MEMORIAL DRIVE DRAINAGE IMPROVEMENTS
PRELIMINARY ENGINEERING REPORT

Prepared for the

MEMORIAL CITY REDEVELOPMENT AUTHORITY

On behalf of

TAX INCREMENT REINVESTMENT ZONE NO. 17
(TIRZ No. 17)

prepared by

Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY

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5/4/2009

LOCKWOOD, ANDREWS & NEWNAM, INC.
FIRM NO. 2614

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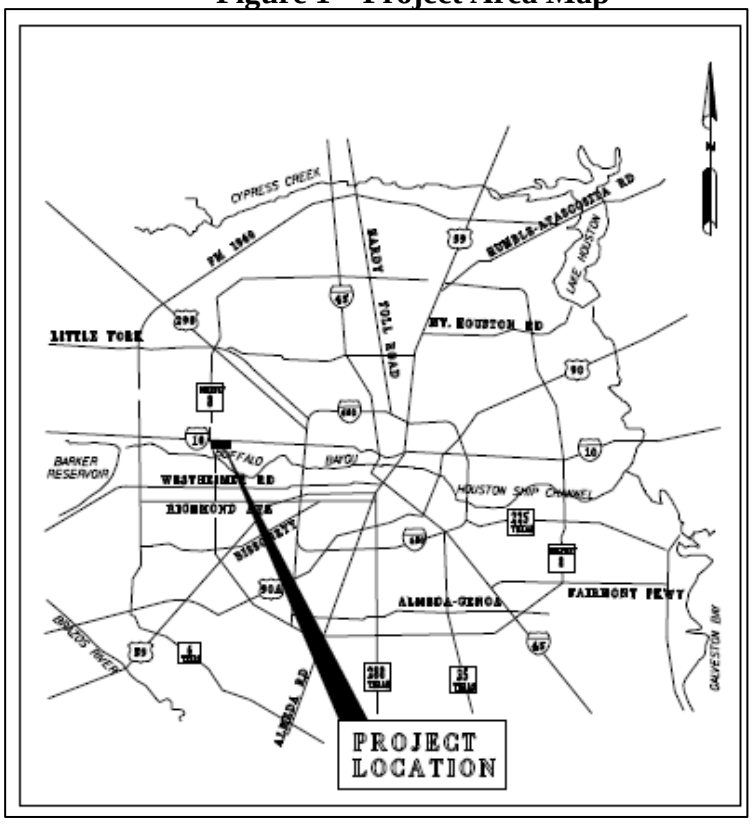
EXECUTIVE SUMMARY

Project Location and Purpose

Located in Harris County and the City of Houston, the existing Memorial Drive storm sewer system consists of approximately 1300 feet of storm sewer trunk line that serves Memorial Drive and a portion of West Bough Lane. The project begins at the Sam Houston Tollway Frontage Road and extends east along Memorial until West Bough Lane. Key Map pages 489H and 489G contain the project limits. The general location for the project is shown in Figure 1. A more detailed map of the project location can be found in **Exhibit 1**.

Figure 1 – Project Area Map



The storm sewer trunk line that serves Memorial Drive was identified by the City of Houston Comprehensive Drainage Plan (COH CDP) as inadequately sized. The Tax Increment Reinvestment Zone No. 17 (TIRZ 17) adopted the project as part of their Drainage Action Plan. The purpose of the project is to analyze and potentially improve the storm sewer facilities (including inlets, trunk lines, and laterals) along Memorial to satisfy the City of Houston Drainage Criteria.

Existing Conditions

Memorial Drive is currently a four-lane, undivided curb and gutter roadway and West Bough Lane is currently a two-lane, undivided roadway served by a combined storm sewer and open ditch. The existing storm sewer consists of 1,300 linear feet of 42", 30", and 24" reinforced concrete pipe (RCP). The system drains into the trunk line along the Sam Houston Tollway Frontage Road and ultimately outfalls into Buffalo Bayou. Memorial Drive is drained by eight type B-B inlets and three grate inlets located within private driveways. The western side of West Bough is drained by one type B-B inlet and three grate inlets. The crown of West Bough Lane serves as a drainage divide and drainage boundary for the Memorial Drive drainage system. The area west of the roadway crown drains west into the Memorial Drive storm sewer system and the area east of the crown drains to a separate trunk system along Memorial Drive. This secondary trunk system drains east along Memorial Drive to a separate outfall. The West Bough Lane storm sewer system was analyzed and found to be adequate within the specified project limits.

The Memorial Drive storm sewer system has a contributing drainage area of 29-acres and the Land Use Type is classified as 'Business District'. The project is bound on the north by Kimberley drive and on the south by the roadway crown of Memorial Drive. No changes in land use are expected as the area is fully developed.

The entire existing storm sewer was analyzed from the outfall at Buffalo Bayou to the upper limits of the existing storm sewer. The existing conditions analysis did not confirm the recommendation of the City of Houston's Comprehensive Drainage Plan (CDP) and did indicate the existing storm sewer trunk line along Memorial Drive has adequate capacity to serve its contributing drainage area.

The discrepancy between the findings of the City's Comprehensive Drainage Plan and this report are as follows. The COH CDP was a broad cursory level investigation that lacked the specific detail included in this study and did not consider drainage on an inlet to inlet basis. Additionally, the COH CDP appears to have incorrectly considered areas west of West Bough Lane as contributing to the Memorial Drive storm sewer system. This additional area would contribute additional flow to the Memorial Drive storm sewer system and potentially could lead to false capacity issues. A 42" diameter section of the trunk line along Memorial Drive was incorrectly identified as 36" RCP in the COH CDP which could lead to additional capacity issues. The City of Houston CDP did not account for the pump station within the Sam Houston Tollway Frontage Road trunk line. The pump station is designed to service the depressed area of the Sam Houston Tollway near Boheme Drive. Without modeling the pump station to account for storage capacity and peak flow attenuation, flows within the storm sewers would be higher.

A number of public and private utilities are in proximity to the Memorial Drive storm sewer system. Record drawings were requested and obtained from the City of Houston, CenterPoint (gas and electric), and Southwestern Bell (AT&T). The existing utilities in the area have been identified and a list of the utilities has been included. A detailed explanation of the existing utilities can be found in Section 2.0 Existing Conditions.

Results

No system deficiencies were identified, thus no alternatives were identified or analyzed. The existing condition of the Memorial Drive storm sewer system satisfy the drainage criteria defined in the *City of Houston Infrastructure Design Manual* Criteria 9.05.C.1.b and Criteria 9.05.D. It was also determined that due to the extremely flat topography of West Bough Lane and the lack of curb and gutter, rainfall runoff drains slowly from the roadway. The lack of elevation change and gutter could prevent the water from effectively reaching storm sewer inlets under low flow conditions.

A parallel mobility study and preliminary engineering report was performed for Memorial Drive and recommended the addition of two eastbound left-turn lanes. As applicable, recommendations for the detailed design portion of the mobility improvements have been included in the following report.

Recommended Project

No-build is the recommendation for the Memorial Drive storm sewer system. The existing system has adequate capacity and satisfies all of the requirements outlined in *City of Houston Infrastructure Design Manual* Criteria 9.05.C.1.b and Criteria 9.05.D.

Section 1 - Introduction

1.1 Project Location

Memorial Drive is located in west Houston just south of Interstate 10 and east of the Sam Houston Tollway. West Bough Lane flows north and south and intersects Memorial Drive approximately one-quarter of a mile east of the Sam Houston Tollway. This location is at the southwest end of the TIRZ-17 boundary. The Memorial Drive storm sewer begins approximately 950 feet north of Memorial Drive on West Bough Lane and continues down Memorial Drive where it connects with the storm sewer trunk line beneath the Sam Houston Tollway Frontage Road. The project area can be found on Key Map page 489H and 489G. **Exhibit 1** shows the location of this project.

1.2 Project Authorization and Scope of Work

Lockwood, Andrews, & Newnam, Inc. has been requested by the Tax Increment Reinvestment Zone No. 17 (TIRZ 17) to prepare a Preliminary Engineering Report (PER) for the Memorial Drive Storm Sewer Improvements Project. The Memorial Drive Storm Sewer Improvement Project originated in the City of Houston (COH) Comprehensive Drainage Plan (CDP) which classified the level of service of the storm sewer as insufficient. The Comprehensive Drainage Plan is a component of the Storm Drainage Facilities Improvements Program which is part of the City's overall Capital Improvement Program (CIP). The CDP identifies inadequate drainage systems that need to be modified or improved. The Memorial Drive Storm System Improvement Project was also included in the TIRZ 17 Drainage Action Plan. The TIRZ 17 Drainage Action Plan summarized available drainage studies and reports for the region and identified potential drainage projects that impact the TIRZ.

The scope of work for the project includes several tasks necessary for the proposed storm sewer design. A summary of the tasks in the scope of this project are listed below and described in more detail in later parts of the report:

- Existing Utilities Research
- Drainage Area Maps
- Overland Flow Pattern Evaluation
- Existing System Analysis Problem Identification
- Improvement Alternatives Preparation*
- Preliminary Engineering Report Preparation

*Improvement Alternatives were not prepared as no-build is the recommendation for the Memorial Drive and West Bough Lane storm sewer systems.

1.3 Design and Analysis Criteria

The design criteria for this project are based on City of Houston (COH) standards which can be found in the *City of Houston Infrastructure Design Manual*, dated October 2008. Storm Sewer design criteria can be found in Section 9.05 C of the *City of Houston Infrastructure Design Manual*.

In accordance with City design standards, the first objective in the analysis of the existing Memorial Drive storm sewer system is to determine the location of hydraulic grade line (HGL) in relation the gutter line for the 2-Year storm event.

The second objective was to ensure that flow from an extreme event (100-Year storm) could be conveyed in the storm sewer and through street sheet flow. The following regulations were used to establish a critical roadway cross-section and then calculate the flow capacity conveyed by the cross-section:

- Streets shall be designed so that consecutive high points in the street will provide for a gravity flow of drainage to the ultimate outlet.
- The maximum depth of ponding at high points shall be 6" above top of curb.
- The maximum depth of ponding at low points shall be 18" above top of curb.
- The maximum ponding elevation for the 100-Year event at any point along the street shall not be higher than the natural ground elevation at the ROW line.

Method 2 from Section 9.05D of the *COH Infrastructure Design Manual* was used as guidance for analyzing the extreme event. This method involves computing an overland flow component (Q_O) using Manning's Equation for the critical section found with the above regulations. Conduit flow (Q_c) was defined as the flow in the storm sewer for the 2-Year design storm. The extreme event consideration required that the flow from the 100-Year event at the ultimate outlet (Q_T) could be carried by the flow in the storm sewer (Q_C), and overland flow in the street (Q_O).

The City of Houston's version of TxDOT WinStorm software, HouStorm, was used to model the existing storm sewer storm sewer network. HouStorm utilizes the rational method to estimate peak runoff rates. The run-off coefficients were determined from the COH criteria shown in **Table 1**. The HouStorm output for this project can be found in ***Appendix B***.

Table 1 - COH Run-off Coefficients

Land Use Type	Run-off Coefficient (C)
Residential Districts	
Lots more than 1/2 acre	0.35
Lots 1/4 - 1/2 acre	0.45
Lots less than 1/4 acre	0.55
Multi-Family area	
Less than 20 Service Units/Acre	0.65
20 Service Units/Acre or Greater	0.80
Business Districts	0.80
Industrial Districts	
Light Areas	0.65
Heavy Areas	0.75
Railroad Yard Areas	0.30
Parks/Open Areas	0.30

Time of concentrations were computed using the following equation as dictated by section 9.05.B.3.b of the *City of Houston Infrastructure Design Manual*:

$$TC = 10A^{0.1761}+15$$

Where: TC = time of concentration (minutes)

A = subarea (acres)

Section 2 - Existing Conditions

2.1 Overview of Existing Conditions

The Memorial Drive storm sewer system drains an area of 29-acres consisting of the Town and Country Village shopping area. This area is currently developed, consists of a high percent of impervious cover, and is not expected to see any additional development. Detailed information regarding the Memorial Drive area was derived from City of Houston as-built drawings for various roadway, storm sewer, and sanitary sewer projects in the area. This information was supplemented through survey drawings provided by Moody Rambin Interests, field visits, aerial photo imagery, and the City of Houston Geographic Information Management System. This combination of information proved to be sufficient for the level of detail required for this report.

2.1.1 Land Use and Development

The contributing drainage area for the Memorial Drive and West Bough Lane storm sewers are categorized as a business district land use type. The Town and Country shopping center is located in the area north of Memorial Drive and is the primary contributor to the two storm sewer systems. The area is a typical shopping center with large parking lots, retail stores and small portions of pervious cover. The described characteristics are consistent with the 'Business District' land use type.

The residential areas just south of Memorial Drive are not part of the Memorial Drive storm sewer system's contributing drainage area and therefore do not affect the overall land use type. The shopping center area east of West Bough Lane is consistent with the overall land use, but ultimately does not contribute to the Memorial Drive storm sewer system.

2.1.2 Existing Pavement and Right-of-Way

Memorial Drive is a four-lane (two lanes each direction) undivided roadway and West Bough Lane is a two-lane (one lane in each direction) roadway. The existing pavement width along Memorial Drive is approximately 45-feet for the entire length of the project. An additional 28-feet of right-of-way (ROW) exists on each side of the pavement for a total of 100-feet of roadway ROW. The existing pavement width along West Bough Lane is approximately 25-feet and an additional 17.5-feet of right-of-way exists on each side of the pavement for a total of 60-feet of roadway ROW.

2.1.3 Existing Public Utilities

Water lines and sanitary sewers are found at a number of locations in the Memorial Drive storm sewer project vicinity. Information on these utilities was obtained from survey data, record drawings from the COH, record drawings from AT&T that showed other utilities on the drawings, and the COH Geographic Information & Management System (GIMS). Public utilities of interest for this project are discussed in this section. **Exhibit 2** shows the existing public utilities for this project.

2.1.3.1 Water Lines

An existing water line is currently located along Memorial Drive in the south ROW behind the back of curb. This line was placed in service in 1995 and has had only one point repair since the City began tracking and associating repairs with individual lines. The water line is a 16" line of unknown material that runs east from the Sam Houston Tollway Frontage Road along Memorial Drive and out of the project boundary. This 16" water line was designed to replace a 12" abandoned line located between the in-service 16" line and the Memorial Drive Back of curb.

Water lines cross the Memorial Drive storm sewer at two different locations along Memorial Drive. The first water line crossing occurs at the eastern-most entrance to the Memorial City Shopping Center on Memorial Drive and is a 6" PVC pipe. This water line, constructed in 1995, crosses under Memorial drive and above the existing 42" storm sewer. The second water line crossing is located at the intersection of Memorial Drive and West Bough Lane and is an 8" steel water line. This water line, also constructed in 1995, crosses under Memorial Drive and is believed to run below the existing 18" and 24" storm sewer pipe. After crossing Memorial Drive, this water line transitions to a combination of 8" asbestos concrete pipe and 8" cast iron pipe that run in the west ROW of West Bough Lane. The portion of water line west of West Bough Lane was constructed in 1966.

A 6" water line of unknown material, with an unknown date of construction crosses under west Bough Lane just south of Pines Presbyterian Church. This waterline serves the shopping center east of West Bough Lane.

2.1.3.2 Sanitary Sewers

Sanitary sewer lines are located in the vicinity of the Memorial Drive storm sewer system but do not cross the Memorial Drive storm sewer system at any point. As-builts of the area, as well as the COH GIMS, did not locate any sanitary sewers that cross the Memorial Drive storm sewer system. There are multiple parallel sanitary storm sewers running the length of West Bough Lane. A 10" force main of unknown material, constructed in 1984, runs the length of West Bough Lane beneath the pavement. This line is in the north bound lane, except for at the intersection of West Bough Lane and Memorial Drive, where it crosses under all lanes of West Bough Lane before crossing Memorial Drive.

A 6" sludge line of unknown material and unknown age parallels the above 10" line for the length of West Bough Lane. This line crosses multiple lanes at the intersection of West Bough Lane and Memorial drive, but otherwise appears to run outside of the current pavement and within the east ROW of West Bough Lane.

Outside of the pavement, but within the east ROW of West Bough Lane there exists an 8" concrete pipe sanitary sewer built from 1965 through 1968 that runs north from the Bank of Texas to Kimberley Lane.

2.1.4 Existing Private Utilities

CenterPoint Energy (CPE) and Southwestern Bell Company (AT&T or AT&T Texas) have private utilities in the Memorial Drive storm sewer's vicinity. Utility information was requested and obtained from both companies. Texas One Call should be contacted at least 48 hours prior to any excavation to establish the locations of all underground utilities. Contacts for these companies are shown in **Table 2**.

Table 2 – Private Utility Contacts

Private Utility Owner	Contact	Contact Information
CenterPoint Energy	Ivan Perez	CenterPoint Energy Engineering Department 1301 Travis Street, Suite 762 Houston, Texas 77002 Phone: 713-207-4622
AT&T	N/A	AT&T Texas Conduit Group 6500 West Loop South Zone 1.3 Bellaire, TX 77401
Texas One Call	N/A	1-800-669-8344 http://www.onecalltexas.com/centers.html

2.1.4.1 Existing CenterPoint Energy Gas Facilities

No CenterPoint Energy Gas Facilities have been identified in the vicinity of the Memorial Drive storm sewer system. A 2" CenterPoint gas line runs on the length of West Bough Lane in the eastern edge of the east ROW of West Bough Line.

2.1.4.2 Underground Electric Facilities

Record drawings were obtained from CenterPoint Energy indicating underground electric facilities. The underground electric distribution lines service the street lights located on the north side of Memorial Drive. These street lights and lines run the length of the Memorial Drive storm sewer and are located approximately 8-feet north of the existing storm sewer line in the Memorial Drive ROW.

2.1.4.3 Existing AT&T Facilities

AT&T conduit lines are located just east of the intersection of the Sam Houston Tollway Frontage Road and Memorial Drive as well as at the intersection of Memorial Drive and West Bough Lane. At the intersection of the Sam Houston Tollway Frontage Road and Memorial Drive, two sets of AT&T conduits run parallel to the Sam Houston Tollway Frontage Road (north-west) from the south side of Memorial Drive and cross under Memorial Drive above the Memorial Drive storm sewer system. The first set is composed of 4 – 4" 'C' PVC (2Wx2H, placed in 1987) in a 14" steel casing. The second parallel set is composed of 2 – 4" cast iron pipe

(2Wx1H, placed in 1998). At the intersection of Memorial Drive and West Bough Lane, one set of AT&T conduits run north-east from the south-west side of Memorial Drive under Memorial Drive. The conduits then run over or under the Memorial Drive storm sewer system and then run in an unknown direction. Due to lack of detailed plans, the alignment of the AT&T conduit is unknown after crossing under Memorial Drive and it is also unknown if the AT&T conduits pass over or under the Memorial Drive storm sewer system. This set of AT&T conduit is composed of 4 – 4" 'C' PVC. Nonintrusive excavation is recommended prior to any mobility improvements in the vicinity of the unknown lines to determine their precise location and avoid costly project delays and change orders.

2.1.4.4 Existing Aerial Facilities

Overhead distribution lines run the length of the West Bough Lane storm sewer system in ROW approximately 4-feet west of the existing storm sewer. Several of the overhead distribution poles are combination streetlights and overhead power line poles.

2.1.4.5 Fiber Optic Communications

There is no evidence of Level 3 Communications or other private fiber optic lines within the project limits. It is recommended that Texas One Call be contact prior to detailed design or construction of mobility improvements to confirm these findings.

2.1.4.6 Trees Inside ROW

A number of large trees are located in the West Bough Lane ROW near the storm sewer system. The trees vary in species and are typically 8-16" in diameter. A tree inventory was not performed as part of the PER, but is recommended as part of future mobility improvements.

2.1.4.7 Miscellaneous Items

Several light poles exist along the Memorial Drive and West Bough Lane storm sewer. A total of five light poles exist on the north side of Memorial Drive. An additional four light poles and four combination light pole power poles exist on the west side of West Bough Lane. CenterPoint also maintains two separate 10-foot wide easements that approximately cross the West Bough Lane storm sewer at 30-feet north of the northernmost and 130-feet north of the southernmost entrances to the Memorial City Shopping Center located on West Bough Lane.

2.1.5 Survey

Current survey data was not available for the Memorial Drive area and will need to be gathered prior to the onset of detailed design and construction of mobility improvements. Detailed information regarding the Kimberley Lane area was derived from City of Houston as-built drawings for various roadway, storm sewer, and sanitary sewer projects in the area. This information was supplemented through survey drawings provided by Moody Rambin Interests, field visits, aerial photo imagery, and the City of Houston Geographic Information Management

System. This combination of information proved to be sufficient for the level of detail required for this report.

2.1.6 Existing Drainage System

The Memorial Drive storm sewer system has a contributing drainage area of 29-acres and the land use is classified as 'Business District'. No changes in land use are expected. The contributing area is bound on the north by Kimberley drive and on the south by the roadway crown of Memorial Drive. The crown of West Bough Lane serves as a drainage divide and drainage boundary for the Memorial Drive drainage system. The area west of the West Bough Lane crown drains into the Memorial Drive storm sewer system and the area east of the crown drains to a separate trunk system along Memorial Drive. This secondary trunk system drains southeast along Memorial Drive to a separate outfall (HCFCD Unit Number W156-00-00). A field visit confirmed this condition.

For modeling purposes, drainage areas were delineated on an inlet to inlet basis only for the inlets required for roadside drainage. Contributing areas for additional inlets, not serving to collect flow from Memorial Drive or West Bough Lane, were included in the existing conditions model but modeled as a manhole. Such inlets were generally part of private off site drainage systems.

The storm sewer system along West Bough Lane is fed by a roadside ditch, three grate inlets, and two B-B inlets connected to the trunk line along Memorial Drive. The trunk line system along Memorial Drive is fed through three grate inlets, one combination grate type B-B inlet, the Memorial City Shopping Center parking lot, and six type B-B inlets.

The existing storm sewer system along West Bough Lane is comprised of approximately 950 feet of 18" reinforced concrete pipe (RCP) flowing south and begins approximately 30-feet north of the northernmost entrance to the Memorial City Shopping Center. West Bough Lane's storm sewer is connected to the Memorial Drive storm sewer system through a 24" RCP at the intersection of Memorial Drive and West Bough Lane. The trunk line system along Memorial Drive remains 24" RCP for approximately 450-feet where it transitions to 30" RCP for an approximate distance of 310-feet and ultimately transitions to 42" RCP for an approximate distance of 520-feet. This 42" RCP section drains west into the Sam Houston Tollway frontage road trunk line system. Refer to **Exhibit 3** for a drainage area and existing storm sewer layout map.

The Sam Houston Tollway Frontage Road system begins as a 42" RCP and gradually increases downstream to a 9'x 8' box culvert. The trunk line transitions from a 90" RCP to a 9' x 8' box culvert at the Verde Pump Station. The Verde Pump Station serves the depressed section of the Sam Houston Tollway main lanes. The Verde Pump Station was determined to supply an additional 55 cfs of flow into the storm sewer for the 2-Year storm event. This is equivalent to one of the two pumps flowing at full capacity. It was determined that the pump station supplies an additional 111 cfs of flow, both pumps at maximum capacity, for the extreme event. The system then continues downstream to Buffalo Bayou (W100-00-00). The existing conditions models extend from the Queensbury Road storm sewer system to the outfall at Buffalo Bayou.

2.1.6.1 Existing Drainage System 2-Year Event Analysis

In accordance with City design standards, the performance of the existing Memorial Drive and West Bough Lane storm sewer systems was determined under the 2-year event through the use of HouStorm. As required by City design standards, the location of hydraulic grade line (HGL) in relation the gutter line was determined. **Exhibit 5** shows profile plots of the main trunk line and HGL elevations for the existing conditions. It was ultimately determined that the HGL in all portions of the Memorial Drive storm sewer system including West Bough Lane was below gutter line or critical elevations, thus meeting City of Houston requirements.

The existing condition of the Memorial Drive and West Bough Lane storm sewer systems satisfy the drainage criteria defined in the *City of Houston Infrastructure Design Manual* Criteria 9.05.C.1.b, which states that the hydraulic grade line must be at or below the gutter line at all points in the storm sewer. Throughout the Memorial Drive and West Bough Lane storm sewer systems the hydraulic grade lines during the 2-year storm event are below the gutter line or critical elevations, fulfilling Criteria 9.05.C.1.b. Refer to ***Appendix B*** for full HouStorm calculations and output for the 2-year event analysis.

2.1.6.2 Existing Drainage System Extreme Event Analysis

Method 2 from Section 9.05D of the *COH Infrastructure Design Manual* was used as guidance for analyzing the extreme event. This method involves computing an overland flow component (Q_O) using Manning's Equation for the critical section found with the above regulations. Conduit flow (Q_c) was defined as the flow in the storm sewer for the 2-Year design storm. The extreme event consideration required that the flow from the 100-Year event at the ultimate outlet (Q_T) could be carried by the flow in the storm sewer (Q_C), and overland flow in the street (Q_O).

It was determined that the required overland flow (Q_O) under the extreme event is 7.6 cubic-feet-per-second. The overland flow capacity of the critical Memorial Drive roadway section at the intersection of Memorial Drive and the Sam Houston Tollway Frontage Road was calculated to be 24.01 cubic-feet-per-second. This overland flow capacity was limited to the maximum ponding elevation (MPE), as dictated by the ROW elevation of 77.3- feet at the roadway low point.

It was determined that the 100-Year overland flow requirement for Memorial Drive could be carried solely in the overland street flow portion. Therefore, the existing condition of the Memorial Drive and West Bough Lane storm sewer systems satisfy the drainage criteria defined in the *City of Houston Infrastructure Design Manual* Criteria 9.05.D, which states that the storm sewer capacity under the 100-year extreme storm event in combination with overland flow capacity must provide enough total capacity storage to prevent hazardous ponding or flooding. When analyzed under the 100-year extreme storm event the Memorial Drive storm sewer system and Memorial Drive roadway provided adequate total capacity. The Memorial Drive critical cross section provides substantially more overland flow capacity than is required to convey the entire 100-year extreme storm event flow, thus meeting Criteria 9.05.D. The full extreme event analysis is detailed in ***Appendix A***.

Due to the roadway geometry of Memorial Drive, there exists minimal potential for ponding within the roadway. As shown in **Exhibit 4**, ponding occurs primarily within the parking lot for the Town and Country Village. This occurs for a number of reasons. Memorial Drive serves as the relative high point and drainage divide for overland sheet flow while the parking lot serves as a relative low point within the overland sheetflow paths. The relative low elevation of portions the parking lot presents the possibility of maximum ponding depths between 1 and 2-feet.

Section 3 - Evaluations and Recommendations

3.1 Evaluation of Alternatives

No system deficiencies were identified, thus no alternatives were identified or analyzed.

3.2 Recommended Project

No-build is the recommendation for the Memorial Drive and West Bough Lane storm sewer systems. The existing system has adequate capacity and satisfies all of the requirements outlined in *City of Houston Infrastructure Design Manual* Criteria 9.05.C.1.b and Criteria 9.05.D.

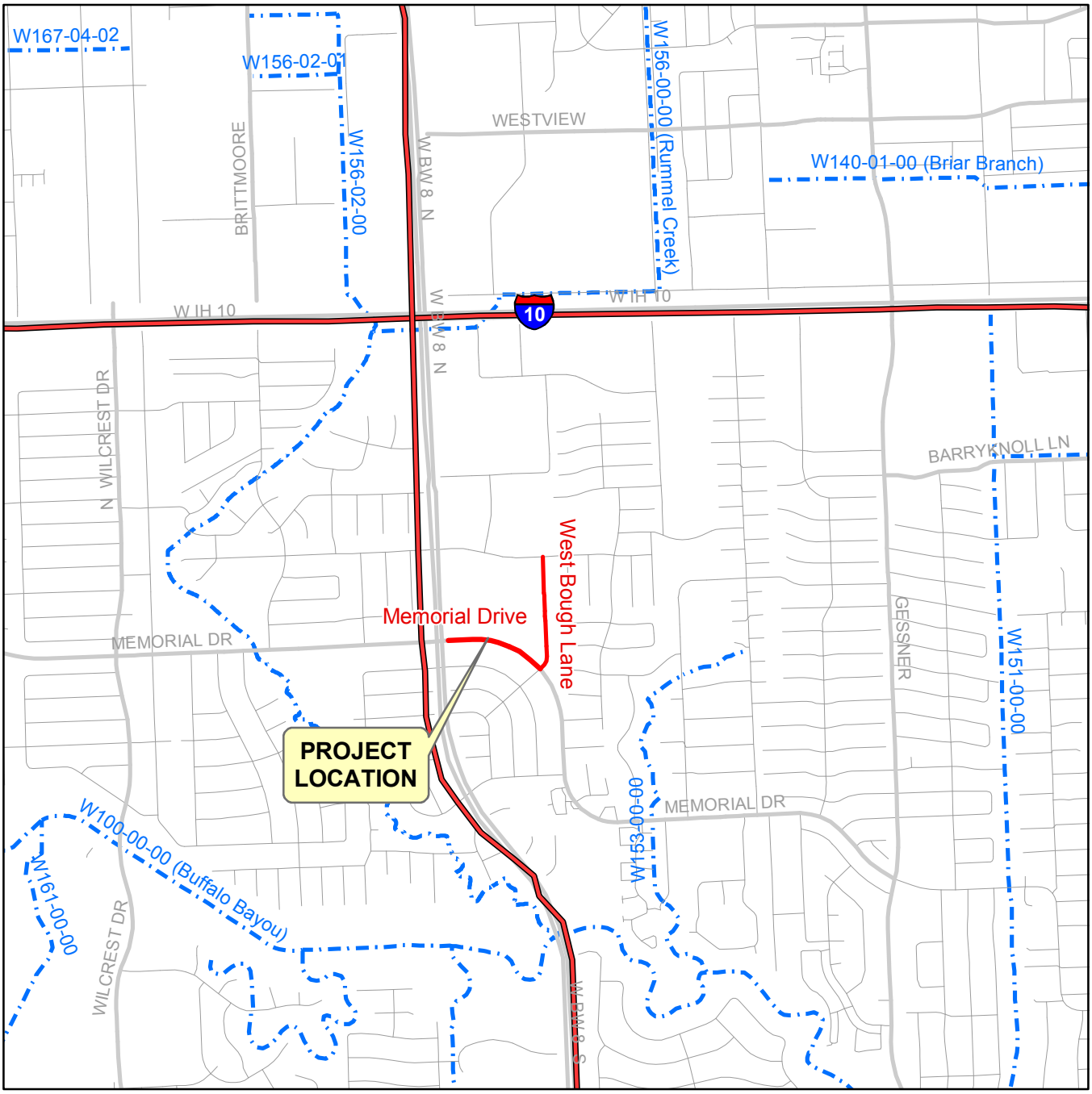
Conclusion

Confirmed through Houstorm hydraulic modeling, the existing storm sewer system along Memorial Drive and West Bough Lane has sufficient capacity and meets all City of Houston Infrastructure Design Requirements. This result is contrary to the City of Houston's Comprehensive Drainage plan, but correct for a variety of reasons.

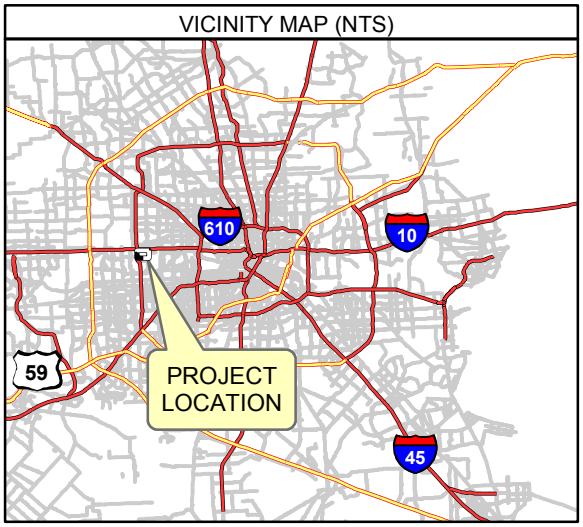
The City of Houston Comprehensive Drainage Plan was a rough order magnitude investigation that lacked the specific detail included in this study and did not consider drainage on an inlet to inlet basis. Additionally, the COH CDP incorrectly considered areas west of West Bough Lane as contributing to the Memorial Drive storm sewer system. This additional area would contribute extra flow to the Memorial Drive storm sewer system and could potentially lead to false capacity issues. A section of the trunk line along Memorial Drive was incorrectly identified as a smaller section of trunk line in the COH CDP which could lead to additional capacity issues.

The specific and detailed analysis of the Memorial Drive and West Bough Lane storm sewer systems has confirmed that the Memorial Drive and West Bough Lane storm sewer systems are sufficient in their current form and do not require rehabilitation or improvement. For this reason, a no-build solution is recommended for the Memorial Drive and West Bough Lane storm sewer systems.

The existing storm sewer system is currently behind the back of curb. It is recommended that a condition assessment be performed to verify the integrity of the pipe prior to any future roadway improvements that might expand the roadway surface to cover the storm sewer systems.



VICINITY MAP (NTS)



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W E
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0 500 1,000 2,000
Feet

MEMORIAL CITY REDEVELOPMENT AUTHORITY
Lockwood, Andrews & Newnam, Inc. A LEO A DALY COMPANY
MEMORIAL DRIVE STORM SEWER IMPROVEMENT PROJECT
PROJECT LOCATION MAP HARRIS COUNTY, TEXAS
EXHIBIT 1

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KIMBERLEY LN

Legend

- Storm Line
- Water Line
- Waste Line
- TIRZ17 Boundary

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EXHIBIT 2 PUBLIC UTILITIES

N

0 100 200 400
Feet

Drainage Area	Contributing Area (Ac)
MH-C	3.04
C-2A10	0.40
C-2A11	0.26
C-2A2	0.17
C-2A20	0.32
MH-C2A21	0.22
MH-C3A1	11.55
C-3A10	0.51
MH-C3A2	1.19
C-3A20	0.33
C-4B1	0.29
C-4B2	0.18
MH-C4B20	9.02
MH-C4C	0.71
C-5A	0.14
C-5B	0.08
C-7A	0.19
MH-C7B	0.80
C-8A	0.18
C-9	0.06
C-10	0.20
C-11	0.12
C-12	3.14

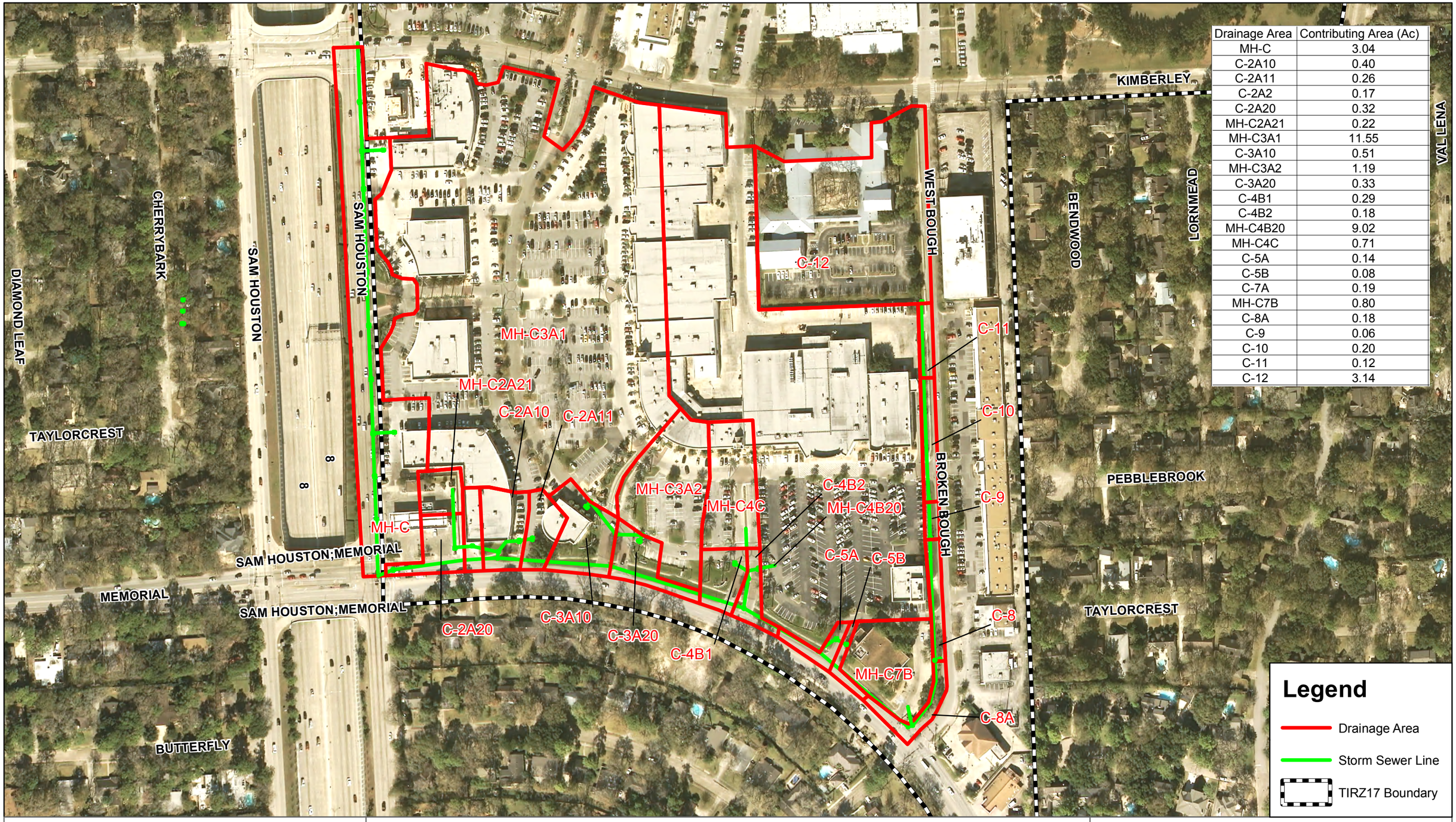

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EXHIBIT 3 EXISTING DRAINAGE AREA AND STORM SEWER

N

0 100 200 400 Feet

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KIMBERLEY LN

Legend

- TIRZ17 Boundary
- Sheet Flow Lines
- DrainageLine25
- DrainageLine10
- DrainageLine5
- DrainageLine1

Ponding Depth (ft)

- 0 - 0.1
- 0.1- 0.5
- 0.5 - 1
- 1 - 2

Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY

EXHIBIT 4 OVERLAND SHEETFLOW PONDING

N

0 100 200 400
Feet

Map Document: (L:\120214\120-10308-000\445\Prod\GIS\Projects\MXD\Report Exhibits\EXH_4_Sheetflow_Ponding.mxd)
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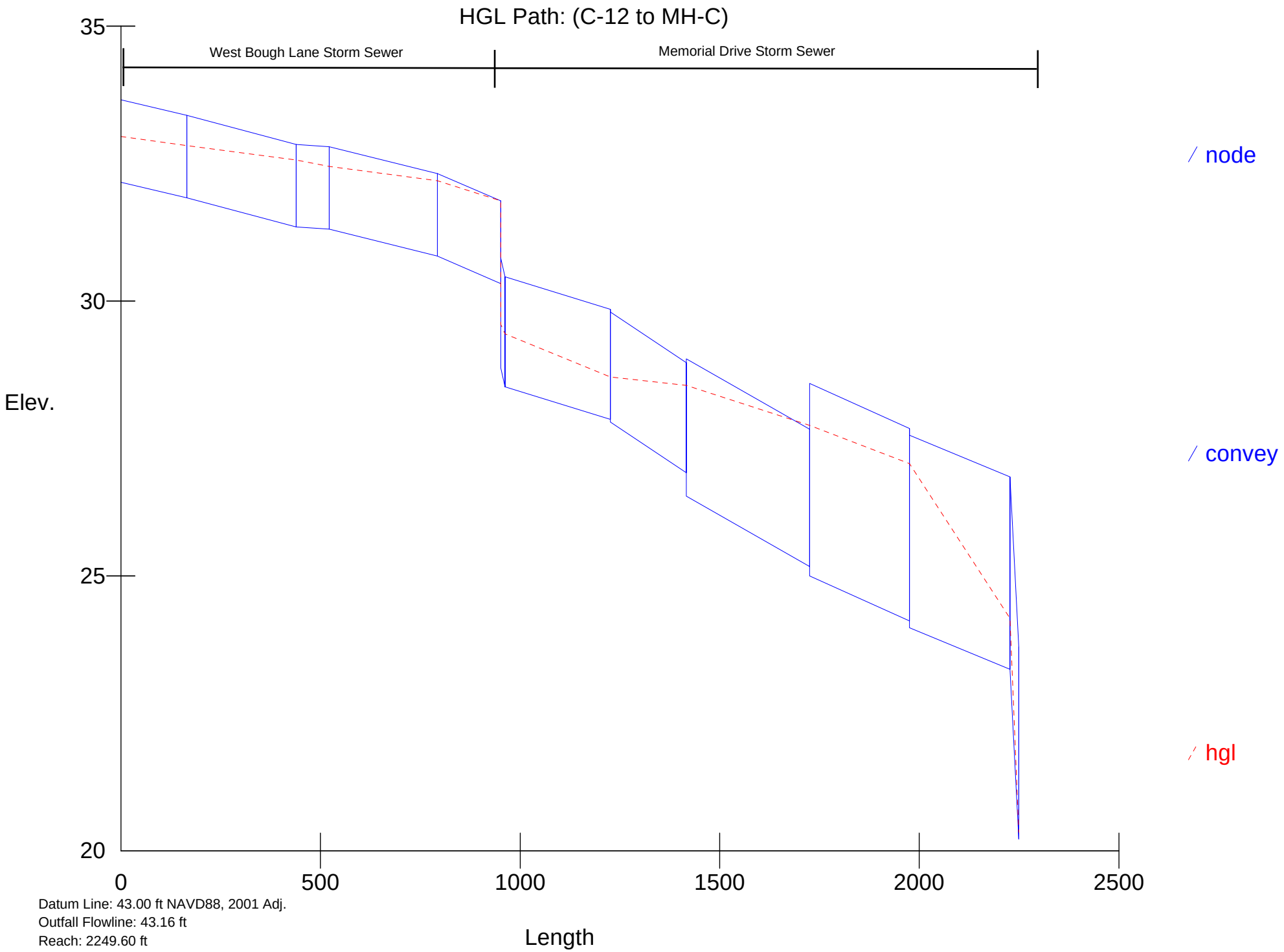
Exhibit 5 - Existing Storm Sewer HGL Plot



Datum Line: 43.00 ft NAVD88, 2001 Adj.
Outfall Flowline: 43.16 ft
Reach: 2249.60 ft

Exhibit 6 - City of Houston Comprehensive Drainage Plan

APPENDIX A – EXTREME EVENT OVERLAND SHEETFLOW ANALYSIS

Appendix A - Extreme Event Overland Sheetflow Analysis

100-Year Overland Sheet Flow Analysis from Chapter 9 of City of Houston Infrastructure Design Manual

Maximum Ponding Elevation:
To Find MPE :

Low Point Elevation (ft)	Allowable Ponding Depth (ft)	Ponding Elevation (ft)
76.8	1.5	78.3

High Point Elevation	Allowable Ponding Depth (ft)	Ponding Elevation (ft)
77.6	0.5	78.1

ROW Elevation at Low Point (ft)
77.3

ROW Elevation at High Point (ft)
77.6

Minimum Elevation Controls, therefore
MPE= 77.3 ft

Appendix A - Extreme Event Overland Sheetflow Analysis

Method 2 100-Year Overland Sheet Flow Analysis from Chapter 9 of City of Houston Infrastructure Design Manual

Qt = Qo + Qc

Where:
Qt is the total flow conveyed
Qo is the overland flow component*
Qc is the calculated flow in the conduit for the 2-Year design***

*Computed using Manning's Equation to a critical roadway cross section(See Below)
**Capacity of Run #20 in Houstorm Model

Assumptions:
Pipe flowing full from contributing storm sewer drainage area
All overland contributing area will flow in street only
Overland flow will not enter storm sewer
Overland flow will only occur on North side of Memorial Drive

Overland Flow Capacity Required:
To Find $Q_{o\ Required}$ **:**

$Q_p = CiA$

Where:
Q_p is the Peak Runoff under a storm event
C is the Runoff Coefficient
i is the Intensity in inches per hour
A is the drainage area in acres

Drainage Area(Ac)	Tc (min)	C Value	Intensity (in/hr)	Q 100-yr (cfs)
1.57	25.83	0.704	6.9	7.6

$Q_{o\ Required}$ =7.6cfs

Overland Flow Capacity Provided:
To Find $Q_{o\ Capacity}$ **:**

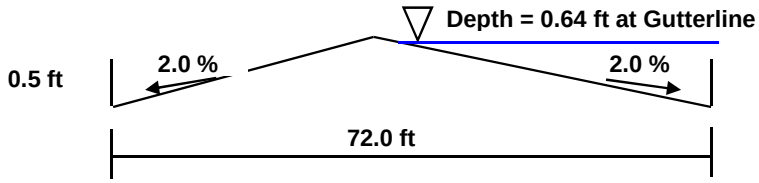
Manning's Equation

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2}$$

Where:
n = 0.015 for street component and 0.02 for outside street component
A = Area in square feet
R = Hydraulic Radius in feet
S = Longitudinal slope

Appendix A - Extreme Event Overland Sheetflow Analysis

Overland Outlet Location - Memorial Drive West



Area	(1/2) x 0.64 x (0.64/0.02) = 10.24 sf
Wetted Perimeter	0.5 + (0.64/).02) = 32.5 ft
Hydraulic Radius	10.24/32.5 = 0.31
Slope (from lidar)	0.0026 ft/ft
Manning's n	0.015
Manning's Capacity: $Q = \frac{1.49}{n} A R_H^{2/3} S_0^{1/2}$	1.49/0.015 x 10.24 x 0.315^(2/3) x 0.0026^(1/2) **=24.01 cfs**

Method 2 Evaluation:

$Q_{o\ Required}$ = 7.6cfs

$Q_{o\ Capacity}$ = 24.01 cfs

$Q_{o\ Capacity} > Q_{o\ Required}$

Therefore the 100-Year Overland Sheet Flow Analysis Requirements are Satisfied

The critical street cross section was designated with a maximum ponding height of 0.14 feet above the top of curb. The capacity of that cross section was found to be 24.01 cfs. The actual overland flow for a 100-YR event is 7.6 cfs. Therefore, the maximum depth of ponding at the low point will be less than 18 inches above top of curb. The high point is 9.6 inches above this point. Therefore, the maximum depth of ponding at the high points will be less than 6 inches above top of curb. Additionally, the depth of ponding will be below the ROW line at the low point as well as the high point.

APPENDIX B – HYDRAULIC CALCULATIONS
HOUSTORM OUTPUT

HouStorm (City Of Houston STORM DRAIN DESIGN) Version 2.1, Update: Nov/01/2007

Run @ 4/30/2009 1:43:44 PM

PROJECT NAME : Existing
JOB NUMBER :
PROJECT DESCRIPTION : Memorial, Beltway 8, & West Bough
PROJECT File: L:\120214\120-10308-000\445\Prod\Data\Refined\HouStorm\Existing

ANALYSYS FREQUENCY : 2 Years
MEASUREMENT UNITS: ENGLISH

==========

OUTPUT FOR ANALYSYS FREQUENCY of: 2 Years

Runoff Computation for Design Frequency.

ID	C Value	Area (acre)	Tc (min)	Tc Used (min)	Intensity (in/hr)	Supply Q (cfs)	Total Q (cfs)
MH-C6	0.8	0.00	10.00	10.00	4.96	0.000	0.000
C-9	0.42	0.06	21.10	21.10	3.70	0.000	0.093
C-10	0.52	0.20	22.50	22.50	3.59	0.000	0.373
MH-C2A	0.8	0.00	10.00	10.00	4.96	0.000	0.000
MH-C2A1	0.8	0.00	10.00	10.00	4.96	0.000	0.000
C-2A10	0.75	0.40	23.50	23.50	3.51	0.000	1.054
C-2A11	0.67	0.26	22.90	22.90	3.56	0.000	0.620
C-2A2	0.76	0.17	22.30	22.30	3.60	0.000	0.466
C-2A20	0.8	0.32	23.20	23.20	3.54	0.000	0.905
MH-C2A21	0.8	0.22	22.60	22.60	3.58	0.000	0.630
MH-C3A	0.8	0.00	10.00	10.00	4.96	0.000	0.000
C-11	0.5	0.12	21.80	21.80	3.64	0.000	0.219
C-12	0.25	3.14	27.20	27.20	3.26	0.000	2.561
MH-C8	0.8	0.00	10.00	10.00	4.96	0.000	0.000
C-7A	0.66	0.19	22.40	22.40	3.60	0.000	0.451
A-1	0.47	1.14	25.20	25.20	3.39	0.000	1.818
B	0.652	29.40	33.14	33.14	2.93	0.000	56.223
D-1	0.47	47.99	34.80	34.80	2.85	0.000	64.346
MH-D1	0.8	0.00	10.00	10.00	4.96	0.000	0.000
E-1	0.57	20.49	31.90	31.90	3.00	0.000	34.981
MH-E1	0.8	0.00	10.00	10.00	4.96	0.000	0.000
MH-E2	0.5	0.00	10.00	10.00	4.96	0.000	0.000
MH-A8	0.8	37.03	33.90	33.90	2.90	0.000	85.772
MH-B11	0.8	0.00	10.00	10.00	4.96	0.000	0.000
MH-B15	0.8	0.00	10.00	10.00	4.96	0.000	0.000
MH-C29	0.85	0.00	10.00	10.00	4.96	0.000	0.000
MH-C28	0.85	0.00	10.00	10.00	4.96	0.000	0.000
MH-C	0.71	3.46	27.44	27.44	3.25	0.000	7.978
MH-C1	0.8	0.00	10.00	10.00	4.96	0.000	0.000
MH-C2	0.8	0.00	10.00	10.00	4.96	0.000	0.000
MH-C3	0.8	0.00	10.00	10.00	4.96	0.000	0.000
MH-C4	0.8	0.00	10.00	10.00	4.96	0.000	0.000
MH-C5	0.8	0.00	10.00	10.00	4.96	0.000	0.000

MH-C3A1	0.79	11.55	30.40	30.40	3.08	0.000	28.059
C-3A10	0.6	0.51	23.90	23.90	3.48	0.000	1.066
MH-C3A2	0.67	1.19	25.30	25.30	3.39	0.000	2.700
C-3A20	0.64	0.33	23.20	23.20	3.54	0.000	0.747
MH-C4A	0.8	0.00	10.00	10.00	4.96	0.000	0.000
MH-C4B	0.8	0.00	10.00	10.00	4.96	0.000	0.000
C-8A	0.51	0.18	22.40	22.40	3.60	0.000	0.330
C-4B1	0.54	0.29	23.00	23.00	3.55	0.000	0.556
C-4B2	0.65	0.18	22.40	22.40	3.60	0.000	0.421
MH-C4B200	0.78	9.02	29.70	29.70	3.11	0.000	21.909
MH-C4C	0.77	0.71	24.40	24.40	3.45	0.000	1.885
C-5A	0.69	0.14	22.00	22.00	3.63	0.000	0.350
C-5B	0.8	0.08	21.40	21.40	3.68	0.000	0.235
MH-C7	0.8	0.00	10.00	10.00	4.96	0.000	0.000
MH-C7B	0.66	0.80	24.60	24.60	3.43	0.000	1.813

Sag Inlets Configuration Data.

Inlet ID	Inlet Type	Length/ Perim (ft)	Grate Area (sf)	Left-Slope Longi (%)	Left-Slope Transv (%)	Right-Slope Longi (%)	Right-Slope Transv (%)	Gutter n	Gutter DeprW (ft)	Head Allowed (ft)
C-10	Grate	4.00	4.00	0.50	2.00	0.50	2.00	0.014	n/a	1.50
C-11	Grate	4.00	4.00	0.50	2.00	0.50	2.00	0.014	n/a	1.50
C-5A	Combi	2.50	1.67	0.50	2.00	0.50	2.00	0.014	1.50	1.50
C-5B	Grate	5.33	3.34	0.50	2.00	0.50	2.00	0.014	n/a	1.50
C-3A10	Curb	5.50	0.00	0.50	2.00	0.50	2.00	0.014	1.50	1.50
C-3A20	Curb	5.50	0.00	0.50	2.00	0.50	2.00	0.014	1.50	1.50
C-4B1	Curb	5.50	0.00	0.50	2.00	0.50	2.00	0.014	1.50	1.50
C-4B2	Curb	5.50	0.00	0.50	2.00	0.50	2.00	0.014	1.50	1.50
C-7A	Curb	6.00	0.00	0.50	2.00	0.50	2.00	0.014	1.50	1.50
C-8A	Curb	3.00	0.00	0.50	2.00	0.50	2.00	0.014	1.50	1.50
C-9	Grate	4.00	4.00	0.50	2.00	0.50	2.00	0.014	n/a	1.50
C-2A10	Curb	5.50	0.00	0.50	2.00	0.50	2.00	0.014	1.50	1.50
C-2A11	Curb	5.50	0.00	0.50	2.00	0.50	2.00	0.014	1.50	1.50
C-2A2	Grate	4.00	4.00	0.50	2.00	0.50	2.00	0.014	n/a	1.50
C-2A20	Grate	4.00	4.00	0.50	2.00	0.50	2.00	0.014	n/a	1.50

Sag Inlets Computation Data.

Inlet ID	Inlet Type	Length (ft)	Grate Perim (ft)	Grate Area (sf)	Total Q (cfs)	Inlet Capacity (cfs)	Actual Head (ft)	Ponded Left (ft)	Width Right (ft)
C-10	Grate	n/a	4.00	4.00	0.373	22.685	0.097	4.15	4.15
C-11	Grate	n/a	4.00	4.00	0.219	22.685	0.068	3.40	3.40
C-5A	Combi	2.50	3.67	1.67	0.350	10.993	0.253	4.05	4.05
C-5B	Grate	n/a	5.33	3.34	0.235	21.985	0.059	3.50	3.50
C-3A10	Curb	5.50	n/a	n/a	1.066	16.525	0.255	6.15	6.15
C-3A20	Curb	5.50	n/a	n/a	0.747	16.525	0.253	5.40	5.40
C-4B1	Curb	5.50	n/a	n/a	0.556	16.525	0.251	4.85	4.85
C-4B2	Curb	5.50	n/a	n/a	0.421	16.525	0.251	4.35	4.35
C-7A	Curb	6.00	n/a	n/a	0.451	18.027	0.251	4.45	4.45
C-8A	Curb	3.00	n/a	n/a	0.330	9.013	0.252	3.95	3.95

C-9	Grate	n/a	4.00	4.00	0.093	22.685	0.038	2.50	2.50
C-2A10	Curb	5.50	n/a	n/a	1.054	16.525	0.255	6.15	6.15
C-2A11	Curb	5.50	n/a	n/a	0.620	16.525	0.252	5.05	5.05
C-2A2	Grate	n/a	4.00	4.00	0.466	22.685	0.112	4.50	4.50
C-2A20	Grate	n/a	4.00	4.00	0.905	22.685	0.175	5.80	5.80

Cumulative Junction Discharge Computations

Node I.D.	Node Type	Weighted C-Value	Cumulat. Dr.Area (acres)	Cumulat. Tc (min)	Intens. (in/hr)	User Supply Q cfs)	Additional Q in Node (cfs)	Total Disch. (cfs)
C-10	Grate	0.274	3.46	29.96	3.10		0.00	2.941
C-11	Grate	0.259	3.26	28.28	3.20		0.00	2.701
A-1	CrcMh	0.000	0.00	0.00	0.00		0.00	0.000
MH-A8	CrcMh	0.800	37.03	33.90	2.90		0.00	85.772
MH-B11	CrcMh	0.800	37.03	34.23	2.88		0.00	85.772
MH-B15	CrcMh	0.800	37.03	34.23	2.88		0.00	85.772
C-12	CrcMh	0.250	3.14	27.20	3.26		0.00	2.561
MH-C8	CrcMh	0.288	3.70	32.46	2.97		0.00	3.162
B	CrcMh	0.735	66.43	34.49	2.87		0.00	139.907
D-1	CrcMh	0.642	147.94	38.69	2.68		0.00	255.003
MH-D1	CrcMh	0.725	99.95	37.09	2.75		0.00	199.310
E-1	CrcMh	0.633	168.43	39.68	2.64		111.40	393.513
MH-E1	CrcMh	0.633	168.43	39.68	2.64		111.40	393.513
MH-E2	CrcMh	0.633	168.43	39.68	2.64		111.40	393.513
MH-C	CrcMh	0.725	99.95	37.09	2.75		0.00	199.309
MH-C1	CrcMh	0.706	30.06	36.71	2.77		0.00	58.690
MH-C2	CrcMh	0.706	30.06	36.71	2.77		0.00	58.690
MH-C3	CrcMh	0.703	28.69	36.09	2.79		0.00	56.369
MH-C2A21	CrcMh	0.800	0.22	22.60	3.58		0.00	0.630
MH-C4C	CrcMh	0.770	0.71	24.40	3.45		0.00	1.885
MH-C4B20	CrcMh	0.780	9.02	29.70	3.11		0.00	21.909
C-5A	Combi	0.730	0.22	22.00	3.63		0.00	0.583
C-5B	Grate	0.800	0.08	21.40	3.68		0.00	0.235
MH-C7B	CrcMh	0.660	0.80	24.60	3.43		0.00	1.813
MH-C7	CrcMh	0.367	4.69	33.24	2.93		0.00	5.034
MH-C5	CrcMh	0.383	4.91	34.55	2.86		0.00	5.385
MH-C6	CrcMh	0.367	4.69	33.24	2.93		0.00	5.034
MH-C3A	CrcMh	0.769	13.58	30.77	3.05		0.00	31.888
MH-C3A1	CrcMh	0.782	12.06	30.40	3.08		0.00	29.000
C-3A10	Curb	0.600	0.51	23.90	3.48		0.00	1.066
MH-C3A2	CrcMh	0.663	1.52	25.30	3.39		0.00	3.415
C-3A20	Curb	0.640	0.33	23.20	3.54		0.00	0.747
MH-C4A	CrcMh	0.770	10.20	29.85	3.11		0.00	24.399
MH-C4B	CrcMh	0.770	10.20	29.85	3.11		0.00	24.399
C-4B1	Curb	0.540	0.29	23.00	3.55		0.00	0.556
C-4B2	Curb	0.777	9.20	29.79	3.11		0.00	22.237
MH-C4	CrcMh	0.644	15.11	35.25	2.83		0.00	27.572
C-7A	Curb	0.660	0.99	24.85	3.42		0.00	2.232
C-8A	Curb	0.510	0.18	22.40	3.60		0.00	0.330
C-9	Grate	0.277	3.52	30.79	3.05		0.00	2.975
MH-C2A	CrcMh	0.756	1.37	24.27	3.46		0.00	3.580
MH-C2A1	CrcMh	0.718	0.66	23.50	3.51		0.00	1.666
C-2A10	Curb	0.718	0.66	23.50	3.51		0.00	1.666
C-2A11	Curb	0.670	0.26	22.90	3.56		0.00	0.620

C-2A2	Grate	0.790	0.71	23.92	3.48	0.00	1.954
C-2A20	Grate	0.800	0.54	23.66	3.50	0.00	1.513
OUT	Outlt	0.633	168.43	39.68	2.64	111.40	393.513

Conveyance Configuration Data

Run #	Node US	I.D. DS	FlowLine Elev. US (ft)	DS (ft)	Shape #	Span (ft)	Rise (ft)	Length (ft)	Slope (%)	n_value
47	MH-A8	MH-B11	68.17	67.60	Cir 1	0.00	3.50	177.0	0.322	0.013
48	MH-B11	MH-B15	67.20	64.49	Cir 1	0.00	4.00	661.0	0.410	0.013
49	MH-B15	B	64.49	64.21	Cir 1	0.00	5.00	112.0	0.250	0.013
50	B	MH-C	64.21	61.36	Cir 1	0.00	5.00	1140.0	0.250	0.013
51	MH-C1	MH-C	66.30	63.21	Cir 1	0.00	3.50	22.7	13.740	0.013
52	MH-C	MH-D1	58.84	56.27	Cir 1	0.00	6.50	1227.0	0.209	0.013
53	MH-D1	D-1	55.77	54.37	Cir 1	0.00	7.00	750.0	0.187	0.013
54	D-1	E-1	53.87	52.86	Cir 1	0.00	7.50	506.0	0.200	0.013
55	E-1	MH-E1	52.36	49.52	Box 1	9.00	8.00	1387.0	0.205	0.013
56	MH-E1	MH-E2	49.52	43.66	Box 1	9.00	8.00	129.0	4.547	0.013
57	MH-E2	OUT	43.66	43.16	Cir 2	0.00	7.50	120.0	0.417	0.024
24	MH-C7B	C-7A	73.43	73.34	Cir 1	0.00	1.00	38.2	0.236	0.013
31	MH-C7	MH-C6	71.78	71.44	Cir 1	0.00	2.00	10.5	3.240	0.013
32	C-5B	C-5A	71.18	71.12	Cir 1	0.00	2.00	26.0	0.230	0.013
33	C-5A	MH-C5	71.12	71.00	Cir 1	0.00	2.00	47.1	0.255	0.013
34	C-4B1	MH-C4B	69.97	69.89	Cir 1	0.00	2.00	33.4	0.240	0.013
35	MH-C4C	MH-C4B	70.12	69.89	Cir 1	0.00	2.00	94.0	0.245	0.013
36	MH-C4B	C-4B2	70.04	69.94	Cir 1	0.00	2.00	38.2	0.262	0.013
37	C-4B2	MH-C4B	69.94	69.89	Cir 1	0.00	2.00	22.9	0.219	0.013
38	MH-C4B	MH-C4A	69.89	69.85	Cir 1	0.00	2.00	16.4	0.244	0.013
40	C-3A10	MH-C3A	68.92	68.68	Cir 1	0.00	2.00	15.6	1.539	0.013
41	MH-C3A	MH-C3A	68.68	68.65	Cir 1	0.00	3.00	91.9	0.033	0.013
42	C-3A20	MH-C3A	68.83	68.80	Cir 1	0.00	2.00	15.2	0.197	0.013
43	MH-C3A	MH-C3A	68.80	68.65	Cir 1	0.00	3.00	59.3	0.253	0.013
39	C-2A11	C-2A10	69.83	69.75	Cir 1	0.00	1.50	29.1	0.275	0.013
12	MH-C2	MH-C1	67.06	66.30	Cir 1	0.00	3.50	251.2	0.303	0.013
14	MH-C3	MH-C2	68.00	67.18	Cir 1	0.00	3.50	250.9	0.327	0.013
15	MH-C4	MH-C3	69.45	68.17	Cir 1	0.00	2.50	308.3	0.415	0.013
16	MH-C5	MH-C4	70.80	69.88	Cir 1	0.00	2.00	190.1	0.484	0.013
17	MH-C6	MH-C5	71.44	70.85	Cir 1	0.00	2.00	264.0	0.223	0.013
22	C-12	C-11	75.16	74.88	Cir 1	0.00	1.50	165.5	0.169	0.013
25	C-11	C-10	74.88	74.35	Cir 1	0.00	1.50	273.6	0.194	0.013
26	C-10	C-9	74.35	74.31	Cir 1	0.00	1.50	82.6	0.048	0.013
27	C-9	MH-C8	74.31	73.82	Cir 1	0.00	1.50	271.2	0.181	0.013
28	C-8A	MH-C8	74.40	73.82	Cir 1	0.00	1.00	8.0	7.269	0.013
29	MH-C8	MH-C7	73.82	73.32	Cir 1	0.00	1.50	159.0	0.314	0.013
30	C-7A	MH-C7	73.34	73.32	Cir 1	0.00	1.50	6.0	0.333	0.013
44	MH-C3A	MH-C3	68.65	68.47	Cir 1	0.00	3.00	70.9	0.254	0.013
45	MH-C4A	MH-C4	69.85	69.68	Cir 1	0.00	2.00	66.5	0.256	0.013
46	C-2A10	MH-C2A	69.75	69.43	Cir 1	0.00	1.50	28.2	1.135	0.013
58	MH-C2A	MH-C2A	69.43	68.36	Cir 1	0.00	2.00	28.2	3.792	0.013
59	MH-C2A	C-2A20	68.92	68.60	Cir 1	0.00	1.50	128.0	0.250	0.013
60	C-2A20	C-2A2	68.60	68.51	Cir 1	0.00	1.50	38.7	0.233	0.013
61	C-2A2	MH-C2A	68.51	68.36	Cir 1	0.00	1.50	58.7	0.256	0.013
62	MH-C2A	MH-C2	68.36	68.07	Cir 1	0.00	2.00	13.8	2.110	0.013

Conveyance Hydraulic Computations. Tailwater = 51.700 (ft)

Run #	Hyd. US (ft)	Gr.line DS (ft)	Crit.Elev US (ft)	Fr.Slope (%)	Depth Unif. (ft)	Depth Actual (ft)	Velocity Unif. (f/s)	Velocity Actual (f/s)	Q (cfs)	Cap (cfs)	Junc Loss (ft)
47	72.22	70.26	78.50	0.721	3.50	3.50	8.92	8.92	85.8	57.3	0.000
48	70.26	69.06	74.21	0.354	3.06	4.00	8.31	6.83	85.8	92.4	0.000
49	69.06	68.90	73.50	0.108	2.96	4.69	7.09	4.49	85.8	130.8	0.000
50	68.90	63.36	72.34	0.286	4.69	4.69	7.32	7.32	139.9	130.8	0.000
51*	67.24	63.36	77.90	0.337	0.94	0.94	28.27	28.27	58.7	374.5	0.000
52	63.36	60.17	73.82	0.143	4.52	4.52	8.09	8.09	199.3	241.0	0.000
53	60.17	58.69	74.00	0.097	4.40	4.40	7.82	7.82	199.3	277.2	0.000
54	58.69	57.17	72.00	0.109	4.82	4.82	8.50	8.50	255.0	344.5	0.000
55	57.17	53.42	67.00	0.084	4.81	4.81	9.09	9.09	393.5	614.1	0.000
56*	53.42	51.93	70.00	0.084	1.60	8.00	27.26	5.47	393.5	2894.2	0.000
57	51.93	51.70	72.00	0.222	4.77	7.50	6.64	4.45	393.5	539.3	0.000
24	74.94	74.84	76.73	0.257	0.87	1.00	2.50	2.31	1.8	1.7	0.000
31*	72.64	72.64	76.34	0.049	0.47	1.20	8.82	4.36	5.0	40.9	0.000
32	72.48	72.42	75.91	0.000	0.20	1.30	1.40	0.11	0.2	10.9	0.000
33	72.42	72.30	75.74	0.001	0.31	1.30	1.91	0.27	0.6	11.5	0.000
34*	73.15	73.15	77.43	0.001	0.30	2.00	1.84	1.36	0.6	11.1	0.000
35	73.37	73.15	76.84	0.007	0.56	2.00	2.65	0.60	1.9	11.2	0.000
36	73.72	73.37	76.24	0.930	2.00	2.00	6.97	6.97	21.9	11.6	0.000
37	73.37	73.15	76.74	0.958	2.00	2.00	7.08	7.08	22.2	10.6	0.000
38	73.15	72.96	76.84	1.153	2.00	2.00	7.77	7.77	24.4	11.2	0.000
40*	71.25	71.25	77.19	0.002	0.27	2.00	4.29	2.80	1.1	28.2	0.000
41	71.25	70.98	75.77	0.187	3.00	3.00	4.10	4.10	29.0	12.1	0.000
42	71.16	71.13	76.54	0.001	0.37	2.00	1.87	0.24	0.7	10.1	0.000
43	71.13	70.98	76.06	0.003	0.65	2.33	3.05	0.58	3.4	33.7	0.000
39	70.29	70.23	76.75	0.003	0.34	0.48	2.06	1.26	0.6	5.5	0.000
12	70.18	67.24	77.50	0.337	3.12	3.12	6.48	6.48	58.7	55.6	0.000
14	70.81	70.18	77.20	0.311	2.81	3.00	6.81	6.43	56.4	57.8	0.000
15	72.19	70.81	76.80	0.448	2.16	2.50	6.11	5.62	27.6	26.5	0.000
16*	72.30	72.19	76.00	0.056	0.81	2.00	4.54	4.45	5.4	15.8	0.000
17	72.64	72.30	76.30	0.049	0.96	1.45	3.35	2.07	5.0	10.7	0.000
22	75.99	75.83	77.71	0.059	0.83	0.95	2.54	2.18	2.6	4.3	0.000
25	75.83	75.57	77.73	0.066	0.82	1.22	2.72	1.76	2.7	4.6	0.000
26	75.57	75.45	76.60	0.078	1.50	1.50	1.66	1.66	2.9	2.3	0.000
27	75.45	75.19	76.00	0.080	0.90	1.37	2.70	1.76	3.0	4.5	0.000
28	75.77	75.19	75.80	0.009	0.13	1.00	5.70	0.42	0.3	9.6	0.000
29	75.19	74.82	76.34	0.090	0.78	1.50	3.39	1.79	3.2	5.9	0.000
30	74.84	74.82	76.34	0.045	0.63	1.50	3.17	1.26	2.2	6.1	0.000
44	70.98	70.81	76.64	0.227	2.33	2.34	5.41	5.39	31.9	33.8	0.000
45	72.96	72.19	76.92	1.153	2.00	2.00	7.77	7.77	24.4	11.5	0.000
46*	70.23	70.18	77.73	0.025	0.39	0.75	4.55	1.88	1.7	11.2	0.000
58*	70.18	70.18	78.08	0.005	0.27	1.82	6.72	3.19	1.7	44.2	0.000
59	70.71	70.39	77.08	0.004	0.35	1.50	2.00	0.36	0.6	5.3	0.000
60	70.39	70.31	77.07	0.021	0.56	1.50	2.50	0.86	1.5	5.1	0.000
61	70.31	70.18	76.89	0.034	0.63	1.50	2.78	1.11	2.0	5.3	0.000
62*	70.18	70.18	77.35	0.025	0.45	2.00	6.86	3.93	3.6	33.0	0.000

* Supercritical flow.

SUMMARY OF STORM DRAIN STRUCTURE QUANTITIES

NOTE:
 The convey length should be from upstream to downstream inside box.
 This length may also be used as Pay Item.
 Using hydraulic length, from node center to node center, may result in profile error,
 and this length should not be used as Pay Item.

LINKS:

Type of Convey Structure	Material	Rise (ft)	Span (ft)	Number of Links of this type	Quantity (ft)
Circular	Concrete	3.5	0.0	4	701.8
Circular	Concrete	4.0	0.0	1	661.0
Circular	Concrete	5.0	0.0	2	1252.0
Circular	Concrete	6.5	0.0	1	1227.0
Circular	Concrete	7.0	0.0	1	750.0
Circular	Concrete	7.5	0.0	1	506.0
Box	Concrete	8.0	9.0	2	1516.0
Circular	Other	7.5	0.0	1	240.0
Circular	Concrete	1.0	0.0	2	46.17
Circular	Concrete	2.0	0.0	15	881.76
Circular	Concrete	3.0	0.0	3	222.04
Circular	Concrete	1.5	0.0	11	1240.5
Circular	Concrete	2.5	0.0	1	308.3

NODES:

Type of Inlet Structure	Type of Grate	Inlet Length (ft)	Grate Width (ft)	Grate Length (ft)	Grate Area (ft)	Grate Perimeter (ft)	Quantity (each)
Grate In Sag	Parallel	0.0	0.0	0.0	4.0	4.0	5
Circular Manhole		0.0	0.0	0.0	0.0	0.0	31
Curb And Grate In Sag	Parallel	2.5	0.0	0.0	1.67	3.67	1
Grate In Sag	Parallel	0.0	0.0	0.0	3.34	5.33	1
Curb In Sag		5.5	0.0	0.0	0.0	0.0	6
Curb In Sag		6.0	0.0	0.0	0.0	0.0	1
Curb In Sag		3.0	0.0	0.0	0.0	0.0	1
Outlet		0.0	0.0	0.0	0.0	0.0	1

END

 NORMAL TERMINATION OF HOUSTORM.

Warning Messages for current project:

        Runoff Frequency of: 2 Years
Discharge decreased downstream node Id= MH-B11 Previous intensity used.
Discharge decreased downstream node Id= MH-B15 Previous intensity used.
Discharge decreased downstream node Id= MH-C4A Previous intensity used.
Discharge decreased downstream node Id= MH-C2A1 Previous intensity used.
Discharge decreased downstream node Id= MH-C6 Previous intensity used.
Discharge decreased downstream node Id= MH-C1 Previous intensity used.
Discharge decreased downstream node Id= MH-D1 Previous intensity used.

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Discharge decreased downstream node Id= MH-E1 Previous intensity used.
Discharge decreased downstream node Id= MH-E2 Previous intensity used.
Decreasing conduit size @ downstream Run# 57
Run# 50  Insufficient capacity.
Run# 12  Insufficient capacity.
Run# 15  Insufficient capacity.
Run# 45  Insufficient capacity.
HGL elevation below invert. Downstream HGL set to soffit elevation at Run# 29
HGL elevation below invert. Downstream HGL set to soffit elevation at Run# 30
Run# 38  Insufficient capacity.
Run# 41  Insufficient capacity.
Run# 24  Insufficient capacity.
Run# 37  Insufficient capacity.
Run# 47  Insufficient capacity.
Run# 36  Insufficient capacity.
Run# 26  Insufficient capacity.
```