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CITY OF MANVEL
MASTER DRAINAGE PLAN

Prepared For

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EXECUTIVE SUMMARY

Klotz Associates (Klotz) was retained by the City of Manvel (CoM) to perform a hydrologic and hydraulic analysis in the form of a Master Drainage Plan (MDP). The underlying objective of this study was to provide recommendations for drainage improvements to the City in order to meet the City's continued growth and future needs.

Updated hydrologic and hydraulic flood models were developed for the primary watercourses in the CoM to determine the flood reduction impacts of potential flood control projects, including conveyance improvements by widening and/or deepening a channel, construction of detention ponds to temporarily store flood waters, hydraulic channelization in some areas, improvement of the conveyance capacity of hydraulic structures; and selected combinations of these different types of projects. Comparison of flooding depths with and without a proposed flood control project for different flood frequencies statistically summed across all structures subject to flooding was used to determine the expected reduction of flood damages achieved by a proposed scenario.

Two scenarios for future drainage improvements are presented in this report. Scenario 1 ROW widths are shown in Exhibit 6-A and reflect an option for the CoM to prepare-for and promote future channel improvements that would convey the 100 year pre-developed (currently existing) flows within the banks of all major channels, and ultimately within the proposed ROW. Any additional detention required as a result of development would be provided by sub-regional detention ponds located at areas north of Highway 6 or by on-site detention, as outlined in the 2012 CoM Design Criteria Manual. Scenario 2 ROW widths are shown on Exhibit 6-B and reflect an option for the CoM to prepare-for and promote future detention mitigation that would convey the 100 year fully-developed flows within the banks of all major channels, and ultimately within the proposed ROW.

Necessary ROW was estimated for both scenarios. Basic scenario components have been used to estimate project costs. Project costs include estimated costs for construction, environmental permitting, engineering, large contingencies, and ROW acquisition and are summarized in the table below.

Table 1: Summary of Costs

Scenario 1 Conditions			Scenario 2 Conditions		
Sub Total		$79,413,499	**Sub Total**		$79,582,650
Engineering	10.00%	$7,941,460	Engineering	10.00%	$7,718,375
Geotech/Survey	10.00%	$7,941,460	Geotech/Survey	10.00%	$7,718,375
Environmental	10.00%	$7,941,460	Environmental	10.00%	$7,718,375
Contingency	30.00%	$23,824,381	Contingency	30.00%	$23,155,126
Scenario 1 Total:		**$127,062,260**			**$125,892,903**

Costs for improved drainage infrastructure, capable of conveying or detaining flood events within the CoM ETJ are significant. The CoM should investigate and consider the various funding options and cost-savings methods presented in this report. With the extreme flooding issues currently existing, it is likely that the CoM could be successful in a receiving help from a number of funding sources.

The CoM can slowly accomplish the necessary drainage infrastructure improvements by continually working with future developments and drainage districts to ensure that appropriate planning, roles, and responsibilities to resolve drainage issues are phased, assigned, and implemented. By coupling proposed projects with city amenity features such as parks, trails, fishing ponds, etc., the CoM can work to couple future beautification projects with drainage infrastructure improvements. The CoM should make every effort to keep this document up-to-date and continue to develop a plan for implementing drainage-related improvements for future developed conditions.

SECTION 1 INTRODUCTION

1.1 Authorization

The development of this City of Manvel Master Drainage Plan (MDP) was authorized by agreement between the City of Manvel (CoM) and Klotz Associates (Klotz) dated April 22, 2013.

1.2 Background

Klotz was hired to perform an engineering analysis in the form of a Master Drainage Plan (MDP) for the City of Manvel (CoM). The overall goal of this MDP is to provide recommendations for drainage improvements to the City in order to meet the City's continued growth and future needs. These recommendations are provided herein primarily in the form of sub-regional detention pond volumes with acquisition acreage, right-of-way acquisition widths for channel improvements, channel improvement geometry, and future conveyance necessary for problematic siphons/culverts.

1.3 Study Purpose and Intent

This high level planning study identifies, broadly describes, and generally evaluates major flood control projects and improvements that can significantly reduce current and future flooding of residential structures in the CoM. Flood damage reduction benefits are estimated and used to identify high priority flood control projects for possible implementation.

The projects identified and broadly described in this MDP are intended to be used as the basis for defining individual projects and features that can be implemented over the years to reduce flooding damages within the City's studied boundary. The results of this Study can serve as a roadmap for implementation of projects which will have long-term cost effectiveness in reducing flooding.

This MDP is a planning study, not a detailed engineering study or a preliminary engineering report (PER). This Study is intended to identify and assess, in broad perspective, potentials for large-scale projects throughout the CoM to cost-effectively reduce current flooding and help plan for future build-out. As such, approximations and professional judgment are incorporated into

the development and assessment of potential flood control projects. Proposed projects are described and evaluated only in broad terms, with the full intention that a detailed engineering study will be required before any one project or portion of any one project developed in this MDP can actually be implemented.

1.4 Project Limits

Manvel is located in the northern portion of Brazoria County in southeast Texas. The city has established an extraterritorial jurisdiction (ETJ) boundary that was used as the general extent of this MDP. Figure 1 below shows the extent of the ETJ boundary. A stand-alone Vicinity Map can be found in Exhibit 1.

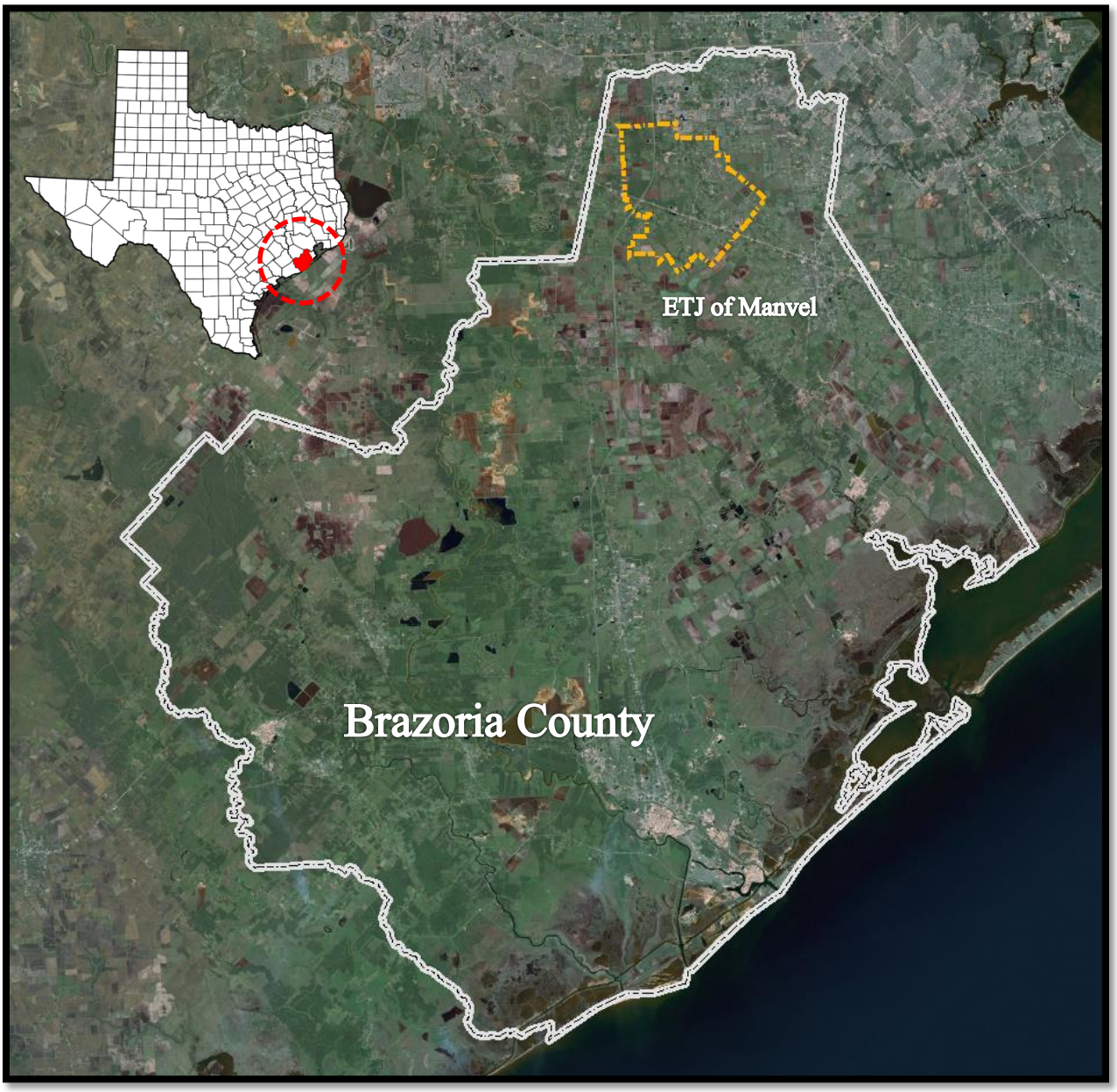

Figure 1: Vicinity Map

SECTION 2 CITY OF MANVEL

2.1 City Overview

Manvel is located in the northern portion of Brazoria County in southeast Texas and has a humid subtropical climatic area, with mild winters and warm summers. Rainfall averages about 48" per year and is somewhat evenly distributed throughout the year. The heaviest rains usually occur during the hurricane season, which extends from about June to October.

The soils in the area are clayey and loamy, and are categorized in two soil associations. The major land area consists of soils in the Beaumont-Morey-Lake Charles association. Other soils in the city are in the Anahuac-Morey-Frost association. These soils have low infiltration rates and high runoff potential. For hydrological purposes with use in the SCS curve number method, the soils are classified in Soil Conservation Service Group D.

2.2 Regional Drainage Relationships

Three different drainage districts are tasked with the responsibility of maintaining the drainage related infrastructure inside the CoM. The central northern and some of the western portions of Manvel are covered by the Pearland Drainage District (DD #4), the eastern portion of the city is covered by Conservation and Reclamation District #3 (C&R #3) and the southern portion of the city is covered by the Brazoria County Drainage District #5 (DD #5). Each of these districts have different tax rates and varying levels of drainage improvements and maintenance. Furthermore, the three drainage districts don't only cover Manvel, but their boundaries encompass large service areas and thus have to spread their limited funds and resources throughout each respective district. See Exhibit 2 which shows the boundaries of the three drainage districts. Because there are four (4) different agencies (including Manvel) that are tasked with drainage or maintenance of the drainage systems in Manvel, there is not a uniform or consistent plan for the city. The existing FEMA floodplain maps (shown in Exhibit 4) indicate drainage problems along Mustang Bayou, along SH 6, and other areas drained by Chocolate Bayou. This is further discussed in the regulatory floodplain section of this report.

Most of the existing roadways in the Manvel area are drained by roadside ditches, cross drainage culverts, and bridges. Maintenance of the roadside drainage system is needed to ensure that

adequate drainage is provided for the existing residents of Manvel. This roadside ditch maintenance is handled by the three drainage districts on various schedules.

An important relationship between the CoM and the three drainage districts, along with Brazoria County, has been established based on the need for all entities to work effectively together toward improving the quality of life in the area. Additionally, the Texas Department of Transportation (TxDOT), Railroads (RR's) and the Gulf Coast Water Authority (GCWA) all have an interest in adequate drainage within the Manvel area and work together on these issues when efforts are needed. The City, Drainage Districts, and the County have a positive and businesslike relationship based on mutual concerns, including transportation, drainage, infrastructure maintenance, criminal justice, recreation, education, and overall health of the system. The various entities deemed responsible for drainage related infrastructure should consider an interlocal agreement for shared responsibilities. An inter local agreement with the Drainage Districts, Brazoria County, TxDOT, RR's, the Gulf Coast Water Authority, etc. may prove to be helpful for all involved with local drainage in Manvel.

Drainage is divided between the drainage districts, CoM, and Brazoria County. The drainage districts mostly have ownership of its drainage easements and rights-of-way and have established relationships with many property owners to allow them access to the drainage ditches to perform selective maintenance. The drainage of roadways is provided by the drainage districts and by the County through its roadway and bridge budget.

Table 2 below shows the percentages of the Drainage Districts and Floodplain information for within the CoM city limits.

Table 2: Area Percentage Breakdown

Description	Sub-Watershed
Pearland Drainage District (DD #4)	27%
Conservation and Reclamation District #3 (C&R #3)	55%
Brazoria County Drainage District #5 (DD #5)	15%
No Drainage District	3%
Floodplains (Excluding Floodway)	34%
Floodway	3%
Floodplain and/or Floodway	37%
No Floodplain/Floodway	63%

2.3 Existing Waterway Breakdown

Manvel is bordered by three major waterways that drain the city through primary and secondary drainage systems. The northern area of the city lies within the Mustang Bayou watershed, a mostly natural meandering waterway extending from its source in Fort Bend County to its mouth at Galveston Bay. To the southwest of Mustang Bayou, New Bayou drains a smaller area of Manvel and eventually meets up with Mustang Bayou further south. New Bayou is smaller and much more channelized than Mustang Bayou. Portions of the CoM lie in Chocolate Bayou, mostly a natural meandering waterway which drains generally the central and southern portions of Manvel. Chocolate Bayou begins in Manvel and drains south to its mouth in Galveston Bay.

There are numerous primary watercourses that serve Manvel. These watercourses are mostly natural drainage watercourses with some of these man-made, straightened, and improved areas. The existing drainage systems are shown in Exhibit 3, the Watershed Map. The primary drainage systems are fed by smaller and secondary watercourses. The secondary watercourses discussed in this report are shown in the same exhibit as a thinner line type.

Table 3: Watercourses

Course Code	Description	Sub-Watershed
E102-00-00	Chocolate Bayou Tributary North of Hwy 6	Basin EF-01A
	Chocolate Bayou Tributary South of Hwy 6	Basin EF-01B
E102-01-00	Small Tributary Chocolate Bayou North of Hwy 6	Local* (Table T-8)
E100-00-00	Chocolate Bayou Upper North of Hwy 6	Basin EF-02A
	Chocolate Bayou Upper South of Hwy 6	Basin EF-02B
	Chocolate Bayou Lower	Basin EF-03
E100-00-01	Small Tributary Chocolate Bayou Lower	Local* (Table T-9)
C100-00-00	C12 Ditch Upper	Basin EF-04B
	C12 Ditch Lower	Basin EF-04A
N100-00-00	New Bayou Upper	Basin NB-01
	New Bayou Middle	Basin NB-02
	New Bayou Lower	Basin NB-03
	New Bayou Far Lower	Basin NB-04
D100-00-00	Mustang Bayou Upper	M-01
	Mustang Bayou Middle	M-02
	Mustang Bayou Lower	M-03
	Mustang Bayou Far Lower	M-04
H100-00-00	Chigger Creek	CC-01 Local* (Table T-10)

Watercourses presented in the table above were all modeled utilizing HEC-HMS (discussed in the methodology portion of this Study) with the exception of sub-watersheds marked as Local*. "Local" watersheds were delineated individually for the smaller tributaries that played important roles in the Manvel drainage infrastructure. Flow off of the sub-watersheds was determined by the SCS curve number method presented in Tables T-8, T-9, and T-10. This was done because these watercourses were (1) not differentiated in the HEC models or (2) not included in any prior model Klotz discovered.

2.4 Regulatory Floodplains

Manvel participates in the regular program of the National Flood Insurance Program (NFIP). The National Flood Insurance Program is a federally sponsored program which makes flood insurance available to residents of communities that adopts and enforces floodplain management ordinances and that have sound land-use practices. The regulatory floodplains in Manvel and the surrounding area were determined by the Federal Emergency Management Agency (FEMA) as documented in the Flood Insurance Study of the CoM, Texas, Brazoria County, and the Flood Insurance Study for Brazoria County (Unincorporated Areas). The 100-year regulatory floodplains are shown on the FEMA Flood Insurance Rate Maps (FIRM) for Manvel effective date December 01, 1981, and Brazoria County, effective date December 15, 1983. The existing FEMA 100-year regulatory floodplains are shown in Exhibit 4. FEMA is currently remapping the coastal communities using new topographic data from LIDAR. FEMA is only remapping the floodplains for Manvel using new topographic data but not changing the hydrology or hydraulics for the streams.

2.5 Data Assembly

2.5.1 Prior Planning, Modeling, and Studies

2.5.1.1 City of Manvel Comprehensive Plan (CoMCP)

The Comprehensive Plan for the CoM, completed in 2007, was a long-range planning tool intended to be used by the city staff, decision-makers, citizens, and developers to guide the growth and physical development of the community for up to twenty years. The plan created a framework for making decisions regarding the future of the City and was based on a community vision formulated through input from the citizens, stakeholders, and local officials. The Comprehensive Plan included a drainage portion that investigated general drainage problems and discussed the need for a Master Drainage Plan. Klotz utilized this plan to identify issues of concern, key drainage areas, and model a pattern for the intensity of future development within the CoM. As the Klotz team understands, drainage problems within Manvel were the most cited concern from citizens during the public participation process of this plan.

2.5.1.2 Brazoria County Master Drainage Plan (BCMDP)

A Master Drainage Plan was prepared for Brazoria County and is dated August 2002. This Master Drainage Plan was a county wide plan aimed at many of the major watersheds and was developed as an implement able plan to improve the drainage with available funding from the drainage districts. The contents of this plan, while helpful to lower portions of Chocolate Bayou and to portions of Mustang Bayou, does not provide much sizing of proposed or needed drainage improvements in the Manvel area.

2.5.1.3 Chocolate Bayou Watershed Flood Control Study (CBWFCS)

The development and preparation of the Chocolate Bayou Watershed Flood Control Study (CBWFCS) was completed for Brazoria County by Klotz Associates, Inc. and dated October 9, 2008, and performed under Texas Water Development Board Grant G218 9/TWDB Flood Protection Planning. The Study was sponsored by the Texas Water Development Board (TWDB), Brazoria County, C&R #3, DD #4, DD #5, and the Brazoria County cities of Manvel, Alvin, and Iowa Colony.

The study included identification, description, assessment, and recommendation of potential flood control options that will address flooding problems in the CBW, with particular focus directed toward reduction in residential structure flooding-induced damages. The refined models created during the CBWFCS represent a base collective of models from various sources including models used in the BCMDP and other models developed by EHRA.

2.6 Historical Perspective

2.6.1 Citizen Reports and Local Knowledge

Periodically, Manvel experiences flooding from stream overflows, ponding, and shallow sheet flow caused by high intensity rainfall. Torrential rainfall often associated with hurricanes, tropical disturbances, and localized thunderstorms have been experienced in the area, primarily from storms passing though southeast Texas in the vicinity of Manvel and Brazoria County. These storm events have produced floods as well as some structural flooding damage in the area. A 100-year storm in the area generally results from an estimated 13.50 inches of stormwater runoff in a 24-hour period [Rainfall Frequency Atlas of the United States. 1961].

During due-diligence through interaction with CoM staff, some areas throughout the ETJ of Manvel were discovered to be more prone to flooding than others. It was the general consensus of the staff that areas north of Highway 6 were more likely to flood than areas south of Highway 6. Previous flooding has been experienced along ditch the upper portions of Chocolate Bayou, along tributaries of Chocolate Bayou, and from Mustang Bayou. Mustang Bayou appeared to have many homes built too close to the main stem. During larger rainfall events, Mustang Bayou will, on occasion, rise to a flood level which impacted property in northern areas of Manvel. Other flooding problems are primarily associated with high water over roadways at stream crossings or restrictions at culverts, bridges, or elevated water canals.

In October of 2006 local flooding occurred and covered all the lanes of SH 6 which caused, not only a drainage and flooding problem, but also a safety problem to the traveling public. This general location is said to be in the approximate location of the Burger Barn.

2.6.2 Repetitive Loss Data

Information on repetitive losses to residential structure flooding damage reported to FEMA was provided by Daniel Scott Engineering, a CoM consultant. Because the data comes from FEMA, the loss data covers only the last 10 years and is current as of 2008.

Losses are either repetitive losses (RL) or severe repetitive losses (SRL) to residential structures. As defined by FEMA [FEMA, 2008], a RL is a flood-induced loss to a National Flood Insurance Program (NFIP)-insured residential structure that has had a least two claim payments of more than $1,000 each in any 10-year period since 1978. A SRL is a flood-induced loss to a NFIP-insured structure and property which in a 10-year period since 1978 has had 4 or more separate claim payments of more than $5,000 each or 2 or more separate claim payments where the total of the payments exceeds the current value of the structure and property.

In essence, incurring more than one flood loss to a residential structure creates a repetitive loss while incurring 4 or more moderate or 2 or more major repetitive losses in last 10-years creates a severe repetitive loss.

The repetitive loss data were used to develop a repetitive loss density map that provides a general overview of where repetitive losses are concentrated; see Exhibit 7. This map, developed using

GIS methods, determines the density of losses by counting the number of losses per unit of area within a circle defined by a particular radius. As the number of losses within the defined radius increase, the loss density increases. The density map shows the following relatively high but isolated loss density areas; improved drainage should be considered for these high loss density areas.

2.6.3 Obstructions Due to Canals, Levees, and Roads

State Highway 6 coupled with parallel elevated water canal and railroad, directly south of Highway 6, represent the single-most problematic drainage component of this MDP. These three (3) elevated elements restrict flows and dam up water to the north of Highway 6 causing flooding problems. This flooding issue can most-certainly be attributed to limited conveyance capacity and elevated nature of these 3 components.

SECTION 3 HYDROLOGIC AND HYDRAULIC MODELING

3.1 Purposes

The drainage capacity of a system is defined to be the maximum amount of flow a channel can convey without significant adverse upstream or downstream impacts. For channels, this usually means the design flow does not exceed the banks of the top of the channel banks; flows are contained in the channel and do not, in general, flow onto adjacent property or into other watersheds.

Various hydrologic and hydraulic analyses were conducted to determine:

1. Capacity: The needed drainage capacity of drainage works (usually channels) for existing and projected conditions (i.e., the channel carries the design flow without bank overflow).

2. Size: The needed size (i.e., dimensions) of a drainage work (usually a channel) necessary to pass or convey a design flow without adverse impacts.

Hydrologic and hydraulic analyses were done to determine 1) what is the capacity of a particular drainage facility, and 2) how big must the drainage facility be to handle the design flow without adverse effects. Hydrologic and hydraulic models were created for the primary watercourses in the ETJ of the CoM. These models were based upon or adapted from existing hydrologic and hydraulic models or modeling parameters to varying degrees, depending upon the particular watercourse of interest and available data. These updated models are used for the following purposes:

- To provide description of existing CoM flooding for selected storm events;
- To provide a basis for assessment of reported flooding problems by comparison of problem locations to floodwater inundation for selected storm events;
- To provide insights to identification of potential flood control options to reduce flooding;
- To describe the reduction in flood inundation that selected flood control options will achieve by modification of the existing condition models to reflect the control option of interest; and

- To assess the effectiveness and benefits of selected flood control options

This section addresses 1) the development of the hydrologic and hydraulic models used in this MDP, and 2) special considerations in the application of the models.

3.1.1 Model Development

Available models from which new models *could* be constructed for this Study starting from the oldest to newest included 1) original 1989 FEMA models [FEMA, 1999] that define the current regulatory floodplains, 2) the models developed for the BCMDP [Klotz Associates and Baker & Lawson, 2002] or 3) the models developed from the CBWFCS in 2009 [Klotz Associates, 2009].

Table 4: Previously Constructed Models

Model	Model Date	Geographic Extent
FEMA	1989	Brazoria County
BCMDP	2002	Brazoria County
CBWFCS	2009	Chocolate Bayou Watershed

The data incorporated into the new models was drawn from both new information (when considered more accurate than older data used in prior modeling) and prior models (when the data from the prior models were considered to be more accurate or just as accurate as new data).

The existing base models for areas within Chocolate Bayou were derived from the existing HEC-RAS and HEC-HMS models developed as part of the CBWFCS. In general, the BCMDP models were utilized in areas where CBWFCS models were not developed [Klotz Associates, 2009]. The FEMA models were the base models used in the BCMDP, and were not utilized in favor of the BCMDP models.

For this Study, HEC-HMS version 3.5 and HEC-RAS version 4.1 were used as the software platforms for model development and application. The models utilized from the BCMDP, particularly in the areas of Mustang Bayou, were developed in an older version of H&H software called HEC1 and HEC2. Through careful manipulation of the data, Klotz was able to successfully convert these models to a newer HMS and RAS version.

3.2 Drainage Areas and Patterns

3.2.1 Definition and Network Structure

The stream network shown in Exhibit 3 was primarily derived from the existing studies discussed in 5.1.1 Model development. The primary drainage systems modeled in prior studies were much more extensive and covered much more area. As such, the waterways utilized in this MDP were isolated from their original source and exported to form a much more uniform and coherent set of model files. Smaller and secondary watercourses were chosen based on perceived importance to the drainage system in Manvel.

3.2.2 Drainage Subwatershed Definition

A river basin is an extent or an area of land to-which surface water from a rainfall event converges to a single point at a lower elevation, typically where the waters join another watercourse (swale, roadside ditch, river, lake, reservoir). River basins are defined as large, macro-scale delineations of areas draining to a major river. The CoM lies entirely within the San Jacinto-Brazos River Basin, pictured below in Figure 2.

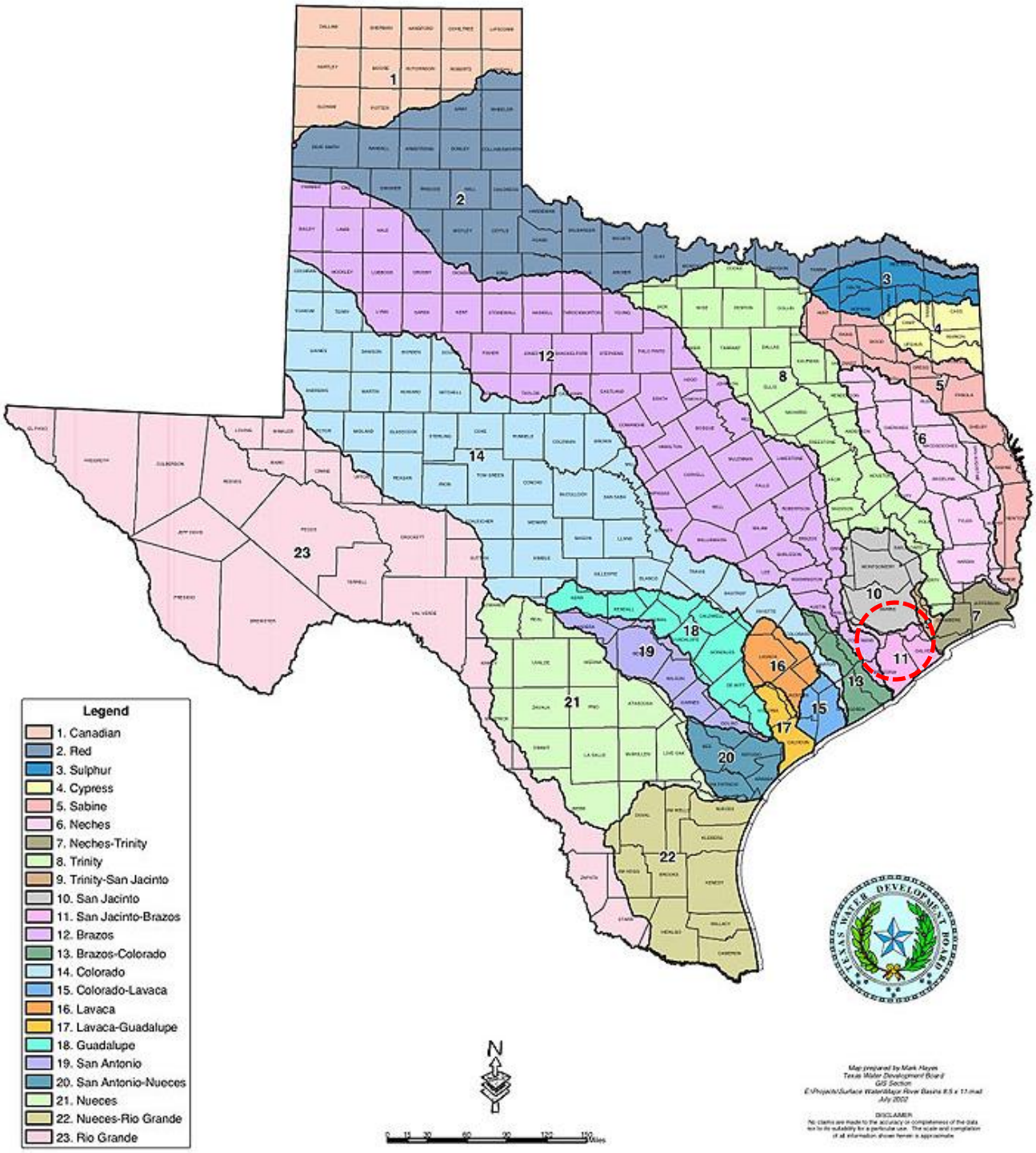

Figure 2: Texas River Basin Map

Watersheds are considered subdivisions of the river basins, while drainage areas (also called sub-watersheds or sub-catchments) are subdivisions of watersheds. Subdivisions of drainage areas are loosely termed catchments or service areas. The delineation of these watersheds and sub-catchments is very important and will essentially tell the model how much water will runoff into the CoM drainage areas. Sub-watershed areas within the ETJ of Manvel were delineated into seven (7) basic areas, as can be seen in Exhibit 3. These seven areas determine which drainage system each drop of water will contribute during a flooding event.

Because the subwatersheds for this MDP were used from prior studies, manipulation of these areas was required. Subwatersheds from prior models has issues with overlapping areas that required redelineation to form a cohesive set of subwatersheds. Changes made to subwatersheds did not, in any case, result in a large area change.

Table 5: Table for Exhibit 3 Subwatershed Breakdown

Region	Map Color	Description
EF1	Cyan	Tributary of the Upper **E**ast **F**ork of Chocolate Bayou
EF2	Green	Upper **E**ast **F**ork of Chocolate Bayou
EF3	Orange	Lower **E**ast **F**ork of Chocolate Bayou
EF4	Red	C12 Ditch Converging with the **E**ast **F**ork of Chocolate Bayou
NB1	Blue	**N**ew **B**ayou
MB	Purple	**M**ustang **B**ayou
CC	Pink	**C**higger **C**reek

3.3 Rainfall Durations for Modeling

Calculations were performed by using the 10, 25, and 100 year rainfall frequencies. Total rainfall for the 100-yr storm event was used to determine ultimate ROW width requirements.

3.4 Hydrologic Model Development

3.4.1 HEC-HMS

The Hydrologic Engineering Center (HEC) Hydrologic Modeling System (HMS) is designed to simulate the precipitation-runoff processes of watershed systems. The software was used to

compute water volumes and flow rates at specific locations for different flooding events within the CoM.

3.4.2 Land-Use and Development (Intensity Zones)

With respect to drainage, the difference between rural/natural (undeveloped) land areas and urban (developed) land areas is the percent increase in impervious cover. Generally speaking, an increase in impervious cover (driveways, rooftops, roadways, etc.) will result in an increase in flows to the conveyance system (streams, ditches, swales, etc.). The CoMCP intensity of development zones were used to model a pattern for the predicted future development within the ETJ of Manvel. The intensity of development numbers (ID-1 to ID-5 and SD) were assigned a percent impervious cover and were ultimately used to determine the percent increase in impervious cover for each subwatershed. This increase in impervious cover was used as input into the models and was used to determine the increased flows each subwatershed would experience along with the predicted increase in flows to the system. An exhibit showing the CoMCP intensity of development zones can be found in Exhibit 5. A depiction of these zones and a table indicating their assigned impervious percentage can be found below in Figure 3.

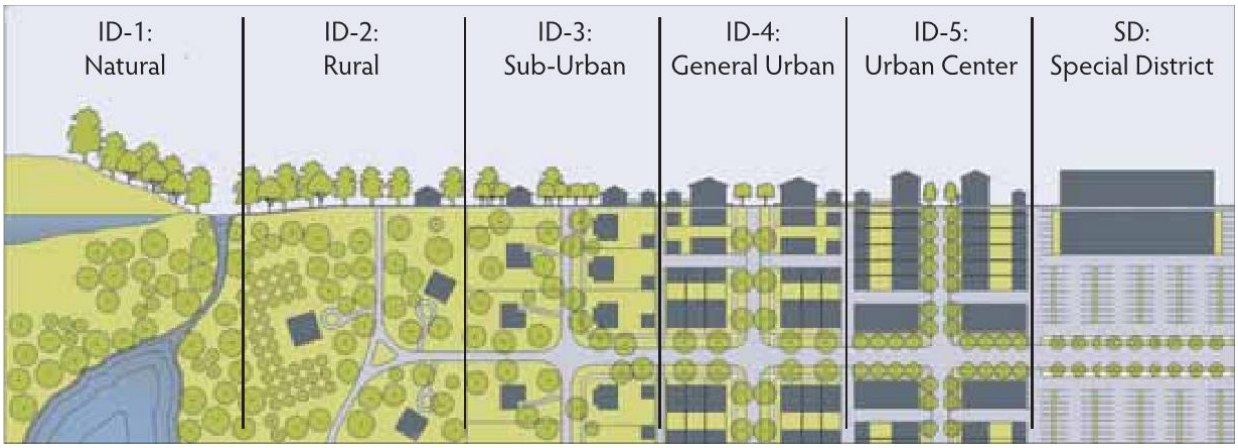

Figure 3: Intensity of Development Zones from the CoMCP

Table 6: Intensity of Development Assigned Impervious Percentages

ID	Description	% Impervious
ID-1	Natural	5%
ID-2	Rural	15%
ID-3	Sub-Urban	40%
ID-4	General Urban	55%
ID-5	Urban Center	80%
SD	Special District	90%

3.4.3 Model Structure and Formation

A hydrologic HEC-HMS model for each of the major watercourses was created by utilizing models produced in prior studies. Increased impervious cover percentages for each subwatershed developed from the intensity of development zones outlined in the CoMCP were updated in the HEC-HMS models to determine the impact to hydrologic components of the system.

3.5 Hydraulic Model Development

The hydraulics of the system for the existing conditions and proposed conveyance capacity was completed using two different methods, based on the level-of-effort required to arrive at a solution. The ROW determination for within the CoM ETJ was completed using a normal depth analysis using spreadsheets, many of which presented in the Tables portion of this report. Computation of water surface elevations and determination of problem areas was completed using the Hydrologic Engineering Center (HEC) River Analysis System (RAS). HEC-RAS is designed to understand the hydraulics of a particular water course and was used to evaluate post-developed flows on the current conveyance geometry. Though both methods use similar formulas to mimic existing hydraulic characteristics and model proposed hydraulic characteristics, each have their advantages.

3.5.1 Normal Depth Analysis

Complications in the HEC-RAS modeling software made channel improvement integration an overly complicated task. As such, the ROW determination for the CoM was completed with a

normal depth analysis. The design discharge for each run was based on the contributing drainage area (hydrologic methodology outlined above), the composite runoff coefficient, the intensity of the storm, and the longest travel time to the upstream node of the run. The most widely used formula for determining the hydraulic characteristics of storm drain networks is the Manning Formula, expressed by the following equation: $Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$

Where:

V = mean rate of flow (ft/s)
R = the hydraulic radius (ft) defined as follows: R = A / WP where:
WP = wetted perimeter (ft)
A = cross sectional area of flow (ft2)
S = the slope of hydraulic gradeline (ft/ft)
n = Manning's roughness coefficient

This basic hydraulic calculation determines how the peak volumetric runoff is conveyed in the storm drainage system. Because of the trapezoidal nature of the proposed cross-section, a secondary method called the Newton-Raphson method was also used to perform iterations on manning equation to optimize a channel section.

Figure 4 below presents the basic dimensions that were used in the determination of the correct ROW needed to convey the proposed flows within the banks of the channel. These dimensions are presented in the proposed scenario write-up in a later section and were computed using the spreadsheet presented in Table T-3.

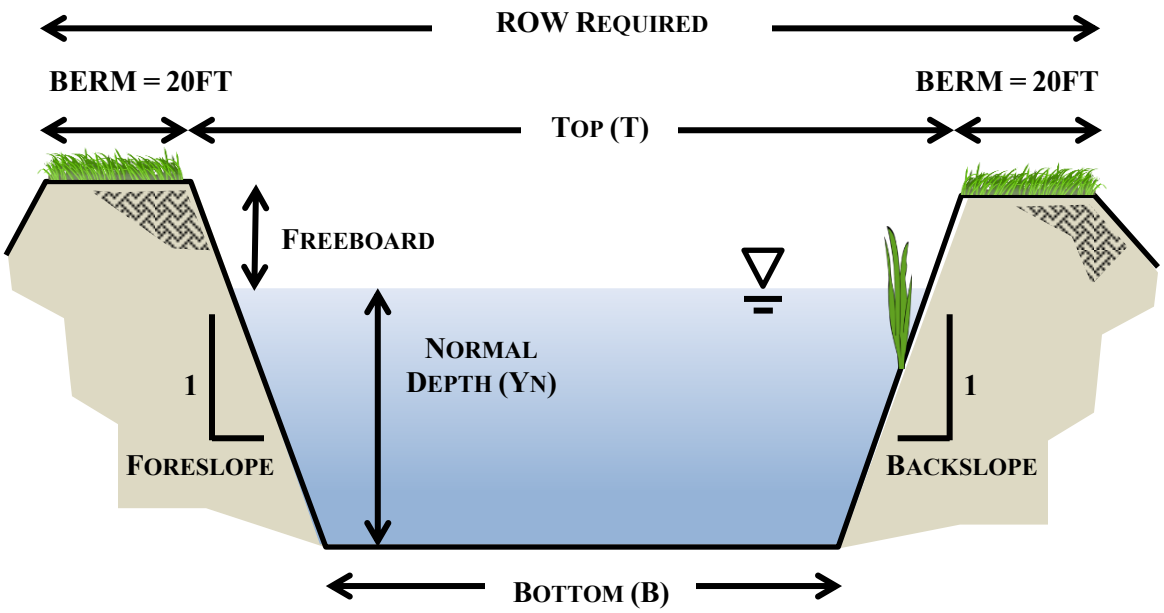

Figure 4: Basic Channel Dimensions

3.5.2 Detention Modeling

Detention was modeled using the small watershed method developed by Dr. Rooney Malcom. This approach calculates the discharge at any given time for both the predevelopment and post development flow conditions. By comparing the two, a detention volume can be determined for each proposed detention location. A summary of these computations is shown in Table T-5 and T-6.

3.5.3 HEC-RAS and Standard Step Water Surface Computations

The HEC-RAS computer program is a one-dimensional steady-flow model that uses the standard step method of energy gradient computation. The program can compute water surface elevations for super-critical or sub-critical flow regimes.

For open channel flow, the HEC-RAS computer program computes water surface elevations for each cross-section based on the energy equation and the standard step method. Typically, Manning's equation is used by the program to estimate head losses from one cross-section to the next. Channel roughness coefficients typically range from approximately 0.03 to 0.04 for grass

lined channels, while channel roughness coefficients may increase to about 0.05 to 0.10 for channels with high weeds and thick trees [Chow, Open Channel Hydraulics, 1959].

The HEC-RAS computer program uses cross-section information to estimate flow conveyance and water surface elevations along a canal system. For consistency, cross-section data is typically input from left to right looking downstream (cross-section stationing increases from left to right in a cross-section). Stream stations typically increase from downstream to upstream. Since HEC-RAS is a one dimensional flow model, each cross-section is oriented such that the direction of flow is perpendicular to the cross-section.

As with the hydrologic models, a hydraulic HEC-RAS model for each of the major watercourses was created by exploiting models produced in prior studies. Flows attained from the HEC-HMS models were imported into the HEC-RAS models to determine the impact of development on the existing drainage system.

3.6 Proposed Conditions Modeling

A proposed conditions modeling uses condition that are anticipated to occur in the future and reaching their ultimate level of development (i.e. using the intensity of development data from the CoMCP as described in the Land-Use and Development section of this report). A future condition model was created from the existing condition model by applying a change to impervious cover and altering parameters within the exiting model that pertained to infiltration, detention, time of concentration, etc. That process is described below:

3.6.1 Proposed Hydrology

The topology (i.e., connectivity of drainage areas and streams) of the HMS models was based on prior hydrologic studies and any necessary redelineation of drainage areas completed for this Study. The general topology defines the drainage areas used for modeling. Proposed drainage areas were not altered from their existing condition model. In-other-words, any single flow path (from any water drop to outlet) was assumed to remain the same in the proposed model as it was in the existing model.

Rainfall losses (i.e., the rainfall that does not runoff) during a storm event are due to depression storage, interception, and infiltration, factors that depend upon soil type, vegetation, topography and imperviousness. Values [HCFCD, 2009] for interception and depression storage in the HCFCD HMS model for Region 3 were used for all models because topography, soil, and vegetative conditions within the CoM are similar to those of the Region 3 area. These values included parameters for the Green-Ampt equation: infiltration and soil type for estimating initial losses, wetting front suction, and hydraulic conductivity.

Rainfall excess (in inches) was transformed into runoff (in cfs) by HEC-HMS software using the Clark Unit-Hydrograph method in conjunction with the T_c & R method. Clark's method uses the time distribution and amount of excess rainfall to determine the runoff from a drainage area using unit hydrograph concepts. The T_c & R method is a HCFCD recommended method [HCFCD, 2004] that provides an empirical estimate of the time of concentration T_c and the storage factor R to define the shape and magnitude of the unit hydrograph. T_c and R coefficients were already determined in prior models, so calculation of these values was not required. New industrial or residential developments will commonly have internal secondary drainage systems that will feed into primary drainage systems so the value of R can change significantly with increased development. As such, the R coefficient required modification in the proposed conditions modeling. In general, the value of R can be estimated to be approximately 3x the value of T_c. Because the prior modeling contained high values for R, 3x T_c did not work in all cases. After a trial and error, the best resulting proposed R value was determined to be the existing R value decreased (in percent) by the change in percent impervious cover (from existing to proposed). In other words:

$$\text{Proposed R (hr)} = \text{Existing R (hr)} - \text{Existing R (hr)} * \Delta \text{ Impervious}$$

3.6.2 Proposed Hydraulics

In addition to the future condition model incorporating the hydrologic changes, the future condition hydraulic models were modified for major channel conveyance improvements, if the scenario called for it.

Major Conveyance Improvements are changes arising from deepening and widening of a channel reach along much of its length in order to significantly increase channel capacity. These conveyance improvements formed options for significant channel capacity improvement. The hydrologic conditions (i.e., the future peak flows determined for "minor drainage improvement" along a channel for the major conveyance remained the same for these high-level analyses while the hydraulic parameters (e.g., channel size, roughness, and slope) were modified to reflect channel modifications for the improvement.

As predicted, proposed condition models show that an increase in impervious cover resulted in an increase in runoff. With the existing channel geometry in place, the models predicted a major increase in the water surface elevation (WSE) from each modeled rainfall event (10, 25, and 100). This increase in the WSE ranges from 1 foot to a maximum of 6-7 feet in areas north of Highway 6. This increased runoff must be mitigated by increasing detention volume or by increasing the conveyance capacity of the stream (i.e. channel improvements and increased ROW).

3.7 Proposed Scenarios

Additional runoff caused from increased impervious cover results in an increase in flows. These increased flows must be mitigated with detention storage. Detention storage is used for two purposes: 1) capture of flood runoff to reduce flows to downstream reaches, and 2) capture of flow to avoid downstream flow increases resulting from channel improvements at upstream points. Detention storage can be accomplished by different means, including:

- Offline detention diverts a portion of the flow in a stream to a storage facility (usually a pond) for temporary storage and then subsequent return to the stream. Offline storage works well for large storage volumes along larger watercourses where complete diversion of watercourse flow is impractical and often unnecessary.

- In-line detention captures all the flow in a stream and passes it through a storage pond with temporary storage before discharge to downstream waters. In-line storage is commonly used for mitigation of increases in runoff from new or upgraded smaller developments for which increases in runoff are limited, and for which, therefore,

necessary storage volume is not large. In-line storage can be used where significant amounts of land are available for construction of a storage pond.

- Conveyance storage over-sizes a channel or underground conduit so that extra volume in the conveyance not needed for actual conveyance can (at least conceptually) serve as a storage device. Conveyance storage usually requires more volume than in-line or offline storage with a pond to achieve the same mitigating effect as a detention pond. The advantage of conveyance storage is the smaller land area needed to provide the storage.

For this MDP, availability of land is not assumed to be a limiting factor in development of mitigation storage since the CoM has considerable open area. With that said, proposed detention locations shown in exhibits (discussed later in the report) are only preliminary determinations of approximate storage volumes at generalized areas. Prime developable real-estate close to Highway 6 will likely outweigh mitigation at the specific locations. The symbology is merely meant to be an approximate positioning of detention locations.

It is also important to note that many of the needed drainage improvements will be built by developers and should be closely coordinated through the CoM. As-such, the drainage improvements evaluated as part of this MDP are assumed to be a joint effort with joint costs divided between the CoM, the drainage districts, and the future land developers.

3.7.1 Scenario 1 – Major Channel Improvements

Scenario 1 ROW widths are shown in Exhibit 6-A. Scenario 1 reflects an option for the CoM to prepare-for and promote future channel improvements that would convey the 100 year *pre-developed* (currently existing) flows within the banks of all major channels, and ultimately within the proposed ROW. Any additional detention required as a result of development would be provided by sub-regional detention ponds located at areas north of Highway 6 or by on-site detention, as outlined in the 2013 CoM Design Criteria Manual.

According to Section 5 of the 2013 CoM Design Criteria Manual, “the use of on-site detention is required in order to mitigate potential damage to existing structures” caused by increased flows to watercourses from developed areas. Though completely necessary in its current form, the use of on-site detention could limit the profitability of a potential developer and on-site detention

typically results in basins on prime taxable land. By providing a ROW width wide enough to allow for the construction of an improved channel to convey pre-developed flows, much of the need for on-site detention could be eliminated by regional detention in the form of detention ponds located near Highway 6.

3.7.2 Scenario 2 – Channel Improvements Paired with Detention

Scenario 2 ROW widths are shown in Exhibit 6-B. Scenario 2 reflects an option for the CoM to prepare-for and promote future detention mitigation that would convey the 100 year *fully-developed* flows within the banks of all major channels, and ultimately within the proposed ROW.

Scenario 2 calls for an increase in the amount of land needed to be acquired. By providing an increased ROW width wide enough to allow for the construction of an improved channel to convey fully developed flows, much of the need for on-site detention could be eliminated, instead substituted by a requirement for a developer to provide "regional mitigation" in the form of oversized channel improvements.

This regional mitigation would offset the need for regional detention within the ETJ of the CoM, however, Scenario 2 would also require mitigation at the most downstream portion at the ETJ boundary. Because channel improvements do little to detain water (i.e. hold water back), without improving channel conveyance to the ultimate outlet (at the coast), detention would be required in order to lower flows to pre-development conditions prior to discharge outside of the ETJ boundary. As water flows downstream, peak flows begin to spread out and attenuate, reducing the peak flow and typically reducing the amount of detention volume required to return flows to predevelopment conditions. This attenuation of waters downstream is one benefit to providing detention at the most-downstream location.

3.8 Future Right-of-Way Determination (ROW)

An estimate of the amount of ROW width needed for channel improvements was based on required volume and the approximate dimensions needed for a typical improved cross section. Hydraulic calculations for ROW determination are summarized in Table T-3 and T-4, with the matching exhibits showing the ROW widths being Exhibit 6-A and 6-B, respectively. Each of

the two scenarios required different hydraulic calculations because each scenario bolstered different assumptions. Figure 4 from the section on normal-depth analysis shows each of the dimension used calculate the total ROW. For the average case, the required ROW width was estimated with assumptions:

- Minimum bottom width (B) of 6 ft. This was allowed to drop below 6 ft. if normal depth (Yn) was less than 10 ft.
- Foreslope and backslope of 4:1 (H:V).
- Ideal channel slope of 0.001 (or 0.1%).
- n-value of 0.04
- Velocities held at less-than 3 ft/sec.
- Berm width of 20 ft. on each side.

Discussion relating to the results of these computations is discussed later in the report.

3.9 Quality Assurance / Quality Control

3.9.1 Existing Conditions

Both the hydrologic and hydraulic models gathered from the various sources were altered to best represent the Manvel area. Modeling approaches for the entire city ETJ is quite different than a modeling approach for a much more localized drainage study. Though this study is considered a high-level analysis, existing models were further investigated and, if necessary, refined to represent the Manvel area in a suitable manner for this MDP.

The quality of the data used in this MDP was paramount regardless of level of effort needed to collect or verify prior plans, models, and studies. Assumptions used in prior models were checked for reasonableness. QA efforts resulted in a highly robust and reliable dataset.

3.9.2 Accuracy of Prior Models

Klotz made a strong effort to correlate prior models to known flooding issues within Manvel. Every reasonable effort was made to check the accuracy and verify assumptions made by other consultancy firms; however, Klotz makes no guarantees as to the accuracy of prior models.

3.9.3 Limitations

Proposed scenario approaches use existing runoff volumes as a base and a "goal" for decreasing flows in the proposed scenarios. The two proposed conditions modeling scenarios are identified at a planning level character; their actual implementation will require additional detailed engineering study and design.

Methods of analysis used in the development of this MDP are consistent with a planning level of this detail. Sizes and capacities specified for proposed new or modified drainage infrastructure is intended only as 1) a guide for preliminary and follow-on detailed engineering and 2) a basis for preliminary estimate of cost for infrastructure development. While procedures consistent with this MDP are generally used, approximations or simplified versions of these procedures were sometimes used because of the planning level nature of this document.

3.9.4 Discrepancies in ROW widths

The proposed sizes of needed ROW shown in this MDP were developed consistent with the models used in these analyses. Close coordination will be needed with the appropriate drainage districts to develop the project sizes and needed ROW requirements. Some drainage districts will impose different criteria and different ROW requirements. Inconsistencies in ROW requirements should be addressed in the PER stages of each project.

3.10 Neglected Alternatives

While this Study has focused on two primary infrastructure alternatives, other important "alternatives" should not be forgotten:

> What is commonly called flooding can have different causes, including ponding due to low topography (e.g., homes built in a topographic low), inadequate or deficiency storm sewer systems (e.g., storm inlets spaced at too great a distance, too small, not enough quantity, etc.), surge levels in coastal areas, and true drainage channel deficiencies. Before committing to construction of a particular project, review and clarify with appropriate engineering investigation and study the true source of the apparent flooding problem. The source of the problem should guide the selection of an appropriate solution.

The combination of cost, available funding, environmental limitations, and the limited impact of the problem may warrant the need for a no-action response to the problem. The benefits (both tangible and intangible) to be achieved with a particular infrastructure improvement may not be sufficient to warrant the necessary expenditure of funds for a project.

SECTION 4 PROJECT COSTS AND FUNDING

4.1 Estimated Project Costs

Project costs include estimated construction cost, environmental permitting costs, engineering cost, ROW costs, and contingency costs. Construction costs are decomposed into four categories as described below. Costs are assumed the same irrespective of ownership. The same methodology and unit costs are applied to both channels and ponds. Project costs are summarized in Table T-7 for both scenarios.

4.1.1 Construction Cost

Excavation and Fill: Because details of construction are not known for planning, the unit costs for excavation and fill are the average of on-site and off-site values.

Crossing Replacement: Crossing replacement costs are costs associated with crossing a road, elevated water canal, or railroad using pipes in the form of a culvert or a siphon. Because of unknown factors such as construction methods, environmental issues, geotechnical findings, and other factors, crossing prices are extremely preliminary and should be revised when new information is available.

Utility Crossings: Information on potential costs of utility lines is limited at the planning stage. Consequently, costs for crossing of water, sewer, storm sewer, etc. pipelines are not approximated in this Study.

4.1.2 ROW Acquisition

An estimate of the amount of fee acreage needed for a detention pond was based on required volume and the approximate dimensions of a pond at a constant 10-foot depth with 4:1 side slopes, 20-foot berm, and a 1-foot freeboard depth. An additional 10% was added for other components such as outfalls structures, entry roads, fencing, etc. Note: assumptions of depth, side slopes, berm dimensions, and freeboard are not site-specific. Site-specific locations will dictate the true attainable dimensions and should be determined in a PER stage.

For channels, the acreage was estimated as the length of the channel multiplied by the required ROW acquisition determined in table T-3 and table T-4 (Scenario 1 and 2, respectively). Note, this acreage includes the additional 20-ft berms on each side of the channel.

The unit cost of land for ROW acquisition is based upon an estimated cost per acre at $10,000 per acre. At first glance, this number is seemingly low, but could be reflective of land purchased in floodplain areas, distant rural areas, or a large-quantity discount the CoM might capitalize on with large tract purchases. ROW is assumed to be purchased by fee simple title. ROW may be acquired using easement at a likely lower cost; however purchase of ROW is assumed for planning purposes.

4.1.3 Other Construction Related Costs

Engineering Costs: These costs, priced at a percentage of total direct construction cost and account for preliminary and detailed engineering; supporting work such as survey; geotechnical investigation; and construction management. Klotz estimated these costs to be approximately 10% of total construction cost.

Geotechnical and Survey: As with any construction project, a geotechnical evaluation is typically performed along with a survey to assist in final design. Klotz estimated these costs to be approximately 10% of total construction cost.

Environmental Protection Costs: Projects may require federal permit because of potential environmental (wetlands, endangered species, etc.) or historical impacts. Drainage and flood control projects usually involve excavation or fill, sometimes within the floodplain. A permit for infrastructure projects with excavation or fill is a key project cost. As projects become larger, environmental permitting costs typically become larger. Klotz estimated these costs to be approximately 10% of total construction cost.

Contingency: Construction contingency is set at a conservative level because of the planning level character of this MDP. Klotz estimated these costs to be approximately 30% of total construction cost.

4.2 Funding Strategies

Prior to the discussion of actual project costs, it must be noted that funding options, including full pass-through to developers, are possible along with various sources for direct project funding. The source that is potentially accessible for a particular project will depend upon the

purpose of the project, the anticipated benefits of the project, estimated overall cost of the project, contributors and the amount of participation by various contributors in providing project funding, and those who benefit from a particular project.

Provided that limitations on use of funds are consistent with the project of interest, potential strategies to most effectively use available funds include the following:

- Phasing of construction to spread funding needs over time
- Expanding internal funding options to use funds from sources under the control of the CoM
- Joint development of projects with other local and regional entities
- Joint development of projects with developers of the project
- Impact fees
- Establishing utility or special districts
- Accessing external funding to generate funds from non-CoM sources

These options are discussed in the following sections.

4.2.1 Project Phasing and Project Decomposition

Large scale, expensive projects can be considered for phased construction, except if the project operation does not lend itself to phased development because of operational issues. Diversions, for example, will usually be excluded from possible phasing because of the impracticality of constructing a diversion in phases. Detention projects and channel improvements, on the other hand, are well suited to phased construction if funds are limited.

For projects to be phased the first phase should usually include ROW acquisition and environmental permitting since inability to obtain ROW or permits would render a project infeasible. For projects that could be phased, the project can be decomposed into sub-projects such that each phase is within feasible funding limits. Thus, e.g., channel improvement can be decomposed into individual reach sub-projects, with each sub-project reach composing a separate project to be built over time.

4.2.2 Developing Additional Internal Funding

Internal funding is project funding provided by the CoM. This funding may be combined with money from other sources to generate the necessary money for a particular project. Internal funding may come from existing or new sources, the latter developed to supplement existing traditional sources.

Traditional sources of funding support the CoM's general fund which can be utilized for a variety of purposes. Some traditional sources are following:

- General sales tax
- Property tax
- General license and permit fees,
- Fines and forfeitures
- Special district fees, such as industrial improvement district fees, collected from operators of industrial or commercial enterprises in specified areas in lieu of property taxes.
- Engineering/civil permits
- Creation of Municipal Utility Districts (MUDs)

Consideration can also be given to funds limited to specific purposes, such as the following:

Service Improvement Fees (e.g., drainage improvement fees): These are fees that are collected for the specific purpose of generating revenue for funding of improvements for certain types of facilities (e.g., drainage systems). These fees are typically the same for each household and/or business and independent of any use levels. The authority to collect such fees can be established by ordinance.

Drainage District Fee Assignment: These are funds collected by a drainage district for the purpose of management and operation of the drainage district system. These monies typically go directly and totally to the drainage district; however, overlap of drainage districts into the CoM could result in mutually beneficial use of drainage dollars.

Special Assessments: These are fees charged to a particular set of individuals or business enterprises that are favorably impacted by a drainage project. Assessments can be either one-time charges or charges of short duration for the particular benefits received because of the project.

Department Transfers: Funds from other operations in the CoM can be transferred to particular drainage projects if benefits to other operations can be identified.

4.2.3 Joint and Cooperative Funding of Projects

By combining county funds with other public agency funds for specific projects, projects that would not be otherwise built can be built using fund leveraging. Partnering with TxDOT, HGAC, TPWD, or drainage districts is an option to use funds available through these agencies. Using cooperative arrangements, external sources can be combined with CoM funds for projects which benefit both the county and partners in the project.

4.2.4 Coordination with Private Developers

Working in coordination with private developers is accomplished by having certain portions or features of a development funded by the CoM while the remaining portions are funded by private parties interested in implementing the project. When the public good can be demonstrated by such coordination, there is justification for city funds being used to construct certain portions of such private development. The development of regional detention systems is a prime example for this Study. The regional detention could serve many private parties as well as the public at large for reducing impacts for anticipated development, not just the current portion of the development. Another example is the acquisition of ROW for future development flow conveyance. Arrangements for CoM coordination with private developments are specific to the situation, but will commonly identify portions of a project, e.g., regional detention, that benefits many parties, including the population at large, as those features in which city support may be provided. Given the low capital requirement, this option is, quite-possibly, the best alternative for the CoM.

4.2.5 Impact Fees

Impact fees are fees assessed property developers that are used to recover anticipated costs to be incurred in the future by a county or municipal entity because of the additional municipal services (including utility) that will arise because of the development. The impact fees can also be used to recover costs already incurred by the county or municipal in project development, such as might arise, for example, from coordination with private developers in the development

of project. Impact fees are commonly assessed at the time of municipal permit application and based upon amount of area to be permitted. The essential features of impact fees are that they be established by ordinance and administered in an unbiased fashion.

4.2.6 Utility or Special Districts

Legally defined special entities with well-defined powers, i.e., state or county created districts, can be used as a means to generate additional revenue through taxation of various types of projects.

Drainage districts or storm water utilities can be established by ordinance for the purpose of providing drainage and/or flood control services. Drainage districts typically have a broader range of responsibilities (e.g., provision of irrigation waters) than storm water utilities, which usually restrict their services to drainage or storm water drainage related issues. The district or utility is established with authority to levy various fees, commonly based upon a surrogate defining the amount of drainage service being provided (e.g., the amount of impervious area in a land parcel because the level of imperviousness affects the amount of runoff generated). Collected revenues are dedicated to provision of drainage and flood control in the service area of the district or utility.

4.2.7 External Funding

External funding sources should always be investigated as part of a particular project. If investigation of funding sources is undertaken as part of preliminary engineering, the design of the project can be possibly modified to meet requirements of particular funding sources so that funds from the funding source can be accessed.

Opportunities for funding different projects depend upon where the project is located, where the benefits of the project will be realized, whom the project will benefit, and the type of project.

External funding sources for flood control projects can encompass flood control ponds and channel improvements to reduced flooding. Water quality and recreational components of a project expands the options for funding from additional sources with water quality responsibilities. External funding is typically accompanied by requirements for financial participation by the entity (often termed the “local sponsor”) seeking the external funding. The

participation party may be a single entity, such the county, or a group of cooperating parties, such as the county, a drainage district, and a city. The following sections identify particular external drainage or flood control project funding sources.

4.2.7.1 External Funding for Drainage and Flood Control Projects

Some examples of funding sources potentially available for drainage improvement or flood control projects include:

FEMA Grants - these are grants usually administered by the Texas Water Development Board or Department of Emergency Management that are directed to prevention or response to floods. Specific types of grants include:

> *Pre-Disaster Mitigation Grants (PDM):* This program provides grants and technical assistance to local communities for cost-effective hazard mitigation activities that complement a comprehensive hazard mitigation program to reduce injuries, loss of life, and damage and destruction of property.
>
> *Flood Mitigation Assistance Grant (FMA):* The FMA grant program provides federal funding to assist states and communities to fund cost effective measures to reduce or eliminate the long-term risk of flood damage to structures insurable under the National Flood Insurance Program (NFIP).
>
> *Repetitive Loss (RL) Grant Program:* This program provides grants for projects which can be shown by a benefit-cost analysis to reduce repetitive losses to residential structures

Texas Water Development Board Loans - the TWDB operates several loan programs for financing planning, design, construction, improvement or expansion of water and wastewater facilities. Wastewater facilities can be interpreted as to include systems that improve storm water quality. Particular loan programs though which such leverage might be achieved include the following:

> *Clean Water State Revolving Fund (CWSRF):* Using federal capitalization grants, the TWDB offers low interest loans through the Clean Water State Revolving Fund

(CWSRF). CWSRF loans may be made to any political subdivision with the authority to own or operate a wastewater system to finance wastewater projects or to political subdivisions to finance nonpoint source pollution control or estuary management projects.

Texas Water Development Fund (DFund): The TWDB offers through the DFund loans with interest rates at approximately 0.35 percent above the TWDB's cost of funds through the state general obligation bond-funded program. DFund loans are available for planning, design and construction of various projects, including flood control project. Detention ponds built for flood mitigation and storm water quality improvement may qualify for loans under this program.

State Participation Program: This program enables the TWDB to assume temporary ownership interest in a regional project when the local sponsors are unable to assume the debt for an optimally sized project.

Amenity Funding by Texas Department of Parks and Wildlife - another external funding source to consider is the Texas Department of Parks and Wildlife (TDPW). Outdoor Recreation Grants are made available from the TDPW Account and the Land and Water Conservation Fund (LWCF) to local governments for the acquisition and/or development of outdoor recreation sites. These funds are available for acquisition and development of State and local park and recreation areas adjacent to storm water detention facilities. Of the various grant programs administered by the TPWD, the following have potential to provide money for detention pond amenity development:

Outdoor Recreation Grants: This program provides matching grant funds to municipalities, counties and other local units of government with a population less than 500,000 to acquire and develop parkland or renovate existing public recreation areas.

Indoor Recreation Facility Grants: This program provides matching funds to municipalities, counties, and other local units of government with a population less than 500,000 for constructing recreation centers, community centers, nature centers and other

facilities (buildings). Such facilities might be included as part of the amenity features for some projects.

Regional Grants: This grant program provides assistance to local governments with the acquisition and development of multi-jurisdictional public recreation areas in the metropolitan areas of the state. It allows cities, counties, water districts, and other units of local government to acquire and develop parkland for both active recreation and conservation opportunities.

Recreational Trail Grants: TPWD also administers the National Recreational Trails Fund in Texas for the Federal Highway Administration (FHWA). This program receives its funding from a portion of federal gas taxes paid on fuel used in non-highway recreational vehicles.

State Administered Grant Programs

Different agencies in the State are involved in administering various grant and loan funds made available from federal sources.

Texas Coastal and Estuarine Land Conservation Program (TCELCP) - Texas General Land Office (GLO) administers the TCELCP program authorized by federal Public Law 107-00 for the purpose of protecting important coastal and estuarine areas that have significant conservation, recreation, ecological, historical, or aesthetic values, or that are threatened by conversion from their natural or recreational state to other uses [GLO, 2009]. Projects are prioritized for funding by the GLO and focus upon land acquisition for conservation purposes.

Texas Department of Rural Affairs - the Texas Department of Rural Affairs (TDRA) provides grants for a variety of rural development purposes. Among the grant programs, TDRA sponsors grants for disaster relief (such as hurricane recovery) and rural planning activities. Some of these grant programs could provide funding for drainage improvements and flood control projects:

Disaster Relief and Urgent Need Fund: Assistance available through this fund can be used for eligible relief activities in situations where the Governor of Texas has declared a state disaster or requested a federal disaster declaration.

Small Towns Environmental Program: Funds in this program are used for water and sewer infrastructure improvements utilizing self-help methods such as local volunteer labor resources.

Disaster Recovery: These are funds allocated to local and county entities for recovery from natural disasters, such as hurricanes, for areas designated by the Governor as a disaster area.

Community Development Funds: These are funds available on a biennial basis for public facilities' development, including water and wastewater infrastructure, street and drainage improvements, housing activities, and some other limited purposes.

U.S. Army Corps of Engineers Project Monies - Executive Order No. 11888 (May 24, 1977) provides funds for floodplain management pursuant to the National Environmental Policy Act of 1969, the National Flood Insurance Act of 1968, and the Flood Disaster Protection Act of 1973. It directs the USACE to undertake projects to minimize the impacts of floods on human safety, health, and welfare, and to restore and preserve the natural and beneficial values served by floodplains by acquiring, managing, and disposing of Federal lands and facilities; providing Federally undertaken, financed, or assisted construction and improvements; and conducting Federal activities and programs affecting land-use.

USACE has joint participation programs in which local governments can financially participate. This participation is by a local sponsor, which might be the CoM. The USACE is usually responsible for the design and construction of the projects, but the local participant assumes responsibility for the subsequent operation and maintenance of the constructed facilitates. The following are of particular interest to the authorities of the USACE.

Multi-Purpose Detention Systems to Access Other Program Funds - while the primary purpose of the sub-regional detention ponds is provision of storage to mitigate increased runoff from land development, sub-regional detention ponds are also considered as opportunities for multi-use activities that provide community amenities and become a community asset. Inclusion of community amenities as part of a detention pond system may also increase the likelihood of obtaining external grant or loan monies for the pond development.

4.3 Issues with Costs

Specific scenario cost options include major, and quite costly, flood control detention or channel conveyance improvements. In examining options in regard to cost, several important cost mitigating factors should be recognized:

Conservative Cost Estimates: Because this Study is a planning study, estimated costs are conservative (i.e., "on the high side") and include a 30% construction contingency.

Staging of Project Implementation: Some projects can be readily accomplished in stages; each stage has a potentially more affordable cost. Conveyance improvements, e.g., can address short length reaches that compose the entire conveyance improvement reach. In such projects, benefits are obtained from each stage and, as well, allow for continuing participation in project costs as additional stages are added.

Excavation Cost Uncertainty: The total cost for most identified projects are dominated by excavation costs. Excavation costs can vary widely from project to project due to the issue of haul and disposal and other uses of the excavated material (a flat rate of $8.00/CY was used in the two scenarios).

SECTION 5 FINDINGS AND RECOMMENDATIONS

5.1 Modeling Results

5.1.1 Hydrologic Findings

Hydrologic model discoveries are condensed in Table T-2. The data presented in this table summarizes most parameters used in developing existing and proposed models as well as the results derived from those alterations. Tables presented are divided by the 10, 25, and 100-year storm frequencies and then by sub-basin. Table T-2 summarized:

Existing vs. proposed area – As discussed in the methodology sections of this Study, the sub-areas in the existing model, altered to the proposed conditions, changed slightly as redelineation was performed as necessary. In total, acreage changes were minimal in comparison to total sub-watershed acreages. The largest changes in acreage occurred in the Mustang Bayou sub-watersheds primarily due to the fact that the sub areas for the Mustang model (derived from the BCMDP) did not perfectly align with the sub areas from the Chocolate Bayou model (derived from the CBWFCS). Some areas required the addition of area and some the subtraction. Areas in the Mustang Bayou model were altered over the Chocolate Bayou model areas.

Existing vs. proposed T_c & R – Large R values in the existing models were discovered. As discussed in the methodology sections of this Study, T_c value from existing to proposed were held constant while the R value was applied a factor related to change in percent impervious cover.

Existing vs. proposed impervious cover – Impervious cover was altered in each sub-watershed and is summarized in this table. Basins inside the CoM, specifically the EF (East Fork) basins were the largest contributors to increased impervious cover. Two sub-area, Basin EF-01A and EF-02A, had a 69.40% and 82.17% increase in impervious cover, respectively.

Existing vs. proposed peak flows – Change in peak flows from existing to proposed ranged from no-change to a 187% increase in Basin EF-01A and 189% increase in Basin EF-02A for the 100-year flood event. Percent changes in flows increased even more

drastically in the 10 and 25-yr storm events. These large changes in flows off of the sub-watersheds are understandable considering the significant increase in impervious cover from the existing to proposed model.

Overall, for all storm events, flows increased significantly from the existing model to the proposed model if impervious cover also significantly increased. For areas with little or no increased impervious cover, flows did not significantly increase.

5.1.2 Scenario 1 vs. Scenario 2

Scenario 1 and 2 represent two different options for the CoM, the primary differences being the amount of acquired ROW needed, the amount of excavation for channel improvements in the ROW, the amount of land for detention storage needed to be acquired, and the conveyance capacity improvements needed under Highway 6 and the elevated water canal. The specifics of these two scenarios have been discussed in previous sections of the report. ROW differences between the scenarios is best visualized by Exhibit 6-A and 6-B. Corresponding detention proposed detention for each scenario is summarized in Table 5 below, and each proposed detention pond general location can be found on the corresponding Exhibit 6-A or 6-B. Each scenario has associated pros and cons. The CoM should weigh these pros and cons to determine an appropriate future plan to ensure that the planning phases, roles, and responsibilities to resolve drainage issues are assigned and implemented.

Table 7: Summary of Detention Volume Requirements

Course Code	Description	Detention Pond Scenario 1		Detention Pond Scenario 2	
		Detention Volume Requirement ac-ft	Detention Volume Requirement yd^3	Detention Volume Requirement ac-ft	Detention Volume Requirement yd^3
E102-00-00	Chocolate Bayou Tributary North of Hwy 6	2,629	4,241,536		
	Chocolate Bayou Tributary South of Hwy 6				
E102-01-00	Small Tributary Chocolate Bayou North of Hwy 6				
E100-00-00	Chocolate Bayou Upper North of Hwy 6	546	881,613		
	Chocolate Bayou Upper South of Hwy 6				
	Chocolate Bayou Lower			2,549	4,112,576
E100-00-01	Small Tributary Chocolate Bayou Lower				
C100-00-00	C12 Ditch	276	445,005		
N100-00-00	New Bayou Upper				
	New Bayou Middle				
	New Bayou Lower	306	494,375	570	919,381
D100-00-00	Mustang Bayou Upper				
	Mustang Bayou Middle				
	Mustang Bayou Lower	428	690,296	479	772,125
H100-00-00	Chigger Creek				
TOTALS:		**4,186**	**6,752,824**	**3,598**	**5,804,082**

5.1.3 Cherry Sand Pit Detention Alternative

Klotz Associates evaluated the utilization of the Cherry Sand pit as a detention basin for the tributary of Chocolate Bayou in a report dated September 11, 2013. The sand pit is located just east of SH 288 and south of the Railroad (RR) track near the SH 6 area and covers approximately 18.6 acres of which some of the land has been partially excavated. The goal of the Cherry Sand Pit Analysis was to evaluate adding a new culvert(s) under the GCWA canal and under the RR track and directing flows from the SH 6 area into the excavated sand pit and thereby reducing flooding in the SH 6 and/or SH 288 area. This proposed detention basin, in its described function, would in-fact contribute to the total drainage requirement presented in Scenario 1 of this report. If determined to be feasible, it is recommended that the CoM make use of this 93 acre-feet to partially offset the detention needed at this location.

A recent update to the ETJ boundary puts this Cherry Sand Pit outside the delineated limit. This limits the City's ability to utilize the pond, but does not eliminate it. Further discussions about joint-use are necessary to determine if the new ETJ boundary will affect the CoM's ability to utilize the pit for detention mitigation.

5.1.4 Hydrologic Findings for ROW Determination

Hydraulic calculations for ROW determination are summarized in Table T-3 and T-4. Each of the two scenarios required different hydraulic calculations because each scenario bolstered different assumptions. Table T-3 contains the computations for Scenario 1, and Table T-4 for Scenario 2. The primary difference between the computational tables is related to the amount of flow (Q) at each junction. Because detention ponds for each scenario are proposed to be at different locations, flows at the specific junctions are altered by the addition of a detention pond. A smaller flow would yield a smaller ROW width, and vice-versa. The results of each scenario, again, can be found in Table T-3 and T-4, with the matching exhibits showing the ROW widths being Exhibit 6-A and 6-B.

At the core of the scenario differences lies a basic give-take relationship. There exists a balance between the acquisition of significantly more ROW for larger improved channel sections or the creation of more-frequent sub-regional detention basins. The reality is that the CoM will require extreme improvements to either convey or detain increased developed flows.

5.2 Cost Discussion

Ironically enough, the cost difference between Scenario 1 and Scenario 2 is negligible considering the grand-scale and total-cost of the projects.

Table 8: Summary of Costs

Scenario 1 Conditions			Scenario 2 Conditions		
Sub Total		$79,413,499	**Sub Total**		$79,582,650
Engineering	10.00%	$7,941,460	Engineering	10.00%	$7,718,375
Geotech/Survey	10.00%	$7,941,460	Geotech/Survey	10.00%	$7,718,375
Environmental	10.00%	$7,941,460	Environmental	10.00%	$7,718,375
Contingency	30.00%	$23,824,381	Contingency	30.00%	$23,155,126
Scenario 1 Total:		**$127,062,260**			**$125,892,903**

The costs of the proposed scenarios are approximately equal at about 130 million dollars. The inherent differences in the scenarios and the effect each scenario will have on the drainage infrastructure was covered in Section 3 of this Study. To facilitate total project implementation over time, projects can be constructed in phases to reduce initial costs while still achieving flood reduction benefits. Note: (A) Costs estimates are extremely high level in nature, (B) roadway crossing estimates can vary widely depending on design constraints unavailable in this high level study, and (C) proposed costs for both scenarios are can be paid for by future developers or other funding methods.

Klotz recognizes that these costs are significant to the CoM. Working to understand the various funding options available will be the primary key to implementation of drainage infrastructure in the future. The CoM can slowly accomplish all necessary infrastructure improvements by continually working with drainage districts, developers, and other entities to ensure that the planning phases, roles, and responsibilities to resolve drainage issues are assigned and implemented.

5.3 Final Recommendations

This section presents the recommended drainage improvements to drainage systems in the CoM based on the observed modeling discoveries in the proposed modeling scenarios.

The primary focus of actions to address drainage issues is upon infrastructure improvements to either improve channel conveyance using channel depth/width modifications or reduce channel flows by partial capture of runoff in detention ponds. Conveyance improvement and detention are the staples to the needed drainage improvements.

Two scenarios for future drainage improvements have been presented and the sub-watersheds have been evaluated for the possible use of sub-regional detention, i.e., detention intended to reduce runoff rates from a sub-watershed with minimal channel conveyance improvements. Sub-regional detention could serve developments generally lying (more or less) within a single sub-watershed and should especially be considered in areas north of Highway 6.

Key elements for each scenario have been estimated. Necessary ROW acquisition has been estimated for the various project options. Basic project dimensions have been used to estimate project costs. Project costs include estimated costs for construction, environmental permitting, engineering, contingencies, and ROW.

Costs for improved drainage infrastructure, capable of conveying or detaining flood events within the CoM ETJ are significant. Klotz recommends the CoM determine, from review of the two proposed scenarios in this report, a general plan for implementation of drainage infrastructure improvements. In general, the first step in this process should include a plan for ROW acquisition or a plan to acquire ROW as part of the development permitting process.

While options presented involving conveyance improvements and detention are generally presented as two separated options, the optimal solution could be a mixture of conveyance improvement and flood storage detention throughout the CoM area. Preliminary engineering studies would be required to identify such an optimal solution because of the numerous trial options that would have to be evaluated.

Optimal Design Frequency: Conveyance improvements and flood control detention ponds were sized to control the 100-yr flood condition. For some project locations, loss of significant benefit by reduction of the design flood (say, to 50-yr or 25-yr) could result in significant cost reduction. When a projection is under consideration, preliminary engineering should investigate the cost savings and change in benefits that could result from reduction of the design flood level.

The CoM should investigate and consider the various funding options and cost-savings methods presented in this report. With the evident flooding issues currently existing in the CoM, it is likely that the CoM could be successful in a receiving help from a number of funding options.

The CoM can slowly accomplish all necessary infrastructure improvements by continually working to ensure that appropriate planning, roles, and responsibilities to resolve drainage issues are phased, assigned, and implemented. By coupling proposed projects with city amenity features such as parks, trails, fishing ponds, etc., the CoM can work to couple future beautification projects with drainage infrastructure improvements.

SECTION 6 REFERENCES

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Tables

Exhibits

Appendix A

Charts

Appendix B

Standard Nomenclature and Abbreviations

Appendix C

2013 Drainage Criteria from the City of Manvel Design Criteria Manual