Gapps Bayou
Alternative Evaluations Watershed Study
Fort Bend County Precinct 1

11/25/2013

STATE OF TEXAS
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November 2013

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1.0 Project Introduction

The Gapps Bayou Flood Protection Planning Study Phase II will develop a recommended alternative plan for flood damage reduction in the Gapps Bayou watershed in Fort Bend County, Texas. This will be accomplished by utilizing the results and hydrologic and hydraulic models established from the Gapps Bayou Existing Conditions Watershed Study, which was a Phase I Watershed Study. This report describes Phase II of a flood protection planning study for the Gapps Bayou watershed, which is funded with a flood protection planning grant from the Texas Water Development Board and matching funds from Fort Bend County Drainage District. The following paragraphs describe the purpose and scope of work of the watershed study.

1.1 Purpose of Project

The purpose of the Phase II flood protection planning study is to develop a recommended plan for flood damage reduction in the Gapps Bayou watershed. Although flooding issues are present throughout the watershed, historical flooding risks are concentrated within the Bridlewood Estates subdivision. While the study will focus on alleviating the flooding issues within the Bridlewood Estates subdivision, it will also provide a comprehensive look at any existing or potential needs elsewhere in the watershed. The primary end product will be an alternatives evaluation report documenting a recommended plan, cost estimates, and implementation consideration.

No overall flooding study or master drainage plan has been completed for the Gapps Bayou watershed. However, urbanization is proceeding at a rapid pace in the subject watershed. Drainage studies are prepared in a piecemeal fashion for individual developments, and there is no clearly defined overall flood protection plan that developers and engineers may reference to ensure that new developments are properly protected and that existing developments are not adversely impacted by new development. Therefore, it is beneficial to complete a flood protection planning study for the Gapps Bayou watershed, which will be based on the results of this phase of the study.

1.2 Scope of Work

The following scope of work describes the major tasks that will be undertaken and completed in connection with Phase II of the proposed flood protection planning study.

1. **Identify Flood Protection Alternatives:** Identify potential flood protection strategies and alternatives for the study watershed, including both structural and non-structural measures.

2. **Complete Environmental Evaluation:** Complete an environmental evaluation of the study watershed, identifying sensitive areas that should be avoided or for which mitigation may be required if disturbed.

3. **Evaluate Flood Protection Alternatives:** Evaluate and prioritize potential flood protection alternatives in relative order of anticipated cost-effectiveness.

4. **Develop Draft Flood Protection Plan:** Develop a preliminary flood protection plan that incorporates the most cost-effective alternatives for the study watershed.

5. **Develop Post-Project Hydrologic Model:** Prepare a post-project hydrologic model for the watershed to reflect the implementation of selected flood protection alternatives. Compute post-project conditions flow rates.

6. **Develop Post-Project Hydraulic Model:** Prepare a post-project hydrologic model for the watershed to reflect the implementation of selected flood protection alternatives. Compute post-project conditions flood levels.

7. **Adjust Flood Protection Plan As Needed:** Adjust the flood protection plan as needed, making necessary changes to post-project conditions hydrologic and hydraulic models. Compute final post-project conditions flood flow rates, flood elevations, and floodway data.

8. **Prepare Conceptual Phasing Plan:** Prepare a conceptual phasing plan for the watershed to allow flood protection measures to be implemented in a fiscally responsible manner.

9. **Analyze Phasing Plan:** Create interim conditions hydrologic and hydraulic models that represent significant milestones in the phasing plan for the watershed. Adjust phasing plans as needed to maximize performance and anticipated cost-effectiveness.

10. **Prepare Cost Estimates & B/C Ratios:** Develop preliminary cost estimates for the watershed to include both interim and fully-implemented flood protection plans. Analyze the potential annual benefits and costs associated with the proposed plans.

11. **Prepare Flood Protection Report:** Prepare a report that describes proposed flood protection measures, phasing plans, and post -project drainage conditions within the subject watershed.

12. **Present Results to Cities, County, FBCDD:** Present the results of the studies to representatives of participating cities, the Fort Bend County Drainage District, and Fort Bend County.

13. **Attend Meetings:** Attend regular monthly meetings with study stakeholders in addition to public meetings held in an effort to gather information or to educate the public with regard to the purposes of the planning effort and the results obtained.

1.3 Public Involvement

As a part of the scope of work, a series of three (3) public meetings were held to inform the general public the progress of the watershed study throughout the duration of the project. The public meetings were held on March 25th, 2013, June 26th, 2013, and July 29th, 2013 at The George Memorial Library, Richmond, Texas. Representatives from R.G. Miller Engineers, Inc. presented the preliminary findings of the study, and representatives from the Fort Bend County Drainage District were on hand to answer any questions as necessary. Prior to the study, the Fort Bend County Drainage District was informed of the grant application which ultimately funded a portion of this watershed study.

1.4 Executive Summary

We have completed a comprehensive hydrologic and hydraulic analysis of the existing condition of the Gapps Bayou watershed in Phase I. Based on the results of the hydrologic and hydraulic modeling data, we have mapped the floodplains of various storm events as shown in Exhibits 6 through 10.

Significant out-of-bank flooding is predicted within the Bridlewood Estates subdivision upstream of Berdett Road during a 1% annual chance (100-year) storm event. Much of this flooding can be attributed to the fact that Farm-to-Market Road (FM) 762 is elevated approximately 2 to 3 feet above natural ground and that the culverts at the Gapps Bayou crossing of FM 762 are undersized. Additionally, some out-of-bank flooding is predicted within the Royal Lakes Estates subdivision in the downstream portion of the watershed. Approximately 81 structures within the Bridlewood Estates and Royal Lakes Estates subdivisions are at risk of flooding during a 1% annual chance (100-year) storm event. The estimated value of these structures and properties is approximately $8.6 million dollars.

Alternative One calls for culvert improvement under FM 762 and a regional basin located between FM 762 and Berdett Road. The proposed regional basin will provide 360 acre-feet of storage volume and will require 44 acres of land. We recommend that the existing four (4) 6-foot by 5-foot RCB culverts under FM 762 will be replaced with four (4) 8-foot by 7-foot RCBs. The proposed alternative plan will decrease the 100-year water surface elevation through Bridlewood subdivision up to 0.6 feet. The approximate cost of the alternative is $8.1 million dollars.

Alternative Two calls for culvert improvement under FM 762 and Berdett Road, a regional basin located between FM 762 and Berdett Road, and a channel improvement between FM 762 and Berdett Road. The proposed regional basin will provide 330 acre-feet of storage volume and will require 38 acres of land. This alternative recommend that the existing three (3) 84-inch diameter and one (1) 78-inch diameter RCPs under Berdett Road will be replaced with three (3) 108-inch and two (2) 72-inch RCPs. Alternative 2 also recommend that the existing four (4) 6-foot by 5-foot RCB culverts under FM 762 will be replaced with four (4) 8-foot by 7-foot RCBs. The proposed alternative plan will decrease the 100-year water surface elevation through Bridlewood subdivision up to 0.8 feet. The approximate cost of the alternative is $8.5 million dollars.

Alternative Three calls for culvert improvement under FM 762 and Berdett Road, a regional basin located approximately 1,800 feet downstream of the FM 762 and Gapps Bayou confluence, and a channel improvement between Berdett Road and proposed detention basin. The proposed regional basin will provide 280 acre-feet of storage volume and will require 33 acres of land. This alternative recommend that the existing three (3) 84-inch diameter and one (1) 78-inch diameter RCPs under Berdett Road will be replaced with three (3) 108-inch and two (2) 72-inch RCPs. Alternative 2 also recommend that the existing four (4) 6-foot by 5-foot RCB culverts under FM 762 will be replaced with four (4) 8-foot by 7-foot RCBs. The proposed alternative plan will decrease the 100-year water surface elevation through Bridlewood subdivision up to 1.1 feet. The approximate cost of the alternative is $8.2 million dollars.

2.0 Existing Watershed Conditions

Data on the existing watershed conditions were collected from a number of available resources, including previous engineering studies, field surveys and observations, light detection and ranging (LiDAR) topographic information, aerial photographs, and soil surveys. The data has been collected from the Fort Bend County Drainage District, the Houston-Galveston Area Council, the Harris-Galveston Subsidence District, and the United States Geological Survey.

2.1 Watershed Location and Description

The Gapps Bayou watershed is located to the southwest of Houston, Texas in Fort Bend County, Texas. Adjoining watersheds include those of Dry Creek and Rabbs Bayou. Gapps Bayou empties into Lower Dry Creek, thence into Big Creek, and ultimately into the Brazos River. A majority of the watershed is located within the unincorporated areas of Fort Bend County, with a small portion in the northwest corner of the watershed located within the corporate limits of the City of Rosenberg. Exhibit 1 illustrates the location of the Gapps Bayou watershed.

Several major roads and railroads are located in the general vicinity of the watershed. The major roads include FM 762, FM 2759, and FM 2977. FM 762 crosses through the central portion of the watershed in a north-south direction, and FM 2977 crosses through the western portion of the watershed in a north-south direction. FM 2759 and a Burlington Northern Santa Fe (BNSF) railroad generally form the northern drainage boundary of the watershed. A map of the watershed is shown in Exhibit 2.

The topography of the watershed may best be described as gently sloping. Ground elevations vary from 97 feet in the western portion of the watershed to 61 feet at the downstream end of the watershed, based on the 2001 adjustment of the North American Vertical Datum of 1988. Ground slope in the watershed varies from about 2 feet per mile to about 11 feet per mile. No unusual changes in topography occur in the watershed except where fill has been placed to allow for development. Exhibit 3 shows a shaded topographic map of the watershed.

The Gapps Bayou watershed is generally developed in the western portions of the watershed and generally undeveloped in the eastern portions of the watershed. Subdivisions within the Gapps Bayou watershed include the Summer Lakes, Summer Creek, Bridlewood Estates, Royal Lakes Estates, Rivers Mist, and River Run at the Brazos. George Ranch High School and Antoinette Reading Junior High School of the Lamar Consolidated Independent School District are also located within the watershed.

2.2 Description of Gapps Bayou

Gapps Bayou is generally a well-maintained earthen channel which flows from west to east. Storm water runoff reaches Gapps Bayou via storm sewer or roadside ditch outfalls from developed areas and via surface flow in undeveloped areas. Within the Bridlewood Estates subdivision, the channel has been widened to provide in-line storm water detention to offset the increase in peak flow rates created by the development of the subdivision. This in-line detention basin maintains a static water surface elevation to provide an amenity to the residents of the Bridlewood Estates subdivision.

In the downstream end of the channel, a significant valley remains along the channel where the former Booth Lake existed. The dam that created the former Booth Lake was breached in the 1950s; however, no additional work has been done to the channel where the lake formerly existed. A significant embankment remains at the downstream end of the former Booth Lake.

2.3 Previous Studies

No overall flooding or master drainage plan has been completed for the Gapps Bayou watershed. Drainage studies are presented in a piecemeal fashion for individual developments, and there is no clearly defined overall flood protection plan that developers and engineers may use to ensure that new developments are properly protected and that existing developments are not adversely impacted by new development. Urbanization within the watershed is proceeding at a rapid pace, and plans for the proposed Grand Parkway (State Highway 99) to pass through the watershed will increase the rate of urbanization of the watershed.

The Bridlewood Estates subdivision, located in the central portion of the watershed, has experienced extensive street and lot flooding problems for a number of years. Approximate modeling data recently developed by Edminster, Hinshaw, Russ, & Stanley indicates that the Bridlewood subdivision would be severely affected during a 1% annual chance storm event. Additionally, drainage studies have been completed as development has occurred within the watershed in a piecemeal fashion.

The last official Flood Insurance Rate Map update for Fort Bend County was completed in 1997, but the Gapps Bayou watershed was not included in that study. Preliminary new FIRM panels for Fort Bend County were released for public review and comment on July 21, 2010. The comment period closed in October 2010, and appeals filed during the comment period are now being processed. Mapping of the floodplain of Gapps Bayou was not included in this set of maps either.

2.4 Phase I – Existing Watershed Conditions

R.G. Miller Engineers completed a comprehensive hydrologic and hydraulic analysis of the existing condition of the Gapps Bayou watershed in Phase I. Based on the results of the hydrologic and hydraulic modeling data, we have mapped the floodplains of various storm events.

The hydrologic analysis for the existing conditions model was based on Fort Bend County Standard Methodology, which is outlined in the "Fort Bend County Drainage Criteria Manual" adopted in 2011. The Fort Bend County Standard Methodology uses watershed parameters (like drainage area, watershed length, channel slope, watershed slope, impervious cover, Manning's roughness coefficient along the watercourse, and percent of the watershed affected by detention) to compute the time-of-concentration and the storage coefficient of each sub-area. The computed time-of-concentration and the storage coefficient can be used to compute peak runoff rates using the Clark Unit Hydrograph Method. These values are shown in Appendix A. The peak runoff rates are shown in the table below.

Table 1: Peak Flow Rates along Gapps Bayou

Hydrologic Element	Description of Hydrologic Element	Peak Flow Rate (cfs)			
		10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Gapps_0302_J	Peak Flow at Reading Rd.	331	452	512	643
Gapps_0294_J	Peak Flow at Benton Rd.	512	697	795	1004
Gapps_0236_J	Peak Flow U/S of Bridlewood Estates	1051	1420	1599	2026
Gapps_0187_J	Peak Flow at Berdett Rd.	1236	1656	1896	2547
Gapps_0161_J	Peak Flow at FM 762	1096	1318	1414	1937
Gapps_0150_J	Peak Flow D/S of George Ranch H.S.	1220	1479	1589	2080
Gapps_0093_J	Peak Flow U/S of Royal Lakes Estates	1546	1984	2188	2666
Gapps_0056_J	Peak Flow D/S of Royal Lakes Estates	1706	2229	2472	3040
Gapps_0000_J	Peak Flow at D/S Limit of Study	1871	2541	2861	3602

Cross-section data for Gapps Bayou was created using field survey data provided by the Fort Bend County Drainage District for structures and points within the channel and LiDAR elevation data for the overbanks of the channel. The field survey data and the LiDAR data were combined to create continuous cross-sections at points along Gapps Bayou. All elevations in this study are based on the 2001 adjustment of the North American Vertical Datum of 1988. A map of the cross-sections used in the hydraulic analysis of Gapps Bayou is shown in Exhibit 5.

We determined the Manning's roughness coefficient, "n", using aerial photographs and field observations of the project site. Values used in this study range from 0.14 for wooded areas with dense vegetation to 0.04 for well-maintained channels.

We used the HEC-RAS Version 4.1 computer program to compute the 10% annual chance (10-year), 2% annual chance (50-year), 1% annual chance (100-year), and 0.2% annual chance (500-year) flood profiles. The flood profiles and detailed output from HEC-RAS are shown in Appendix D. Table 2 shows the water surface elevations for the 10% annual chance (10-year), 2% annual chance (50-year), 1% annual chance (100-year), and 0.2% annual chance (500-year) storm events at significant crossings in the watershed.

Table 2: Flood Levels along Gapps Bayou

River Station	Location of River Station	Flood Level (ft)			
		10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
30204.2	D/S of Reading Rd.	82.08	83.14	83.44	83.86
29428.5	U/S of Benton Rd.	81.81	82.89	83.19	83.54
29344.3	D/S of Benton Rd.	81.23	81.99	82.30	82.80
23757.9	U/S of Bridlewood Estates	77.73	77.97	78.03	78.31
18528.1	U/S of Berdett Rd.	77.68	77.91	77.96	78.24
18402.6	D/S of Berdett Rd.	77.68	77.90	77.95	78.23
16085.5	U/S of FM 762	77.66	77.88	77.92	78.19
15977.7	D/S of FM 762	75.58	75.85	75.95	76.34
15075.6	D/S of George Ranch H.S.	74.72	75.00	75.10	75.48
9354.3	U/S of Royal Lakes Estates	69.20	69.85	70.12	70.72
7595.5	U/S of Royal Lakes Ln.	68.48	69.08	69.34	69.92
7330.7	D/S of Royal Lakes Ln.	68.43	69.00	69.24	69.79
6557.7	U/S of King Forest Ln.	68.32	68.87	69.11	69.63
6350.4	D/S of King Forest Ln.	68.27	68.78	69.00	69.46
5682.4	D/S of Royal Lakes Estates	68.23	68.74	68.95	69.41
1.9	D/S Limit of Study	67.79	65.32	68.41	68.81

The HEC-RAS platform called GeoRAS, which interacts with ArcGIS software, was used to map the floodplain for the various storm events based on the computed flood levels along Gapps Bayou and the ground elevations obtained from LiDAR topographic elevation data. The floodplains for the 10% annual chance (10-year), 2% annual chance (50-year), 1% annual chance (100-year), and 0.2% annual chance (500-year) storm events are shown in Exhibits 6 through 9, respectively.

A floodway is a portion of the floodplain, centered about the channel, which is capable of conveying the 1% annual chance (100-year) flow at a water surface elevation 1.0 foot above the existing 100-year flood elevation. The HEC-RAS program offers five (5) methods for computing floodway data. The method used in this analysis is Method 4, in which preliminary floodway boundaries are determined based on equal reduction of flow conveyance from the floodplain on each side of the channel, then Method 1 in which the user defines the limits of the floodway on each side of the channel to finalize all floodway computations. The floodway boundaries computed for Gapps Bayou are shown on Exhibit 10. Detailed HEC-RAS output for the floodway computations is shown in Appendix F. The results of this analysis do not include backwater conditions from the Brazos River or a detailed localized analysis of storm sewer system or roadside ditch drainage infrastructure.

Significant out-of-bank flooding is predicted within the Bridlewood Estates subdivision upstream of Berdett Road during a 1% annual chance (100-year) storm event. Much of this flooding can be attributed to the fact that Farm-to-Market Road (FM) 762 is elevated approximately 2 to 3 feet above natural ground and that the culverts at the Gapps Bayou crossing of FM 762 are undersized. Additionally, some out-of-bank flooding is predicted within the Royal Lakes Estates subdivision in the downstream portion of the watershed. Approximately 79 structures within the Bridlewood Estates and Royal Lakes Estates subdivisions are at risk of flooding during a 1% annual chance (100-year) storm event. In addition, approximately 26 residential lots are at risk

of flood inundation during a 1% annual chance storm event, but its structures are located above 100-year flood elevation. The estimated value of these structures and properties is approximately $8.6 million dollars.

During storm events with rainfall totals greater than a 20% annual chance (5-year) storm, the hydraulic modeling data predicts that Berdett Road becomes impassible due to flooding near its intersection with Gapps Bayou. Additionally, the hydraulic modeling data predicts that FM 762 will be overtopped with storm water when rainfall amounts exceed the 10% annual chance (10-year) storm. However, Royal Lakes Lane and King Forest Lane are not predicted to be overtopped during a storm event up to and including the 0.2% annual chance (500-year) storm.

Based on the results of Phase I analysis, we believe that flooding within the Gapps Bayou watershed poses a significant threat to public safety and homes within the northern section of the Bridlewood Estates subdivision and along Gapps Bayou within the Royal Lakes Estates subdivision. Additionally, two major thoroughfares within the watershed are predicted to become impassible during storm events greater than a 10% annual chance (10-year) storm, which poses a safety hazard to area residents.

Based on the results of Phase I analysis, we recommend that the results of Phase I analysis serve as a basis for publishing new flood insurance rate maps of the Gapps Bayou watershed and an addition to the Fort Bend County flood insurance study. Publication of the flood insurance rate maps would aid the general public in knowing the risk of flooding within the Gapps Bayou watershed.

3.0 Phase II Conditions – Alternative Evaluations

This section of the report describes the methods used to determine the peak flow rates and flood levels along Gapps Bayou for various flood reduction alternatives for the Flood Protection Planning Study of Gapps Bayou.

A recent hydraulic model prepared by R.G. Miller Engineers, Inc. indicates that 1% annual chance flood levels will reach an elevation of approximately 78.0 feet upstream of FM 762. At that elevation, a significant portion of the Bridlewood Estates subdivision will be flooded. The approximate extent of flooding is indicated on Figure 1. Potential overflows to the Dry Creek watershed are possible at the predicted 1% annual chance flood level.

Figure 1: Bridlewood Estates Flooding

Approximately 79 structures in the Gapps Bayou watershed are at risk of flooding during a 1% annual chance storm event. The estimated value of the homes potentially affected by flooding is approximately $8.6 million dollars during a 1% annual chance storm event. Home values were determined based on the Fort Bend Central Appraisal District property values in the flood affected areas along Gapps Bayou. Undeveloped lots were not included in the estimate. Each lots were given three categories of damage: complete or partial structure inundation (100% damage), partial structure inundation with significant lot inundation (10% damage), and significant lot inundation but no visible structure inundation (5% damage). Appendix AC – Damage Cost Analysis shows the detailed calculations including exhibits. Please note that the 100-year floodplain delineation was based on the LiDAR contour lines, and the actual estimated damage value could be re-defined with the topographic survey data or elevation certificates of the affected lots.

By examining the existing conditions hydrologic and hydraulic model and evaluating different alternative solutions, we found that the most cost effective solution to the flood damage reduction to Gapps Bayou is by improving the culvert crossings under FM 762 and Berdett Road. By opening these culverts, it created the best flood reduction results for the Bridlewood subdivision; however, it may cause an impact on the downstream side of Gapps Bayou. A regional basin is proposed to mitigate the impact caused by improving culverts under FM 762 and Berdett Road. Storage volume required to mitigate the proposed improvements are relatively significant due to the presence of large floodplain storage between Berdett Road and FM 762, which was caused by the storm water backing from FM 762. We have developed three alternatives for providing sufficient flood damage reduction throughout the Gapps Bayou watershed.

3.1 Alternative One – Regional Basin Between Berdett Road and FM 762

Alternative One calls for culvert improvement under FM 762 and a regional basin located between FM 762 and Berdett Road. The existing conditions hydrologic model created by R.G. Miller Engineers, Inc. was modified to simulate reduced flows by adding a regional detention pond just upstream of FM 762 and a culvert improvement at the FM 762 crossing. We recommend that the existing four (4) 6-foot by 5-foot RCB culverts under FM 762 will be replaced with four (4) 8-foot by 7-foot RCBs or equivalent. The proposed detention pond is located just upstream of FM 762 and south of Gapps Bayou to maximize storage depth and prevent any issues with the proposed Grand Parkway and future major thoroughfare alignment. We are proposing to place the outfall pipe downstream of FM 762, which would allow the detention basin to be deeper due to the depth constraints of Gapps Bayou upstream of FM 762. The total area needed to construct proposed detention basin is 44 acres providing approximately 360 acre-feet of storage volume at elevation 76.7 feet. It consists of a 30 foot maintenance berm, 4:1 (horizontal to vertical) side slope, and a 48" RCP outfall pipe to Gapps Bayou. The toe of the bank elevation is set at 66.7 feet, and the top of the bank elevation is set at 76.7 feet. A diversion structure is proposed to be located to divert the flows from Gapps Bayou to the proposed regional detention basin. The diversion structure consists of an overflow weir and inflow pipe. The weir is proposed to have a crest elevation of 75.0 feet and a crest length of 50 feet. The inflow pipe is proposed to be a 60" RCP at a flowline elevation of 68.0 feet. Table 3 provides a summary of the Alternative 1 detention basin routing data. A layout map of Alternative 1 is shown in Exhibit 11.

Table 3: Elevation-Storage-Discharge Relationship for the Alternative 1 Basin

Elevation (ft)	Storage (ac-ft)	Discharge (cfs)
66.7	0.0	0.0
67.7	34.0	1.4
68.7	68.4	5.8
69.7	103.3	12.8
70.7	138.7	21.4
71.7	174.5	30.5
72.7	210.9	51.2
73.7	247.7	55.3
74.7	285.1	59.1
75.2	303.9	60.9
75.7	322.9	62.7
76.2	342.0	64.4
76.7	361.3	66.0

Modified Puls routing data for Gapps Bayou has been changed to reflect the improvements in the watershed for the Alternative 1 detention conditions. The existing discharge data of all the reaches in the watershed were incorporated into the Alternative 1 HEC-RAS steady flow model to create the storage outflow data for the channel. The Alternative 1 storage outflow from HEC-

RAS was then updated in the HEC-HMS Alternative 1 model to determine the peak outflows. Please see Appendix G for routing data.

The HEC-HMS Version 3.3 software package developed by the U.S. Army Corps of Engineers is used to compute the proposed peak runoff rates and runoff hydrographs for the 10%, 2%, 1% and 0.2% storm events of 24-hour duration. The peak flow rates computed with the Alternative 1 conditions HEC-HMS hydrologic model are shown below in Table 4 along with the existing conditions values. Detailed results of the Alternative 1 conditions HEC-HMS model are shown in Appendix H.

Table 4: Existing v. Alternative 1 Peak Flow Rates

Hydrologic Element	10% Annual Chance			2% Annual Chance			1% Annual Chance			0.2% Annual Chance		
	Existing	Alternative 1	Difference	Existing	Alternative 1	Difference	Existing	Alternative 1	Difference	Existing	Alternative 1	Difference
Gapps_0302_J	331.2	331.2	0.0	452.6	452.6	0.0	512.2	512.2	0.0	643.3	643.3	0.0
Gapps_0294_J	512.7	512.7	0.0	697.9	697.7	-0.2	795.1	795.0	-0.1	1004.4	1004.4	0.0
Gapps_0236_J	1051.2	1055.4	4.2	1420.8	1417.2	-3.6	1599.9	1596.5	-3.4	2026.2	2028.6	2.4
Gapps_0187_J	1236.2	1081.8	-154.4	1656.1	1671.1	15.0	1896.5	1879.4	-17.1	2547.6	2489.4	-58.2
Gapps_0161_J	1096.7	941.1	-155.6	1318.4	1205.8	-112.6	1414.1	1291.0	-123.1	1937.1	1514.5	-422.6
Gapps_0150_J	1220.5	1079.1	-141.4	1479.0	1389.1	-89.9	1589.4	1505.2	-84.2	2080.9	1768.5	-312.4
Gapps_0093_J	1546.2	1429.0	-117.2	1984.5	1891.2	-93.3	2188.3	2097.8	-90.5	2666.9	2577.5	-89.4
Gapps_0056_J	1706.3	1602.4	-103.9	2229.4	2137.4	-92.0	2472.2	2382.2	-90.0	3040.3	2951.2	-89.1
Gapps_0000_J	1871.8	1811.8	-60.0	2541.2	2474.2	-67.0	2861.0	2787.3	-73.7	3602.6	3521.2	-81.4

As shown in Table 4, minor impacts on flow rates along Gapps Bayou are shown after detention is applied for storm events up to and including the 0.2% annual chance (500-year) storm events. However, the increase in flow rates does not cause impact on the flood levels along Gapps Bayou.

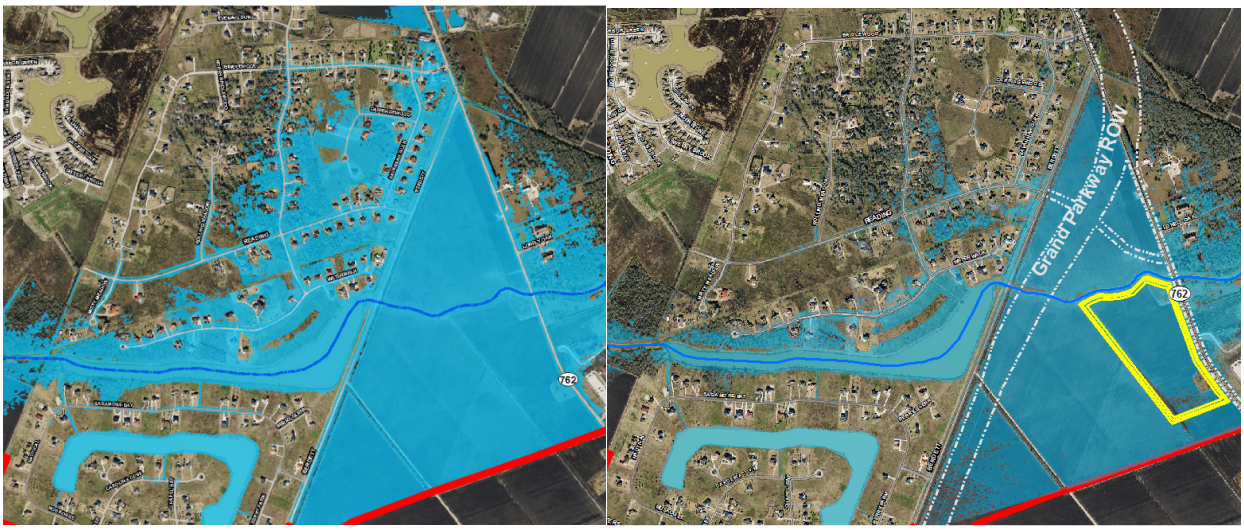
The existing conditions HEC-RAS model created by R.G. Miller Engineers was modified to account for the proposed detention pond and the updated culvert crossing at FM 762. The table below shows the comparison between the existing and Alternative 1 conditions. HEC-RAS model results are included in Appendix I. The results of the analysis are shown in Table 5 below.

Table 5: Existing v. Alternative 1 Peak Water Surface Elevations

River Station	Location	Existing Conditions Flood Levels				Alternative 1 Conditions Flood Levels				Difference	
		10%	2%	1%	0.20%	10%	2%	1%	0.20%	10%	1%
29344.3	Bonbrook	81.24	81.99	82.30	82.80	81.22	81.99	82.30	82.80	-0.02	0.00
28494.4	Bonbrook	80.82	81.53	81.83	82.31	80.80	81.52	81.82	82.31	-0.02	-0.01
27602	Bonbrook	80.37	80.98	81.26	81.68	80.34	80.97	81.25	81.67	-0.03	-0.01
26717.3	Bonbrook	79.94	80.35	80.54	80.82	79.90	80.35	80.53	80.82	-0.04	-0.01
23757.9	Bridlewood	77.72	77.92	78.00	78.27	77.01	77.35	77.45	77.75	-0.71	-0.55
23044.2	Bridlewood	77.72	77.93	78.02	78.29	77.02	77.37	77.48	77.78	-0.70	-0.54
22087.5	Bridlewood	77.72	77.93	78.01	78.28	77.01	77.36	77.46	77.76	-0.71	-0.55
21218.3	Bridlewood	77.72	77.93	78.01	78.27	77.01	77.35	77.45	77.74	-0.71	-0.56
20195.4	Bridlewood	77.72	77.92	78.01	78.26	77.01	77.35	77.45	77.74	-0.71	-0.56
19150.5	Bridlewood	77.72	77.92	78.00	78.26	77.00	77.34	77.45	77.73	-0.72	-0.55
18693	Bridlewood	77.68	77.88	77.95	78.20	76.92	77.21	77.29	77.55	-0.76	-0.66
18528.1	Bridlewood	77.68	77.87	77.95	78.20	76.74	76.97	77.05	77.38	-0.94	-0.90
18402.6	Alt. 1 Detention	77.68	77.87	77.95	78.18	76.38	76.88	77.03	77.44	-1.30	-0.92
17679.2	Alt. 1 Detention	77.67	77.87	77.95	78.17	76.12	76.70	76.88	77.37	-1.55	-1.07
16850	Alt. 1 Detention	77.67	77.86	77.94	78.16	75.92	76.57	76.78	77.32	-1.75	-1.16
16085.5	Alt. 1 Detention	77.66	77.85	77.93	78.15	75.82	76.53	76.75	77.31	-1.84	-1.18
8175.8	Royal Lake Estates	68.61	69.23	69.51	70.09	68.50	69.14	69.41	70.01	-0.11	-0.10
7595.5	Royal Lake Estates	68.49	69.09	69.36	69.92	68.40	69.00	69.26	69.85	-0.09	-0.10
7330.7	Royal Lake Estates	68.44	69.00	69.26	69.78	68.35	68.93	69.18	69.72	-0.09	-0.08
6955.1	Royal Lake Estates	68.39	68.97	69.22	69.74	68.32	68.89	69.14	69.68	-0.07	-0.08
6557.7	Royal Lake Estates	68.32	68.88	69.13	69.63	68.26	68.81	69.05	69.57	-0.06	-0.08
6350.4	Royal Lake Estates	68.26	68.79	69.02	69.46	68.21	68.73	68.95	69.41	-0.05	-0.07
5682.4	Royal Lake Estates	68.24	68.75	68.98	69.41	68.18	68.69	68.90	69.36	-0.06	-0.08

As shown in the table above, water surface elevations along Gapps Bayou were decreased compared to the existing conditions hydraulic model. In Bonbrook Plantation, the 1% annual chance water surface elevation was lowered on average 0.01 feet. In Bridlewood Estates, the 1% annual chance water surface elevation was lowered on average 0.6 feet. In Royal Lake Estates, the 1% annual chance water surface elevation was lowered on average 0.1 feet. The figure below shows a comparison between the existing and Alternative 1 1% annual chance floodplain in the Bridlewood Estates subdivision. Exhibits 12-15 show the mapped floodplains for the 10%, 2%, 1% and 0.5% annual chance storm event.

Figure 2: Existing v. Alternative 1 1% Annual Chance Floodplain



Our floodway analysis indicates that the floodway between FM 762 and Berdett Road has reduced for Alternative One. The floodway boundaries computed for Alternative 1 are shown on Exhibit 16. Detailed HEC-RAS output for the floodway computations is shown in Appendix J.

The cost for construction of the Alternative 1 detention pond and culvert replacements would be approximately $8.1 million dollars including $1 million dollars for land acquisition. The total expected damage when the Alternative 1 is implemented is $4.6 million dollars during a 1% annual chance storm event, which reduced approximately $4.0 million dollars from the existing expected damage amount of $8.6 million dollars. Therefore, the benefit amount for Alternative 1 is $4.0 million dollars. The benefit to cost ratio for Alternative 1 is 0.5. Detailed computations are shown in Appendix K.

3.2 Alternative Two – Channel Improvements and Regional Detention Basin

Alternative Two calls for culvert improvement under FM 762 and Berdett Road, a regional basin located between FM 762 and Berdett Road, and a channel improvement between FM 762 and Berdett Road. The existing conditions hydrologic model created by R.G. Miller Engineers, Inc. was modified to reflect the drainage improvement proposed in Alternative 2. This alternative recommends that the existing three (3) 84-inch diameter and one (1) 78-inch diameter RCPs under Berdett Road will be replaced with three (3) 108-inch and two (2) 72-inch RCPs or equivalent. Alternative 2 also recommend that the existing four (4) 6-foot by 5-foot RCB culverts under FM 762 will be replaced with four (4) 8-foot by 7-foot RCBs or equivalent. Channel between FM 762 and Berdett Road is proposed to be deepened and widened with average of 200-foot wop width. The new channel will require maximum 300-foot R.O.W. for the channel improvements.

The proposed detention pond is located just upstream of FM 762 and south of Gapps Bayou to maximize storage depth and prevent any issues with the proposed Grand Parkway and future major thoroughfare alignment. The total area needed to construct proposed detention basin is 38 acres, which will provide approximately 330 acre-feet of storage at the elevation 76.5 feet. It

consists of a 30 foot maintenance berm, 4:1 (horizontal to vertical) side slope, and a 48" RCP outfall pipe to Gapps Bayou. The toe of the bank elevation is set at 66.7 feet and the top of the bank elevation is set at 76.5 feet. A diversion structure is proposed to be located to divert the flows from Gapps Bayou to the proposed regional detention basin. The diversion structure consists of an overflow weir and inflow pipe. The weir is proposed to have a crest elevation of 75.0 feet and a crest length of 100 feet. The inflow pipe is proposed to be a 48" RCP at a flowline elevation of 68.0 feet. Table 6 provides a summary of the Alternative 2 detention basin routing data. A layout map of Alternative 2 is shown in Exhibit 17.

Table 6: Elevation-Storage-Discharge Relationship for the Alternative 2 Basin

Elevation (ft)	Storage (ac-ft)	Discharge (cfs)
66.7	0.0	0.0
67.7	31.8	1.4
68.7	63.9	5.8
69.7	96.6	12.8
70.7	129.7	21.4
71.7	163.2	30.5
72.7	197.2	51.2
73.7	231.6	55.3
74.7	266.5	59.1
75.2	284.2	60.9
75.7	301.9	62.7
76.2	319.8	64.4
76.7	337.8	66.0

Modified Puls routing data for Gapps Bayou has been changed to reflect the improvements in the watershed for the Alternative 2 detention conditions. The existing discharge data of all the reaches in the watershed were incorporated into the Alternative 2 HEC-RAS steady flow model to create the storage outflow data for the channel. The Alternative 2 storage outflow from HEC-RAS was then updated in the HEC-HMS Alternative 2 model to determine the peak outflows. Please see Appendix L for routing data.

The HEC-HMS software package developed by the U.S. Army Corps of Engineers is used to compute the proposed peak runoff rates and runoff hydrographs for the 10%, 2%, 1% and 0.2% storm events of 24-hour duration. The peak flow rates computed with the Alternative 2 conditions HEC-HMS hydrologic model are shown below in Table 7 along with the existing conditions values. Detailed results of the Alternative 2 conditions HEC-HMS model are shown in Appendix M.

Table 7: Existing v. Alternative 2 Peak Flow Rates

Hydrologic Element	10% Annual Chance			2% Annual Chance			1% Annual Chance			0.2% Annual Chance		
	Existing	Alternative 2	Difference	Existing	Alternative 2	Difference	Existing	Alternative 2	Difference	Existing	Alternative 2	Difference
Gapps_0302_J	331.2	331.2	0.0	452.6	452.6	0.0	512.2	512.2	0.0	643.3	643.3	0.0
Gapps_0294_J	512.7	512.6	-0.1	697.9	697.3	-0.6	795.1	795.1	0.0	1004.4	1004.3	-0.1
Gapps_0236_J	1051.2	1055.3	4.1	1420.8	1423.2	2.4	1599.9	1606.3	6.4	2026.2	2022.0	-4.2
Gapps_0187_J	1236.2	1046.5	-189.7	1656.1	1561.7	-94.4	1896.5	1853.7	-42.8	2547.6	2483.1	-64.5
Gapps_0161_J	1096.7	937.1	-159.6	1318.4	1239.3	-79.1	1414.1	1365.4	-48.7	1937.1	1617.1	-320.0
Gapps_0150_J	1220.5	1065.2	-155.3	1479.0	1416.8	-62.2	1589.4	1571.9	-17.5	2080.9	1886.0	-194.9
Gapps_0093_J	1546.2	1398.2	-148.0	1984.5	1896.8	-87.7	2188.3	2128.0	-60.3	2666.9	2636.4	-30.5
Gapps_0056_J	1706.3	1563.0	-143.3	2229.4	2134.9	-94.5	2472.2	2401.5	-70.7	3040.3	2999.3	-41.0
Gapps_0000_J	1871.8	1765.2	-106.6	2541.2	2434.3	-106.9	2861.0	2763.4	-97.6	3602.6	3529.3	-73.3

As shown in Table 7, minor impacts on flow rates along Gapps Bayou are shown at node Gapps_0294_J after detention is applied for storm events up to and including the 1% annual chance (100-year) storm events. However, the increase in flow rates are negated by the proposed channel improvements along Gapps Bayou.

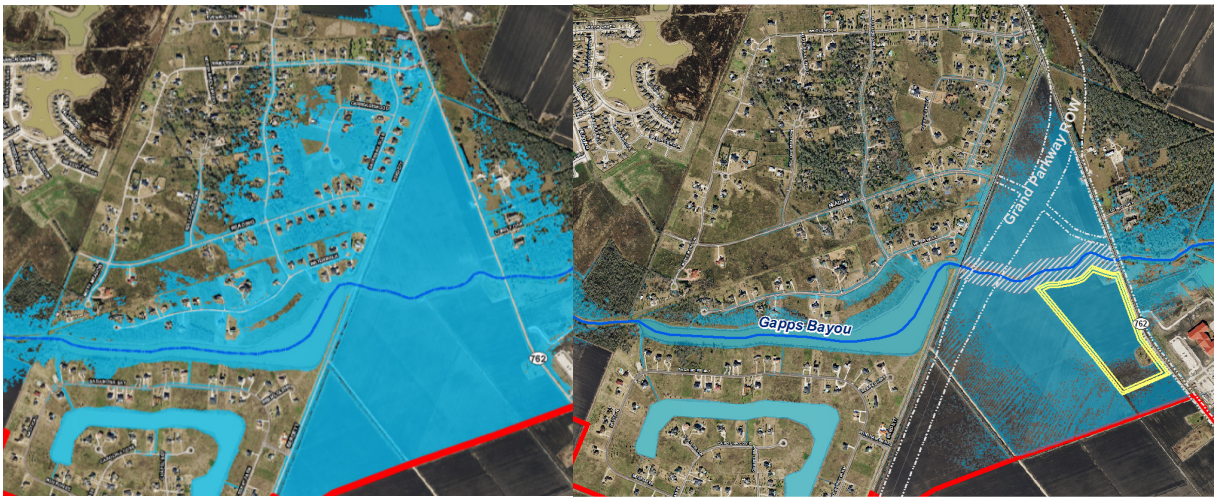
The existing conditions HEC-RAS model created by R.G. Miller Engineers was modified to account for the proposed detention pond and the updated culvert crossings at Berdett Road and FM 762. The table below shows the comparison between the existing and Alternative 2 conditions. HEC-RAS model results are included in Appendix N. The results of the analysis are shown in Table 8 below.

Table 8: Existing v. Alternative 2 Peak Water Surface Elevations

River Station	Location	Existing Conditions Flood Levels				Alternative 2 Conditions Flood Levels				Difference	
		10%	2%	1%	0.20%	10%	2%	1%	0.20%	10%	1%
29344.3	Bonbrook	81.24	81.99	82.30	82.80	81.20	81.99	82.29	82.80	-0.04	-0.01
28494.4	Bonbrook	80.82	81.53	81.83	82.31	80.78	81.52	81.82	82.31	-0.04	-0.01
27602	Bonbrook	80.37	80.98	81.26	81.68	80.32	80.97	81.24	81.68	-0.05	-0.02
26717.3	Bonbrook	79.94	80.35	80.54	80.82	79.87	80.34	80.52	80.82	-0.07	-0.02
23757.9	Bridlewood	77.72	77.92	78.00	78.27	76.29	77.00	77.18	77.71	-1.43	-0.82
23044.2	Bridlewood	77.72	77.93	78.02	78.29	76.32	77.02	77.21	77.74	-1.40	-0.81
22087.5	Bridlewood	77.72	77.93	78.01	78.28	76.31	77.01	77.20	77.72	-1.41	-0.81
21218.3	Bridlewood	77.72	77.93	78.01	78.27	76.30	77.00	77.18	77.70	-1.42	-0.83
20195.4	Bridlewood	77.72	77.92	78.01	78.26	76.30	77.00	77.18	77.70	-1.42	-0.83
19150.5	Bridlewood	77.72	77.92	78.00	78.26	76.29	76.99	77.18	77.69	-1.43	-0.82
18693	Bridlewood	77.68	77.88	77.95	78.20	76.24	76.91	77.08	77.58	-1.44	-0.87
18528.1	Bridlewood	77.68	77.87	77.95	78.20	76.20	76.85	77.01	77.55	-1.48	-0.94
18402.6	Alt. 2 Detention	77.68	77.87	77.95	78.18	75.83	76.62	76.94	77.57	-1.85	-1.01
17679.2	Alt. 2 Detention	77.67	77.87	77.95	78.17	75.82	76.61	76.93	77.56	-1.85	-1.02
16850	Alt. 2 Detention	77.67	77.86	77.94	78.16	75.82	76.61	76.92	77.56	-1.85	-1.02
16085.5	Alt. 2 Detention	77.66	77.85	77.93	78.15	75.81	76.60	76.92	77.56	-1.85	-1.01
8175.8	Royal Lake Estates	68.61	69.23	69.51	70.09	68.45	69.12	69.41	70.04	-0.16	-0.10
7595.5	Royal Lake Estates	68.49	69.09	69.36	69.92	68.35	68.98	69.26	69.88	-0.14	-0.10
7330.7	Royal Lake Estates	68.44	69.00	69.26	69.78	68.31	68.91	69.17	69.74	-0.13	-0.09
6955.1	Royal Lake Estates	68.39	68.97	69.22	69.74	68.27	68.87	69.13	69.70	-0.12	-0.09
6557.7	Royal Lake Estates	68.32	68.88	69.13	69.63	68.21	68.78	69.04	69.59	-0.11	-0.09
6350.4	Royal Lake Estates	68.26	68.79	69.02	69.46	68.16	68.70	68.93	69.42	-0.10	-0.09
5682.4	Royal Lake Estates	68.24	68.75	68.98	69.41	68.14	68.66	68.89	69.37	-0.10	-0.09

As shown in the table above, water surface elevations along Gapps Bayou were decreased compared to the existing conditions hydraulic model. In Bonbrook Plantation, the 1% annual chance water surface elevation was lowered on average 0.01 feet. In Bridlewood Estates, the 1% annual chance water surface elevation was lowered on average 0.85 feet. In Royal Lake Estates, the 1% annual chance water surface elevation was lowered on average 0.1 feet. The figure below shows a comparison between the existing and Alternative 2 1% annual chance floodplain in the Bridlewood Estates subdivision. Exhibits 18-21 show the mapped floodplains for the 10%, 2%, 1% and 0.5% annual chance storm event.

Figure 3: Existing v. Alternative 2 1% Annual Chance Floodplain



Our floodway analysis indicates that the floodway between FM 762 and Berdett Road has reduced for Alternative Two. The floodway boundaries computed for Alternative 2 are shown on Exhibit 22. Detailed HEC-RAS output for the floodway computations is shown in Appendix O.

The cost for construction of the Alternative 2 detention pond, channel improvements, and culvert replacements would be approximately $8.5 million dollars including $1.0 million dollars for land acquisition. This alternative may require individual permit from the U.S. Army Corps of Engineers for the proposed channel improvement. The total expected damage when the Alternative 2 is implemented is $2.5 million dollars during a 100 year storm event, which reduced approximately $6.1 million dollars from the existing expected damage amount of $8.6 million dollars. Therefore, the benefit amount for Alternative 2 is $6.1 million dollars. The benefit to cost ratio for Alternative 2 is 0.7. Detailed Computations are shown in Appendix P.

3.3 Alternative Three – Channel Improvements and Downstream Detentin Basin

Alternative Three calls for culvert improvement under FM 762 and Berdett Road, a regional basin located approximately 1,800 feet downstream of the FM 762 and Gapps Bayou confluence, and a channel improvement between Berdett Road and proposed detention basin. The existing conditions hydrologic model created by R.G. Miller Engineers, Inc. was modified to reflect the drainage improvement proposed in Alternative 3. This alternative recommends that the existing three (3) 84-inch diameter and one (1) 78-inch diameter RCPs under Berdett Road will be replaced with three (3) 108-inch and two (2) 72-inch RCPs. Alternative 3 also recommend that the existing four (4) 6-foot by 5-foot RCB culverts under FM 762 will be replaced with four (4) 8-foot by 7-foot RCBs. Channel between Berdett Road and the proposed detention basin is proposed to be deepened and widened with average of 200-foot wop width. The new channel will require maximum 300-foot R.O.W. for the channel improvements.

The proposed detention pond is located approximately 1,800 feet downstream of FM 762 and south of Gapps Bayou to prevent any issues with any future major thoroughfare alignment. The total area needed to construct proposed detention basin is 33 acres, which will provide approximately 280 acre-feet of storage at the elevation 74.1 feet. It consists of a 30-foot maintenance berm, 4:1 (horizontal to vertical) side slope, and a 48" RCP outfall pipe to Gapps Bayou. The toe of the bank elevation is set at 64.2 feet and the top of the bank elevation is set at 75.2 feet. A diversion structure is proposed to be located to divert the flows from Gapps Bayou to the proposed regional detention basin. The diversion structure consists of an overflow weir and inflow pipe. The weir is proposed to have a crest elevation of 73.0 feet and a crest length of 30 feet. The inflow pipe is proposed to be a 60" RCP at a flowline elevation of 67.0 feet. Table 9 provides a summary of the Alternative 3 detention basin routing data. A layout map of Alternative 3 is shown in Exhibit 23.

Table 9: Elevation-Storage-Discharge Relationship for the Alternative 3 Basin

Elevation (ft)	Storage (ac-ft)	Discharge (cfs)
64.2	0.0	0.0
65.2	26.7	1.4
66.2	53.9	5.8
67.2	81.5	12.8
68.2	109.5	21.4
69.2	137.9	30.5
70.2	166.7	58.6
71.2	196.0	63.4
72.2	225.7	67.9
73.2	255.9	72.1
74.2	286.5	76.1
75.2	317.5	79.9
76.2	348.6	83.5

Modified Puls routing data for Gapps Bayou has been changed to reflect the improvements in the watershed for the Alternative 3 detention conditions. The existing discharge data of all the reaches in the watershed were incorporated into the Alternative 3 HEC-RAS steady flow model to create the storage outflow data for the channel. The Alternative 3 storage outflow from HEC-RAS was then updated in the HEC-HMS Alternative 3 model to determine the peak outflows. Please see Appendix Q for routing data.

The HEC-HMS software package developed by the U.S. Army Corps of Engineers is used to compute the proposed peak runoff rates and runoff hydrographs for the 10%, 2%, 1% and 0.2% storm events of 24-hour duration. The peak flow rates computed with the Alternative 3 conditions HEC-HMS hydrologic model are shown below in Table 10 along with the existing conditions values. Detailed results of the Alternative 3 conditions HEC-HMS model are shown in Appendix R.

Table 10: Existing v. Alternative 3 Peak Flow Rates

Hydrologic Element	10% Annual Chance			2% Annual Chance			1% Annual Chance			0.2% Annual Chance		
	Existing	Alternative 3	Difference	Existing	Alternative 3	Difference	Existing	Alternative 3	Difference	Existing	Alternative 3	Difference
Gapps_0302_J	331.2	331.2	0.0	452.6	452.6	0.0	512.2	512.2	0.0	643.3	643.3	0.0
Gapps_0294_J	512.7	512.6	-0.1	697.9	697.6	-0.3	795.1	794.9	-0.2	1004.4	1004.5	0.1
Gapps_0236_J	1051.2	1055.3	4.1	1420.8	1419.2	-1.6	1599.9	1588.7	-11.2	2026.2	2022.7	-3.5
Gapps_0187_J	1236.2	1034.6	-201.6	1656.1	1539.2	-116.9	1896.5	1829.3	-67.2	2547.6	2342.3	-205.3
Gapps_0161_J	1096.7	1093.4	-3.3	1318.4	1454.3	135.9	1414.1	1594.7	180.6	1937.1	1906.8	-30.3
Gapps_0150_J	1220.5	1212.8	-7.7	1479.0	1606.7	127.7	1589.4	1765.6	176.2	2080.9	2093.5	12.6
Gapps_0093_J	1546.2	1354.3	-191.9	1984.5	1820.6	-163.9	2188.3	2038.1	-150.2	2666.9	2512.9	-154.0
Gapps_0056_J	1706.3	1524.5	-181.8	2229.4	2056.8	-172.6	2472.2	2308.0	-164.2	3040.3	2875.0	-165.3
Gapps_0000_J	1871.8	1726.5	-145.3	2541.2	2358.9	-182.3	2861.0	2669.1	-191.9	3602.6	3400.9	-201.7

As shown in Table 10, minor impacts on flow rates along Gapps Bayou are shown after detention is applied for storm events up to and including the 1% annual chance (100-year) storm events. However, the increase in flow rates is mitigated by the proposed channel improvements along Gapps Bayou.

The existing conditions HEC-RAS model created by R.G. Miller Engineers was modified to account for the proposed detention pond and the updated culvert crossings at Berdett Road and FM 762. The table below shows the comparison between the existing and Alternative 3 conditions. HEC-RAS model results are included in Appendix S. The results of the analysis are shown in Table 11 below.

Table 11: Existing v. Alternative 3 Peak Water Surface Elevations

River Station	Location	Existing Conditions Flood Levels				Alternative 3 Conditions Flood Levels				Difference	
		10%	2%	1%	0.20%	10%	2%	1%	0.20%	10%	1%
29344.3	Bonbrook	81.24	81.99	82.30	82.80	81.20	81.98	82.30	82.80	-0.04	0.00
28494.4	Bonbrook	80.82	81.53	81.83	82.31	80.78	81.51	81.82	82.31	-0.04	-0.01
27602	Bonbrook	80.37	80.98	81.25	81.68	80.31	80.96	81.25	81.68	-0.06	0.00
26717.3	Bonbrook	79.94	80.35	80.54	80.82	79.86	80.33	80.52	80.82	-0.08	-0.02
23757.9	Bridlewood	77.72	77.92	78.03	78.27	75.33	76.65	76.96	77.71	-2.39	-1.07
23044.2	Bridlewood	77.72	77.93	78.05	78.29	75.37	76.69	77.00	77.75	-2.35	-1.05
22087.5	Bridlewood	77.72	77.93	78.04	78.28	75.36	76.67	76.98	77.73	-2.36	-1.06
21218.3	Bridlewood	77.72	77.93	78.03	78.27	75.35	76.66	76.97	77.71	-2.37	-1.06
20195.4	Bridlewood	77.72	77.92	78.03	78.26	75.34	76.65	76.96	77.70	-2.38	-1.07
19150.5	Bridlewood	77.72	77.92	78.02	78.26	75.34	76.65	76.96	77.70	-2.38	-1.06
18693	Bridlewood	77.68	77.88	77.98	78.20	75.26	76.56	76.84	77.60	-2.42	-1.14
18528.1	Bridlewood	77.68	77.87	77.96	78.20	75.18	76.47	76.75	77.58	-2.50	-1.21
18402.6	DA-05	77.68	77.87	77.95	78.18	74.78	75.80	76.17	77.60	-2.90	-1.78
17679.2	DA-05	77.67	77.87	77.93	78.17	74.76	75.78	76.14	77.59	-2.91	-1.79
16850	DA-05	77.67	77.86	77.92	78.16	74.75	75.76	76.12	77.58	-2.92	-1.80
16085.5	DA-05	77.66	77.85	77.92	78.15	74.74	75.75	76.11	77.58	-2.92	-1.81
15977.7	D/S FM 762	75.57	75.85	75.95	76.35	74.07	74.78	74.99	75.53	-1.50	-0.96
15075.6	D/S George Ranch H.S.	74.72	75.00	75.10	75.49	73.46	74.18	74.39	74.76	-1.26	-0.71
14123.4	Alt. 3 Detention	73.80	74.17	74.29	74.76	72.99	73.70	73.92	74.26	-0.81	-0.37
13183.6	Alt. 3 Detention	72.88	73.26	73.41	73.97	72.36	73.01	73.22	73.59	-0.52	-0.19
12867.8	Alt. 3 Detention	72.60	72.96	73.10	73.64	72.10	72.73	72.92	73.29	-0.50	-0.18
8175.8	Royal Lake Estates	68.61	69.23	69.49	70.09	68.48	69.11	69.38	69.99	-0.13	-0.11
7595.5	Royal Lake Estates	68.49	69.09	69.34	69.92	68.36	68.96	69.22	69.81	-0.13	-0.12
7330.7	Royal Lake Estates	68.44	69.00	69.24	69.78	68.31	68.88	69.12	69.67	-0.13	-0.12
6955.1	Royal Lake Estates	68.39	68.97	69.20	69.74	68.27	68.83	69.08	69.63	-0.12	-0.12
6557.7	Royal Lake Estates	68.32	68.88	69.11	69.63	68.19	68.74	68.98	69.51	-0.13	-0.13
6350.4	Royal Lake Estates	68.26	68.79	69.00	69.46	68.13	68.65	68.87	69.34	-0.13	-0.13
5682.4	Royal Lake Estates	68.24	68.75	68.95	69.41	68.10	68.61	68.83	69.29	-0.14	-0.12

As shown in the table above, water surface elevations along Gapps Bayou were decreased compared to the existing conditions hydraulic model. In Bonbrook Plantation, the 1% annual chance water surface elevation was lowered on average 0.01 feet. In Bridlewood Estates, the 1% annual chance water surface elevation was lowered on average 1.06 feet. In Royal Lake Estates, the 1% annual chance water surface elevation was lowered on average 0.12 feet. The figure below shows a comparison between the existing and Alternative 3 1% annual chance floodplain in the Bridlewood Estates subdivision. Exhibits 24-27 show the mapped floodplains for the 10%, 2%, 1% and 0.5% annual chance storm event.

Figure 4: Existing v. Alternative 3 1% Annual Chance Floodplain

The method used in to analyze the Alternative 3 floodway is Method 4, in which preliminary floodway boundaries are determined based on equal reduction of flow conveyance from the floodplain on each side of the channel, then Method 1 in which the user defines the limits of the floodway on each side of the channel to finalize all floodway computations. The floodway boundaries computed for Alternative 3 are shown on Exhibit 28. Detailed HEC-RAS output for the floodway computations is shown in Appendix T.

The cost for construction of the Alternative 3 detention pond, channel improvements, and culvert replacements would be approximately $8.2 million dollars including $1 million dollars for land acquisition. This alternative may require individual permit from the U.S. Army Corps of Engineers for the proposed channel improvement. The total expected damage when the Alternative 3 is implemented during a 100 year storm event is $2.5 million dollars, which reduced approximately $6.1 million dollars from the existing expected damage amount of $8.6 million dollars. Therefore, the benefit amount for Alternative 3 is $6.1 million dollars. The benefit to cost ratio for Alternative 3 is 0.7. Detailed computations are shown in Appendix U.

4.0 Ultimate Flood Protection Planning Evaluation

This section of the report describes the ultimate flood protection planning evaluation as a planning tool for a review agency to regulate the future development within the Gapps Bayou watershed. R.G. Miller Engineers, Inc. analyzed the impacts of a fully developed watershed on the peak flow rates and water surface elevations on Gapps Bayou. Please note that this report assumed that approximately 1,200 feet of undeveloped land on either side of Gapps Bayou would be developed without on-site detention requirements. This was done in recommendation by Fort Bend County Drainage District to account for the tracts that may place their detention basin near Gapps Bayou, which would be incorporated into ultimate channel size, if Gapps Bayou expanded in future. We fully recommend that all development within Gapps Bayou developed with detention basin on site as required by Fort Bend County Drainage District. For new development, we determined the impervious cover value would be 40% based on existing

landuse trends in the watershed. The time of concentration and storage coefficients for most of the drainage areas were modified to reflect the change in the percent impervious cover and ultimate development condition of the watershed. Drainage area DA-11 did not change because it is already considered fully developed. The ultimate development condition also considers the development of Grand Parkway in drainage area DA-05. The table below summarizes the model parameters for the existing and ultimate conditions. Detailed computations are shown in Appendix V.

Table 12: Existing v. Ultimate Hydrologic Parameters

Drainage Area	Existing Conditions			Ultimate Conditions		
	Percent Impervious (%)	Time of Concentration (hrs)	Storage Coefficient (hrs)	Percent Impervious (%)	Time of Concentration (hrs)	Storage Coefficient (hrs)
DA-01	25%	1.43	4.42	40.2%	1.45	4.49
DA-02	39%	0.50	3.97	40.9%	0.50	3.97
DA-03	13%	2.58	5.38	20.8%	2.07	4.30
DA-04	19%	3.24	11.69	19.4%	1.89	6.82
DA-05	0%	1.29	5.83	18.4%	0.77	3.51
DA-06	16%	1.59	5.06	40.0%	1.12	3.56
DA-07	0%	2.21	6.33	38.0%	1.19	3.40
DA-08	27%	4.62	10.00	29.5%	4.59	9.93
DA-09	0%	2.49	7.86	38.0%	1.57	4.96
DA-10	0%	2.15	3.28	38.0%	1.10	1.68
DA-11	40%	5.50	16.50	40.0%	5.00	16.50

In order to keep ultimate conditions peak water surface elevations at the same level or better than the existing conditions water surface elevation, channel improvements approach along Gapps Bayou were considered. Modified Puls routing data for Gapps Bayou was changed to reflect the improvements in the watershed for the ultimate conditions. Exhibit 29 shows the typical cross section for the channel improvements along Gapps Bayou. The existing discharge data of all the reaches in the watershed were incorporated into the ultimate conditions HEC-RAS steady flow model to create the storage outflow data for the channel. The ultimate conditions storage outflow from HEC-RAS was then updated in the HEC-HMS ultimate conditions model to determine the peak outflows. Please see Appendix W for routing data.

The HEC-HMS Version 3.3 software package developed by the U.S. Army Corps of Engineers is used to compute the proposed peak runoff rates and runoff hydrographs for the 10%, 2%, 1% and 0.2% storm events of 24-hour duration. The peak flow rates computed with the ultimate conditions HEC-HMS hydrologic model are shown below in Table 13 along with the existing conditions values. Detailed results of the ultimate conditions HEC-HMS model are shown in Appendix X.

Table 13: Existing v. Ultimate Peak Flow Rates

Hydrologic Element	1% Annual Chance		
	Existing	Ultimate	Difference
Gapps_0302_J	512.2	507.3	-4.9
Gapps_0294_J	795.1	784.5	-10.6
Gapps_0236_J	1599.9	1782.3	182.4
Gapps_0187_J	1896.5	2146.4	249.9
Gapps_0161_J	1414.1	2288.2	874.1
Gapps_0150_J	1589.4	2434.7	845.3
Gapps_0093_J	2188.3	3068.4	880.1
Gapps_0056_J	2472.2	3357.4	885.2
Gapps_0000_J	2861.0	3691.3	830.3

The existing conditions HEC-RAS model created by R.G. Miller Engineers, inc. was modified to account for the proposed channel improvements and the updated culvert crossings at Berdett Road and FM 762. The table below shows the comparison between the existing and ultimate conditions. HEC-RAS model results are included in Appendix Y. The results of the analysis are shown in Table 14 below.

Table 14: Existing v. Ultimate Peak Water Surface Elevations

River Station	Location	Existing 1% Annual Chance	Ultimate 1% Annual Chance
29344.3	Bonbrook	82.30	80.94
28494.4	Bonbrook	81.83	80.66
27602	Bonbrook	81.25	80.44
26717.3	Bonbrook	80.54	80.29
23757.9	Bridlewood	78.03	77.93
23044.2	Bridlewood	78.05	77.95
22087.5	Bridlewood	78.04	77.94
21218.3	Bridlewood	78.03	77.92
20195.4	Bridlewood	78.03	77.92
19150.5	Bridlewood	78.02	77.92
18693	Bridlewood	77.98	77.85
18528.1	Bridlewood	77.96	77.84
8175.8	Royal Lake Estates	69.49	69.20
7595.5	Royal Lake Estates	69.34	68.92
7330.7	Royal Lake Estates	69.24	68.71
6955.1	Royal Lake Estates	69.20	68.63
6557.7	Royal Lake Estates	69.11	68.39
6350.4	Royal Lake Estates	69.00	68.16
5682.4	Royal Lake Estates	68.95	68.02

As shown in the table above, water surface elevations along Gapps Bayou have generally decreased throughout Gapps Bayou. Exhibit 30 shows the 1% annual chance storm event floodplain.

The method used in to analyze the ultimate floodway is Method 4, in which preliminary floodway boundaries are determined based on equal reduction of flow conveyance from the floodplain on each side of the channel, then Method 1 in which the user defines the limits of the floodway on each side of the channel to finalize all floodway computations. The floodway boundaries computed for Alternative 1 are shown on Exhibit 31. Detailed HEC-RAS output for the floodway computations is shown in Appendix Z.

The ultimate right-of-way limits of Gapps Bayou were determined based on the 1% annual chance storm event. The right-of-way varies from 120 feet near the upstream limit of Gapps Bayou to 230 feet near the downstream limit. Existing right-of-way limits in areas that were developed along Gapps Bayou remained the same, such as Bonbrook Plantation, Bridlewood Estates and Royal Lake Estates. Exhibit 32 shows the right-of-way limits of Gapps Bayou.

5.0 Environmental Evaluation

Crouch Environmental Services, Inc. conducted an environmental study for the Gapps Bayou watershed. The objective was to identify potential features in or near the review area that might affect environmental permitting or construction requirements. It was determined that several fringe and isolated wetland areas were located within the watershed. Crouch also identified that the bald eagle, a threatened species, has a reported range area near the confluence of Gapps Bayou and Rabbs Bayou. Forested areas, known as Austin's Woods, were identified within the Gapps Bayou watershed. Also, a closed construction debris landfill was located on the northern boundary of the Gapps Bayou watershed. It was recommended by Crouch Environmental Services, Inc. that a detailed study would be needed prior to construction. The analysis by Crouch Environmental Services, Inc. is shown in Appendix AB.

6.0 Recommendations & Conclusion

Based on the results of our analysis, all three alternatives presented in this analysis mitigated existing flood damaged within the Gapps Bayou watershed. Our preliminary cost estimate analysis indicates that the cost to implement each alternative is practically same, and they are within the error of margin. Although Alternative Three showed the best flood level reduction throughout the reach, each alternative presented viable solution to the flooding issues within the watershed. Alternative One is considered if channel improvement option is not available at the time of the construction. Alternative Two and Three showed that detention basin can be placed either upstream or downstream of FM 762. We consider that the Alternative Three is the best scenario for this watershed; however, it will depend on the availability and the cost of the tract, since the location of the proposed detention basin on Alternative Two is entirely located within the floodplain of Gapps Bayou, it might be more readily available and economical to be purchased.

After careful consideration and evaluation, we concluded that the real viable and economical option for flood damage reduction in the Gapps Bayou watershed is to open up culvert crossing under FM 762. The construction of proposed culvert improvement must be completed at the same time or after the completion of the regional detention basin. Therefore, implementation of phasing plan for any of the alternatives presented is not recommended. Furthermore, we recommend that the results of the Phase I analysis serve as a basis for publishing new Flood

Insurance Rate Maps of the Gapps Bayou watershed and an addition to the Fort Bend County Flood Insurance Study. Publication of the flood insurance rate maps would aid the general public in knowing the risks of flooding within the Gapps Bayou watershed.

7.0 References

Fort Bend County Drainage District, 2011, Drainage Criteria Manual for Fort Bend County, Texas, p. 2-4.

Fort Bend County Drainage District, 2010, Flood Insurance Study for Fort Bend County, Texas and Incorporated Areas.

4Site Engineering, 2005, Drainage Analysis for the Proposed Summer Creek Subdivision, Fort Bend County, TX.

U.S. Army Corps of Engineers Hydrologic Engineering Center, 2000, HEC-HMS Technical Reference Manual, p. 38-51.