NORTH HOUSTON DISTRICT DRAINAGE EVALUATION REPORT

Prepared for

NORTH HOUSTON DISTRICT

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Firm: Lockwood, Andrews & Newnam, Inc
Firm ID: 2614
Date: 11/29/2016

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November 2016

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, Inc.
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Executive Summary

The North Houston District (NHD) contracted with Lockwood, Andrews & Newnam, Inc. (LAN) to evaluate the performance of the local and regional drainage systems stressed by the recent April 17-18, 2016 (Tax Day) storm event. The primary goal of the study was to determine the root cause(s) of the severe flooding during the event including: overland/overflow, collection system and out of bank Greens Bayou floodplain. In addition to analyzing existing conditions, LAN was tasked to determine the effect of the future Kuykendahl and Glen Forest basins on the study area. Following the development of an existing conditions and post basins models of the region, LAN was also charged with recommending potential improvement measures that NHD can pursue to provide flood relief for the area.

The Greens Bayou watershed in North Houston District (formerly known as the Greenspoint District) is approximately 6.14 square miles and generally bounded by Rankin Road to the North, Beltway 8 to the South, I-45 to the West, and Hardy Road to the East (Exhibit 3). Greens Bayou runs through the center of the area and functions as a major drainage outfall channel. This region was evaluated using a high-level 2D InfoWorks ICM model within the study area in order to understand the regional flooding sources and overland sheet flow patterns.

Existing Conditions:

The Tax Day storm event of April 17 - 18, 2016, a storm with an annual exceedance probability (AEP) of approximately 2% (50-year), was simulated and validated using the hydrodynamic 2D InfoWorks ICM model. Actual storm event information in the form of monitored rainfall time series data and gaged Greens Bayou stages was used to simulate/model the event. The Tax Day event included two intense rain periods that were relatively close together.

Peak 1: During the first rain period (Peak 1) the area experienced significant ponding and flooding due to approximately 4.9-inches of rain fall in 1-hour. The primary cause of this flooding was the lack of local storm sewer capacity and insufficient overland sheet flow paths. During Peak 1, Greens Bayou remained within its banks and did not directly contribute to the localized flooding event. Generally, the ponding remained mostly within the streets and at a times was several feet deep in multiple locations along Imperial Valley and Greens Road. Greens Road was subject to overland sheet flow entering from Imperial Valley and continuing to flow downgrade where it was ultimately blocked by challenging topography. Overland flow travels from the north, with some limited flow exiting to Greens Bayou. The overall direction of flow can be seen in Exhibit 7 through velocity arrows.

The area south of Greens Road and north of Greens Bayou has multiple locations lower than the banks of Greens Bayou. This topographic restriction creates a large “bowled” area that water cascades via overland from north of Greens Road and then ultimately requires the storm sewer system in order to fully drain back to Greens Bayou. For instance, the intersection of Greens Road

and Imperial Valley is lower than the elevations of Imperial Valley as it approaches Greens Bayou. The ponding and flooding extents resulting from Peak 1 can be seen in Exhibit 4.

Peak 2: During the second rain period (Peak 2) the area experienced additional ponding and flooding due to an additional 5.2-inches of rain fall in approximately 1.5-hours. Localized flooding was further impacted by high levels and overflows from Greens Bayou. It was during this second peak that Greens Bayou exceeded it banks approximately 900 feet north of the intersection of Greens Road and Greens Bayou. Upon leaving Greens Bayou, the flow cascades into Imperial Valley and Greens Road and flowing to the south and east. This additional overland flow exacerbated the flooding condition that resulted from Peak 1 creating areas with significant ponding and structural flooding, matching observations and flooding reports. Given the magnitude of the event (50-year) it is not surprising that Greens Bayou exceeded its banks. A significant portion of the study area is within the FEMA effective 100-year floodway and floodplain for Greens Bayou.

The simulation of the Tax Day event confirmed that the study area has two primary flood risk sources including localized overland flow and collection system deficiencies and out of bank riverine flooding from Greens Bayou.

Post-Basin Conditions:

A second analysis was performed that simulated a post basin condition and included the two future upstream detention basins - Kuykendahl (HCFCD Unit No. P545-01-00) Detention Basin and Glen Forest (HCFCD Unit No. P500-08-00) Detention Basin. The basins are part of a regional watershed improvement designed to target a 10-year level of protection.

It was determined that the two future detention basins will have a clear benefit to the Greens Bayou watershed in NHD, but will not completely solve the majority of the flooding issues within the watershed. This is expected as the basins only represent a portion of the regional project and do not include the future/planned Greens Bayou channel improvements. Exhibit 14 documents the benefits of the basins on the study area.

Post-Basin with Berm Conditions:

Given that the out of bank flooding from Greens Bayou in the vicinity of the Glen Forest (HCFCD Unit No. P500-08-00) Detention Basin is a significant contributor to flooding in the district, NHD requested that LAN evaluate the impacts of constructing a berm to the south and east of Glen Forest Detention Basin between the basin and Greens Bayou. To accomplish this, a simplistic evaluation of a berm along the southern and eastern perimeters of the Glen Forest (HCFCD Unit No. P500-08-00) Detention Basin was performed. An improvement such as this comes with significant challenges, starting with demonstrating no adverse impacts resulting from an obstruction in the floodplain.

In order to determine the potential positive and negative impacts of the basin, several storm events were simulated. The theoretical design storms for the 100-year and 10-year, 24-hour storm events

were evaluated in order to determine potential impacts for severe events while evaluating potential benefits during high frequency storm events.

The result of the berm adjacent to the Glen Forest (HCFCD Unit No. P500-08-00) Detention Basin was overall a moderate benefit for the study area during the 10-year, 24-hour storm event. Marginal water surface reductions were seen within the areas south of Greens Road and north of Greens Bayou. Even with the benefits of the basin with an overland flow limiting berm, the localized flooding issues are not resolved. These localized flooding issues are due to insufficient storm sewer capacity and adverse overland sheet flow paths within the region.

It is important to note that the simulation indicated the placement of a berm adjacent to the Glen Forest (HCFCD Unit No. P500-08-00) Detention Basin resulted in the potential for adverse impacts during the 100-year event west and north of the basin. The berm adversely impacted the areas north of Greens Road, south of Resthaven Memorial Gardens, west of the berm, and east of I-45 as seen on Exhibit 16. A berm in the path of an established overbank flow path is potentially detrimental to overall floodplain conveyance and reduces the overall capacity of the area resulting in potential upstream water surface impacts. Due to the adverse impacts within the region, the berm is not recommended without significant additional analysis and engineering.

The preliminary findings in the simulation are useful to understand the existing flood patterns and the potential localized benefits from the two future detention basins as well as the impact from the potential berm.

Recommendations and considerations going forward:

1. Address localized conveyance issues - Conveyance improvements on Greens Road and Imperial Valley Drive should be considered to assist in providing additional conveyance capacity for the extreme storm event. This will assist in addressing local intense rain events and reduce overall ponding depths and durations within the area. It will also help to protect the area during the extreme regional events following the completion of the Greens Bayou Regional Flood Control projects. A primary challenge will be mitigating the improvements to prevent downstream impacts on Greens Bayou. This can be accomplished with localized detention within the NHD or within the project corridors.

2. Buyouts – the NHD's current buyout plan is justified and warranted given the significant and frequent flooding with the region. Many of the recently and frequently flooded properties are repetitive loss and severe repetitive losses properties which mean they have filed multiple flood insurance claims. The most severe flooding is located in the lowest point of the area south of Greens Road adjacent to Greens Bayou. We recommend continuing the pursuit of the buyouts of repetitive and severe repetitive loss properties.

3. Localized Detention – If buyouts are actively pursued, the cleared buyout property could be repurposed for a multiuse park and localized detention facility. Detention local to the NHD

can assist with mitigating the future localized conveyance improvements described in recommendation 1. If the buyout properties are large enough, it may be possible to provide additional sub-regional flood reduction.

4. Grants - A variety of grants exist to assist the NHD with flood risk mitigation projects and studies. Each grant available has varying application timelines, reimbursement procedures, cost sharing breakdowns, and overall project type restrictions. A small sampling of the grants potentially available to the NHD include the following: Flood Protection Planning Grant through the Texas Water Development Board (TWDB), Flood Mitigation Assistance through the TWDB and FEMA, Severe Repetitive Loss through the TWDB and FEMA, Hazard Mitigation Grant Program through the Texas Division of Emergency Management and FEMA, Housing and Urban Development (HUD) through the General Land Office (GLO), and Disaster Recovery through FEMA. It is recommended that these grant opportunities be fully vetted for potential funding options for the NHD.

5. Detailed Feasibility Analysis – A detailed feasibility analysis of the above described solutions is recommended in order to better refine the overall improvement concepts and challenges associated with each recommendation. This detailed feasibility analysis would incorporate a more detailed modeling approach and preliminary engineering to identify key design elements. Key design elements to be evaluated should include major utility conflict analysis, topographic evaluations, preliminary conveyance sizing, alignment determinations, construction cost estimates, and cost/benefit ratios of structures removed from flooding. A detailed feasibility analysis would also assist the NHD in grant preparation and potential federal support through a detailed project understanding.

1 Introduction

1.1 Purpose and Scope

A significant flood event occurred over the northern and western portions of Harris County from the evening hours of April 17th into the day of April 18th, 2016 (Tax Day storm event), considerably impacting North Houston District area. To better understand the regional flooding sources and patterns, North Houston District (formerly known as the Greenspoint District) retained Lockwood, Andrews & Newnam, Inc (LAN) to conduct a high-level 2D storm water analysis, with particular focuses on the Tax Day storm event and the potential impact of the future construction of Kuykendahl (HCFCD Unit No. P545-01-00) and Glen Forest (HCFCD Unit No. P500-08-00) regional detention basins.

1.2 Location

The North Houston District is located at the intersection of Intersection 45 and Beltway 8 with Greens Bayou (HCFCD Unit No. P100-00-00) running through its center. The study corridor along Greens Bayou is generally bounded by Rankin Road to the North, Beltway 8 to the South, I-45 to the West, and Hardy Road to the East (Exhibit 3).

1.3 Floodplain Information

The FEMA Flood Insurance Rate Map (FIRM) No. 48201C0460M, Panel 460 of 1150 (Effective Date October 16, 2013) indicated that the Greens Bayou Corridor in the study region is designated as Zone AE with Base Flood Elevation ranging between elevation 80 near Hardy Tool Road and elevation 89 near I-45 in reference based on NAVD88 (Exhibit 1).

1.4 Data Collection

The 2008 LiDAR data from the HGAC was utilized for this study. The primary data sources for the existing stormwater system in the study area was based on district provided GIS data and City of Houston GIMS website, supplemented with field reconnaissance. The GIS data and as-built information was datum leveled against known LiDAR elevations before being imported to the models. Where flowlines or pipe sizes were missing, inferences were made based on the surrounding pipe sizes and flowlines. Gaged rainfall data and Greens Bayou stage hydrographs of Tax Day storm event at downstream and upstream sides of the study region were downloaded from Harris County Flood Warning System (www.harriscountyfws.org).

To investigate the impact of the Kuykendahl and Glen Forest regional detention basins, the hydraulic models and results from an ongoing HCFCD study - ***HCFCD Kuykendahl (P545-01-00) and Glen Forest (P500-08-00) Stormwater Detention Basin Hydrology & Hydraulic Mode Updates and Performance Re-evaluation*** were utilized for use in this study.

1.5 Study Datum

Horizontal control for the study was based on the Texas State Grid Coordinate System, South Central Zone, NAD1983. The vertical datum for the study was the North American Vertical Datum of 1988, 2001 Adjustment.

1.6 Site Visits

One site visit was conducted at the beginning of the project to confirm information such as storm sewer sizes and flowlines, street drainage inlet locations, and outfall locations at Greens Bayou.

2 Hydrology and Hydraulics

2.1 Hydrology

The project drainage area is approximately 6.14 square miles and generally bounded by Rankin Road to the North, Beltway 8 to the South, I-45 to the West, and Hardy Road to the East (Exhibit 3).

The built-in direct rainfall method in InfoWorks-ICM was used to simulate rainfall-runoff process which tracks and aggregates the storm water runoff generated from each 2D mesh cell.

Time of Concentration (Tc) or Storage Coefficient (R) was not required for direct rainfall method in the 2D models in order to create the required hydrographs. Rainfall is routed through the 2D surface according to the terrain topography and overland roughness coefficients. In InfoWorks ICM direct rainfall modeling, hydrologic and hydraulic process are coupled internally in a seamless way.

2.2 Hydraulics

The hydraulic analysis for the existing drainage and riverine system and the potential impact of the Kuykendahl and Glen Forest regional detention basins are based on simulation results obtained from 2-dimensional InfoWorks ICM models.

2.2.1 Model Development

InfoWorks-ICM V6.5 2-dimensional models were created in order to better understand the drainage issues observed in the study area. The models simulated the storm runoff carried by Greens Bayou, the subsurface storm sewer infrastructure at major roadways, and their interaction with the ground surface.

In the 2D model, a triangular mesh was generated to perform the surface flow analysis using the built-in InfoWorks mesh creation process. Elevations at the vertices of and areas within the generated mesh elements were developed from the LiDAR provided by the HGAC. Overland roughness zones were incorporated into the 2D mesh surface to account for variations in surface roughness such as the change from concrete areas to grassed areas. Roughness zones were generate based on zoning information, aerial imagery, information provided by the district, and field visits.

Like the rest of the ground surface in the study area, Greens Bayou was modeled as 2D surface with 2D mesh cells at different elevations representing its conveyance capacity. Storm sewer connectivity, sizes, and flowlines from GIS data were adjusted in order to match the district provided as-built information and field reconnaissance. Where flowline or size information was not available from as-built information, it was assumed or interpolated from surrounding pipes.

Inlets were modeled as a two part element consisting of an upstream modeling node interacting with the 2D mesh surface, connected to a “capped” weir, connected to a sealed

node, representing the connection to the downstream storm sewer system (lateral or trunkline depending on the location). The upstream modeling node was set to a “2D” flood type to interact with the 2D mesh without any restrictions. The “capped” weir consists of parameters describing the physical inlet such as throat elevation, throat width, and opening height. The “capped” weir represents both the weir regime of flow to the inlet and the orifice regime of inlet flow after the inlet opening height has been exceeded and is surcharged. Weir parameters were assigned based on field survey to account for inlet type, width, and height.

Manning’s Roughness parameters for conduits were established as 0.013 for precast concrete pipe and 0.024 for corrugated metal pipe where appropriate.

3 Tax Day Storm Event Results

3.1 Tax Day Storm Event

From the evening hours of April 17th into the day of April 18th, 2016, a slow moving and powerful upper level storm system over the southwest US combined with near record moisture levels for mid-April produced a significant flood event over the northern and western portions of Harris County including the North Houston District.

According to the memo of ***Final April 17-18, 2016 (Tax Day) Storm and Flood Information*** compiled by HCFCD, the total rainfall amounts averaged 12.0-16.0 inches over northwest Harris County from Katy to Addicks to Waller and over 10.0 inches west of a line from Spring to Greenspoint to Stafford. For Greens Bayou, water levels averaged below the 10% (10-year) from the Houston Ship Channel to FM 525 and between the 10% (10-year) and 2% (50-year) west of FM 525 to SH 249 including North Houston District.

3.2 Tax Day Storm Event Results

To simulate the tax day event, two scenarios were developed within the InfoWorks-ICM 2D models:

Scenario 1: Existing Condition - Tax Day Storm Event

Scenario 2: Post Basin Condition - Tax Day Storm Event with Regional Detention Basins in place

Scenario 1: Existing Condition - Tax Day Storm Event

InfoWorks-ICM 2D model was set up to simulate the tax day storm event. The gaged rainfall and stage data (Gage: P100_1660 Greens Bayou @ Knobcrest Drive) during Tax Day storm event was downloaded from Harris County Flood Warning System (www.harriscountyfws.org) as rainfall input and the upstream boundary condition of Greens Bayou. Since there was no gage nearby, the downstream boundary stage values at Hardy Toll Road were interpolated between I-45 and Beltway 8 at Greens Bayou. A dynamic stage hydrograph was applied for a boundary level conditions for I-45 and Hardy Toll Road. The 2D model was run continuously for 24 hours starting from 21:05 April 17, 2016 to 21:05 April 18, 2016. The modeled results of flood inundation extents and ponding depths were compared with the observations provided by the district including high water marks, flood reports and complaints, photos and aerials provided by HCFCD. Efforts were made to validate the model by adjusting roughness zones and roughness coefficients. Building footprints were added as high roughness zones to better represent overland flow paths and concentrate flow between developments. With this approach, storm water would be able to enter the buildings but would not offer conveyance pathwards. Adjusting the roughness zones yielded a closer calibration than those without building footprints between the model outputs and recorded high water marks.

As shown on Exhibit 4 through 8, the overall model results are in good accordance with what were observed and recorded during Tax Day storm event.

Overall, the study area is hindered by its topography, inadequate local drainage systems, and high tailwater conditions of Greens Bayou. Exhibit 3 shows the topology of the study area. The areas of interest, just north of Greens Bayou, is in a topographically low region. The area further north near Rankin Road is higher and the overland flow travels south towards Greens Bayou.

The general region experienced two distinct ponding peaks during the Tax Day event, as shown in Exhibits 4-5. For the Tax Day storm event, Peak one occurs at 1:45 am on April 18, 2016 before Greens Bayou reached its channel capacity. The rainfall associated with peak one had a rainfall duration of one hour and a total depth of 4.9 inches. Many streets were flooded such as Greens Road and Imperial Valley Drive. Greens Road was adversely impacted by sheet flow coming from Imperial Valley Drive, which received significant offsite sheetflow from the west. Much of the flow enters Greens Road, as seen in Results Line 7 on Exhibit 8, where it outfalls at Greens Bayou near Hardy Toll Road. The general direction of overland flow can be seen in Exhibit 7 illustrated through velocity arrows. Since the water surface elevations within Greens Bayou were still relatively low during this point in the storm, it was determined that the storm sewer systems were undersized for an extreme event and local flooding occurs.

In addition to undersized storm sewer systems for this event, the region is further hindered by its topography. Both north and south of the channel have elevations lower than that of the channel banks. Water is unable to drain unless the “bowled” area fills up and spills over to roads such as Greens Road where it uses storm sewer conveyance to ultimately travel to Greens Bayou. The intersection of Greens Road and Imperial Valley Drive is lower in elevation than further south, closer to Greens Bayou. Ponding for Peak One can be seen in Exhibit 4.

During Peak Two, the second rain period of the Tax Day Event, Greens Bayou became bank full. Peak Two occurs at approximately 6:00 am, lasts for approximately 1.5 hours and has a total rainfall depth of 5.2 inches. Once Greens Bayou reaches its global peak, local drainage systems do not have an adequate difference in water surface elevations (water heads) required to maintain positive drainage into the channel. Greens Bayou lacks the volume to convey all of the flow downstream and therefore flow leaves Greens Bayou and travels south and east in places such as Imperial Valley Drive, Knobcrest Drive, and Newcrest Circle. These locations correspond with Results Lines 4-5,1 and 2 respectively on Exhibit 8. Overall the flow is traveling southeast as shown by Results Line 6 in Exhibit 8. Overland flows that reach the channel along Results Line 8 are eventually able to drain but pond from 4:00 am on April 18 to 2:00 pm. Water does not exit the channel along Results Line 8, which is north and parallel of Greens Bayou from Wayforest Drive to West Hardy road. Ponding for Peak Two can be seen in Exhibit 5.At its maximum ponding depth, many critical intersections have over three feet of ponding as shown in Exhibit 6. South of Newcrest Drive and north of Southbrook Circle water leaves Greens Bayou and enters the District’s study area as shown in Exhibit 7-8. Water also leaves Greens Bayou north of Rockridge Place apartments and east of Amherst at Cityview apartments. The combination of water surface elevations in Greens Bayou and inadequate

local drainage systems yield deep ponding with long ponding durations. The peak ponding time for each region is shown in Exhibit 9 as a means to illustrate which part of the storm drove the peak water surface inundation for the area. Areas around Greens Bayou experience maximum ponding depths around the same time as Greens Bayou further confirming that these areas are heavily influenced by Greens Bayou tailwater conditions.

Scenario 2: Post Basin Condition - Tax Day Storm Event under Impact of Regional Detention Basins

As part of the Greens Bayou watershed flood mitigation projects funded by HCFCD, two regional detention basins will be constructed in the near future along Greens Bayou, Kuykendahl (HCFCD Unit No. P545-01-00) Detention Basin and Glen Forest (HCFCD Unit No. P500-08-00) Detention Basin. As indicated on Exhibit 18, P545-01-00 is a multi-cell basin located at the intersection of P145-03-00 and P145-00-00 with an approximate storage capacity of 2,325 acre-feet, while P500-08-00 is also a multi-cell basin located on the east of I-145 along Greens Bayou with a maximum storage capacity of approximately 894 acre-feet.

To investigate the potential benefits of these two detention basins during the Tax Day storm event, the post basins condition InfoWorks-ICM 2D model was set up to simulate this scenario. The two detention basins were not physically modeled in the 2D model for the Tax Day Event, instead, the upstream and downstream boundary conditions from Scenario 1 model at I-45 and Hardy Toll Road of Greens Bayou were revised to reflect the changes in terms of peak flow reduction (flood attenuation) and peak time delaying by examining the HEC-RAS model results from the ongoing HCFCD study - ***HCFCD Kuykendahl (P545-01-00) and Glen Forest (P500-08-00) Stormwater Detention Basin Hydrology & Hydraulic Mode Updates and Performance Re-evaluation***.

As shown on Exhibit 10 through 12, the flood inundation extents are reduced and ponding depths are decreased by approximately 0.01 to 0.75 feet compared to the existing conditions (Scenario 1). In addition to depth reductions, the flooding footprint is reduced as well. Some areas that were inundated before the addition of the basin are dry after basin implementation. However, many critical intersections such as Imperial Valley Drive, Greens Road, and Seminar Drive are still inundated and not passable. The reasons for flooding are similar to Scenario 1, inadequate local infrastructure, and high tailwater conditions in Greens Bayou. While the basins provide some relief, they do not offer enough storage to completely remove ponding during a significant event like the Tax Day Storm Event of 2016. After all, the basins were intended to provide temporary flood water storage and mitigate flood attenuation in Greens Bayou for a 10-year recurrence interval.

4 Design Storm Flood Event Results

4.1 Design Storm Flood Event

For the project area, the Tax Day storm event is one with an AEP similar to that of a 2% (50-year) storm event. To further investigate the post basin flooding conditions under different AEP storm events, a series of hypothetical storm events were set up and imported to the InfoWorks-ICM 2D models. Greens Bayou upstream and downstream boundary conditions (stage hydrographs) were acquired from the HEC-RAS models of ongoing HCFCD study - ***HCFCD Kuykendahl (P545-01-00) and Glen Forest (P500-08-00) Stormwater Detention Basin Hydrology & Hydraulic Mode Updates and Performance Re-evaluation***.

Per the requirements of HCFCD Hydrology & Hydraulics Guidance Manual (H&H Manual), December 2009, 24-hour standard frequency storms in Harris County Region 2 were adopted and used in the direct rainfall method of 2D modeling. The standard rainfall frequency and duration data excerpted from HCFCD H&H Manual is listed Table 5-1.

Table 5-1 Harris County Region 2 Rainfall (inches) for Greens Bayou Watershed

Duration	Exceedance Probability (Frequency)							
	50% (2-Year)	20% (5-Year)	10% (10-Year)	4% (25-Year)	2% (50-Year)	1% (100-Year)	0.4% (250-Year)	0.2% (500-Year)
5 Minutes	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
15 Minutes	1.1	1.4	1.5	1.7	1.9	2.1	2.4	2.6
30 Minutes	1.5	1.8	2.1	2.4	2.7	3.0	3.4	3.8
60 Minutes	2.0	2.5	2.9	3.4	3.8	4.3	4.9	5.5
2 Hours	2.3	3.1	3.6	4.3	5.0	5.7	6.7	7.6
3 Hours	2.6	3.5	4.1	5.0	5.8	6.7	8.0	9.2
6 Hours	3.1	4.3	5.1	6.4	7.6	8.9	10.9	12.8
12 Hours	3.7	5.1	6.2	7.8	9.2	10.8	13.3	15.5
24 Hours	4.4	6.2	7.6	9.6	11.3	13.2	16.2	18.9
2 Days	5.0	7.1	8.6	10.8	12.5	14.5	17.4	20.0
4 Days	5.8	8.1	9.8	12.1	14.0	15.9	18.8	21.1

4.2 Design Storm Flood Event Results

Three different flood scenarios were modeled within the InfoWorks ICM models. The scenarios are as follows:

Scenario 3: Existing Condition – 24-hour 100-year Storm Event and 10-year Storm Event

Scenario 4: Post Basin Condition – 24-hour 100-year Storm Event

Scenario 5: Post Basin Condition with a Berm to the south of the Glen Forest Detention Basin – 24-hour 100-year and 10-year Storm Event

Scenario 3: Existing Condition – 24-hour 100-year Storm Event and 10-year Storm Event

The Tax Day storm event existing condition InfoWorks-ICM 2D model was revised to model the design 24-hour 100-year storm event and 24-hour 10 year storm event. The 100-year and 10-year frequency storm time series data (intensity vs. time) was acquired from the effective HEC-HMS model downloaded from HCFCD M3 website. The Greens Bayou upstream and downstream boundary conditions (stage hydrographs) were retrieved from the HEC-RAS model results of the ongoing HCFCD study - ***HCFCD Kuykendahl (P545-01-00) and Glen Forest (P500-08-00) Stormwater Detention Basin Hydrology & Hydraulic Mode Updates and Performance Re-evaluation***. The upstream stage boundary condition was taken at HEC-RAS cross section 168445.4 near I-45 and the downstream stage boundary condition was take at HEC-RAS cross section 156281.6 near Hardy Toll Road.

As shown on Exhibit 13, the ponding depths under 24-hour 100-year storm is greater than those shown on Exhibit 6 of Tax Day storm event existing condition. This is because the tax day storm event with an AEP of about 2% (50-year) is a smaller event than the 100-year frequency storm. The storms sewer systems are not designed to convey flows created from a 100-year frequency storm event and are undersized relative to an extreme event. In addition, elevated water surface elevations in Greens Bayou does not allow water to drain downstream as water surface elevations downstream need to be less than that of upstream.

In contrast, the 24-hour 10-year storm event has significantly less ponding than the 100-year. During the 24-hour 10-year storm event Greens Bayou becomes bank full and water does not have positive drainage to flow downstream. Several roads are impassable during this event such as Greens Road, Seminar Drive, and Imperial Valley Drive.

Scenario 4: Post Basin Condition - 24-hour 100-year Storm Event

As part of the Greens Bayou watershed flood mitigation projects funded by HCFCD, two regional detention basins are to be constructed in the near future along Greens Bayou, namely Kuykendahl (HCFCD Unit No. P545-01-00) Detention Basin and Glen Forest (HCFCD Unit No. P500-08-00) Detention Basin. As indicated on Exhibit 18, P545-01-00 is a multi-cell basin located at the intersection of P145-03-00 and P145-00-00 with an approximate storage capacity of 2,325 acre-feet, while P500-08-00 is also a multi-cell basin located on the east of I-145 along Greens Bayou with a maximum storage capacity of approximately 894 acre-feet.

To evaluate the flood mitigation impact of these two detention basins, the existing conditions InfoWorks-ICM 2D model was modified to simulate this scenario:

a. To model Kuykendahl (HCFCD Unit No. P545-01-00) Detention Basin, the HEC-RAS model from the ongoing HCFCD study was revised by removing Glen Forest Detention from the proposed condition geometry. The net effect of this revision are Greens Bayou stage hydrographs at upstream and downstream side of the study area that reflect the benefit of only the Kuykendahl Detention Basin.
b. To model Glen Forest (HCFCD Unit No. P500-08-00) Detention Basin, the 2D surface in the InfoWorks 2D model was revised by incorporating the proposed basin grading

geometry into the 2D meshes, and culvert connectivity. Hereby, the basin is modeled as part of the 2D surface, and not included in boundary condition developments.

As seen in Exhibit 14, 100-year storm event post-basin flooding offers some benefit over existing conditions. Depths are reduced from approximately 0.01 feet to 1 feet depending on location. While the water surface elevations are reduced, the reduction in values does not completely solve the flooding problem in the region of street flooding and structural flooding. The basins were not designed with a 100 year storm in mind and thus provide minimal benefit during a 100 year storm event. Flow continues to leave Green Bayou and enters the streets and structures within the study area.

Scenario 5: Post Basin Condition with a Berm to the south of the Glen Forest Detention Basin - 24-hour 100-year and 10-year Storm Event

North Houston District desired to understand the impact of a potential berm the south of Glen Forest Detention Basin in between the basin and Greens Bayou to mitigate flooding in the region. This berm would surround the southern and eastern boundaries of the future Glen Forest Detention Basin. The berm is approximately 500 feet long and 10 feet high. To help the District answer this question of potential benefit from the berm, LAN modeled this new scenario by incorporating the berm elevations into the 2D surface of the InfoWorks 2D model.

The purpose of the berm investigation was to determine if a berm construction would be beneficial to the study area or if it would cause any adverse impacts. It was understood that there is significant offsite flow coming from the north and the west. The berm was placed to block this flowpath from reaching Imperial Valley Drive and Greens Road.

The potential effect of the berm was analyzed during the 100-year storm event. The berm lowered the water surface elevations in some places within the North Houston District, but as seen in Exhibit 16, some other areas were adversely impacted and experienced an increase in ponding depths. The berm adversely impacted the areas of north of Greens Road, west of the berm, and east of I-45. Greens Bayou experiences adverse impacts both east and west of its banks. Knobcrest Drive, Falworth Drive, Folway Drive, Newcrest Drive, Kingford Drive, Southbrook Drive are several of the streets adversely impacted by the berms construction. Water that usually would flow downstream in these areas instead is trapped by the berm and stacks up resulting in higher water surface elevations. Ultimately, the water traveled around the berm and flowed in the same direction that it would have flowed without the berm and therefore, it does not decrease water surface elevations significantly south and east of the berm.

In addition to a 100-year storm, a 10-year frequency storm was modeled to determine the potential impacts or benefits of the berm during a more frequent event. As seen in Exhibit 17 the berm caused a mixture of beneficial and adverse impacts in the vicinity of the North Houston Districts. Some areas that did not flood prior to the berm before experienced flooding

after the implementation of the berm. This adverse impact would preclude the berm's construction.

Overall, the two regional detention basins have some benefits in terms of flood mitigation and reduction, even though the benefits are not substantial. A berm in between Glen Forest Detention Basin and Greens Bayou has an adverse impact in some areas and minimal benefits in others, and therefore is not recommended.

5 Conclusions and Recommendations

The North Houston District is served by Greens Bayou with multiple storm sewer systems. This region was evaluated using a 2-dimensional InfoWorks ICM model at a high level to develop an understanding of the region's subsurface and overland flow patterns. The Tax Day Storm Event model was validated against District's reporting flooding depths and was found to be in good agreement with reported field conditions. The performance of the stormwater infrastructure within the North Houston District was evaluated for the Tax Day event as well as the 100-, and 10-year 24 hour frequency storm events and found to be functionally deficient in several locations throughout the region. The general cause of such deficiencies were undersized storm sewer systems, lack of defined overland flow paths, and elevated tailwaters in Greens Bayou.

Five scenarios were modeled to evaluate the region's flooding issues and examine the potential impact from the two future detention basins (Kuykendahl Detention Basin (P545-01-00) and Glen Forest Detention Basin (P500-08-00)) under the Tax Day storm event, 24-hour 100-year, and 10-year frequency storm events. The two future detention basins will not relieve the majority of the flooded properties during an event with equal or greater severity to Tax Day storm event. The effect from a potential berm between Glen Forest Detention Basin and Greens Bayou was simulated as Scenario 5 and had limited benefit in some areas and had an adverse effect in others. Due to the adverse impacts, the berm is not recommended.

Recommendations and considerations going forward:

1. Address localized conveyance issues - Conveyance improvements on Greens Road, Imperial Valley Drive, and West Hardy should be considered to assist in providing additional conveyance capacity for the extreme storm event. This will assist in addressing local intense rain events and reduce overall ponding depths and durations within the area. It will also help to protect the area during the extreme regional events following the completion of the Greens Bayou Regional Flood Control projects. A primary challenge will be mitigating the improvements to prevent downstream impacts on Greens Bayou. This can be accomplished with localized detention within the NHD or within the project corridors.

2. Buyouts – the NHD's current buyout plan is justified and warranted given the significant and frequent flooding with the region. Many of the recently and frequently flooded properties are repetitive loss and severe repetitive losses properties which mean they have filed multiple flood insurance claims. The most severe flooding is located in the lowest point of the area south of Greens Road adjacent to Greens Bayou. We recommend continuing the pursuit of the buyouts of repetitive and severe repetitive loss properties.

3. Localized Detention – If buyouts are actively pursued, the cleared buyout property could be repurposed for a multiuse park and localized detention facility. Detention local to the NHD can assist with mitigating the future localized conveyance improvements described in

recommendation 1. If the buyout properties are large enough, it may be possible to provide additional sub-regional flood reduction.

4. Grants - A variety of grants exist to assist the NHD with flood risk mitigation projects and studies. Each grant available has varying application timelines, reimbursement procedures, cost sharing breakdowns, and overall project type restrictions. A small sampling of the grants potentially available to the NHD include the following: Flood Protection Planning Grant through the Texas Water Development Board (TWDB), Flood Mitigation Assistance through the TWDB and FEMA, Severe Repetitive Loss through the TWDB and FEMA, Hazard Mitigation Grant Program through the Texas Division of Emergency Management and FEMA, Housing and Urban Development (HUD) through the General Land Office (GLO), and Disaster Recovery through FEMA. It is recommended that these grant opportunities be fully vetted for potential funding options for the NHD.

5. Detailed Feasibility Analysis – A detailed feasibility analysis of the above described solutions is recommended in order to better refine the overall improvement concepts and challenges associated with each recommendation. This detailed feasibility analysis would incorporate a more detailed modeling approach and preliminary engineering to identify key design elements. Key design elements to be evaluated should include major utility conflict analysis, topographic evaluations, preliminary conveyance sizing, alignment determinations, construction cost estimates, and cost/benefit ratios of structures removed from flooding. A detailed feasibility analysis would also assist the NHD in grant preparation and potential federal support through a detailed project understanding.

EXHIBITS

Legend

- Floodway
- 100-YR Floodplain
- 500-YR Floodplain

0 250 500 1,000
Feet

NORTH HOUSTON DISTRICT

EFFECTIVE FLOODPLAINS

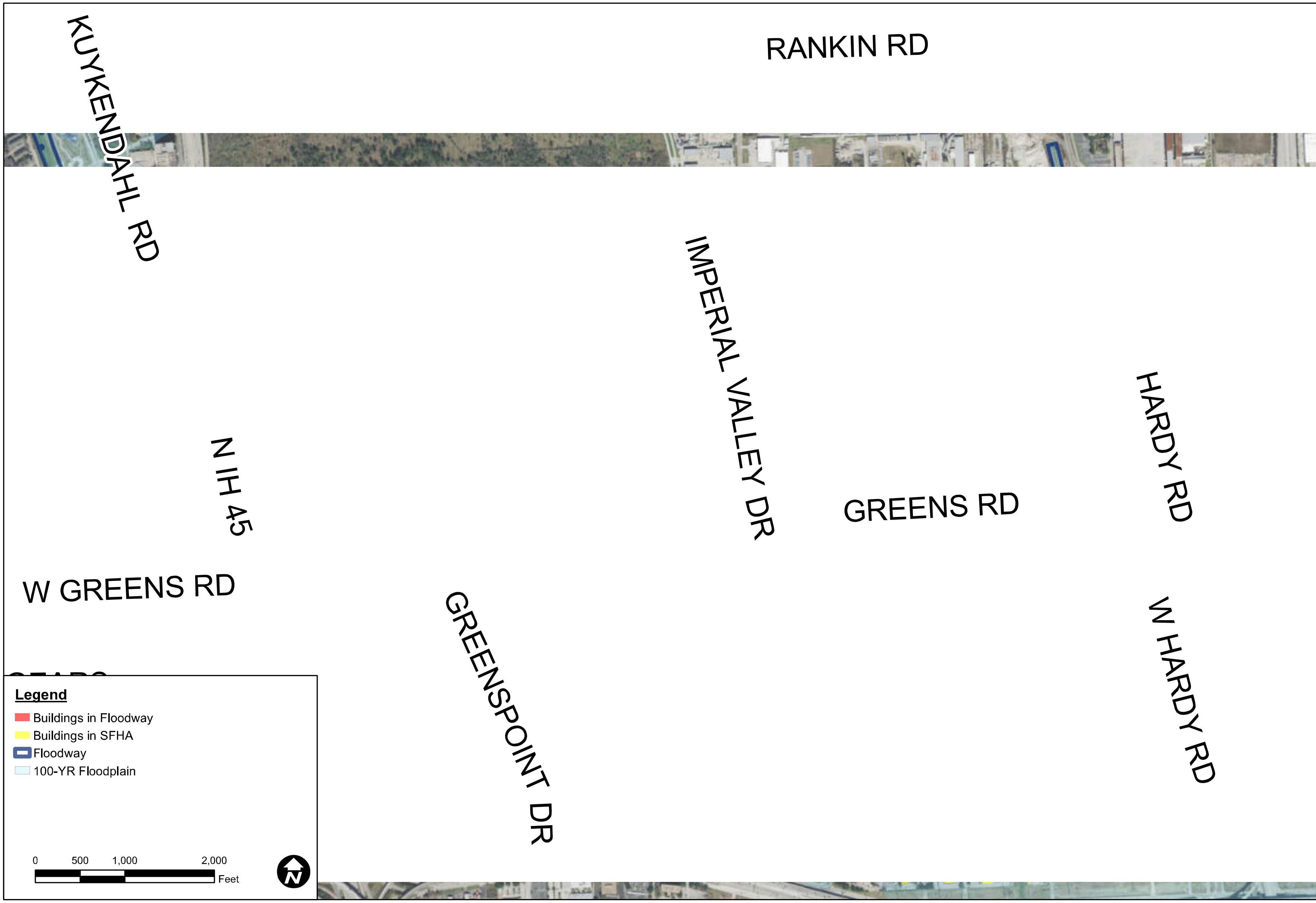
PREPARED: ELO
CHECKED: MJM
APPROVED: DST

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

North Houston District

DATE: OCT. 2016
SCALE: AS NOTED

EXHIBIT
1



NORTH HOUSTON DISTRICT

BUILDINGS WITHIN FLOODWAY AND SFHA

PREPARED: ELO
CHECKED: MJM
APPROVED: DST

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

North Houston District

DATE: OCT. 2016
SCALE: AS NOTED

EXHIBIT 2

P:\120\120-11959-000\9-0-Non-Projectwise_Data\9-01-GIS\ArcMapProjects\Reports\resized\Legend Moved\Exhibit3_Topo.mxd 10/21/2016 1:51:59 PM User Name

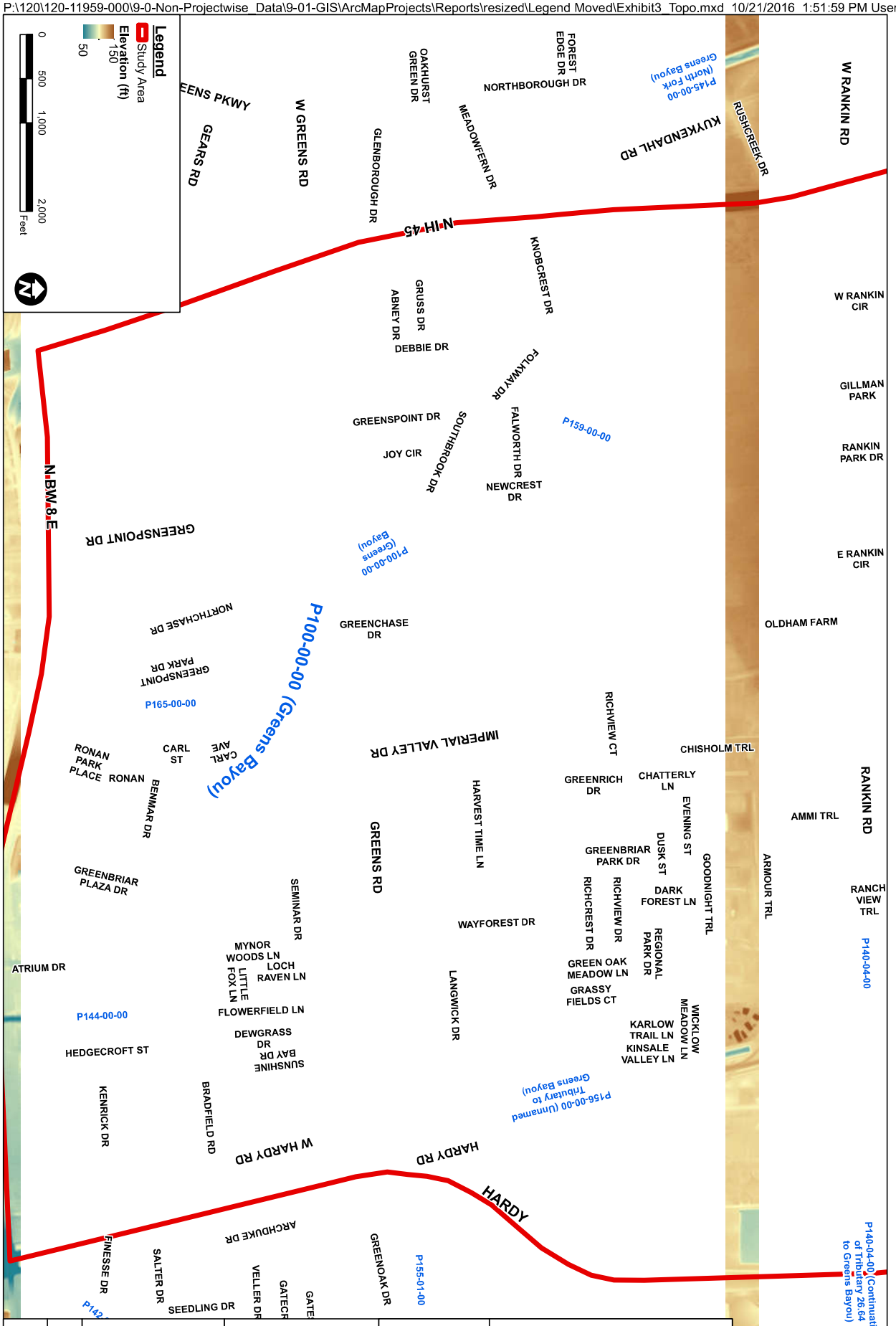
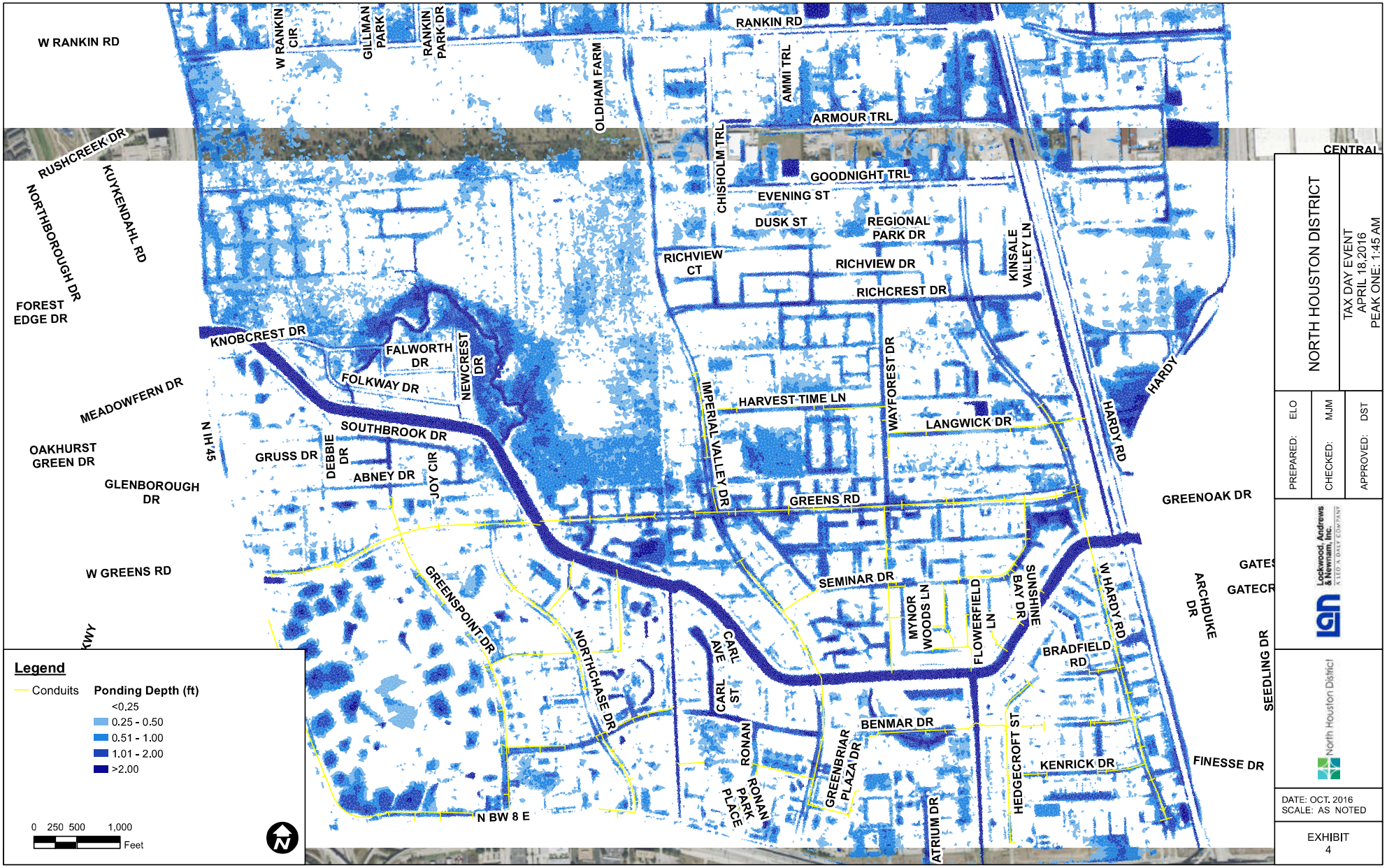


EXHIBIT 3	DATE: OCT. 2016 SCALE: AS NOTED	North Houston District	Lockwood, Andrews & Newnam, Inc. A LEO A DALY COMPANY	PREPARED: ELO CHECKED: MJM APPROVED: DST	NORTH HOUSTON DISTRICT OVERALL PROJECT AREA TOPOGRAPHY



NORTH HOUSTON DISTRICT

TAX DAY EVENT
APRIL 18,2016
PEAK ONE: 1:45 AM

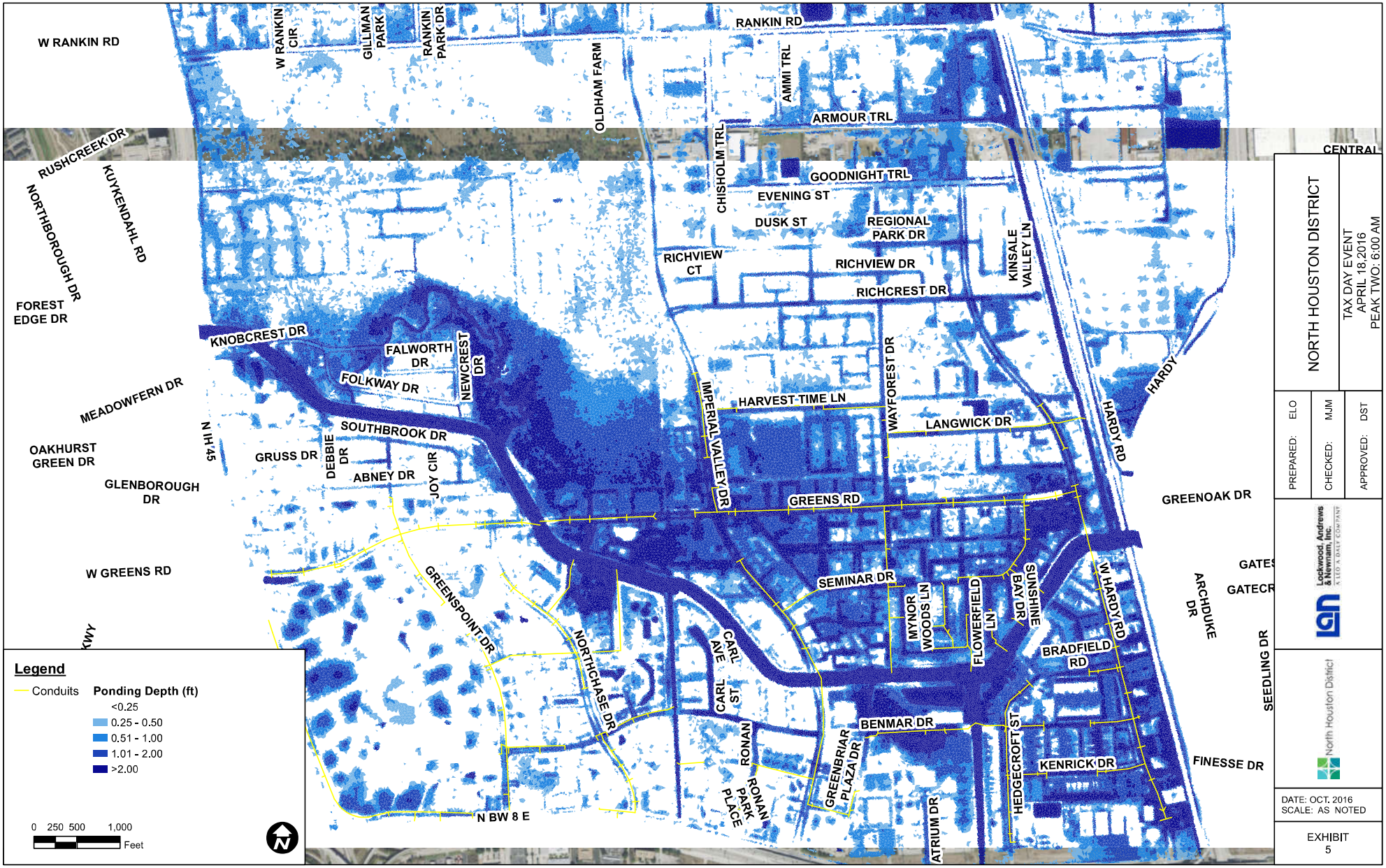
PREPARED: ELO
CHECKED: MJM
APPROVED: DST

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

North Houston District

DATE: OCT. 2016
SCALE: AS NOTED

EXHIBIT
4



NORTH HOUSTON DISTRICT

TAX DAY EVENT
APRIL 18.2016
PEAK TWO: 6:00 AM

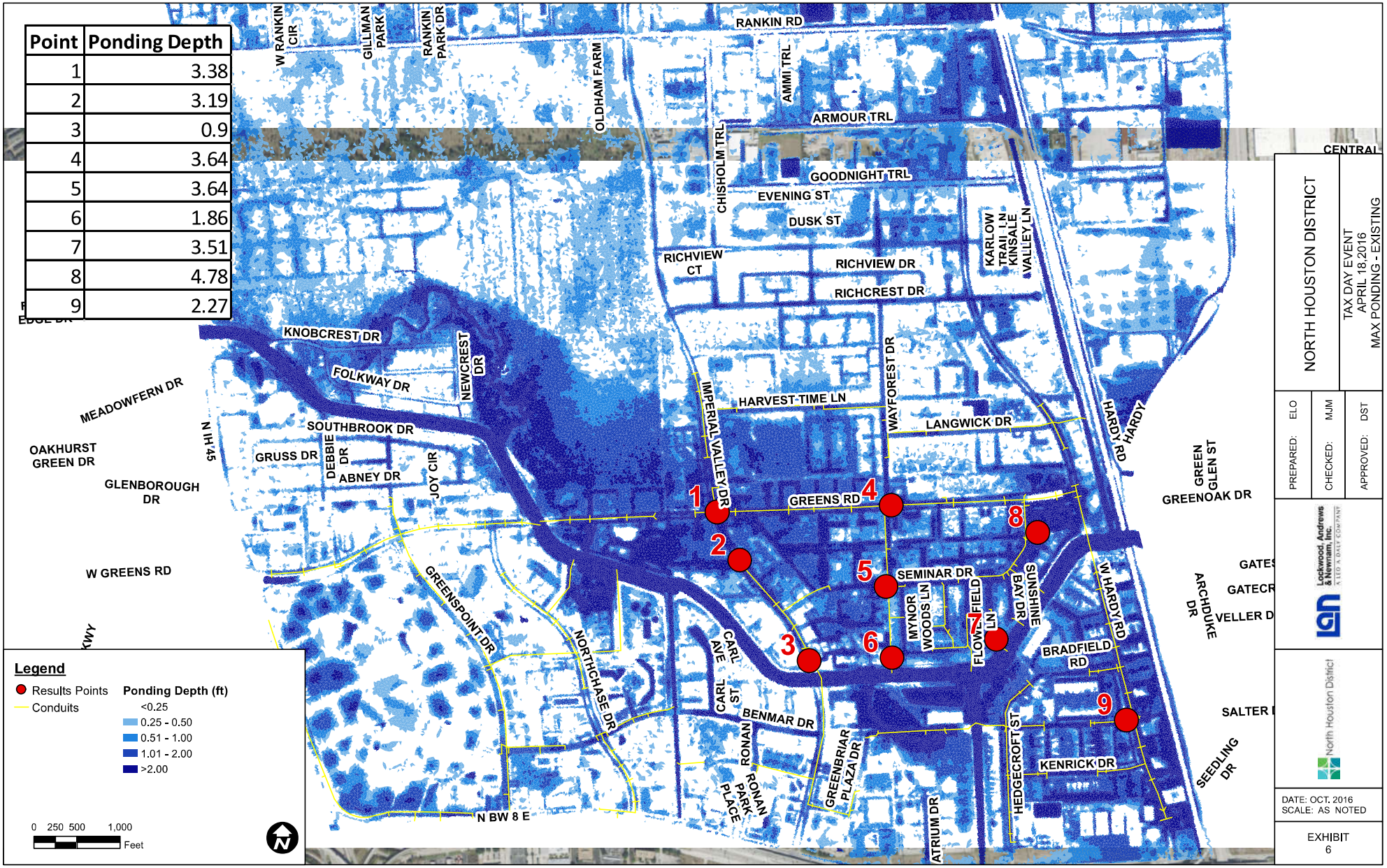
PREPARED: ELO
CHECKED: MJM
APPROVED: DST

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

North Houston District

DATE: OCT. 2016
SCALE: AS NOTED

EXHIBIT
5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3 | 0.9
4 | 3.64
5 | 3.64
6 | 1.86
7 | 3.51
8 | 4.78
9 | 2.27
RANKIN RD
W RANKIN CIR
GILLMAN PARK
RANKIN PARK DR
OLDHAM FARM
AMMI TRL
ARMOUR TRL
CHISHOLM TRL
GOODNIGHT TRL
EVENING ST
DUSK ST
RICHVIEW CT
RICHVIEW DR
RICHCREST DR
KARLOW TRAIL LN
KINSALE VALLEY LN
KNOBCREST DR
FOLKWAY DR
NEWCREST DR
MEADOWFERN DR
SOUTHBROOK DR
OAKHURST GREEN DR
GLENBOROUGH DR
GRUSS DR
DEBBIE DR
ABNEY DR
JOY CIR
N IH 45
W GREENS RD
IMPERIAL VALLEY DR
HARVEST-TIME LN
WAYFOREST DR
LANGWICK DR
HARDY RD
GREEN GLEN ST
GREENOAK DR
GREENS RD
SEMINAR DR
SUNSHINE BAY DR
MYNOR WOODS LN
FLOWERFIELD LN
W HARDY RD
BRADFIELD RD
GREENSPOINT DR
NORTHCHASE DR
CARL AVE
CARL ST
BENMAR DR
RONAN PARK PLACE
GREENBRIAR PLAZA DR
HEDGECROFT ST
KENRICK DR
SEEDLING DR
ATRIUM DR
ARCHDUKE DR
VELLER D
GATES
GATECR
SALTER
N BW 8 E
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3
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5
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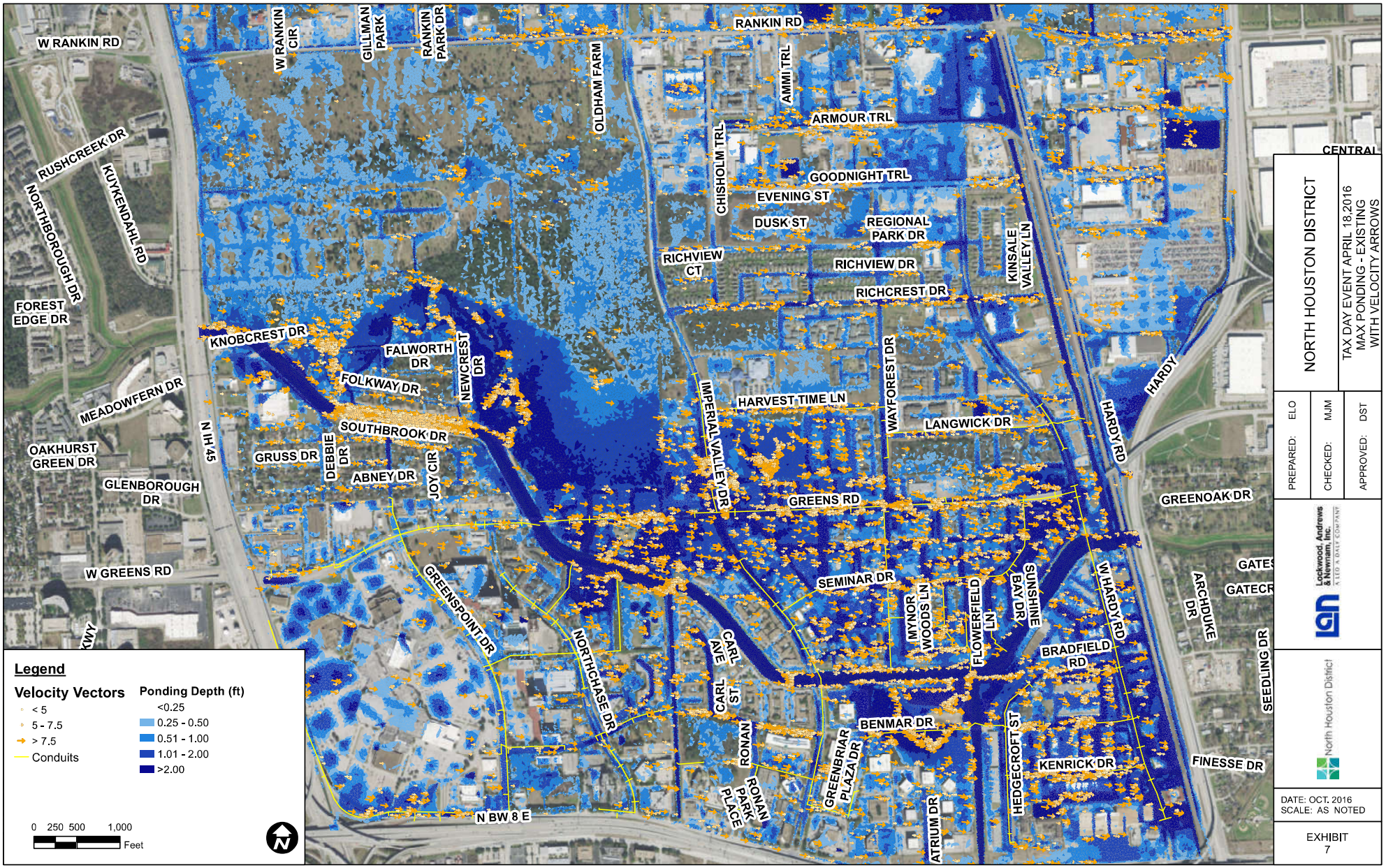
7
8
9
Legend
Results Points
Conduits
Ponding Depth (ft)
<0.25
0.25 - 0.50
0.51 - 1.00
1.01 - 2.00
>2.00
0 250 500 1,000
Feet
NORTH HOUSTON DISTRICT
TAX DAY EVENT
APRIL 18,2016
MAX PONDING - EXISTING
PREPARED: ELO
CHECKED: MJM
APPROVED: DST
Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
North Houston District
DATE: OCT. 2016
SCALE: AS NOTED
EXHIBIT
6


W RANKIN RD
W RANKIN CIR
GILLMAN PARK
RANKIN PARK DR
OLDHAM FARM
RANKIN RD
AMMI TRL
ARMOUR TRL
CHISHOLM TRL
GOODNIGHT TRL
EVENING ST
DUSK ST
REGIONAL PARK DR
RICHVIEW CT
RICHVIEW DR
KINSALE VALLEY LN
RICHCREST DR
RUSHCREEK DR
KUYKENDAHL RD
NORTHBOROUGH DR
FOREST EDGE DR
KNOBCREST DR
FALWORTH DR
NEWCREST DR
FOLKWAY DR
MEADOWFERN DR
N IH 45
SOUTHBROOK DR
OAKHURST GREEN DR
GRUSS DR
DEBBIE DR
ABNEY DR
JOY CIR
GLENBOROUGH DR
IMPERIAL VALLEY DR
HARVEST TIME LN
WAYFOREST DR
LANGWICK DR
HARDY RD
HARDY
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GREENSPOINT DR
SEMINAR DR
MYNOR WOODS LN
SUNSHINE BAY DR
FLOWERFIELD LN
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BRADFIELD RD
ARCHDUKE DR
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NORTHCHASE DR
CARL AVE
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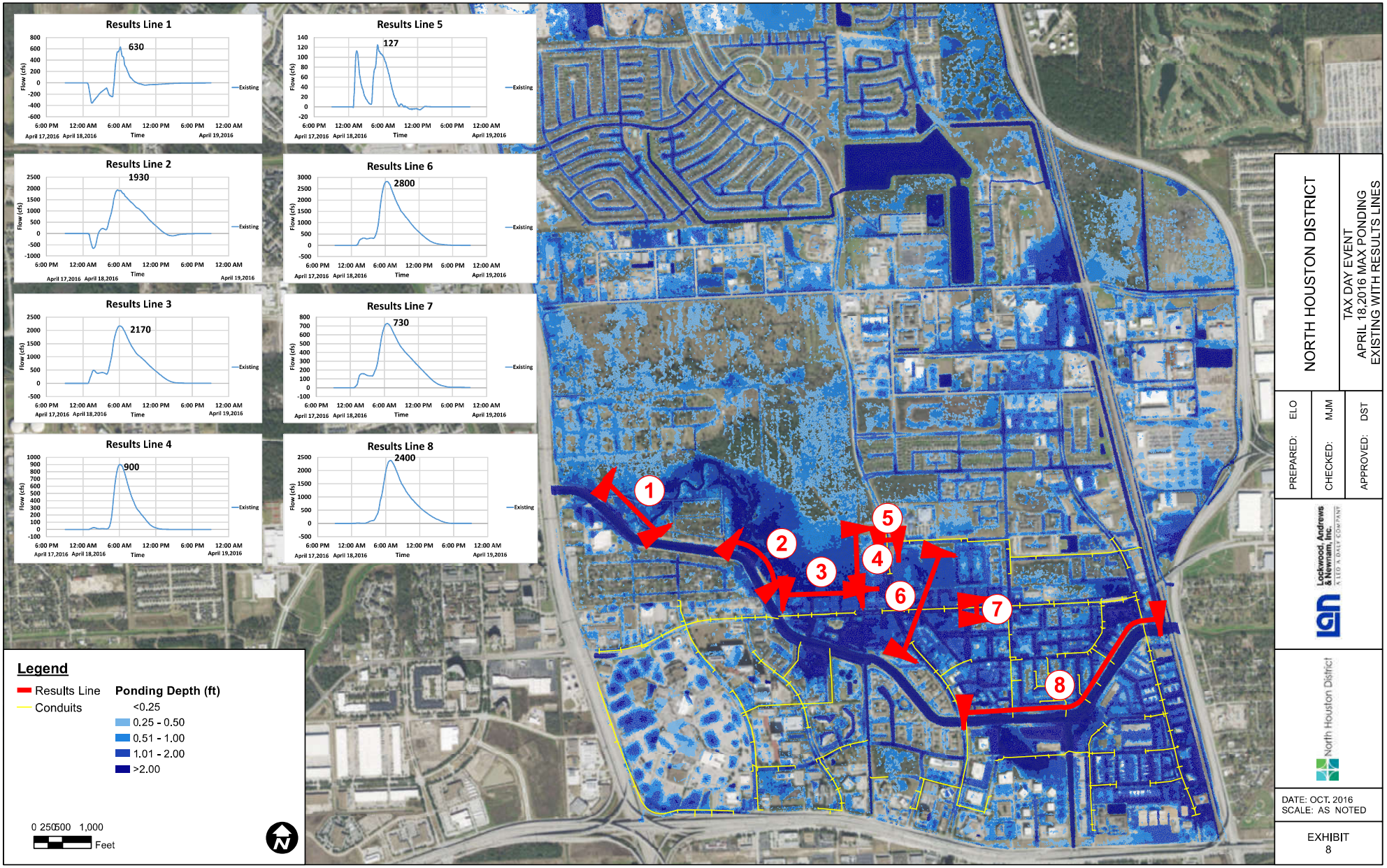
RONAN PARK PLACE
BENMAR DR
GREENBRIAR PLAZA DR
HEDGECROFT ST
KENRICK DR
FINESSE DR
ATRIUM DR
N BW 8 E
Legend
Velocity Vectors
< 5
5 - 7.5
> 7.5
Conduits
Ponding Depth (ft)
<0.25
0.25 - 0.50
0.51 - 1.00
1.01 - 2.00
>2.00
0 250 500 1,000
Feet
CENTRAL
NORTH HOUSTON DISTRICT
TAX DAY EVENT APRIL 18,2016
MAX PONDING - EXISTING
WITH VELOCITY ARROWS
PREPARED: ELO
CHECKED: MJM
APPROVED: DST
Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
North Houston District
DATE: OCT. 2016
SCALE: AS NOTED
EXHIBIT
7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6:00 PM 12:00 AM 6:00 AM 12:00 PM 6:00 PM 12:00 AM
April 17,2016 April 18,2016 Time April 19,2016
Results Line 5
127
Results Line 2
1930
Results Line 6
2800
Results Line 3
2170
Results Line 7
730
Results Line 4
900
Results Line 8
2400
1
2
3
4
5
6
7
8
Legend
Results Line
Conduits
Ponding Depth (ft)
<0.25
0.25 - 0.50
0.51 - 1.00
1.01 - 2.00
>2.00
0 250 500 1,000
Feet
NORTH HOUSTON DISTRICT
TAX DAY EVENT
APRIL 18,2016 MAX PONDING
EXISTING WITH RESULTS LINES
PREPARED: ELO
CHECKED: MJM
APPROVED: DST
Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
North Houston District
DATE: OCT. 2016
SCALE: AS NOTED
EXHIBIT
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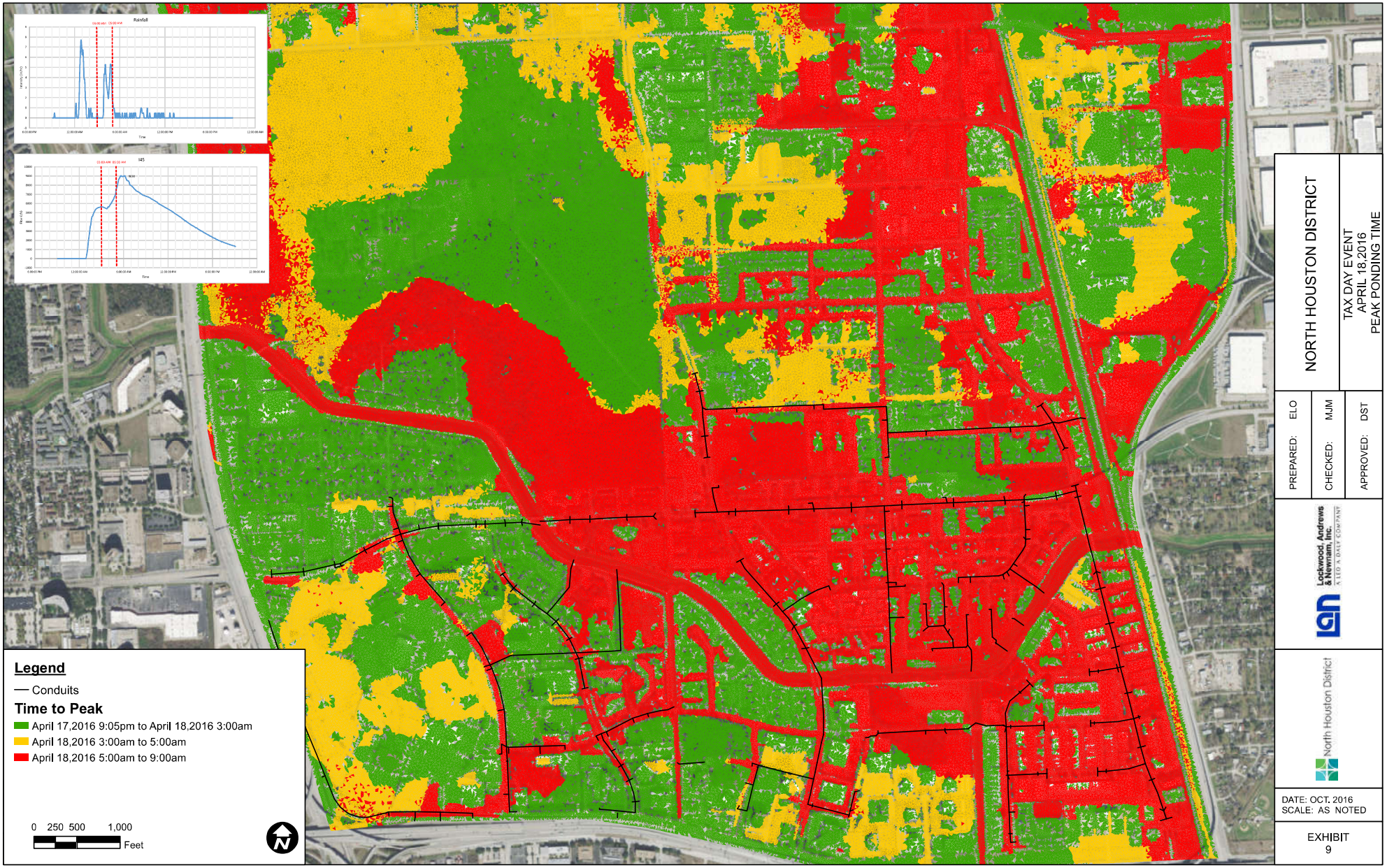


NORTH HOUSTON DISTRICT

TAX DAY EVENT
APRIL 18,2016
PEAK PONDING TIME

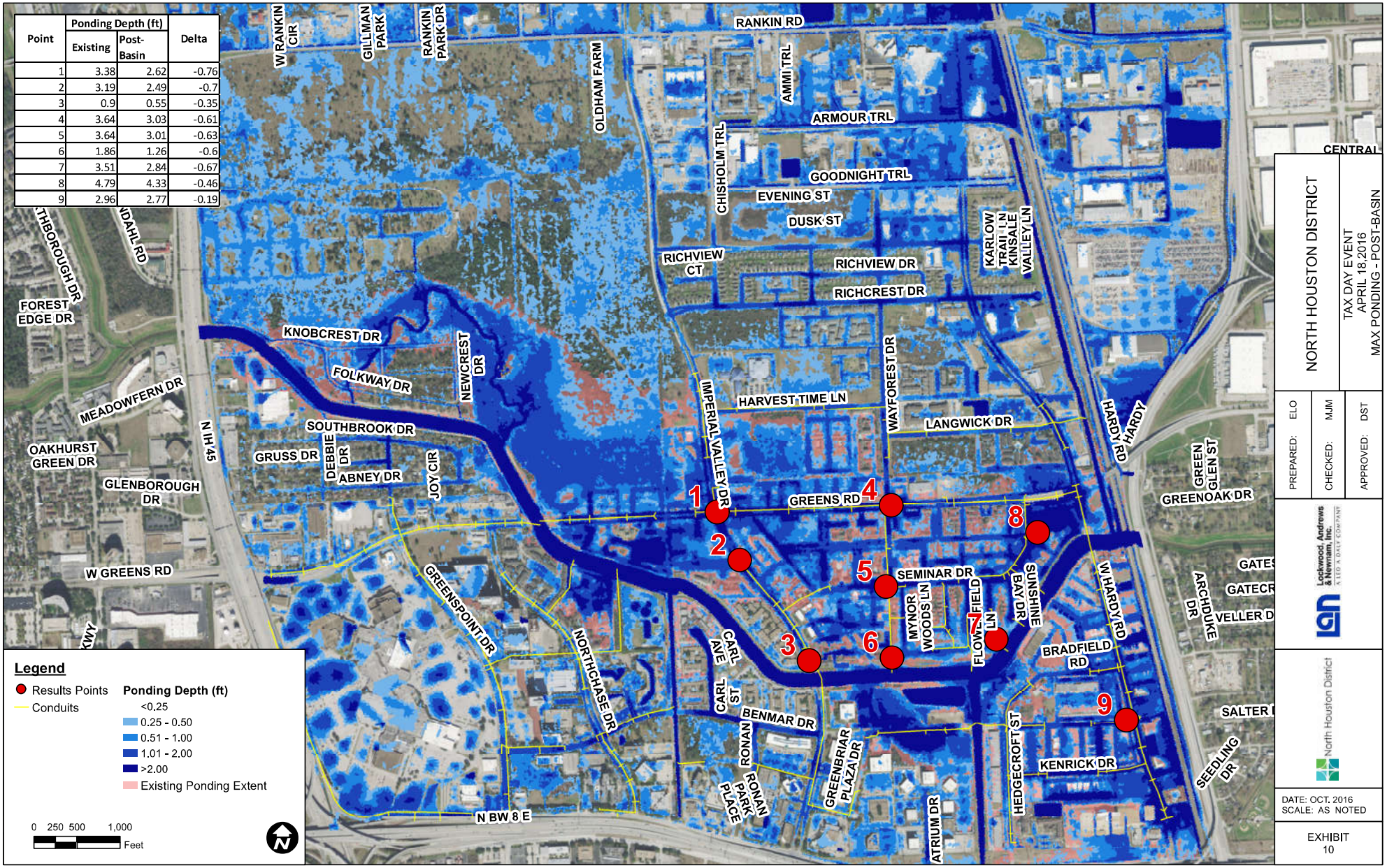
PREPARED: ELO
CHECKED: MJM
APPROVED: DST

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

North Houston District

DATE: OCT. 2016
SCALE: AS NOTED

EXHIBIT
9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Ponding Depth (ft)
Existing
Post-Basin
Delta
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2 3.19 2.49 -0.7
3 0.9 0.55 -0.35
4 3.64 3.03 -0.61
5 3.64 3.01 -0.63
6 1.86 1.26 -0.6
7 3.51 2.84 -0.67
8 4.79 4.33 -0.46
9 2.96 2.77 -0.19
RANKIN RD
W RANKIN CIR
GILLMAN PARK
RANKIN PARK DR
OLDHAM FARM
AMMI TRL
ARMOUR TRL
CHISHOLM TRL
GOODNIGHT TRL
EVENING ST
DUSK ST
KARLOW TRAIL LN
KINSALE VALLEY LN
RICHVIEW CT
RICHVIEW DR
RICHCREST DR
FOREST EDGE DR
KNOBCREST DR
FOLKWAY DR
NEWCREST DR
IMPERIAL VALLEY DR
HARVEST TIME LN
WAYFOREST DR
LANGWICK DR
HARDY RD
MEADOWFERN DR
N IH 45
SOUTHBROOK DR
DEBBIE DR
GRUSS DR
ABNEY DR
JOY CIR
OAKHURST GREEN DR
GLENBOROUGH DR
GREENS RD
GREEN GLEN ST
GREENOAK DR
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GREENSPOINT DR
NORTHCHASE DR
SEMINAR DR
MYNOR WOODS LN
SUNSHINE BAY DR
FLOWERFIELD LN
W HARDY RD
BRADFIELD RD
CARL AVE
CARL ST
BENMAR DR
RONAN
RONAN PARK PLACE
GREENBRIAR PLAZA DR
HEDGECROFT ST
KENRICK DR
SEEDLING DR
ATRIUM DR
N BW 8 E
ARCHDUKE DR
VELLER D
SALTER
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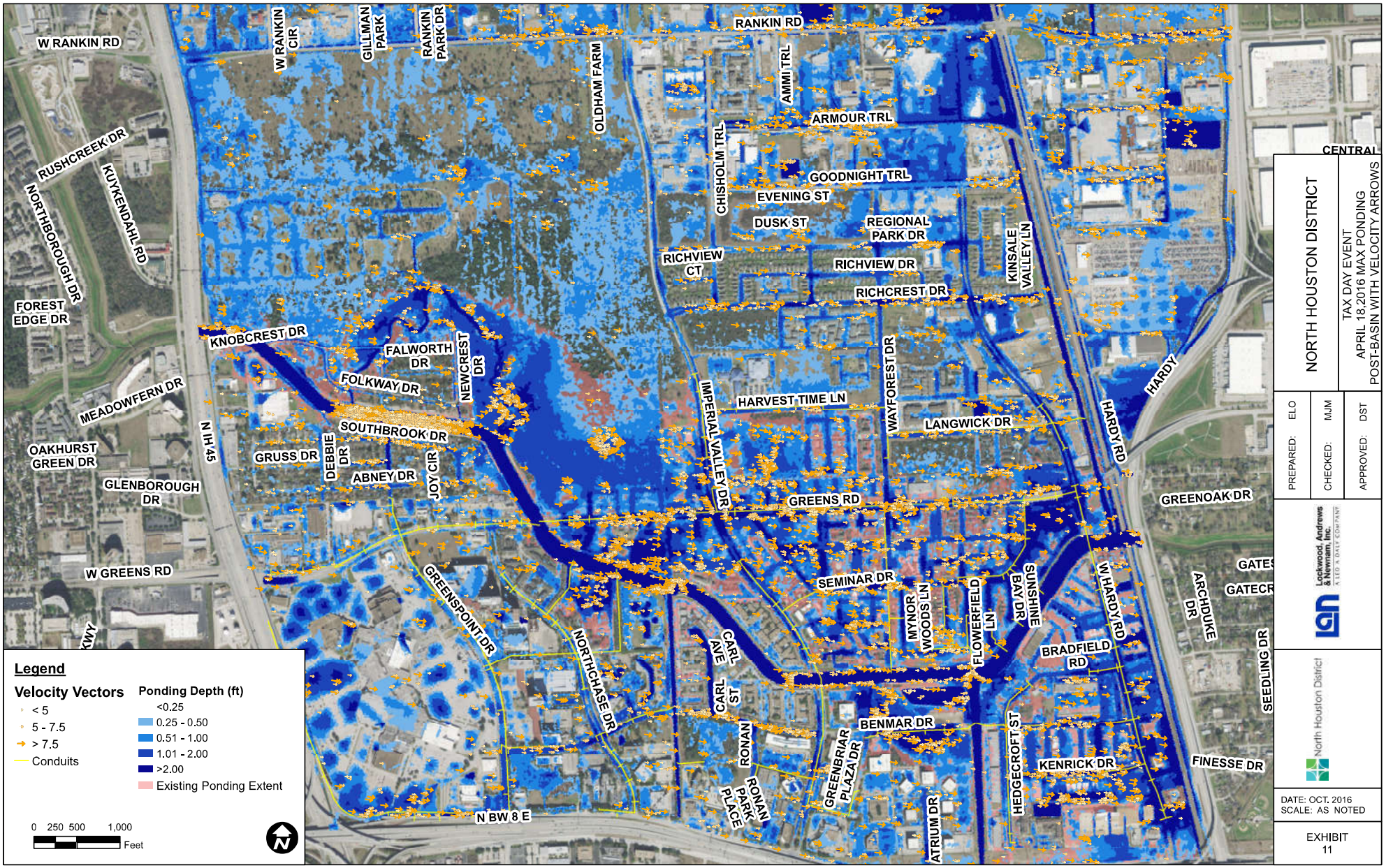
8
9
Legend
Results Points
Conduits
Ponding Depth (ft)
<0.25
0.25 - 0.50
0.51 - 1.00
1.01 - 2.00
>2.00
Existing Ponding Extent
0 250 500 1,000
Feet
CENTRAL
NORTH HOUSTON DISTRICT
TAX DAY EVENT
APRIL 18 2016
MAX PONDING - POST-BASIN
PREPARED: ELO
CHECKED: MJM
APPROVED: DST
Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
North Houston District
DATE: OCT. 2016
SCALE: AS NOTED
EXHIBIT
10



Legend

Velocity Vectors
- < 5
- 5 - 7.5
- > 7.5
- Conduits

Ponding Depth (ft)
- <0.25
- 0.25 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00
- >2.00
- Existing Ponding Extent

0 250 500 1,000 Feet

NORTH HOUSTON DISTRICT

TAX DAY EVENT
APRIL 18,2016 MAX PONDING
POST-BASIN WITH VELOCITY ARROWS

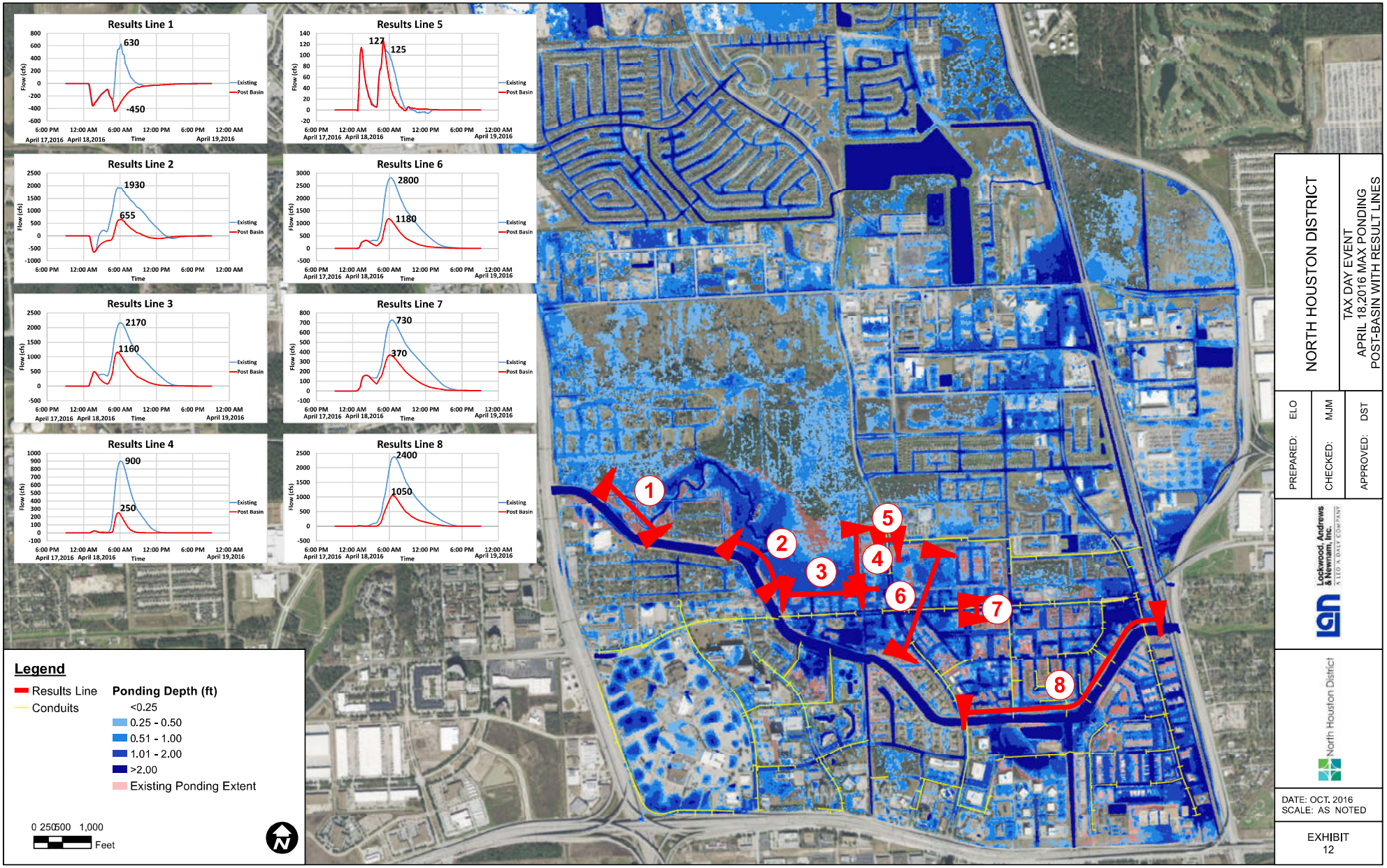
PREPARED:	ELO	
CHECKED:	MJM	
APPROVED:	DST	

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

North Houston District

DATE: OCT. 2016
SCALE: AS NOTED

EXHIBIT
11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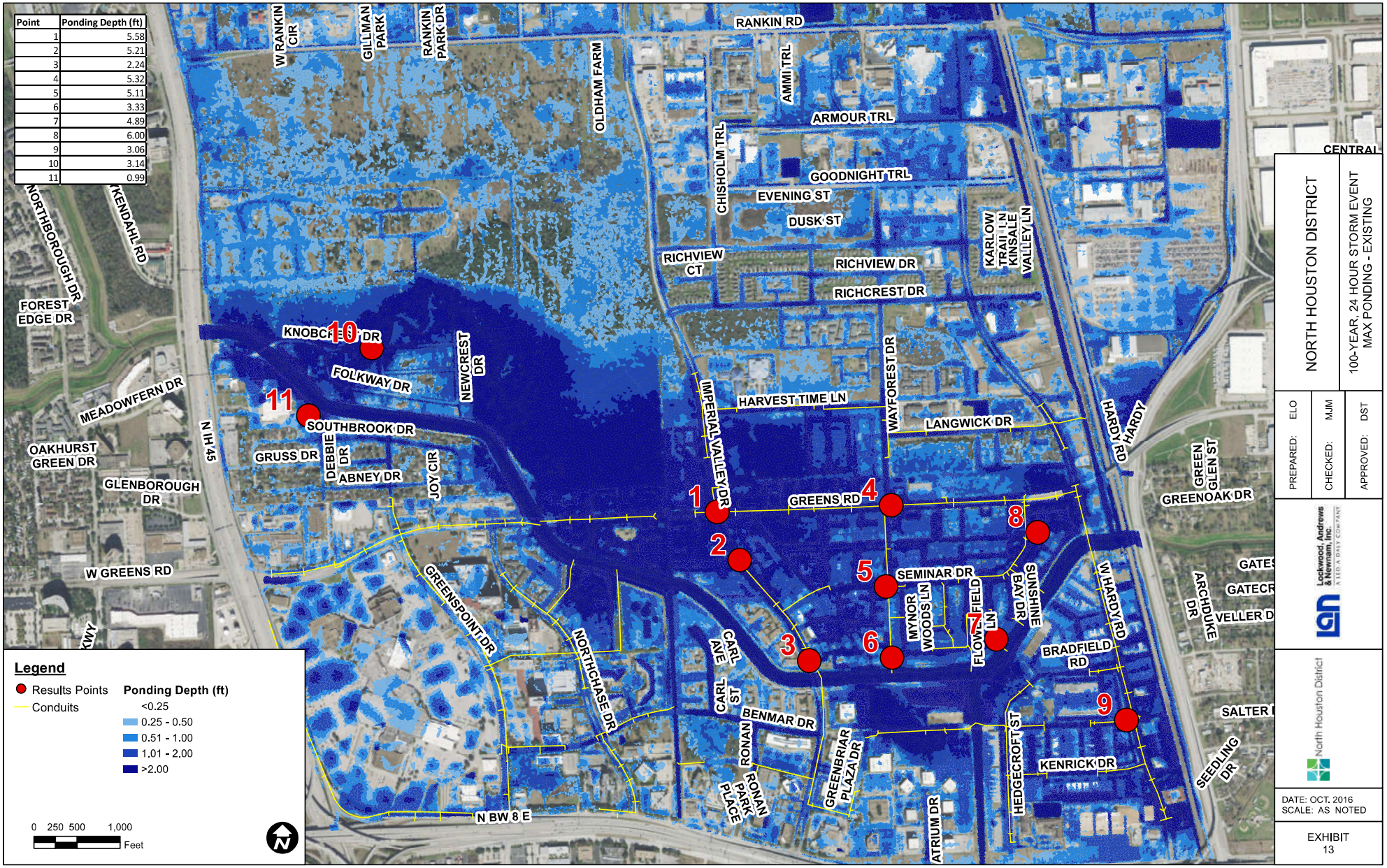
630
-450
Results Line 2
1930
655
Results Line 3
2170
1160
Results Line 4
900
250
Results Line 5
127
125
Results Line 6
2800
1180
Results Line 7
730
370
Results Line 8
2400
1050
Flow (cfs)
Time
Existing
Post Basin
6:00 PM
12:00 AM
6:00 AM
12:00 PM
April 17,2016
April 18,2016
April 19,2016
1
2
3
4
5
6
7
8
Legend
Results Line
Conduits
Ponding Depth (ft)
<0.25
0.25 - 0.50
0.51 - 1.00
1.01 - 2.00
>2.00
Existing Ponding Extent
0 250500 1,000
Feet
NORTH HOUSTON DISTRICT
TAX DAY EVENT
APRIL 18,2016 MAX PONDING
POST-BASIN WITH RESULT LINES
PREPARED: ELO
CHECKED: MJM
APPROVED: DST
Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
North Houston District
DATE: OCT. 2016
SCALE: AS NOTED
EXHIBIT
12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5 | 5.11
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7 | 4.89
8 | 6.00
9 | 3.06
10 | 3.14
11 | 0.99
RANKIN RD
W RANKIN CIR
GILLMAN PARK
RANKIN PARK DR
OLDHAM FARM
AMMI TRL
ARMOUR TRL
CHISHOLM TRL
GOODNIGHT TRL
EVENING ST
DUSK ST
RICHVIEW CT
RICHVIEW DR
RICHCREST DR
KARLOW TRAIL LN
KINSALE VALLEY LN
NORTHBOROUGH DR
KENDAHL RD
FOREST EDGE DR
KNOBCREEK DR
FOLKWAY DR
NEWCREST DR
MEADOWFERN DR
SOUTHBROOK DR
OAKHURST GREEN DR
GRUSS DR
DEBBIE DR
ABNEY DR
JOY CIR
GLENBOROUGH DR
N IH 45
W GREENS RD
GREENSPOINT DR
IMPERIAL VALLEY DR
HARVEST TIME LN
WAYFOREST DR
LANGWICK DR
GREENS RD
SEMINAR DR
MYNOR WOODS LN
SUNSHINE BAY DR
FLOWERFIELD LN
HARDY RD
GREEN GLEN ST
GREENOAK DR
GATES
GATECR
ARCHDUKE DR
VELLER D
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BRADFIELD RD
SALTER
SEEDLING DR
KENRICK DR
HEDGECROFT ST
NORTHCHASE DR
CARL AVE
CARL ST
BENMAR DR
RONAN
RONAN PARK PLACE
GREENBRIAR PLAZA DR
ATRIUM DR
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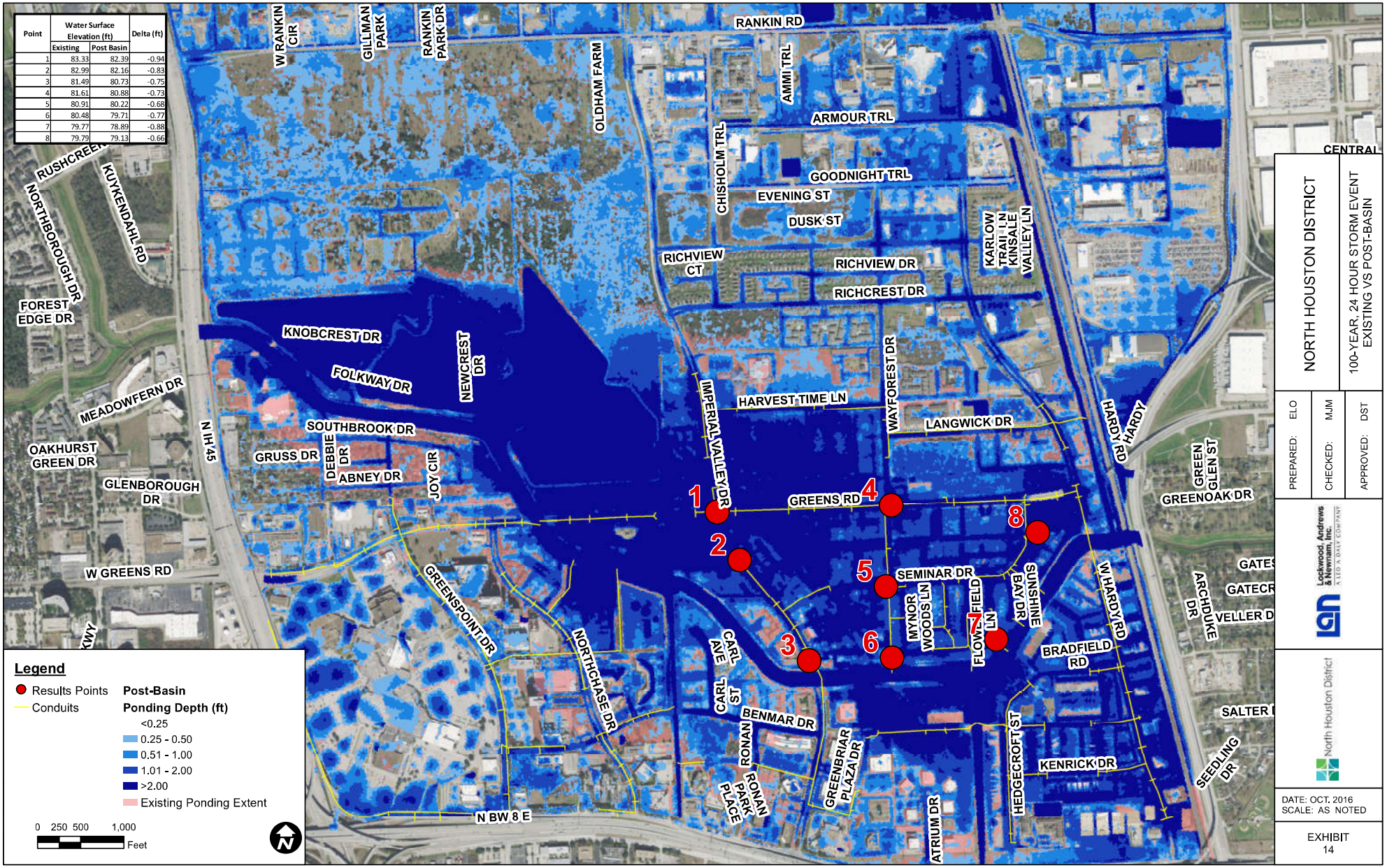
11
Legend
Results Points
Conduits
Ponding Depth (ft)
<0.25
0.25 - 0.50
0.51 - 1.00
1.01 - 2.00
>2.00
0 250 500 1,000
Feet
CENTRAL
NORTH HOUSTON DISTRICT
100-YEAR, 24 HOUR STORM EVENT
MAX PONDING - EXISTING
PREPARED: ELO
CHECKED: MJM
APPROVED: DST
Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
North Houston District
DATE: OCT. 2016
SCALE: AS NOTED
EXHIBIT
13


Point
Water Surface Elevation (ft)
Existing
Post Basin
Delta (ft)
1 83.33 82.39 -0.94
2 82.99 82.16 -0.83
3 81.49 80.73 -0.75
4 81.61 80.88 -0.73
5 80.91 80.22 -0.68
6 80.48 79.71 -0.77
7 79.77 78.89 -0.88
8 79.79 79.13 -0.66
RANKIN RD
W RANKIN CIR
GILLMAN PARK
RANKIN PARK DR
OLDHAM FARM
AMMI TRL
ARMOUR TRL
CHISHOLM TRL
GOODNIGHT TRL
EVENING ST
DUSK ST
RICHVIEW CT
RICHVIEW DR
RICHCREST DR
KARLOW TRAIL LN
KINSALE VALLEY LN
RUSHCREEK
KUYKENDAHL RD
NORTHBOROUGH DR
FOREST EDGE DR
KNOBCREST DR
FOLKWAY DR
NEWCREST DR
MEADOWFERN DR
OAKHURST GREEN DR
GLENBOROUGH DR
N IH 45
SOUTHBROOK DR
GRUSS DR
DEBBIE DR
ABNEY DR
JOY CIR
IMPERIAL VALLEY DR
HARVEST TIME LN
WAYFOREST DR
LANGWICK DR
HARDY RD
GREEN GLEN ST
GREENOAK DR
GREENS RD
W GREENS RD
GREENSPOINT DR
NORTHCHASE DR
CARL AVE
CARL ST
BENMAR DR
RONAN
RONAN PARK PLACE
GREENBRIAR PLAZA DR
N BW 8 E
SEMINAR DR
MYNOR WOODS LN
SUNSHINE BAY DR
FLOWERFIELD LN
W HARDY RD
BRADFIELD RD
HEDGECROFT ST
KENRICK DR
ATRIUM DR
SEEDLING DR
ARCHDUKE DR
VELLER D
SALTER
GATES
GATECR
CENTRAL
1
2
3
4
5
6
7
8
Legend
Results Points
Conduits
Post-Basin Ponding Depth (ft)
<0.25
0.25 - 0.50
0.51 - 1.00
1.01 - 2.00
>2.00
Existing Ponding Extent
0 250 500 1,000
Feet
N
NORTH HOUSTON DISTRICT
100-YEAR, 24 HOUR STORM EVENT
EXISTING VS POST-BASIN
PREPARED: ELO
CHECKED: MJM
APPROVED: DST
Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
North Houston District
DATE: OCT. 2016
SCALE: AS NOTED
EXHIBIT
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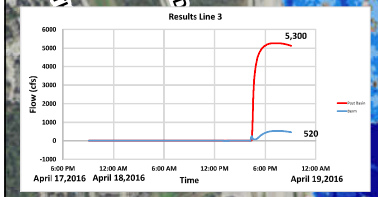
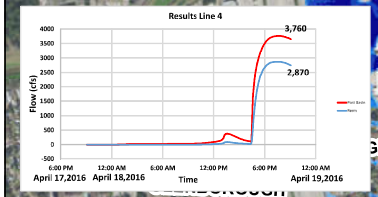
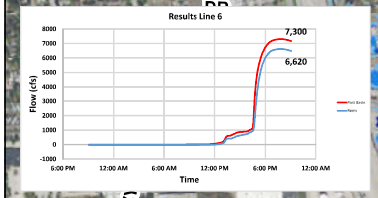
Point	Ponding Depth (ft)		Delta
	Post-Basin	Post-Basin W/Berm	
1	4.72	4.59	-0.13
2	4.7	4.56	-0.14
3	2.41	2.33	-0.08
4	4.58	4.49	-0.09
5	4.5	4.35	-0.15
6	2.51	2.46	-0.05
7	3.98	4.04	0.06
8	5.35	5.31	-0.04
9	3.16	3.15	-0.01
10	2.52	3.12	0.6
11	0.51	0.85	0.34







Legend

- Results Line
- Results Points
- Conduits

Post Basin W/ Berm Ponding Depth (ft)

- <0.25
- 0.25 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00
- >2.00
- Post-Basin Ponding Extent

0 250 500 1,000 Feet

NORTH HOUSTON DISTRICT

100-YEAR, 24 HOUR STORM EVENT
POST-BASIN VS
POST-BASIN W/ BERM

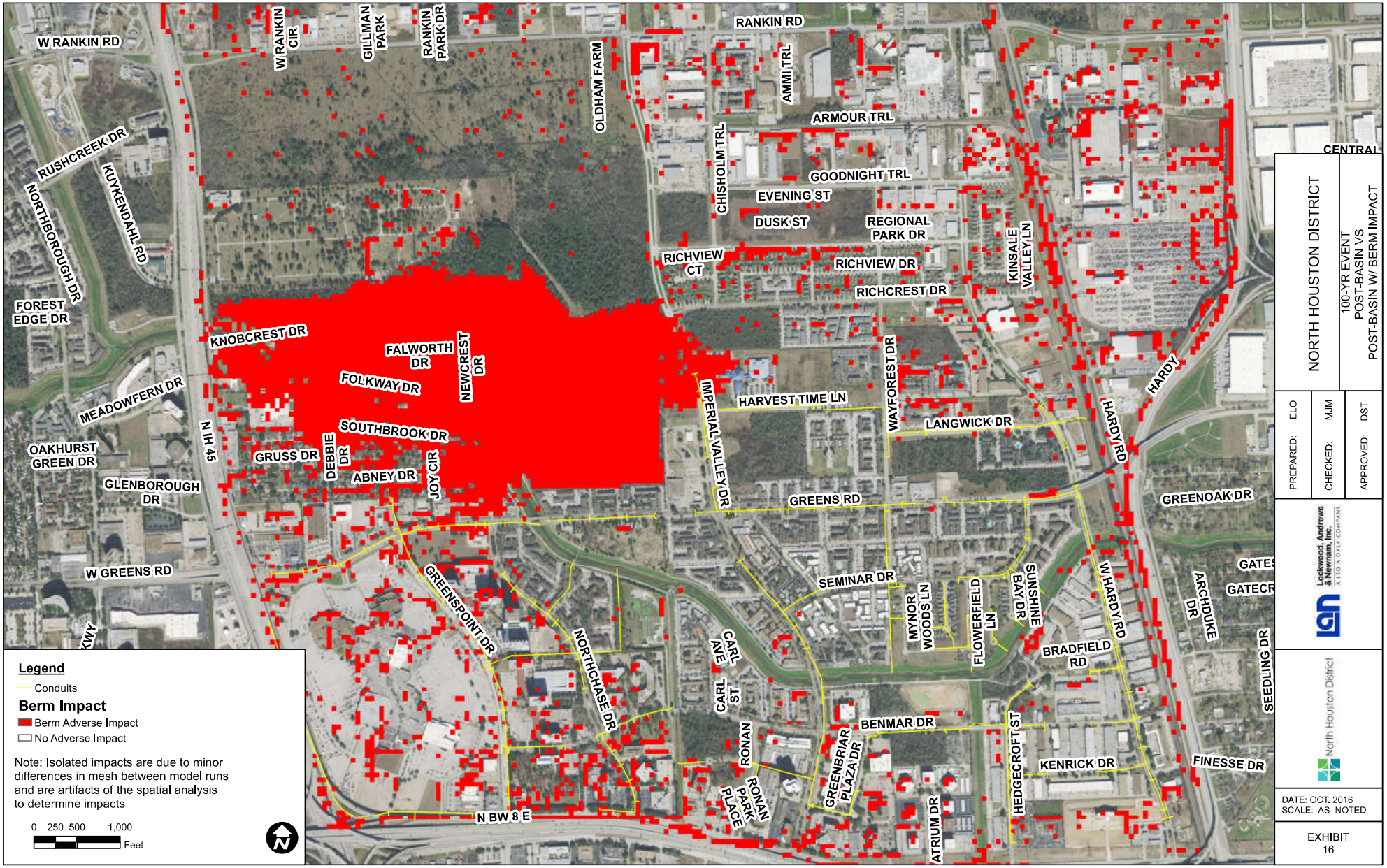
PREPARED: ELO
CHECKED: MJM
APPROVED: DST

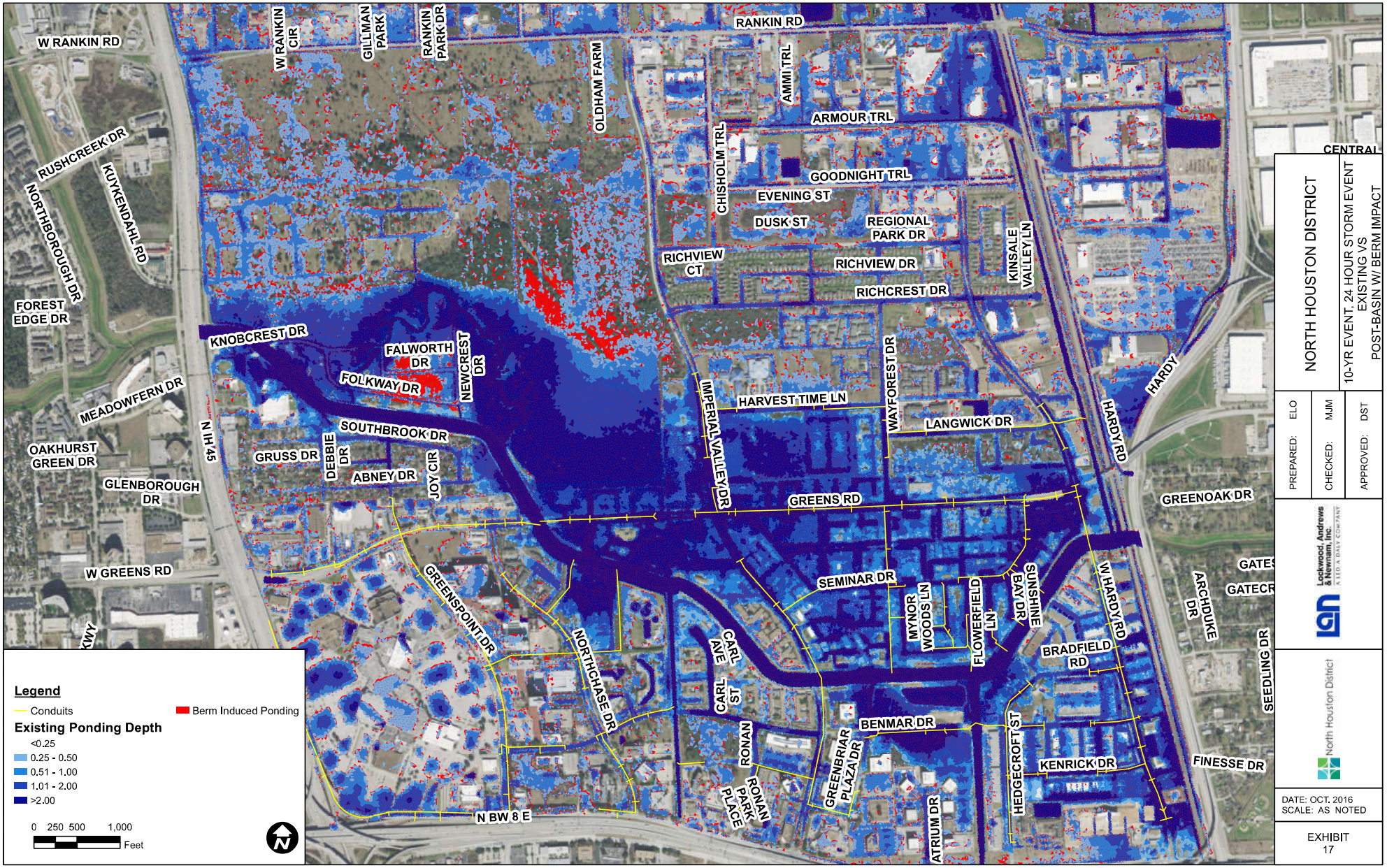
Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY

North Houston District

DATE: OCT. 2016
SCALE: AS NOTED

EXHIBIT
15


W RANKIN RD
W RANKIN CIR
GILLMAN PARK
RANKIN PARK DR
OLDHAM FARM
RANKIN RD
AMMI TRL
ARMOUR TRL
CHISHOLM TRL
GOODNIGHT TRL
EVENING ST
DUSK ST
REGIONAL PARK DR
RICHVIEW CT
RICHVIEW DR
RICHCREST DR
KINSALE VALLEY LN
RUSHCREEK DR
KUYKENDAHL RD
NORTHBOROUGH DR
FOREST EDGE DR
KNOBCREST DR
FALWORTH DR
NEWCREST DR
FOLKWAY DR
MEADOWFERN DR
N IH 45
SOUTHBROOK DR
GRUSS DR
DEBBIE DR
ABNEY DR
JOY CIR
OAKHURST GREEN DR
GLENBOROUGH DR
IMPERIAL VALLEY DR
HARVEST TIME LN
WAYFOREST DR
LANGWICK DR
HARDY RD
HARDY
GREENS RD
GREENOAK DR
W GREENS RD
GREENSPOINT DR
SEMINAR DR
NORTHCHASE DR
CARL AVE
CARL ST
MYNOR WOODS LN
FLOWERFIELD LN
SUNSHINE BAY DR
W HARDY RD
BRADFIELD RD
ARCHDUKE DR
SEEDLING DR
BENMAR DR
RONAN
RONAN PARK PLACE
GREENBRIAR PLAZA DR
HEDGECROFT ST
KENRICK DR
FINESSE DR
ATRIUM DR
N BW 8 E
CENTRAL
GATES
GATECR
Legend
Conduits
Berm Impact
Berm Adverse Impact
No Adverse Impact
Note: Isolated impacts are due to minor differences in mesh between model runs and are artifacts of the spatial analysis to determine impacts
0 250 500 1,000
Feet
NORTH HOUSTON DISTRICT
100-YR EVENT
POST-BASIN VS
POST-BASIN W/ BERM IMPACT
PREPARED: ELO
CHECKED: MJM
APPROVED: DST
Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
North Houston District
DATE: OCT. 2016
SCALE: AS NOTED
EXHIBIT
16


W RANKIN RD
W RANKIN CIR
GILLMAN PARK
RANKIN PARK DR
OLDHAM FARM
RANKIN RD
AMMI TRL
ARMOUR TRL
CHISHOLM TRL
GOODNIGHT TRL
EVENING ST
DUSK ST
REGIONAL PARK DR
RICHVIEW CT
RICHVIEW DR
RICHCREST DR
KINSALE VALLEY LN
RUSHCREEK DR
KUYKENDAHL RD
NORTHBOROUGH DR
FOREST EDGE DR
KNOBCREST DR
FALWORTH DR
NEWCREST DR
FOLKWAY DR
MEADOWFERN DR
N IH 45
SOUTHBROOK DR
OAKHURST GREEN DR
GRUSS DR
DEBBIE DR
ABNEY DR
JOY CIR
GLENBOROUGH DR
IMPERIAL VALLEY DR
HARVEST TIME LN
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GREENOAK DR
W GREENS RD
GREENSPOINT DR
NORTHCHASE DR
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SEEDLING DR
CARL AVE
CARL ST
RONAN
RONAN PARK PLACE
BENMAR DR
GREENBRIAR PLAZA DR
HEDGECROFT ST
KENRICK DR
FINESSE DR
ATRIUM DR
N BW 8 E
Legend
Conduits
Berm Induced Ponding
Existing Ponding Depth
<0.25
0.25 - 0.50
0.51 - 1.00
1.01 - 2.00
>2.00
0 250 500 1,000
Feet
CENTRAL
NORTH HOUSTON DISTRICT
10-YR EVENT, 24 HOUR STORM EVENT
EXISTING VS
POST-BASIN W/ BERM IMPACT
PREPARED: ELO
CHECKED: MJM
APPROVED: DST
Lockwood, Andrews & Newnam, Inc.
A LEO A DALY COMPANY
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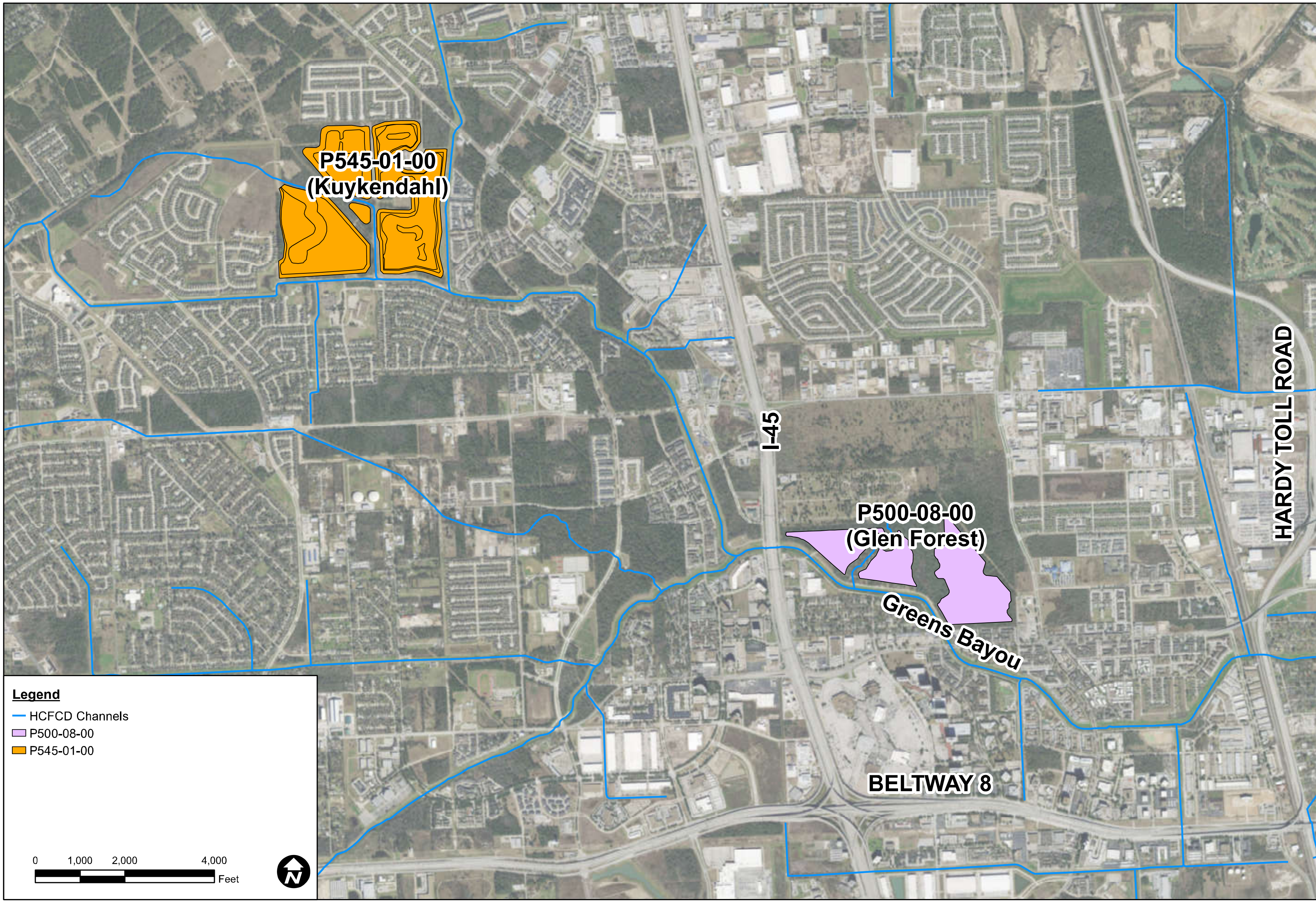

NORTH HOUSTON DISTRICT

P545-01-00 and P500-08-00
REGIONAL DETENTION BASIN LOCATION

PREPARED: ELO
CHECKED: MJM
APPROVED: DST

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

North Houston District

DATE: OCT. 2016
SCALE: AS NOTED

EXHIBIT
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