# CITY OF BELLAIRE TEXAS

**BUILDING AND STANDARDS COMMISSION**

**NOVEMBER 16, 2016**

| Council Chamber | Workshop Session | 6:00 PM |
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**7008 S. RICE AVENUE**
**BELLAIRE, TX 77401**

| Chairman | Commissioner | |
|---|---|---|
| Laura Thurmond | Mike Baker | |
| **Commissioner** | **Vice Chairman** | **Commissioner** |
| Paul Katz | Danny Spencer | Charles Formica |
| **Commissioner** | **Commissioner** | |
| Burt Martin | Lee Hampton | |

***Mission Statement:***
***The City of Bellaire is dedicated to outstanding quality service and facilities to ensure an open, progressive, and secure community.***

## I. WORKSHOP SESSION

**1. Call to Order & Announcement of Quorum**

2. Presentation of the City of Bellaire Drainage Study Report (presented to City Council on September 19, 2016), as prepared by ARKK Engineers.

3. Discussion on the Environmental and Sustainability Board's proposed changes to Chapter 9, Buildings, Article XI, Trees, Section 9-350 M., Undesirable Trees and Section 9-352 D., Tree Disposition Plan, of The City of Bellaire Code of Ordinances.

**4. Adjournment**

**Building and Standards Commission**
Council Chamber, First Floor of City Hall
Bellaire, TX 77401

Meeting: 11/16/16 06:00 PM
Department: Development Services
Category: Presentation
Department Head: John McDonald
DOC ID: 2080

**SCHEDULED**
**INFORMATION ITEM (ID # 2080)**

## Item Title:

Presentation of the City of Bellaire Drainage Study Report (presented to City Council on September 19, 2016), as prepared by ARKK Engineers.

## Background/Summary:

City Engineer, James Andrews of ARKK Engineers will be present to review the City of Bellaire Drainage Study Report with the Commission. A copy of the report is attached.

**ATTACHMENTS:**

- 2016 City of Bellaire Drainage Study Report (PDF)

September 7, 2016

Mr. Brant Gary
Director of Public Works
City of Bellaire
7008 S. Rice Avenue
Bellaire, Texas 77401

Re: City of Bellaire, Texas
FY 2016 Drainage Study

Dear Mr. Gary:

ARKK Engineers, LLC (ARKK) is pleased to submit an electronic copy of the City of Bellaire, Texas Drainage Study Report. Please note that we are finalizing the Flooded Structures Area Map and Geographic Information System (GIS) location of detention systems that will be included as Appendix C and Appendix D, respectively. We are also working on the presentation material for the September 19, 2016 Council meeting that will highlight expectations and future implementation strategies.

This report addresses drainage problems local to Bellaire and those regional to the Bellaire area. The recommended improvements include providing strategically located underground detention systems to replace the typical 2 – year design storm sewers on a select group of streets in areas to reduce the depth of flooding.

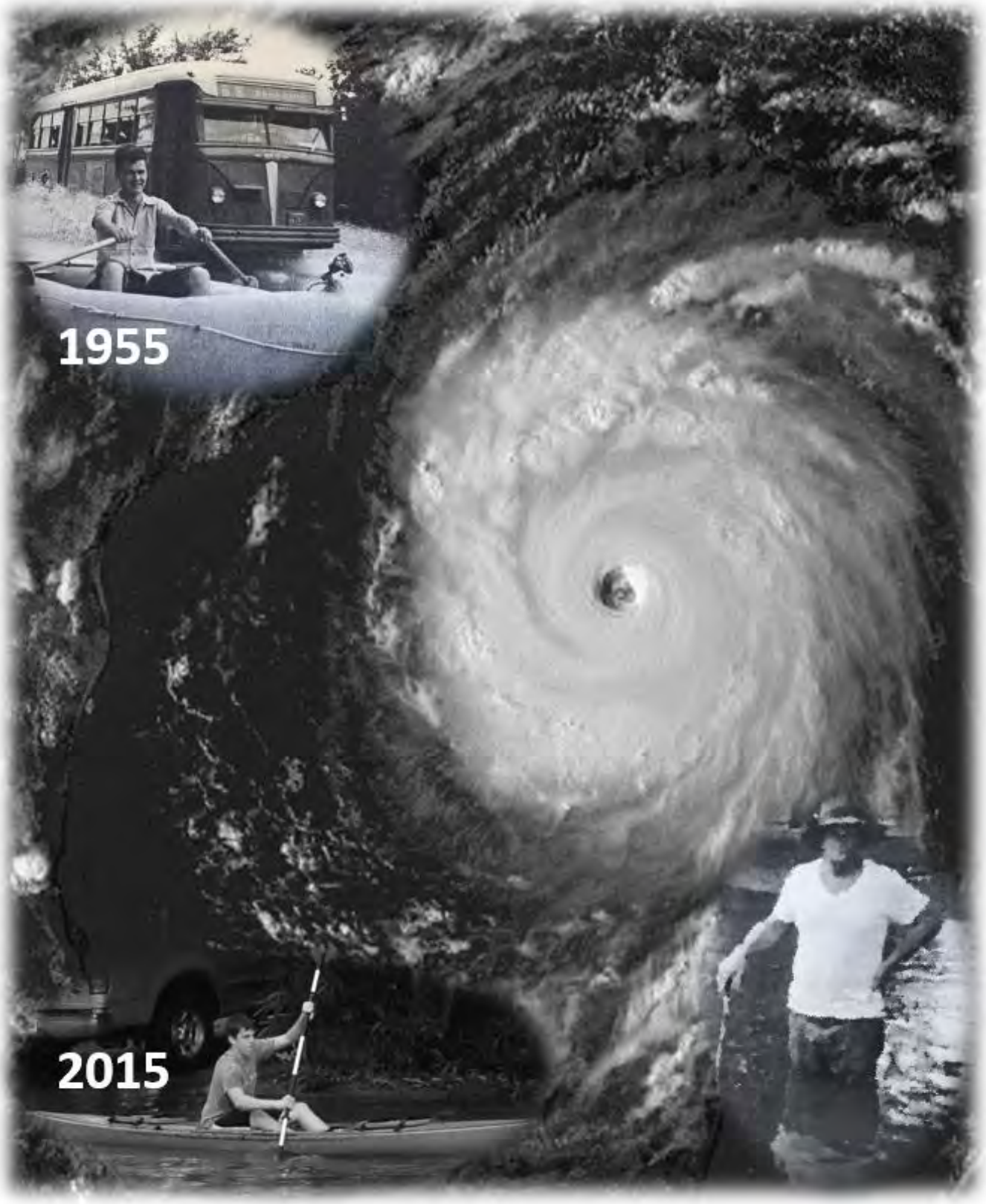
We want to thank you and Fire Chief, Mr. Darryl Anderson and your departments for your assistance with this report and in particular helping to identify properties and areas of the City that flooded during recent severe storms.

ARKK Engineers, LLC appreciates the opportunity to work on this important project for the City of Bellaire. We are available at your convenience to discuss the Drainage Study.

Sincerely,
ARKK Engineers, LLC

James B. Andrews, P.E.
City Engineer

7322 Southwest Fwy Suite 1040 • Houston, TX 77074 • (713)-400-ARKK • www.arkkengineers.com • TX PE Firm No. 13872




# City of Bellaire, Texas
# Drainage Study
# September 2016

ARKK ENGINEERS

SIRRUS ENGINEERS,

# City of Bellaire Drainage Study

## TABLE OF CONTENTS



# City of Bellaire Drainage Study

## TABLE OF CONTENTS

## Figures



## Tables

Preliminary Culvert sizes and Cost estimate tables

## Exhibits

Exhibit 1 – City Limits and Location Map
Exhibit 2 – City of Bellaire Draiange Systems
Exhibit 3– FEMA FIRM- FloodPlain Map
Exhibit 4– Contour Map and Base Flood Elevations
Exhibit 5 – Results of Flooding above 0.5-foot from 2-D model for 6-in/Hr Rainfall – low areas with water
Exhibit 6 – Results of Flooding from 2-D model for 6-in/Hr Rainfall – low areas with water
Exhibit 7 – Results of Flooding above 0.5-foot from 2-D model for 4-in/Hr Rainfall – low areas with water
Exhibit 8 – Results of Flooding from 2-D model for 4-in/Hr Rainfall – low areas with water
Exhibit 9 – Results of Flooding above 0.5-foot from 2-D model for 3-in/Hr Rainfall – low areas with water
Exhibit 10 – Results of Flooding from 2-D model for 3-in/Hr Rainfall – low areas with water
Exhibit 11 – Results of Flooding above 0.5-foot from 2-D model for 2-in/Hr Rainfall – low areas with water
Exhibit 12 – Results of Flooding from 2-D model for 2-in/Hr Rainfall – low areas with water
Exhibit 13 – Proposed City Wide Storm Sewer Improvements
Exhibit 14 – Regional Projects with Participation By Others
Exhibit 15 – Results of Flooding from 2-D Model for 4-in/hr. Rainfall- Low Areas with Water – Estimated Street Flooding approximate to 1% Flood
Exhibit 16 – Proposed City Wide Storm Sewer Improvements

## Appendix

Appendix A – 2-D run Videos
Appendix B –City of Bellaire Overall Drainage Area Map, Flows and Sample Calculation for the Underground Culvert Sizing
Appendix C – Flooded Structures Area Maps – May 25-26 Storm, April 18 2016 Storm
Appendix D – GIS Location of Detention Systems

# City of Bellaire Drainage Study

## Executive Summary

The City of Bellaire, Texas retained ARKK Engineers, LLC to conduct a Drainage Study to investigate possible alternatives to reduce the occurrence of structures flooding within the city. This study discusses the types of floods that are prevalent in the Bellaire area and practical improvements the City of Bellaire may implement on its own and suggestions for regional projects that Bellaire could partner with other entities for mutual flood control benefits. It is anticipated that the recommendations for drainage improvements in this study will help prioritize future street and drainage capital improvements.

The Drainage Study also addresses plans for removing certain areas of the City from the floodplain by Letter of Map Revision (LOMR). The goal of the LOMR is to remove as many homes from the Flood Insurance Rate Map designated floodplain as possible and significantly lower flood insurance cost for those residents. Currently, there are 4,780 flood insurance policies in Bellaire costing residents almost $5.6 million every year. It is important to note that this exercise is not intended to suggest that flood insurance is not needed in any area of Bellaire, but to simply reduce the cost of flood insurance to Bellaire residents. The LOMR process is currently underway and should be ready to submit to the Harris County Flood Control District (HCFCD) for their review and approval this year. If the LOMR is approved, the cost saving to the citizens of Bellaire is anticipated to be approximately $3 million every year.

ARKK teamed with SIRRUS Engineers, Inc. to develop a storm water overland flow model to understand flow patterns in and around Bellaire and to help determine areas of the City most in need of drainage improvements. The model showed areas more likely to pond to elevations that could flood structures before flowing overland during various rainfall intensities. Once the flooding areas were identified, potential storm drainage improvements were identified to lower flood elevations anticipated during a localized 100 – year storm event.

The Drainage Study included a background review of storm intensity history, including the major rainfall event during May 25-26, 2015 and more recently the April 18, 2016 or Tax Day event. Rainfall data, stream data and the general location of structures flooded during Tropical Storm Allison were also reviewed and compared to the model results.

### General

The City of Bellaire is located in southeast Texas and has a population of approximately 17,000 residents. Bellaire is a small developed city with an area of 3.6 square miles that is surrounded by the City of Houston and is located just west of the cities of West University Place and Southside Place and very near downtown Houston, the Galleria and the Texas Medical Center.

Bellaire is part of the 137 square mile Brays Bayou watershed and the entire City is within Brays Bayou watershed.

**Factors Contributing to Flooding in Bellaire**

Bellaire has flooded from various severe storms over the last century. Various degrees of flooding have plagued the City of Bellaire and for that matter Southeast Texas for decades. Recently, heavy rainfall amounts and a large number of severe storms have produced more occasions for flooding than normal. While the City of Bellaire is dedicated to minimizing adverse impacts associated with flood events, there are many factors not within the city's control that contribute to flooding in Bellaire. Some of these are:

- very high average annual rainfall of about 50 inches
- very flat topography
- clay soils that do not absorb water very well
- close proximity to an undersized Brays Bayou
- large amounts of storm water from the City of Houston flow into Bellaire from the north
- localized storm water runoff from Bellaire drains into undersized drainage systems owned by the City of Houston
- Below base flood finished floor elevations of homes constructed prior to the National Flood Insurance Rate Standards.

The City of Bellaire does control the drainage improvements constructed within the City limits and the finished floor elevation requirements for new residential and commercial development. Residential lot drainage and fill requirements and requires storm water detention on commercial development are also controlled by City of Bellaire.

**Recent Flood Events**

Over a recent 13-month period, Harris County experienced six (6) significant flood events occurring on the following dates:

May 12-13, 2015
May25-26 2015
Oct. 24-25, 2015
Oct. 31 2015
April 18 2016
May 25-27, 2016

Each one of these events resulted in rainfall totals over eight (8) inches in portions of Harris County. Never, in modern records, has Harris County experienced such frequent back to back flooding events. The only year that comes close is 1998 when three major floods affected the county in September (Frances), October, and November.

Two of these recent significant events caused major flooding in Bellaire. The May 25-26th 2015 flood event within the City of Bellaire resulted in approximately 220 homes being flooded. Fire Department records indicate approximately 175 of those homes flooded were located east of IH 610. A handful of homes flooded during the April Tax Day storm of 2016.

It is important to note that all storm events are different. A review of the Tropical Storm Allison flood event documentation of 2001 shows approximately 1,432 homes were flooded in Bellaire with 1,015 of those homes located east of IH 610.

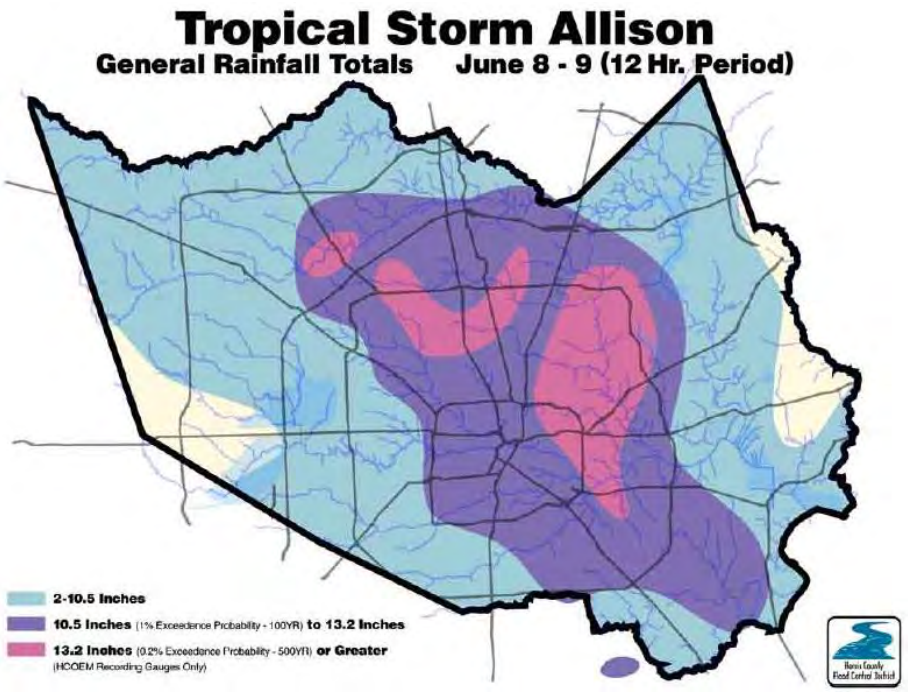



Figure 1- HCFCD Tropical Storm Allison Rainfall Totals (Source HCFCD)

This HCFCD graphic shows considerably higher rainfall totals occurred inside the Loop within Bellaire than outside the Loop.

## TYPES OF FLOODS

Flooding occurs in the Bellaire area because of shallow floodplain flooding or ponding/overland flow problems or some combination of both.

### Shallow Floodplain Flooding

Shallow floodplains exist throughout much of Harris County. Bellaire is located very near Brays Bayou and is in the shallow floodplain of Brays Bayou.

When the Bayou capacity is exceeded and flood waters overtop the bayou banks, flooding occurs in the land areas near the bayou that are located at lower elevations. Land areas can remain flooded for hours until water surface elevations drop in the bayou.

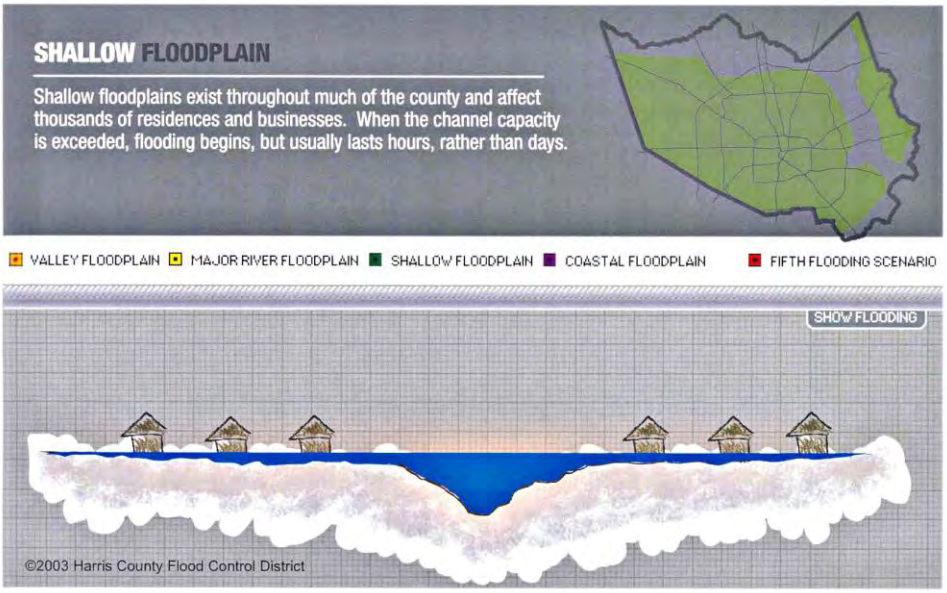



**Figure 2- HCFCD Shallow Floodplain (Source HCFCD)**

Ponding/Overland Flow Flooding

Ponding or overland flow flooding occurs when intense local rainfall exceeds storm sewer or roadside ditch capacity, the water can “pond” in the streets deep enough to flood residences that are away from the bayou.

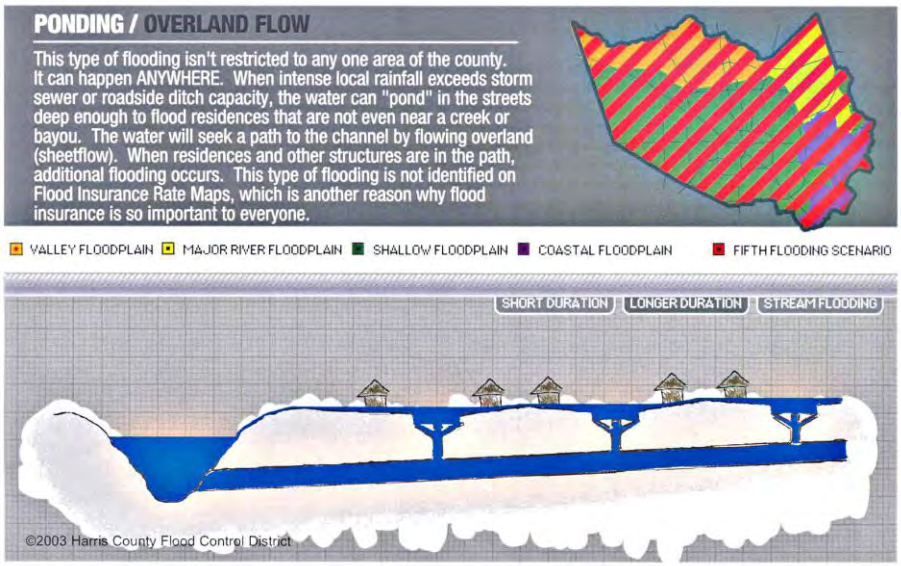



Figure 3- HCFCD Ponding/Overland Flow (Source HCFCD)

This type of flood is not restricted to any one area. It can happen anywhere. The storm water ponds until it eventually seeks a path to the outfall by flowing overland. When residences and other structures are below the surrounding land elevation or in the path of the overland flow, flooding may occur. The probability of this type of flooding is not shown as a floodplain on the Flood Insurance Rate Maps.

## Floodplain in Bellaire

The ARKK/SIRRUS team performed a preliminary review of the existing FEMA flood insurance rate maps for the City of Bellaire. The current FEMA Flood Insurance Rate Maps were prepared based on FEMA Hydrological and Hydraulic models. The review of the models revealed inconsistencies that have been discussed with the Harris County Flood Control District. The preliminary review of the mapping and the models indicates the floodplain water surface elevation changes by approximately 2.75 feet from the IH610 Bridge upstream to the west city limits. This is a significant increase in only about a mile upstream when there is no dramatic increase in flows through this reach. It appears that the HEC-RAS model used in mapping the floodplain incorrectly shows an obstruction that results in an increase in the water surface elevation within the City of Bellaire west of IH610. This higher base flood elevation may erroneously place more Bellaire properties within the designated floodplain.

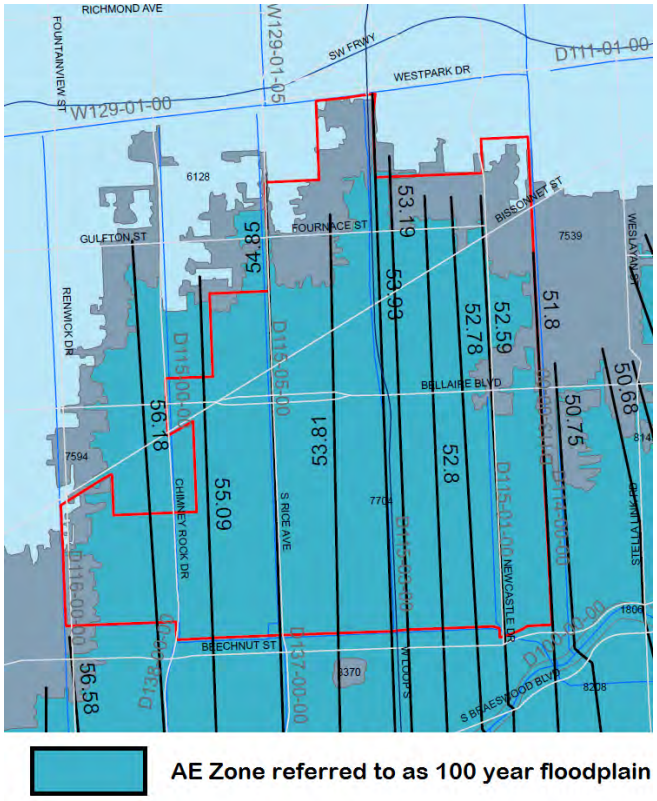



Figure 4- 100-year or 1% Floodplain in Bellaire

The HCFCD has indicated they will consider this new information during their planned remapping effort of the floodplain to reflect improvements completed to date because of Project Brays. Project Brays is an over $400 million major flood control project being undertaken with the Corps of Engineers with major improvements already completed and providing benefits to the Brays Bayou watershed. The HCFCD plans to be begin a new floodplain mapping project in 2017 to show the reduction in floodplain realized due to the ongoing construction of Project Brays. This remapping effort by the HCFCD could take a minimum of five years to complete, because it must be approved by FEMA.

**Letter of Map Revision**

On a more immediate basis and as recommended by this study, the City of Bellaire is currently developing a Letter of Map Revision report that will be submitted to the HCFCD to potentially remove certain areas within the City of Bellaire from the floodplain as shown on the existing FEMA maps. The current floodplain maps do not reflect the spatial ground realities like the presence of buildings, fences and other obstructions that can prevent flood waters from flowing back into the City of Bellaire when flood water elevations exceed the capacity of Brays Bayou. This remapping effort will attempt to remove properties from the flood plain showing the backwater flow to be through the street system versus through the obstructions. If this remapping effort is successful and approved by the HCFCD and FEMA, many Bellaire properties will be removed from the mapped 100-year floodplain, thus providing significantly lower flood insurance premiums for those citizens of Bellaire.

This immediate effort to remap the FIRM will be submitted directly to the HCFCD as the local FEMA designated partner. Possibly as soon as four (4) months after the letter of map revisions are submitted to the HCFCD, the revised maps may be used to determine lower insurance premiums for those citizens located in the affective area.

**Drainage Improvement Alternatives**

The Drainage Study team looked at several alternatives for drainage improvements. Some improvement options, while theoretically could protect the City of Bellaire from both the Shallow Floodplain Flood and the Ponding/Overland Flood, are very cost prohibitive. The recommended alternative identified, provided increased flood protection during the very intense local storms and suggests the need to partner with other entities to reduce the probability of flooding from Brays Bayou overtopping its banks.

To prevent the City of Bellaire from flooding from a 100-year localized flood event, where large amounts of rainwater fall directly within the the city and from flooding occurring from the backwater effects of Brays Bayou water overtopping the banks is possible. In other words, the City of Bellaire requirements of protection during the 100-year flood event requires improvements outside Bellaire and thus are not solely under Bellaire's control.

100-Year Level of Protection for All Drainage Systems Alternative

Improve Brays Bayou to completely contain the 100-year storm, improve Cypress Ditch to contain the 100-year event, improve all North/South major drainage arterials to transport the 100-year storm water flows through the City of Bellaire and to Cypress Ditch or Brays Bayou and improve all local storm sewers and local street systems to convey 100-year flows to their respective outfalls. The improvements to Brays Bayou alone would cost much more than current Project Brays which is anticipated to provide a 10-year level of flood protection. The current Project Brays has an estimated price tag of over $400 million and does not provide protection from the 100-year event. Cypress Ditch drains approximately 2,400 acres of the City of Houston and the City of Bellaire. There is insufficient right-of-way to construct an open channel section capable of carrying the 100-year event and it is estimated that a closed conduit section to accommodate the 100-year event would cost over $80.1 million. To reconstruct all of the interior pipe systems to the 100-year level of service is estimated to cost another $236 million. The total upgrade to the entire drainage system serving the City of Bellaire is not an economically feasible option considering the number of homes flooded during the historical major storm events previously discussed.

Neighborhood Detention Pond Alternative

This alternative considers building detention ponds capable of storing flood waters generated from localized extreme storm events within each individual neighborhood. A 10 acre-ft. pond could be constructed for each 40 or so homes. The storm drainage systems would need to be improved to the 100-year capacity to transport storm water to ponds and improvements to Brays Bayou to contain the 100-year event so flood waters from the bayou would not back up into the city would be required as previously described. This option would displace homes to build detention ponds and significantly displace neighborhoods and therefore was not considered a viable option.

Levee System Alternative

This option would consider constructing a levee system around the City of Bellaire similar to the levees in Fort Bend County for subdivisions located within the floodplain. The levee would prevent storm water that overtops the banks of Brays Bayou from entering or back flowing into the City from the south and block overland flow from City of Houston to the north from entering Bellaire. The City of Bellaire's internal storm sewers would operate at a 100-year level of protection with large storm water pump stations and storage areas required to prevent the localized storms from flooding the City. The storage would be required to offset the loss of floodplain storage the City of Bellaire is providing to the Brays Bayou watershed. This option would require large amounts of land within City of Bellaire, several pump stations, blocking the City of Houston off-site sheet flows into Bellaire, and changes to the road elevations exiting the City of Bellaire to drive over the perimeter levee. The levee alternative perhaps would be viable if the City of Bellaire was being developed from scratch but would not be practical to try and retrofit a levee system in a fully developed urban area.

Strategic Underground Detention Storage Recommended Alternative

Using new technologies available, a more practical and cost effective alternative was developed to provide reasonable flood protection to the City of Bellaire. This option involved identifying potential ponding areas within the City utilizing a SOBEK 2-D model supplemented with observed flooding locations within the City of Bellaire. The 2-D complex urban drainage model analyzed different rainfall intensities to predict flooding areas.

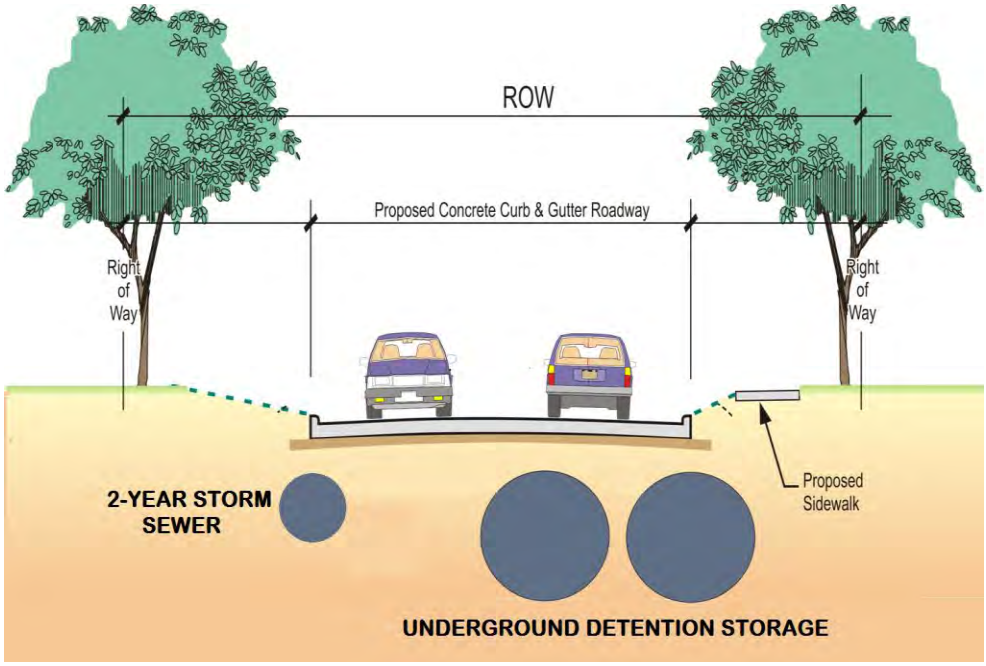



Figure 5- Underground Detention

This option would include strategically locating underground storage pipes within the existing street right-of-way within the ponding or flooding areas identified and constructed as part of new street and drainage reconstruction projects were undertaken. The typical two-year underground storm sewer pipe system constructed during the total reconstruction of a roadway improvement project would be upsized to store a 100-year localized rainfall event. The goal would be to lower the height of the floodwaters during a localized 100–year storm event in areas where overland flow problems exist.

This underground storm sewer drainage and detention systems would limit the flow at the respective outlet to the existing conditions and not require the entire underground system downstream of these detention systems to be improved. Costly mitigation efforts for potentially increasing flows to downstream areas would also be avoided.

Based on the ponding maps from the 2-D model video, individual storm sewer detention locations for the 100-year flood event were identified and a preliminary cost estimate was provided. The final location and size configuration of these storage systems should be

determined during the Preliminary Engineering Phase of each street reconstruction project. The available outfall depth is critical to determine the vertical dimension of the storage system. Also during this PER stage, the detention system material type will be determined. Reinforced Concrete Boxes, Reinforced Concrete Pipe and High Density Polyethylene Pipe would be considered suitable for the detention storage systems.

These detention systems would replace the two-year design storm sewer systems normally used during street reconstruction on a particular block at a cost of about five to six times that of a typical two-year design storm sewer system. These localized detention storage systems constructed by the City of Bellaire would not increase flows downstream because the outfall would be restricted to the 2-year storm flows or existing flows.

The approximate location of the individual localized underground detention systems are shown on Exhibit 13 of this report. The approximate cost of the 100-year capacity storm sewer detention systems associated with major drainage areas is as follows:

- Chimney Rock Rd. system $1.3 million
- South Rice system $2.9 million
- IH 610 West Loop system $41.1 million
- Newcastle system $36.7 million
- Rail Road system area north of Bellaire Blvd. $2.9 million
- Southdale system $0.9 million

The estimated total cost of the storm water storage systems is $85.8 million versus approximately $30 million for the two year systems or an increase of approximately $56 million to the overall Street and Drainage reconstruction program. The underground detention storage systems would allow for storing the 100-year storm water underground with the exception of the allowable six inches to one foot of water ponding in the street. Storm water ponding in the street is typical to storm water management in Harris County.

This underground detention storage option would be focused on reducing the localized flooding events and would not prevent flood waters from Brays Bayou from flowing back into the City as water surface elevations in the bayou exceeded the top of banks.

It is suggested that the City consider the viability of building backflow systems such as flap gates within the major underground North/South drainage arterials to help prevent back water flows from the bayou from taking up the capacity of Bellaire's local systems when waters start to rise in Brays Bayou. These local detention systems and back flow devices would provide less and less protection from flooding as more and more storm water overflowed the banks of Brays Bayou.

It is also recommended that Bellaire continue to require the finished floors of new structures to be built above the base flood elevation. The vast majority of homes flooded during the recent storms were older original Bellaire homes constructed at a low elevation compared to the

surrounding land. There were a few homes flooded that were rebuilt prior to the current ordinance requiring finished floors to be above the 100-year base flood elevation.

Cost sharing regional projects with TxDOT, the City of Houston, the Texas Water Development Board, FEMA and the HCFCD are also recommended to be considered when others entities in addition to City of Bellaire would benefit from drainage system improvements. The most benefit to all being additional improvements to Brays Bayou to completely contain the 100-year or 1% storm events.

In summary, this Drainage Study recommends the City of Bellaire consider the following:

1. Construct local underground storage systems by increasing the normal two-year design storm sewer system to store the 100-year storm volumes at selected strategic locations.

2. Construct backflow prevention systems at several of the major drainage system outfalls like the Newcastle and IH 610 system outfalls to Cypress Ditch to prevent back water flow from Brays Bayou backing up into these systems during high water flood stages.

3. Prepare and submit a LOMR to the HCFCD for approval to remove certain areas of the City of Bellaire from the floodplain.

4. Request TxDOT to improve the IH 610 drainage system to properly receive the existing drainage area storm water runoff and convey to Brays Bayou. The system should be increased to meet their current design criteria for a system receiving this amount of runoff from such a large drainage area.

5. Request interim improvements to the system directly adjacent to the proposed improvements associated with the US69/IH610 interchange improvements to receive the storm water runoff from the existing drainage area and meter the outfall until such time as downstream improvements are constructed as mentioned above.

6. Request the City of Houston/Texas Water Development Board/FEMA to participate in conveyance and storage capability improvements within the Chimney Rock and S. Rice Ave. drainage systems because they serve such large areas of the City of Houston as well.

7. Develop inter-local agreements with the City of Houston for future improvements and maintenance for drainage facilities that serve both entities. These agreements should consider development and detention requirement standards for any new development.

8. Request the City of Houston and/or the City of West University Place to consider installing back flow prevention systems in Cypress Ditch, Kilmarnock Ditch and the Railroad Ditch to prevent back water from Brays Bayou backing up into these systems during high water flood stages.

9. Remove existing identified utility conflicts within the major N/S drainage systems, where possible.

The City of Bellaire would concentrate funding for local improvements to reduce localized flooding within Bellaire and request regional partners to help with the larger projects like improving Brays Bayou, Cypress Ditch and the major North/South drainage arterials that also benefit other entities.

The priority for proposed localized detention storage improvements should consider the severity of flooding by area as it relates to structures flooding and the potential for lowering the water surface from a localized 100-year storm event. This improvement need would be weighted with other needs like the level of roadway condition, gutter ponding and pedestrian and traffic volumes to determine the priority order of street and drainage reconstruction projects.

The City Engineer and the Director of Public works are currently formulating the implementation strategy for the prioritizing the storm water improvements as part of the next street and drainage reconstruction program.

## 1.0 Introduction

### 1.1 Project Location and Background

City of Bellaire is located in southeast Texas and has a population of over 17,000 residents. Bellaire was founded in 1908 as a residential neighborhood and agricultural trading center. Bellaire is located southwest of downtown Houston and the Houston Galleria, Major universities and the Texas Medical Center are very close to Bellaire. The approximately 6500 homes in the city are a mix of 1940 - 1960's ranch homes and newly constructed large two-plus story homes and commercial properties located in several sectors of the city. Bellaire is a zoned community, and known as the City of Homes. The City of Bellaire is part of the 137 square mile Brays Bayou watershed. The Brays Bayou watershed is fully urbanized, although several large urban parks and regions of open space are located within the watershed. See Exhibit 1 for the City Limits and Location Map.

Bellaire, like most of southeast Texas near the Gulf of Mexico, is subject to flooding because of high amounts of rainfall typical of area, very flat topography, clay soils that do not absorb water very well and the inability of the main flood control facility (Brays Bayou for the Bellaire area) to contain extreme event storms. As pointed out on the HCFCD website, the flooding problems in most of Harris County are severe. Several hundred thousand homes and businesses are in the identified floodplain (not all flooding areas are mapped), and projects to reduce the risk of flooding are estimated in the billions of dollars.

Harris County Flood Control District (HCFCD) is the agency in charge of flood control for Harris County. HCFCD is a special purpose district that was created by the State Legislature in 1937 in response to devasting floods occurring in 1929 and 1935. The HCFCD boundaries are coincident with Harris County and is responsible for devising flood damage reduction plans, and maintaining the primary drainage infrastructure.

Communities like the City of Houston and the City of Bellaire are floodplain administrators for their own community and participate in the National Flood Insurance Program (NFIP). Everyone living in a participating community of the NFIP can buy flood insurance. Just because your home is not mapped within the 100-year floodplain does not mean that you are free from the potential to flood. The mapped floodplain is only an estimate of where flooding is predicted to occur from a bayou or creek, given a set of parameters including a hypothetical rainfall occurring over a watershed for an assumed amount of time. FEMA Flood Insurance Rate Maps (FIRMs) show areas subject to flooding from a primary flooding source, typically major rivers, bayous and their tributaries, and are meant to help determine the risk of flooding for a property. However, flooding from sources that are not identified on the FIRMs is possible and occurs often in Harris County and sometimes in Bellaire. Many homes flood because excess storm water cannot drain into a storm drainage system fast enough to prevent localized ponding from reaching the inside of a home. On a national basis, one-third of the flood loss claims are from property located outside of the mapped 1% (100-year) floodplain. This does

not mean the FIRMs are wrong. It simply means that not all flooding sources are mapped and that more severe floods can occur than the ones mapped. It is costlier for homes located within the floodplain to purchase flood insurance because the risk of flooding is considered greater at these locations than those properties located outside the mapped floodplains.

It is important to realize that preventing all flooding in Harris County "is virtually impossible" as stated on the HCFCD website, however larger storm sewers, more street storage and detention systems help each community cope with flooding by reducing the risk and more particularly, the frequency of flood damage.

Most of Harris County is in the San Jacinto River watershed. Within that larger area, most Harris County watersheds drain into one of nearly two dozen major creeks and bayous. The City of Bellaire is in the Brays Bayou watershed, the rain that falls in the City of Bellaire will eventually end up in Brays Bayou. The Brays Bayou watershed is located in southwest Harris County and portions of Ft. Bend County and drains parts of the cities of Houston, Missouri City, Stafford, Bellaire, West University Place, Southside Place and Meadows Place. The bayou flows eastward from Fort Bend County to its confluence with the Houston Ship Channel.

Currently, the HCFCD is partnering with the U.S. Army Corps of Engineers (the Corps) on a major flood damage reduction project called "Project Brays." Project Brays (or the Brays Bayou Flood Damage Reduction Project), is a muti-year, $413 million project to reduce the risks associated with flooding. For local drainage projects, the City of Bellaire generally follows the City of Houston's design criteria for the design of storm sewers, street drainage and also stormwater detention systems.

Stormwater detention basins are a place to store damaging flood waters temporarily until the channels or storm sewers can safely carry the water away. As flat as Harris County is, most of our stormwater storage has to be excavated. The HCFCD detention basins are typically large regional facilities that may be several hundred acres in size. New developments often use stormwater detention to offset or mitigate the negative effect development may have on flooding (due to covering up soil with buildings and concrete, and speeding up the rate water runs off an area).

The City of Bellaire was built prior to our current understanding of flooding potential and prior to current regulations that restrict certain uses of flood-prone land. Streets and storm sewers are typically designed for normal rainfall events and, when heavy rains fall, the systems are overloaded. Water will begin to pond in the streets and then try to flow overland to Cypress Ditch or Brays Bayou, sometimes flooding houses along the way.

Flooding occurs in the Bellaire area because of shallow floodplain flooding or ponding/overland flow problems or some combination of both. Shallow floodplains exist throughout much of Harris County. The City of Bellaire is located very near Brays Bayou and when the Bayou capacity is exceeded and flood waters overtop the bayou banks, flooding occurs. Land areas can remain flooded for hours until water surface elevations recede.

Ponding or overland flow flooding is not restricted to any one area. It can happen anywhere. When intense local rainfall exceeds storm sewer or roadside ditch capacity, the water can "pond" in the streets deep enough to flood residences that are away from the bayou. The storm water ponds until it eventually seeks a path to the outfall by flowing overland. When residences and other structures are below the surrounding land elevation or are in the path of the overland flow, flooding may occur. The probability of this type of flooding is not shown as a floodplain on the Flood Insurance Rate Maps.

In most areas, the streets are considered to be a part of the drainage system. During a typical rainfall event, water will flow through storm sewers located underneath the street or in roadside ditches to a drainage channel such as a ditch or bayou. When the capacity of the storm sewers or roadside ditches is exceeded, the street itself will hold the water until the storm sewer or roadside ditch has additional room to drain the water. Just because your home is not mapped within the 100-year floodplain does not mean that you are free from the potential to flood. Restricted development is permitted in the 1% (100-year) floodplain. The floodplain administrators at each municipality within Harris County are responsible for enforcing floodplain management rules and regulations that govern construction in the floodplain. The City of Bellaire requires the finished floor of new structures to be a minimum of one foot above the base flood elevation. Bellaire also restricts the amount of fill allowed on residential lots.

## 1.2 Definitions for this Drainage Study

The definition of some of the terms used in this drainage study and defined by HCFCD with changes to reflect the City of Bellaire are listed below:

**1% (100-year) Floodplain**
The area of land that has a 1% chance of being inundated by flood waters from a bayou, stream or creek in a given year. It is commonly referred to as the 100-year floodplain. This is a regulatory standard used to administer floodplain management programs, the National Flood Insurance Program (NFIP) and to set building requirements for new construction. Statistically, the 1% (100-year) flood has a 26% chance of occurring during a 30-year period of time – the length of many mortgages. The 1% (100-year) floodplain is the Base Flood or Special Flood Hazard Area. It is referred to as Zones AE, AO, A, or VE for insurance purposes on Flood Insurance Rate Maps (FIRMs). Properties located in these mapped zones are required to have flood insurance if the owner has a federally backed mortgage on the property.

**1% (100-year) Rainfall**
An amount of rain having a 1% chance of being equaled or exceeded in any given year. For City of Bellaire this amount of rainfall is just over 13 inches in 24 hours or just under 11 inches in 12 hours.

**Base Flood**
A flood having a 1 % chance of being equaled or exceeded in any given year. This flood is sometimes called the 1% or 100-year flood.

**Base Flood Elevation**
This is the elevation above the average sea level that waters from a 1% (100-year) flood will reach at a given point along a creek or bayou. These elevations are determined using hydrology and hydraulic computer models. The elevations are then mapped on the topographic data for the county to produce the 1% (100-year) floodplain.

**FEMA (Federal Emergency Management Agency)**
The federal agency responsible for providing leadership and support to reduce loss of life and property and to protect our institutions from all types of hazards. This is accomplished through a comprehensive, risk based, all hazards emergency management program consisting of mitigation, preparedness, response, and recovery. In relation to flooding hazards, FEMA is the federal agency responsible for administering the National Flood Insurance Program (NFIP).

**FIRM Panel FIRM stands for Flood Insurance Rate Map**
In order to print the FEMA Flood Insurance Rate Maps at a scale of 1-inch = 1,000-feet, the maps are broken out into over 150 FIRM panels that cover the entire Harris County area. The City of Bellaire is located on one (1) FIRM panel.

**Flood Insurance Rate Maps**
Prepared by FEMA, Flood Insurance Rate Maps, or FIRMs, show areas that have the highest probability of flooding and illustrate the extent of flood hazards in a flood-prone community. These maps are used to determine flood insurance rates for communities participating in the National Flood Insurance Program (NFIP). Properties located in mapped zones AE, AO, A, or VE are required to have flood insurance if the owner has a federally backed mortgage on the property.

**Floodplain**
From time to time, bayous and creeks naturally come out of their banks due to heavy rainfall and inundate the adjacent land. This area that is inundated is referred to as a floodplain. Residences and businesses within the floodplain are considered to be at risk of being damaged by flooding. The floodplain is typically expressed by stating its frequency of occurrence. For example, the 1% (100-year) floodplain represents an area of inundation having a 1% chance of being equaled or exceeded in any given year, whereas the 2% (50-year) flood plain has a 2% chance of being equaled or exceeded in any given year. FEMA Flood Insurance Rate Maps (FIRMs) show the 1% (100-year) and 0.2% (500-year) floodplains.

**Infrastructure**
For the Harris County Flood Control District, infrastructure typically refers to the primary drainage system, including channels and detention basins. The City of Bellaire's streets, storm

sewers, detention systems, storm inlets and roadside ditches are considered storm water management infrastructure.

**Insufficient Capacity**
Exists when the desired capacity of an infrastructure exceeds the existing capacity; that is, when the infrastructure cannot carry or hold all of the stormwater that could flow to it.

**Lidar**
LiDAR for Light Detection and Ranging. A highly detailed ground elevation data through cutting-edge technology that utilizes the projection of millions of laser signals to the ground from a specially equipped aircraft. Using powerful software, the data from these LiDAR reflections is collected by measuring the time it takes for the aircraft to receive each of the millions of laser reflections. The resulting data is then combined and converted into an image that looks exactly like the terrain below, including buildings, trees, roadways, creeks and bayous.

**Levee**
A physical barrier constructed to protect areas from rising floodwaters.

**LOMR**
(Letter of Map Revision) - FEMA's modification to an effective Flood Insurance Rate Map (FIRM), or Flood Boundary and Floodway Map (FBFM), or both. LOMRs are generally based on the implementation of physical measures that affect the hydrologic or hydraulic characteristics of a flooding source and thus result in the modification of the existing regulatory floodway, the effective Base Flood Elevations (BFEs), or the Special Flood Hazard Area (SFHA). The LOMR officially revises the Flood Insurance Rate Map (FIRM) or Flood Boundary and Floodway Map (FBFM), and sometimes the Flood Insurance Study (FIS) report, and when appropriate, includes a description of the modifications. The LOMR is generally accompanied by an annotated copy of the affected portions of the FIRM, FBFM, or FIS report. An Appeal/Protest period exists only when there is a change in the BFE.

**NFIP**
(National Flood Insurance Program) - Created by Congress in 1968 to provide low cost flood insurance for property owners in flood-prone communities. In exchange for flood insurance eligibility, communities agree to implement and enforce floodplain management measures to reduce the possibilities of future damage. FEMA arranges for periodic community assistance visits with local officials to provide technical assistance regarding complying with NFIP floodplain management requirements. FEMA works with local officials to evaluate the FIRMs and associated Flood Insurance Study and conducts updates as needs and priorities dictate. Harris County and the incorporated cities within the county are participants in the NFIP, so flood insurance is available to all residents.

**Rainfall Event**

(Rain Events for the modeling) – A 4-inch/hr rainfall is defined as the rainfall amount when measured for an hour equals a total rainfall of 4-inches. Similarly, 2-in/hr, 3-in/hr and 6-in/hr represents the amount of rainfall measured in an hour.

**Repetitive Loss**

Repetitive Loss property is any insurable building for which two or more claims of more than $1,000 were paid by the National Flood Insurance Program (NFIP) within any rolling ten-year period, since 1978. A Repetitive Loss property may or may not be currently insured by the NFIP.

**Sheet Flow**

(Overland Flow Flooding) - Flooding that occurs when intense local rainfall flows overland to reach a channel. Frequently, this conditions exists when runoff exceeds storm sewer or roadside ditch capacity, and the water can "pond" in the streets deep enough to flood residences that are not even near a creek of bayou. The water will seek a path to the channel by flowing overland (Sheet Flow). When residences and other structures are in that path, flooding occurs and this type of flooding is not identified on the Flood Insurance Rate Maps.

## 1.3 History of Drainage in Bellaire

Bellaire has been subjected to flooding from various severe storms and hurricanes over the last century. The City of Bellaire has remained dedicated to minimizing the loss of life and property that is associated with flood events as evidenced by historical improvements


Figure 6- A History of Flooding

Bellaire's drainage systems have evolved from natural flow from the northwest to the southeast to ditch systems to underground systems. Prior to development of the Bellaire area, storm water followed the natural topography of the land, which sloped from the northwest to the southeast. Storm water traveled overland through gulleys and creeks to the Bay. Natural flow was first disrupted by the Galveston/Harrisburg and San Antonio railroad built to the east and the San Antonio and Aransas Pass railroad built to the north.

The first drainage system improvements consisted of small open ditches discharging into deep open drainage ditches located parallel to North-South streets and the Railroad. These North-South ditches were located within and on the west side of the rights-of-way of the Railroad, Avenue A (Newcastle), Avenue C (IH 610), Rice Avenue, Avenue D (Chimney Rock) and smaller North-South ditches on Sixth (Ferris) and Ninth (Alder) Streets. These North-South ditches, except the Railroad ditch, converged into Cypress Ditch at the south city limits. Cypress Ditch discharged into Brays just upstream from the Railroad crossing over the Bayou. The North-South ditch in the Railroad right-of-way flowed from Old Richmond Road (Bissonnet) under the tracks and into Brays Bayou.

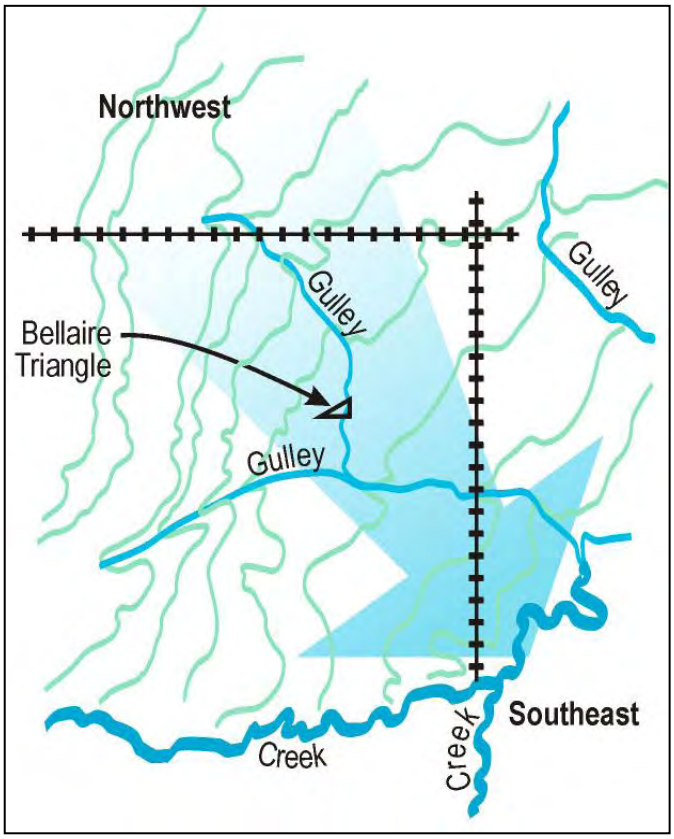



Figure 7- Natural Flow

This first drainage system was designed and constructed with the idea of a ditch and levee from the railroad to Cypress Ditch at approximately one-half mile intervals and parallel to North-South streets. The levee was placed on the east side of the ditch to confine all of the drainage from the west in this ditch. Records indicate that properties near the ditch sometimes flooded, but a large portion of the area was dry a few minutes after rain stopped. As the area developed, small laterals were constructed into the ditch from the east and most of the levee was removed. As a result, the storm water no longer was confined to the ditch into which it was supposed to flow, but overflowed to the next ditch which was not designed to handle this additional stormwater, and so on to the east side of town where the most serious flooding occurred.

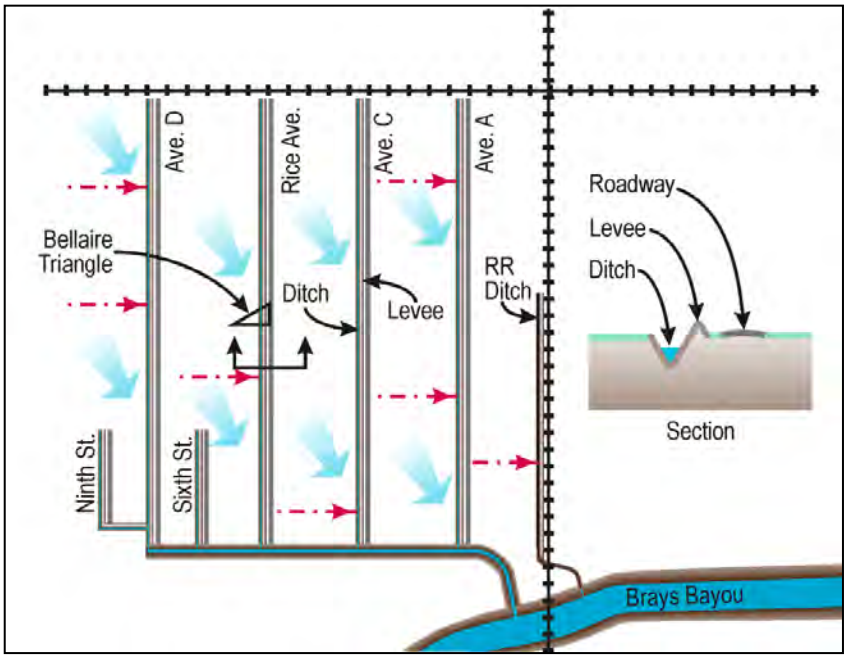



Figure 8- Early Drainage Improvements

During the early development of Bellaire, these existing surface ditches probably were sufficient to carry the floodwaters away within a few hours. However, as areas within the City of Bellaire developed from a prairie to homes and businesses with paved streets, driveways and terraced lawns, the rate of storm water runoff increased and these main drainage ditches became inadequate. The City of Bellaire and the Harris County Flood Control District attempted to improve the capacity of these main drainage ditches. However, very little was accomplished within the limited right-of-way and flat topography.

### 1.3.1 1950 Improvements

The drainage ditch overflow problem combined with the increasing development of the area prompted the City to engage a consultant to study and recommend improvements to the

drainage system. Their 1953 Drainage Master Plan recommended replacing these N/S ditches with underground trunk sewers in lieu of widening because of limited right-of-way and disruption to private property.

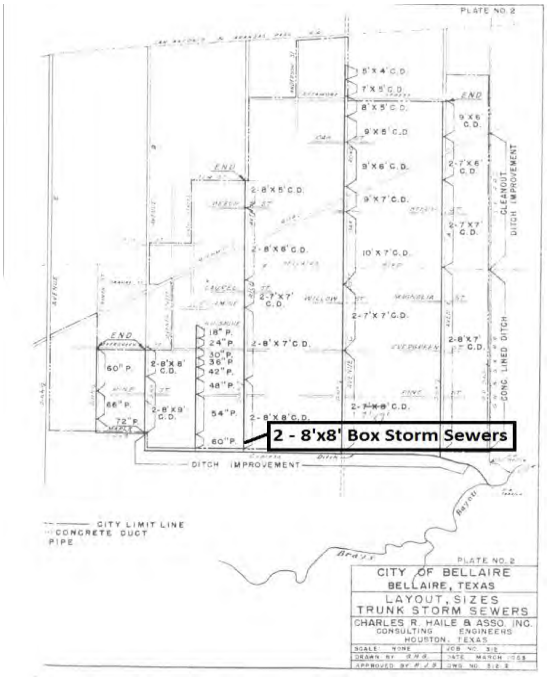



Figure 9- 1950 Drainage Improvements within City of Bellaire

The consultant recommended the following:

1. Improve Cypress Ditch from Brays Bayou to Ave. D (Chimney Rock).
2. Improve the Railroad Ditch from south city limits to Richmond Road.
3. Enclose Avenue A (Newcastle) Ditch from Cypress Ditch to Sycamore Street (Glenmont).
4. Enclose Avenue C (Post Oak Road) Ditch from Cypress Ditch to the north city limits.
5. Enclose Rice Avenue Ditch from Cypress Ditch to Elm Street.
6. Enclose Sixth Street (Ferris) Ditch from Cypress Ditch to Huisache Street.
7. Enclose Avenue D (Chimney Rock) Ditch from Maple Street to Evergreen Street.
8. And, enclose Ninth Street (Alder) Ditch from Maple to Evergreen Street.

Some of these improvements were made over the years and others were changed.

### 1.3.2 Today's System

The City's major North/South storm sewer systems that exist today include:

- 2 – 10'x12' Box Culverts on Renwick owned by the City of Houston
- A 42" Storm Sewer on Alder outfall to Maple currently being replaced with an outfall to Valerie then to S Rice.
- Double 7'x10'Boxes on Chimney Rock
- Storm Sewer on Ferris
- Double 8'x8' Boxes on S. Rice Ave.
- Double 8'x7' Boxes on Newcastle
- The Railroad Ditch
- A 96-inch monolithic storm sewer and open ditch system along the east side of Bellaire discharging to Kilmarnock Ditch east of the railroad tracks, and
- The Loop 610 system

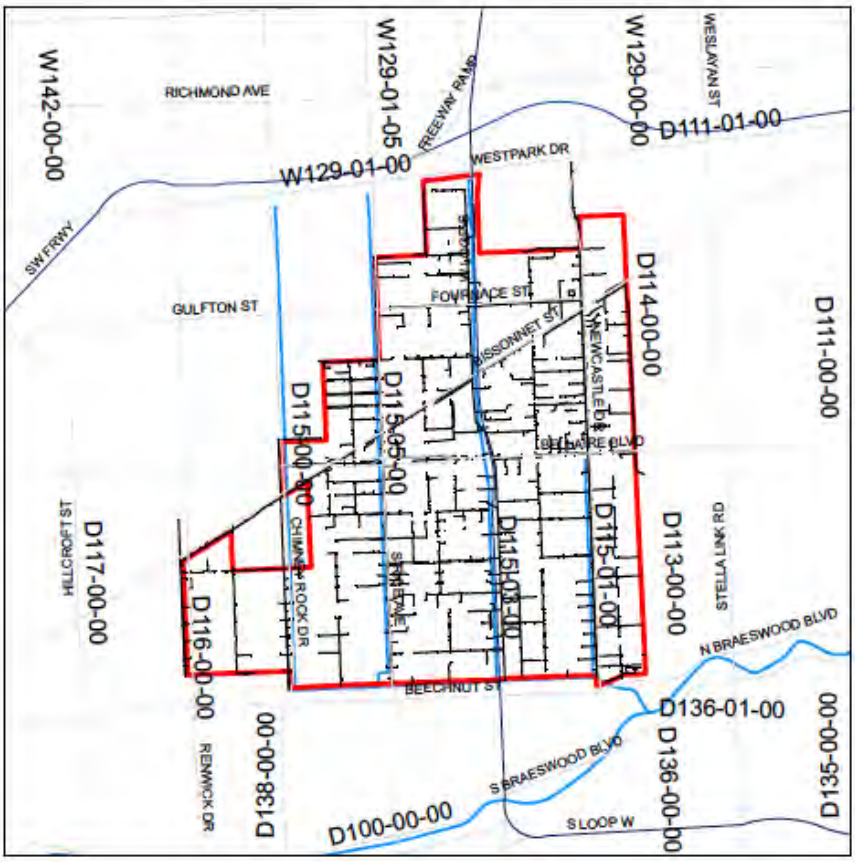



Figure 10- **Today's Drainage Systems**

### 1.3.3 IH 610 Drainage Improvements

In 1965, the State of Texas replaced Post Oak Road with a freeway. The drainage system was modified to accommodate the new freeway geometrics. The overall system remained about the same size as the 1953 drainage plan had suggested. In the late 90's, the Texas Department of Transportation (TxDOT) began designing upgrades to IH 610 through the City of Bellaire. TxDOT's original plan did not include any drainage improvements. The City of Bellaire requested that the very undersized drainage system for the Loop be improved because it was inadequate for the large drainage area it served and for the simple fact that the original construction of the Loop did not consider the increased impervious cover created when the freeway replaced a much smaller road.

An agreement was reached for the City of Bellaire to partner with TxDOT to increase the capacity of the IH 610-drainage system in 2000 by adding a 10' x 10' box culvert underground system from south of Bellaire Blvd. to Cypress Ditch. The new box was constructed on the east side of the IH 610 right-of-way with 7- 48-inch reinforced concrete pipes tunneled under the freeway to provide outfall points for drainage west of IH 610.

This additional drainage structure provided improvements to the IH 610 drainage system, but not enough for the amount of storm water runoff it receives.

This system serves over 750 acres of fully developed urban drainage area. To convey and fully mitigate the 100–year storm event within the TxDOT right-of-way for this very large drainage area could require as many as 13- 10' x 10' box culverts versus the 2–10" x 10' boxes that exist today.

## 1.4 Drainage System Responsibilities

There are many components to the drainage systems that serve Bellaire. And, there are many entities besides Bellaire that are responsible for the maintenance and improvements to these systems. These various components and system responsibilities are listed below:

- Brays Bayou – HCFCD and the US Army Corps of Engineers
- Cypress Ditch – HCFCD and the City of Houston
- Renwick Drainage System – City of Houston
- Alder, Chimney Rock, S. Rice – City of Houston and City of Bellaire
- Ferris, Englewood, Ave. B, Newcastle and Baldwin – City of Bellaire
- IH 610 – TxDOT
- 96-inch Monolithic Pipe in railroad right-of-way – City of Houston and City of West

University

- Railroad Ditch – City of Houston and Harris County

There are many different entities responsible for the reliability and sufficiency of the drainage systems that serve the City of Bellaire requiring coordinated efforts for stormwater management.

The City of Bellaire has identified several areas of the city that frequently pond water in the street. Before major reconstruction of the old street and drainage system is planned on some streets, it is recommended that the city televise the existing storm sewer system to identify failure of the pipes and if any blockages can be addressed in ongoing maintenance projects. In some instances, the inlet capacity is found to be insufficient and can be improved at a relatively low cost.

Past inspections of drainage recommendations included removing all unnecessary pipe conflicts that run through the large North South drainage arterials and correct the two-foot off-set in the flowline of the S. Rice boxes near Bellaire High School to improve flow.

Cypress Ditch, the Railroad Ditch and the storm sewer outside the City limits require periodic maintenance or the systems become inefficient. The City of Bellaire should coordinate and ensure that these are maintained to the intended storm design capacities for conveyance.

**1.5 Flood Insurance and Recent Flooding**

The City of Bellaire participates in the National Flood Insurance Program and in the Community Rating System (CRS), a voluntary federal program that rewards communities that implement higher standards by providing discounts on flood insurance policies. Currently, there are approximately 4,780 Bellaire flood insurance policy holders and Bellaire holds a CRS classification of Class 7, which saves policy holders 15 % on their flood insurance premiums each year. Bellaire is designated as a Repetitive Loss Community and the current Floodplain map shows most of the Bellaire to be within the 1% or 100-year flood frequency limits.

Over the last 13 months, Harris County experienced six (6) significant flood events:

May 12-13, 2015
May 25-26 2015
Oct. 24-25, 2015
Oct. 31 2015
April 18 2016
May 25-27, 2016

Each one of these events resulted in rainfall totals over eight (8) inches in portions of Harris County. Never, in modern records, has Harris County experienced such frequent back to back

flooding events. The only year that comes close is 1998 when three major floods affected the county in September (Frances), October, and November.

Two of these recent significant events caused major flooding in Bellaire. The 2015 May 25-26th flood event within the City of Bellaire resulted in approximately 220 homes being flooded. Approximately 175 homes flooded were located east of the IH 610.

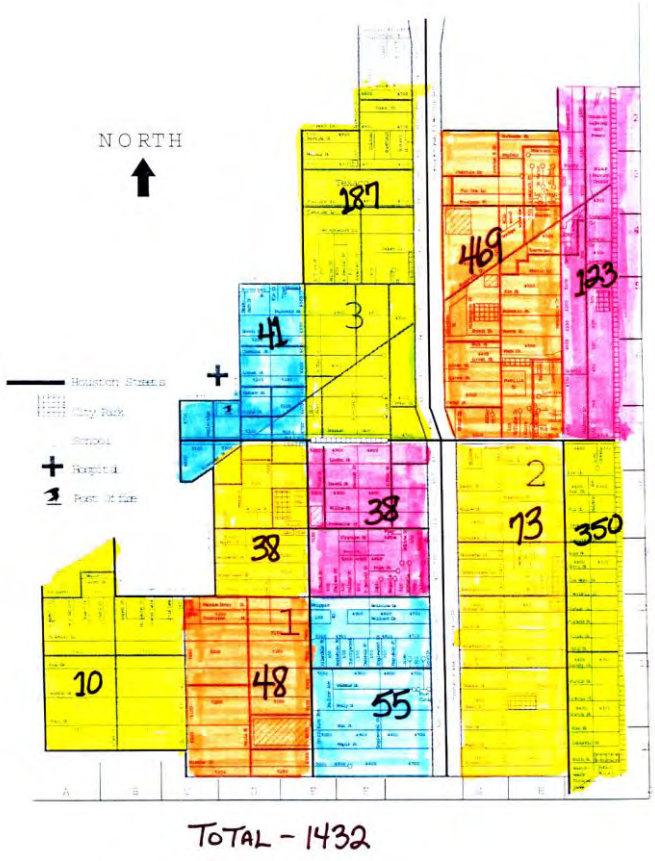



Figure 11- Structures Flooded due to Tropical Storm Allison within City of Bellaire

A review of the Tropical Storm Allison flood event documentation of the 2001 shows 1432 homes being flooded with 1015 homes flooded east of IH 610 and approximately 417 homes were flooded west of IH610. Exhibit 17 shows the historical information of some of the events where there were flooded homes. There are approximately 57 homes in City of Bellaire that can be considered as repetitive loss properties. FEMA, State and HCFCD funds may be available to purchase those properties that flood repeatedly.

### 1.6 Coordination and Discussions with Other Agencies

HCFCD is in charge of the Project Brays and anything outside the City of Bellaire involves coordination with City of Houston and subsequent studies to demonstrate that there are no downstream or upstream impacts on the receiving channels.

The following tasks are outlined for the coordination and discussions with other agencies:

1. Prepare and submit a LOMR to the HCFCD for approval to remove certain areas of the City of Bellaire from the floodplain.

2. Request TxDOT to improve the IH 610 drainage system to properly receive the existing drainage area storm water runoff and convey to Brays Bayou. The system should be increased to meet their current design criteria for a system receiving this amount of runoff from such a large drainage area.

3. Request interim improvements to the system directly adjacent to the proposed improvements associated with the US69/IH610 interchange improvements to receive the storm water runoff from the existing drainage area and meter the outfall until such time as downstream improvements are constructed as mentioned above.

4. Request the City of Houston/Texas Water Development Board/FEMA to participate in conveyance and storage capability improvements within the Chimney Rock and S. Rice Ave. drainage systems because they serve such large areas of the City of Houston as well.

5. Develop inter-local agreements with the City of Houston for future improvements and maintenance for drainage facilities that serve both entities. These agreements should consider development and detention requirement standards for any new development.

6. Request the City of Houston to consider installing back flow prevention systems like a flap gate in Cypress Ditch and the Railroad Ditch to prevent back water from Brays Bayou backing up into these systems during high water flood stages.

**2.0 Drainage Problems and Possible Solutions**

Certain areas of the City of Bellaire are more susceptible to flooding than others because the internal underground drainage infrastructure, overland sheet flow capabilities through the street system and the receiving outfall systems are not adequate to drain intense rainfall events. In general, the overall drainage problems can be attributed to the following:

- very high average annual rainfall of about 50 inches
- very flat topography
- clay soils that do not absorb water very well
- close proximity to an undersized Brays Bayou
- large amounts of storm water from the City of Houston flow into Bellaire from the north
- localized storm water runoff from Bellaire drains into undersized drainage systems owned by the City of Houston
- Below base flood finished floor elevations of homes constructed prior to the National Flood Insurance Rate Standards.

The underground drainage infrastructure within the City of Bellaire is generally designed to carry the industry standard 2-year design storm on newer streets and much less rain events on the older streets are not capable of adequately handling the 2-year storm event. In fact, some neighborhood streets have little or no underground storm sewers.

The street system grades from one end of the City to the other are very flat and in some cases pond water during heavy rainfalls. On occasion, the ponding elevations in certain locations around the City of Bellaire reach a height that will flood structures that are built at a low elevation until the storm sewer system eventually drains the area.

The major outfalls for Bellaire are also inadequate to handle the 100–year storm event. Ideally, the major North/South systems such as IH 610, Newcastle, S. Rice and Chimney Rock should be capable of handling the 100-year event storm event. These systems currently cannot adequately handle a 2-year storm event. The Cypress Ditch drainage area is over 2,400 acres of urban runoff and should be designed to carry the 100-year event and the Project Brays does not address this limitation. Currently, the largest section of Cypress Ditch cannot adequately handle the 10-year storm event. These system inadequacies all contribute to flooding in the City of Bellaire.

The street system was originally constructed prior to current sheet flow cascading guidelines and because of the very flat topography across Bellaire is not practical to completely correct. Ideally, the street network system would be graded to an overall slope of about a 0.2% from the northwest city limit to the southeast city limit or to the top of the bank of Brays Bayou. That would be about a 30-ft. fall across Bellaire.

Brays Bayou has received significant improvements during the HCFCD and Army Corps of Engineers' Project Brays, however much more improvements are necessary to improve the bayou system to the 100-year flow capability. Bellaire should maintain pressure on HCFCD and the federal government to continue improvements to the Brays Bayou system

The City of Bellaire does have control over their internal underground drainage systems to some degree. While Bellaire can control the size of the internal drainage systems, it is important to note that increases in the size and efficiencies of the City owned drainage systems should not cause adverse impacts to downstream property owners. With this in mind, it is recommended that the City of Bellaire selectively locate areas that pond or flood during heavy rainfall events and increase the size of underground storm sewer to store the 100–year flow volume. This would lower the height of floodwaters in a particular area by storing the water underground and releasing it slowing into existing downstream systems. The various options for this drainage study are considered are described below:

## 2.1 100-Year Level of Protection for All Drainage Systems Alternative

Improve Brays Bayou to completely contain the 100-year storm, improve Cypress Ditch to contain the 100-year event, improve all North/South major drainage arterials to transport the 100-year storm water flows through the City of Bellaire and to Cypress Ditch or Brays Bayou and improve all local storm sewers and local street systems to convey 100-year flows to their respective outfalls. The improvements to Brays Bayou alone would cost much more than current Project Brays which is anticipated to provide a 10-year level of flood protection. The current Project Brays has an estimated price tag of over $400 million and does not provide protection from the 100-year event. Cypress Ditch drains approximately 2,400 acres of the City of Houston and the City of Bellaire. There is insufficient right-of-way to construct an open channel section capable of carrying the 100-year event and it is estimated that a closed conduit section to accommodate the 100-year event would cost over $80.1 million. To reconstruct all of the interior pipe systems to the 100-year level of service is estimated to cost another $236 million. The total upgrade to the entire drainage system serving the City of Bellaire is not an economically feasible option considering the number of homes flooded during the historical major storm events previously discussed.

## 2.2 Neighborhood Detention Pond Alternative

This alternative considers building detention ponds capable of storing flood waters generated from localized extreme storm events within each individual neighborhood. A 10-acre-ft. pond could be constructed for each 40 or so homes. The storm drainage systems would need to be improved to the 100-year capacity to transport storm water to ponds and improvements to Brays Bayou to contain the 100-year event so flood waters from the bayou would not back up into the city would be required as previously described. This option would displace homes to build detention ponds and significantly displace neighborhoods and therefore was not considered a viable option.

## 2.3 Levee System Alternative

This option would consider constructing a levee system around the City of Bellaire similar to the levees in Fort Bend County for subdivisions located within the floodplain. The levee would prevent storm water that overtops the banks of Brays Bayou from entering or back flowing into the City from the south and block overland flow from City of Houston to the north from entering Bellaire. The City of Bellaire's internal storm sewers would operate at a 100-year level of protection with large storm water pump stations and storage areas required to prevent the localized storms from flooding the City. The storage would be required to offset the loss of floodplain storage the City of Bellaire is providing to the Brays Bayou watershed. This option would require large amounts of land within City of Bellaire, several pump stations, blocking the City of Houston off-site sheet flows into Bellaire, and changes to the road elevations exiting the City of Bellaire to drive over the perimeter levee. The levee alternative perhaps would be viable if the City of Bellaire was being developed from scratch but would not be practical to try and retrofit a levee system in a fully developed urban area.

Levee systems must meet and continue to meet minimum design, operation, and maintenance requirements to receive recognition by FEMA under the National Flood Insurance Program (NFIP) as providing protection from the 100-year flood on the Flood Insurance Rate Maps (FIRM's).

The Feasibility of an Urban Levee District which encompasses City of Bellaire was considered as an alternative to prevent the backing up of the Brays Bayou into City of Bellaire. The legislature of the State of Texas has manifested an intention to protect the public interest by establishing a centralized and coordinated method for planning and review of drainage and reclamation activity. The Levee district formation to protect the public from flooding is established under Texas Water Code Chapters 5, 16, and 57, that pertains to implement this policy by the promulgation of these sections. The TCEQ Chapter 301-Levee Improvement Districts, District Plans of Reclamation, and Levees and Other Improvements should be considered as a funding mechanism to create and implement an overall plan of improvements to reduce flooding within City of Bellaire.

The levee system around the City of Bellaire would be to prevent any areas of the City of Houston upstream of Bellaire from draining excessively into the City of Bellaire infrastructure. This levee would also prevent storm water overflowing from Brays Bayou from backing up into the city. The levee system drainage systems would be designed to convey the 100-year local rainfall event out of the levee area. Flap gates would be installed to prevent Brays Bayou overflow water from coming back into the City. Another levee option would be to include all of the areas outside the City of Bellaire that shall drain through the City of Bellaire and include as an overall Urban Levee district. This would require City of Houston cooperation and approval.

TCEQ requires the creation of a Levee District shall obtain the approval of the Harris County Commissioners Court. This Levee district if formed can levees an ad valorem tax each year on all taxable property to pay for the bonds that are used to finance the design and construction of the levee systems and other related flood control works.

## 2.4 Strategic Underground Detention Storage Recommended Alternative

Using new technologies available, a more practical and cost effective alternative was developed to provide reasonable flood protection to the City of Bellaire. This option involved identifying potential ponding areas within the City utilizing a SOBEK 2-D model supplemented with observed flooding locations within the City of Bellaire. The 2-D complex urban drainage model analyzed different rainfall intensities to predict flooding areas.

This option would include strategically locating underground storage pipes within the existing street right-of-way within the ponding or flooding areas identified and constructed as part of new street and drainage reconstruction projects were undertaken. The typical two-year underground storm sewer pipe system constructed during the total reconstruction of a roadway improvement project would be upsized to store a 100-year localized rainfall event.

The goal would be to lower the height of the floodwaters during a localized 100–year storm event in areas where overland flow problems exist.

This underground storm sewer drainage and detention systems would limit the flow at the respective outlet to the existing conditions and not require the entire underground system downstream of these detention systems to be improved. Costly mitigation efforts for potentially increasing flows to downstream areas would also be avoided. Further discussions and description is provided in the below sections. These detention systems would replace the two-year design storm sewer systems normally used during street reconstruction on a particular block at a cost of about four (4) times that of a typical two-year design storm sewer system. These localized detention storage systems constructed by the City of Bellaire would not increase flows downstream because the outfall would be restricted to the 2-year storm flows or existing flows.

### 2.5 Backflow prevention from the storm sewer outfalls

The City of Bellaire should consider the construction of backflow prevention systems at several of the major drainage system outfalls and any proposed improvements within the City of Bellaire where localized detention storm sewers are constructed. Back flow prevention systems prohibit back water flow from Brays Bayou backing up into these systems during high water flood stages. The feasibility of the back flow devices would be determined during the PER stage of each street and drainage reconstruction project.

## 3.0 2-D Model and Findings

SOBEK is a program used to develop a 2-D model and offers one software environment for the simulation of all management problems in the areas of rivers and drainage systems. This allows for combinations of flow in closed conduits, open channels, rivers overland flows, as well as a variety of hydraulic, hydrological and environmental processes. An Integrated approach which combines the 1-D and 2-D modeling methods. SOBEK is a fully dynamic 2-D hydraulic model, which can be used for floodplain modeling. The SOBEK model is grid based and the solution scheme utilizes the finite difference method.

An overland flow model of SOBEK with the ground topography represented by the HCFCD LiDAR was converted to a 150-ft grid so as to encompass a wider area in determining appropriate boundary conditions and the flow patterns. A free outlet condition at the end of the LiDAR boundary represents the outfall to the boundary conditions. The 2-D model was developed to understand the potential ponding and flow patterns within the City of Bellaire.

Several rainfall intensities were studied along with the topography and anticipated flow paths to identify ponding/flooding problem areas. The 2-D model uses LiDAR land terrain and a hydraulic model component to determine potential flooding locations. This was considered as the first step in locating the drainage improvement needs.

Once the flow patterns were established and the areas of ponding or flooding identified, underground systems capable of detaining the localized 100-year storm event were determined. The size of the underground system was determined based on 100-year storm flows and a sample calculation along with the drainage area exhibit is shown in Appendix B. A description of the required detention recommended for each major drainage system is presented in the sections that follow.

The various SOBEK model videos are provided in Appendix A for various storm events which are based on the 2-inch/hr., 3-inch/hr., 4-inch/hr. and 6-inch/hr. and includes a 3-hour and 6-hour event. For example, the rainfall event of 3-inch/hr. assumes that the entire City of Bellaire experiences a rainfall of 3-inches per hour for a SOBEK model run for 12-hour duration. Similarly, a 3-inches for 3-hours translates to 3- inches of rainfall for a duration of 3 hours. Based on the runs, it is evident that there is ponding within the City of Bellaire given flow patterns.

Individual storm sewer detention locations for the 100-year flood event were identified and a preliminary cost estimate was provided based on the 2-D model video. The final location and size configuration of these storage systems should be determined during the Preliminary Engineering Phase of each street reconstruction project. The available outfall depth is critical to determine the vertical dimension of the storage system. Also during this PER stage, the detention system material type will be determined. Reinforced Concrete Boxes, Reinforced Concrete Pipe and High Density Polyethylene Pipe would be considered suitable for the detention storage systems.

The various flood event models provided in Exhibits 5 - 12 show the extent of ponding within the City of Bellaire for the various runs. These 2-D models were used in evaluating a best possible option in determining the storm sewer options which are described in Section 4.0.

Based on the above assumption and by limiting the outflow from the proposed storm sewer improvements to the existing conditions, no additional detention is required as the current release rate is maintained. The storm sewer sizes and the estimated cost are presented in the Tables section of the report. The individual storm sewer systems are shown in Exhibit 14 which shows the city wide storm sewer improvements and the basis for these improvements is an approximate 4-in/hr. rain which simulates a 100-year flood frequency event. See Exhibit 15 for the extents of ponding.

It is important to point out that model shows IH 610 acts as a barrier to the flow path and the underground system along IH 610 is not able to adequately drain the runoff, consequently, the feeder streets flood during heavy rains.

**4.0 Recommended Drainage System Improvements by Drainage area**

A Capital Improvement Program (CIP) to correct the ponding or flooding occurrence based on increasing the current industry standard 2-year storm sewer system to a 100-year or 1% flood

event in selected areas of the city and based on various rainfall amounts and durations was estimated on a conceptual level with associated costs. Those costs associated with each major drainage area are described in the following sections. It is important to note that partnerships with various entities should be investigated to share in the cost of those improvements that would also benefit from them.

### 4.1 Renwick System

The Renwick underground drainage system is owned and operated by the City of Houston with the exception of the storm sewers located in the 5400 blocks of Bellaire that drain into the Renwick system. Approximately 50 acres of Bellaire drains into the Renwick storm sewer system of various sizes (see Appendix B for the overall storm sewer map.) This area of the City of Bellaire appears to drain well even during severe storms and the SOBEK model does not indicate significant amount of ponding issues. Accordingly, no storm sewer detention improvements are proposed for this area.

### 4.2 Alder System

The Alder drainage system consists of an underground system that drains to the City of Houston's Maple system which then outfalls into the Chimney Rock storm sewer system. For the storm sewer sizes see Appendix B for the overall storm sewer map. Based on the Sobek model, this area of the City of Bellaire does not show significant ponding during extreme events and no storm sewer detention improvements at this time are recommended.

Currently, the Alder Drainage System is being improved during Rebuild Bellaire. The outfall is changing to Valerie St. and a direct restrictor will be added to prevent increase in downstream storm sewer flows.

### 4.3 Chimney Rock System

The Chimney Rock drainage system drains a significant area of the City of Houston north of Bellaire and approximately 164 acres of the City of Bellaire. The drainage area from the City of Bellaire outfalls into the Chimney Rock storm sewer system via existing storm sewer infrastructure of various sizes. See Appendix B for the overall storm sewer map. The total drainage outfall area at the Bellaire city limits near Maple St. is approximately 790 acres and outfalls from the City of Bellaire with two 7' x 10' Reinforced Concrete Box culverts to a City of Houston open ditch system and eventually flowing into Brays Bayou.

The Chimney Rock storm sewer system is undersized for the large urban watershed area currently serviced by the major trunk line that outfalls into Brays Bayou. It is estimated that the current system is not capable of carrying the two-year roadway standard design storm and furthermore, should be sized to handle the 100-year event for such a major storm sewer system. At a minimum the system should handle a 10- year event given the large drainage area

it serves. A 10-year storm system would cost approximately $51.5 million and a 100-year storm system would cost approximately $80.1 million. (See Tables section of the report.)

The preliminary sizes of the culverts for the trunk line are provided in the table section of the report and it is anticipated that a restrictor prior to the discharge into the receiving channel will limit the flows to the existing conditions flow rate so as not to impact the Chimney Rock ditch. The sizes and the number of the culverts would present a challenge and may be impractical because of limited road ROW. This storm outfall system would also require improvements within the lateral streets to convey the 100-year event to the Chimney Rock system.

Each contributing drainage area from the Chimney Rock storm sewer system within the City of Bellaire has been identified and is shown in Appendix B. Based on the Sobek runs that identifies ponding areas, localized storm sewer improvements are proposed and shown on the City wide storm sewer exhibit. Within this drainage area, a storm sewer designed to either a 10-year or a 100-year flood frequency capacity with appropriate inlets and other appurtenances so that the flow from this is captured within the storm sewer and released at the existing release rate is recommended. Based on the assumption, the storm sewer sizes and the estimated cost are presented in the Tables section of the report. The approximate cost is $1.0 million for 10-year and $1.3 million for the 100-year flood frequencies. Exhibit 13 shows the proposed location of these storm sewer improvements. These storm sewer improvements create underground storage systems and the flows are locally captured prior to the release into Chimney Rock storm sewer system. This should improve the local drainage issues; however, backwater effects may still flood the improved areas with these enlarged storm sewers because they are sized for the local drainage area and not overflow from outside areas. The proposed recommended storm sewer improvements solve the localized flood by storing the storm waters in the underground storage system. Regardless, the Chimney Rock storm sewer system is undersized and should be enlarged for the benefit of City of Bellaire and City of Houston.

### 4.4 Ferris System

The Ferris Street storm sewer system was reconstructed in 2007 during the Bellaire Millennium Renewal project. The underground system sizes are provided in Appendix B on the overall storm sewer map. The new outfall was approved by the City of Houston. The overall storm sewer system is in good shape with a few intersecting streets experiencing some ponding.

### 4.5 S. Rice System

This drainage area from the City of Bellaire outfalls into the South Rice storm sewer system via existing storm infrastructure of various sizes. See Appendix B for the overall storm sewer map. The S. Rice drainage system within the City of Bellaire serves approximately 507 acres of the City of Houston and 116 acres of the City of Bellaire and outfalls to Cypress Ditch with 2-8’x8’ Reinforced Concrete Boxes (RCB). There is also an overflow pipe to the S. Rice ditch south of Beechnut.

The South Rice storm sewer system is undersized for the large urban watershed area currently serviced by the major trunk line that outfalls into Brays Bayou. It is estimated that the current system is not capable of carrying the roadway standard design storm and furthermore, should be sized to handle the 100-year event for such a major storm sewer system and at the minimum, a 10- year event given the large drainage area it serves. A 10-year storm system would cost approximately $88.6 million and a 100-year storm system would cost approximately $129.7 million. (See Tables section of the report.)

The preliminary sizes of the culverts for the trunk line are provided in the table section of the report and it is anticipated that a restrictor prior to the discharge into the receiving channel would be constructed to limit the flows to the existing conditions flow rate. The sizes and the number of the culverts would present a challenge and because of limited road ROW. A combination of conveyance pipe and mitigation storage or receiving stream improvements may be more practical. Even if this overall system was improved to receive the extreme event storm, improvements within the lateral streets would still be required for conveyance to this system.

Each contributing drainage area from the South Rice storm sewer system within the City of Bellaire has been identified and is shown in Appendix B. Based on the Sobek runs that identify ponding areas, localized storm sewer improvements are proposed and shown on the City wide storm sewer exhibit. Within this drainage area, a storm sewer designed to either a 10-year or a 100-year flood frequency capacity with appropriate inlets and other appurtenances so that the flow from this is captured within the storm sewer and released at the existing release rate is recommended. Based on the assumption, the storm sewer sizes and the estimated cost are presented in the Tables section of the report. The approximate cost is $2.5 million for 10-year and $2.9 million for the 100-year flood frequencies. Exhibit 13 shows the proposed location of these storm sewer improvements. These storm sewer improvements create underground storage systems and the flows are locally captured prior to the release into South Rice storm sewer system. This should help solve the local flooding issues; however, backwater effects may still flood the improved areas with storm sewers. The proposed recommended storm sewer improvements solve the localized flood by storing the storm waters in this underground storage system. Regardless, the South Rice storm sewer system is undersized and should be enlarged for the benefit of City of Bellaire and City of Houston.

### 4.6 Englewood System

The City of Bellaire's Englewood storm sewer system serves approximately 58.9 acres and with a 36-inch storm sewer outfalls into the Cypress Ditch. See Appendix B for the overall storm sewer map. Overall this system is in good shape with a few intersecting streets experiencing some ponding during severe storms.

### 4.7 IH 610 West Loop System

The West Loop drainage area from the City of Bellaire outfalls into the IH610 storm sewer system from the existing storm infrastructure of various sizes see Appendix B for the overall

storm sewer map. The total drainage area at the City of Bellaire limits is approximately 758.5 acres and outfalls into Cypress Ditch with 2-10' x 10' RCB.

The IH 610 freeway intercepts the off site sheet flow west of IH610 and ponding occurs at several intersections. Historically, the sheet flow was to the east of IH610 but the freeway dams the water and the cascading effect to the downstream outfall is not present. It appears that this was not considered at the time of the original design or during the 2000 design. Current TxDOT and HCFCD requirements require that the design of the storm sewer should account for the offsite areas draining into the roadway in its current development condition.

The IH610 storm sewer system should be designed to account for this offsite sheet flow. The City should request TxDOT to size this outfall for a minimum 10-year or preferably a 100-year storm sewer design to serve as a main outfall and the expected cost is $77.8 million for 10-year and $158.2 million for the 100-year flood frequency (see Tables section of the report.) The sizes of the culverts are preliminary and it is anticipated that a restrictor prior to discharge into Cypress ditch would limit the flows to the existing conditions flow rate.

In addition to the needed TxDOT IH 610 storm sewer improvements, the offsite sheet flows from the West Loop drainage areas should be designed based on the ponding conditions. Each contributing drainage area from IH610 within the City of Bellaire has been identified. Within this drainage area a storm sewer designed to either a 10-year or a 100-year flood frequency capacity with appropriate inlets and other appurtenances so that the flow from this designated area cascades and is captured in the storm sewer and released at the existing release rate. Based on the above assumption, the storm sewer sizes and the estimated cost are presented in the Tables section of the report the expected cost is $29.2 million for 10-year and $41.1 million for the 100-year flood frequencies. Exhibit 13 shows the proposed location of these storm sewer improvements. The cost of this storm sewer is significantly different than the overall IH610 system cost as the flows are locally captured prior to the release into the IH610 system. During the preliminary engineering, a design to limit the flows accessing this storage should be considered and includes, the weir within the storm sewer systems, roadway speed bumps to prevent the cascading water from entering the street with increased underground storage.

Recent storm events have flooded areas adjacent to IH 610 and the feeder street are impassible and inaccessible to the emergency vehicles. The City of Bellaire should partner with TxDOT to improve the IH 610 drainage system to reduce this frequent nuisance flooding.

### 4.8 Newcastle System

The drainage area from the City of Bellaire outfalls into the Newcastle storm sewer system via existing storm infrastructure of various sizes. See Appendix B for the overall storm sewer map. The Newcastle storm sewer system drainage area within the City of Bellaire serves approximately 572.2 acres. The total drainage outfall area at the City of Bellaire city limits is approximately 761.9 acres and outfalls to Cypress Ditch through 2-8' x 7' RCB.

The Newcastle storm sewer system is undersized for the large urban watershed area currently serviced by this major trunk line. It is estimated that the current system is not capable of carrying the roadway standard design storm and furthermore, should be sized to handle the 100-year event for such a major storm sewer system and at a minimum, a 10- year event given the large drainage area it serves. A 10-year storm system would cost approximately $61.5 million and a 100-year storm system would cost approximately $126 million. (See Tables section of the report.)

The preliminary sizes of the culverts for the trunk line are provided in the table section of the report and it is anticipated that a restrictor prior to the discharge into the receiving channel will limit the flows to the existing conditions flow rate. The sizes and number of the culverts would present a challenge due to limited road ROW because the lateral streets would still require storm sewer improvements to convey the extreme event flows to the underground system along Newcastle

Each contributing drainage area from the Newcastle storm sewer system within the City of Bellaire has been identified and is shown in Appendix B. Based on the Sobek runs that identify ponding areas, localized storm sewer improvements are proposed and shown on the City wide storm sewer exhibit. Within this drainage area, a storm sewer designed to either a 10-year or a 100-year flood frequency capacity with appropriate inlets and other appurtenances so that the flow from this is captured within the storm sewer and released at the existing release rate is recommended. Based on the assumption, the storm sewer sizes and the estimated cost are presented in the Tables section of the report. The approximate cost is $27.1 million for 10-year and $36.7 million for the 100-year flood frequencies. Exhibit 13 shows the proposed location of these storm sewer improvements. These storm sewer improvements create underground storage systems and the flows are locally captured prior to the release into South Rice storm sewer system. This should help solve the local flooding issues; however, backwater effects may still flood the improved areas with storm sewers. The proposed recommended storm sewer improvements solve the localized flood by storing the storm waters in this underground storage system.

### 4.9 Railroad 96-inch Storm Sewer System

The drainage area east of the Newcastle system and north of Bellaire Blvd. outfalls as individual storm sewer systems into a 60-inch to 96-inch monolithic storm sewer system within the Southern Pacific Railroad ROW and is designated as HCFCD Unit No. D113-00-00. This system of monolithic pipes begins south of Bissonnet and runs south along the west side of the railroad tracks. Approximately 500 feet south of Bellaire Blvd., this storm sewer turns southeast under the tracks and outfalls to Kilmarnock Ditch owned by West University Place. This pipe and ditch system should be studied in a joint venture with West University Place for potential improvements benefiting both cities.

For the existing storm sewer of various sizes see Appendix B for the overall storm sewer map.

Based on the Sobek runs this area has substantial ponding and as such storm sewer improvements are needed. The storm sewers are proposed on Mulberry and other lateral streets as shown on the City wide storm sewer improvements exhibit.

Each contributing drainage area to the Southern Pacific Railroad storm sewer system within the City of Bellaire has a designation identified in the preliminary cost calculations tables. Within this drainage area, a storm sewer designed to either a 10-year or a 100-year flood frequency capacity with appropriate inlets and other appurtenances so that the flow from this designated area cascades and gets captured in the storm sewer and released at the existing release rate. Based on the above assumption, the storm sewer sizes and the estimated cost are presented in the Tables section of the report the expected cost is $2.1 million for 10-year and $2.9 million for the 100-year flood frequencies. Exhibit 13 shows the proposed location of these storm sewer improvements. These storm sewer improvements create underground storage systems and the flows are locally captured prior to the release into the outfall pipe. This should help solve the local flooding issues but the backwater effects of Brays Bayou could at times flood this area. During the preliminary engineering report stage of the reconstruction projects, a design to limit the flows accessing this additional storm sewer storage should be considered and includes, the weir within the storm sewer systems, roadway speed bumps to prevent the cascading entering the street with increased underground storage.

### 4.10 Southdale Drainage Systems

The drainage area east of the Newcastle system and south of Bellaire outfall as individual systems into the Southern Pacific Railroad ditch which is HCFCD Unit No. D113-00-00. This is a concrete lined open channel beginning at Ione St. and drains south towards North Braeswood Blvd. This ditch outfalls into two 6’ culverts and merges with Kilmarnock Ditch before emptying into Brays Bayou. The ditch, when kept free from debris, actually has an approximately 10- year capacity, but is greatly influenced by the water surface elevation in Brays Bayou. It is important that Bellaire develop an arrangement with Harris County to periodically clean this ditch and explore the possibility of placing back flow prevention devices on the outfall structures to prevent backwater from flowing into Southdale. For the existing storm sewer of various sizes see Appendix B for the overall storm sewer map.

The Baldwin Ave. extreme event storm sewer will be the primary drainage system for Southdale after all the intersecting streets have been reconstructed. It should be noted that additional inlets at the intersecting streets may be required to convey the extreme event storm water into the new system under Baldwin. Citizens on Mildred have suggested that their street floods more now, after the Baldwin system was constructed. A preliminary analysis indicates that there is a low area on Baldwin at the Mildred/Verone St. area that may collect overland flow storm water from areas to the north before overtopping a high point on Baldwin to the south. This may be corrected by adding additional inlets at the intersecting streets to allow runoff to enter the large underground pipe system.

There are some storm sewer improvements which the City has undertaken and as such the Sobek runs identify isolated ponding areas and these ponding areas need some storm sewer improvements.

The model identified the need to place several detention system pipes under various streets within Southdale to lower the water ponding height during severe storms. The storm sewer sizes and the estimated cost are presented in the Tables section of the report the expected cost is $0.7 million for 10-year and $0.9 million for the 100-year flood frequencies. Exhibit 13 shows the proposed location of these storm sewer improvements. These storm sewer improvements create underground storage systems and the flows are locally captured prior to the release into Southern Pacific Railroad ditch or Baldwin storm sewer system. This should help solve the local drainage issues but the ditch may overtop from the banks and flood the streets given the backwater of the Brays Bayou. During the preliminary engineering report stage of the reconstruction projects, a design to limit the flows accessing this additional storm sewer storage should be considered and includes, the weir within the storm sewer systems, roadway speed bumps to prevent the cascading entering the street with increased under ground storage.

### 4.11 Cypress Ditch

Cypress Ditch is the primary channel that carries storm water runoff from the City of Bellaire to Brays Bayou. Cypress Ditch flows eastward from its upstream end located about 50-feet east of Chimney Rock and outfalls into Brays Bayou about one-half mile west of Stella Link. The ditch is located outside the City of Bellaire and in the City of Houston. The ditch is concrete lined from its outfall at Brays Bayou to a point about 50-feet west of South Rice Avenue. Under the S. Rice Ave. Bridge, directly opposite the storm sewer outfall to Cypress Ditch, is an 84-inch diameter diversion pipe which outfalls to the S. Rice Ave. open ditch beginning south of Beechnut. Records indicate the Ditch is located within a street right-of-way dedicated for the passage of pedestrians and vehicles only. It is owned and operated by the City of Houston.

The HCFCD has stated they are not responsible for Cypress Ditch. Cypress Ditch computed flows from FEMA models show that a flow of approximately 1.5 cfs per acre was used which is not consistent with the highly urbanized developed flows into the Cypress Ditch. A cursory review of the existing HEC-HMS model indicates the drainage area for the Cypress Ditch is 2,387.2 acres and the computed flow for the 100-year flow is 2379.9 cfs and the 10-year flow is 1368.6 cfs. This translates into 1cfs/ac for this highly urbanized system. This HEC-HMS flow computed is not consistent with the developed flows. The above information is presented to aid future HCFCD mapping updates so that appropriate modeling method is used to depict the flows from this area to properly document the flooding risks.

Cypress Ditch does not have adequate ROW to convey the expected flows. For example, an earthen channel receiving this much runoff would require approximately 300 feet of ROW. Alternatively, a closed RCB for the 10-year and the 100-year sizes were estimated and cost is presented in the Tables section of the report the expected cost is $51.5 million for 10-year and

$80.1 million for the 100-year flood frequencies. To consider any of these improvements, regional participation for funding and implementation must be discussed.

### 4.12 Summary of Recommendations

The recommended storm sewer systems that outfall into the Chimney Rock Rd. system the preliminary estimated cost is $1.3 million, similarly the South Rice system the preliminary estimated cost is $2.9 million, West Loop system the preliminary estimated cost is $41.1 million, Newcastle system the preliminary estimated cost is $36.7 million, Rail Road system area north of Bellaire Blvd. $2.9 million and Southdale system $0.9 million. The anticipated benefits from the storm sewer detention improvements is shown in Exhibit 16 and the reduced depth from flooding during the 100-year localized rainfall is approximated to be between half a foot to 1 ½ reduction depending on the drainage area. Some consideration for preventing sheet flow from outside the drainage areas is recommended during the Preliminary Engineering Report phase.

This preferred option would be focused on reducing the localized flooding events and would not prevent flood waters from Brays Bayou from flowing back into the City as water surface elevations in the bayou reached flood stages or exceeded the top of banks. It is suggested that the City consider the viability of building backflow systems such as flap gates within the large North/South drainage arterials to help prevent back water flows from the bayou from taking up the capacity of Bellaire's local systems.

It is also recommended that Bellaire continue to require the finished floors of new structures to be built above the base flood elevation. The vast majority of homes flooded during the recent storms were older homes constructed at a low elevation compared to the surrounding land.

## 5.0 Floodplain Re-Mapping

The existing current FEMA flood Insurance Map is attached as Exhibit 3. A description of the floodplain and re-mapping is described in below sections.

### 5.1 Current FEMA Models

The existing current FEMA flood Insurance Map was prepared by the current available Hydrological and Hydraulic models. A cursory review of the mapping and the models indicates that seven (7) FEMA designated HEC-RAS cross sections define the floodplain west of IH610. The elevation change is approximately 2.75-feet from IH610 Bridge upstream to the city limits which is approximately a mile upstream. Within the City of Bellaire, the FEMA elevation change is approximately 4.4-feet that translating into 2.75-ft on the west side of IH 610 and 1.35-ft east side of IH 610. Based on the documented damages for the various events, the majority of the flooding damage within the Bellaire occurs east of IH610. This documented difference when compared with the FEMA models and mapping reveal that the Hydraulic models have encroachments stations modeled which may artificially increase the water surface elevations

west of IH610. The floodplain mapping through the urban developed areas should reflect the spatial ground realities like presence of the buildings and other obstructions that prevent the the flood waters travelling backwards through these obstructions which is not currently accounted for in the existing floodplain mapping.

### 5.2 HCFCD Project Brays Re-Mapping

HCFCD has indicated they will consider this new information during their planned remapping effort of the floodplain to reflect improvements completed to date because of Project Brays. Project Brays is an over $400 million major flood control project being undertaken with the Corps of Engineers with major improvements already completed and providing benefits to the Brays Bayou watershed. The HCFCD plans to be begin a new floodplain mapping project in 2017 to show the reduction in floodplain realized due to the ongoing construction of Project Brays. This remapping effort by the HCFCD could take a minimum of five years to complete, because it must be approved by FEMA.

### 5.3 City of Bellaire Letter of Map Revision

On a more immediate basis and as recommended by this study, the City of Bellaire is currently developing a Letter of Map Revision report that will be submitted to the HCFCD to potentially remove certain areas within the City of Bellaire from the floodplain as shown on the existing FEMA maps. The current floodplain maps do not reflect the spatial ground realities like the presence of buildings, fences and other obstructions that can prevent flood waters from flowing back into the City of Bellaire when flood water elevations exceed the capacity of Brays Bayou. This remapping effort will attempt to remove properties from the flood plain showing the backwater flow to be through the street system versus through the obstructions. If this remapping effort is successful and approved by the HCFCD and FEMA, many Bellaire properties will be removed from the mapped 100-year floodplain, thus providing significantly lower flood insurance premiums for those citizens of Bellaire.

This immediate effort to remap the FIRM will be submitted directly to the HCFCD as the local FEMA designated partner. Possibly as soon as four (4) months after the letter of map revisions are submitted to the HCFCD, the revised maps may be used to determine lower insurance premiums for those citizens located in the affective area.

## 6.0 Recommendations

Based on the drainage study investigations, it is recommended that the City of Bellaire consider the following:

1. Construct local underground storage systems by increasing the normal two-year design storm sewer system to store the 100-year storm volumes at selected strategic locations.

2. Construct backflow prevention systems at several of the major drainage system outfalls like the Newcastle and IH 610 system outfalls to Cypress Ditch to prevent back water flow from Brays Bayou backing up into these systems during high water flood stages.

3. Prepare and submit a LOMR to the HCFCD for approval to remove certain areas of the City of Bellaire from the floodplain.

4. Request TxDOT to improve the IH 610 drainage system to properly receive the existing drainage area storm water runoff and convey to Brays Bayou. The system should be increased to meet their current design criteria for a system receiving this amount of runoff from such a large drainage area.

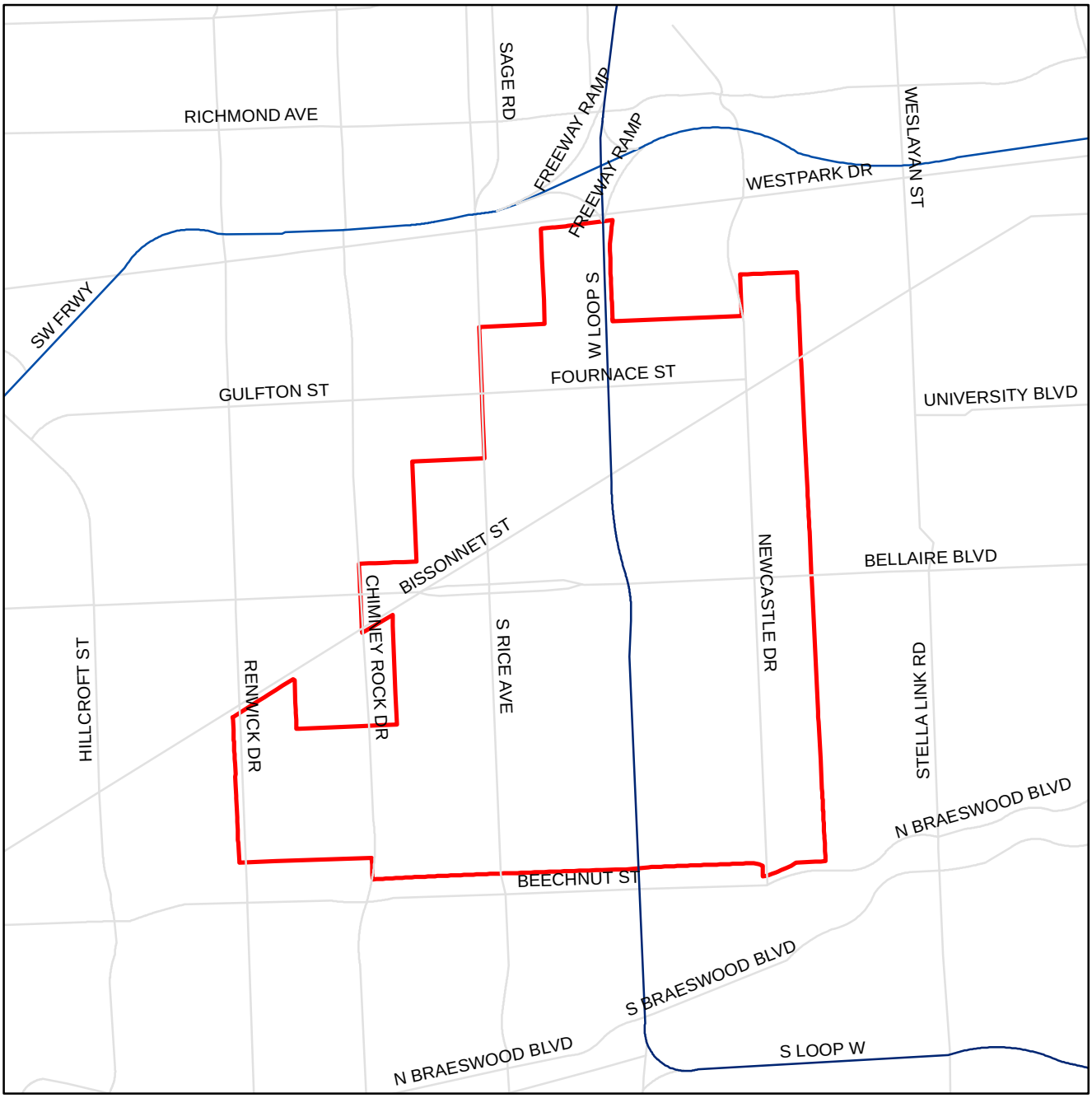
5. Request interim improvements to the system directly adjacent to the proposed improvements associated with the US69/IH610 interchange improvements to receive the storm water runoff from the existing drainage area and meter the outfall until such time as downstream improvements are constructed as mentioned above.

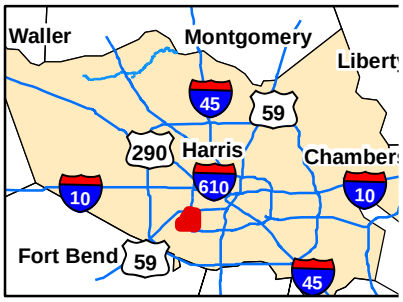
6. Request the City of Houston/Texas Water Development Board/FEMA to participate in conveyance and storage capability improvements within the Chimney Rock and S. Rice Ave. drainage systems because they serve such large areas of the City of Houston as well.

7. Develop inter-local agreements with the City of Houston for future improvements and maintenance for drainage facilities that serve both entities. These agreements should consider development and detention requirement standards for any new development.

8. Request the City of Houston and/or City of West University Place to consider installing back flow prevention systems in Cypress Ditch and Kilmarnock Ditch to prevent back water from Brays Bayou backing up into these systems during high water flood stages.

9. Remove existing identified utility conflicts where possible.




**Legend**

City of Bellaire

**mjroad_n83**

St.

**HWY_NO**

59

610

# City of Bellaire Drainage Study

## City Limits and Location Map

# EXHIBIT 1

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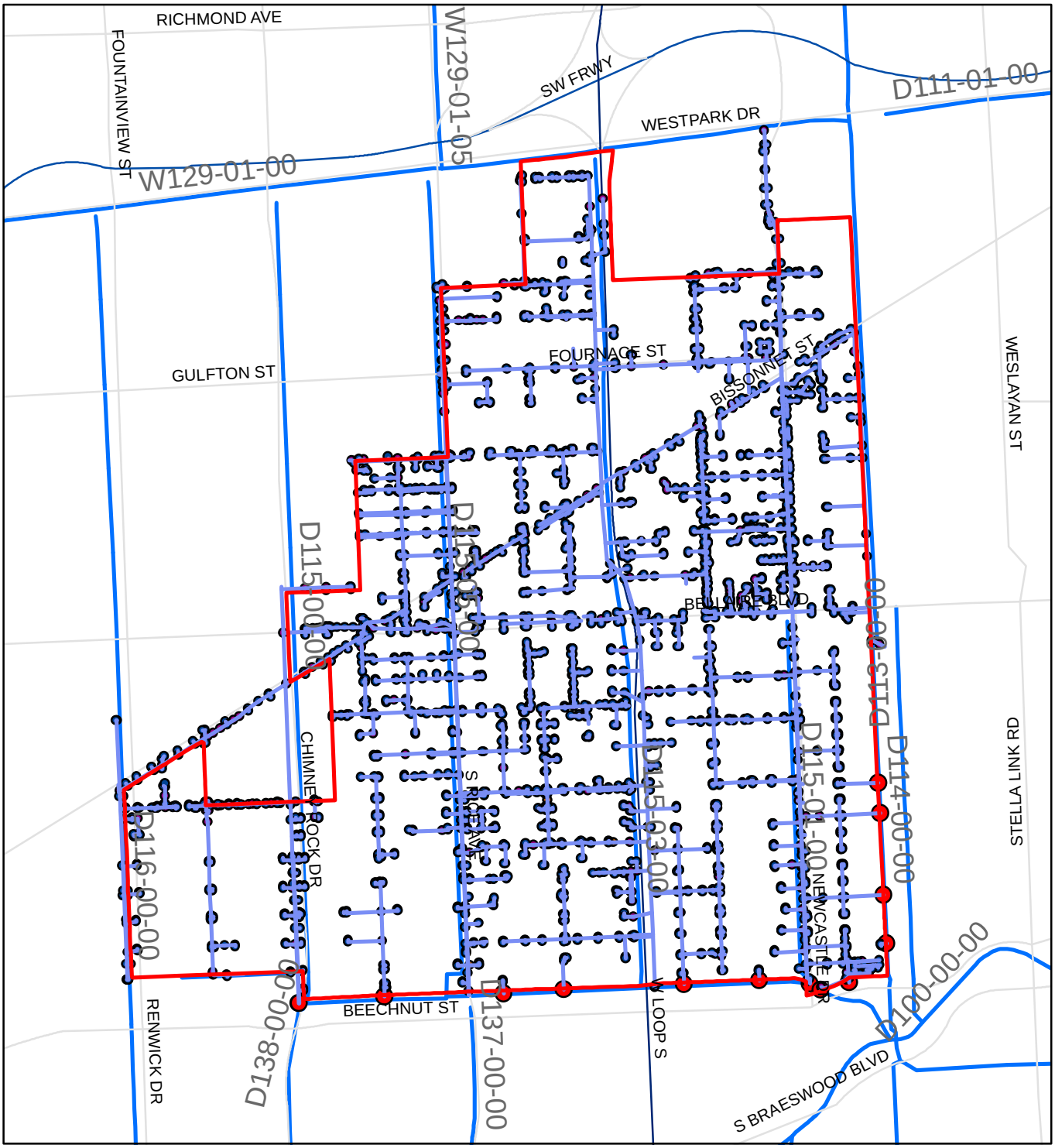
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




Attachment: 2016 City of Bellaire Drainage Study Report (2080 : Presentation-Drainage Study)

**Legend**

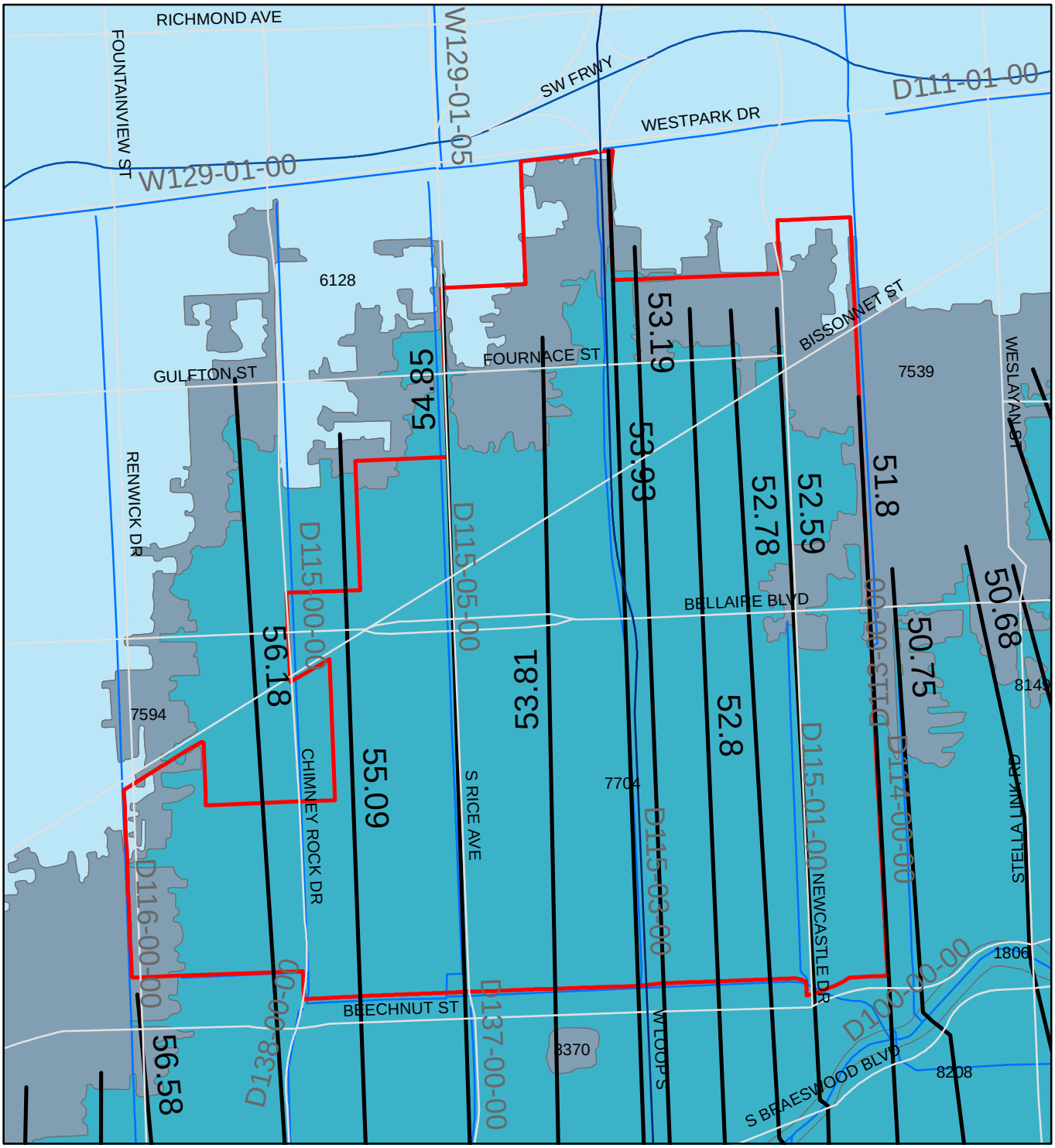
- City of Bellaire
- Outfall
- Manholes_Storm
- JunctionBoxes
- Inlets
- STMains
- cap2000_n83

# City of Bellaire Drainage Study

## City of Bellaire Drainage Systems

# EXHIBIT 2

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




Attachment: 2016 City of Bellaire Drainage Study Report (2080 : Presentation-Drainage Study)

**Legend**

- FEMA Base Flood Elev.
- City of Bellaire
- cap2000_n83

**FLD_ZONE**

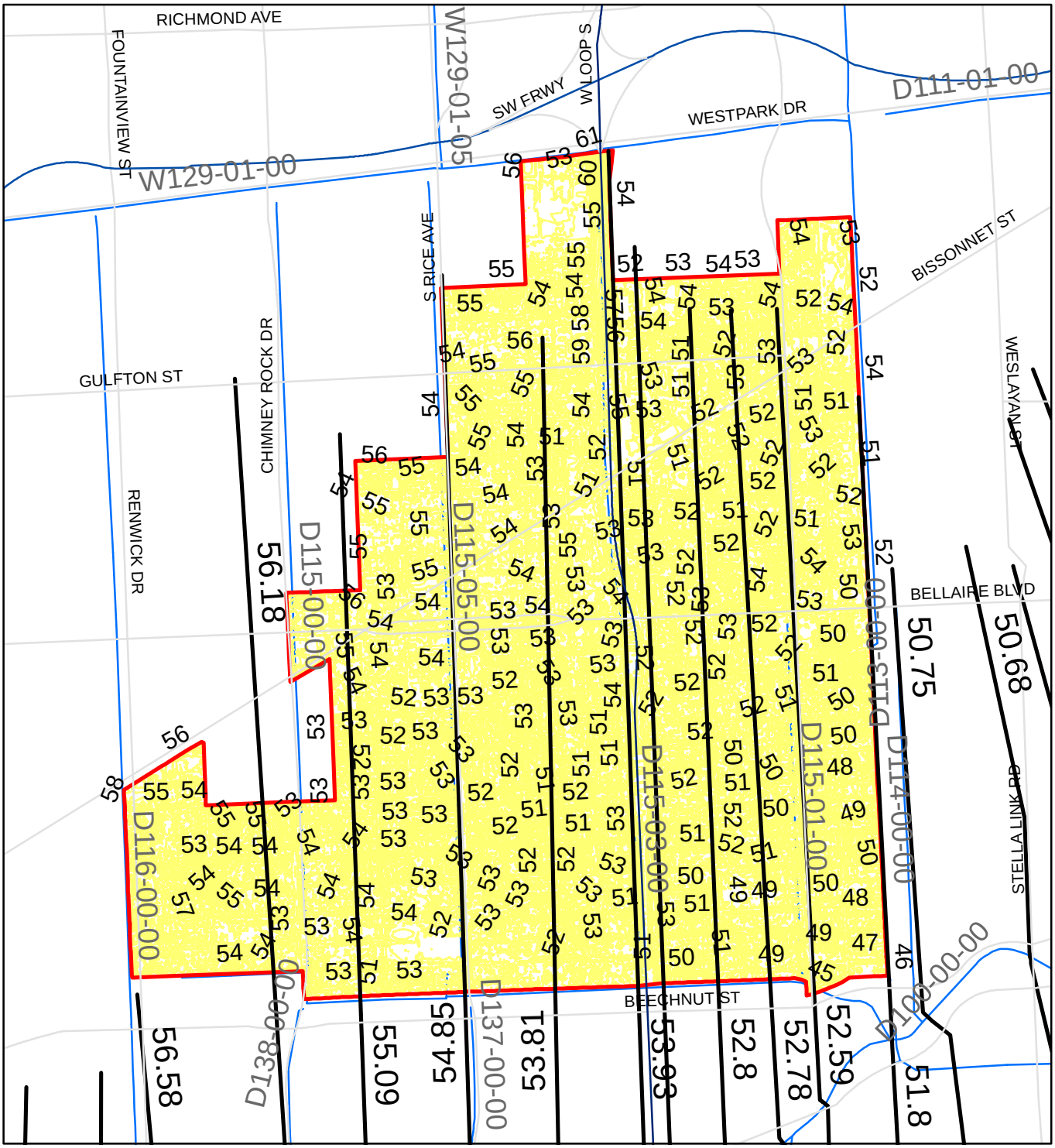
- 0.2 PCT ANNUAL CHANCE FLOOD HAZARD
- AE
- X

# City of Bellaire Drainage Study

## FEMA FIRM MAP

# EXHIBIT 3

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901






# City of Bellaire Drainage Study

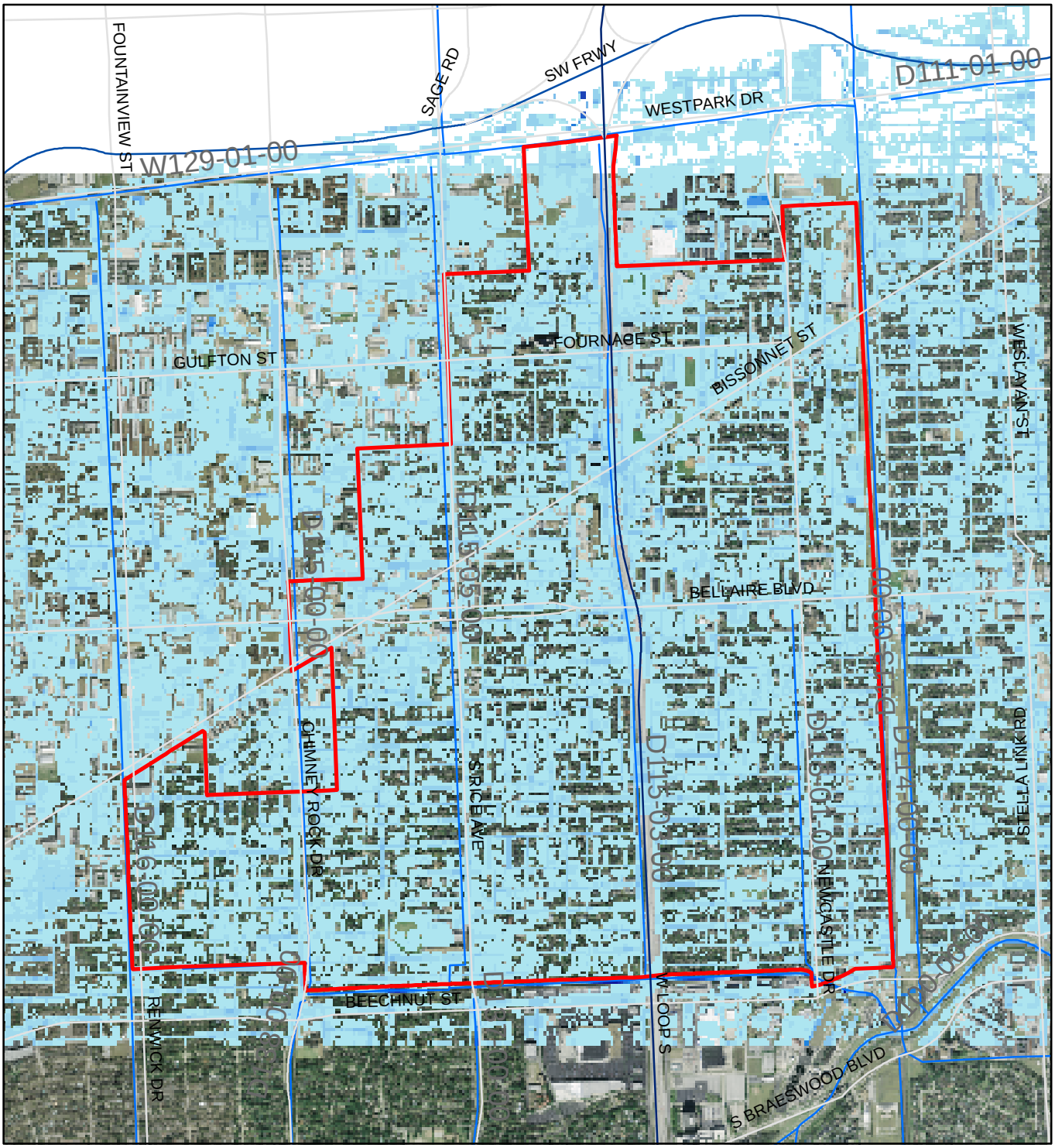
## Contour Map and Base Flood Elevations

**Legend**

- FEMA Base Flood Elev.
- City of Bellaire
- cap2000_n83
- B_CONTOUR_Clip

# EXHIBIT 4

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




# City of Bellaire Drainage Study

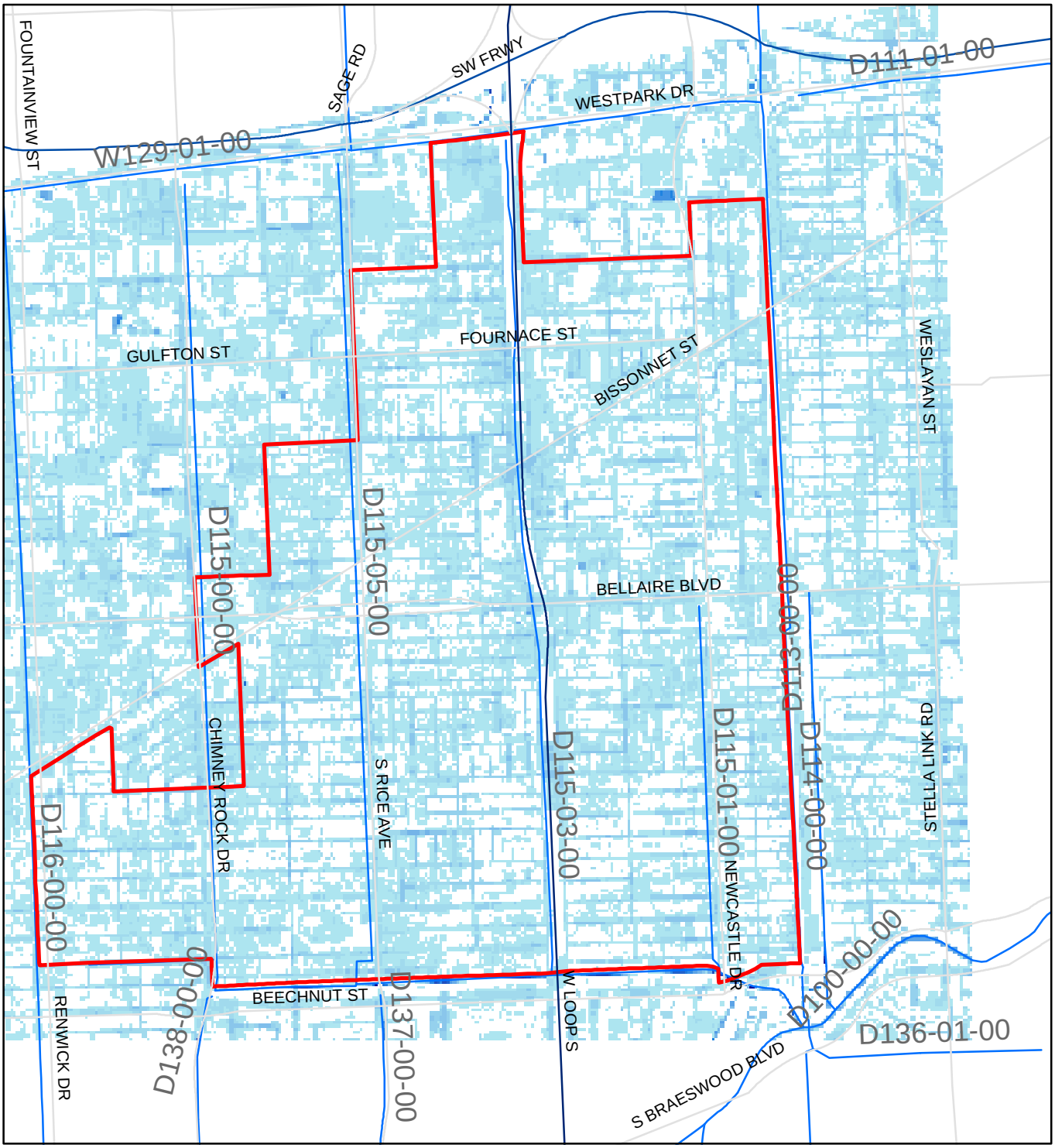
## Results of flooding above 0.5-foot from 2-D Model for 6-in/hr Rainfall-Low areas with water

# EXHIBIT 5

**Legend**

- City of Bellaire
- cap2000_n83

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




# City of Bellaire Drainage Study

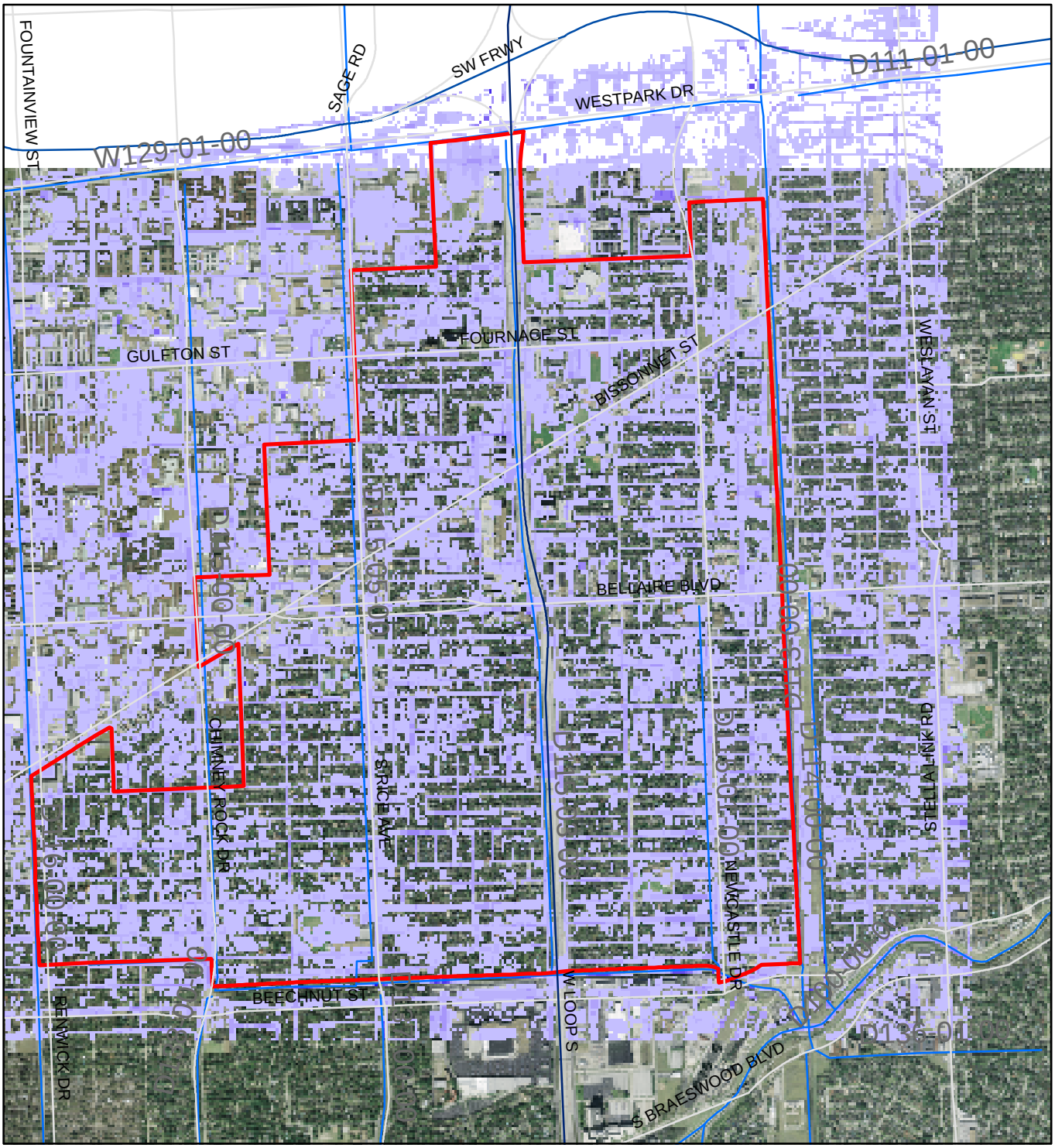
## Results of flooding from 2-D Model for 6-in/hr Rainfall-Low areas with water

# EXHIBIT 6

**Legend**

- City of Bellaire
- cap2000_n83

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




# City of Bellaire Drainage Study

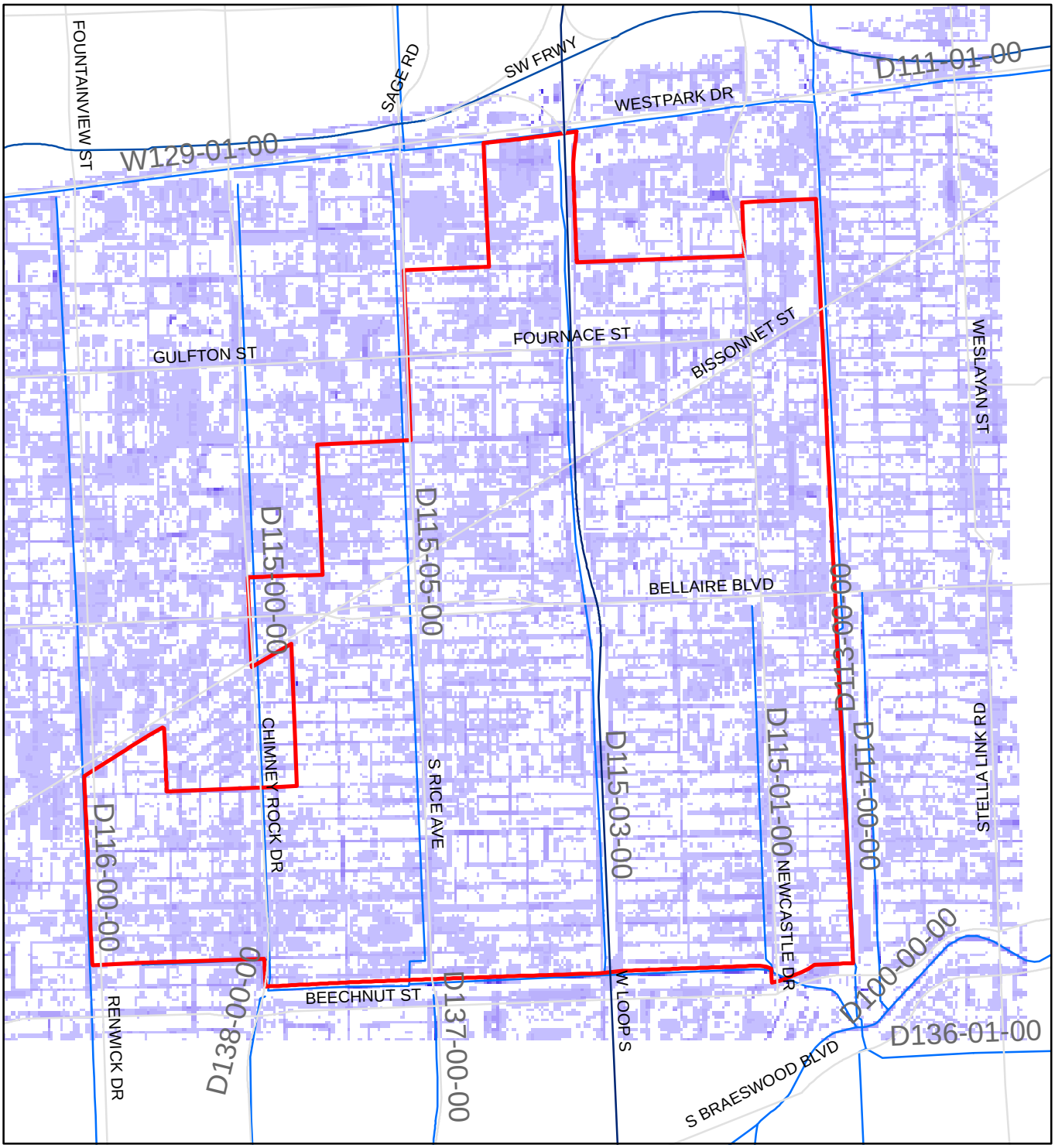
## Results of flooding above 0.5-foot from 2-D Model for 4-in/hr Rainfall-Low areas with water

# EXHIBIT 7

**Legend**

- City of Bellaire
- cap2000_n83

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




Attachment: 2016 City of Bellaire Drainage Study Report (2080 : Presentation-Drainage Study)

# City of Bellaire Drainage Study

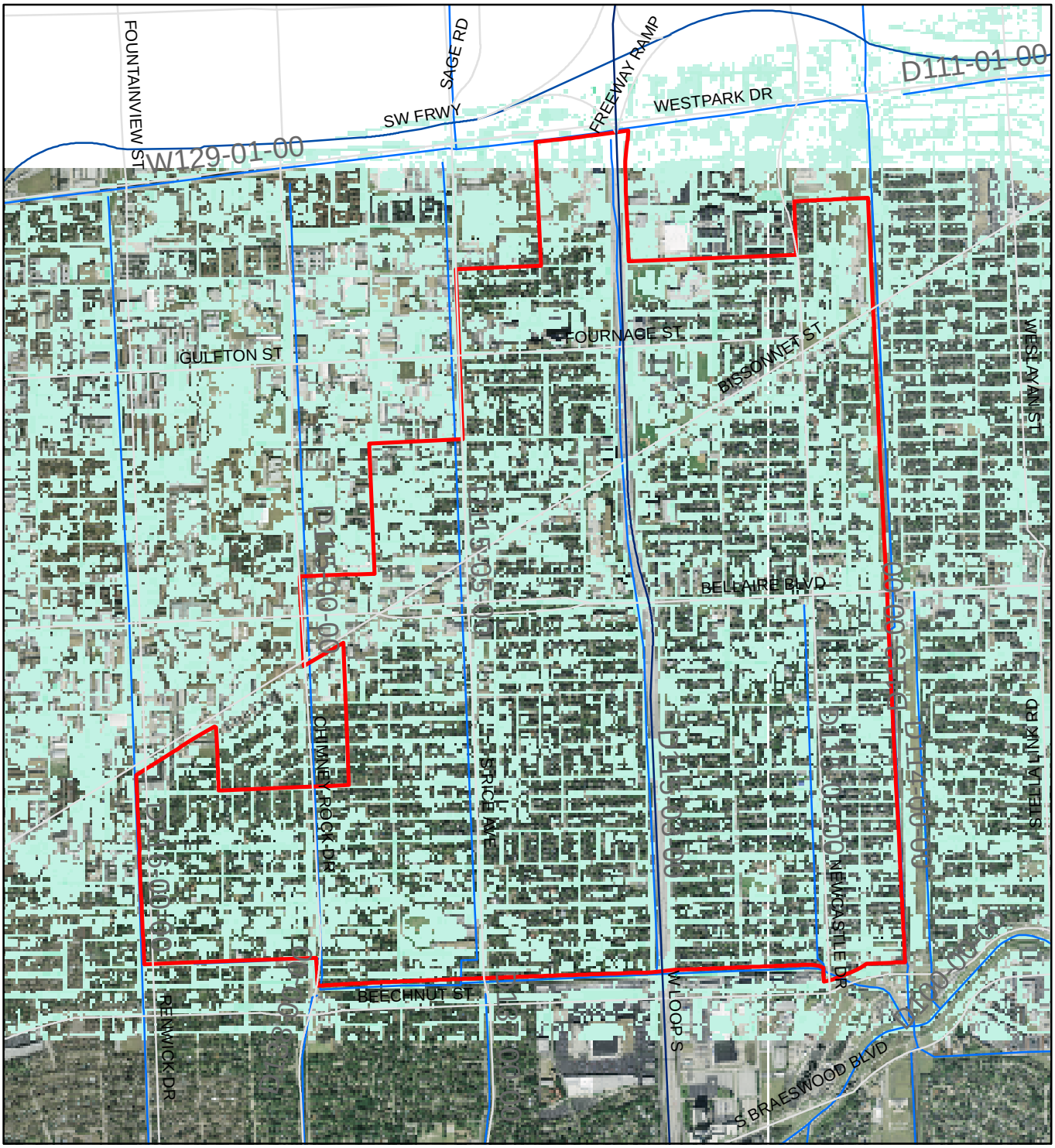
## Results of flooding from 2-D Model for 4-in/hr Rainfall-Low areas with water

# EXHIBIT 8

**Legend**

- City of Bellaire
- cap2000_n83

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




# City of Bellaire Drainage Study

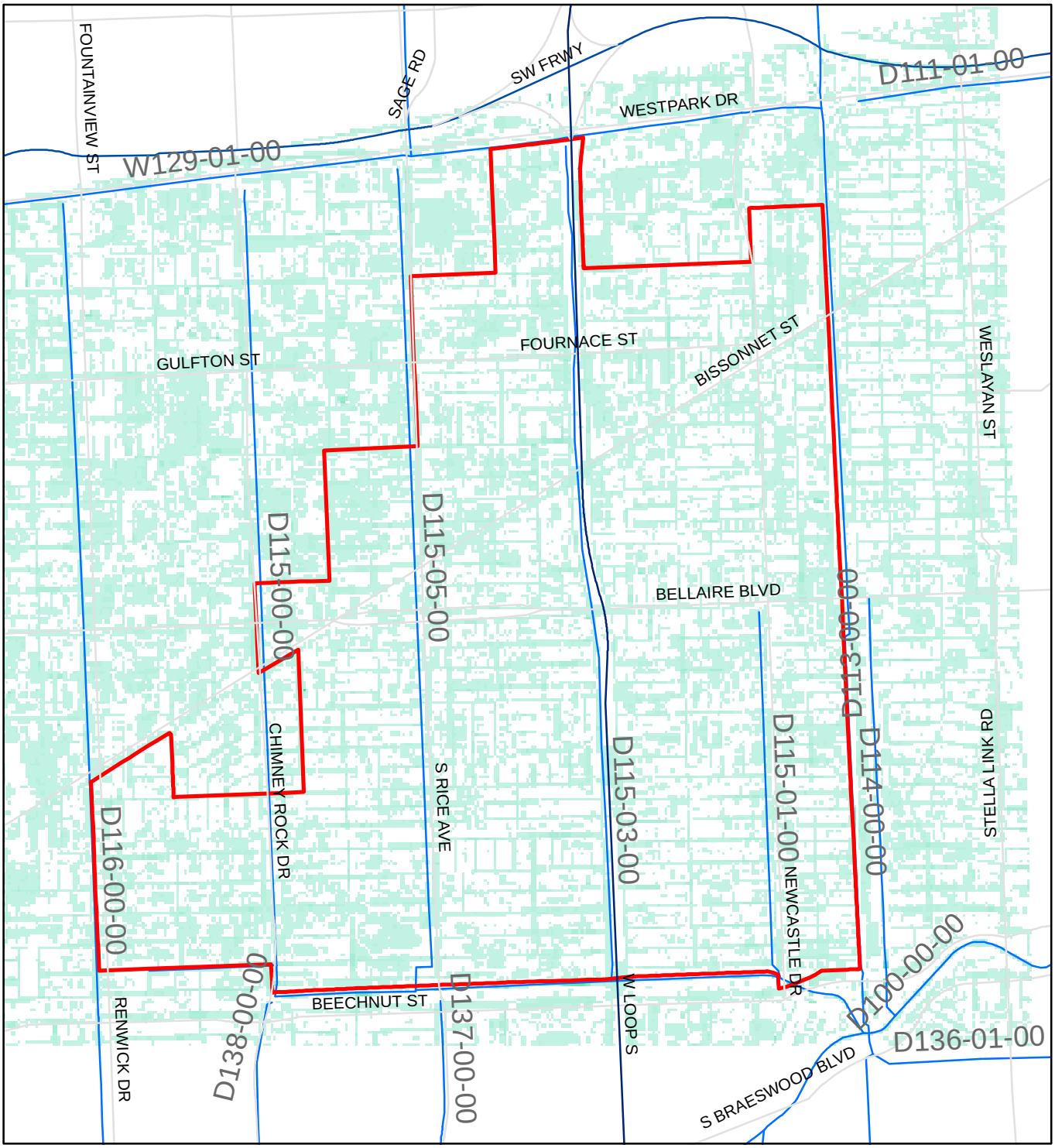
## Results of flooding above 0.5-foot from 2-D Model for 3-in/hr Rainfall-Low areas with water

# EXHIBIT 9

**Legend**

- City of Bellaire
- cap2000_n83

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




Attachment: 2016 City of Bellaire Drainage Study Report (2080 : Presentation-Drainage Study)

# City of Bellaire Drainage Study

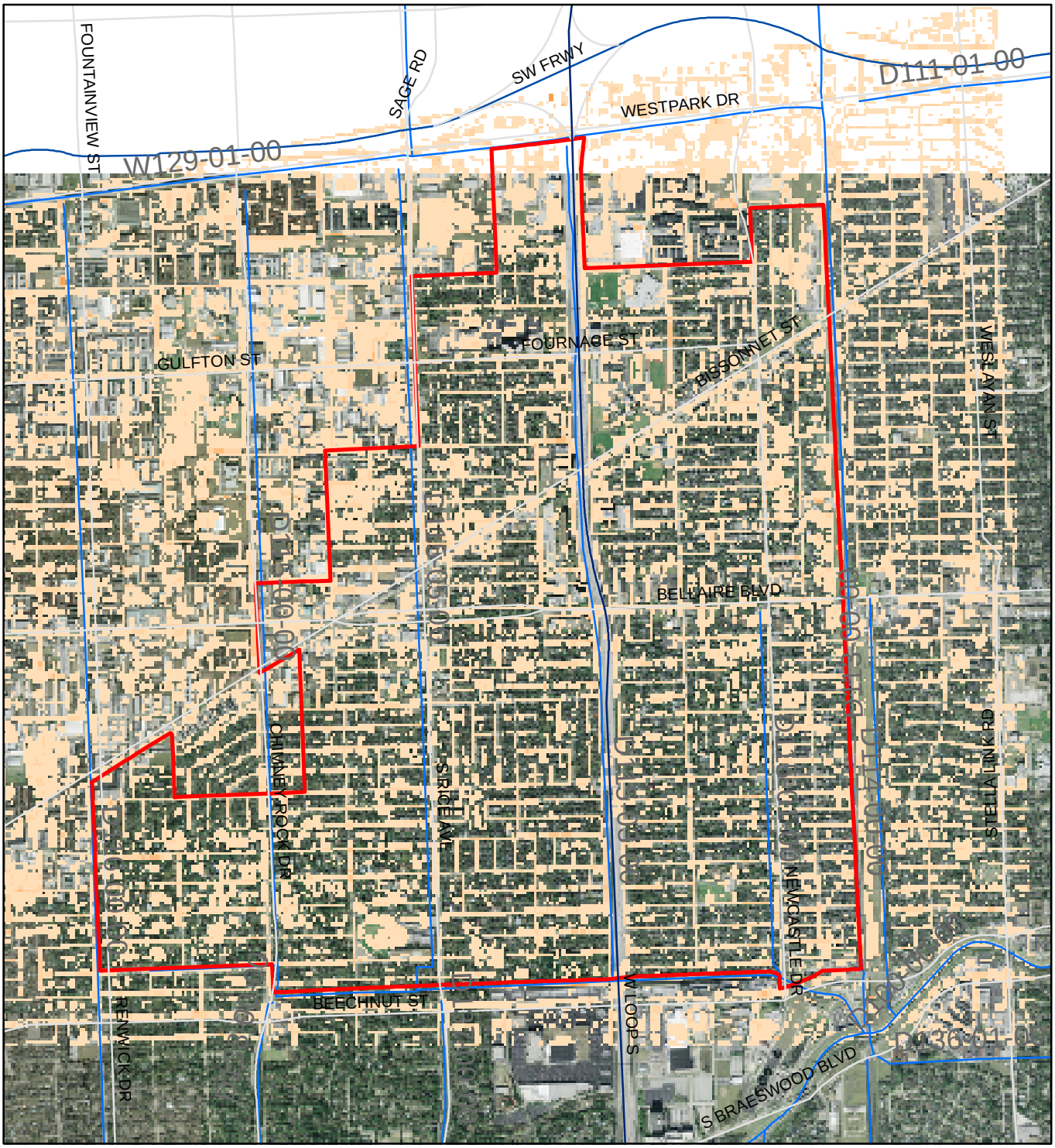
## Results of flooding from 2-D Model for 3-in/hr Rainfall-Low areas with water

# EXHIBIT 10

**Legend**

- City of Bellaire
- cap2000_n83

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




# City of Bellaire Drainage Study

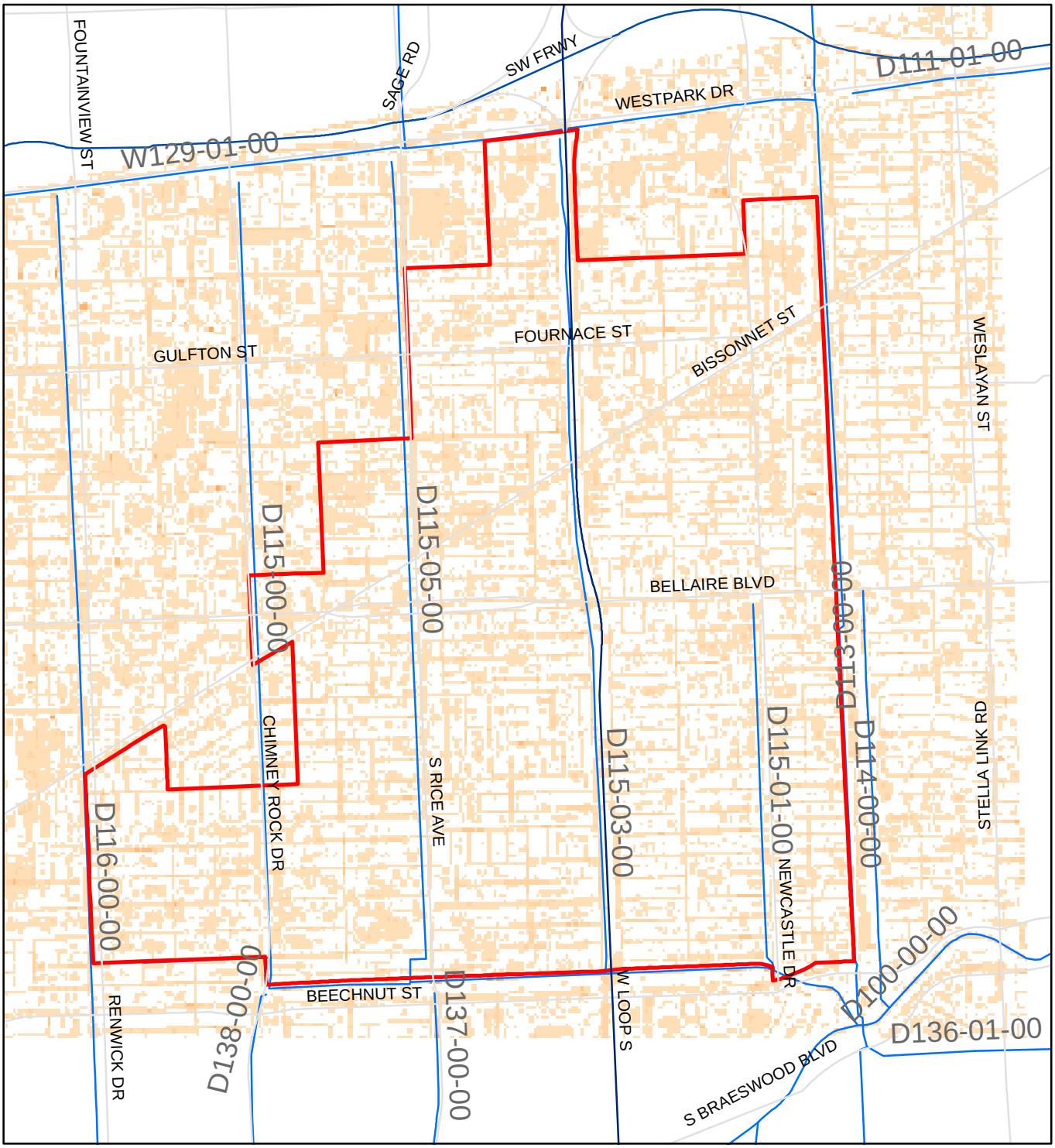
## Results of flooding above 0.5-foot from 2-D Model for 2-in/hr Rainfall-Low areas with water

# EXHIBIT 11

**Legend**

- City of Bellaire
- cap2000_n83

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




# City of Bellaire Drainage Study

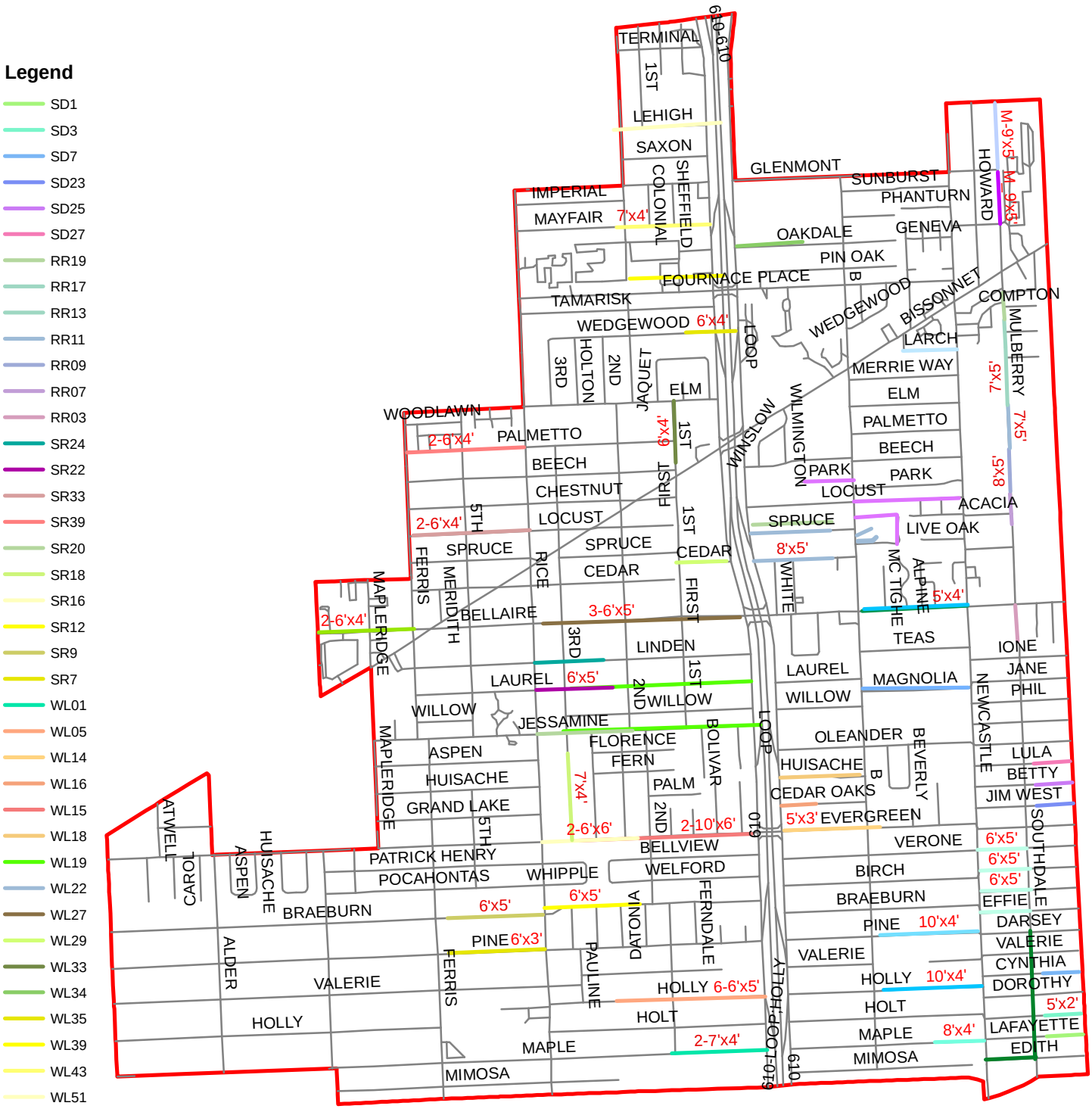
## Results of flooding from 2-D Model for 2-in/hr Rainfall-Low areas with water

# EXHIBIT 12

**Legend**

- City of Bellaire
- cap2000_n83

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901

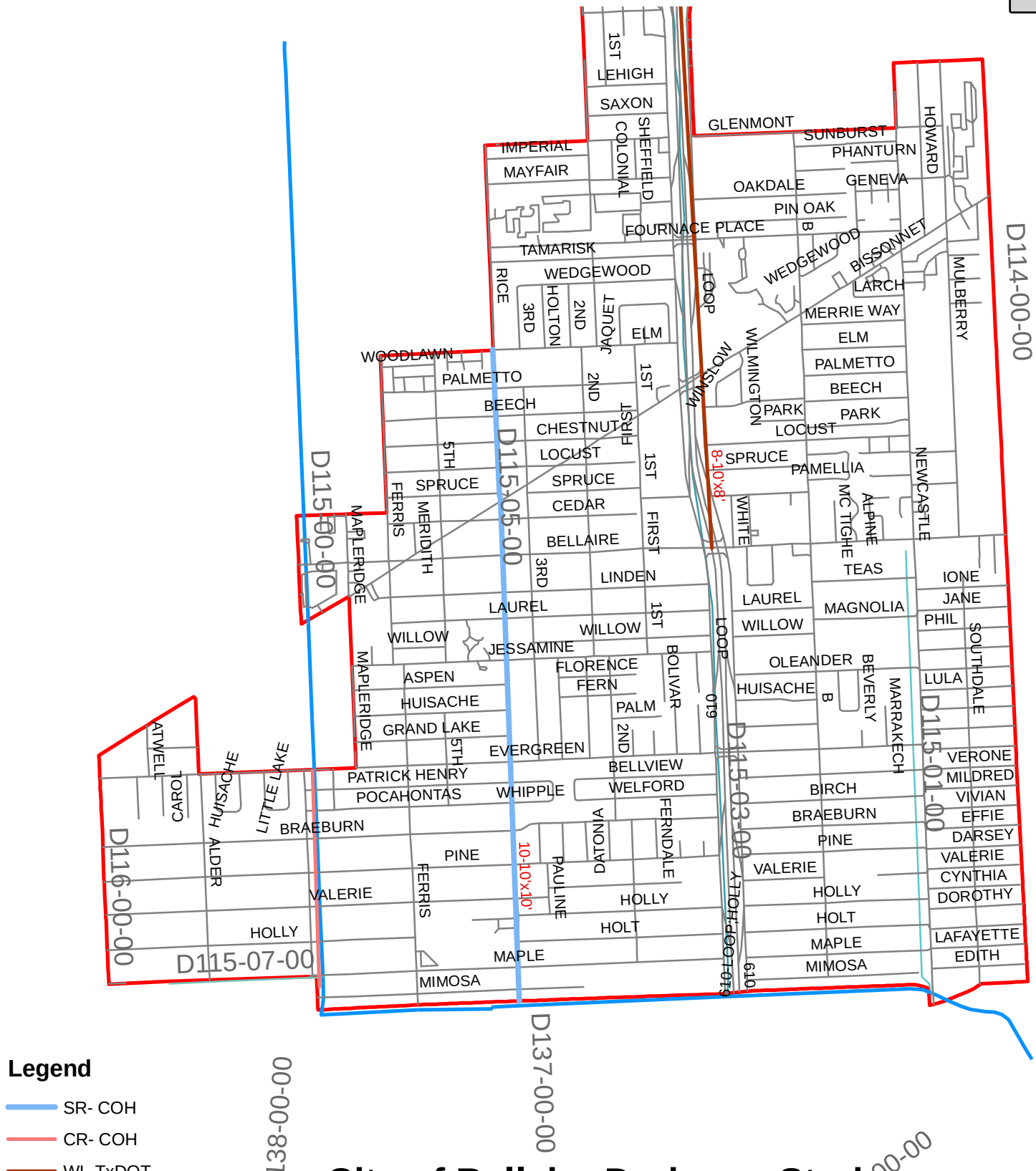



# City of Bellaire Drainage Study

## Proposed City Wide Storm Sewer Improvements

# EXHIBIT 13

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




**Legend**

- SR- COH
- CR- COH
- WL-TxDOT

**HCFCD**

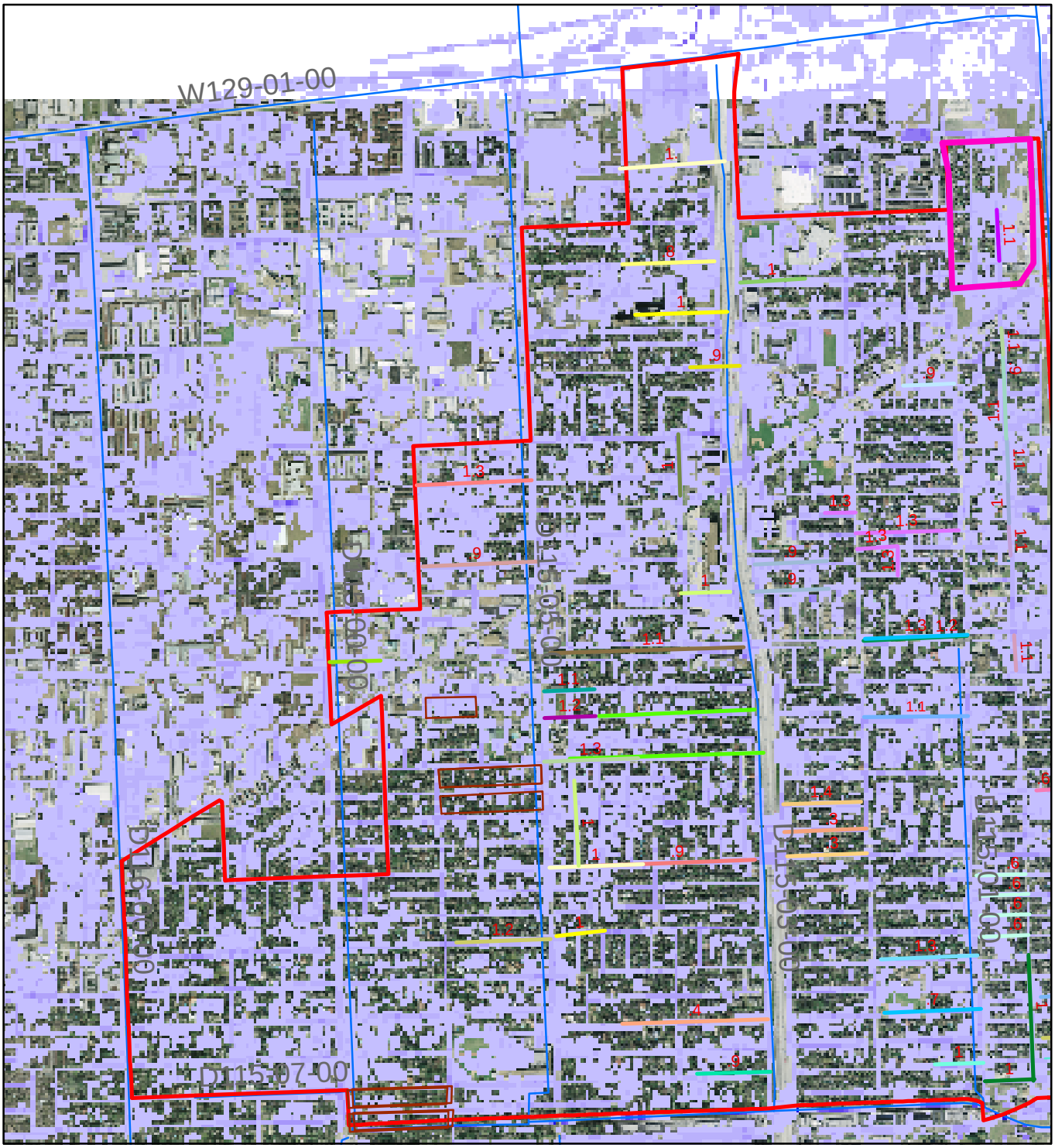
- D115-00-00
- D115-01-00
- D115-03-00
- D115-07-00
- COB_ROADS

# City of Bellaire Drainage Study

## Regional Projects With Participation By Others

# EXHIBIT 14

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901



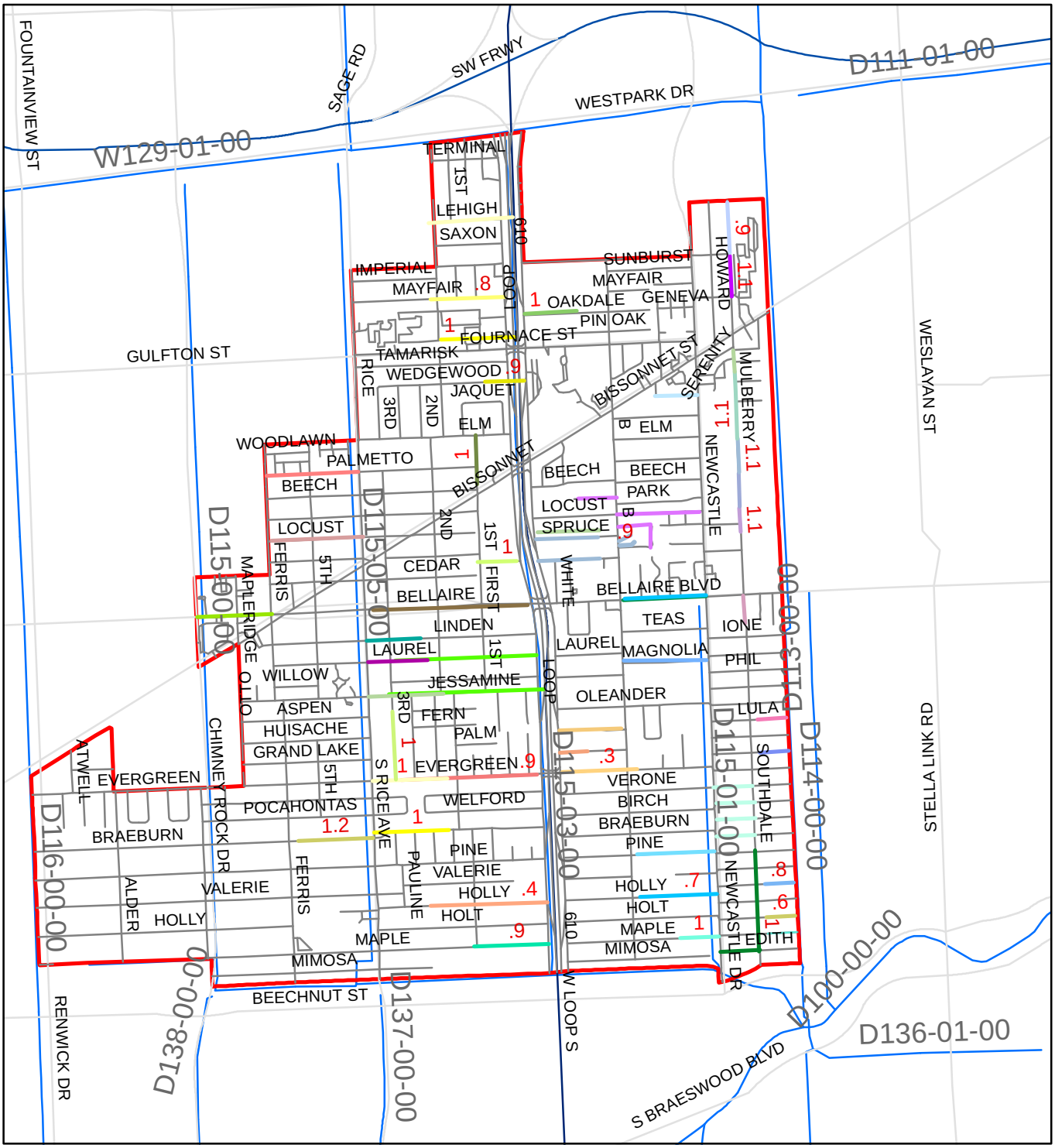

# City of Bellaire Drainage Study

## Estimated Benefits With Storm Sewer Improvements

**Assumptions in Benefits see Text**

# EXHIBIT 15

SIRRUS
ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901



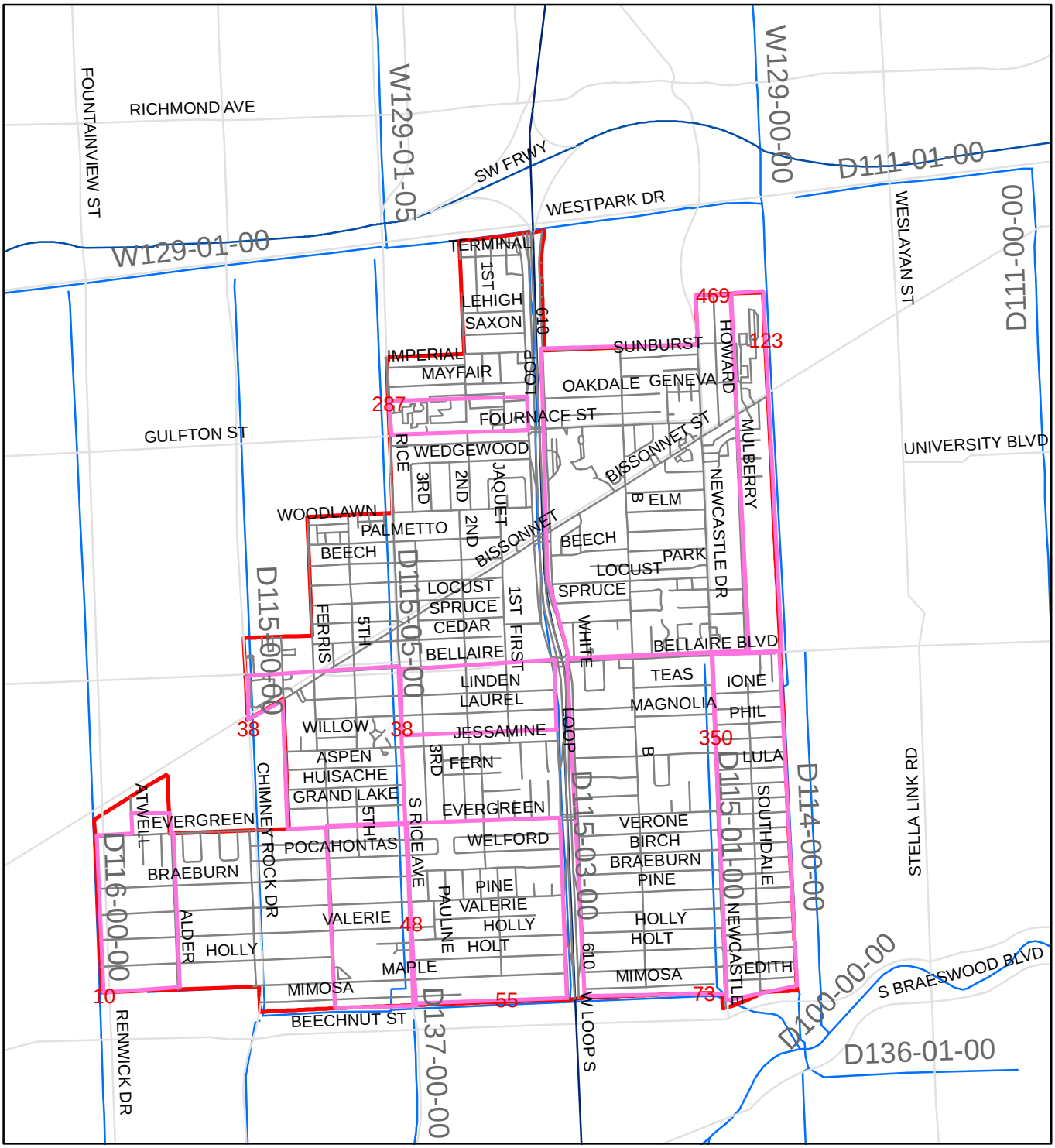

# City of Bellaire Drainage Study

## Benefits of Localized Storm Sewer Improvements

### Estimated Reduction in Water Surface Elevations

# EXHIBIT 16

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




Attachment: 2016 City of Bellaire Drainage Study Report (2080 : Presentation-Drainage Study)

# City of Bellaire Drainage Study

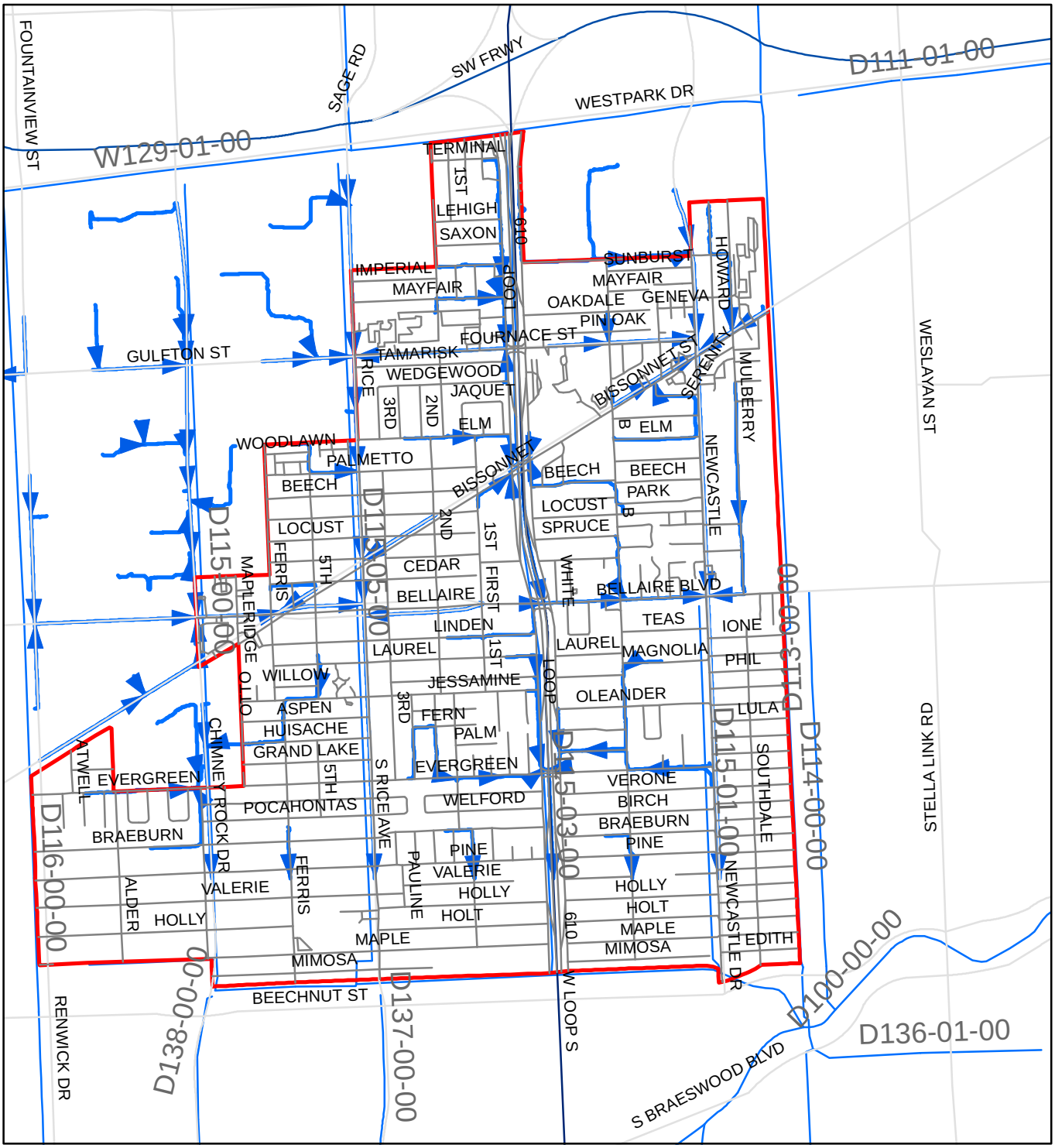
## Historical Flooding Information (TSARP)

**Legend**

- Historical_Flooding_Str
- City of Bellaire

# EXHIBIT 17

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901




# City of Bellaire Drainage Study

## Flow Paths

# EXHIBIT 18

SIRRUS ENGINEERS, INC.
3100 TIMMONS LN. SUITE 500
HOUSTON, TX 77027
TEXAS FIRM REGISTRATION NO. 5901

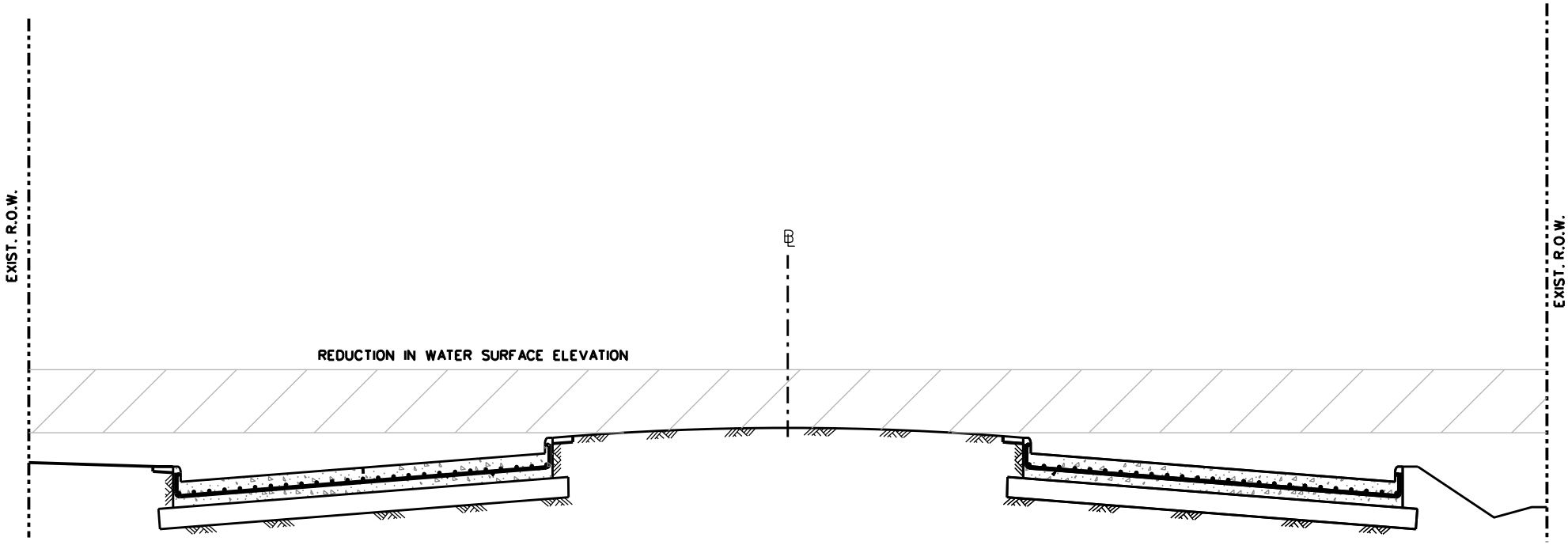
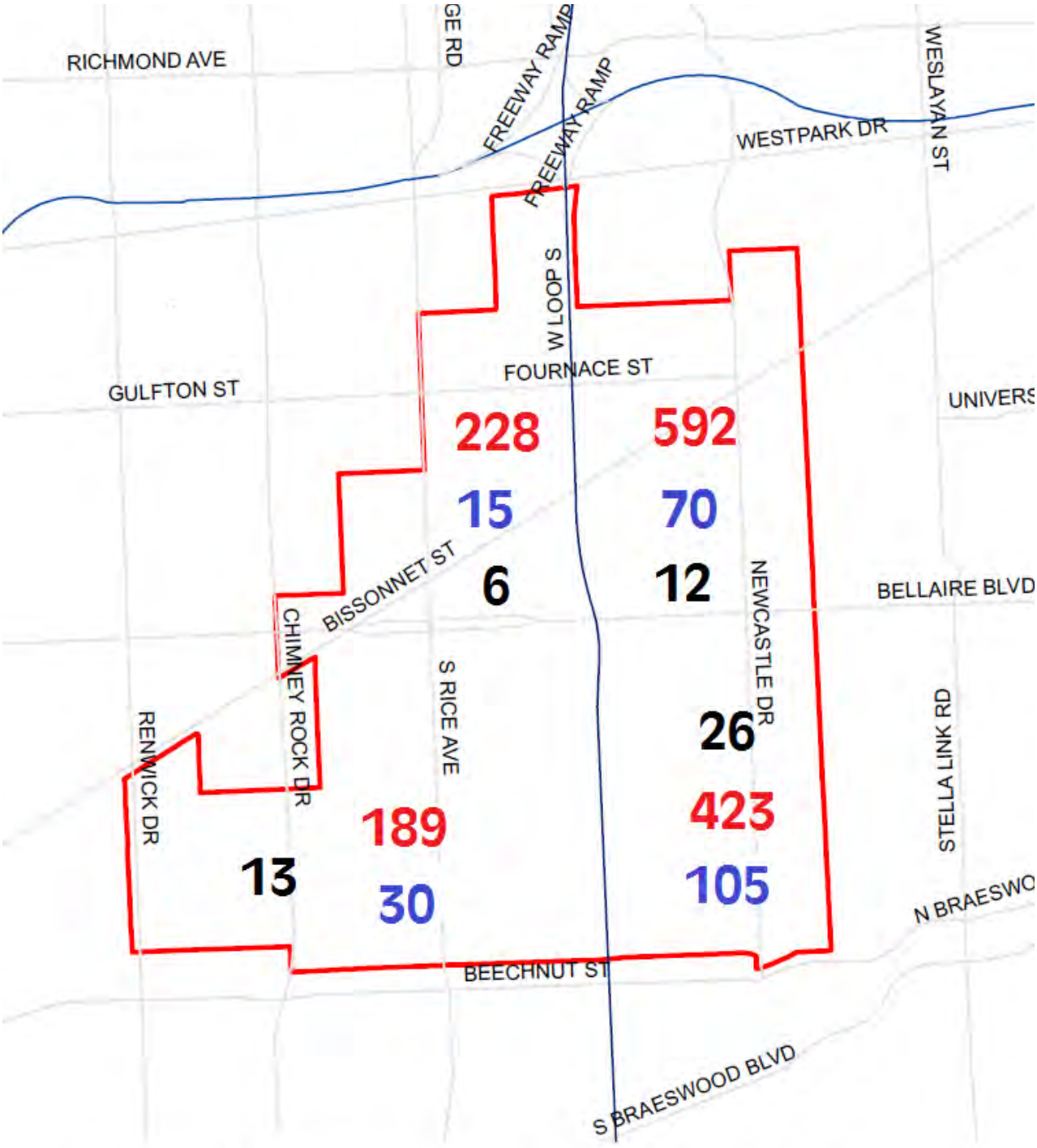



EXHIBIT 17




# Reported Structures Flooded

**Allison 1432** **May 2015 220**

**Repetitive Loss 57**

ARKK ENGINEERS

**Building and Standards Commission**
Council Chamber, First Floor of City Hall
Bellaire, TX 77401

Meeting: 11/16/16 06:00 PM
Department: Development Services
Category: Discussion
Department Head: John McDonald
DOC ID: 2083

**SCHEDULED**
**INFORMATION ITEM (ID # 2083)**

---

**Item Title:**

Discussion on the Environmental and Sustainability Board's proposed changes to Chapter 9, Buildings, Article XI, Trees, Section 9-350 M., Undesirable Trees and Section 9-352 D., Tree Disposition Plan, of The City of Bellaire Code of Ordinances.

**Background/Summary:**

This item is to allow for a discussion of the Environmental and Sustainability Board's (ESB)recommended changes to the following sections of Chapter 9, Article XI-Trees of the Bellaire Code of Ordinances:

- Sec. 9-350 Definitions, M. Undesirable Trees
- Sec. 9-352 D. Tree Disposition Plan

The proposed changes are attached, with the original language in red and the recommended language in blue.

**ATTACHMENTS:**

- Proposed Changes to Chapter 9 of the Code of Ordinances (DOCX)

Sec. 9-350. - Definitions.

M. Undesirable trees. Chinese Tallow (Sapium sebiferum), Arizona Ash (Fraxinus velutina), Hackberry (Celtis laevigata or Celtis occidentalis), Silver Maple (Acer saccharinum), and Cottonwood (Populus spp.) variety trees.

| Tree or Shrub Common Name | Scientific name |
|---|---|
| Glossy Abelia | *Abelia x grandiflora (chinensis x uniflora)* |
| Boxwood | *Buxus L. or microphylla* |
| Butterfly Bush | *Buddleja* spp. |
| Callery pear (Bradford pear) | *Pyrus calleryana* |
| Camphor Tree | *Cinnamomum camphora* |
| Chinaberry | *Melia azedarach* |
| Chinese Elm | *Ulmus parvifolia all cultivars* |
| Chinese Parasol Tree | *Firmiana simplex* |
| Chinese Pistache | *Pistacia chnensis* |
| Chinese Privet | *Ligustrum sinense* |
| Chinese Tallow | *Sapium sebiferum; Triadica sebifera* |
| Crape Myrtle | *Lagerstroemia indica (and indica x fauriei)* |
| Eleagnus or olive | *Elaeagnus x ebbingei (macrophylla x pungens)* |
| Eucalyptus | *Eucalyptus* spp |
| Euonymus Creeper | *Euonymus fortunei* |
| False Jerusalem Cherry | *Solanum capsicastrum* |
| Golden Rain Tree | *Koelreuteria paniculata* |
| Heavenly Bamboo/Nandina | *Nandina domestica* |
| Indian Hawthorn | *Rhaphiolepis indica* |
| Jerusalem Cherry | *Solanum pseudocapsicum* |
| Lantana | *Lantana camara* |
| Lilac Chaste Tree | *Vitex agnus-castus* |
| Loquat | *Eriobotrya japonica* |
| Loropetalum/Fringe flower | *Loropetalum chinense* |
| Macartney/Cherokee Rose | *Rosa bracteata* |
| Mexican Hydrangea | *Clerodendrum bungei* |
| Mimosa, Silk Tree | *Albizia julibrissin* |
| Palm trees-non native | *Arecaceae, Palmae or Palmaceae* |
| Oleander | *Nerium L* |
| Paper Mulberry | *Broussonetia papyrifera* |
| Pittosporum | *Pittosporum tobira* |
| Red tip Photinia | *Photinia x fraseri* |
| Rose of Sharon | *Hibiscus syriacus* |
| Sago Palm | *Cycas revoluta, Metroxylon sagu* |
| Salt Cedar | *Tamarix* spp. |
| Sawtooth Oak | *Quercus acutissima Carruthers* |
| Siberian Elm | *Ulmus pumila* |
| Tree of Heaven | *Ailanthus altissima* |
| Trifoliate Orange | *Poncirus trifoliata* |
| Wax Leaf Ligustrum | *Lugustrum japonicum,lucidum, quihoui* |
| White Mulberry | *Morus alba* |
| Xylosma | *Xylosma congestum* |
| Zelkova | *Zelkova Spach or serrata Makino* |

Sec. 9-352 D. Tree disposition plan.

The property owner or the building contractor shall be responsible for developing a tree disposition plan for the preservation and replacement of trees on the property. A sample tree disposition plan will be available from the Bellaire Community Development Department. The code enforcement officer will verify the tree disposition plan.

The property owner or the building contractor shall be responsible for removal of undesirable trees and develop the following:

1. A plan for the preservation of desirable trees on the property and
2. A plan for replacement of any desirable trees removed from the property.

A sample tree disposition plan will be available from the Development Services Department. This plan may not include any of the plants on the list of undesirable trees and shrubs. The code enforcement officer will verify the tree disposition plan.