UTRGV Edinburg Campus Two-Dimensional Flood Modeling for Development of Flood Inundation Map

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UTRGV EDINBURG CAMPUS TWO-DIMENSIONAL FLOOD MODELING FOR DEVELOPMENT OF FLOOD INUNDATION MAP

A Thesis

by

ROXANA TELLO

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ABSTRACT

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Severe flooding is a natural hazard worldwide, potentially subjecting people to life threatening situations and leaving infrastructure vulnerable to structural damage or complete destruction. The common threat of flooding poses constant challenges for state and local agencies in identifying flood risks and proposing the necessary mitigation improvements. Developing hydraulic models to predict the hydrological interactions and identify areas at risk is a beneficial tool for urban planning. The Lower Rio Grande Valley (LRGV) is a rapid growing region in South Texas along the border of Mexico and west of the Gulf of Mexico. The LRGV has historically suffered through various storm events of excessive and prolonged rainfall, resulting in ponding stormwater along the flat terrain. The objective of this study is to develop a hydraulic model to generate a flood inundation map for the UTRGV Edinburg Campus in the LRGV. The modeling approach utilizes HEC-RAS rain-on-grid methods over a two-dimensional mesh. Modeling results are evaluated against delineated Special Flood Hazard Areas (SHFA) and Base Flood Elevations (BFE) recorded on FEMA Flood Insurance Rate Maps (FIRM). The results revealed that approximately 94% and 96% of the total campus area is at risk for ponding, for a 100-year and 200-year storm event respectively. The modeled results of ponding depths and flooding extents is useful information for the development of an

integrated early flood warning system model, for emergency management entities. The results of this 2D HEC-RAS model will be further processed and implemented with available rainfall data for the creation of an automated real time early flood warning system.

DEDICATION

I dedicate my work to my family and friends who have been a constant source of encouragement and support throughout my academic career.

ACKNOWLEDGMENT

I would like to extend my gratitude and appreciation to Dr. Jungseok Ho for his valuable advice and guidance throughout my undergraduate and graduate career. Also special thanks to my committee members for their review and valuable advice.

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CHAPTER I

INTRODUCTION

Flooding is a common natural hazard worldwide, caused by storm events of excessive and prolonged rainfall. These storm events frequently result in devastating and costly effects for flood-prone or urban areas. In the state of Texas, over 400 people have died in flood related incidents and over $4 billion in infrastructure damage has occurred since 1988 (Texas Water Development Board, 2015). Examples of infrastructure damage include residential properties, commercial properties, critical facilities, and roadways, also affecting evacuation routes. Aside from physical damage to infrastructure, health concerns also arise when public utility systems are exposed to severe storm events. During heavy rainfall, sanitary sewer lines and manholes may backup from increased inflow of stormwater runoff. As a result, water lines and exposed structures or roads might become contaminated with the runoff. Therefore, the threat of flooding has detrimental effects to public infrastructure and public health. This threat is projected to rise since climate models show Texas is susceptible to significant climate change and increasing temperatures (Environmental Protection Agency, 2016).

Aside from climate change, the severity of flooding is also influenced by several factors such as land use, soil characteristics and topography. Population trends estimate a massive rural-to-urban population shift across Texas. One of the areas predicted with the greatest growth encompasses the southernmost tip of Texas, known as the Lower Rio Grande Valley (LRGV) area. The LRGV contains multiple local entities, stretched out throughout four counties, Cameron, Hidalgo, Willacy, and Starr Counties. This region consists of rapidly growing urbanized areas, combined with stretches of large rural farm and ranch lands. Land development of previously rural areas leads to increased impervious cover, such as residential and commercial structures, paved streets, parking lots, sidewalks, and driveways. These factors, combined with inadequate existing stormwater infrastructure and poor urban growth regulations, leads to severe flooding in urbanized areas (F.N. Nkeki et al., 2022). This poses constant challenges for state and local agencies in identifying flood risks and proposing the necessary mitigation improvements. Although preventing storm events is not possible, the related impacts can be reduced by developing efficient and accurate flood models to predict and identify areas at flood risk.

Flood models serve many purposes, such as flood risk mapping, real-time forecasting, water resources planning, contaminant transport, floodplain management and more. The majority of flood models are based on a hydrodynamic approach, which imitates water movement by solving equations applying the laws of physics (J.Teng, et al., 2017). The models can be classified as one-dimensional (1D), two-dimensional (2D), or three-dimensional (3D), depending on the representation of the channel or floodplain flow. The simplest model treats flow as one-dimensional along the center line of the channel. While 1D models are simple and the most computationally efficient to run, they have modeling restrictions such as the discretization of terrain as single cross sections rather than a continuous surface (Lea Dasallas, et al., 2019). 2D models simulate floodplain flow with the assumption that water depth is shallow in comparison to the other two dimensions (J. Teng, et al., 2017). Although requiring higher data and computational time, 2D models are recommended and widely used for detailed flood risk mapping and estimation studies versus 1D models (Ongdas, et al., 2020).

A commonly used hydrodynamic model is the U.S. Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS) software. HEC-RAS is intended to execute 1D, 2D or coupled 1D/2D hydraulic flow calculations for channels and floodplain areas, in addition to sediment transport and water quality modeling (U.S. Army Corps of Engineers, n.d.). This research focuses on HEC-RAS's ability to run a complete 2D Rain-on-Grid model to an urban campus area. Rain-on-Grid modeling is an increasingly popular approach among the water resources community, where the hydrodynamic flood processes are modelled entirely within the 2D model domain (Costabile, et al., 2021). This method applies a precipitation boundary condition to the 2D flow area as a time series of rainfall excesses (U.S. Army Corps of Engineers, n.d.). Doing so requires applying an integrated modeling approach of using HEC-HMS output as model input for the precipitation boundary into HEC-RAS.

The purpose of this study was to use HEC-RAS 2D Rain-on-Grid modeling capabilities to identify inundated areas and depths during different design storm events, applied to an urban campus area. Results were compared with historical storm events and floodplain status, for validation. The 2D model will be further processed and implemented with available rainfall data for the creation of an automated early flood warning system.

Study Area

The University of Texas Rio Grande Valley (UTRGV) extends throughout the Lower Rio Grande Valley (LRGV), a region covering the southernmost tip of Texas along the Mexican border and Rio Grande River. The LRGV is bounded by the Gulf of Mexico to the east, making it susceptible to tropical storms and hurricanes. The region's topography is relatively flat, generally sloping from west to east towards the coastline. In general, the soil consists of calcareous to neutral clays, clay loams and sandy loams (Rio Grande Regional Water Planning Group, 2016). This soil is associated with low infiltration rates, resulting in rapid stormwater runoff during storm events. These hydrological and topographical characteristics of the LRGV increases the region's vulnerability to flooding.

This study focuses on the UTRGV campus in the city of Edinburg, Hidalgo County, Texas. The Edinburg campus encompasses an area of approximately 180 acres, made up of different academic facilities, parking lots, paved walking trails, and open green space. For the past three fall semesters since 2022, UTRGV has recorded a first-day enrollment of more than 32,000 students attending classes (News and Internal Communications, 2022). Rising enrollment rates often mean an increased demand for the UTRGV campus to grow and expand by building new facilities or parking lots. Rise in urban development impacts stormwater runoff and flooding extents by increasing impervious cover in a watershed.

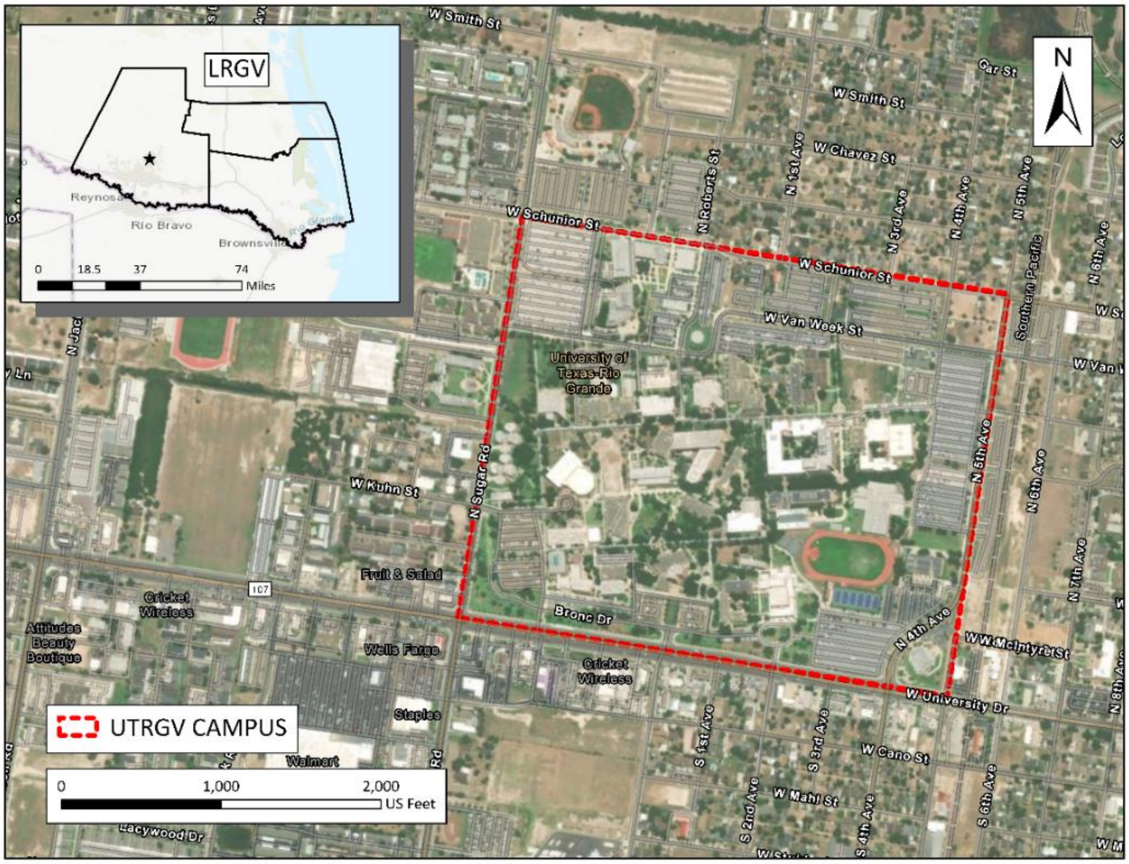

Figure 1: Location Map of the Study Area

FEMA Floodplain Status

In 1968, the National Flood Insurance Program (NFIP) was initiated by the United States Congress to provide government backed insurance protection to property residents living in flood prone areas. The NFIP is administered by the Federal Emergency Management Agency (FEMA), the lead agency responsible for responding and managing federal disasters in the United States. The NFIP is based on a mutual agreement between the government and participating communities, regulating floodplain development according to specified regulations. FEMA developed regulatory products, serving as the basis for official actions required by the NFIP. One of those products are Flood Insurance Rate Maps (FIRM), which show areas that are at high-risk of flooding by a 100-year storm event. This storm event is also referred to as a 1-percent annual chance flood or the “Base Flood”. The high-risk areas are categorized into different flood zones, as shown in Table 1. Areas within the special flood hazard area (SFHA) typically have Base Flood Elevation (BFE) profiles, where the 100-year BFE is recorded on the FIRM. These maps help communities recognize potential flood risk and establish a property’s flood insurance requirement. The information recorded on FIRMs also aids in validating flood models for floodplain management.

Table 1 – FEMA Flood Zone Areas and Descriptions.

Flood Area	Zone	Description
Special Flood Hazard Areas (SFHA)	Zone A	No BFE determined.
	Zone AE	BFE determined.
	Zone AH	Flood depths of 1 to 3 feet (usually areas of ponding); BFE determined.
	Zone AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined.
	Zone A99	To be protected from 100-year flood by Federal flood protection system under construction; no BFE determined.
	Zone V/VE	Coastal flood with velocity hazard (wave action).
Other Flood Areas	Zone X (Shaded)	Areas of 500-year flood; areas of 100-year flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 100-year flood.
	Zone X (Unshaded)	Areas determined to be outside 500-year floodplain.
	Zone D	Areas in which flood hazards are undetermined.

The study area falls within FEMA Community Edinburg, Texas Hidalgo County and FIRM Panel 480338 0015 E and 480338 0020 E, both with effective dates of June 6, 2000. The UTRGV Edinburg campus falls within SFHA Zone AH, which are areas inundated by a 100-year flood with ponding depths of 1 to 3 feet. As noted in the FIRM, the BFE within Zone AH is 96 feet.

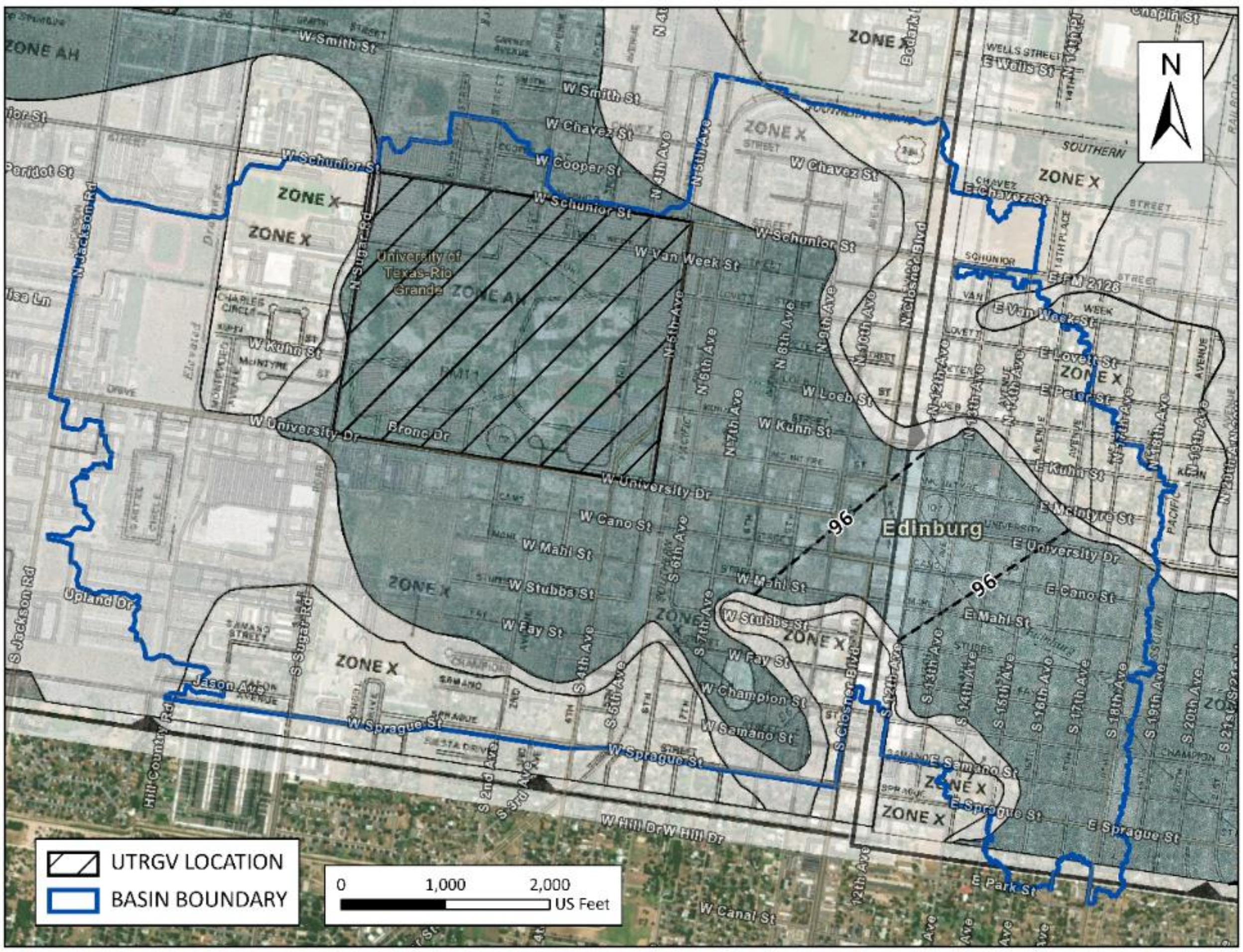

Figure 2: FEMA FIRM Panels over the study area and basin boundary

Historical Rain Events

The LRGV has experienced significant hurricanes and storm events in the past that left roadways, homes, and businesses underwater for multiple days. The majority of the LRGV is flat, which creates major issues with stormwater drainage when heavy prolonged rain impacts the region. Two rainfall events that occurred in the past decade were identified as producing noticeable flooding in the UTRGV Edinburg campus and surrounding areas.

The Great June Flood of 2018 occurred from June 18th to June 22nd and had observed accumulative rainfall of approximately 10.16 inches in the Edinburg area (National Weather Service, 2018). The storm event consisted of continuous torrential rainfall for an extended period, overwhelming existing drainage systems across the region. This storm event left much of the UTRGV Edinburg campus underwater, flooding parking lots and neighboring roadways. Students and faculty were left stranded at the Edinburg campus, waiting for the ponding to recede (KRGV, 2018). Preliminary damage assessments indicated more than 20,000 residences, businesses, and public facilities were affected throughout the LRGV (National Weather Service, 2018). Flooding pictures from local news media are shown below.

Figure 3: Picture from 2018 June storm event, facing west on University Drive (SH 107), south of UTRGV Edinburg Campus (KRGV, 2018).

Figure 4: Picture from 2018 June storm event, facing southeast at UTRGV Performing Arts Complex B parking lot (KRGV,2018).

Hurricane Hanna, the 2020 Atlantic season's first hurricane, made landfall on the LRGV coastline on July 25th, traveling steadily into Hidalgo County on the 26th. Hanna strengthened into a Category One hurricane right before making landfall. Rainfall reports from July 24th to July 29th recorded an accumulative rainfall amount of approximately 9.78 inches in the Edinburg area (National Weather Service, 2020). It is estimated that Hurricane Hanna caused over 1.1 billion dollars in damage, primarily to existing infrastructure and crops across the LRGV (NOAA, 2021). The heavy rainfall created flash flooding and resulted in road closures for several days after landfall (Caltabiano-Ponce, 2020). The UTRGV campuses were closed in response to the flooding and power outages. The Hidalgo County Drainage District No. 1 (HCDD1) provided pictures of the hurricane's aftermath, at locations east of the campus, near the Hidalgo County Courthouse in Edinburg, Texas.

Figure 5: Picture from 2020 Hurricane Hanna, facing east on E. Cano Street near the Hidalgo County Courthouse (HCDD1, 2020).

Figure 6: Picture from 2020 Hurricane Hanna, facing east towards University Drive (SH 107) near the Hidalgo County Courthouse (HCDD1, 2020)

CHAPTER II

METHODOLOGY

This section summarizes the overall study parameters and methodology in delineating the contributing watershed, calculating excess rainfall, and developing the 2D model. The result is a flood inundation map for three different simulated storm events. Software utilized in this study includes ArcGIS Pro 2.2, HEC-HMS 4.9, and HEC-RAS 6.2

Data Collection and Processing

To characterize the study area and develop the models, various datasets were collected in different formats. Certain spatial datasets were further processed and modified to the desired output and symbology, using Geographic Information System (GIS) software.

Table 2 – Data collected for the study area.

Data	Format	Source
South Texas LiDAR (2018) (1-m)	Raster	USGS, TNRIS
Soil Data	Vector	USDA
Land Parcels (2021)	Vector	HCAD, TNRIS
Land Cover (2019)	Raster	USGS, TNRIS
Roadways	Vector	TxDOT
Precipitation Frequency Estimates	CSV	NOAA
FEMA FIRM Map	JPEG	FEMA

Elevation data is crucial information for watershed delineation and 2D hydraulic flooding model. Light Detection and Ranging (LiDAR) data with a 1-meter grid resolution was obtained for the study area. LiDAR data is collected by a remote sensing method using lasers to map terrain. This data is the foundation for building a Digital Elevation Map (DEM). The LiDAR data obtained consisted of separate rasters overlapping the study area with ground surface elevation values in meters. Using GIS, a DEM was created by mosaicking the separate rasters, converting values to feet, and clipping to the desired study area extent. The resulting DEM serves as the base for the watershed delineation and terrain model for the 2D hydraulic model.

Other important properties that affect flooding patterns are soil and land cover information. Soil data for the study area was obtained from the Web Soil Survey (WSS) produced by the Natural Resources Conservation Service (NRCS) in vector format. This dataset categorizes the soil for the study area by hydrologic soil group, describing the runoff potential when wet. Soils are assigned to a group based on the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive rainfall from long-duration storms (United States Department of Agriculture, 1986). There are four groups, defined below. For the urban study area, the soils were classified as Group B and Group D. These soils have moderate to very slow infiltration rates, describing the rate at which water enters the soil at the ground surface. Therefore, the slower the infiltration rates, the higher the stormwater runoff potential due to the impervious cover and clayey soils.

Table 3 – Hydrological soil groups descriptions for soils, as classified by the NRCS.

Hydrological Soil Group	Description	Soil Type
Group A	High infiltration rate (low runoff potential) when thoroughly wet. High rate of water transmission.	Deep sand, deep loess, aggregated silts.
Group B	Moderate infiltration rate when thoroughly wet. Moderate rate of water transmission.	Shallow loess, sandy loam.
Group C	Slow infiltration rate when thoroughly wet. Slow rate of water transmission.	Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay.
Group D	Very slow infiltration rate (high runoff potential) when thoroughly wet. Very slow rate of water transmission.	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils.

Land cover data for this study was obtained from the National Land Cover Database (NLCD) 2019 in raster format with a 30-meter grid resolution. Each grid is assigned a land cover class, such as cultivated crops, developed high intensity or open water. Other datasets obtained for development of the model are land parcels and roadways, both in vector format. The land parcels show the property ID, legal area, and tax state codes for each parcel. The tax codes classify each parcel with an ID describing the land type, such as residential single family, commercial, industrial, and agricultural.

National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Volume 11 records precipitation frequency estimates for different durations and storm events across the state of

Texas. The data is published in an online data server based on location. The estimates were obtained for the study area and extracted in CSV format. The FEMA FIRM Map was obtained online and downloaded in JPEG format. Using GIS, the JPEG was georeferenced over the study area. A new polygon feature class dataset was created, and the corresponding FEMA flood zones were manually traced from the JPEG. This facilitates later analysis by having the flood zones as a spatial dataset. All processed spatial datasets for the delineated study area are shown in Figure 7.

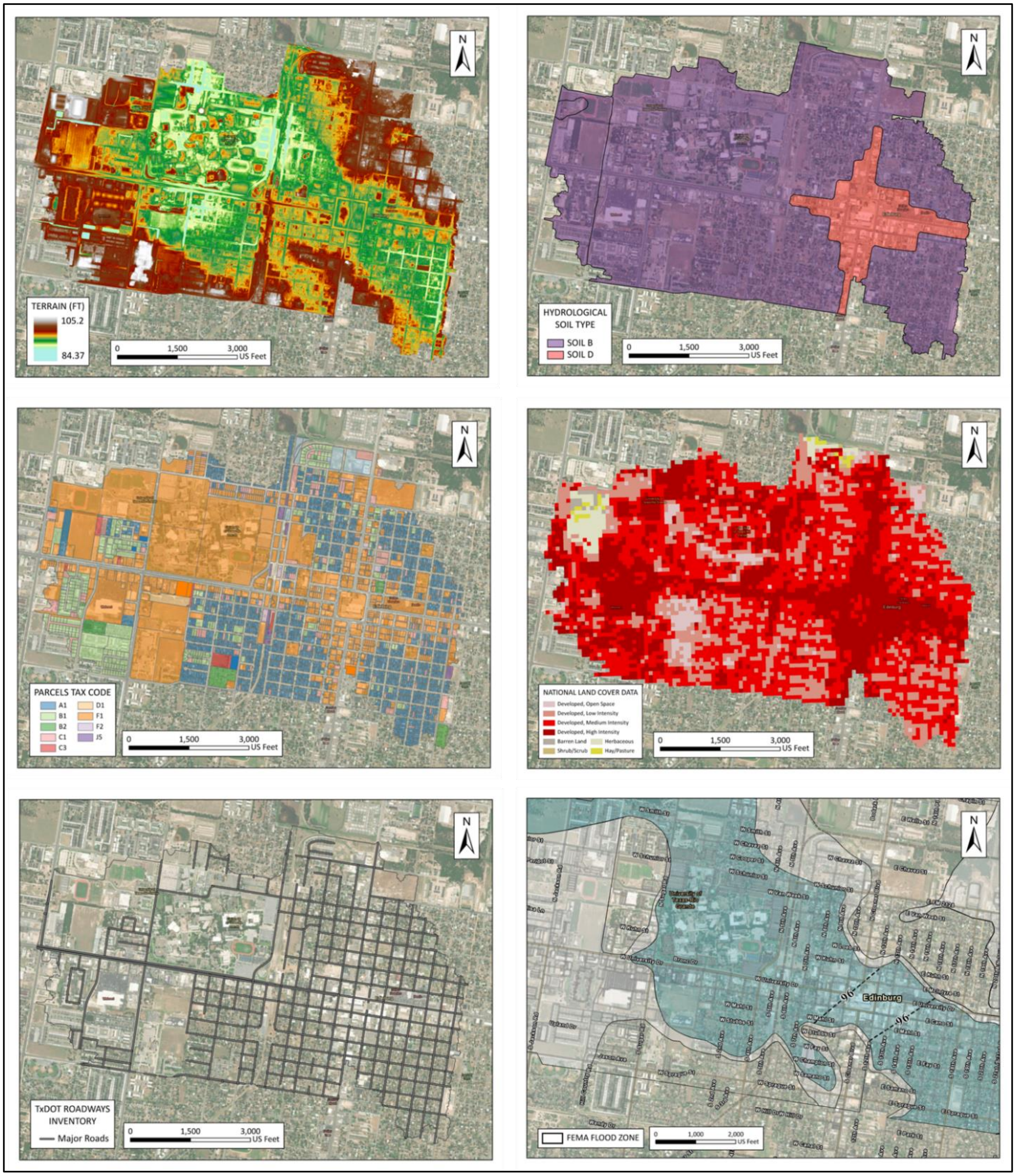

Figure 7 – Processed spatial datasets for the delineated basin study area.

Watershed Delineation

A watershed is defined as the contributing land area where all surface water drains to a common outfall point. Watershed size is dependent on the land terrain and location of the outfall point. For this study, a watershed was delineated for the Edinburg UTRGV Campus and surrounding areas. Delineation efforts were carried out in GIS using the Hydrology toolset.

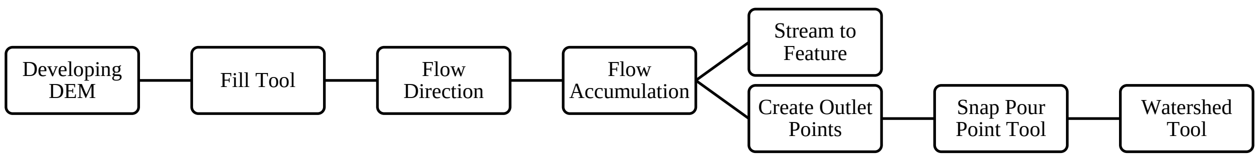

Figure 8 – Methodological framework for watershed delineation.

Any small imperfections in the DEM are removed using the Fill tool, producing a new depression less DEM. Using that DEM, a flow direction grid is created indicating the path that surface water travels based on the elevation terrain values. Next, each cell in the grid is assigned a flow accumulation value based on the number of upstream cells flowing into it. Therefore, cells located along a roadside ditch or drainage channels result in cells with a high flow accumulation value. The resulting flow accumulation raster is processed into a vector dataset, using the stream to feature tool. Now, the flow path of surface water traveling along the ground surface is represented by the stream network. This feature aids in visually identifying the outlet points for the study area. Four outlet points were manually created, referenced at locations where multiple streams join. For validation with available BFE values from the FEMA FIRM map, the study area was extended further east of the campus. Lastly, the watershed tool delineates the area upstream of the outlet points, based on the flow direction generated from the DEM. The results are four basins, encompassing the UTRGV campus and surrounding areas.

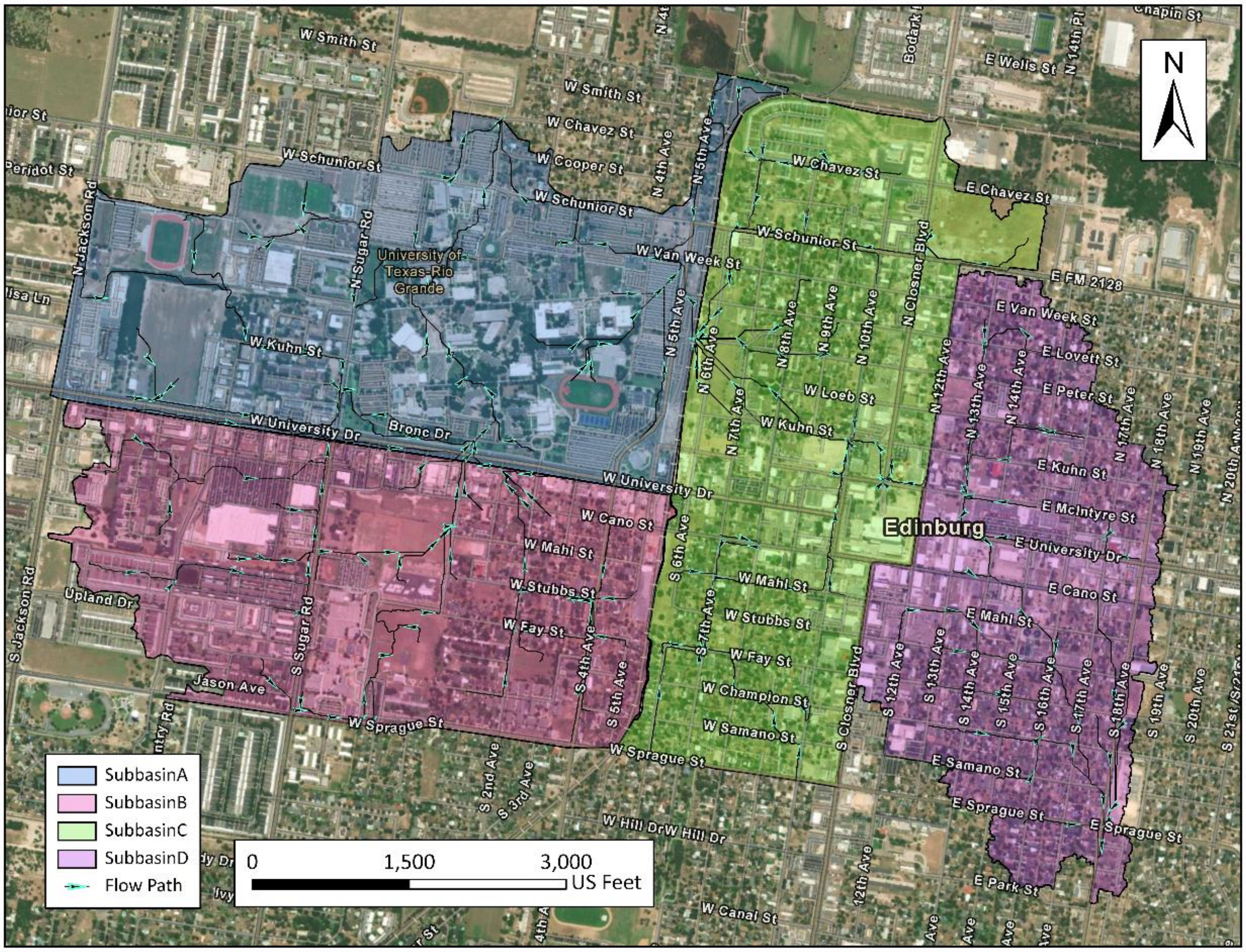

Figure 9 – Map showing delineated subbasins and existing flow paths for the study area.

Excess Rainfall Hydrologic Model

HEC-HMS is intended to simulate precipitation-runoff processes of watershed systems, providing information such as estimates of runoff volumes and peak flow rates. For this study, HEC-HMS was used to determine the excess precipitation amounts for a 100-year and 200-year storm event. The delineated basins were imported into HEC-HMS, georeferencing their location. This represents the Basin Model component in HEC-HMS (Figure 10). In that component, there are various user defined variables dependent on the loss and transform method selected.

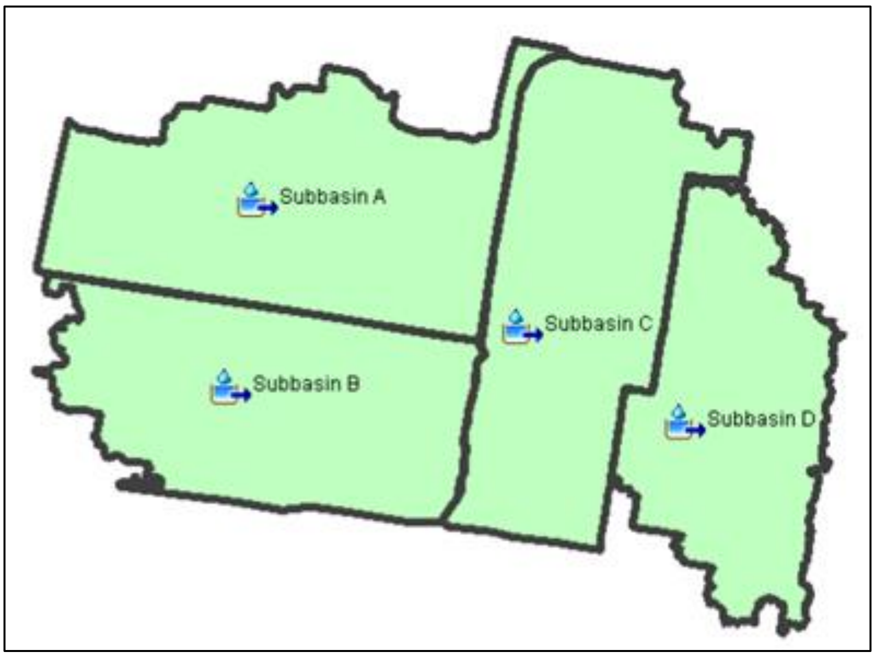

Figure 10 – HEC-HMS basin model component for hydrological calculations.

Within HEC-HMS, the Soil Conservation Service (SCS) curve number (CN) method was selected, which estimates precipitation as a function of cumulative precipitation, soil cover, land use and antecedent moisture, as described in TR-55. The SCS CN method is based on the relationship shown below, where *Q* is runoff (inches), *P* is rainfall (inches), *S* is potential storage, and I_a is initial abstraction. Until the accumulated rainfall is greater than the initial abstraction, runoff will be zero.

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad \textbf{\textit{(Equation 1)}}$$

Initial abstraction accounts for all losses prior to runoff, due to factors such as soil infiltration, evaporation, interception, and surface depressions. The SCS developed an empirical relationship for initial abstraction and potential storage, shown below.

$$I_a = 0.2S \qquad \textbf{\textit{(Equation 2)}}$$

Therefore, substituting the relationship into the first equation gives runoff as:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad \textbf{\textit{(Equation 3)}}$$

The maximum retention, *S*, can be determined based on the equation shown below, where *CN* is the curve number. The CN is a function of land cover type and hydrologic soil group.

$$S = \frac{1000}{CN} - 10 \quad \textbf{\textit{(Equation 4)}}$$

The National Engineering Handbook, Part 630, Hydrology, Chapter 15, contains information on the watershed characteristics influencing the shape and peak of the runoff hydrograph. Lag time for a watershed is the delay between the time runoff from a rainfall event begins until runoff reaches its maximum peak. Time of concentration is the time required for runoff to travel from the hydraulically most remote point in the watershed to the outlet. Studies found that for average natural watershed conditions and an approximately uniform distribution of runoff, the relationship between lag and time of concentration can be defined as shown below. Where L is lag time (hours) and T_C is time of concentration (hours).

$$L = 0.6T_C \quad \textbf{\textit{(Equation 5)}}$$

The SCS method for watershed lag is shown below, developed for a wide-ranging set of watershed characteristics. Where L is lag time (hours), L_W is flow length (feet), S is the maximum retention (in), and Y is average watershed land slope (percent).

$$L = \frac{L_W^{0.8}(S+1)^{0.7}}{1900(Y^{0.5})} \quad \textbf{\textit{(Equation 6)}}$$

Each of those hydrologic parameters were calculated, based on the delineated basins for the study area. Soil data and parcel maps for the basins were joined together using the intersect tool in GIS. This created one attribute table, where each row specifies every parcel by basin name, soil, and land type. This facilitated calculating the weighted CN for each basin, based on the variability in cover and soil type. CN values were obtained from TR-55 for urban areas (Figure 11). Theoretically, the CN can range from 0 to 100, one-hundred percent rainfall infiltration to impervious (Texas Department of Transportation, 2019). Therefore, high CN's are typically associated with urbanized areas with higher runoff potential rates. The calculated weighted CN's for the study area ranged from approximately 83 to 87, for each basin.

Table 2-2a Runoff curve numbers for urban areas [1]

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
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.

2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Figure 11 – Runoff curve numbers for urban areas, based on NRCS report for urban hydrology for small watersheds.

A frequency based hypothetical storm method was used for the HEC-HMS Meteorological Model component. This method defines a storm event based on input precipitation depths that have a constant exceedance probability for various storm durations. As mentioned, precipitation depths were referenced from NOAA's Precipitation Frequency Data Server for Atlas 14. The precipitation depths entered in the HEC-HMS model are shown below.

Table 4 – NOAA Atlas 14 precipitation depths for a 100-year and 200-year storm event.

Precipitation Data							
	15 min.	**60 min.**	**2 hrs.**	**3 hrs.**	**6 hrs.**	**12 hrs.**	**24 hrs.**
100-Year	2.40	4.41	5.75	6.63	8.08	9.40	10.70
200-Year	2.67	4.94	6.55	7.63	9.41	11.00	12.50

2D Rain-on-Grid Flood Model

The flood inundation extents for the study area were generated using HEC-RAS by developing a two-dimensional (2D) unsteady flow model, using a precipitation boundary condition. HEC-RAS performs the 2D unsteady flow routing with either the Shallow Water Equations (SWE) or the Diffusion Wave Equations (DWE) (U.S. Army Corps of Engineers, n.d.). The program has the DWE set as default, since it runs faster and more stable when compared to the SWE. For this study, the DWE was selected for the simulation. HEC-RAS uses a sub-grid bathymetry approach for either equation. This approach utilizes the underlying grid terrain to develop the geometric and hydraulic property tables that represent each individual cell and cell faces (U.S. Army Corps of Engineers, n.d.). HEC-RAS has a 2D flow area pre-processor that automatically computes the cells detailed property tables as a function of water depth.

To develop the 2D geometry, the terrain model is imported and projected. This dataset is a necessary requirement for 2D modeling since it determines the geometric and hydraulic properties of each 2D cell and face. The terrain is also required for developing the flood inundation mapping of the study area. Once the terrain model is inputted, each delineated basin is imported as a 2D flow area. The 2D computational mesh was generated for each flow area, choosing a 50 x 50 feet grid. The mesh was further refined by enforcing break lines representing existing roadways across the flow area. Land cover data was imported to populate Manning's n values within the flow areas. A different n value was selected corresponding to each land cover type in the area (U.S. Army Corps of Engineers, n.d.).

Once the geometry is complete, boundary and initial conditions must be applied to run the simulation. In HEC-RAS, boundary conditions consist of either external boundary conditions along the perimeter of the 2D flow area, internal and global boundary conditions that are applied to the entire model extent. For this study, an internal boundary condition was selected using precipitation, representing a rain-on-grid model. The excess rainfall time series data computed by the SCS method in HEC-HMS is applied uniformly over each 2D cell.

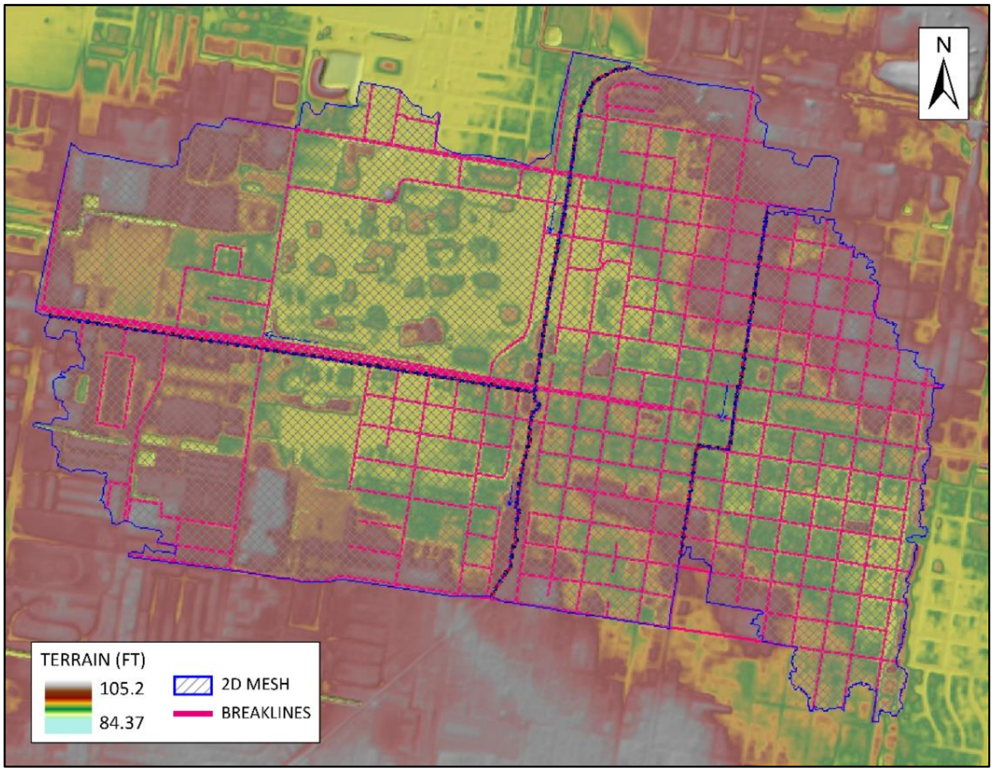

Figure 12 – HEC-RAS 2D mesh geometry for the study area, overlaying the terrain data.

Table 5 – Recommended Manning's n value for each NLCD value.

NLCD Value	Description	n Value
11	Open Water	0.02
21	Developed, Open Space	0.05
22	Developed, Low Intensity	0.12
23	Developed, Medium Intensity	0.16
24	Developed, High Intensity	0.20
31	Barren Land Rock-Sand-Clay	0.03
52	Shrub-Scrub	0.16
71	Grassland-Herbaceous	0.05
81	Pasture-Hay	0.05
82	Cultivated Crops	0.05

CHAPTER III

RESULTS

2D Flood Inundation Map

The HEC-RAS 2D model simulation resulted in the flood extent and numerical depths for the UTRGV Edinburg campus for a 100-year and 200-year storm event. The total campus area modeled is 180 acres. The model results identified approximately 94% and 96% of the area at risk for ponding, for a 100-year and 200-year storm event respectively. Table 6 classifies the modeled flood depths in terms of inundated areas by acreage for each modeled storm event, solely for the campus area. As the modeled storm event magnitude increased, so did the total inundated area for the campus. Both modeling scenarios exhibit most of the campus area experiencing ponding depths between 1 to 2 feet. Directly comparing the area for ponding depths between 0 to 2 feet, the inundated area decreases for the 200-year storm event. Although there is a decrease in area, this does not mean that there is less ponding for the 200-year storm event model simulation. While less area is inundated by depths between 0 to 2 feet, there was an increase in inundated areas experiencing depths of 2 feet and above. This is expected for a 200-year storm event since the magnitude increased. Figures 13 and 14 illustrate the inundation maps for the entire study area, covering the campus and portions of Edinburg, Texas. At the campus, much of the ponding is collected near the parking lots and along University Drive. For the entire study area, ponding accumulates mainly near the Hidalgo County Courthouse. Those are all areas at low elevation.

Table 6 – Ponding depths classified by inundated area in acreage.

Ponding Depth (ft)	**100-Year (ac)**	**200-Year (ac)**
0.0 – 1.0	38.2	29.4
1.0 – 2.0	78.0	67.2
2.0 – 3.0	48.7	66.8
> 3	4.1	9.6
Sum of Total Inundated Area:	169.0	173.0
Total Campus Area:	180.0	

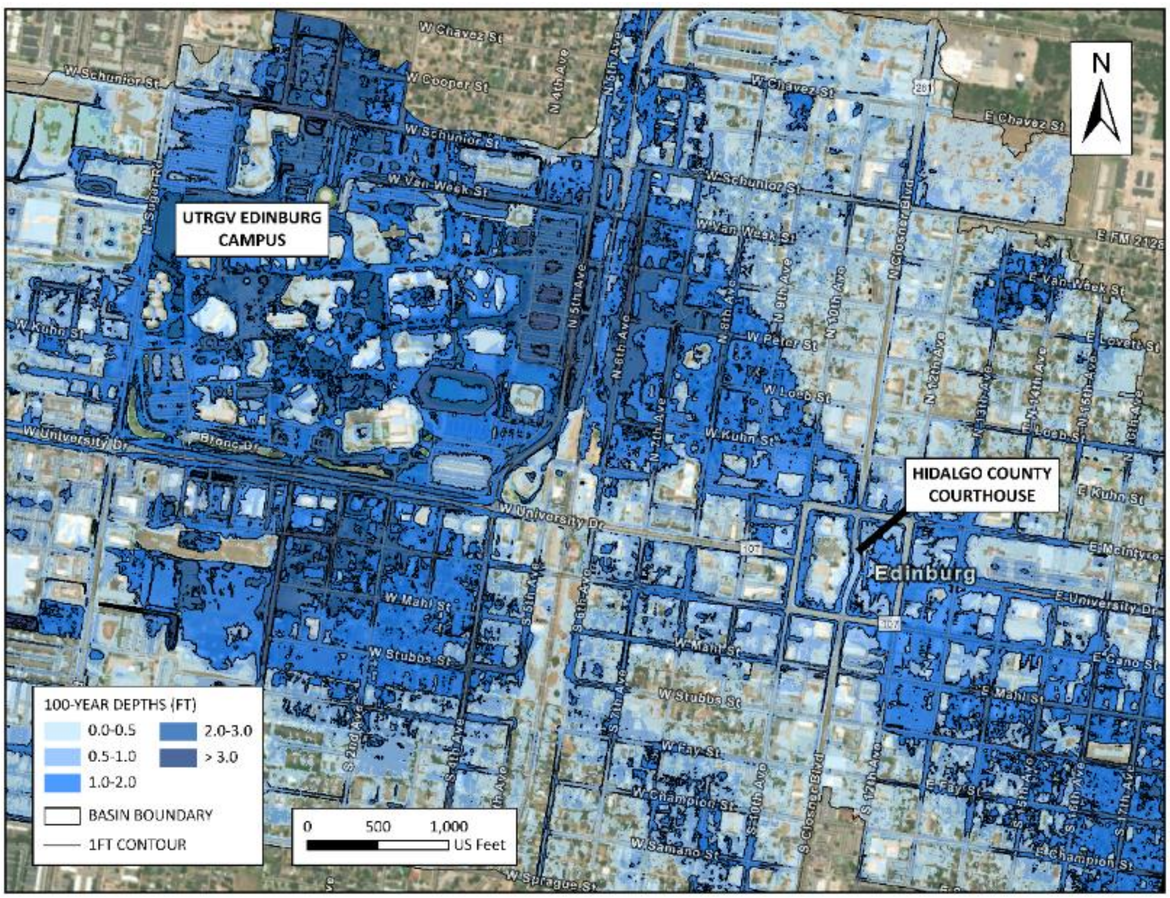

Figure 13 – A map denoting the 100-year storm event ponding depths for the study area.

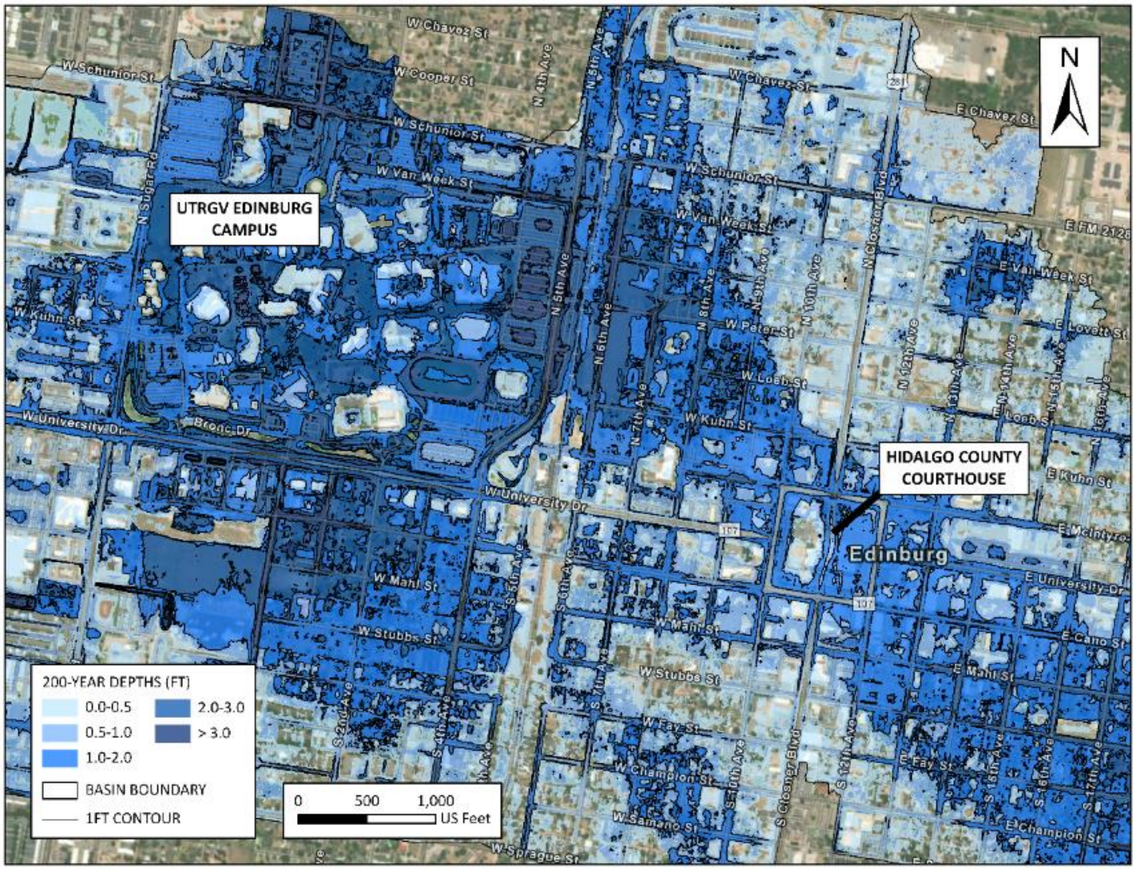

Figure 14 – A map denoting the 200-year storm event ponding depths for the study area.

Comparison with Available Data

Validating flood models in urbanized areas poses challenges when there is lack of gauge data (Krvavica, et al., 2020). However, with information available such as FEMA FIRM products and photos from local media, validation is possible by comparison.

While the study focused on developing an inundation map for the UTRGV Edinburg main campus, the watershed delineation extents were extended to the entire SFHA indicated on the FEMA FIRM. This was done to compare and validate the 100-year storm event simulation results with the BFE profile lines recorded on the FIRM. The FIRM identified two BFE lines near the Hidalgo County Courthouse, east of the campus. Both BFE profile lines recorded a water surface elevation of 96 feet for a 100-year storm event (Figure 15).

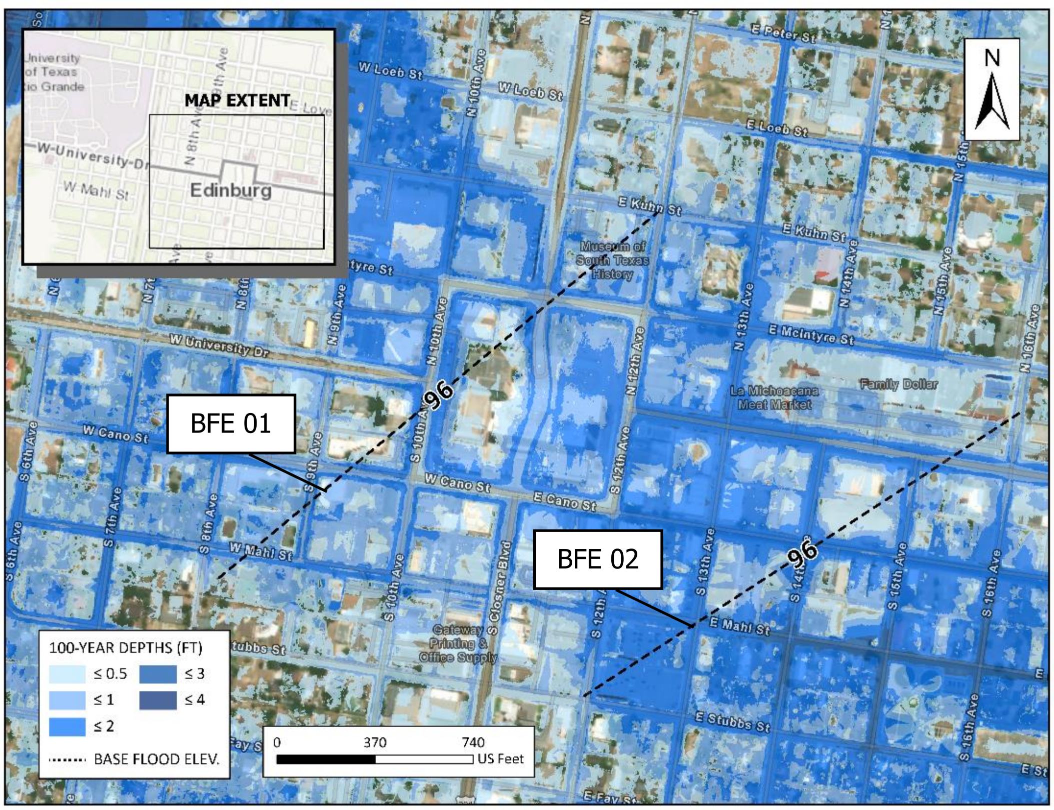

Figure 15 – Location of FEMA FIRM BFE profile lines overlayed on the 100-year storm event ponding depths.

HEC-RAS Mapper has the capability to plot the computed results for user defined profile lines along the 2D mesh, such as ponding depths and water surface elevations. Profile lines were drawn at the same location as the BFE cross sections, plotting the computed water surface elevations for the 100-year storm event (Figure 16 and 17). The model results depict values between 96 feet to 96.5 feet, which is consistent with the FEMA FIRM BFE values.

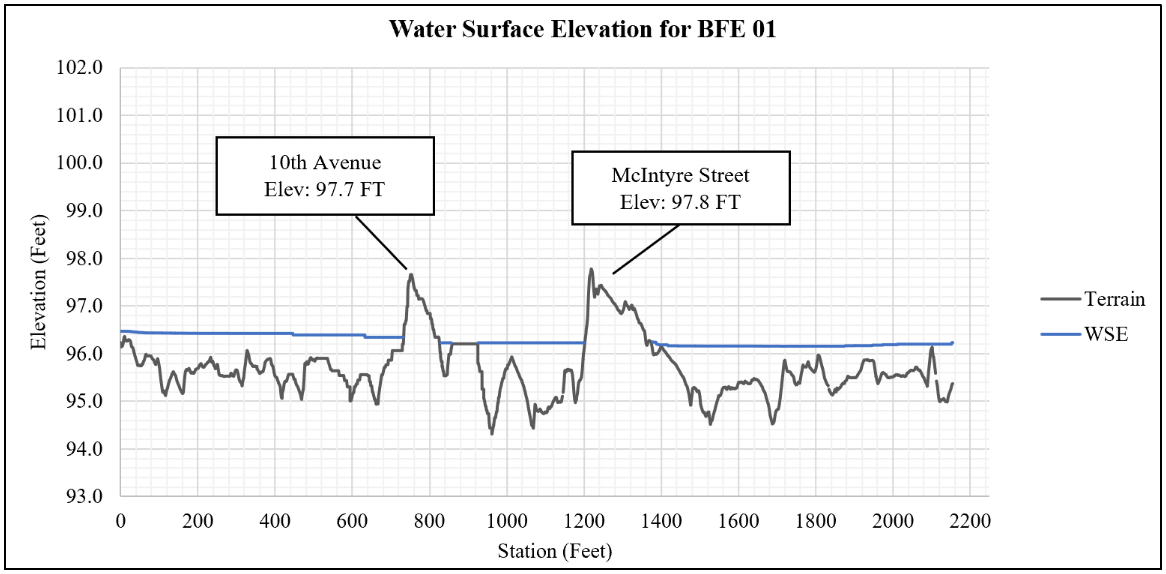

Figure 16 – Computed 100-year water surface elevation values for BFE 01.

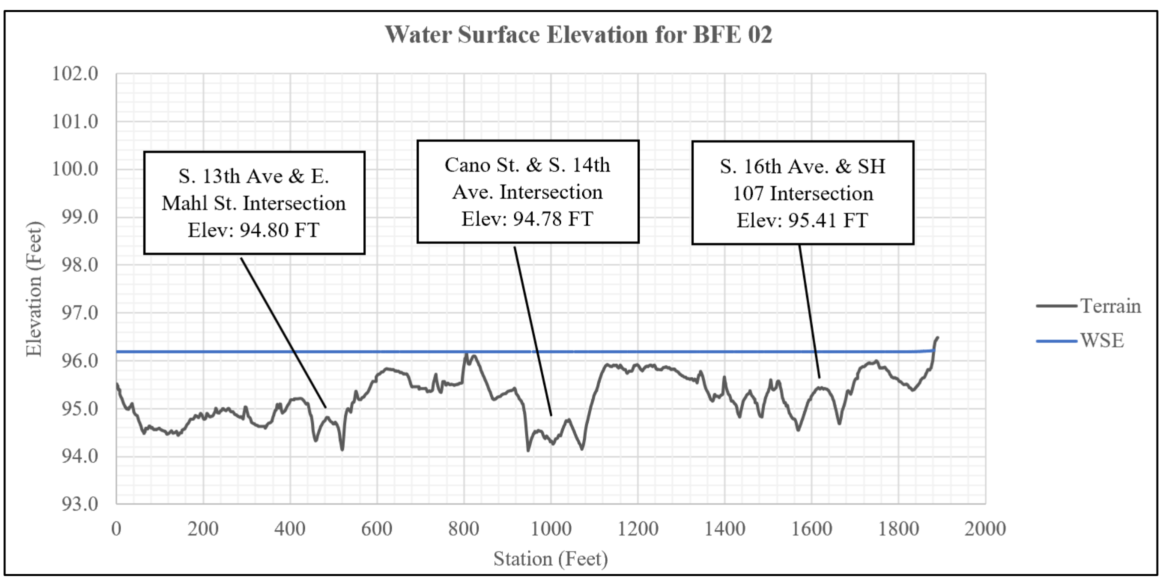

Figure 17 – Computed 100-year water surface elevation values for BFE 02.

The entire campus area and much of the study area lies in Zone AH, as recorded in the FEMA FIRM. As discussed previously, Zone AH are areas subject to ponding between 1 to 3 feet for a 100-year storm event. Figure 18 depicts the computed extents for depths between 1 to 3 feet overlaid on the FEMA FIRM. The extents match the outline of the Zone AH well, however there are some small deviations in the computed ponding depths. The simulation shows some ponding greater than 1 foot in Zone X shaded and unshaded.

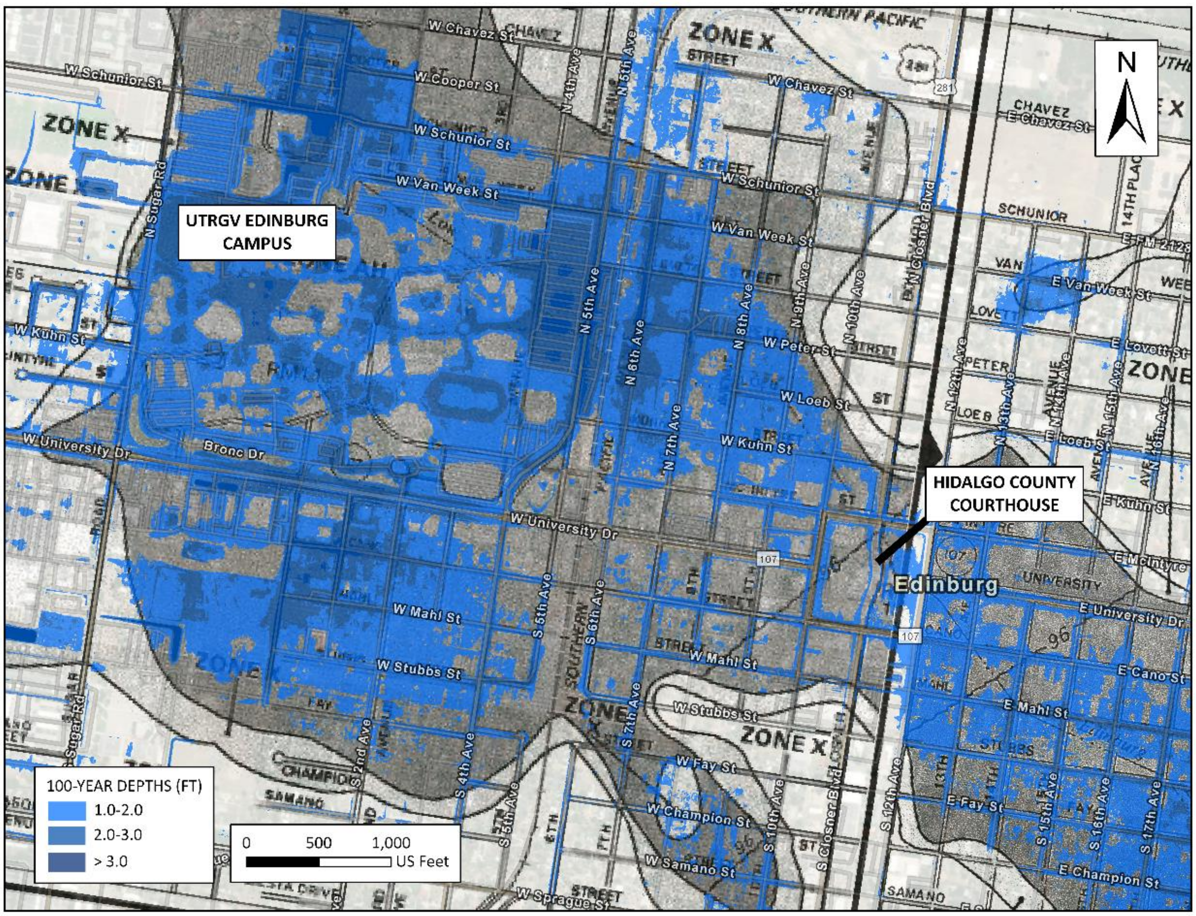

Figure 18 – Computed 100-year ponding depths extents between 1 to 3 feet superimposed on FEMA Zone AH.

Figure 19 illustrates ponding depths greater than 3 feet for the campus area, which is mainly along existing paved roads and parking lots. Based on the total campus area, about 2% of ponding depths are above what is recorded on the FEMA FIRM. This is relatively minimal and can also be expected since the maps were developed in 2001, not considering the amount of urbanization the campus and surrounding areas has undertaken since then.

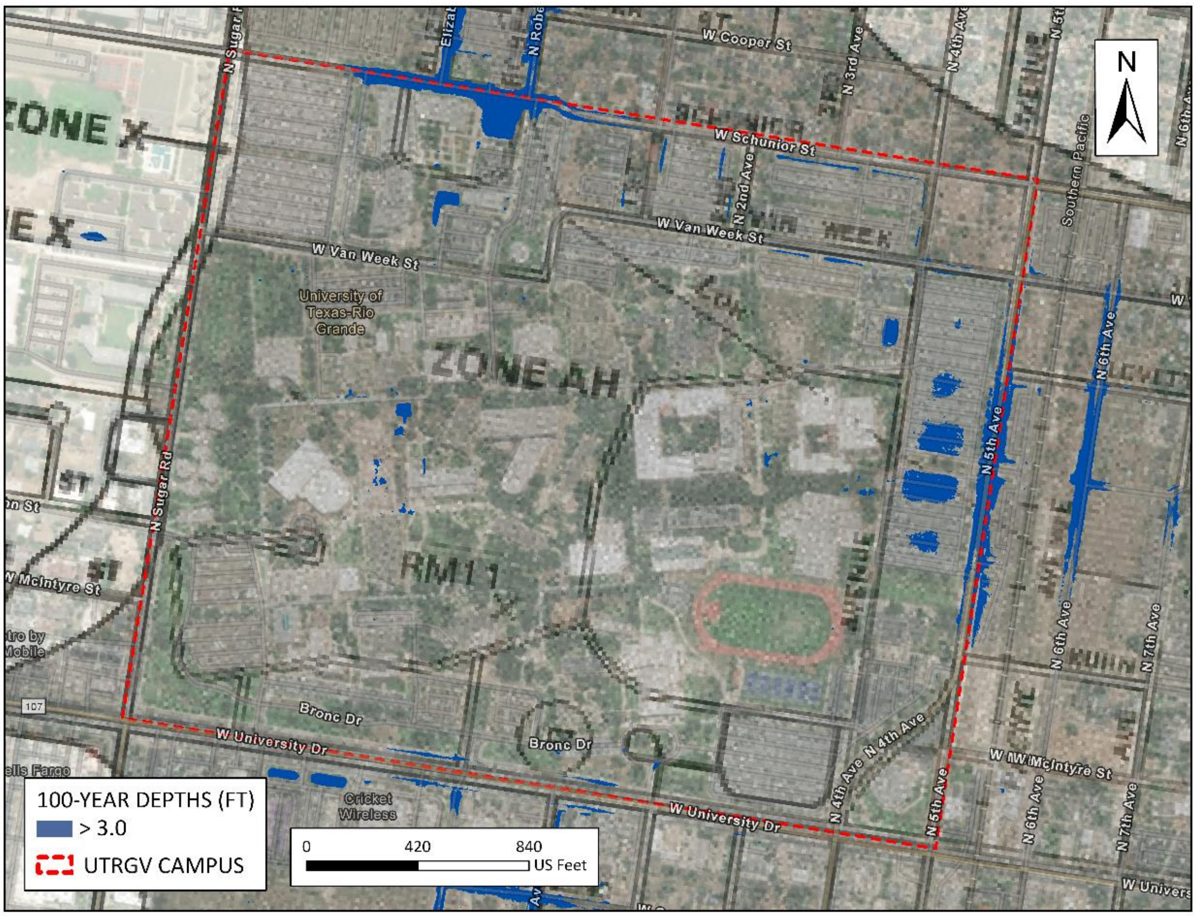

Figure 19 – Computed 100-year ponding depths extents greater than 3 feet superimposed on FEMA Zone AH.

As per HCDD1 personnel, the 2018 June Storm Event is believed to have been between a 100-year to 250-year storm event for the area. The model results for a 200-year storm event were compared to photos of flooding on campus and neighboring streets, providing a qualitative comparison. Figure 20 shows flooding photos along the southern edge of the campus, parallel to University Drive (SH 107). The photos overlay the simulated 200-year flooding extents. The photos clearly show flooded streets and parking lots on the campus.

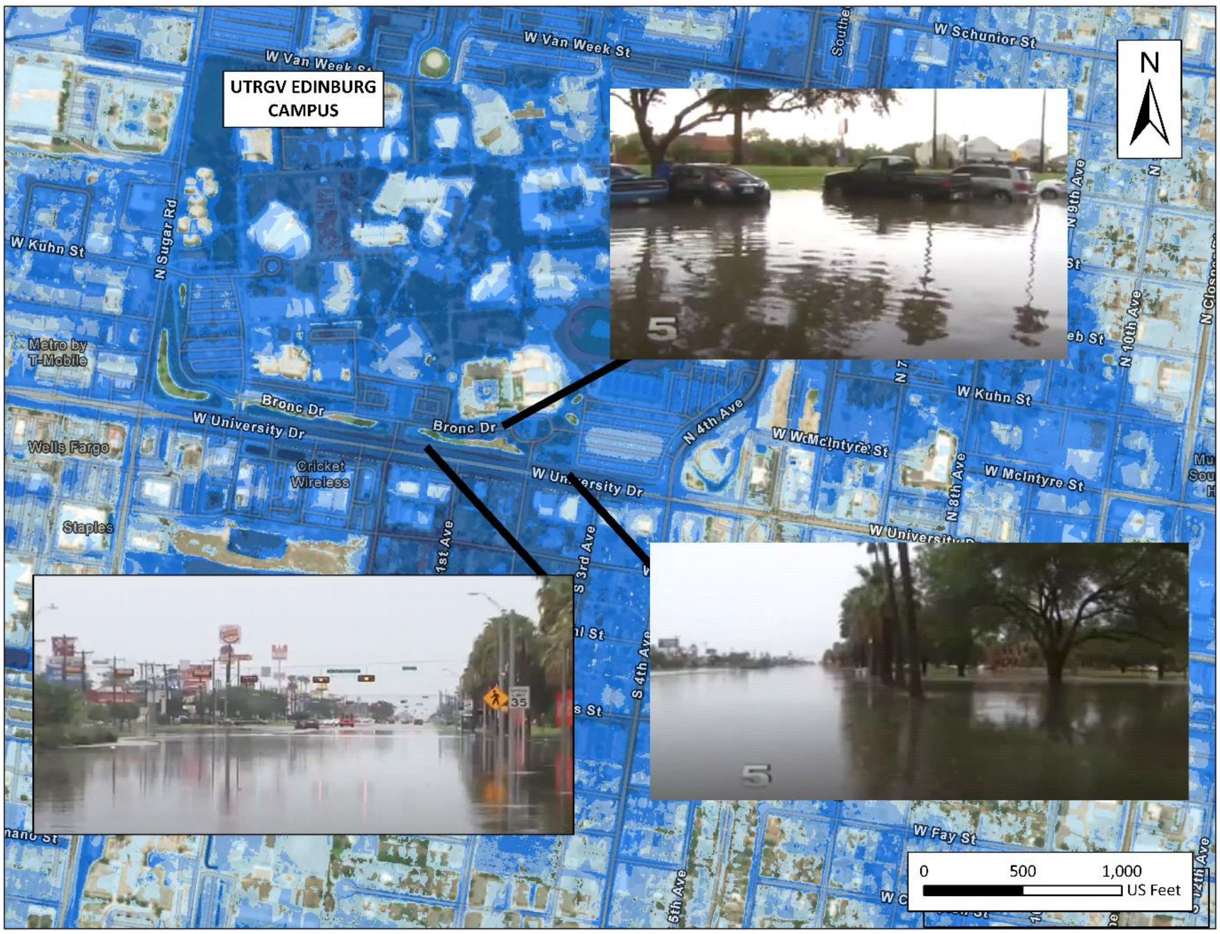

Figure 20 – Computed 200-year ponding depths with flooding pictures from 2018 storm event (KRGV, 2018).

Model Limitations

While 2D models exhibits a major advancement over 1D models by involving fewer assumptions from users and presenting a more intuitive graphical representation of results, there are still some limitations and uncertainties (Robinson, et al., 2019). For the study area, there is no gauge data or monitoring equipment nearby to validate the results from HEC-HMS. Therefore, there is some uncertainty present. Additionally, the HEC-RAS model does not include any hydraulic structures modeled in the geometry. In urbanized areas, some of the natural flow paths in the watershed are replaced by pipes, curbs, paved gutters, and other stormwater system elements (United States Department of Agriculture, 1986). Flow in complex stormwater systems cannot be hydraulically modeled in HEC-RAS. Therefore, none was modeled in this study for the campus area. Secondly, there are no existing drainage channels within the modeled mesh area for the urban campus. The nearest channel is about one mile west of the campus, called the North Main Drain III owned and maintained by the Hidalgo County Drainage District No. 1. This study solely looked at the results for the urban campus area within the user defined mesh and an applied excess rainfall boundary condition, based on the terrain.

CHAPTER IV

CONCLUSION

Flooding due to severe storm events is a prevalent issue worldwide, responsible for numerous detrimental impacts to people, properties, and public infrastructure. Due to climate change and changing land cover, urban areas are increasingly being negatively affected by flooding. Therefore, flood risk models are an imperative tool in providing valuable information such as runoff peak values, inundation maps, and identifying high risk areas for urban planning. Aside from urban planning, flood risk modeling is essential for emergency management if combined with a flood warning system to issue out evacuation times and routes. However, creating a 1D flood model for urbanized areas can be a challenging, time consuming and costly endeavor for entities. Many models need extensive datasets to build the study area geometry and boundary conditions, such as topographic information, soil type, gauge data and others. Utilizing a fully 2D flood modeling approach facilitates gathering extensive survey and field data, by using publicly available datasets for terrain and soil data.

This research focused on using a simple integrated HEC-RAS 2D Rain-on-Grid modeling approach to generate a flood inundation map for the UTRGV Edinburg Campus area. Model calibration or validation is crucial in ensuring accurate and realistic results for flood models.

Calibrating the model is a challenge with the lack of gauge sites or monitoring equipment near the study area. Therefore, the results were compared with FEMA FIRM flood zones and past photos of severe rain events. Both comparisons showed similar results with the limited information available. Two storm events were modeled using HEC-HMS for a 100-year and 200-year storm event. The model results identified approximately 94% and 96% of the area is prone to ponding, for a 100-year and 200-year storm event respectively. Ponding is a main concern at the campus' parking lots and on University Drive (SH 107) since this not only damages the pavement but also leads to road closures and affects evacuation routes.

This HEC-RAS 2D model is the first step in creating a real time flood warning system for the campus. With the base geometry set up done, further studies will focus on updating the model's boundary conditions with real time rainfall data. The result will be a flood warning system depicting flood extents and depths expected for any rainfall forecasted, specifically for the campus. This real time data provides sufficient information for students, professors, or campus decision makers to take the most appropriate actions before flood disasters strike and mitigate any flood risk.

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APPENDIX

APPENDIX

HYDROLOGICAL CALCULATIONS FOR HEC-HMS INPUTS

The following figures show the different calculated characteristics for each delineated subbasin. These parameters were inputted into the HEC-HMS model to determine the excess rainfall.

Subbasin A
Soil B

Land Use	CN	Area (sq. ft.)	Wt. %
Residential Small	70	1,350,747	0.085
Residential Multi Fam	85	606,633	0.038
Open Space	69	354,022	0.022
Industrial/Commercial	88	11,392,588	0.713
Impervious Areas	98	2,278,135	0.143

Total Area (Soil B):	15,982,125	sq. ft.
	0.57	sq. mi.
	366.9	ac
Composite CN:	87.37	
Hydr. Length:	7225.61	ft.
Lag Time:	5.379	hr.
	322.767	min.

Figure 21: HEC-HMS inputs for Subbasin A.

Subbasin B

Soil B

Land Use	CN	Area (sq. ft.)	Wt. %
Residential Small	70	3,998,587	0.294
Residential Multi Fam	85	3,025,081	0.223
Open Space	69	898,912	0.066
Industrial/Commercial	88	3,125,250	0.230
Impervious Areas	98	2,545,108	0.187

Total Area (Soil B):	13,592,938	sq. ft.
	0.49	sq. mi.
	312.05	ac
Composite CN:	82.65	
Hydr. Length:	6556.65	ft.
Lag Time:	5.874	hr.
	352.442	min.

Figure 22: HEC-HMS inputs for Subbasin B.

		Soil B			Soil D	
Land Use	**CN**	**Area (sq. ft.)**	**Wt. %**	**CN**	**Area (sq. ft.)**	**Wt. %**
Residential Small	70	3,964,012	0.432	85	18,289	0.008
Residential Multi Fam	85	364,924	0.040	92	61,609	0.028
Open Space	69	396,928	0.043	84	32,453	0.015
Industrial/Commercial	88	1,336,527	0.146	95	2,083,456	0.949
Impervious Areas	98	3,113,816	0.339	-	-	-

Subbasin C

Total Area (Soil B):	9,176,207	sq. ft.
Total Area (Soil D):	2,195,807	sq. ft.
Total Area:	11,372,014	sq. ft.
	0.41	sq. mi.
	261.07	ac
Composite CN:	84.17	
Hydr. Length:	5891.1	ft.
Lag Time:	5.123	hr.
	307.403	min.

Figure 23: HEC-HMS inputs for Subbasin C.

Subbasin D

	Soil B			Soil D		
Land Use	**CN**	**Area (sq. ft.)**	**Wt. %**	**CN**	**Area (sq. ft.)**	**Wt. %**
Residential Small	70	3,964,012	0.432	85	18,289	0.008
Residential Multi Fam	85	364,924	0.040	92	61,909	0.028
Open Space	69	396,928	0.043	84	35,453	0.016
Industrial/Commercial	88	1,336,527	0.146	95	2,083,456	0.947
Impervious Areas	98	3,113,816	0.339	-	-	-

Total Area (Soil B):	9,176,207	sq. ft.
Total Area (Soil D):	2,199,107	sq. ft.
Total Area:	11,375,314	sq. ft.
	0.41	sq. mi.
	261.14	ac
Composite CN:	84.17	
Hydr. Length:	5891.1	ft.
Lag Time:	5.124	hr.
	307.444	min.

Figure 24: HEC-HMS inputs for Subbasin D.

BIOGRAPHICAL SKETCH

Roxana Tello earned her bachelor’s degree in civil engineering from the University of Texas Rio Grande Valley in May 2019. Ms. Tello also earned her Master of Science in Civil Engineering, with a concentration in Environmental and Water Resources in July 2023.

During her undergraduate career, Roxana participated in summer internship programs. She worked at the Hidalgo County Drainage District No. 1, the government entity responsible for managing the Hidalgo County Master Drainage System by maintenance and implementing drainage improvements countywide. Additionally, she participated in the U.S. Department of State’s Pathways Internship Program in Yosemite National Park under the Design and Engineering Division. Both opportunities gave her significant experience and knowledge in the design, construction, and management of water resources related projects. Roxana passed the Fundamentals of Engineering (FE) exam in December 2019 and gained her Engineer in Training (EIT) title in January 2020. She passed the Principles and Practice of Engineering (PE) exam in October 2021, in the Water Resources and Environmental concentration. She looks forward to continuing working at a local consulting engineering firm, gaining work experience towards obtaining her Professional Engineer license.

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