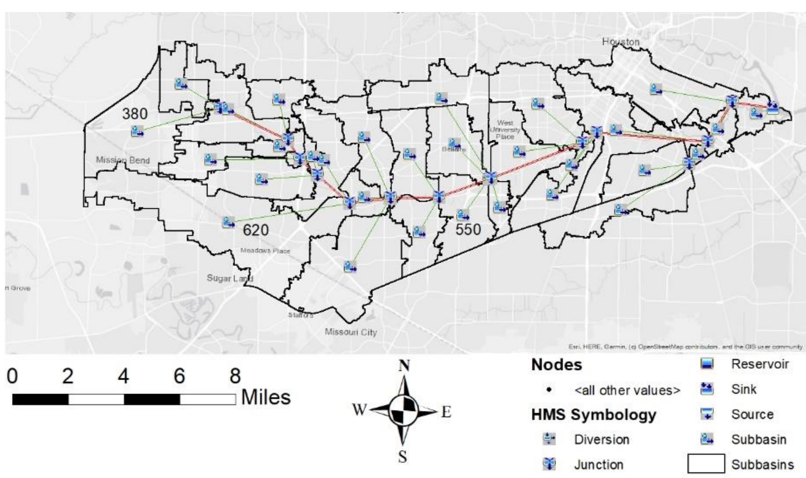

Figure 5.4 Sub basin map of Brays Bayou Watershed

The next step was to next step was to analyze the changes within the watershed. As seen in figure C.2, 36 cross sections were taken from the Brays Bayou Watershed. The max depth was recorded at the center of the stream to maintain consistency of results. All six rainfall events were rain to compare the changes of rainfall events on the watershed. Just as with the discharges the changes were plotted on a graph from west to east to show the change of maximum depth along Brays Bayou. These results were used to be able to compare the results from the HEC-HMS model.

CHAPTER VI:

RESULTS AND DISCUSSION

6.1 Introduction

This chapter focus on the results obtained through ArcMap, HEC-HMS and HEC-RAS. The results from Arc Map shows that there was a 12% difference between the computed outline and the accepted outline of the Brays Bayou Watershed. The average discharge showed a general increase from upstream to downstream. The addition of the detention ponds to the watershed could have reduced the peak discharge from Hurricane Harvey by 3.75% and the volume by 15.07% at Junction 9. The change in depth from HEC-RAS showed three areas of peak discharge, at cross section 7, 20, and 29.

6.2 ArcGIS results

While conducting the preparation for HEC-GEOHMS hydrologic preprocessing had to be done on the raw DEM data. This included delineating the watershed from scratch. As seen in figure 6.1, the black outline shows the new proposed outline of the Brays Bayou Watershed. The red outline shows the currently accepted outline of the watershed. The results show the watershed increasing from 128 square miles to 143 square miles. This increase shows an 11.7% increase in the area of the Brays Bayou Watershed. This increase would have significant changes of how Brays Bayou acts. This could also have huge impacts of Buffalo Bayou which is the watershed just north of Brays Bayou. This increase in size could be due to all the engineering work that has been conducted within the city of Houston over the past decade. These results are only delineating the watershed based off the 2018 Lidar DEM data. This outline does not look at where the drainage is pointing in the areas. In proposed new areas of the Brays Bayou Watershed, the drainage is pointing north to Buffalo Bayou. These results could make modeling accurately very difficult. That is because the drainage is trying to push the water north to Buffalo Bayou, while the elevation is trying to push the water south Brays Bayou. During smaller storms when the storm drains are not overflowing, the most likely work fine pushing the water into Buffalo Bayou. The confusion could be during massive storms when the storm drains get filled up and the water wants to flow in the path of least resistance. In that case the water will most likely flow down into Brays Bayou.

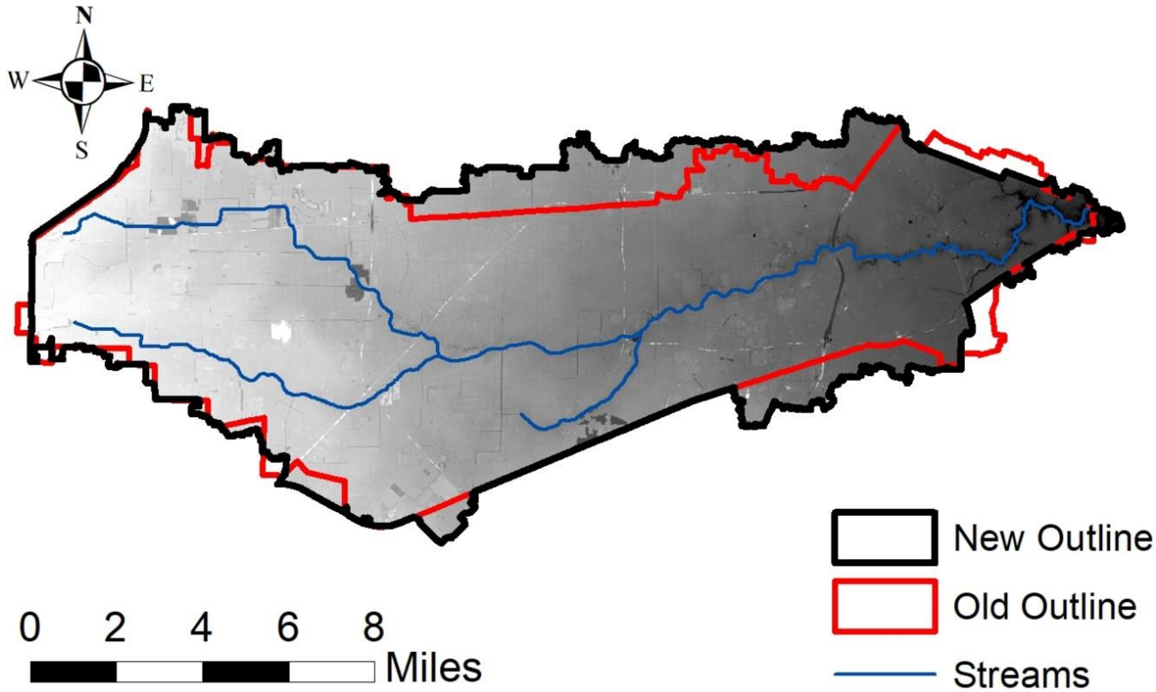

Figure 6.1 Comparison of the accepted old outline to the outline determined from the watershed delineation in Arc-Map

6.3 HEC-HMS Results

6.3.1 100 Year 24 Hour Event

The rainfall from the previous 100-year 24 event to the updated 100-year 24 event increased by 27.27% for the mid-range values. As seen in Figure 6.3, the peak discharge for the mid values were raised from 46928 CFS to 60575.6 CFS. This is going to result in an increase discharge of 13,647 CFS. The percent change in discharge is 29.3%. The upper limit for the percent change of rainfall was 81.06%, while the increase in change of discharge was 87.77%. This variability between the median and upper range for rainfall numbers shows that there should be more thought of analyzing the flood plain from the upper range. Considering, that the rainfall for the upper range of the new 100-year rainfall event comes within one inch of the 500 Year 24-Hour median rainfall number. The increases in rainfall and discharge will ultimately change what is the 100-year flood plains.

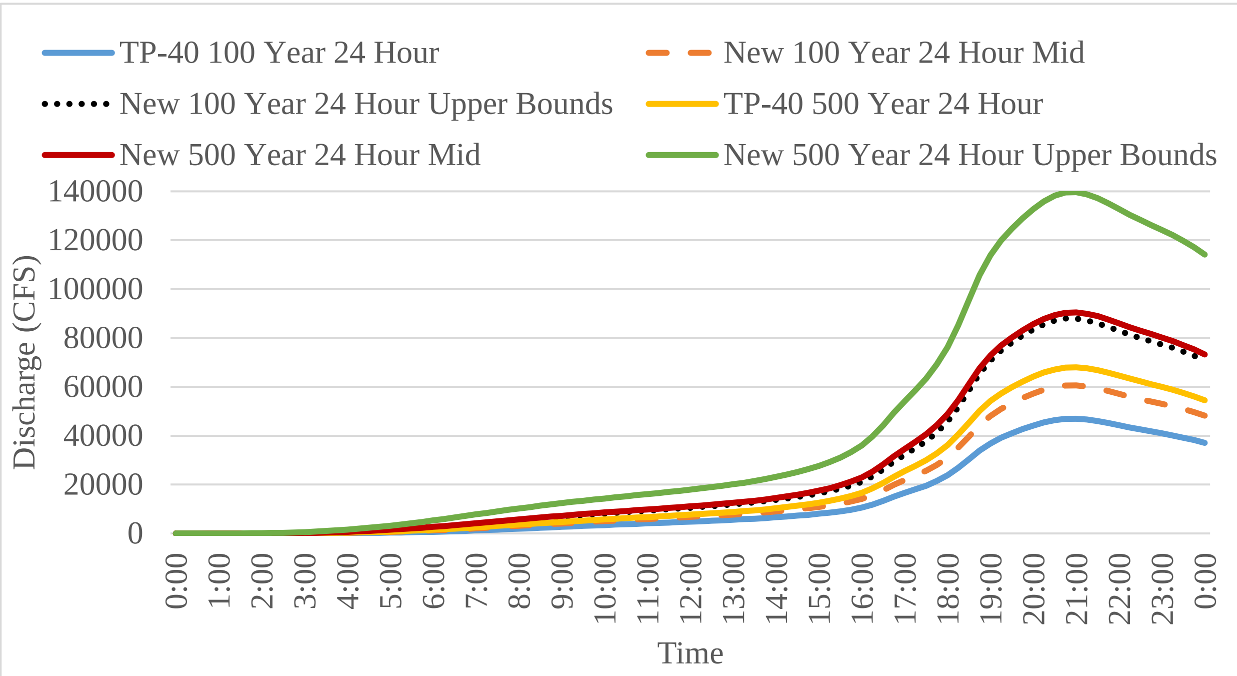

Figure 6.2 Comparison of old TP-40 100 and 500 Year 24 Hour event values with new NOAA Atlas 14 Volume 2 100 and 500 Year Mid and Upper Bounds rainfall values.

As seen in figure 6.2, the results of increased discharge from the change in increased rainfall. The rainfall increased from 18.9 from the previous numbers to inches to 24.9 for an increase of 31.75%. The results from HEC-HMS showed that the discharge for the mid-range values increased from 67972.6 to 90555.9 CFS. The percentage increase resulted from these results was 33.06%. The percent change for rainfall for the 500-year upper limits was 99.47%, while the percent discharge increased by 104.46%. Just as the with 100 Year-24 Hour results these changes will have drastic impacts on the 500-year floodplains of Houston.

The change in discharge at the junctions within Brays Bayou was the next thing analyzed. Figure C.1 shows the locations of the junctions used for this examination. Figure 6.3 shows the trend of discharge from the upper part of the watershed in the west to the outlet in the east. From J 1 to J 4 the discharge remained low. That is most likely due to that the Westheimer, Eldridge, and Arthur Story detention ponds were located within the stretch of Brays Bayou. Keegan Bayou enters Brays Bayou at J 5 is what is causing the increase in peak discharge. The reduction in discharge is J 9 is due to the Willow Waterhole detention pond being located on sub basin that enters the stream at this junction. Overall this figure 6.3 shows that there is a general increase in peak discharge from upstream to downstream.

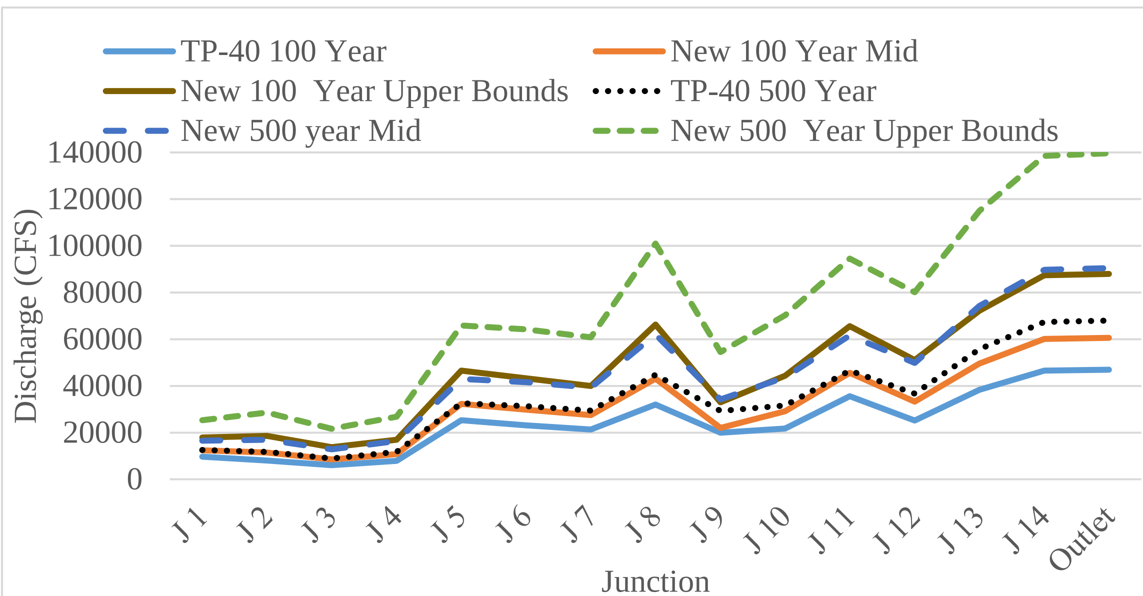

Figure 6.3 Change in Discharge at junctions within Brays Bayou from west to east.

6.3.2 Comparing the 100 Year and 500 Year Results

The 100 year 24-hour event showed a difference 1.73% in change between the rainfall and discharge increases for the mid event and 6.64% change for the high limit event. While, the 500 year 24-hour event showed an increase in 1.32% between the rainfall and discharges increases for the mid-range and 5.99% for the high range values. This could show that there is a correlation between the increase in rainfall and discharge.

6.3.4 Comparison of Added Detention Ponds Results

Figure 6.3 shows the results from added detention ponds. For this simulation Hurricane Harvey was chosen with it being the most recent catastrophic event to occur in the Brays Bayou Watershed. The peak discharge reduction at J15 was 3.75%. While, the volume of water flowing through the junction was reduced by 15.07%. These numbers show that although the peak discharge of Hurricane Harvey would not have significantly been reduced, the amount of water flowing through the area would have been significantly reduced. The reduction in volume of water helps to prove that the added detention ponds could have helped reduced the amount of damage to the neighborhood of Meyerland.

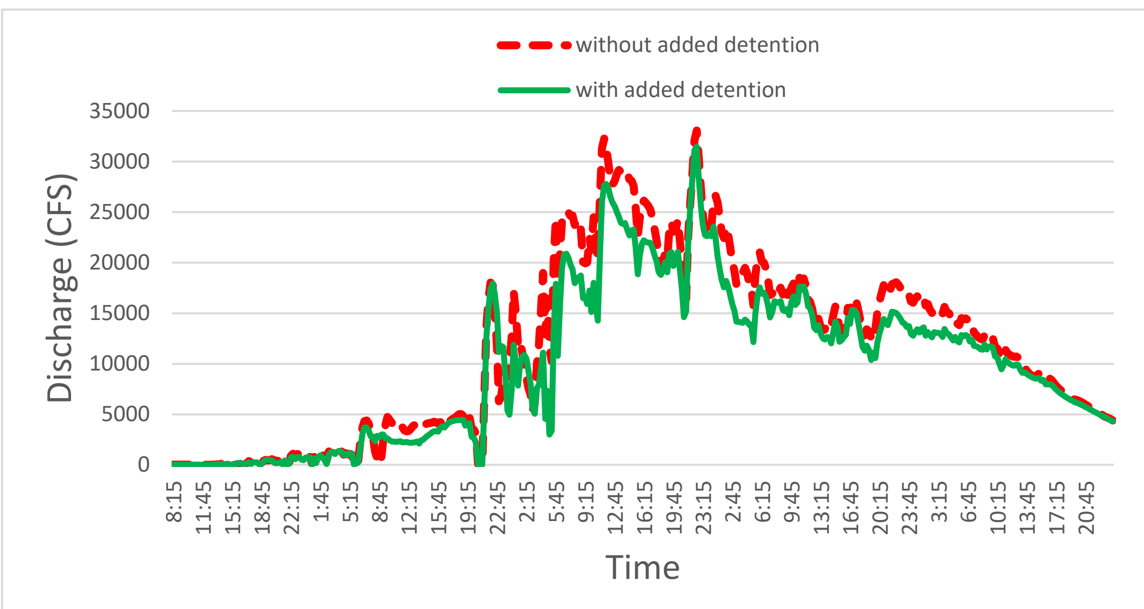

Figure 6.4 Simulation of Hurricane Harvey at Junction 115 with and without proposed detention of Westwood and Breaburn ponds

6.3.5 Comparison of new model to M3 model

The Harris County Flood Control District (HCFCD) has HEC-HMS models of all the basins of Harris County. These models were finished in 2007 using the Lidar data from 2002. This was before any of the detention basins were completed in Brays Bayou. Their model had 77 sub basins created within the watershed, while our model has 31 sub basins. The reason for this is we had a recurring error when attempting to run the Longest Flow Path in ArcMap. The only way to solve it was to lower the number of sub-basins to 31. For the loss parameter in our model we used the Curve number, while the HCFCD used the Green and Ampt. For the routing method for the reaches HCFCD used the Modified Puls, while we used the Muskingum method. Another difference is that they set up different basins of the Brays Bayou Watershed depending on the type of rainfall event. We built one model and used it for all the rainfall events.

As seen in figure 6.6 the time of peak discharge and peak discharges for the two models were almost the same. After the peak discharges our model saw a significant decline in discharge. This was before the M3 model took a sharp decline in discharge near the last half of the second day. As noted, before there are many variables that are different between the two models. One that could have been a reason for the sharper decline at the beginning in our model was the four detention basins. These could have helped to reduce the amount of discharge following the peak discharge.

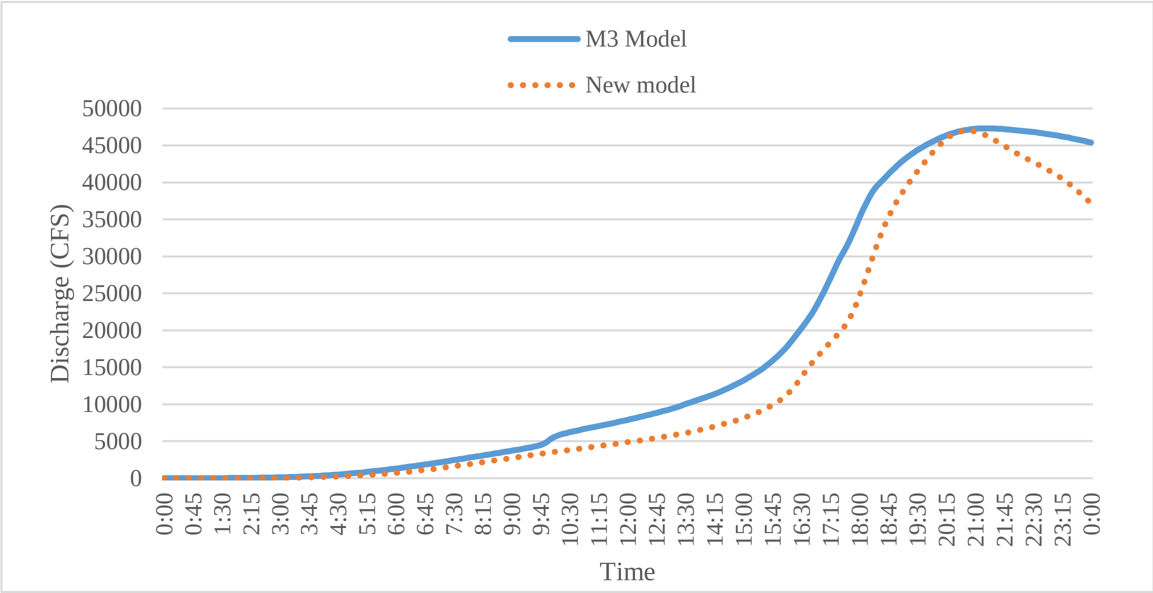

Figure 6.5 Comparison of Old 100-year 24 Hour rainfall event in M3 model and Our Model

There were some similarities and differences between the 100-year and 500-year events. Although the 100 Year 24-Hour events had a similar peak discharge, figure 6.7 show that our model had a peak discharge significantly higher than the M3 model had. This difference could be due to that the M3 model has different basin models built for each event. The two models have consistent curves between them and the 100-Year models. The slower increase in discharge is more apparent in our model in the 500 Year 24-Hour event, than the 100 Year 24-Hour event.

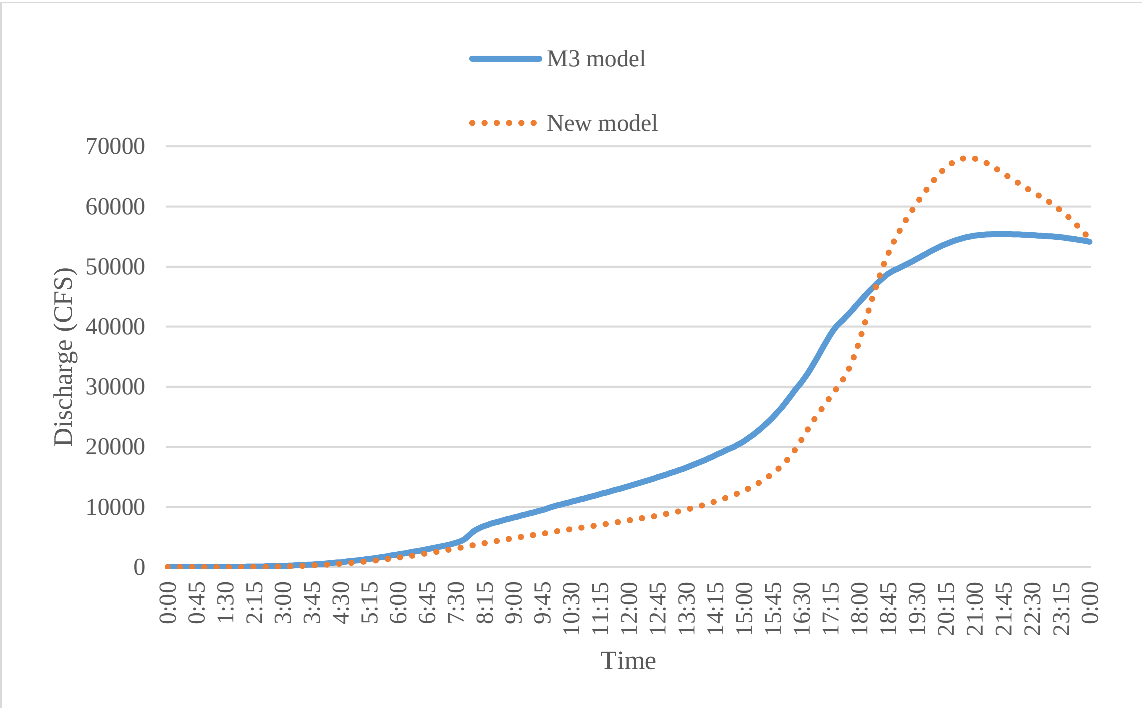

Figure 6.6 Comparison of the old 500 Year 24-Hour Event between the M3 model and Our Model Over Two Days

6.3.6 2040 Analysis

The values for the curve number were updated to reflect the predictions for 2040. Figure 6.7 and 6.8 show the increase in discharge for the 100- and 500-Year rainfall events. The percent increase in discharge for the 100 Year 24-Hour event was 5.01% and 4.08% for the median and upper limit numbers. The percent increase for amount of water was 7.99 and 6.99% for the 100 Year 24-Hour median and upper limits. While, the 500 Year 24-Hour 2040 volume numbers increased by 6.89 and 5.67%. The 500 Year showed an increase of 4.17% and 3.10% in peak discharge. These percentage changes show a general downward trend from lowest rainfall numbers to higher rainfall numbers. This increase in peak discharge and volume is the result of the increased curve numbers in 12 of the 31 sub-basins within the watershed. This increase reflects that at minimum, the entire watershed will have curve numbers equal to residential areas with ¼ acre lot sizes on class D hydrologic soils. The percentage increase in peak discharge and volume tend to decrease when going from the mid to upper limits of rainfall. Figures 6.7 and 6.8 show that while the peak discharges increase with the change from the 2018 to 2040 models, the end discharge stayed the same for all four rainfall events. These hydrographs are a direct indication of how the curve number affects the discharge.

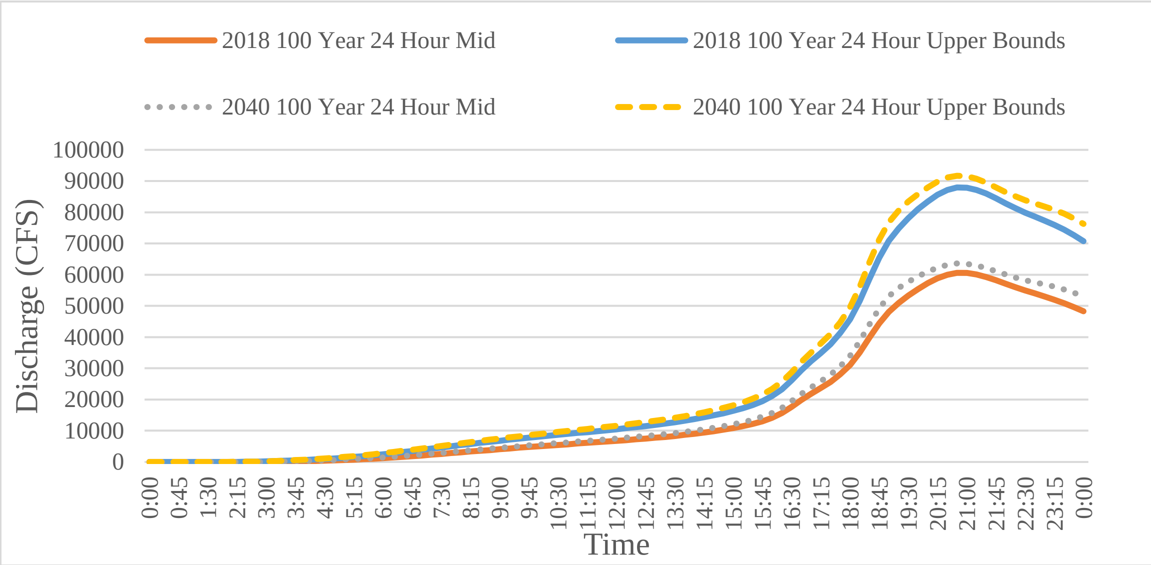

Figure 6.7 Change in Discharge for 100 year Mid and Upper values Between 2018 and 2040 Prediction Model

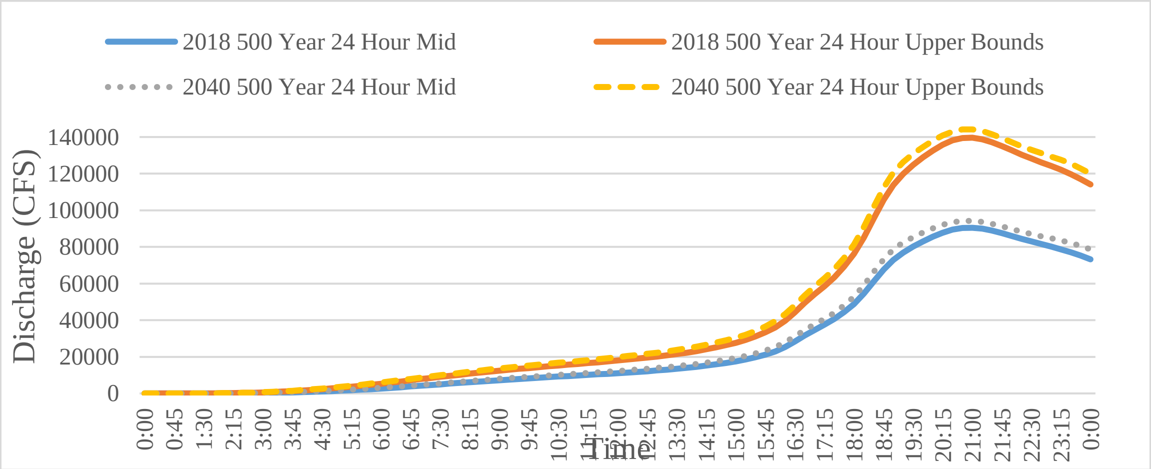

Figure 6.8 Change in Discharge for 500 year Mid and Upper Values Between 2018 and 2040 Prediction Model

6.4 HEC-RAS Results

The first thing that was compared was the change in depth at the stream from east to west. Figure 6.9 shows that the water changing significantly at three locations. Figure C.1 shows the locations of the cross sections. Figure C.2 shows the locations on a topographic map of the three important cross sections. The depth significantly increases from cross sections 6 to 7. One reason for the lower depths from cross section 1 to 6, is that this is the area with were most of the detention ponds area. Within a five-mile reach of Brays Bayou there are three major detention ponds. These low depths in the upper part of the watershed shows that the detention ponds area helping to reduce the max depth of the stream in the area. Cross section 29 is located at the point where the topography is changing significantly, narrowing into a V. This sharp change in elevation is what is most likely leading the sharp increase in water depth. Then the water depth decreases as the topography gets more level as seen in figure C.2. The sharp peak at cross section 20 is partly due that this is the location of the inflow of water from Willow Waterhole. There is a similar smaller peak at cross section 10, which is next to the inflow coming in from Keegan Bayou. This shows that there is more leading to this increase in peak discharge. Just like with the location of cross section 8, the Meyerland area around cross section 20, has a large change in elevation change in this area. Cross section 29 is located at a location of significant change in elevation just like with the other mentioned cross sections. All three cross sections with peaks in discharge are located directly downstream from a highway crossing Brays Bayou. From the DEM, it appears that the highways could be creating a weir type of flow, which is narrowing the area of flow at the cross section of the highway.

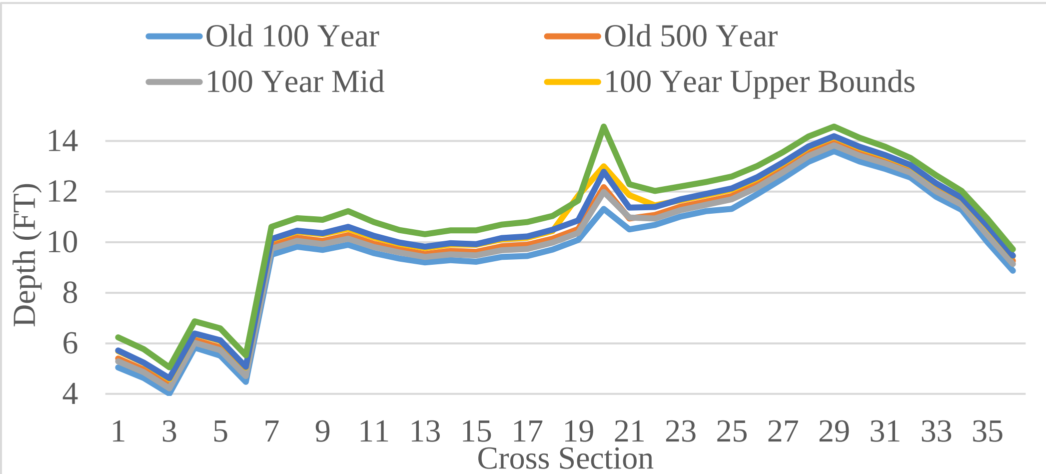

Figure 6.9 Graph Comparing the depth at the stream of all rainfall events, with cross sections going from upstream to downstream.

The percent change in depth from upstream to downstream was not consistent as seen in figure 6.10. The values in the upstream part of the watershed varied more than the values in the downstream areas. The variations of change from cross sections 1 through 6 may be due to this area having the three major detention ponds in the area. The reason for the variation around cross section 20 is the introduction of flow from Willow Waterhole. A similar change in percentage change can be seen at cross section 10 where there is a slight uptick in percent change from the new 500 Year upper bounds and old 500-year value. The other reason could be that this is combined with this area having a significant change in elevation. After cross section 20, the percent changes appear to level out for the rest of the stream, except for the last three cross sections. This is could be due that there are no more flows being introduced, thus leveling out the flows.

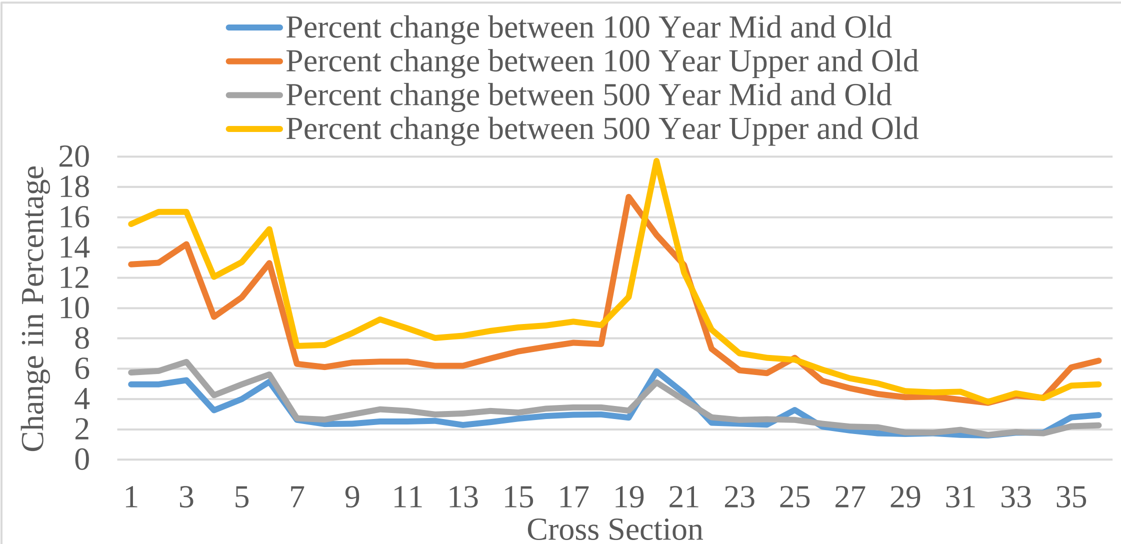

Figure 6.10 Percent change of depth from old TP-40 rainfall values to new mid and upper bounds rainfall values from upstream to downstream.

6.5 Chapter Summary

This chapter summarized the results from ArcGIS, HEC-HMS, and HEC-RAS. Each software presented its own viewpoint of what has been going on within the watershed.

The results from ArcGIS show that the actual watershed is 143 square miles, compared to the 128 square miles of the accepted outline of the watershed. The problem here is what is the definition of a watershed. In the northern part of the watershed the water drains north, while the slope points south. This makes it very difficult to figure out where to draw the lines of the watersheds Harris County.

The results from HEC-HMS showed that the discharges will change considerably for the 100 year and 500-year 24 Hour rainfall events. The results from the 2040 forecast shows that, although the watershed is very urbanized, the peak discharge could still rise by 3-7% depending on the rainfall event. The changes in the slopes of the hydrographs from our model and the M3 model showed the need for the model to be updated.

The results from HEC-RAS helped prove that the detention ponds in the upper part of the watershed have a large positive impact on the maximum water depth of the stream. This model also showed that the highways that cross Brays Bayou may contribute to the maximum flooding depth. Another factor of the depth of the water is the topography. All three peak water depths occurred in areas of significant drop in elevation.

CHAPTER VII:
CONCLUSION

The research presented in the first three chapters was meant to show the true extent of the problem of flooding of Houston. It is common for people to blame one factor on the flooding. The most common answer people will give is that there is too much concrete in the watershed. While this is true, there are many other factors that play a major role. Such as the location and climate of Houston puts the city at risk of tropical storms, hurricanes, and just bad rainfall events. Another factor that the watershed has a lot of impermeable clay soils, with a clay geologic lay that lies below. Adding to this is that the topography is already very flat and has had a lot of subsidence throughout the past 100 years. All these factors come together to make managing flood risk in Houston a very difficult task.

7.1 Limitations

Two limitations were identified in this research project. These include: 1) the model was well calibrated for extreme rainfall events but more than one optimization trial is recommended to confirm the results for smaller rainfall events; and 2) the HEC-RAS model should be explored in more depth considering the 1D & 2D setup in order to establish the water flow within the channels and delineate floodplains.

7.2 Summary of results

The results from HEC-HMS showed that the 100-Year 24-Hour rainfall event discharges at the outlet will increase by 29.3% for the mid value, and 87.7% for the high values. The 500-year 24 Hour rainfall event discharges will be increased by 33.1% and 105.5%. These values help to show why it is very difficult when attempting to place the 100- and 500-year flood plains at. The flood mitigation measures showed a decrease in peak discharge of 3.75% and a reduction of volume of water of 15.00%. These numbers help to demonstrate that the addition of the proposed detention ponds would not only decrease the height of the flooding, but the overall amount by reducing the amount of water flowing through the area. The results from the 2040 prediction shows that there is still room for the discharge values within the watershed to get worse, unless more mitigation is done within the watershed.

The results from HEC-RAS helped to show another part of the story of flooding within the Brays Bayou Watershed. With no drains modeled within the program, HEC-RAS acted under conditions were the drains were already filled. The model showed that the watershed does not naturally push water toward the bayou. Instead, the water flows from west to east parallel to Brays Bayou. This demonstrates the importance of drains and their capacity within the watershed, because without them the water will not naturally flow into Brays Bayou. The 36 cross sections were drawn to show the relation of depth to amount of rainfall. These cross sections helped to show where their areas that may be more susceptible to flooding. The area of Meyerland showed the highest peak depth. This is most likely due the confluence of water from 610, the high elevation changes in the area, and the extra discharge coming in from Willow Water Hole. The lack of space left in the watershed will limit the amount of mitigation projects in the future.

7.3 Future Work

Although there have been many problems answered with the newly created HEC-HMS and HEC-RAS models, there is always other questions to be asked. Although the majority of the lower parts of Brays Bayou is concrete lined, most of the upper part of the stream, and Keegan Bayou are unlined. This opens the door to possibly conduct surface erosion and sediment routing studies on events such are Hurricane Harvey. With a watershed such as Brays Bayou where there is always engineering work being conducted, there will be a need for the models that were created to be regularly updated and examine how these changes could impact the 100 and 500 Year 24-Hour rainfall events.

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APPENDIX A:

PROCESSESING OF LIDAR DEM

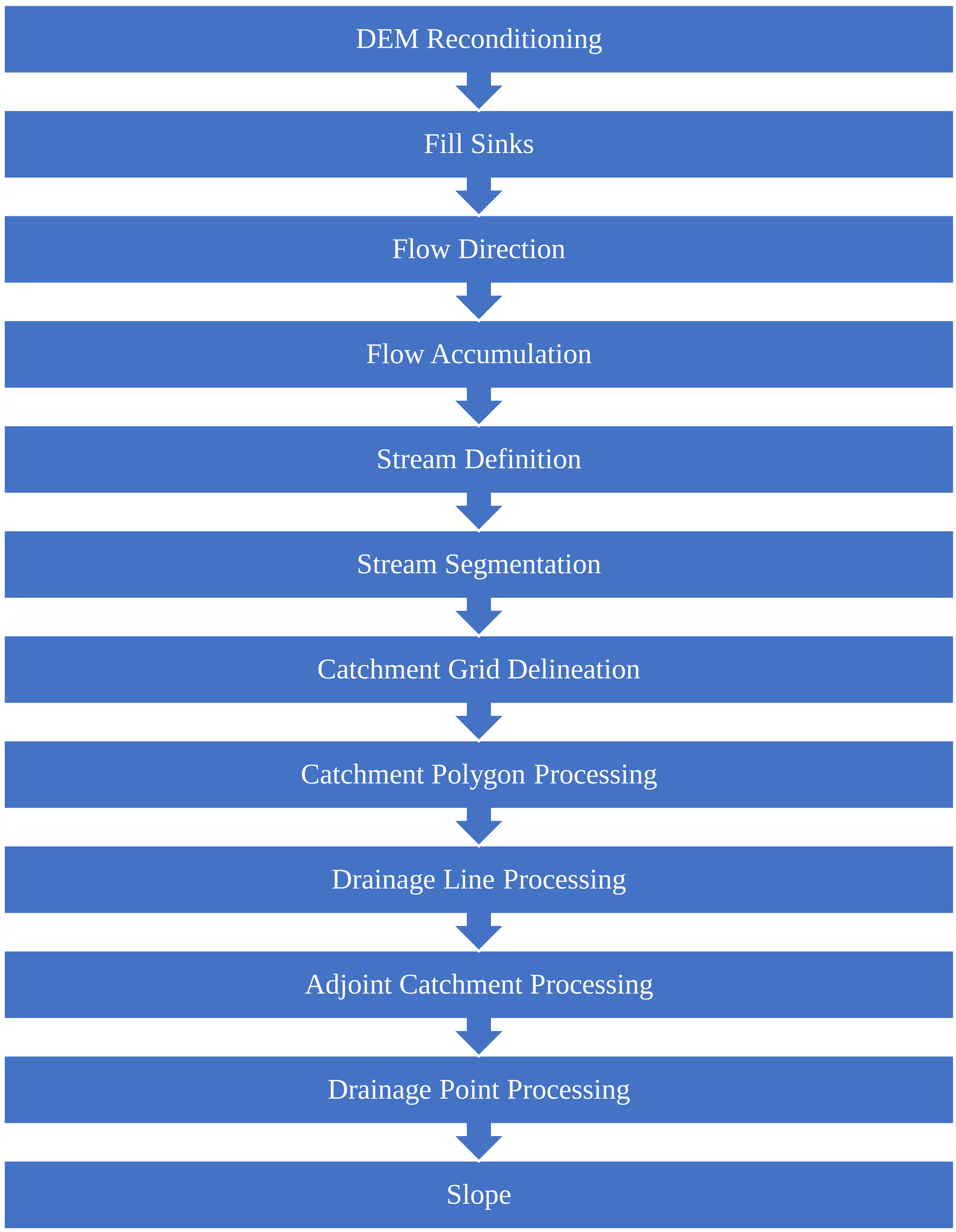

Figure A.1 Process of running Arc Hydro

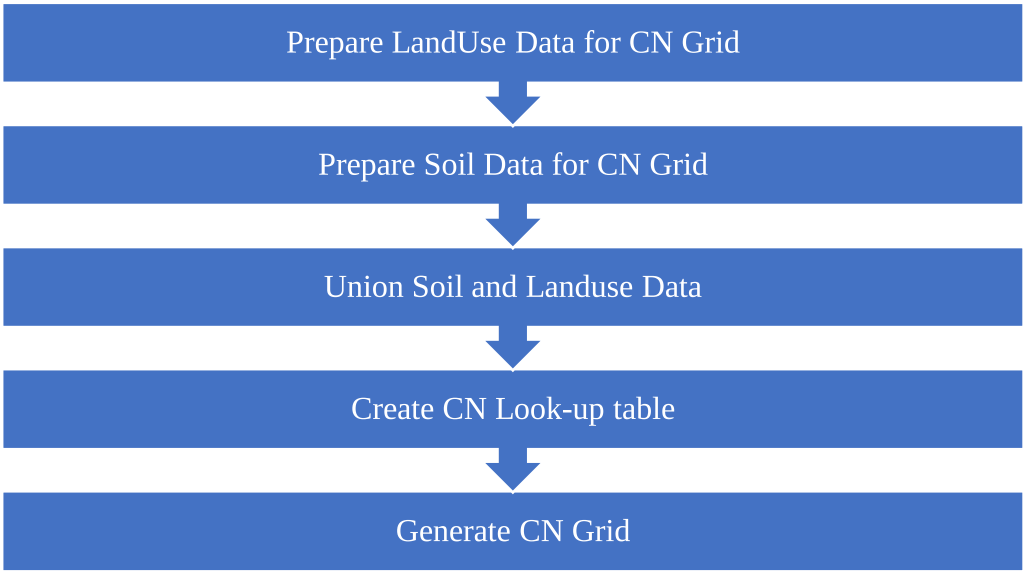

Figure A.2 Process for creating Curve Number

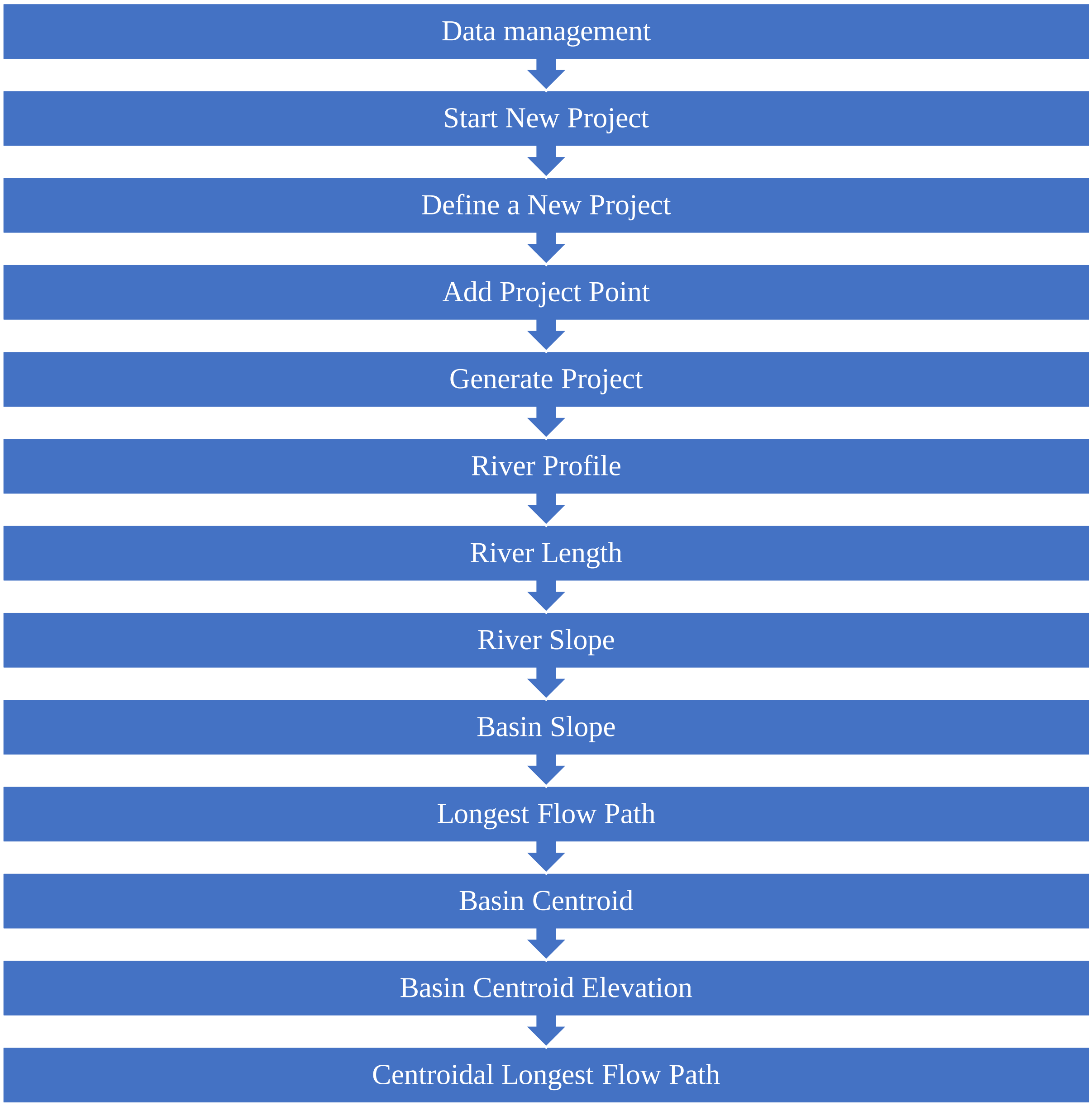

Figure A.3 Order of Operations for Preprocessing in HEC-GEOHMS

Figure A.4 Process of Setting up HEC-HMS model in HEC-GEOHMS

APENDIX B:

RAINFALL EVENT NUMBERS

Table B.1

Old 100-year 24-Hour Event

Duration	Depth (IN)
5 Minutes	1.2
15 Minutes	2.1
1 Hour	4.3
2 Hours	5.7
3 Hours	6.7
6 Hours	8.9
12 Hours	10.8
1 Day	13.2

Table B.2

Old 500-Year 24-Hour Event

Duration	Depth (IN)
5 Minutes	1.4
15 Minutes	2.6
1 Hour	5.5
2 Hours	7.6
3 Hours	9.2
6 Hours	12.8
12 Hours	15.5
1 Day	18.9

Table B.3

New 100-Year 24-Hour Mid

Duration	Depth (IN)
5 Minutes	1.5
15 Minutes	2.7
1 Hour	5.5
2 Hours	7.2
3 Hours	8.5
6 Hours	11.3
12 Hours	13.7
1 Day	16.8

Table B.4

New 500 Year 24 Hour Mid

Duration	Depth (IN)
5 Minutes	1.8
15 Minutes	3.4
1 Hour	7.2
2 Hours	9.9
3 Hours	12.1
6 Hours	16.8
12 Hours	20.4
1 Day	24.9

Table B.5

New 100-Year 24-Hour Upper Limits

Duration	Depth (IN)
5 Minutes	2.2
15 Minutes	3.8
1 Hour	7.8
2 Hours	10.3
3 Hours	12.1
6 Hours	16.1
12 Hours	19.5
1 Day	23.9

Table B.6

New 500 Year 24 Hour Upper Limits

Duration	Depth (IN)
5 Minutes	2.8
15 Minutes	5.2
1 Hour	10.9
2 Hours	15.1
3 Hours	18.3
6 Hours	25.5
12 Hours	30.8
1 Day	37.7

APPENDIX C:

EXTRA MAPS

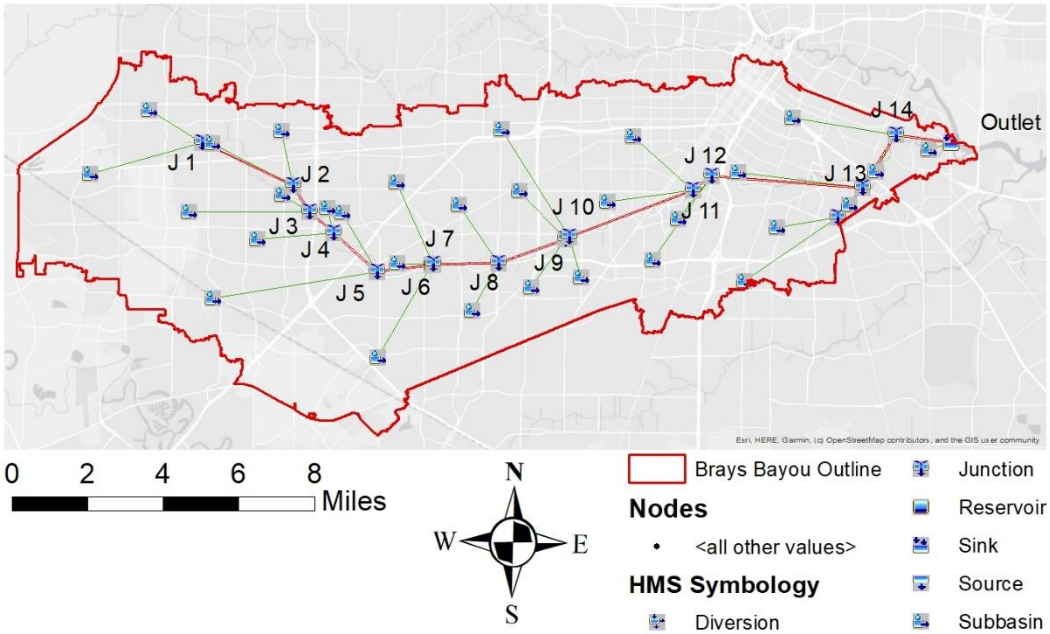

Figure C.1 Location of all junctions used to analyze the HEC-HMS change in discharge

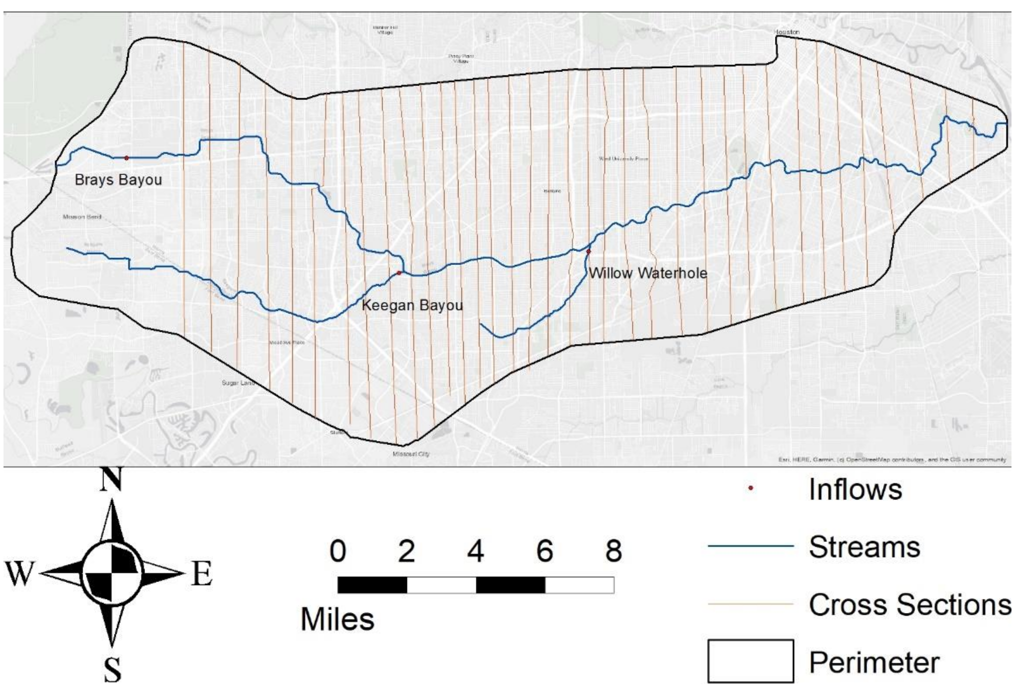

Figure C.2 Cross section map used for depth analysis in Brays Bayou

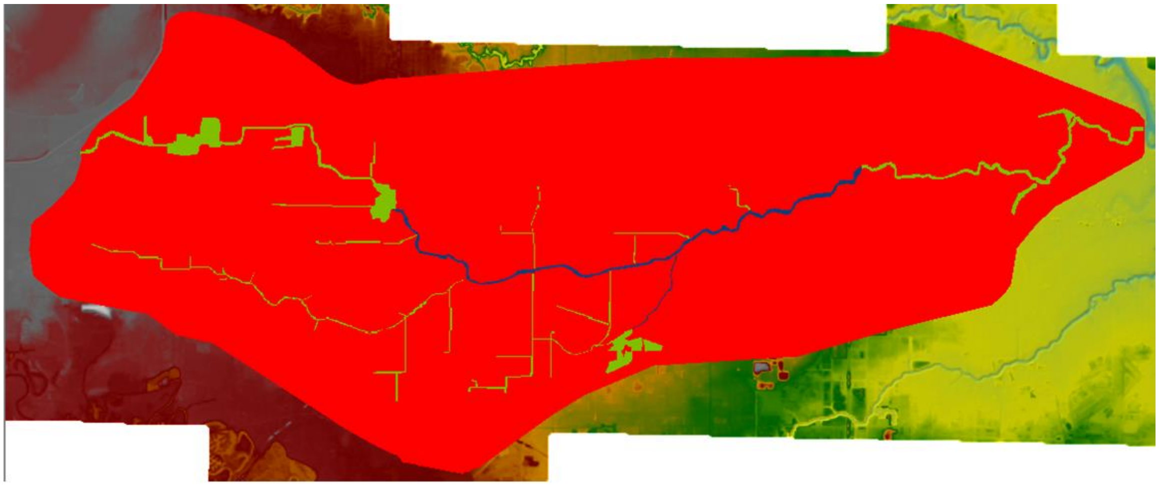

Figure C.3 Manning's N Value map of Brays Bayou Watershed. Yellow is equal to .025, blue is equal to .015, red is equal to .05.

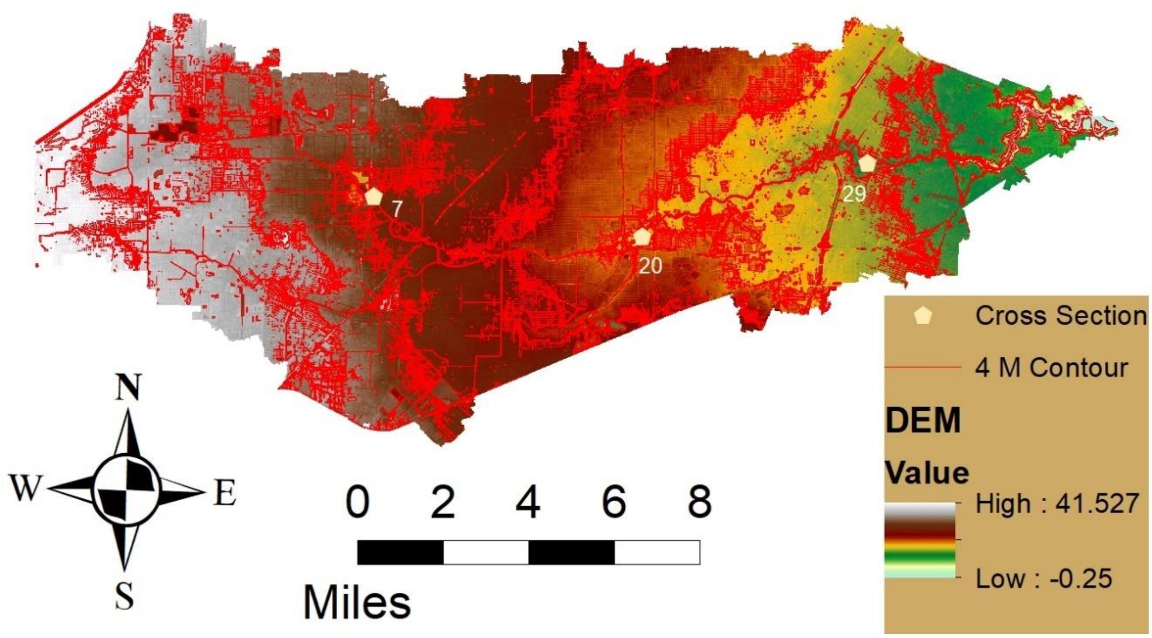

Figure C.4 Contour Map of Brays Bayou Watershed with locations of important cross sections.