TPW Stormwater Management 200
Texas Street Fort Worth, TX 76102

Cumulative Impacts Analysis

City of Fort Worth Project No. SWS-087

February 16, 2022

TETRA TECH

LIVABLE PLANS & CODES

CONTENTS

1.0 Introduction

A recurring complaint in the City of Fort Worth is that new developments are creating adverse impacts to existing nearby developments. These situations continue to occur despite rigorous drainage review efforts, and the complaints are being elevated to City leadership and Plan/Zoning Commissions. The City has an established methodology to evaluate cumulative impacts in the "Ultimate Development Conditions" hydrologic design standards, defined as full build-out of the entire drainage basin as anticipated by land use zoning adopted at the time of that analysis. However, the City's zoning regulations allow the possibility of more impervious surface area than is accounted for in the Ultimate Development Conditions. There is concern that current procedures may not be adequate to mitigate the cumulative impacts of development on flooding. Analysis is therefore needed to assess whether modifications in procedures used for cumulative impact evaluation are needed.

Tetra Tech was contracted by the City to study the impacts of changes in impervious cover on stormwater runoff volumes and peak flows in two developed watersheds - Central Arlington Heights (CAH) and Near West Side Linwood/Bailey's Industrial Area (LB), shown in Figure 1.

CAH is an older "fully developed" basin experiencing changes in runoff volumes and peak flood flows due to changes in impervious cover not reflected in Zoning or current Drainage Design standards. Infill development and redevelopment to more dense land uses, and developments below the 1.0-acre design review threshold are frequent complaints. Flooding is also frequent in this area due to the undersized storm drain system.

The LB basin drains to a levee sump area along the West Fork Trinity River, fully developed since the 1950s. This area is currently experiencing rapid redevelopment and gentrification due to its proximity to Downtown Fort Worth and the Trinity River Vision project. Existing commercial and industrial developments are being repurposed into mixed use and multifamily residential developments. Drainage in this area is also compromised by flap gates on outfalls that close when the West Fork Trinity River flood elevation is high. Therefore, additional runoff volumes have the potential to impact affected properties for extended periods until the river levels drop.

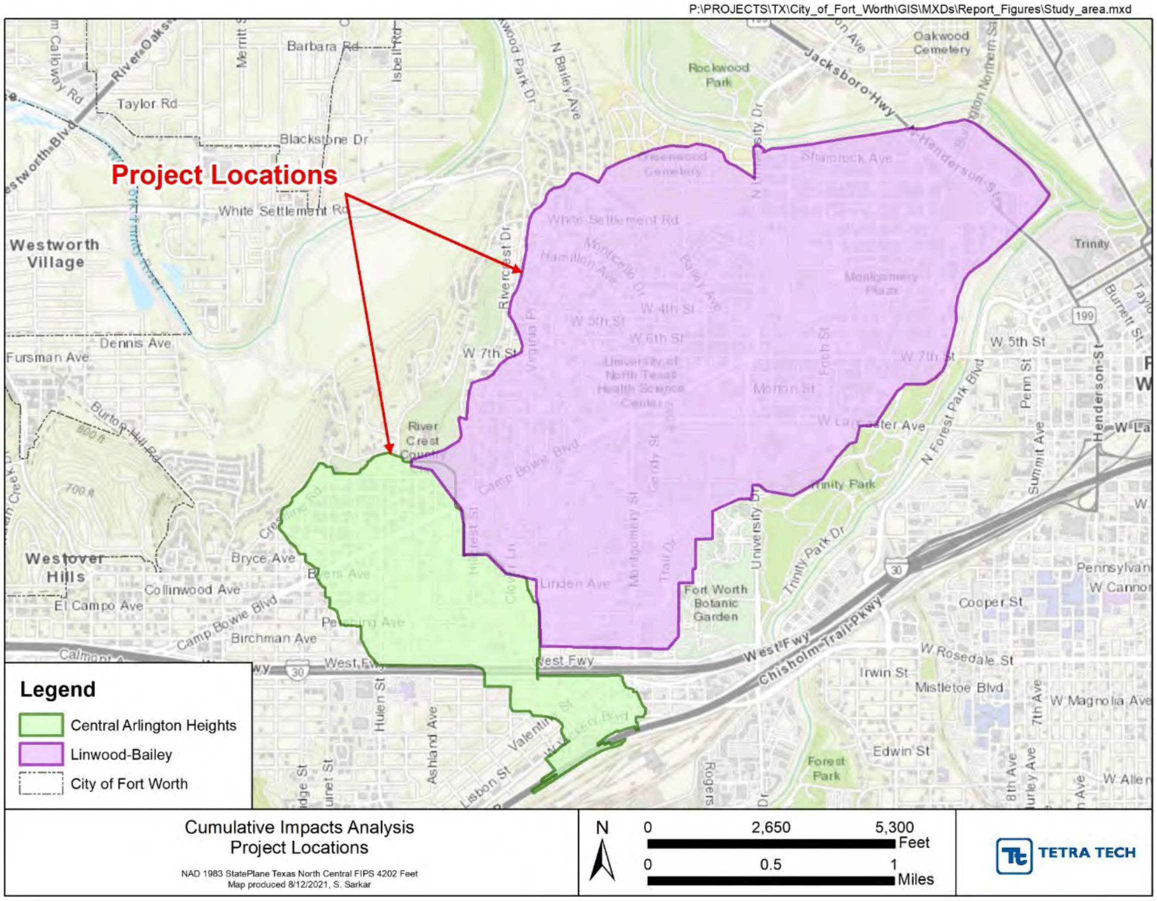

Figure 1. Cumulative Impacts Analysis Study Areas.

Cumulative hydrologic impacts were assessed for three (3) impervious cover scenarios as defined under Task 3 - Impervious Cover Development of the Statement of Work (SOW) for this project (SWS-087). Hydrology and Hydraulic (H&H) models were developed for the two watersheds and cumulative hydrologic impacts were analyzed for the three (3) impervious cover Scenarios, as described in Task 4 - Hydrology and Hydraulics Modeling of the SOW.

2.0 Impervious Cover Development

Scenario 1 - Baseline Impervious Coverage

For each case study area (CAH and LB watersheds), a baseline condition percent impervious cover was established using the City's existing impervious cover dataset and aerial photographs. The existing impervious cover dataset was developed by the City by combining various layers digitized by the City including the impervious cover for stormwater billing, edge-of-pavement, and sidewalk datasets. The existing impervious cover dataset also incorporates an infrared analysis of the 2014 Seamless Image Database (SID) aerial photographs. The City's existing impervious cover dataset was checked for accuracy against 2020 aerial photographs and edited as necessary. Some typical inconsistencies observed between the existing impervious cover dataset and the aerial photographs that were addressed as part of Scenario 1 are as follows -

1) New developments - As noted above, the City's impervious coverage dataset uses 2014 aerial photographs. However, several developments and re-developments have occurred since 2014 and are visible in the 2020 aerial photographs (typical example shown in Figure 2). We, therefore, revised the City's impervious coverage dataset to represent the impervious areas associated with these new developments. The City's building permits and building footprints layers were also used to make informed decisions on new developments and their associated impervious footprints.

Figure 2. City's Existing Impervious Coverage (left) and Edited Coverage (right) for a New Development.

2) Pervious areas characterized as impervious - Based on the examination of the City's impervious coverage and the 2020 aerial photographs, it was evident that some pervious areas such as parks and trails, and areas adjacent to roads and highways were characterized as impervious (typical example shown in Figure 3). We revised the existing impervious coverage dataset to remove such pervious areas from the impervious coverage.

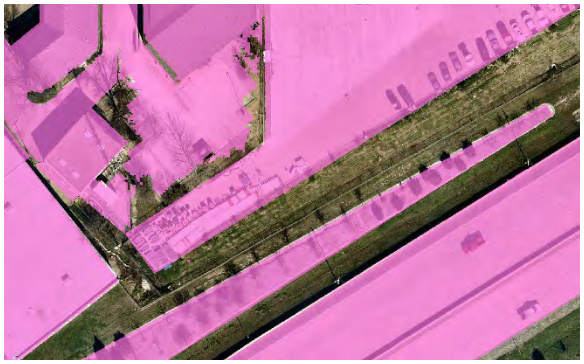

Figure 3. Pervious Areas Characterized as Impervious (left) and Edited Coverage (right) for a Selected Location.

Existing impervious areas and percent imperviousness at the parcel-scale for the CAH are shown in Figure 4 and Figure 5, respectively. Impervious areas and parcel-scale percent imperviousness for the LB watershed are depicted in Figure 6 and Figure 7, respectively.

Note that an effort was undertaken to remove any major inconsistencies in the City's impervious coverage based on visual comparisons with 2020 aerial photographs. However, given the manual nature of the process, minor inconsistencies are still expected in the revised impervious coverage dataset. Such minor inconsistencies are not expected to have significant impacts on the hydrologic impacts analysis at the catchment scale.

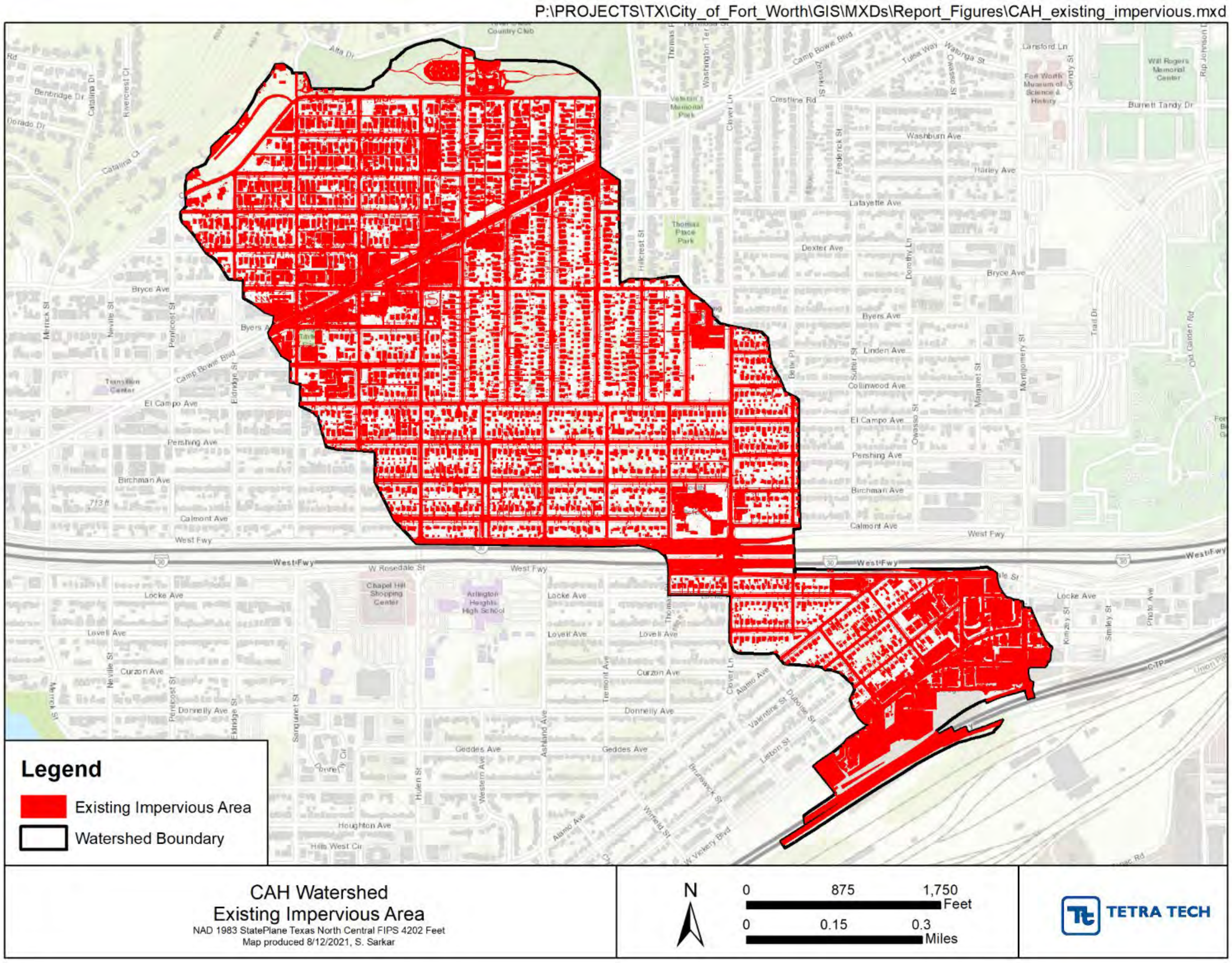

Figure 4. Existing Impervious Areas in the CAH Watershed.

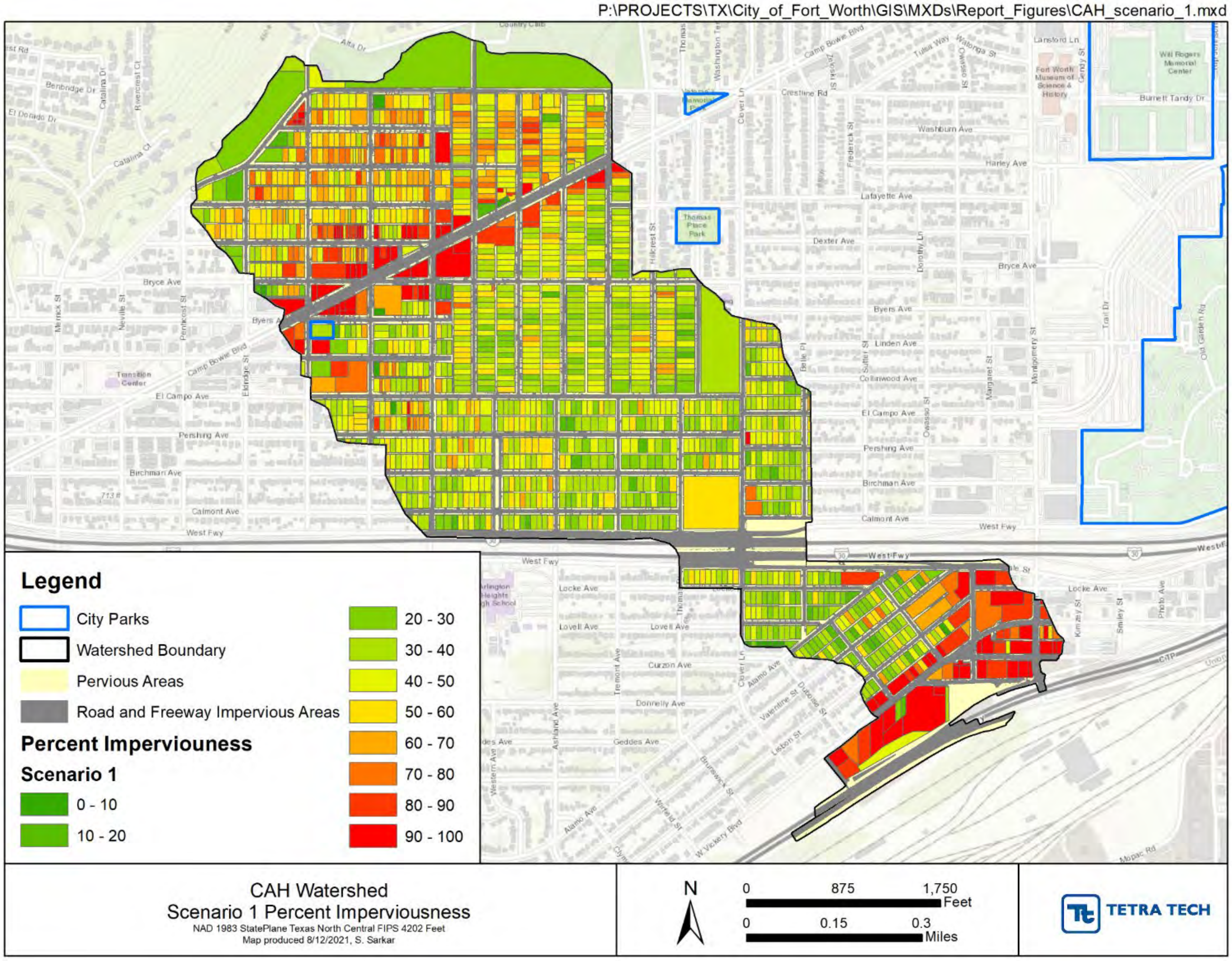

Figure 5. Parcel-Scale Percent Impervious for Scenario 1 for the CAH Watershed.

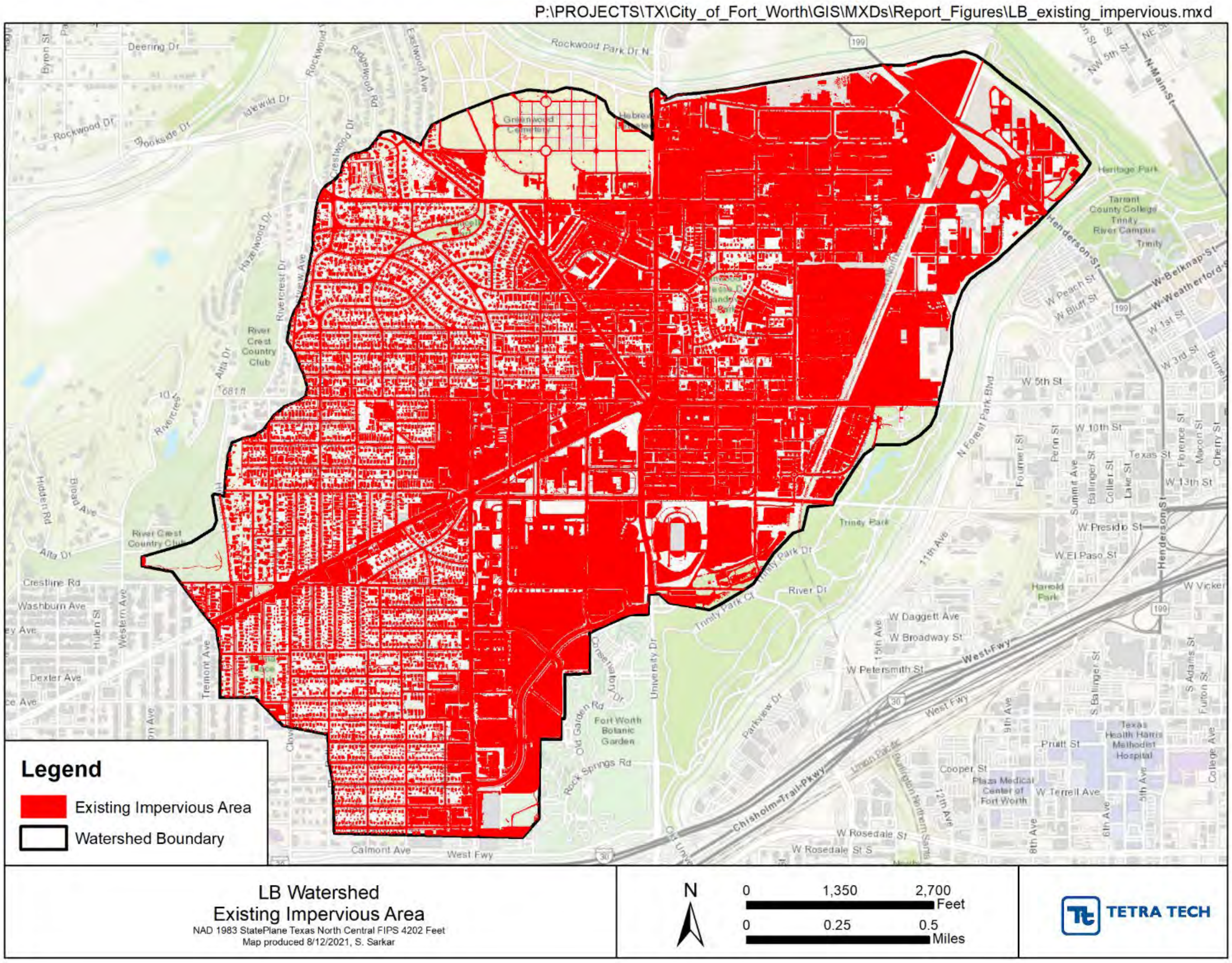

Figure 6. Existing Impervious Areas in the LB Watershed.

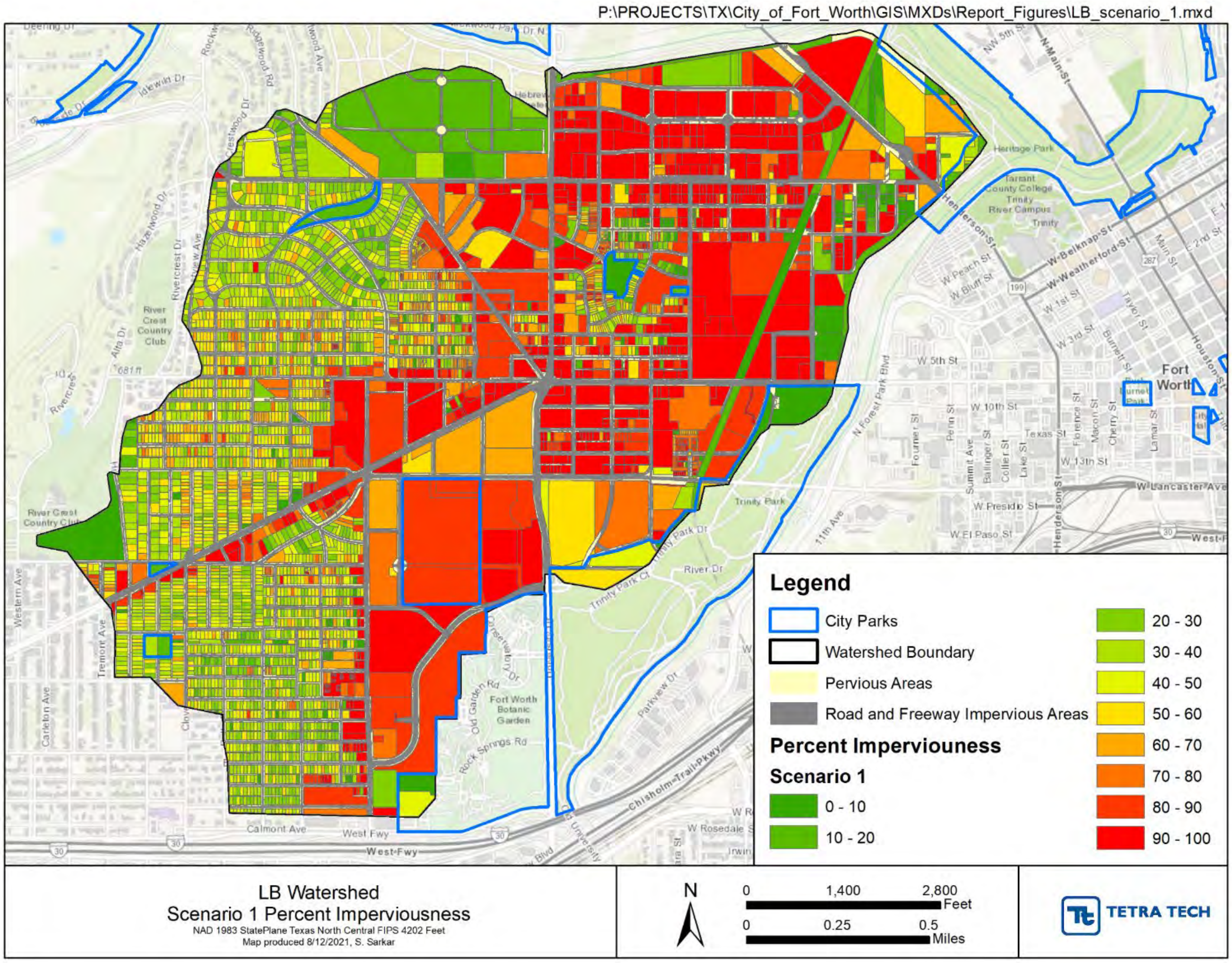

Figure 7. Parcel-Scale Percent Impervious for Scenario 1 for the LB Watershed.

Scenario 2 - Impervious Coverage based on the Stormwater Criteria Manual

The impervious coverage for this Scenario was developed based on the City's existing zoning standards and allowable impervious cover based on the Stormwater Criteria Manual. Land parcels acquired from the Tarrant Appraisal District (TAD) in the CAH and LB watersheds were first assigned a zoning class based on the City's zoning layer. The maximum allowable percent impervious per Table 3.5 of the Stormwater Criteria Manual (Table 1) were subsequently assigned to each parcel based on zoning. While the Stormwater Criteria Manual served as the basis for impervious cover development for this Scenario, some unique considerations encountered during the analysis are as follows. Note this Scenario solely uses the City's Stormwater Criteria Manual to determine percent imperviousness at the parcel-scale. The percent impervious are expected to be different from the existing actual imperviousness determined under Scenario 1.

1) The Stormwater Criteria Manual does not provide permissible percent impervious values for certain zoning classes in the CAH and LB watersheds. For such cases, an educated assumption was made based on the land use description (as summarized in Table 2) and minimum landscaping requirements per zoning ordinance.
2) Several parcels in the CAH and LB watersheds are identified as Planned Development (PD), as shown in Figure 8. Base zoning for such parcels was determined using the City's base zoning layer and impervious percentages were assigned based on their respective base zoning category and Table 3.5 of the Stormwater Criteria Manual. Parcels identified as PD were randomly selected and "spot-checked" against their respective ordinances to ensure consistency with base zoning.
3) Impervious areas associated with roads and freeways are assumed to be the same as Scenario 1.

Table 1. Impervious Percentages by Land Use per Table 3.5 of the City's Stormwater Criteria Manual.

Table 3.5 Runoff Coefficients

Description of Land Use	% Impervious	Runoff Coefficient "C"
Residential "A-43" one-acre lots (1) (2)	35	0.51
Residential "A-21" half-acre lots	37	0.52
Residential "A-10" 10,000 SF lots	49	0.59
Residential "A-7.5" (3)	55	0.63
Residential "A-5" (3)	61	0.67
Residential "MH", "A-R", "B", "R-1", & "R-2" (3)	65	0.69
Multi-family		
"CR"	64	0.69
"C"	79	0.77
"D"	93	0.86
Commercial/Industrial/House of Worship/School		
4% Open Space (Default if no site plan)	96	0.88
10% Open Space (Site plan required)	90	0.84
20% Open Space (Site plan required)	80	0.78
Parks, Cemeteries	7	0.34
Railroad Yard Areas	29	0.47
Streets: Asphalt, Concrete and Brick	100	0.90
Drives, Walks, and Roofs	100	0.90
Gravel Areas	43	0.56
Unimproved Areas	0	0.30

Assumptions:

(1) For Residential Calculations:
- Current CFW development standards for minimum lot size and maximum lot coverage (structure) for each classification
- Assumed 10.5' Parkway and 18' driveway
- Assumed 29' B-B street dimension
- Calculated by applying 90% runoff from impervious areas and 30% runoff from pervious areas

(2) Calculated from designated set-backs

Table 2. Assumed Impervious Percentages for Zoning Classes not Explicitly Identified in Table 3.5 of the Stormwater Criteria Manual.

Zoning Class and Description	% Impervious
UR - Urban Residential	90
MU-1 - Mixed Use, low intensity	90
MU-2 - Mixed Use, high intensity	90
CB - Camp Bowie	90
ER - Neighborhood Restricted, low intensity	70
E - Neighborhood, low intensity	80
F - General Commercial	90
FR - General Commercial, restricted, mod. intensity	90
FR - General Commercial, mod. intensity	90
G - Intensive Commercial, restricted	90
H - Central Business	95
I - Light Industrial	95
J - Medium Industrial	95
K - Heavy Industrial	95

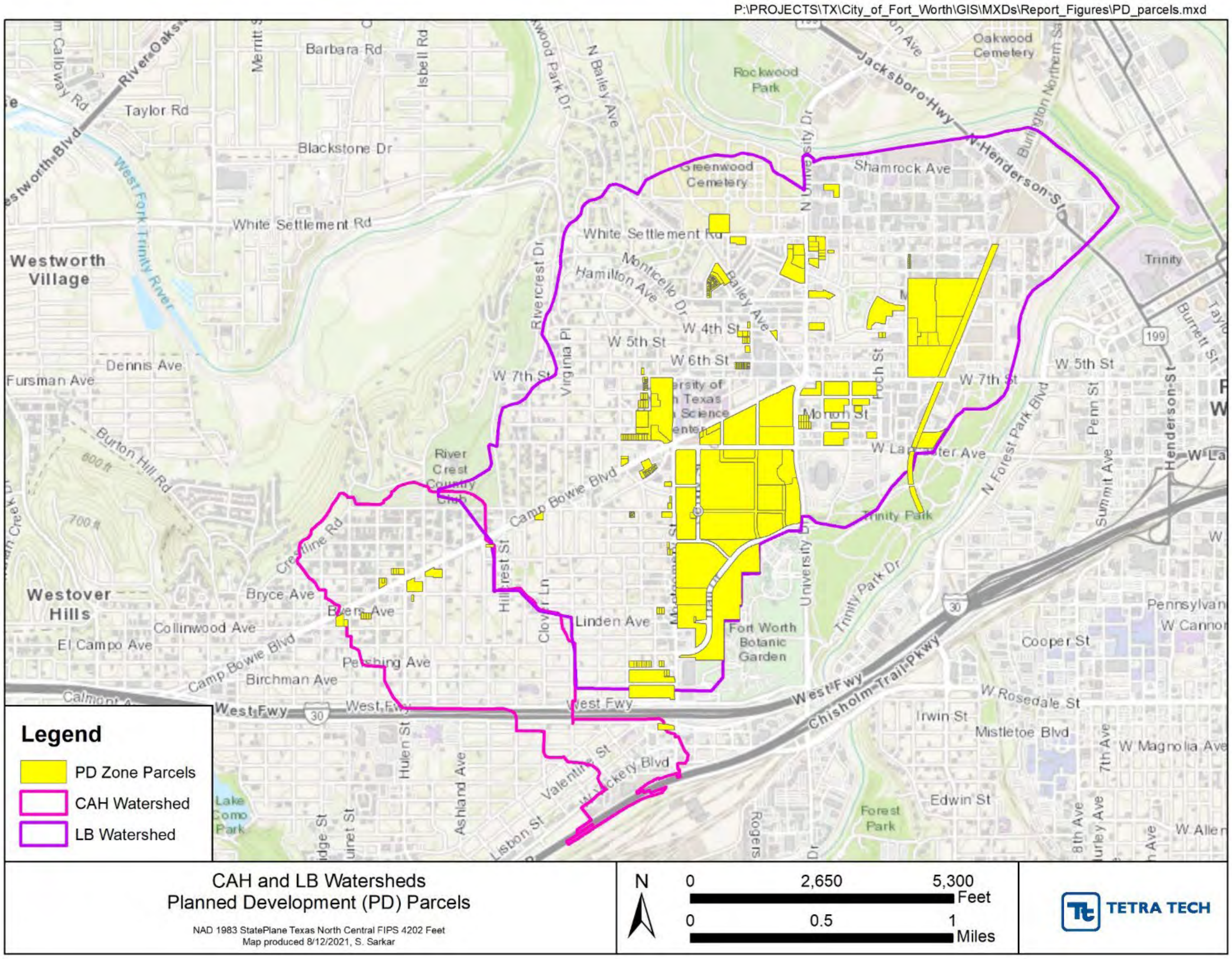

Figure 8. Planned Development (PD) Parcels in the CAH and LB Watersheds.

Based on the Stormwater Criteria Manual and other considerations summarized above, Figure 9 and Figure 10 show Scenario 2 percent impervious for the CAH and LB watersheds, respectively. The impervious areas associated with roads and rights-of-way under this Scenario are assumed to be the same as Scenario 1. For the CAH watershed, higher percent impervious (greater than 80%) are centered around Camp Bowie Boulevard. Pockets of higher percent impervious are also seen in the areas between West Freeway (I-30), and W. Vickery Boulevard/Chisholm Trail Parkway.

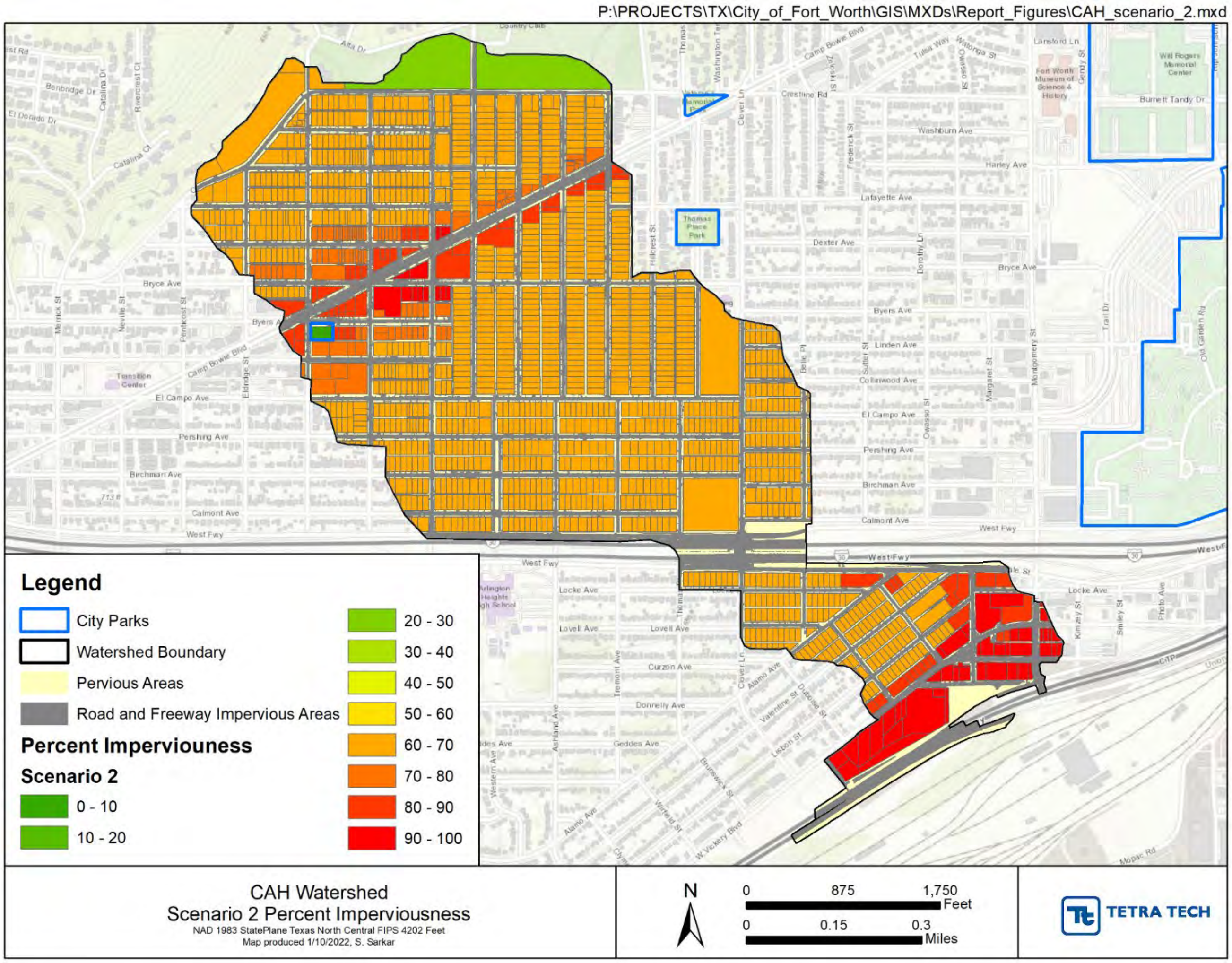

Figure 9. Parcel-Scale Percent Impervious for Scenario 2 for the CAH Watershed.

In the LB watershed, higher percent impervious (greater than 80%) are determined for areas west of University Drive. The area of the watershed between University Drive and Montgomery Street, the areas immediately adjacent to Camp Bowie Boulevard, and between Bailey Avenue and N. University Drive also exhibit higher levels of percent impervious.

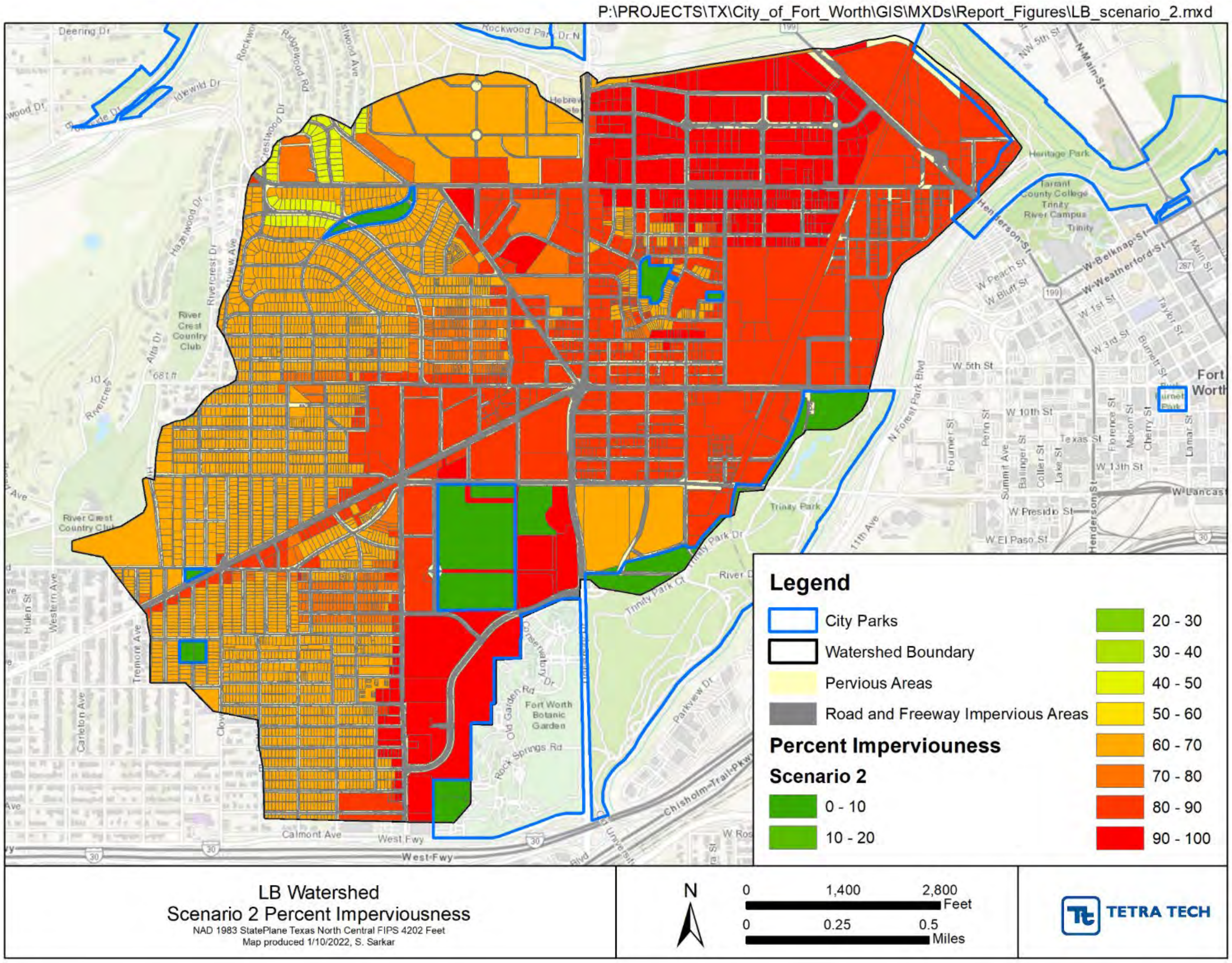

Figure 10. Parcel-Scale Percent Impervious for Scenario 2 for the LB Watershed.

Scenario 3 - Full Buildout Impervious Coverage

Future potential impervious coverages for the CAH and LB watersheds for this Scenario were determined based on current development trends, permissible maximum percent impervious based on zoning, and other considerations based on discussions with the City staff. This consisted of but not limited to reviewing recently approved projects, projects in review, or redevelopment plans under construction in each watershed.

Typical projects developed in the last 5-10 years (based on approved site plans or data on building and pavement coverages) were identified to establish an average impervious cover ratio trend for recently redeveloped lots. Typical impervious cover ratios for recently approved lots/projects under the purview of the neighborhood association review were also considered in the analysis. The potential for redevelopment of a property was based on the improvement value to lot value ratio based on the most recently available TAD valuation, current applications for rezoning or redevelopment, and other planning or redevelopment initiatives. Impervious cover associated with developments were determined based on review of aerial photographs, building permits dataset TAD property information. The methods used to develop impervious coverages under this Scenario for the CAH and LB watersheds are summarized below.

1) CAH watershed
    a. Residential Parcels - Based on a review of current and anticipated changes, we assumed that existing single-family homes with an A-7.5 zoning is likely to be rezoned to an R-1 or R-2, with zero-lot lines, and the maximum permissible 50% impervious in the front and 100% impervious in the rear. The average percent impervious for existing single-family homes ranged from 30% to 40% while those for new homes ranged from 54% to 94%. Assuming that the average percent impervious of new residential homes is applicable to all residential properties, the average percent impervious increases from 55% to 65%.
    b. Commercial Parcels - The average percent impervious for existing commercial properties ranged from 26% to 70% while those for new commercial developments including the Camp Bowie Boulevard Commercial District ranged from 84% to 98%. Assuming that the average percent impervious of new commercial properties is applicable to all existing and future commercial properties, the average percent impervious increases from 70% to 95%.

2) LB watershed
    a. Residential Parcels - Based on current and anticipated changes, we assume that existing single-family homes will likely be rezoned to an MU, with zero-lot lines, and the maximum permissible 50% impervious in the front and 100% impervious in the rear. The average percent impervious for LB for existing single-family homes ranged from 22% to 46% while those for new homes ranged from 61% to 98%. Assuming that the average percent impervious of new residential homes is applicable to all residential properties within the neighborhood, the average percent impervious increases from 31% to 90%.
    b. Commercial Parcels - The average percent impervious for LB for existing commercial properties ranged from 17% to 73% and new commercial areas including future Camp Bowie Boulevard Commercial District ranged from 87% to 100%. Assuming that the average percent impervious of new commercial developments are applicable to all existing and future commercial properties, the average percent impervious increases from 53% to 95%.
3) Impervious areas associated with roads and freeways are assumed to be the same as Scenario 1.
4) The percent imperviousness associated with public parks, cemeteries, and golf courses under Scenario 3 are assumed to be the same as Scenario 1.

Figure 11 and Figure 12 show Scenario 3 percent impervious for the CAH and LB watersheds, respectively. The impervious areas associated with roads and rights-of-way under this Scenario are assumed to be the same as Scenario 1. In the CAH watershed, areas with higher percent impervious (greater than 80%) increase slightly around Camp Bowie Boulevard compared to Scenario 2. In general, the percent impervious for single-family residential lots increase compared to Scenario 2.

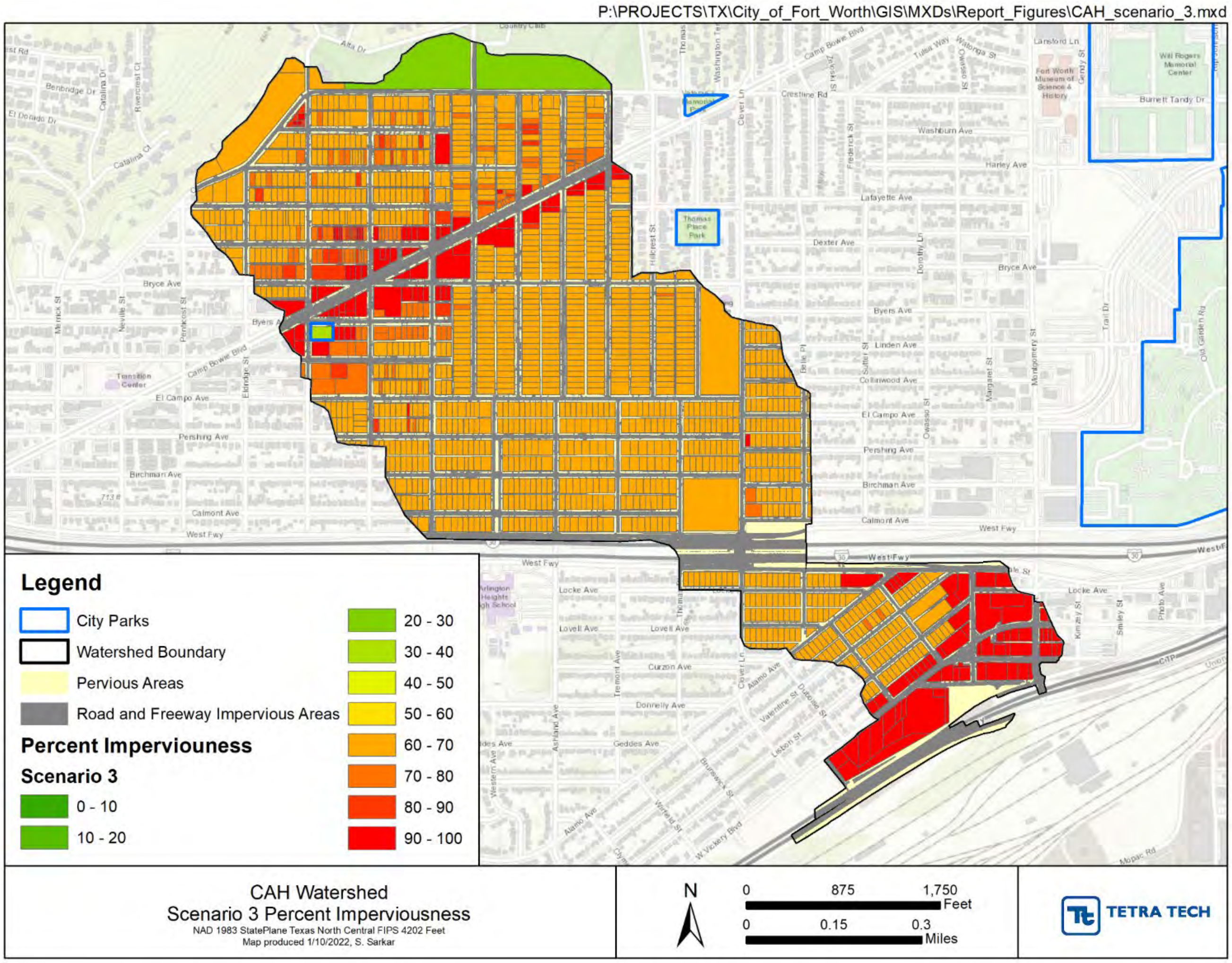

Figure 11. Parcel-Scale Percent Impervious for Scenario 3 for the CAH Watershed.

The average percent impervious generally increases for the entire LB watershed under Scenario 3 including areas that were not developed under Scenario 2.

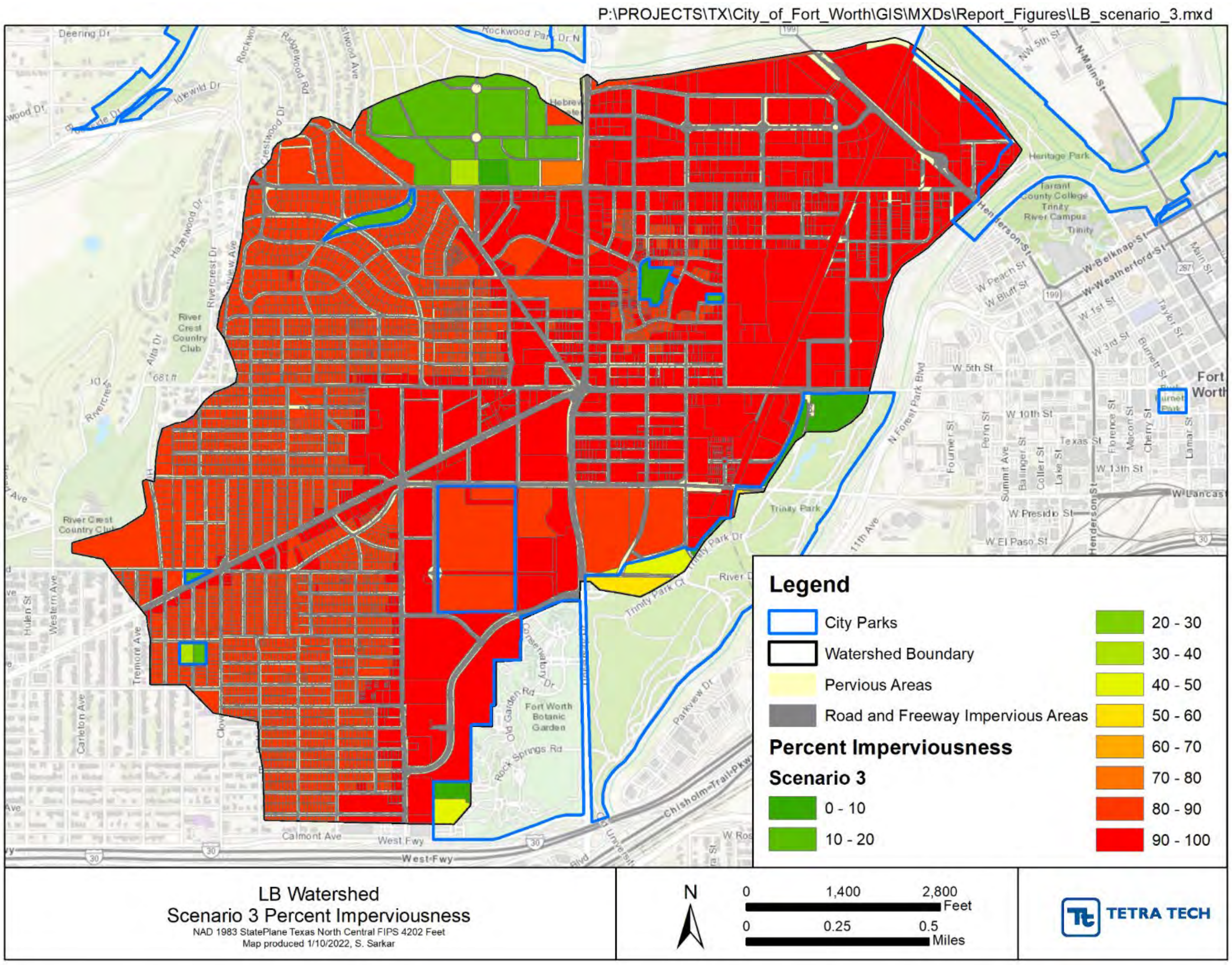

Figure 12. Parcel-Scale Percent Impervious for Scenario 3 for the LB Watershed.

3.0 Hydrology and Hydraulic (H&H) Modeling

The H&H models for the three Scenarios were developed using XPSWMM and are based on InfoWorks ICM models for the CAH and LB watersheds provided to Tetra Tech by the City. Consistent with the City's Stormwater Criteria Manual (CFW, 2015), runoff generation in the XPSWMM models are based on the SCS Unit Hydrograph method. Hydrologic and hydraulics impacts in the CAH and LB watershed were simulated for three design storms.

3.1 Rainfall

H&H for each impervious Scenario were simulated for the 1-year, 5-year and 10-year return interval 24-hour duration design storms. Rainfall intensities provided in the iSWM Hydrology Technical Manual (NCTCOG, 2020), recently updated based on the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 precipitation frequency estimates, were used for the H&H modeling (summarized in Table 3). A Type II rainfall distribution was used for all simulated design storms, as shown in Figure 13.

Table 3. Rainfall Intensities for Tarrant County based on NOAA Atlas 14.

Rainfall Type	Cumulative Depth (inches)
1-year 24-hour	3.191
5-year 24-hour	4.776
100-year 24-hour	9.175

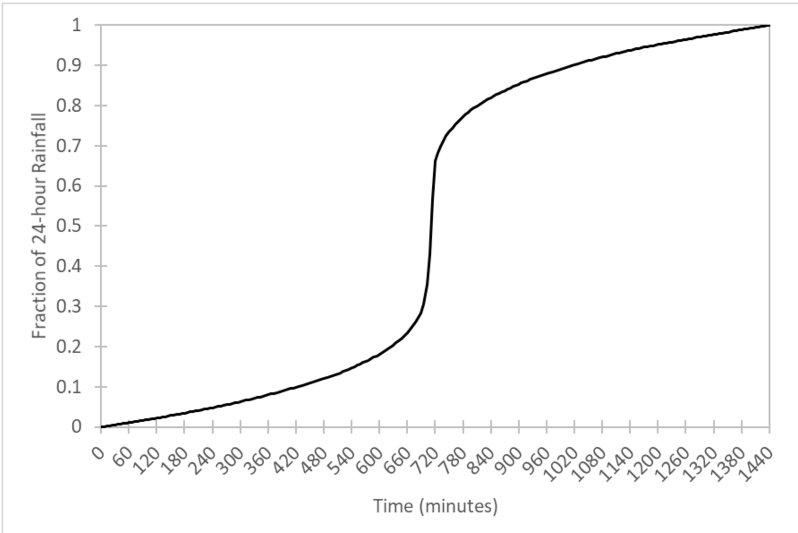

Figure 13. Type II Rainfall Distribution.

3.2 CAH Watershed

3.2.1 Impervious Cover

The percent imperviousness at the parcel scale was aggregated to the catchment scale using an area-weighing approach. Catchment scale imperviousness for Scenarios 1, 2, and 3 are summarized in Table 4 and shown individually in Figure 14, Figure 15, and Figure 16, respectively.

Table 4. CAH Percent Imperviousness for Scenarios 1, 2 and 3.

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
1	FI-036A-1.2D	Alamo	55.902	66.07	68.184
2	DI-012.2D	Ashland.1	38.521	55.613	59.219
3	J-008.2D	Ashland.2	47.834	63.533	66.207
4	EI-005.2D	Birchman	44.812	62.914	63.905
5	BI-030.2D	Bryce	73.874	77.076	83.369

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
6	DM-006-S	BryceXTremont	53.281	57.445	60.077
7	DI-006a.2D	BryceXTremont.2	49.249	62.857	66.358
8	J-005.2D	Carleton	47.366	60.701	63.210
9	J-035B	Chambers	46.690	61.804	63.428
10	EI-011.2D	Clover.1	58.876	64.906	67.488
11	J-022B	Clover.2	69.066	71.219	71.769
12	DI-016.2D	ElCampo.1	48.430	61.065	63.434
13	DI-016.2D	ElCampo.2	47.451	62.177	64.152
14	DI-016.2D	ElCampo.3	43.812	61.395	62.85
15	J-021	IH-30WxTremont.1	51.872	65.234	67.261
16	J-021	IH-30WxTremont.2	56.389	62.906	65.992
17	J-034B	Lisbon	50.734	64.705	64.752
18	J-030	Locke	39.833	60.589	63.418
19	J-025	LockeXBelle	47.207	61.442	63.757
20	FI-036.2D	Lovell	38.506	58.030	60.600
21	J-017.2D	Pershing.1	44.472	61.941	63.959
22	J-017.2D	Pershing.2	44.468	62.393	63.194
23	J-018.2D	Thomas	39.380	59.133	60.790
24	DI-015.2D	TremontXElCampo	44.252	60.731	63.761
25	j-033	Valentine	37.357	59.53	60.793
26	CI-003.2D	Western	51.644	63.52	66.244
27	J-003C.2D	WesternEastAlley	33.773	55.565	59.084
28	FM-003-S	BelleXBirchman	42.758	61.596	64.458
29	FM-004-S	BelleXCalmont	48.103	59.887	64.023
30	FJ-015-S	BelleXElCampo	46.035	62.044	64.517
31	FM-002-S	BelleXPershing	52.769	62.733	65.764
32	BI-013.2D	Bryce.US.E	73.290	86.776	87.888
33	AM-004-S	Bryce.US.W	68.246	74.139	76.454
34	BM-002-S	Byers	43.320	66.530	66.530
35	BJ-010-S	Collinwood.E	54.049	68.515	69.204
36	BM-004-S	Collinwood.W	63.983	72.396	77.705

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
37	AM-006-S	Crestline.E	37.226	38.267	38.574
38	AM-002-S	Crestline.W	42.640	61.351	65.161
39	BM-003-S	ElCampo.4	55.574	64.382	67.013
40	BM-005-S	ElCampo.5	61.484	69.42	70.069
41	AJ-011-S	Harley.E	70.886	66.417	75.704
42	AM-001-S	Harley.W	62.388	64.444	67.797
43	AJ-014-S	Lafayette.E	60.004	64.682	68.137
44	AM-003-S	Lafayette.W	57.566	63.117	66.388
45	FJ-003-S	ThomasPlace	43.437	64.446	66.967
46	FI-003A.2D	ThomasXClover	41.255	65.698	66.062
47	AJ-005-S	Washburn	59.714	65.777	68.914
48	AI-041B.2D	WesternXCampBowie	72.120	75.948	79.452
49	C1-F	C1	96.961	96.961	96.961
50	POND	DA 8	18.615	24.069	24.319
51	LINE 9.US	DA 9	63.371	63.371	63.371
51	LINE_9.US	DA 9	83.488	95.000	96.091
52	K1.2D	K1	99.833	99.833	99.833
53	MB-01	MB-01	96.889	96.889	96.889
54	MB-02	MB-02	93.891	93.891	93.891
55	MH-MV-02	Montgomery	88.871	92.529	93.906
56	MV-10B	MV-10	90.687	90.307	91.812
57	MV-11	MV-11	49.932	50.368	50.845
58	MV-12	MV-12	64.954	64.954	64.954
59	gj-001	Vickery	84.683	85.980	90.352
60	J-035H	Landers	74.680	79.764	82.871

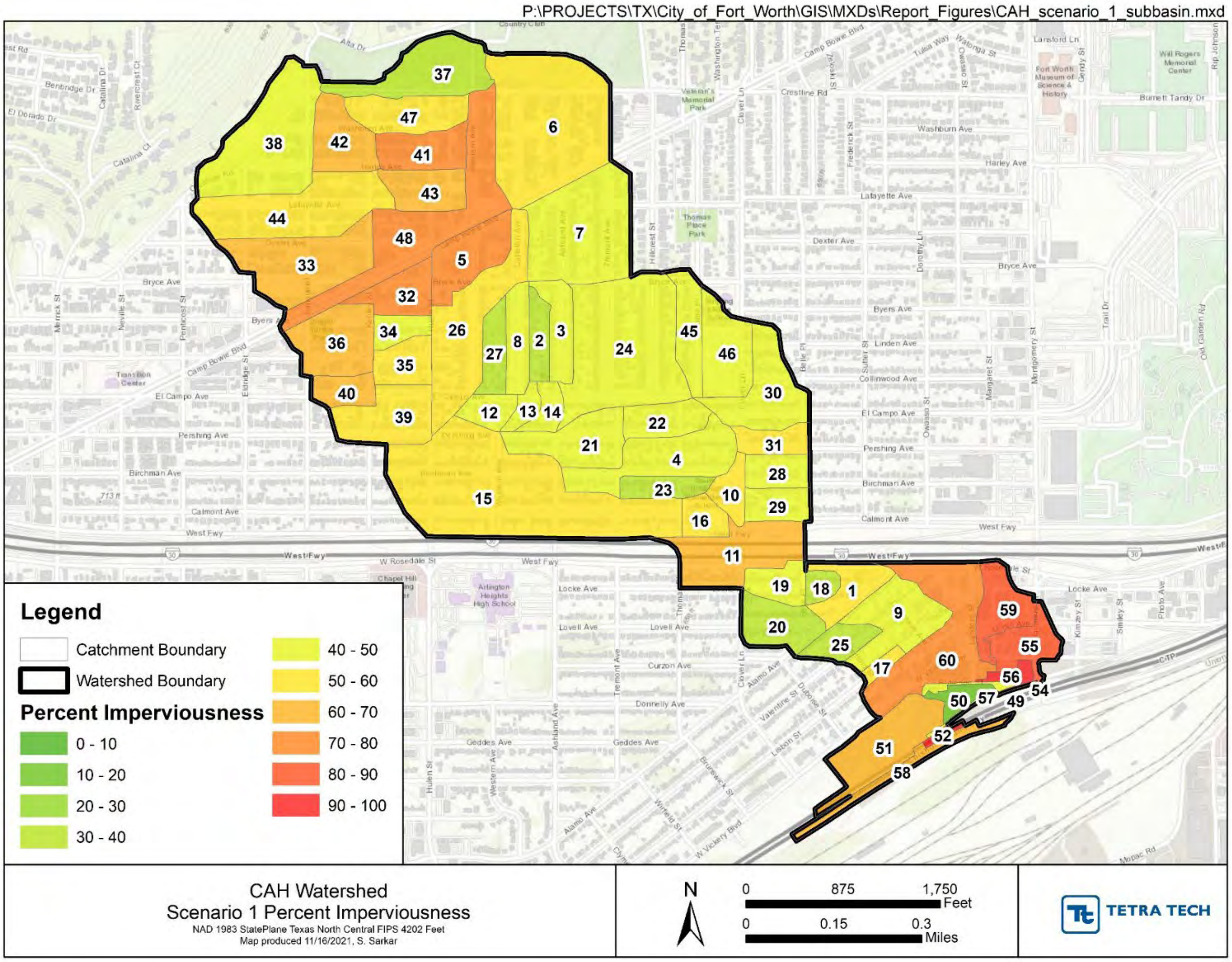

Figure 14. Scenario 1 Imperviousness at the Catchment Scale for the CAH Watershed.

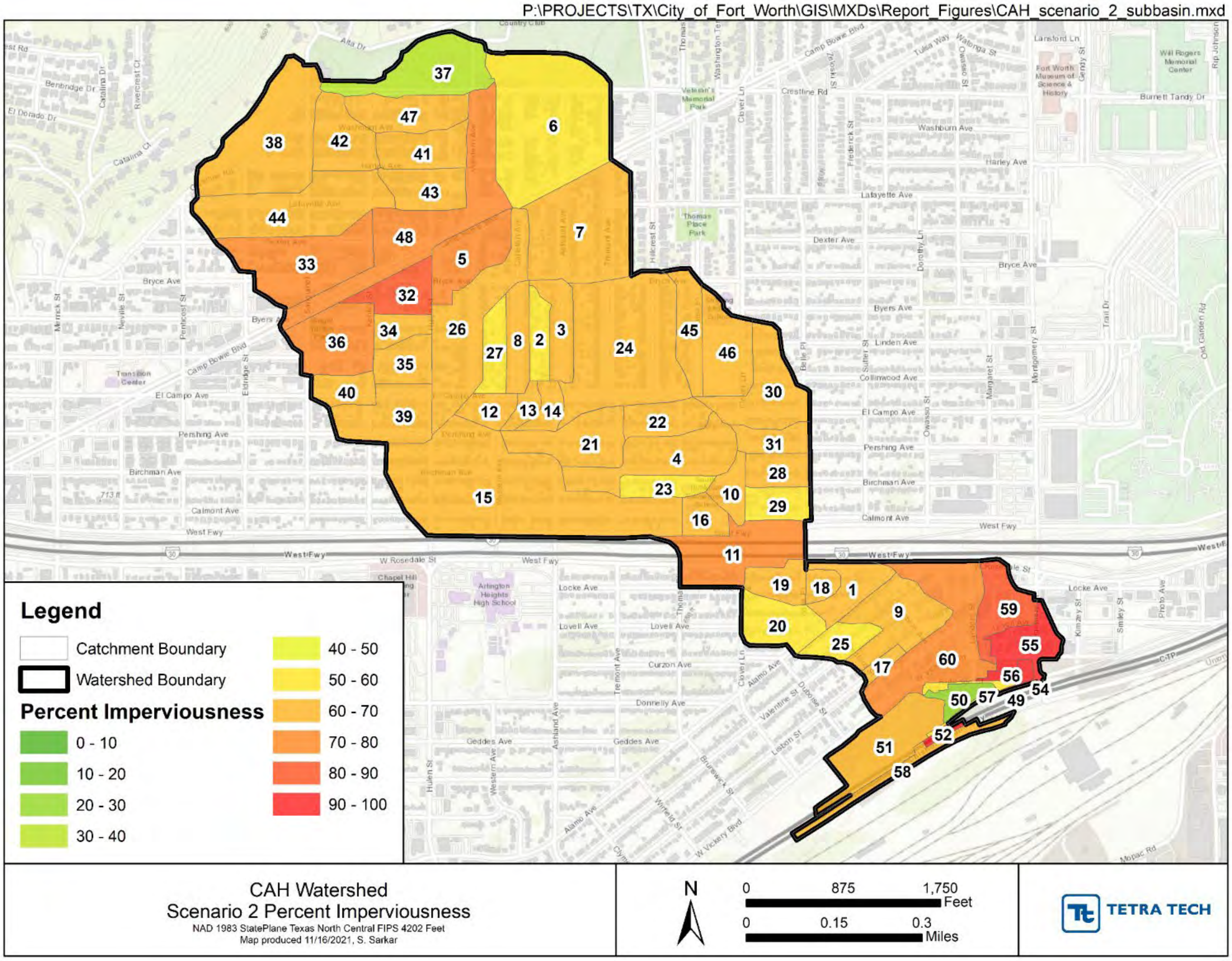

Figure 15. Scenario 2 Imperviousness at the Catchment Scale for the CAH Watershed.

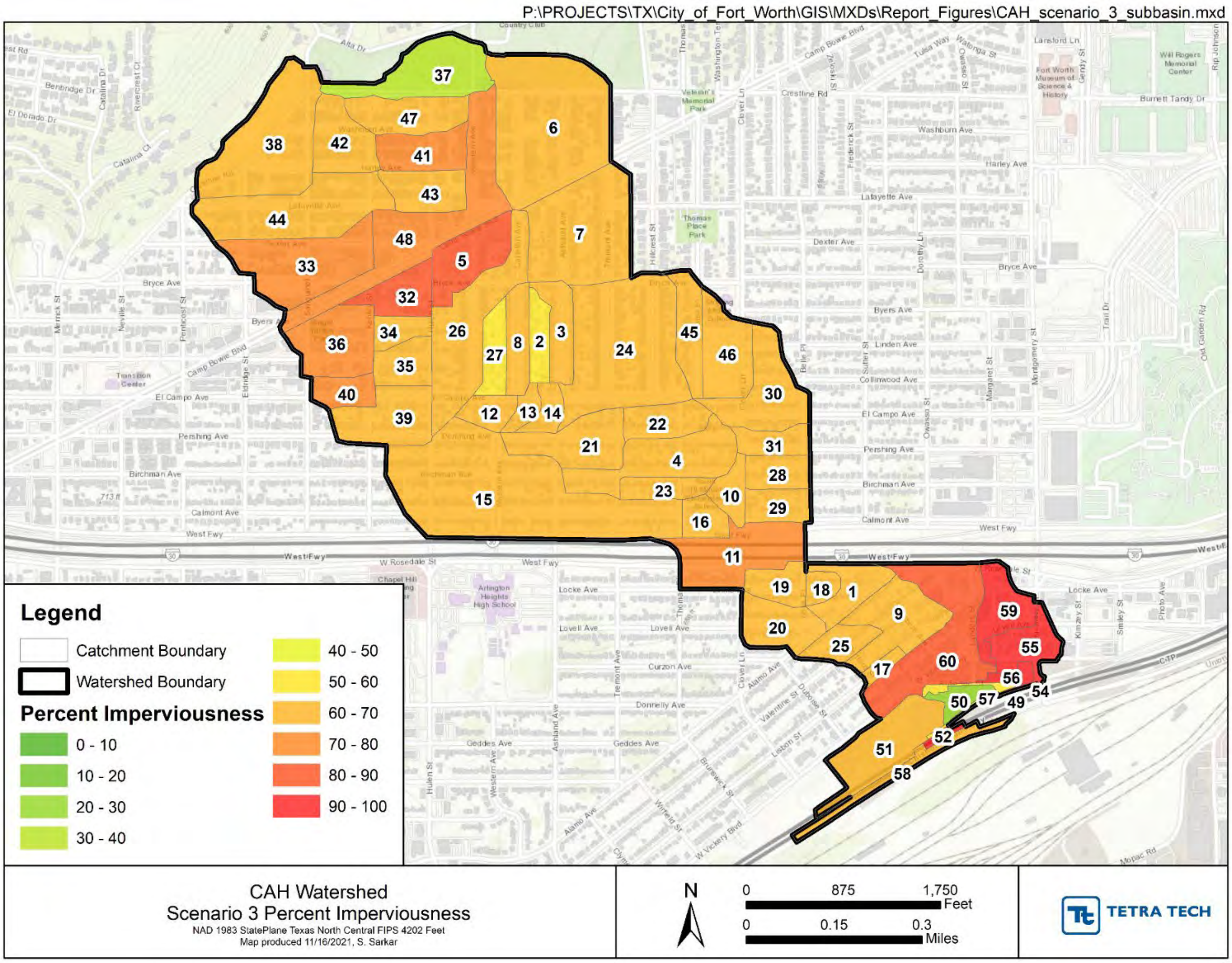

Figure 16. Scenario 3 Imperviousness at the Catchment Scale for the CAH Watershed.

3.2.2 Land Use and Pervious Curve Numbers

Land use in the CAH watershed based on the City's zoning classification is shown in Figure 17. Pervious curve numbers (CN) were determined using hydrologic soil group (HSG) information reported by the US Soil Survey Geographic (SSURGO) database for Tarrant County. The major soils reported for the watershed are Bolar (C), Urban Land (D), Aledo (D), Luckenbach (C), and Sanger (D). Pervious curve numbers of 74 and 80 were used for HSG C and D soils, respectively, equivalent to open space in good hydrologic condition. The assumption of open space in good condition for pervious areas is consistent with the methods implemented in the iSWM Hydrology Technical Manual (NCTCOG, 2020) for calculation of composite curve numbers of urban land uses. **Pervious curve numbers at the catchment scale were specified in the XPSWMM models and do not change across the impervious Scenarios.** XPSWMM internally calculates a composite curve number for each impervious Scenario based on catchment percent imperviousness, pervious curve number and an assumed impervious curve number of 98.

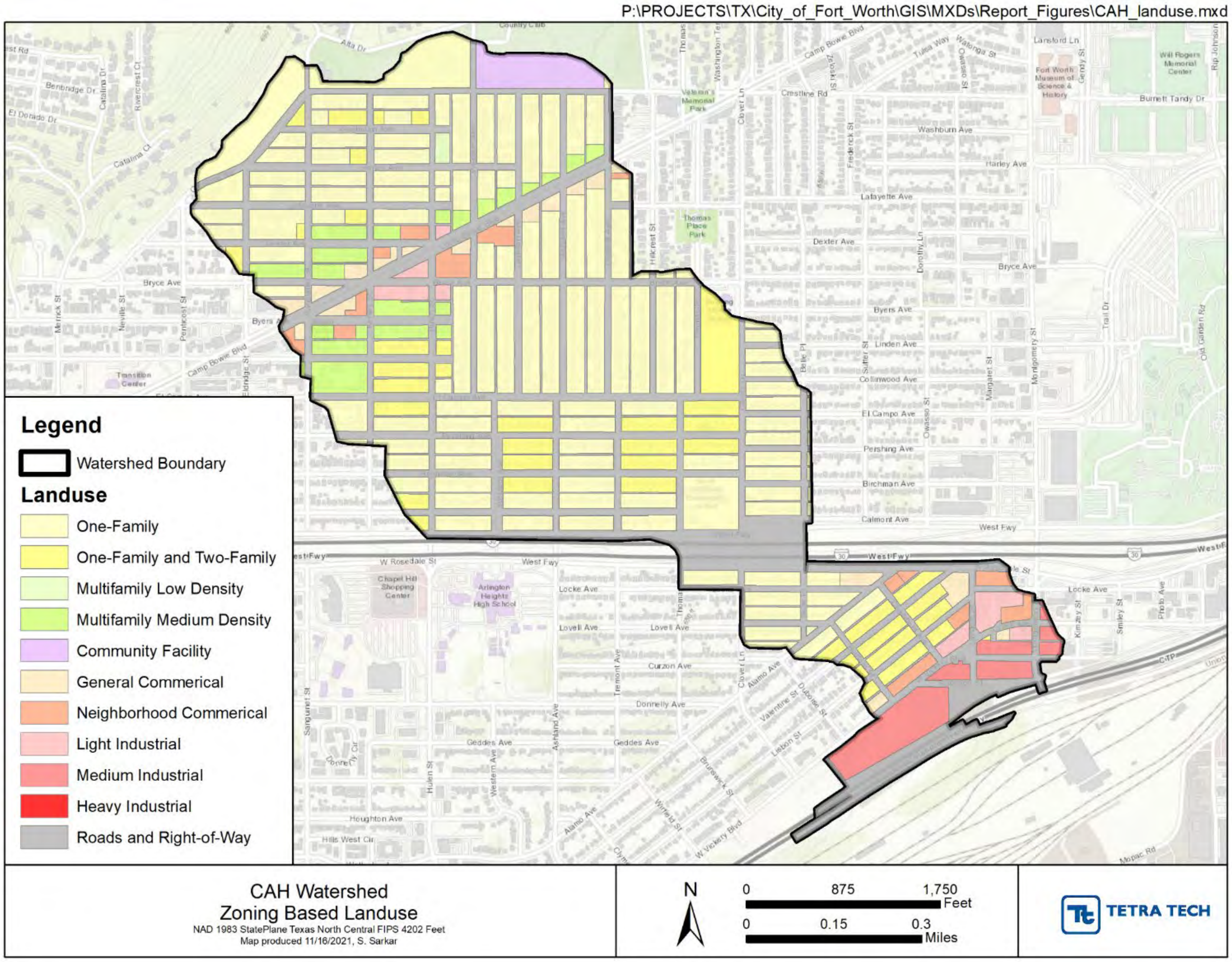

Figure 17. Land use in the CAH Watershed.

3.2.3 Longest Flow Path and Travel Time

The longest flow path for each catchment in the CAH watershed was determined using Arc Hydro Tools. The following procedure was implemented.

1) Export each catchment as a separate polygon using the “Split by Attributes” tool in ArcGIS.
2) Save DEM for the CAH watershed as “LevelDEM” in Arc Hydro Tools.
3) Perform “DEM Reconditioning” to burn in streams in Arc Hydro Tools. Since both watersheds are urban with no defined stream features, the streamlines for each catchment consisted of the portion of the storm pipe from the runoff node to its intersection with the catchment boundary. This ensures that the longest flow paths generally terminate at the runoff node for each catchment.
4) Run “Fill Sinks” to remove sinks in the DEMs setting the fill threshold to 100-ft in Arc Hydro Tools. The burnt in streams are filled if a threshold is not specified.
5) Run “Flow Direction” on the filled DEM with the watershed polygon as the outer wall in Arc Hydro Tools.

6) Run "Longest Flow Path for Catchments" in batch mode for each catchment polygon in Arc Hydro Tools using the flow direction grid.

The travel time for each catchment in the CAH watershed was determined using the following procedure. The sheet flow, shallow concentrated flow and total travel times for catchments in the CAH watershed are summarized in Table 5, Table 6 and Table 7, respectively. **Note that the travel times at the catchment scale are the same across the impervious Scenarios.**

1) Run "Define TR55 Zones for Longest Flow Path" in Arc Hydro Tools setting the overland flow distance to 50-ft.
2) Calculate slopes for the TR55 segments using "Compute Line Parameters" in Arc Hydro Tools.
3) Assign Manning's n value of 0.011 (smooth surfaces) or 0.15 (grass) based on visual inspection of aerials for the sheet flow length.
4) Determine if the shallow concentrated flow segments are going over "unpaved" or "paved" areas. Split the shallow concentrated flow segments as needed if they are going over both unpaved and paved areas.
5) Determine travel time in minutes for sheet flow and shallow concentrated flow using equations 1.9, 1.10, 1.11, and 1.12 in the iSWM Hydrology Technical Manual (NCTCOG, 2020). Sum sheet flow and shallow concentrated flow travel times to get total travel time setting a minimum total travel time to 6 minutes.

Table 5. CAH Catchments Sheet Flow Travel Times.

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr Rainfall, in)	T_{sheet} (mins)
1	FI-036A-1.2D	Alamo	50	0.116	0.150	3.522	2.7
2	DI-012.2D	Ashland.1	50	0.086	0.011	3.522	0.4
3	J-008.2D	Ashland.2	50	0.020	0.150	3.522	5.3
4	EI-005.2D	Birchman	50	0.031	0.150	3.522	4.5
5	BI-030.2D	Bryce	50	0.024	0.011	3.522	0.6
6	DM-006-S	BryceXTremont	50	0.026	0.011	3.522	0.6
7	DI-006a.2D	BryceXTremont.2	50	0.011	0.011	3.522	0.8
8	J-005.2D	Carleton	50	0.019	0.011	3.522	0.7
9	J-035B	Chambers	50	0.013	0.011	3.522	0.8
10	EI-011.2D	Clover.1	50	0.056	0.011	3.522	0.4
11	J-022B	Clover.2	50	0.049	0.011	3.522	0.5
12	DI-016.2D	ElCampo.1	50	0.015	0.150	3.522	6.1
13	DI-016.2D	ElCampo.2	50	0.030	0.150	3.522	4.6
14	DI-016.2D	ElCampo.3	50	0.046	0.150	3.522	3.8
15	J-021	IH-30WxTremont.1	50	0.019	0.150	3.522	5.5
16	J-021	IH-30WxTremont.2	50	0.051	0.011	3.522	0.5
17	J-034B	Lisbon	50	0.044	0.150	3.522	3.9
18	J-030	Locke	50	0.018	0.150	3.522	5.6
19	J-025	LockeXBelle	50	0.043	0.011	3.522	0.5

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr Rainfall, in)	T_{sheet} (mins)
20	FI-036.2D	Lovell	50	0.012	0.011	3.522	0.8
21	J-017.2D	Pershing.1	50	0.049	0.150	3.522	3.8
22	J-017.2D	Pershing.2	50	0.106	0.011	3.522	0.3
23	J-018.2D	Thomas	50	0.040	0.150	3.522	4.1
24	DI-015.2D	TremontXElCampo	50	0.050	0.011	3.522	0.5
25	j-033	Valentine	50	0.011	0.150	3.522	6.8
26	CI-003.2D	Western	50	0.014	0.011	3.522	0.8
27	J-003C.2D	WesternEastAlley	50	0.033	0.150	3.522	4.4
28	FM-003-S	BelleXBirchman	50	0.055	0.150	3.522	3.6
29	FM-004-S	BelleXCalmont	50	0.031	0.011	3.522	0.6
30	FJ-015-S	BelleXElCampo	50	0.035	0.150	3.522	4.3
31	FM-002-S	BelleXPershing	50	0.033	0.150	3.522	4.4
32	BI-013.2D	Bryce.US.E	50	0.026	0.150	3.522	4.8
33	AM-004-S	Bryce.US.W	50	0.008	0.150	3.522	7.9
34	BM-002-S	Byers	50	0.045	0.150	3.522	3.9
35	BJ-010-S	Collinwood.E	50	0.010	0.150	3.522	7.0
36	BM-004-S	Collinwood.W	50	0.029	0.011	3.522	0.6
37	AM-006-S	Crestline.E	50	0.062	0.150	3.522	3.4
38	AM-002-S	Crestline.W	50	0.010	0.150	3.522	7.0
39	BM-003-S	ElCampo.4	50	0.020	0.011	3.522	0.7
40	BM-005-S	ElCampo.5	50	0.010	0.011	3.522	0.9
41	AJ-011-S	Harley.E	50	0.017	0.150	3.522	5.8
42	AM-001-S	Harley.W	50	0.023	0.011	3.522	0.6
43	AJ-014-S	Lafayette.E	50	0.029	0.150	3.522	4.6
44	AM-003-S	Lafayette.W	50	0.025	0.011	3.522	0.6
45	FJ-003-S	ThomasPlace	50	0.020	0.011	3.522	0.7
46	FI-003A.2D	ThomasXClover	50	0.039	0.150	3.522	4.1
47	AJ-005-S	Washburn	50	0.021	0.011	3.522	0.6
48	AI-041B.2D	WesternXCampBowie	50	0.017	0.011	3.522	0.7
49	C1-F	C1	50	0.016	0.011	3.522	0.7
50	POND	DA 8	50	0.043	0.011	3.522	0.5

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr Rainfall, in)	T_{sheet} (mins)
51	LINE 9.US	DA 9	50	0.076	0.011	3.522	0.4
52	K1.2D	K1	50	0.008	0.011	3.522	1.0
53	MB-01	MB-01	40	0.468	0.011	3.522	0.2
54	MB-02	MB-02	50	0.404	0.011	3.522	0.2
55	MH-MV-02	Montgomery	50	0.018	0.011	3.522	0.7
56	MV-10B	MV-10	50	0.015	0.011	3.522	0.7
57	MV-11	MV-11	50	0.035	0.150	3.522	4.3
58	MV-12	MV-12	50	0.039	0.011	3.522	0.5
59	gj-001	Vickery	50	0.001	0.011	3.522	2.0
60	J-035H	Landers	50	0.045	0.150	3.522	3.9

Table 6. CAH Catchments Shallow Concentrated Flow Travel Times.

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
1	FI-036A-1.2D	Alamo	1,140	0.005	Paved	13.6
2	DI-012.2D	Ashland.1	460	0.036	Unpaved	2.5
3	J-008.2D	Ashland.2	1,224	0.027	Paved	6.1
4	EI-005.2D	Birchman	719	0.024	Paved	3.8
4	EI-005.2D	Birchman	116	0.073	Unpaved	0.4
5	BI-030.2D	Bryce	835	0.030	Paved	4.0
6	DM-006-S	BryceXTremont	1,002	0.013	Paved	7.3
7	DI-006a.2D	BryceXTremont.2	1,034	0.016	Paved	6.6
7	DI-006a.2D	BryceXTremont.2	313	0.017	Unpaved	2.5
8	J-005.2D	Carleton	755	0.035	Paved	3.3
9	J-035B	Chambers	480	0.012	Paved	3.6
9	J-035B	Chambers	264	0.023	Unpaved	1.8
10	EI-011.2D	Clover.1	703	0.033	Paved	3.2
11	J-022B	Clover.2	780	0.056	Paved	2.7
12	DI-016.2D	ElCampo.1	534	0.039	Paved	2.2
13	DI-016.2D	ElCampo.2	379	0.046	Unpaved	1.8
13	DI-016.2D	ElCampo.2	140	0.052	Paved	0.5

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
14	DI-016.2D	ElCampo.3	309	0.050	Unpaved	1.4
14	DI-016.2D	ElCampo.3	225	0.023	Paved	1.2
15	J-021	IH-30WxTremont.1	3,083	0.019	Paved	18.4
15	J-021	IH-30WxTremont.1	562	0.013	Unpaved	5.1
16	J-021	IH-30WxTremont.2	412	0.018	Unpaved	3.2
16	J-021	IH-30WxTremont.2	226	0.006	Paved	2.5
17	J-034B	Lisbon	459	0.015	Paved	3.0
18	J-030	Locke	288	0.006	Unpaved	4.0
19	J-025	LockeXBelle	546	0.027	Paved	2.7
20	FI-036.2D	Lovell	983	0.017	Paved	6.2
21	J-017.2D	Pershing.1	847	0.038	Paved	3.6
22	J-017.2D	Pershing.2	569	0.037	Paved	2.4
23	J-018.2D	Thomas	600	0.036	Unpaved	3.3
24	DI-015.2D	TremontXElCampo	732	0.022	Paved	4.0
24	DI-015.2D	TremontXElCampo	453	0.020	Unpaved	3.3
25	j-033	Valentine	496	0.014	Paved	3.4
26	CI-003.2D	Western	1,545	0.021	Paved	8.8
27	J-003C.2D	WesternEastAlley	497	0.024	Unpaved	3.3
28	FM-003-S	BelleXBirchman	357	0.038	Unpaved	1.9
28	FM-003-S	BelleXBirchman	185	0.018	Paved	1.1
29	FM-004-S	BelleXCalmont	508	0.010	Paved	4.2
29	FM-004-S	BelleXCalmont	252	0.035	Unpaved	1.4
30	FJ-015-S	BelleXElCampo	749	0.025	Unpaved	4.8
30	FJ-015-S	BelleXElCampo	307	0.008	Paved	2.7
31	FM-002-S	BelleXPershing	670	0.028	Paved	3.3
32	BI-013.2D	Bryce.US.E	418	0.019	Paved	2.5
32	BI-013.2D	Bryce.US.E	260	0.031	Unpaved	1.5
33	AM-004-S	Bryce.US.W	1,553	0.026	Paved	7.9
34	BM-002-S	Byers	420	0.029	Unpaved	2.5
34	BM-002-S	Byers	317	0.020	Paved	1.8
35	BJ-010-S	Collinwood.E	542	0.034	Paved	2.4
35	BJ-010-S	Collinwood.E	135	0.025	Unpaved	0.9

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
36	BM-004-S	Collinwood.W	1,040	0.025	Paved	5.3
37	AM-006-S	Crestline.E	1,114	0.012	Paved	8.2
38	AM-002-S	Crestline.W	1,513	0.017	Paved	9.6
39	BM-003-S	ElCampo.4	1,147	0.017	Paved	7.3
39	BM-003-S	ElCampo.4	262	0.021	Unpaved	1.8
40	BM-005-S	ElCampo.5	575	0.013	Paved	4.2
41	AJ-011-S	Harley.E	505	0.014	Paved	3.5
41	AJ-011-S	Harley.E	309	0.013	Unpaved	2.8
42	AM-001-S	Harley.W	927	0.013	Paved	6.8
42	AM-001-S	Harley.W	315	0.036	Unpaved	1.7
43	AJ-014-S	Lafayette.E	384	0.029	Unpaved	2.3
43	AJ-014-S	Lafayette.E	132	0.013	Paved	0.9
44	AM-003-S	Lafayette.W	1,516	0.025	Paved	7.9
45	FJ-003-S	ThomasPlace	928	0.020	Paved	5.4
46	FI-003A.2D	ThomasXClover	1,158	0.018	Paved	7.1
47	AJ-005-S	Washburn	889	0.015	Paved	5.9
48	AI-041B.2D	WesternXCampBowie	1,762	0.023	Paved	9.6
49	C1-F	C1	24	0.314	Paved	0.0
50	POND	DA 8	185	0.105	Unpaved	0.6
50	POND	DA 8	145	0.027	Paved	0.7
51	LINE 9.US	DA 9	890	0.007	Unpaved	10.6
52	K1.2D	K1	430	0.007	Paved	4.2
54	MB-02	MB-02	45	0.018	Paved	0.3
55	MH-MV-02	Montgomery	551	0.007	Paved	5.2
56	MV-10B	MV-10	333	0.014	Paved	2.3
57	MV-11	MV-11	409	0.004	Unpaved	6.6
58	MV-12	MV-12	2,105	0.008	Unpaved	23.6
59	gj-001	Vickery	664	0.015	Paved	4.4
60	J-035H	Landers	1,529	0.011	Paved	11.8

Table 7. CAH Catchments Total Travel Times.

ID	XPSWMM Node ID	Catchment Name	T_{total} (mins)
1	FI-036A-1.2D	Alamo	16.3
2	DI-012.2D	Ashland.1	6.0
3	J-008.2D	Ashland.2	11.5
4	EI-005.2D	Birchman	8.7
5	BI-030.2D	Bryce	6.0
6	DM-006-S	BryceXTremont	7.9
7	DI-006a.2D	BryceXTremont.2	10.0
8	J-005.2D	Carleton	6.0
9	J-035B	Chambers	6.2
10	EI-011.2D	Clover.1	6.0
11	J-022B	Clover.2	6.0
12	DI-016.2D	ElCampo.1	8.3
13	DI-016.2D	ElCampo.2	6.9
14	DI-016.2D	ElCampo.3	6.5
15	J-021	IH-30WxTremont.1	29.1
16	J-021	IH-30WxTremont.2	6.1
17	J-034B	Lisbon	6.9
18	J-030	Locke	9.6
19	J-025	LockeXBelle	6.0
20	FI-036.2D	Lovell	7.0
21	J-017.2D	Pershing.1	7.3
22	J-017.2D	Pershing.2	6.0
23	J-018.2D	Thomas	7.3
24	DI-015.2D	TremontXElCampo	7.8
25	j-033	Valentine	10.2
26	CI-003.2D	Western	9.5
27	J-003C.2D	WesternEastAlley	7.7
28	FM-003-S	BelleXBirchman	6.6
29	FM-004-S	BelleXCalmont	6.2
30	FJ-015-S	BelleXElCampo	11.8
31	FM-002-S	BelleXPershing	7.7

ID	XPSWMM Node ID	Catchment Name	T_{total} (mins)
32	BI-013.2D	Bryce.US.E	8.9
33	AM-004-S	Bryce.US.W	15.8
34	BM-002-S	Byers	8.2
35	BJ-010-S	Collinwood.E	10.3
36	BM-004-S	Collinwood.W	6.0
37	AM-006-S	Crestline.E	11.6
38	AM-002-S	Crestline.W	16.6
39	BM-003-S	ElCampo.4	9.8
40	BM-005-S	ElCampo.5	6.0
41	AJ-011-S	Harley.E	12.1
42	AM-001-S	Harley.W	9.1
43	AJ-014-S	Lafayette.E	7.9
44	AM-003-S	Lafayette.W	8.5
45	FJ-003-S	ThomasPlace	6.1
46	FI-003A.2D	ThomasXClover	11.2
47	AJ-005-S	Washburn	6.6
48	AI-041B.2D	WesternXCampBowie	10.3
49	C1-F	C1	6.0
50	POND	DA 8	6.0
51	LINE 9.US	DA 9	11.0
52	K1.2D	K1	6.0
53	MB-01	MB-01	6.0
54	MB-02	MB-02	6.0
55	MH-MV-02	Montgomery	6.0
56	MV-10B	MV-10	6.0
57	MV-11	MV-11	10.9
58	MV-12	MV-12	24.1
59	gj-001	Vickery	6.4
60	J-035H	Landers	15.7

3.2.4 Hydraulics

Hydrology and hydraulics were simulated simultaneously in the XPSWMM models. The models were configured in 1D-2D mode wherein runoff generation is simulated in 1D and conveyed to the stormwater inlets. The stormwater inlets are connected to the 2D terrain allowing for excess water to spill to the 2D terrain when the capacity of the stormwater system is exceeded. XPSWMM uses physically based methods to simulate hydraulics of the flooded water in the 2D terrain. The 2D terrain in the XPSWMM models are based on Lidar data acquired by Digital Aerial Solutions, LLC for the US Geological Survey (USGS) for portions of 21 counties over north, central, and west Texas between January 26, 2019, and July 12, 2019. Data products including Lidar Point Cloud and DEM are publicly available for download from the Texas Natural Resources Information System (TNRIS). The Central Arlington Heights (CAH) and Linwood-Bailey (LB) watersheds are covered by this project. The DEM for the study area at a spatial resolution of 1-meter was generated by Tetra Tech using the Lidar Point Cloud in ArcGIS using the following procedure.

1) Lidar Point Cloud in “laz” format were converted to “las” format using the “pylas” module in the Python programming language.
2) The “las” files were subsequently converted to 1-meter resolution DEMs using the “LAS Dataset to Raster” tool in ArcGIS for the “Bare-Earth Ground” class. The DEMs for the individual tiles (shown in Figure 1) were combined using the “Mosaic to New Raster” tool in ArcGIS.

As discussed above, the XPSWMM models are based on the City’ InfoWorks ICM models for the CAH watershed. The following changes from the InfoWorks ICM model are implemented in the CAH XPSWMM model.

1) Areas of the watershed north of Bryce Ave and west of Western Ave were simulated in 1D in the InfoWorks ICM model with the streets configured as open channel links connected to inlets. These “pseudo” links accumulate flood waters in instances of surcharging inlets and convey the flood waters to the 2D area. In the CAH XPSWMM models, the 2D area is extended to these areas which are simulated in 1D in the InfoWorks ICM model. The “pseudo” road links have been removed and the stormwater inlets are directly connected to the 2D terrain.
2) Hulen Bryce Pond at Hulen Ave and Camp Bowie Blvd, and the detention area immediately south of Rutledge St and Landers St were simulated in 1D-2D mode in the InfoWorks ICM model. These areas have been converted to 2D areas in the XPSWMM models.

The 2D grid was specified at a 10-ft resolution. Sub-Grid Sampling (SGS) was enabled in the XPSWMM models with the “Exact” depth interpolation and sampling distance of 3-ft. The XP2D Extreme engine was used for 2D simulations.

Land use specific Manning’s n values were based on the Harris County Flood Control District (HCFCD, 2018) suggestions for flood routing within a 2D domain (summarized in Table 8). The Manning’s n values adopted for the CAH XPSWMM models are shown in Figure 18. The City’s building footprints layer was used to define inactive 2D areas in the XPSWMM models.

Table 8. HCFCD 2D Domain Manning’s n Value Recommendations (HCFCD, 2018).

Land Classification	Manning’s n		
	Minimum	Recommended	Maximum
Open Water	0.01	0.02	0.03
Developed High Intensity	0.02	0.03	0.06
Developed Med Intensity	0.06	0.18	0.20
Developed Low Intensity	0.06	0.16	0.20
Developed Open Space	0.04	0.06	0.10

Land Classification	Manning's n		
	Minimum	Recommended	Maximum
Barren Lands	0.06	0.20	0.30
Forest/Shrubs	0.18	0.25	0.30
Pasture/Grasslands	0.15	0.22	0.30
Cultivated Crops	0.10	0.17	0.30
Wetlands	0.03	0.08	0.10
Building	10.00	10.00	10.00
Pavement	0.015	0.02	0.025

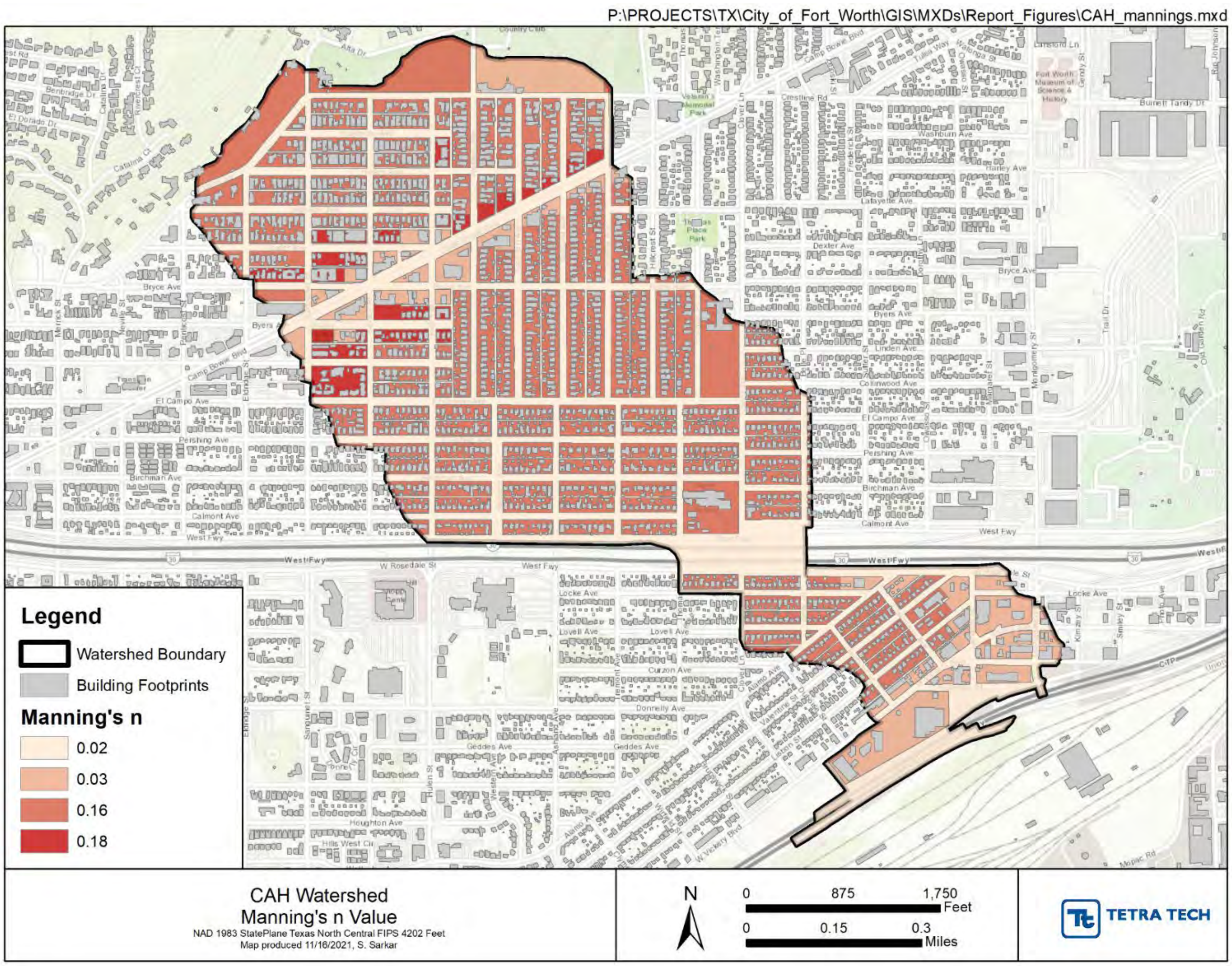

Figure 18. Manning's n Values for the CAH Watershed.

Based on analysis of the movement of flooded water on the 2D terrain in the XPSWMM models, 2D outfalls were specified along the eastern and southern edges of the CAH watershed.

3.2.5 Results and Discussion

Runoff volumes simulated by the XPSWMM models at the watershed scale for the three impervious Scenarios and design storms are summarized in Table 9.

Table 9. Simulated Runoff Depths and Volumes for the CAH Watershed.

Scenario #	Cumulative Runoff Depth (in)			Cumulative Runoff Volume (ac-ft)		
	1-yr 24-hr	5-yr 24-hr	100-yr 24-hr	1-yr 24-hr	5-yr 24-hr	100-yr 24-hr
1	2.020	3.495	7.753	79.7	137.8	305.8
2	2.195	3.702	8.000	86.6	146.0	315.5
3	2.240	3.754	8.060	88.4	148.1	317.9

The depths and extents of inundation simulated by the XPSWMM models for the impervious Scenarios and design storms are shown in Figure 19 to Figure 27. The change in inundation extents and depths for Scenarios 3 and 2 compared to Scenario 1 are shown in Figure 28 to Figure 33. The results of the H&H modeling for the Scenarios in terms of key indicators are summarized in Table 10 and actual flooding incidents are shown in Table 11.

Table 10. XPSWMM Results Summary for the CAH Watershed.

Indicator	1-year 24-hour			5-year 24-hour			100-year 24-hour		
	Scn 1	Scn 2	Scn 3	Scn 1	Scn 2	Scn 3	Scn 1	Scn 2	Scn 3
Acres of inundation	38.1	39.9	40.8	54.2	65.3	70.4	75.9	89.8	91.6
Depth range of inundation on private properties (ft)	2.98	3.00	3.06	4.26	6.37	7.51	5.53	8.48	9.25
Average increase in private property inundation depth (ft)	-	0.001	0.022	-	0.256	0.433	-	0.466	0.537
Maximum increase in private property inundation depth (ft)	-	0.47	0.49	-	2.43	3.71	-	4.39	5.31
Depth range of inundation on roads (ft)	5.65	10.49	11.27	5.79	12.39	13.55	6.33	12.75	13.77
Average increase in inundation depth on roads (ft)	-	0.006	0.027	-	0.375	0.583	-	0.589	0.658
Average length of time inlets are surcharging (mins)	380.1	465.0	554.0	173.0	490.0	558.6	415.5	511.2	569.2
Number of flood prone properties*	247	249 (205)	252 (251)	316	362 (362)	381 (381)	424	468 (467)	473 (473)

*The number in parenthesis represents the number of flood prone properties with increased inundation depths.

Table 11. Table of Actual Reported Flood Incidents since 2000 for the CAH Watershed.

Reported Flooding Type	Count in CAH
Structure	24
Vehicle	24
Rescue	2
Road Overtop	33
Other (Fire Response and General Investigation)	3
FEMA Classified Repetitive Loss Structure	4

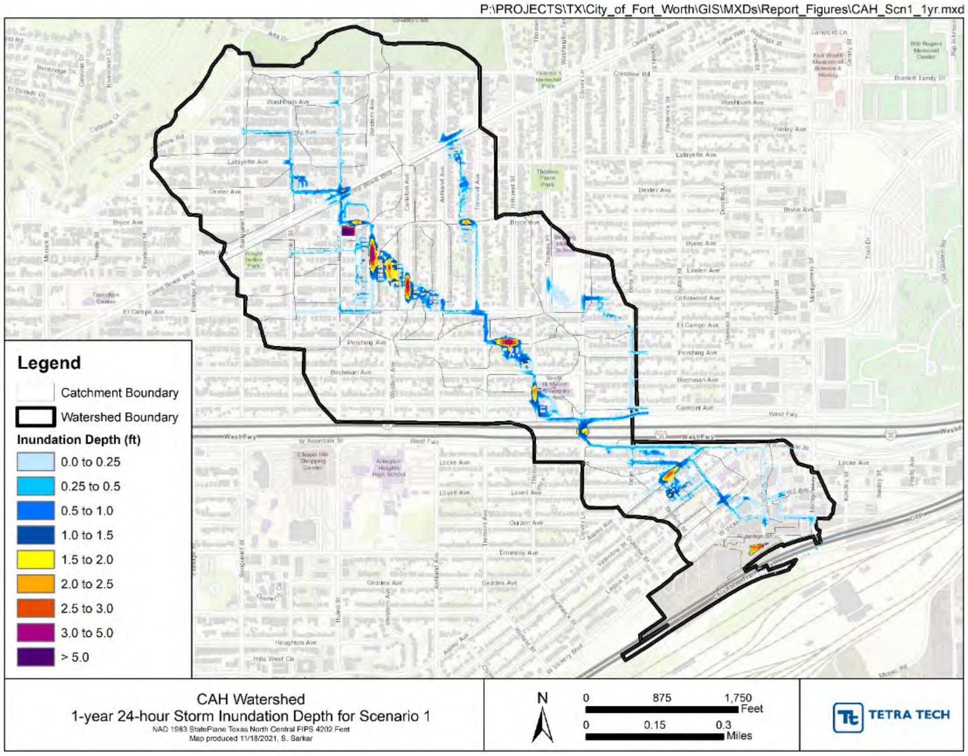

Figure 19. Inundation Depth and Extent for 1-year 24-Storm for CAH Watershed Scenario 1.

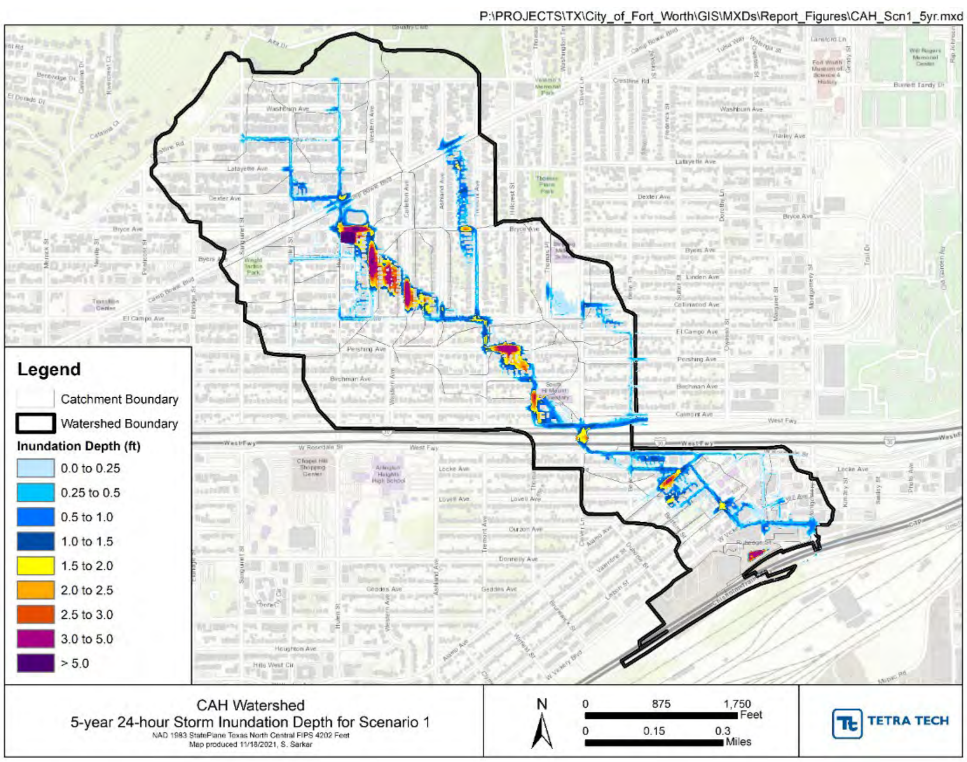

Figure 20. Inundation Depth and Extent for 5-year 24-Storm for CAH Watershed Scenario 1.

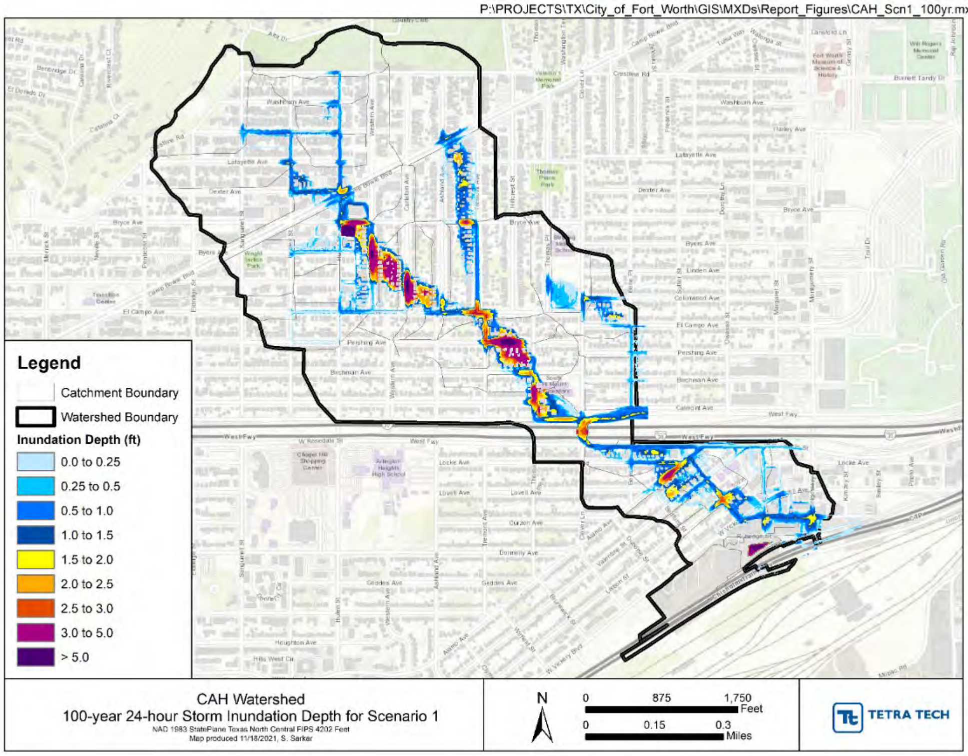

Figure 21. Inundation Depth and Extent for 100-year 24-Storm for CAH Watershed Scenario 1.

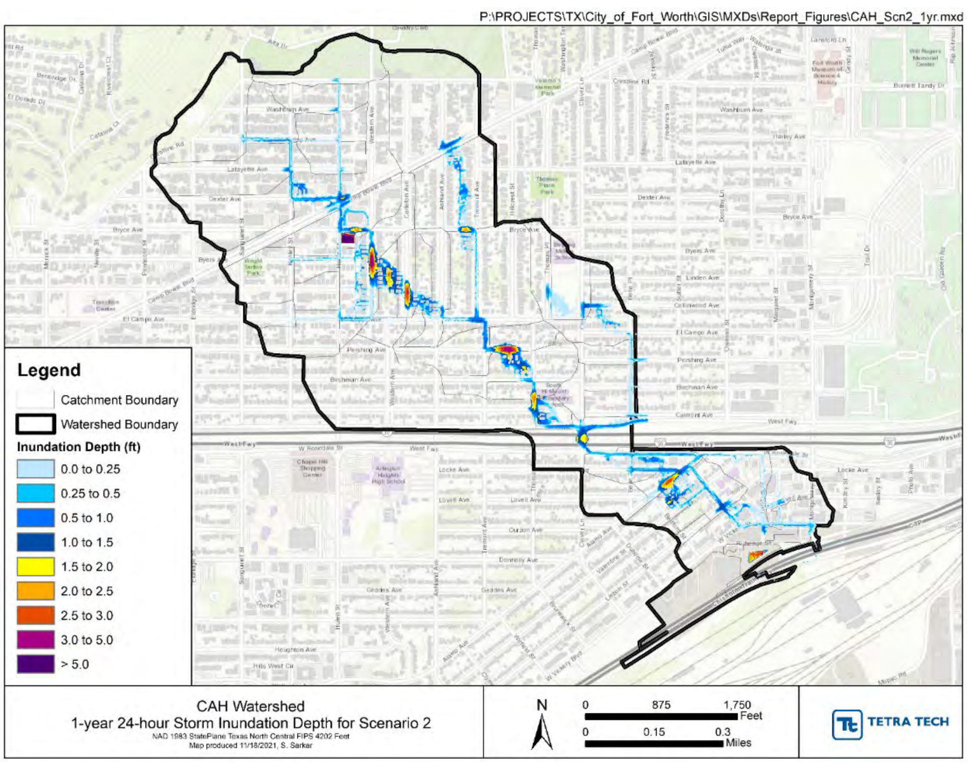

Figure 22. Inundation Depth and Extent for 1-year 24-Storm for CAH Watershed Scenario 2.

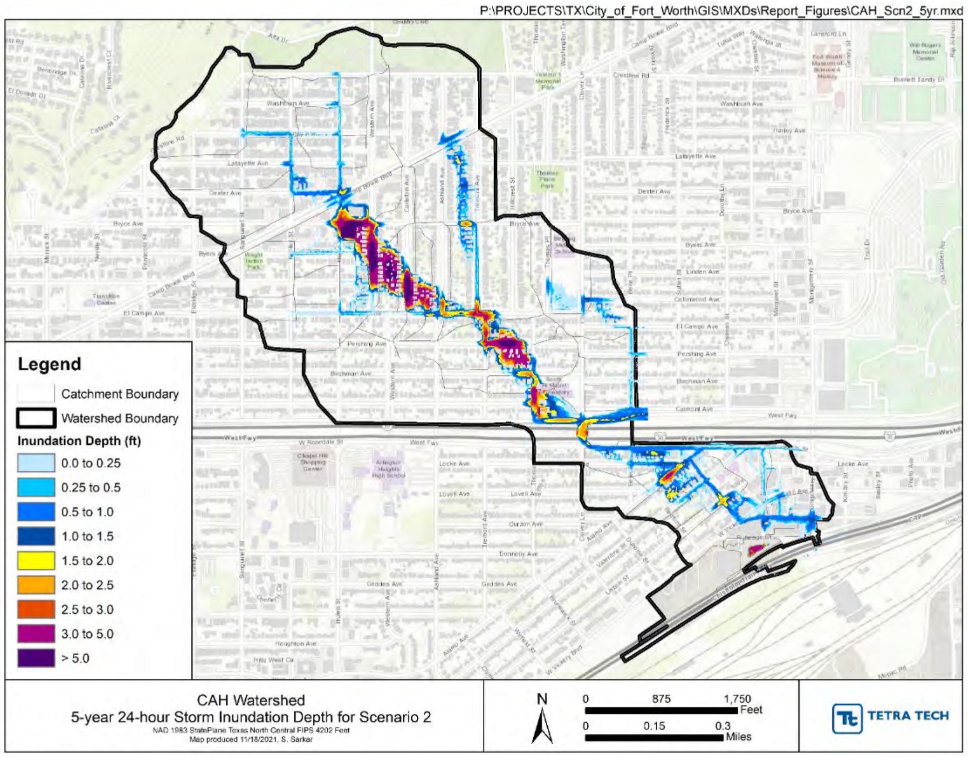

Figure 23. Inundation Depth and Extent for 5-year 24-Storm for CAH Watershed Scenario 2.

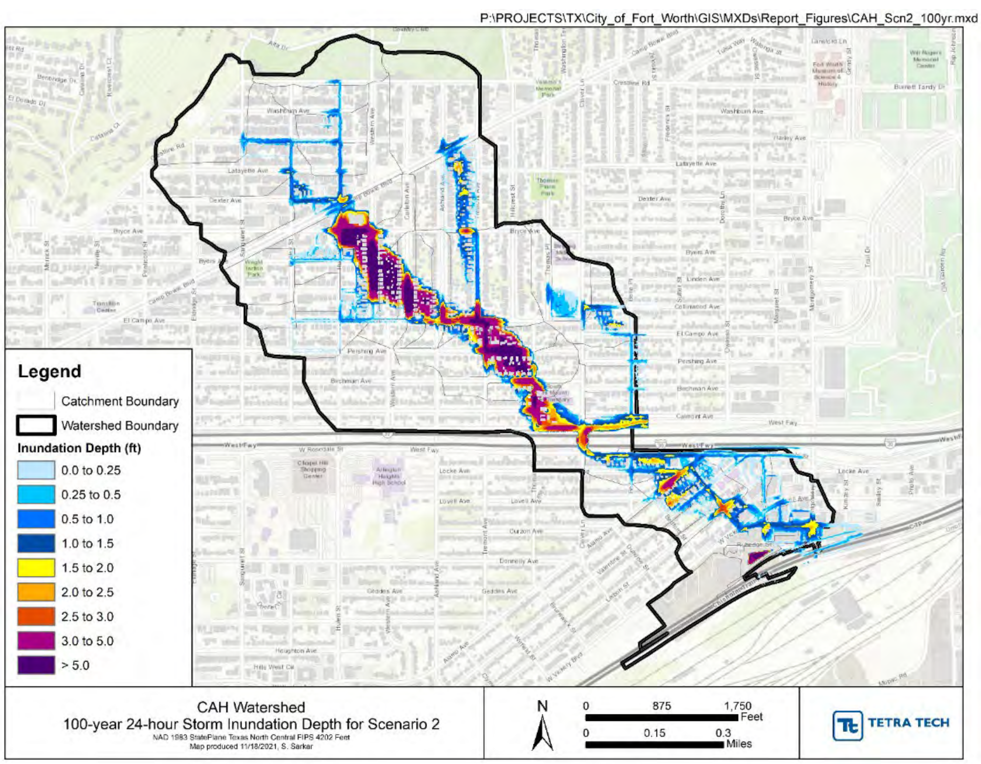

Figure 24. Inundation Depth and Extent for 100-year 24-Storm for CAH Watershed Scenario 2.

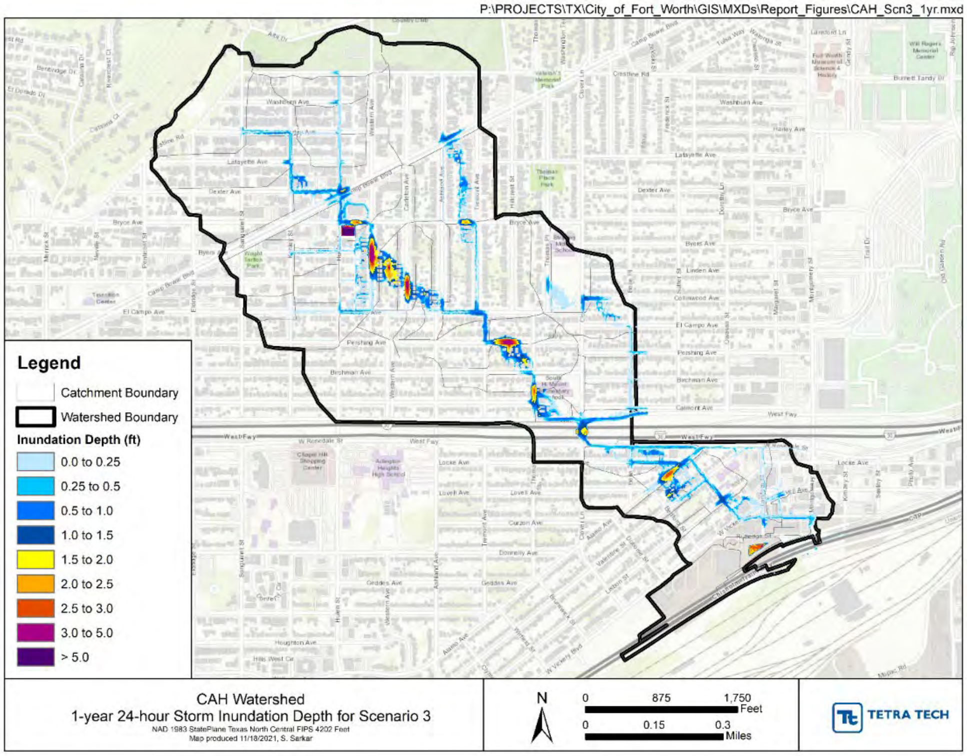

Figure 25. Inundation Depth and Extent for 1-year 24-Storm for CAH Watershed Scenario 3.

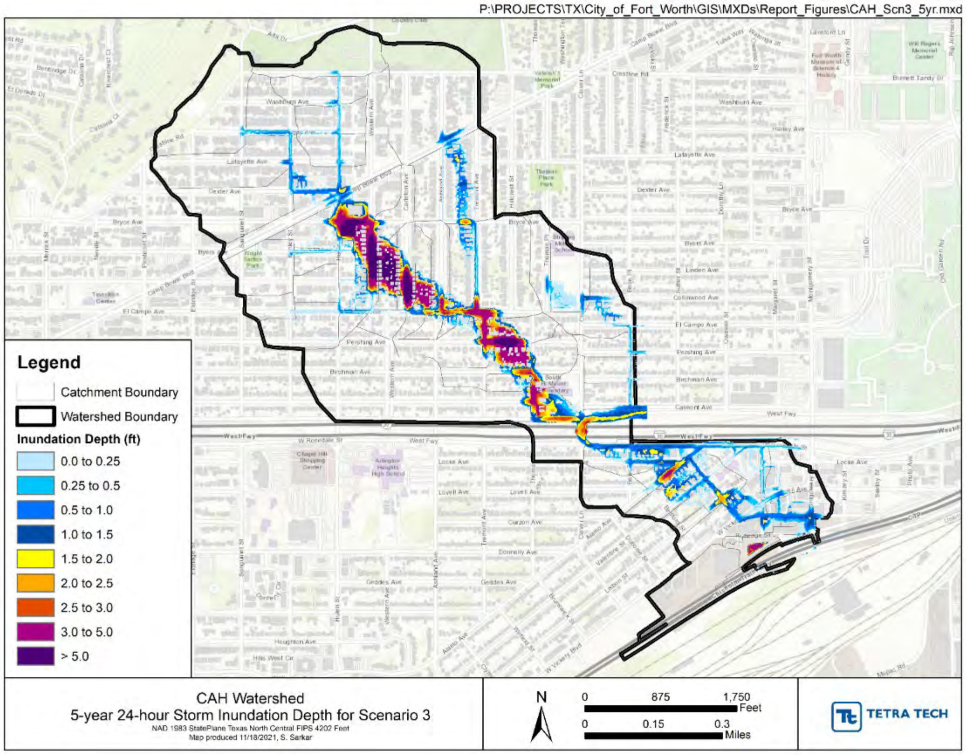

Figure 26. Inundation Depth and Extent for 5-year 24-Storm for CAH Watershed Scenario 3.

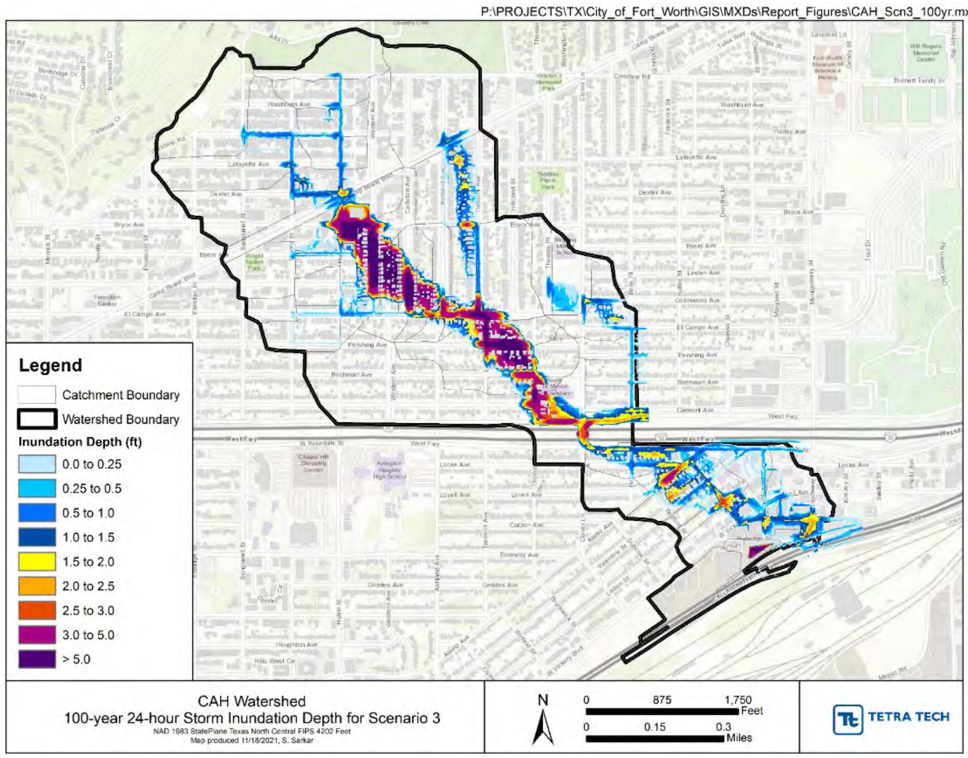

Figure 27. Inundation Depth and Extent for 100-year 24-Storm for CAH Watershed Scenario 3.

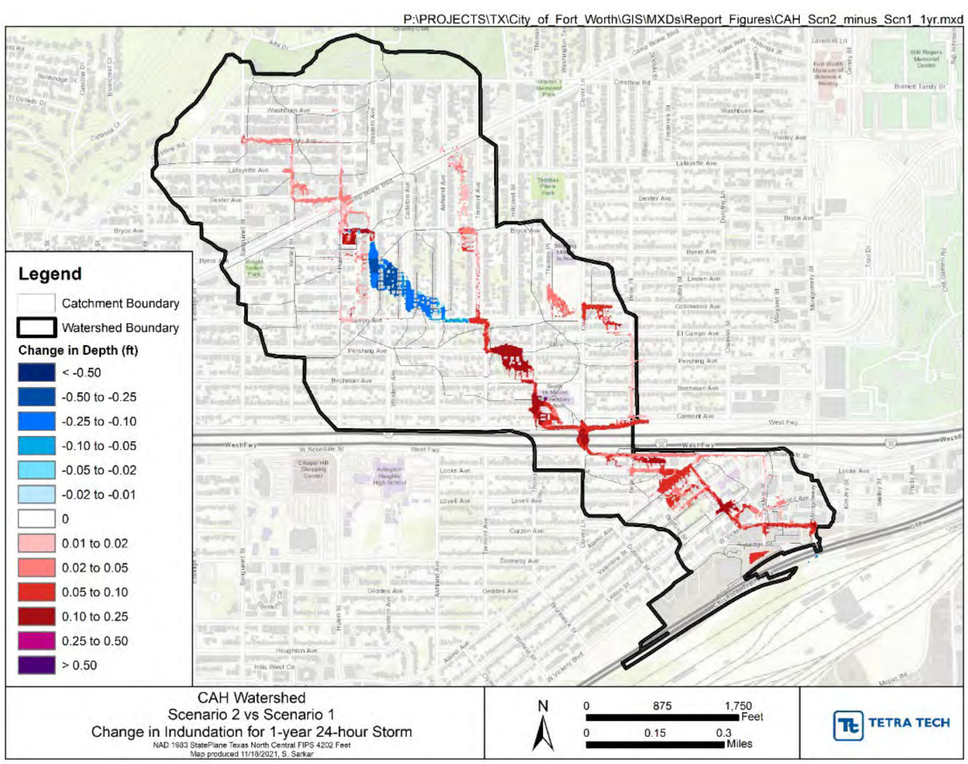

Figure 28. Change in Inundation Depth and Extent for 1-year 24-Storm for Scenario 2 vs Scenario 1.

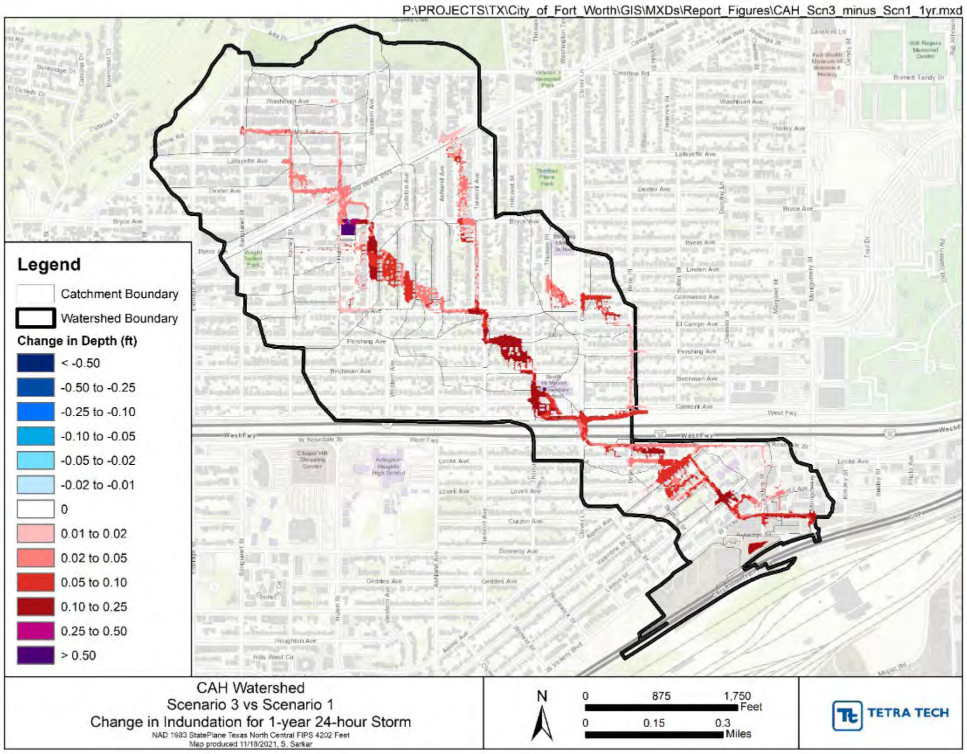

Figure 29. Change in Inundation Depth and Extent for 1-year 24-Storm for Scenario 3 vs Scenario 1.

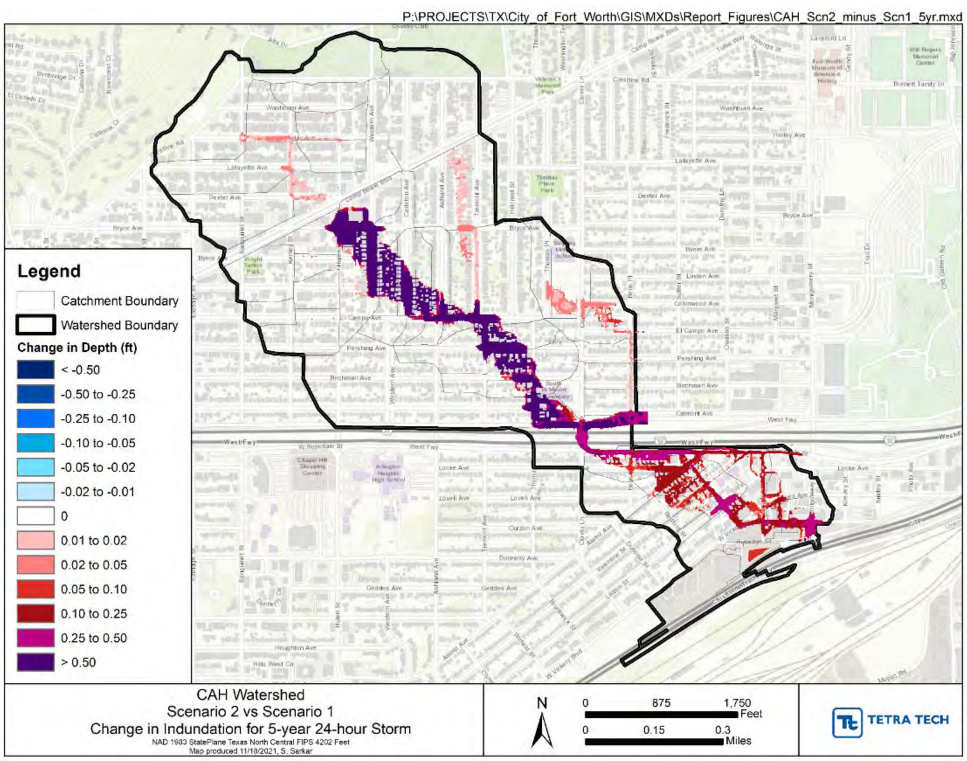

Figure 30. Change in Inundation Depth and Extent for 5-year 24-Storm for Scenario 2 vs Scenario 1.

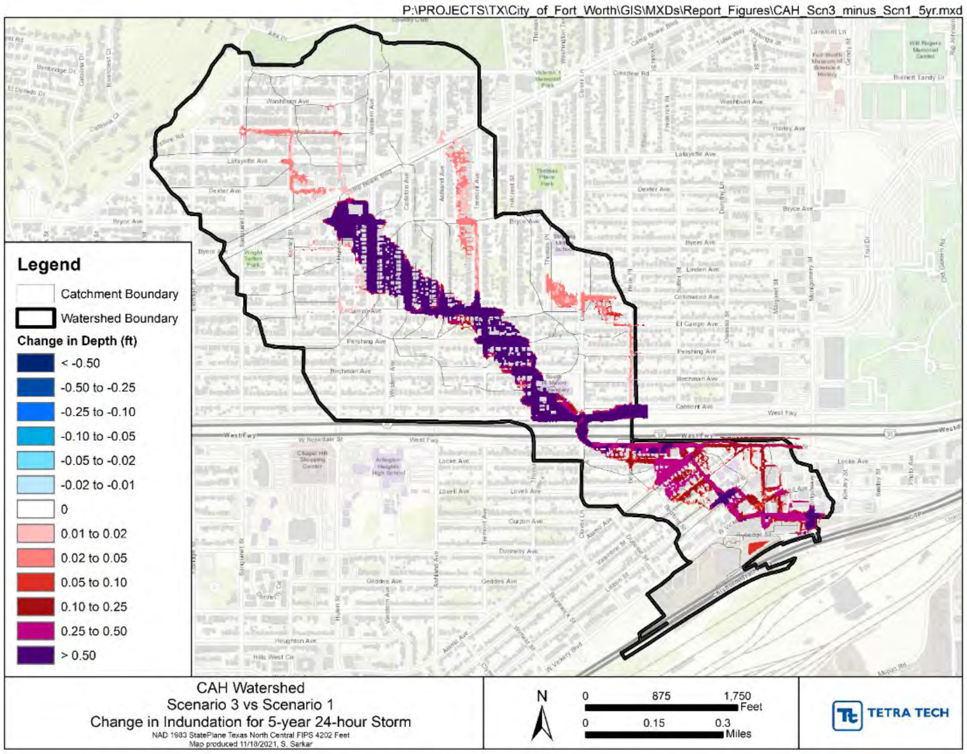

Figure 31. Change in Inundation Depth and Extent for 5-year 24-Storm for Scenario 3 vs Scenario 1.

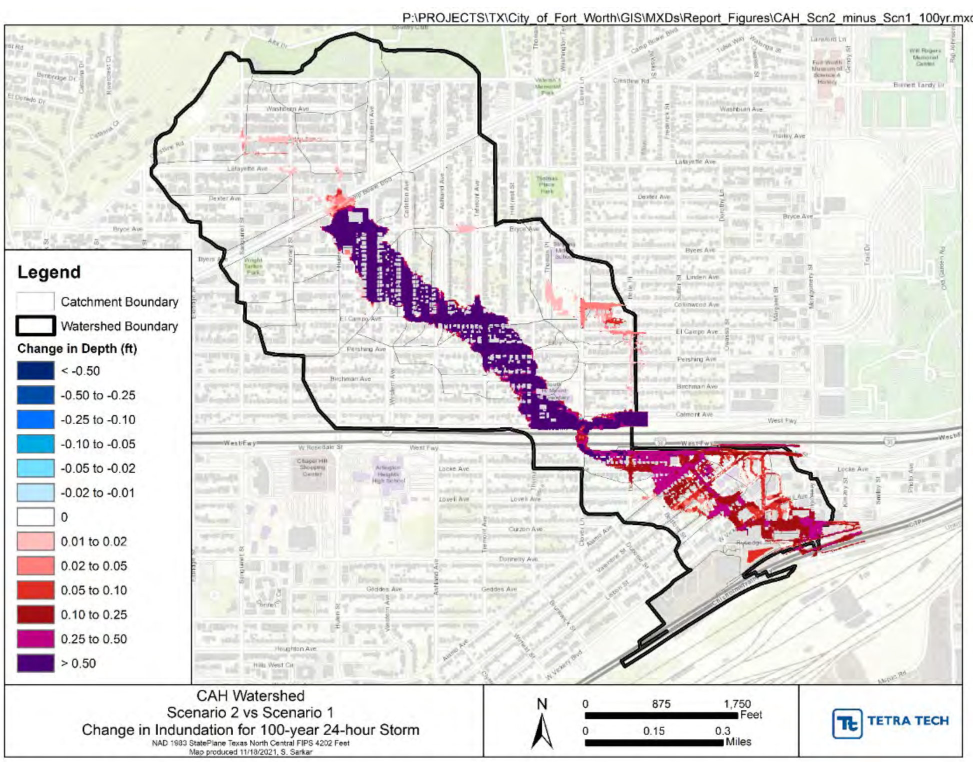

Figure 32. Change in Inundation Depth and Extent for 100-year 24-Storm for Scenario 2 vs Scenario 1.

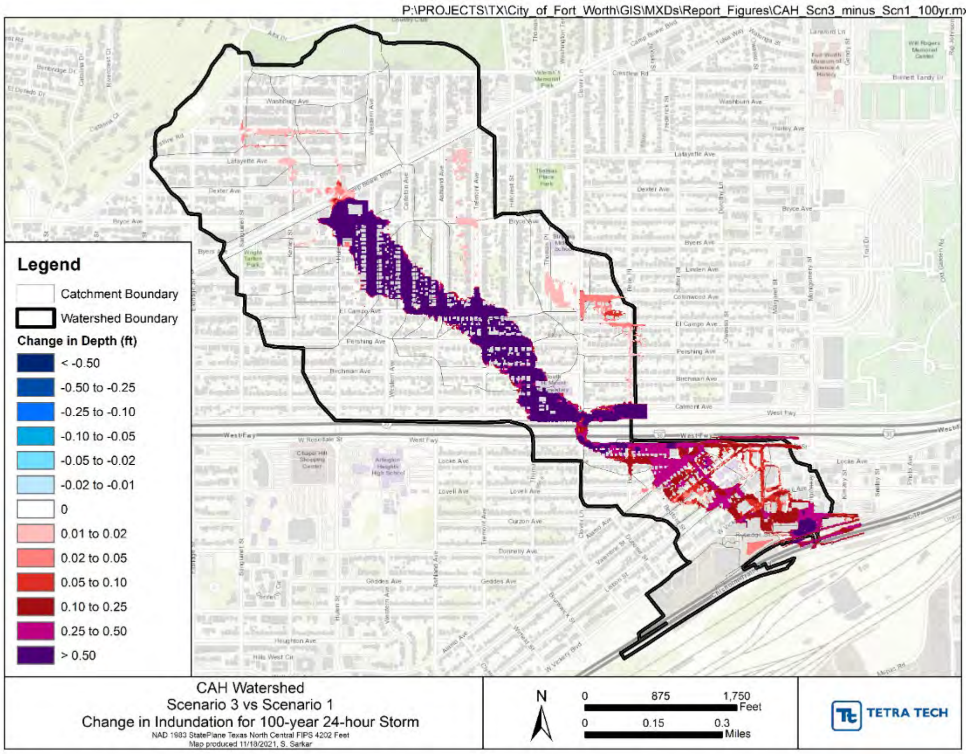

Figure 33. Change in Inundation Depth and Extent for 100-year 24-Storm for Scenario 3 vs Scenario 1.

3.3 LB Watershed

3.3.1 Impervious Cover

Percent imperviousness at the parcel scale were aggregated to the catchment scale using an area-weighing approach. Catchment scale imperviousness for Scenarios 1, 2, and 3 are shown in Figure 34, Figure 35, and Figure 36, respectively, and summarized in Table 12.

Table 12. LB Percent Imperviousness for Scenarios 1, 2, and 3.

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
1	MH004695A	10	60.019	90.907	96.102
2	MH005493A	100	75.559	85.476	91.083
3	MH005383A	101	75.439	88.543	93.652
4	MH005384A	102	57.048	79.554	83.310
5	MH004729A	103	84.992	87.712	92.343
6	MH004730A	104	90.744	88.881	93.988
7	MH004707A	105	90.774	89.100	93.038
8	MH004701	106	92.639	89.711	93.635
9	MH004728	107	79.741	85.076	88.971
10	MH004715	108	77.677	80.290	88.977
11	MH004714	109	89.239	79.205	89.635
12	MH004717	110	89.567	81.268	92.944
13	MH005493	111	89.594	80.100	92.185
14	MH005487	112	80.984	80.961	81.198
15	MH004691	113	85.994	82.559	92.888
16	MH004719	114	89.132	83.749	95.346
17	MH004035A	115	77.142	82.812	91.752
18	MH014695A	116	69.438	80.120	90.442
19	MH005907	117	90.817	88.572	93.449
20	MH014100	118	80.191	82.858	87.826
21	MH004699	119	77.276	82.704	88.435
22	MH004708	120	69.787	78.930	83.806
23	MH005908	121	76.192	83.968	87.738
24	MH005834A	122	82.970	88.754	93.165
25	MH004697	123	65.293	82.427	86.392

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
26	MH005834	124	90.414	87.192	91.545
27	MH004690	125	83.868	88.358	92.654
28	MH004709	126	69.017	80.894	92.103
29	MH005321	127	42.210	55.562	64.739
30	MH005910	128	67.960	77.727	87.482
31	MH005328	129	72.939	78.549	89.904
32	MH005329	130	92.484	91.841	95.011
33	MH005486B	131	61.360	74.409	75.018
34	MH012101C	132	72.458	88.137	90.811
35	MH005308	133	94.206	92.293	94.992
36	MH005320	134	67.853	74.155	84.126
37	MH005327	135	73.656	82.475	88.456
38	MH005322	136	59.281	82.878	90.354
39	MH005323	137	46.158	76.092	85.765
40	MH005326	138	85.717	89.956	90.693
41	MH005325A	139	91.636	91.651	93.252
42	MH005325	140	92.083	92.593	93.781
43	MH005333	141	88.324	92.530	94.465
44	MH005330	142	82.851	89.764	91.07
45	MH005334	143	77.803	92.257	93.158
46	MH005337	144	83.949	90.594	92.21
47	MH005332	145	87.800	90.464	92.242
48	MH005335	146	93.675	93.552	95.796
49	MH005336	147	98.358	96.585	98.404
50	MH005331	148	87.727	91.437	93.015
51	IF005415	149	75.212	83.610	88.65
52	IN037719A	150	58.781	92.864	95.70
53	MH005315	151	88.250	87.846	89.283
54	MH012101	152	92.775	91.190	93.298
55	IF009284	153	56.320	78.192	79.634
56	MH005311	154	89.177	92.579	94.842

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
57	MH005317	155	90.211	95.212	96.940
58	MH005312	156	91.871	93.755	96.198
59	MH005316	157	92.382	92.753	94.218
60	MH005309	158	88.625	88.709	89.953
61	MH012100	159	59.801	89.722	91.882
62	MH012108	160	69.379	90.595	92.577
63	IF005415	161	28.699	90.000	95.000
64	MH008289A	162	58.851	88.129	92.199
65	MH008290B	163	54.765	87.285	91.74
66	MH008274	164	62.642	85.434	89.482
67	MH008278	165	29.919	78.686	82.999
68	MH008279	166	37.484	85.146	89.281
69	MH008282	167	44.067	84.638	88.580
70	MH008276	168	60.079	83.677	87.782
71	MH008275	169	73.437	89.369	94.359
72	MH013460	170	64.018	89.795	94.504
73	LB1	171	81.865	89.739	94.062
74	LB4	172	73.177	90.846	95.423
75	MH005911	173	85.209	84.382	87.389
76	MH005377A	174	93.674	90.000	95.846
77	MH005379A	175	95.479	89.730	95.953
78	MH012993A	176	55.503	89.218	94.131
79	MH005918	177	72.263	90.000	95.553
80	MH005917E	178	93.934	90.000	95.003
81	MH005917J	179	87.849	90.379	94.822
82	MH005917B	180	61.169	90.222	95.000
83	MH005917A	181	74.989	90.000	95.071
84	MH004705B	182	69.918	89.207	94.516
85	MH005382	183	68.096	77.591	80.565
86	LB10	184	35.718	37.786	36.344
87	MH014510	185	99.405	92.933	99.405

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
88	LB11	186	78.051	91.020	98.350
89	MH005380	188	73.644	75.163	77.186
90	MH004734	189	61.819	75.091	81.945
91	MH005381	190	68.647	79.372	82.604
92	MH012429C	57	80.931	82.633	91.286
93	MH004036	58	79.079	76.340	86.654
94	MH004037	59	85.333	24.155	85.333
95	MH008122	60	67.238	90.473	93.496
96	MH012429B	61	93.545	91.575	95.637
97	MH012429A	62	85.046	89.295	93.126
98	MH004726	63	88.322	87.016	94.253
99	MH004723B	64	73.245	81.016	92.216
100	MH004859	65	83.681	53.505	90.302
101	FR1	66	53.011	61.000	90.000
102	MH004710	67	63.843	51.552	70.402
103	MH004713	68	60.028	80.640	88.147
104	MH007597	69	67.406	81.028	94.726
105	MH004727A	70	61.570	79.342	93.245
106	MH013005	71	70.714	64.537	85.305
107	MH004704	72	91.439	87.340	92.575
108	MH004733	73	89.044	88.243	92.807
109	MH004022	74	91.055	88.509	92.686
110	MH004732	75	88.908	88.231	92.404
111	MH004707	76	87.536	84.518	88.649
112	MH004702	77	92.640	87.706	92.640
113	MH004686	78	80.046	86.404	91.773
114	MH005490	79	79.268	82.385	91.650
115	MH005640	80	91.617	87.062	93.589
116	MH012430	81	83.126	87.406	93.457
117	MH008130C	82	94.451	90.488	96.138
118	MH008130B	83	93.280	89.251	93.902

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
119	MH008130	84	87.538	83.437	87.701
120	MH012436	85	51.836	67.649	84.762
121	MH004039	86	70.109	81.358	88.018
122	MH012496	87	55.617	77.061	85.497
123	MH004041	88	52.945	74.164	82.958
124	MH005489B	89	58.405	68.522	83.038
125	MH012435	90	59.542	65.136	80.916
126	MH005489B	91	59.558	74.557	85.649
127	MH004689C	92	79.870	77.468	86.514
128	MH004688	93	62.408	69.502	87.489
129	MH005494	94	81.434	82.045	84.985
130	MH005909	95	84.706	85.271	88.772
131	MH004687	96	85.219	85.300	92.850
132	MH007596	97	81.965	88.381	92.904
133	MH004686	98	88.563	85.457	89.879
134	MH005492A	99	58.888	71.763	86.032
135	A1	A1	13.703	60.847	85.522
136	A13	A13	47.902	63.004	82.149
137	A15	A15	43.654	63.382	82.280
138	A2	A2	42.413	61.133	84.901
139	A25	A25	43.779	62.665	80.340
140	A8	A8	58.065	67.023	84.488
141	A9a	A9a	40.793	51.193	70.935
142	B1	B1	65.956	73.060	87.913
143	B5	B5	50.313	68.505	85.443
144	C1	C1	54.020	74.042	83.768
145	C8	C8	46.391	66.635	82.883
146	MH005492	CEM	22.191	63.537	24.352
147	D1	D1	54.561	67.643	84.312
148	D4	D4	31.784	43.861	55.050
149	D5	D5	83.818	92.475	92.487

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
150	H3a	H3a	90.125	93.932	94.091
151	IB1	IB1	55.775	71.270	85.734
152	IB2	IB2	86.502	86.744	86.744
153	IC1	IC1	69.717	71.310	86.710
154	IC2	IC2	86.871	89.576	89.576
155	IC3	IC3	77.168	78.089	90.324
156	IC4	IC4	89.738	91.022	91.022
157	ID1	ID1	94.445	94.724	94.724
158	M1	M1	64.064	76.309	85.534
159	M2	M2	57.000	78.972	88.421
160	OW	OW	49.484	65.760	79.909
161	MH010575A	X1	88.247	7.000	88.247
162	MH004929	X2	88.247	7.000	88.247
163	MH004925	X3	88.247	7.000	88.247
164	MH004927C	X4	82.347	21.429	82.347
165	MH004927B	X5	89.104	18.842	89.132
166	MH004927	X6	90.151	31.142	90.289
167	MH005511A	X7	92.004	80.220	93.626
168	MH005511	X8	91.791	92.932	93.016
169	CR-1	X9	59.307	21.554	59.643
170	MH005512A	Y1	47.429	62.480	83.912
171	MH005868	Y10	45.898	64.084	87.239
172	MH005867	Y11	48.029	64.191	87.067
173	MH005181	Y12	47.851	58.584	82.517
174	MH005181D	Y13	36.972	42.298	53.604
175	MH005181C	Y14	33.616	37.245	46.556
176	MH005181B	Y15	45.974	53.048	62.157
177	IN009216D	Y16	45.364	64.024	84.509
178	IN009216C	Y17	40.597	59.698	85.256
179	IN009216A	Y18	57.311	75.347	74.308
180	MH005181A1	Y19	52.241	69.042	85.787

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
181	MH005458	Y2	53.449	63.335	82.641
182	MH005179	Y3	53.751	63.212	84.159
183	MH005177	Y4	50.873	62.870	83.592
184	MH012969F	Y5	49.038	63.106	83.086
185	MH012969D	Y6	59.661	70.031	86.701
186	MH012969C	Y7	55.685	67.554	83.304
187	MH012969A	Y8	54.608	66.307	83.714
188	MH005180	Y9	51.194	66.651	86.071
189	MH004864C	Z1	50.269	63.889	85.138
190	MH004916	Z10	70.380	78.434	94.266
191	MH010573A	Z11	72.873	76.877	92.564
192	MH004920	Z12	77.228	79.808	92.433
193	MH004862D	Z13	88.247	7.000	88.247
194	MH004862C	Z14	88.247	7.000	88.247
195	MH004862B	Z15	88.247	7.000	88.247
196	MH004862A	Z16	88.247	7.000	88.247
197	MH004862A	Z17	88.247	7.000	88.247
198	MH004904	Z18	74.811	44.538	75.26
199	MH004860	Z19	88.325	17.357	88.325
200	MH004864A	Z2	58.298	69.412	89.071
201	MH004908	Z20	90.343	30.724	90.343
202	MH004860C	Z21	89.020	16.831	89.02
203	MH004861A	Z22	88.247	7.000	88.247
204	MH004866	Z23	88.582	23.028	88.582
205	MH004907	Z24	89.202	15.509	89.202
206	MH004921C	Z25	89.048	18.117	89.048
207	MH004898B	Z26	91.195	52.249	91.257
208	MH004900B	Z27	92.650	92.261	94.592
209	MH004903	Z28	78.213	81.599	92.882
210	MH004864	Z3	52.427	62.657	84.085
211	MH004863A	Z4	69.215	79.737	90.498

ID	XPSWMM Node ID	Catchment Name	Percent Imperviousness		
			Scenario 1	Scenario 2	Scenario 3
212	MH004863	Z5	52.946	68.878	86.065
213	MH013049A	Z6	58.890	71.452	86.087
214	MH013049	Z7	79.234	78.805	90.744
215	MH010581	Z8	52.569	64.109	80.933
216	MH010573B	Z9	55.068	69.784	87.015

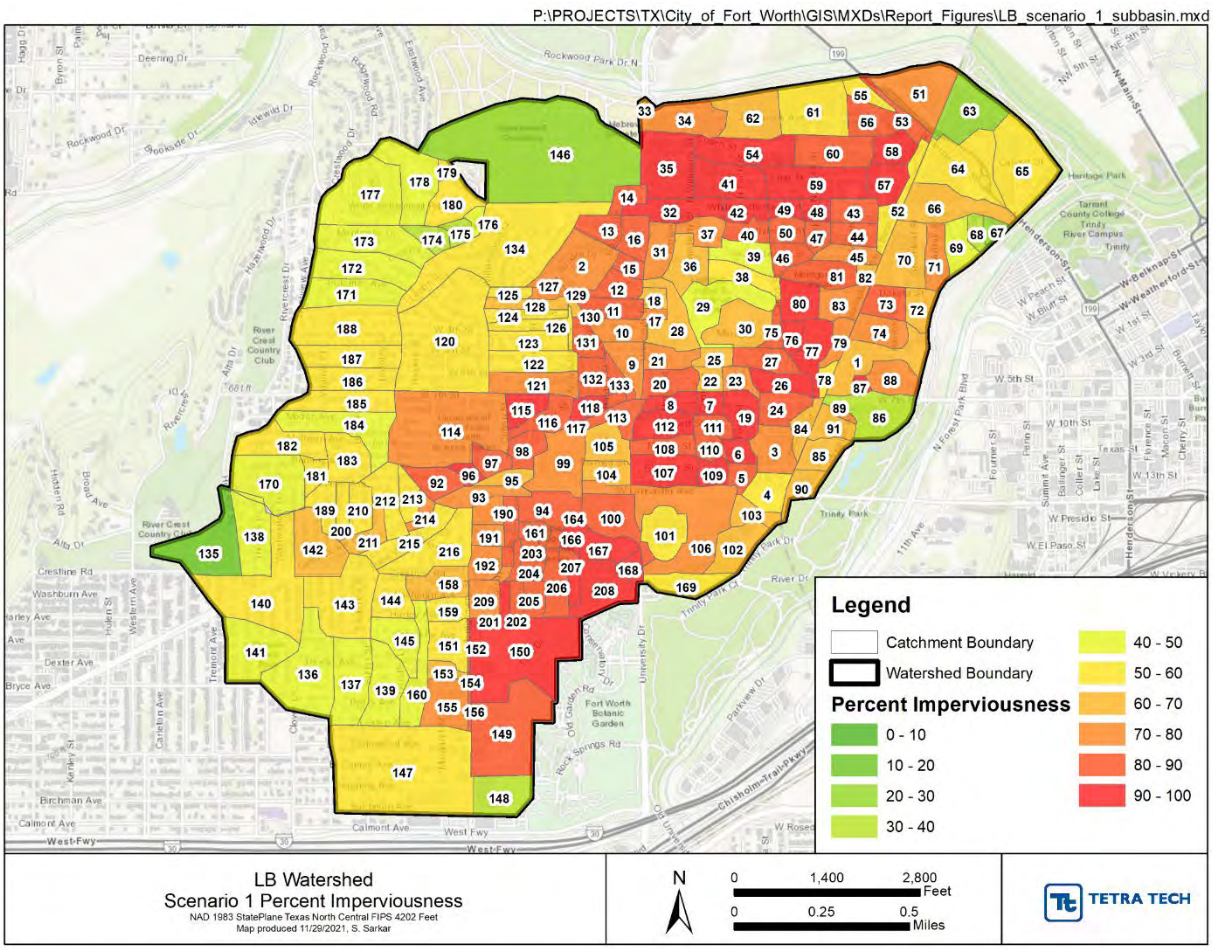

Figure 34. Scenario 1 Imperviousness at the Catchment Scale for the LB Watershed.

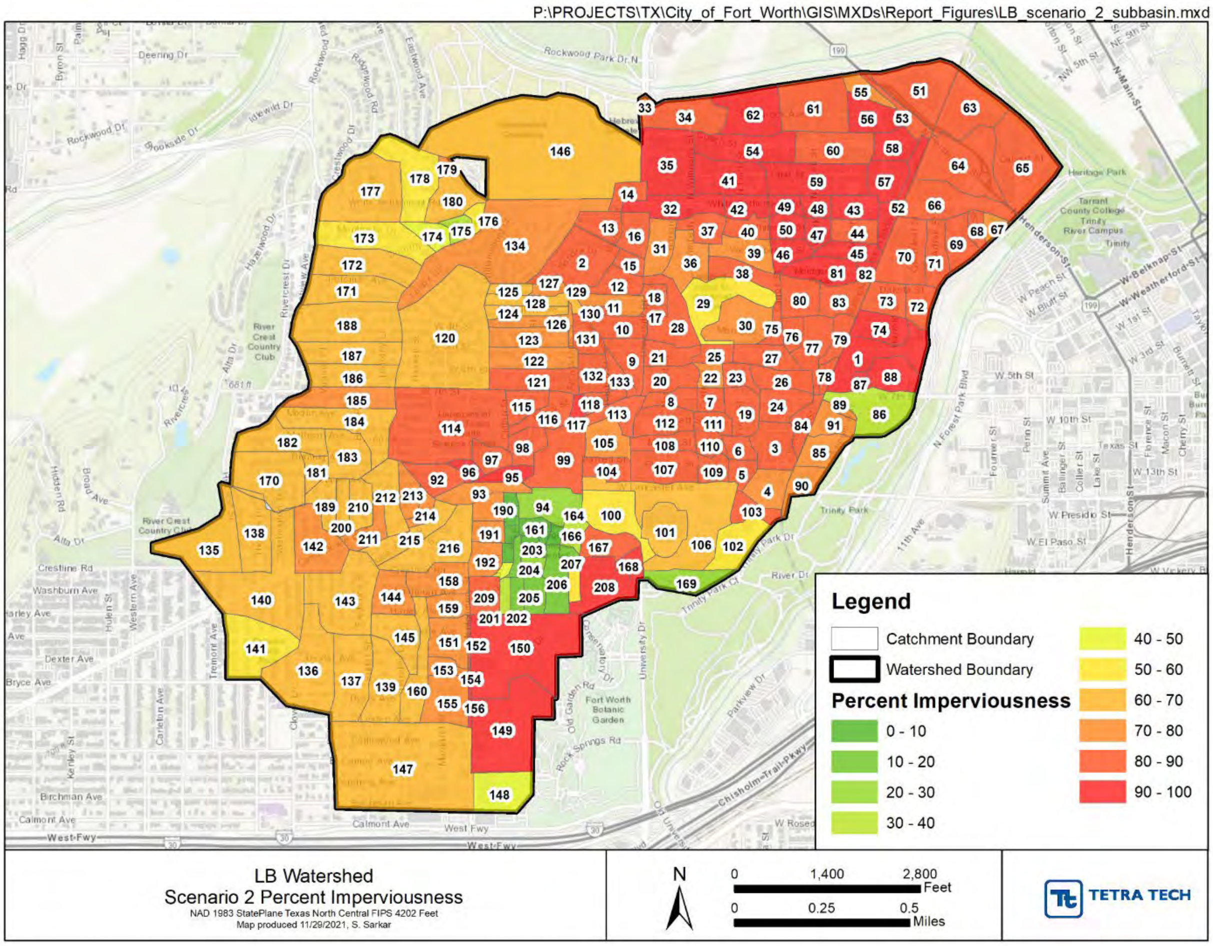

Figure 35. Scenario 2 Imperviousness at the Catchment Scale for the LB Watershed.

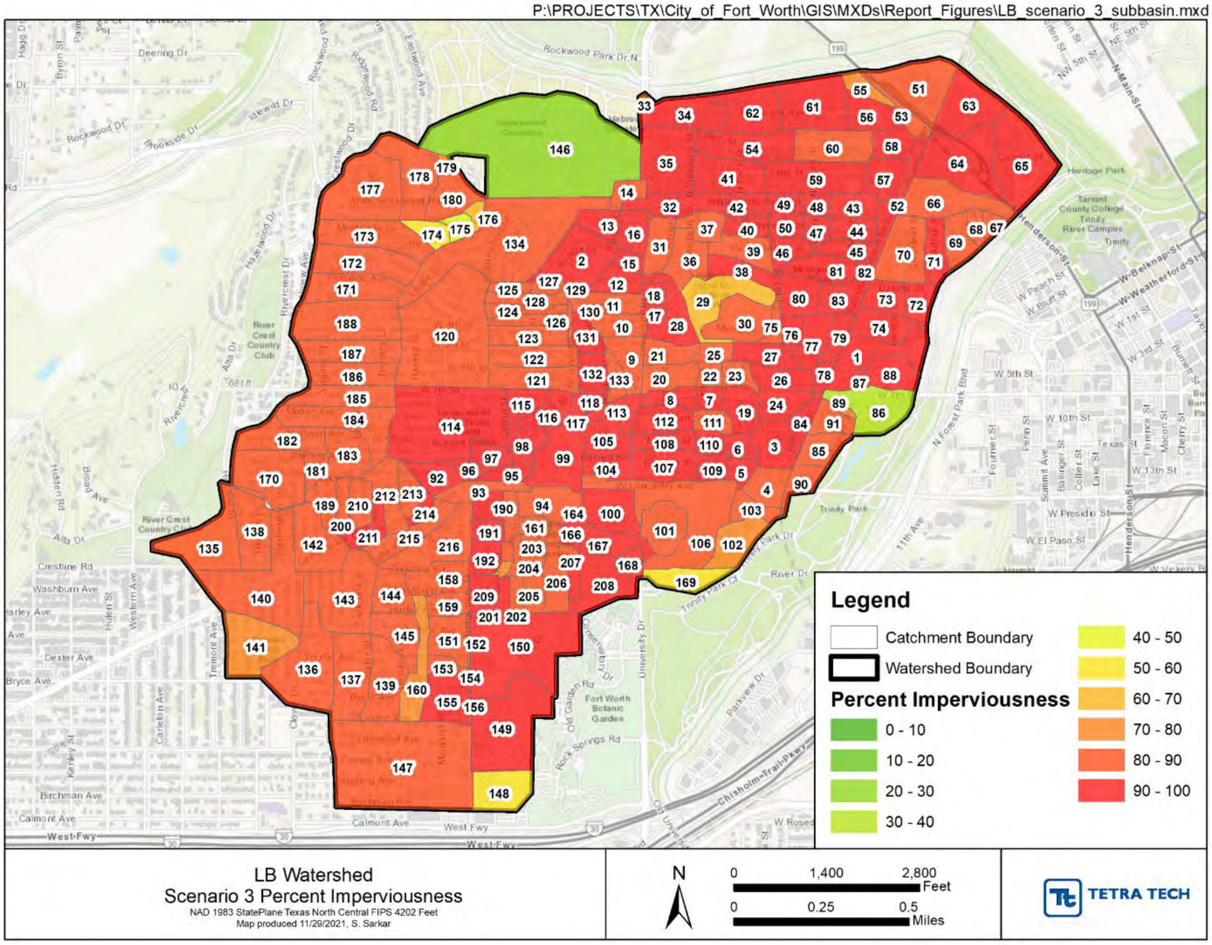

Figure 36. Scenario 3 Imperviousness at the Catchment Scale for the LB Watershed.

3.3.2 Land Use and Pervious Curve Numbers

Land use in the LB watershed based on the City's zoning classification is shown in Figure 17. Pervious curve numbers (CN) were determined using hydrologic soil group (HSG) information reported by the US Soil Survey Geographic (SSURGO) database for Tarrant County. The major soils reported for the watershed are Aledo (D), Batsil (B), Bolar (C), Frio (C), Luckenbach (C), Purves (D), Sanger (D), Sunev (B) and Urban Land (D). Pervious curve numbers of 61, 74 and 80 were used for HSG B, C and D soils, respectively, equivalent to open space in good hydrologic condition. The assumption of open space in good condition for pervious areas is consistent with the methods implemented in the iSWM Hydrology Technical Manual (NCTCOG, 2020) for calculation of composite curve numbers of urban land uses. **Pervious curve numbers at the catchment scale were specified in the XPSWMM models and do not change across the impervious Scenarios.** XPSWMM internally calculates a composite curve number for each impervious Scenario based on catchment percent imperviousness, pervious curve number and an assumed impervious curve number of 98.

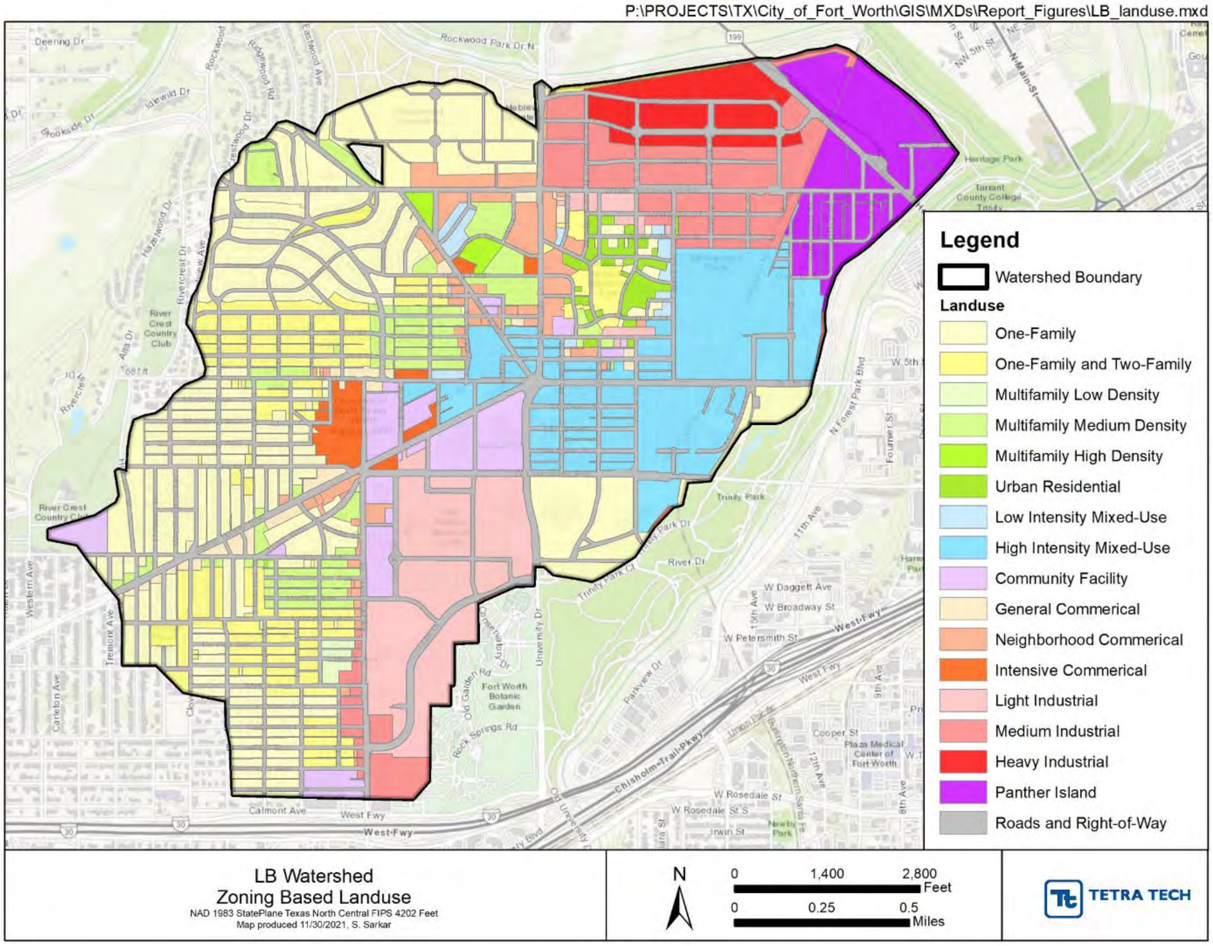

Figure 37. Land Use in the LB Watershed.

3.3.3 Longest Flow Path and Travel Time

The longest flow path for each catchment in the LB watershed were determined using Arc Hydro Tools. The following procedure was implemented.

7) Export each catchment as a separate polygon using the “Split by Attributes” tool in ArcGIS.
8) Save DEM for the LB watershed as “LevelDEM” in ArcGIS.
9) Perform “DEM Reconditioning” to burn in streams in Arc Hydro Tools. Since both watersheds are urban with no defined stream features, the streamlines for each catchment consisted of the portion of the storm pipe from the runoff node to its intersection with the catchment boundary. This ensures that longest flow paths generally terminate at the runoff node for each catchment.
10) Run “Fill Sinks” to remove sinks in the DEMs setting the fill threshold to 100-ft in Arc Hydro Tools. The burnt in streams are filled if a threshold is not specified.
11) Run “Flow Direction” on the filled DEM with the watershed polygon as the outer wall in Arc Hydro Tools.
12) Run “Longest Flow Path for Catchments” in batch mode for each catchment polygon in Arc Hydro Tools using the flow direction grid.

The travel time for each catchment in the LB watershed was determined using the following procedure. The sheet flow, shallow concentrated flow and total travel times for catchments in the LB watershed are summarized in Table 13, Table 14, and Table 15, respectively. **Note that the travel times at the catchment scale are the same across the impervious Scenarios.**

6) Run "Define TR55 Zones for Longest Flow Path" in Arc Hydro Tools setting the overland flow distance to 50-ft.
7) Calculate slopes for the TR55 segments using "Compute Line Parameters" in Arc Hydro Tools.
8) Assign Manning's n value of 0.011 (smooth surfaces) or 0.15 (grass) based on visual inspection of aerials for the sheet flow length.
9) Determine if the shallow concentrated flow segments are going over "unpaved" or "paved" areas. Split the shallow concentrated flow segments as needed if they are going over both unpaved and paved areas.
10) Determine travel time in minutes for sheet flow and shallow concentrated flow using equations 1.9, 1.10, 1.11 and 1.12 in the iSWM Hydrology Technical Manual (NCTCOG, 2020). Sum sheet flow and shallow concentrated flow travel times to get total travel time setting a minimum total travel time to 6 minutes.

Table 13. LB Catchments Sheet Flow Travel Times.

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr rainfall, in)	T_{sheet} (min)
1	MH004695A	10	50	0.175	0.150	3.522	2.3
2	MH005493A	100	50	0.043	0.011	3.522	0.5
3	MH005383A	101	50	0.019	0.150	3.522	5.5
4	MH005384A	102	50	0.093	0.150	3.522	2.9
5	MH004729A	103	50	0.041	0.011	3.522	0.5
6	MH004730A	104	50	0.015	0.011	3.522	0.7
7	MH004707A	105	50	0.037	0.011	3.522	0.5
8	MH004701	106	50	0.038	0.011	3.522	0.5
9	MH004728	107	50	0.020	0.011	3.522	0.7
10	MH004715	108	50	0.007	0.011	3.522	1.0
11	MH004714	109	50	0.024	0.011	3.522	0.6
12	MH004717	110	50	0.052	0.011	3.522	0.5
13	MH005493	111	50	0.043	0.011	3.522	0.5
14	MH005487	112	50	0.013	0.011	3.522	0.8
15	MH004691	113	50	0.028	0.011	3.522	0.6
16	MH004719	114	50	0.020	0.011	3.522	0.7
17	MH004035A	115	50	0.009	0.011	3.522	0.9
18	MH014695A	116	50	0.036	0.011	3.522	0.5
19	MH005907	117	50	0.002	0.011	3.522	1.7
20	MH014100	118	50	0.033	0.011	3.522	0.5
21	MH004699	119	50	0.007	0.011	3.522	1.0

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr rainfall, in)	T_{sheet} (min)
22	MH004708	120	50	0.019	0.150	3.522	5.5
23	MH005908	121	50	0.019	0.011	3.522	0.7
24	MH005834A	122	50	0.061	0.011	3.522	0.4
25	MH004697	123	50	0.025	0.150	3.522	4.9
26	MH005834	124	50	0.020	0.011	3.522	0.7
27	MH004690	125	50	0.001	0.011	3.522	2.4
28	MH004709	126	50	0.020	0.011	3.522	0.7
29	MH005321	127	50	0.050	0.150	3.522	3.7
30	MH005910	128	50	0.015	0.150	3.522	6.1
31	MH005328	129	50	0.049	0.011	3.522	0.5
32	MH005329	130	50	0.021	0.011	3.522	0.6
33	MH005486B	131	50	0.044	0.150	3.522	3.9
34	MH012101C	132	50	0.012	0.011	3.522	0.8
35	MH005308	133	50	0.081	0.011	3.522	0.4
36	MH005320	134	50	0.030	0.150	3.522	4.6
37	MH005327	135	50	0.014	0.011	3.522	0.8
38	MH005322	136	50	0.012	0.011	3.522	0.8
39	MH005323	137	50	0.003	0.011	3.522	1.5
40	MH005326	138	50	0.004	0.011	3.522	1.2
41	MH005325A	139	50	0.013	0.011	3.522	0.8
42	MH005325	140	50	0.032	0.011	3.522	0.6
43	MH005333	141	50	0.029	0.011	3.522	0.6
44	MH005330	142	50	0.005	0.011	3.522	1.2
45	MH005334	143	50	0.173	0.150	3.522	2.3
46	MH005337	144	50	0.011	0.011	3.522	0.9
47	MH005332	145	50	0.032	0.011	3.522	0.5
48	MH005335	146	50	0.031	0.011	3.522	0.6
49	MH005336	147	50	0.001	0.011	3.522	2.0
50	MH005331	148	50	0.015	0.011	3.522	0.8
51	IF005415	149	50	0.026	0.011	3.522	0.6
52	IN037719A	150	50	0.025	0.011	3.522	0.6
53	MH005315	151	50	0.019	0.150	3.522	5.4

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr rainfall, in)	T_{sheet} (min)
54	MH012101	152	50	0.002	0.011	3.522	1.6
55	IF009284	153	50	0.157	0.150	3.522	2.4
56	MH005311	154	50	0.004	0.011	3.522	1.3
57	MH005317	155	50	0.021	0.011	3.522	0.7
58	MH005312	156	50	0.029	0.011	3.522	0.6
59	MH005316	157	50	0.007	0.011	3.522	1.0
60	MH005309	158	50	0.001	0.011	3.522	2.1
61	MH012100	159	50	0.171	0.150	3.522	2.3
62	MH012108	160	50	0.170	0.150	3.522	2.3
63	IF005415	161	50	0.280	0.150	3.522	1.9
64	MH008289A	162	50	0.024	0.011	3.522	0.6
65	MH008290B	163	50	0.028	0.011	3.522	0.6
66	MH008274	164	50	0.053	0.150	3.522	3.6
67	MH008278	165	50	0.010	0.011	3.522	0.9
68	MH008279	166	50	0.013	0.011	3.522	0.8
69	MH008282	167	50	0.214	0.150	3.522	2.1
70	MH008276	168	50	0.010	0.150	3.522	7.1
71	MH008275	169	50	0.205	0.150	3.522	2.1
72	MH013460	170	50	0.212	0.150	3.522	2.1
73	LB1	171	50	0.002	0.011	3.522	1.7
74	LB4	172	50	0.020	0.011	3.522	0.7
75	MH005911	173	50	0.042	0.150	3.522	4.0
76	MH005377A	174	50	0.025	0.011	3.522	0.6
77	MH005379A	175	50	0.010	0.011	3.522	0.9
78	MH012993A	176	50	0.030	0.011	3.522	0.6
79	MH005918	177	50	0.026	0.011	3.522	0.6
80	MH005917E	178	50	0.030	0.011	3.522	0.6
81	MH005917J	179	50	0.004	0.011	3.522	1.2
82	MH005917B	180	50	0.044	0.150	3.522	3.9
83	MH005917A	181	50	0.020	0.150	3.522	5.3
84	MH004705B	182	50	0.015	0.011	3.522	0.7
85	MH005382	183	50	0.049	0.011	3.522	0.5

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr rainfall, in)	T_{sheet} (min)
86	LB10	184	50	0.288	0.150	3.522	1.8
87	MH014510	185	50	0.010	0.011	3.522	0.9
88	LB11	186	50	0.086	0.150	3.522	3.0
89	MH005380	188	50	0.018	0.011	3.522	0.7
90	MH004734	189	50	0.181	0.150	3.522	2.2
91	MH005381	190	50	0.088	0.150	3.522	3.0
92	MH012429C	57	50	0.015	0.011	3.522	0.7
93	MH004036	58	50	0.023	0.011	3.522	0.6
94	MH004037	59	50	0.030	0.150	3.522	4.6
95	MH008122	60	50	0.122	0.011	3.522	0.3
96	MH012429B	61	50	0.068	0.011	3.522	0.4
97	MH012429A	62	50	0.038	0.011	3.522	0.5
98	MH004726	63	50	0.164	0.011	3.522	0.3
99	MH004723B	64	50	0.053	0.011	3.522	0.4
100	MH004859	65	50	0.008	0.011	3.522	0.9
101	FR1	66	50	0.020	0.150	3.522	5.4
102	MH004710	67	50	0.028	0.011	3.522	0.6
103	MH004713	68	50	0.257	0.150	3.522	1.9
104	MH007597	69	50	0.025	0.011	3.522	0.6
105	MH004727A	70	50	0.005	0.011	3.522	1.1
106	MH013005	71	50	0.056	0.011	3.522	0.4
107	MH004704	72	50	0.019	0.011	3.522	0.7
108	MH004733	73	50	0.028	0.011	3.522	0.6
109	MH004022	74	50	0.013	0.011	3.522	0.8
110	MH004732	75	50	0.021	0.011	3.522	0.7
111	MH004707	76	50	0.004	0.011	3.522	1.2
112	MH004702	77	50	0.001	0.011	3.522	1.9
113	MH004686	78	50	0.114	0.150	3.522	2.7
114	MH005490	79	50	0.021	0.011	3.522	0.7
115	MH005640	80	50	0.130	0.011	3.522	0.3
116	MH012430	81	50	0.054	0.011	3.522	0.4
117	MH008130C	82	50	0.025	0.011	3.522	0.6

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr rainfall, in)	T_{sheet} (min)
118	MH008130B	83	50	0.099	0.011	3.522	0.3
119	MH008130	84	50	0.030	0.011	3.522	0.6
120	MH012436	85	50	0.036	0.150	3.522	4.3
121	MH004039	86	50	0.059	0.011	3.522	0.4
122	MH012496	87	50	0.067	0.011	3.522	0.4
123	MH004041	88	50	0.026	0.150	3.522	4.8
124	MH005489B	89	50	0.032	0.150	3.522	4.4
125	MH012435	90	50	0.030	0.150	3.522	4.6
126	MH005489B	91	50	0.047	0.011	3.522	0.5
127	MH004689C	92	50	0.059	0.011	3.522	0.4
128	MH004688	93	50	0.037	0.150	3.522	4.2
129	MH005494	94	50	0.021	0.011	3.522	0.6
130	MH005909	95	50	0.048	0.011	3.522	0.5
131	MH004687	96	50	0.009	0.011	3.522	0.9
132	MH007596	97	50	0.009	0.011	3.522	0.9
133	MH004686	98	50	0.050	0.011	3.522	0.5
134	MH005492A	99	50	0.062	0.011	3.522	0.4
135	A1	A1	50	0.051	0.011	3.522	0.5
136	A13	A13	50	0.023	0.011	3.522	0.6
137	A15	A15	50	0.032	0.150	3.522	4.5
138	A2	A2	50	0.019	0.150	3.522	5.4
139	A25	A25	50	0.097	0.011	3.522	0.4
140	A8	A8	50	0.032	0.011	3.522	0.6
141	A9a	A9a	50	0.048	0.011	3.522	0.5
142	B1	B1	50	0.025	0.011	3.522	0.6
143	B5	B5	50	0.040	0.011	3.522	0.5
144	C1	C1	50	0.037	0.011	3.522	0.5
145	C8	C8	50	0.061	0.011	3.522	0.4
146	MH005492	CEM	50	0.015	0.150	3.522	6.1
147	D1	D1	50	0.026	0.011	3.522	0.6
148	D4	D4	50	0.032	0.011	3.522	0.6
149	D5	D5	50	0.081	0.011	3.522	0.4

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr rainfall, in)	T_{sheet} (min)
150	H3a	H3a	50	0.018	0.011	3.522	0.7
151	IB1	IB1	50	0.029	0.150	3.522	4.6
152	IB2	IB2	50	0.021	0.011	3.522	0.6
153	IC1	IC1	50	0.019	0.011	3.522	0.7
154	IC2	IC2	50	0.029	0.011	3.522	0.6
155	IC3	IC3	50	0.029	0.011	3.522	0.6
156	IC4	IC4	50	0.016	0.011	3.522	0.7
157	ID1	ID1	50	0.017	0.011	3.522	0.7
158	M1	M1	50	0.025	0.150	3.522	4.9
159	M2	M2	50	0.032	0.150	3.522	4.5
160	OW	OW	50	0.037	0.011	3.522	0.5
161	MH010575A	X1	50	0.100	0.150	3.522	2.8
162	MH004929	X2	50	0.017	0.011	3.522	0.7
163	MH004925	X3	50	0.009	0.011	3.522	0.9
164	MH004927C	X4	50	0.020	0.011	3.522	0.7
165	MH004927B	X5	50	0.013	0.011	3.522	0.8
166	MH004927	X6	50	0.028	0.011	3.522	0.6
167	MH005511A	X7	50	0.009	0.011	3.522	0.9
168	MH005511	X8	50	0.026	0.011	3.522	0.6
169	CR-1	X9	50	0.076	0.150	3.522	3.2
170	MH005512A	Y1	50	0.019	0.011	3.522	0.7
171	MH005868	Y10	50	0.044	0.150	3.522	3.9
172	MH005867	Y11	50	0.017	0.150	3.522	5.7
173	MH005181	Y12	50	0.073	0.150	3.522	3.2
174	MH005181D	Y13	50	0.043	0.011	3.522	0.5
175	MH005181C	Y14	50	0.053	0.150	3.522	3.6
176	MH005181B	Y15	50	0.041	0.150	3.522	4.0
177	IN009216D	Y16	50	0.049	0.150	3.522	3.8
178	IN009216C	Y17	50	0.029	0.011	3.522	0.6
179	IN009216A	Y18	50	0.054	0.011	3.522	0.4
180	MH005181A1	Y19	50	0.018	0.150	3.522	5.6
181	MH005458	Y2	50	0.061	0.011	3.522	0.4

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr rainfall, in)	T_{sheet} (min)
182	MH005179	Y3	50	0.037	0.011	3.522	0.5
183	MH005177	Y4	50	0.039	0.011	3.522	0.5
184	MH012969F	Y5	50	0.043	0.011	3.522	0.5
185	MH012969D	Y6	50	0.019	0.011	3.522	0.7
186	MH012969C	Y7	50	0.036	0.011	3.522	0.5
187	MH012969A	Y8	50	0.008	0.011	3.522	0.9
188	MH005180	Y9	50	0.051	0.150	3.522	3.7
189	MH004864C	Z1	50	0.046	0.011	3.522	0.5
190	MH004916	Z10	50	0.030	0.011	3.522	0.6
191	MH010573A	Z11	50	0.046	0.011	3.522	0.5
192	MH004920	Z12	50	0.039	0.011	3.522	0.5
193	MH004862D	Z13	50	0.053	0.011	3.522	0.4
194	MH004862C	Z14	50	0.035	0.011	3.522	0.5
195	MH004862B	Z15	50	0.040	0.011	3.522	0.5
196	MH004862A	Z16	50	0.040	0.011	3.522	0.5
197	MH004862A	Z17	50	0.060	0.011	3.522	0.4
198	MH004904	Z18	50	0.032	0.150	3.522	4.4
199	MH004860	Z19	50	0.051	0.011	3.522	0.5
200	MH004864A	Z2	50	0.028	0.011	3.522	0.6
201	MH004908	Z20	50	0.061	0.011	3.522	0.4
202	MH004860C	Z21	50	0.017	0.011	3.522	0.7
203	MH004861A	Z22	50	0.035	0.011	3.522	0.5
204	MH004866	Z23	50	0.032	0.011	3.522	0.5
205	MH004907	Z24	50	0.025	0.011	3.522	0.6
206	MH004921C	Z25	50	0.011	0.011	3.522	0.9
207	MH004898B	Z26	50	0.023	0.011	3.522	0.6
208	MH004900B	Z27	50	0.040	0.011	3.522	0.5
209	MH004903	Z28	50	0.001	0.011	3.522	2.1
210	MH004864	Z3	50	0.032	0.011	3.522	0.5
211	MH004863A	Z4	50	0.034	0.011	3.522	0.5
212	MH004863	Z5	50	0.025	0.011	3.522	0.6
213	MH013049A	Z6	50	0.030	0.150	3.522	4.6

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Manning's n	P_2 (2-yr 24-hr rainfall, in)	T_{sheet} (min)
214	MH013049	Z7	50	0.259	0.011	3.522	0.2
215	MH010581	Z8	50	0.020	0.011	3.522	0.7
216	MH010573B	Z9	50	0.046	0.011	3.522	0.5

Table 14. LB Catchments Shallow Concentrated Flow Travel Times.

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
1	MH004695A	10	335	0.030	Paved	2.0
2	MH005493A	100	1,251	0.021	Paved	7.1
3	MH005383A	101	74	0.046	Paved	0.3
3	MH005383A	101	243	0.029	Unpaved	1.5
4	MH005384A	102	392	0.053	Paved	1.8
5	MH004729A	103	353	0.013	Paved	2.6
6	MH004730A	104	408	0.013	Paved	2.9
7	MH004707A	105	405	0.008	Paved	3.6
8	MH004701	106	252	0.021	Paved	1.4
9	MH004728	107	513	0.019	Paved	3.1
10	MH004715	108	775	0.018	Paved	4.7
11	MH004714	109	1,122	0.017	Paved	7.1
12	MH004717	110	1,030	0.024	Paved	5.5
13	MH005493	111	746	0.025	Paved	3.9
14	MH005487	112	879	0.016	Paved	5.7
15	MH004691	113	431	0.015	Paved	2.8
16	MH004719	114	721	0.012	Paved	5.4
17	MH004035A	115	336	0.026	Paved	1.7
18	MH014695A	116	479	0.023	Paved	2.6
19	MH005907	117	589	0.018	Paved	3.6
20	MH014100	118	541	0.035	Paved	2.4
21	MH004699	119	368	0.014	Paved	2.5
22	MH004708	120	280	0.023	Paved	1.5
23	MH005908	121	252	0.020	Paved	1.5

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
24	MH005834A	122	427	0.020	Paved	2.5
25	MH004697	123	300	0.018	Paved	1.8
25	MH004697	123	78	0.030	Unpaved	0.5
26	MH005834	124	445	0.012	Paved	3.4
27	MH004690	125	454	0.017	Paved	2.9
28	MH004709	126	561	0.014	Paved	3.8
29	MH005321	127	524	0.020	Paved	3.1
29	MH005321	127	134	0.050	Unpaved	0.6
30	MH005910	128	400	0.015	Paved	2.7
30	MH005910	128	150	0.035	Unpaved	0.8
31	MH005328	129	336	0.017	Paved	2.1
31	MH005328	129	242	0.017	Unpaved	1.9
32	MH005329	130	934	0.017	Paved	5.9
33	MH005486B	131	270	0.028	Paved	1.3
34	MH012101C	132	971	0.022	Paved	5.4
34	MH012101C	132	417	0.060	Unpaved	1.8
35	MH005308	133	770	0.016	Paved	5.0
36	MH005320	134	144	0.028	Paved	0.7
36	MH005320	134	341	0.063	Unpaved	1.4
37	MH005327	135	428	0.021	Paved	2.4
38	MH005322	136	293	0.018	Paved	1.8
38	MH005322	136	134	0.032	Unpaved	0.8
39	MH005323	137	262	0.013	Paved	1.9
40	MH005326	138	211	0.009	Paved	1.8
40	MH005326	138	97	0.020	Unpaved	0.7
41	MH005325A	139	575	0.008	Paved	5.2
42	MH005325	140	347	0.017	Paved	2.2
43	MH005333	141	393	0.024	Paved	2.1
43	MH005333	141	111	0.415	Unpaved	0.2
44	MH005330	142	445	0.016	Paved	2.9
45	MH005334	143	512	0.026	Paved	2.6
46	MH005337	144	594	0.017	Paved	3.8

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
47	MH005332	145	405	0.012	Paved	3.0
48	MH005335	146	454	0.010	Paved	3.8
49	MH005336	147	370	0.019	Paved	2.2
50	MH005331	148	175	0.015	Paved	1.2
51	IF005415	149	419	0.030	Paved	2.0
51	IF005415	149	247	0.135	Unpaved	0.7
52	IN037719A	150	254	0.224	Paved	0.4
53	MH005315	151	364	0.040	Paved	1.5
54	MH012101	152	447	0.008	Paved	4.0
55	IF009284	153	389	0.009	Paved	3.4
55	IF009284	153	162	0.151	Unpaved	0.4
56	MH005311	154	336	0.016	Paved	2.2
57	MH005317	155	441	0.024	Paved	2.3
58	MH005312	156	606	0.021	Paved	3.4
59	MH005316	157	509	0.010	Paved	4.3
60	MH005309	158	525	0.012	Paved	3.9
61	MH012100	159	307	0.013	Paved	2.2
61	MH012100	159	480	0.047	Unpaved	2.3
62	MH012108	160	208	0.019	Paved	1.2
62	MH012108	160	419	0.113	Unpaved	1.3
63	IF005415	161	962	0.058	Paved	4.1
64	MH008289A	162	251	0.011	Paved	1.9
64	MH008289A	162	349	0.040	Unpaved	1.8
65	MH008290B	163	514	0.028	Paved	2.5
65	MH008290B	163	423	0.038	Unpaved	2.2
66	MH008274	164	496	0.029	Paved	2.4
66	MH008274	164	191	0.027	Unpaved	1.2
67	MH008278	165	299	0.069	Paved	1.2
68	MH008279	166	73	0.012	Paved	0.5
68	MH008279	166	234	0.017	Unpaved	1.9
69	MH008282	167	293	0.027	Paved	1.5
70	MH008276	168	454	0.016	Paved	3.0

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
70	MH008276	168	149	0.060	Unpaved	0.6
71	MH008275	169	288	0.009	Paved	2.5
71	MH008275	169	187	0.046	Unpaved	0.9
72	MH013460	170	189	0.024	Paved	1.0
72	MH013460	170	427	0.040	Unpaved	2.2
73	LB1	171	290	0.016	Paved	1.9
74	LB4	172	323	0.047	Paved	1.2
75	MH005911	173	301	0.025	Paved	1.5
75	MH005911	173	102	0.048	Unpaved	0.5
76	MH005377A	174	263	0.016	Paved	1.7
77	MH005379A	175	381	0.010	Paved	3.2
78	MH012993A	176	337	0.031	Paved	1.6
78	MH012993A	176	96	0.021	Unpaved	0.7
79	MH005918	177	418	0.018	Paved	2.6
80	MH005917E	178	467	0.016	Paved	3.1
81	MH005917J	179	294	0.009	Paved	2.5
82	MH005917B	180	228	0.030	Paved	1.4
83	MH005917A	181	439	0.024	Paved	2.3
84	MH004705B	182	195	0.016	Paved	1.3
84	MH004705B	182	90	0.135	Unpaved	0.3
85	MH005382	183	449	0.021	Paved	2.5
85	MH005382	183	128	0.080	Unpaved	0.5
86	LB10	184	587	0.023	Paved	4.0
87	MH014510	185	163	0.020	Paved	0.9
88	LB11	186	374	0.022	Paved	2.1
88	LB11	186	109	0.022	Unpaved	0.8
89	MH005380	188	86	0.017	Paved	0.5
89	MH005380	188	31	0.015	Unpaved	0.3
90	MH004734	189	395	0.028	Paved	1.9
90	MH004734	189	410	0.037	Unpaved	2.2
91	MH005381	190	341	0.008	Paved	3.2
92	MH012429C	57	1,049	0.036	Paved	4.5

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
93	MH004036	58	1,566	0.039	Paved	6.5
94	MH004037	59	1,198	0.017	Paved	7.5
95	MH008122	60	253	0.034	Paved	1.1
95	MH008122	60	417	0.129	Unpaved	1.2
96	MH012429B	61	587	0.047	Paved	2.2
97	MH012429A	62	592	0.074	Paved	1.8
98	MH004726	63	609	0.041	Paved	2.5
99	MH004723B	64	1,842	0.023	Paved	10.0
100	MH004859	65	1,485	0.017	Paved	9.4
101	FR1	66	111	0.014	Paved	0.8
101	FR1	66	328	0.037	Unpaved	1.8
102	MH004710	67	566	0.020	Paved	3.3
102	MH004710	67	158	0.017	Unpaved	1.3
103	MH004713	68	350	0.020	Paved	2.0
103	MH004713	68	369	0.068	Unpaved	1.5
104	MH007597	69	957	0.019	Paved	5.7
105	MH004727A	70	590	0.023	Paved	3.2
106	MH013005	71	1,501	0.019	Paved	8.9
106	MH013005	71	421	0.027	Unpaved	2.7
107	MH004704	72	749	0.039	Paved	3.1
108	MH004733	73	615	0.035	Paved	2.7
109	MH004022	74	443	0.014	Paved	3.1
110	MH004732	75	230	0.020	Paved	1.3
111	MH004707	76	323	0.007	Paved	3.2
112	MH004702	77	604	0.007	Paved	5.7
113	MH004686	78	1,084	0.029	Paved	5.3
114	MH005490	79	2,807	0.031	Paved	13.1
115	MH005640	80	527	0.032	Paved	2.4
115	MH005640	80	262	0.036	Unpaved	1.4
116	MH012430	81	706	0.037	Paved	3.0
117	MH008130C	82	641	0.018	Paved	3.9
118	MH008130B	83	458	0.018	Paved	2.8

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
119	MH008130	84	264	0.023	Paved	1.4
119	MH008130	84	78	0.021	Unpaved	0.6
120	MH012436	85	2,392	0.035	Paved	10.4
121	MH004039	86	1,180	0.032	Paved	5.4
121	MH004039	86	443	0.040	Unpaved	2.3
122	MH012496	87	1,230	0.029	Paved	5.9
122	MH012496	87	356	0.032	Unpaved	2.1
123	MH004041	88	1,028	0.030	Paved	4.9
123	MH004041	88	494	0.030	Unpaved	3.0
124	MH005489B	89	986	0.031	Paved	4.6
124	MH005489B	89	406	0.040	Unpaved	2.1
125	MH012435	90	587	0.027	Paved	2.9
125	MH012435	90	156	0.041	Unpaved	0.8
126	MH005489B	91	341	0.019	Paved	2.0
126	MH005489B	91	334	0.018	Unpaved	2.6
127	MH004689C	92	608	0.024	Paved	3.2
128	MH004688	93	189	0.021	Paved	1.1
128	MH004688	93	548	0.032	Unpaved	3.2
129	MH005494	94	97	0.029	Paved	0.5
129	MH005494	94	37	0.037	Unpaved	0.2
130	MH005909	95	324	0.023	Paved	1.7
131	MH004687	96	387	0.024	Paved	2.0
131	MH004687	96	330	0.030	Unpaved	2.0
132	MH007596	97	324	0.013	Paved	2.3
132	MH007596	97	310	0.011	Unpaved	3.0
133	MH004686	98	667	0.029	Paved	3.2
134	MH005492A	99	2,578	0.034	Paved	11.5
135	A1	A1	1,002	0.029	Paved	4.8
135	A1	A1	513	0.024	Unpaved	3.4
136	A13	A13	1,069	0.031	Paved	5.0
136	A13	A13	273	0.037	Unpaved	1.5
137	A15	A15	1,094	0.037	Paved	4.6

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
138	A2	A2	886	0.029	Paved	4.2
138	A2	A2	801	0.034	Unpaved	4.5
139	A25	A25	234	0.028	Paved	1.1
139	A25	A25	533	0.034	Unpaved	3.0
140	A8	A8	1,392	0.033	Paved	6.3
140	A8	A8	667	0.030	Unpaved	4.0
141	A9a	A9a	1,458	0.031	Paved	6.8
142	B1	B1	1,913	0.025	Paved	10.0
143	B5	B5	750	0.028	Paved	3.7
143	B5	B5	598	0.031	Unpaved	3.5
144	C1	C1	631	0.037	Paved	2.7
145	C8	C8	822	0.033	Paved	3.7
145	C8	C8	299	0.035	Unpaved	1.6
146	MH005492	CEM	2,297	0.020	Paved	13.2
146	MH005492	CEM	2,053	0.028	Unpaved	12.8
147	D1	D1	3,021	0.027	Paved	15.1
148	D4	D4	566	0.016	Paved	3.7
148	D4	D4	559	0.034	Unpaved	3.1
149	D5	D5	1,338	0.020	Paved	7.7
150	H3a	H3a	1,376	0.023	Paved	7.5
151	IB1	IB1	892	0.018	Paved	5.5
151	IB1	IB1	515	0.083	Unpaved	1.8
152	IB2	IB2	854	0.016	Paved	5.6
153	IC1	IC1	473	0.046	Paved	1.8
153	IC1	IC1	161	0.043	Unpaved	0.8
154	IC2	IC2	114	0.037	Paved	0.5
155	IC3	IC3	1,043	0.046	Paved	4.0
156	IC4	IC4	478	0.028	Paved	2.4
157	ID1	ID1	95	0.056	Paved	0.3
158	M1	M1	1,074	0.047	Paved	4.1
159	M2	M2	446	0.055	Paved	1.6
159	M2	M2	430	0.067	Unpaved	1.7

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
160	OW	OW	905	0.050	Paved	3.3
161	MH010575A	X1	544	0.014	Paved	3.8
162	MH004929	X2	48	0.008	Paved	0.4
163	MH004925	X3	233	0.011	Paved	1.8
164	MH004927C	X4	114	0.019	Paved	0.7
165	MH004927B	X5	350	0.018	Paved	2.1
166	MH004927	X6	449	0.017	Paved	2.8
167	MH005511A	X7	827	0.018	Paved	5.1
168	MH005511	X8	561	0.035	Paved	2.5
169	CR-1	X9	405	0.016	Paved	2.6
169	CR-1	X9	218	0.036	Unpaved	1.2
170	MH005512A	Y1	1,552	0.029	Paved	7.5
171	MH005868	Y10	799	0.044	Paved	3.1
172	MH005867	Y11	1,068	0.032	Paved	4.9
172	MH005867	Y11	617	0.032	Unpaved	3.5
173	MH005181	Y12	1,485	0.027	Paved	7.4
173	MH005181	Y12	432	0.034	Unpaved	2.4
174	MH005181D	Y13	113	0.014	Paved	0.5
174	MH005181D	Y13	209	0.035	Unpaved	1.1
175	MH005181C	Y14	533	0.020	Paved	3.9
176	MH005181B	Y15	554	0.020	Paved	3.2
177	IN009216D	Y16	1,613	0.022	Paved	8.9
178	IN009216C	Y17	1,169	0.024	Paved	6.3
179	IN009216A	Y18	180	0.024	Paved	0.9
180	MH005181A1	Y19	1,129	0.023	Paved	6.1
181	MH005458	Y2	644	0.029	Paved	3.1
182	MH005179	Y3	1,155	0.029	Paved	5.5
183	MH005177	Y4	694	0.026	Paved	3.5
183	MH005177	Y4	344	0.031	Unpaved	2.0
184	MH012969F	Y5	1,445	0.028	Paved	7.1
185	MH012969D	Y6	693	0.027	Paved	3.4
185	MH012969D	Y6	227	0.047	Unpaved	1.1

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
186	MH012969C	Y7	993	0.040	Paved	4.1
187	MH012969A	Y8	919	0.040	Paved	3.7
187	MH012969A	Y8	391	0.049	Unpaved	1.8
188	MH005180	Y9	1,441	0.029	Paved	6.9
188	MH005180	Y9	474	0.044	Unpaved	2.3
189	MH004864C	Z1	386	0.028	Paved	1.9
189	MH004864C	Z1	378	0.024	Unpaved	2.5
190	MH004916	Z10	576	0.026	Paved	2.9
191	MH010573A	Z11	705	0.047	Paved	2.7
192	MH004920	Z12	726	0.019	Paved	4.4
193	MH004862D	Z13	308	0.030	Paved	1.5
194	MH004862C	Z14	196	0.025	Paved	1.0
195	MH004862B	Z15	217	0.028	Paved	1.1
196	MH004862A	Z16	257	0.028	Paved	1.3
197	MH004862A	Z17	333	0.017	Paved	2.1
198	MH004904	Z18	183	0.021	Paved	1.0
198	MH004904	Z18	72	0.023	Unpaved	0.5
199	MH004860	Z19	223	0.021	Paved	1.3
200	MH004864A	Z2	635	0.018	Paved	3.9
201	MH004908	Z20	504	0.020	Paved	3.0
202	MH004860C	Z21	553	0.027	Paved	2.8
203	MH004861A	Z22	580	0.021	Paved	3.2
204	MH004866	Z23	481	0.027	Paved	2.4
205	MH004907	Z24	476	0.015	Paved	3.2
206	MH004921C	Z25	526	0.016	Paved	3.4
207	MH004898B	Z26	534	0.021	Paved	3.0
208	MH004900B	Z27	982	0.026	Paved	5.0
209	MH004903	Z28	815	0.020	Paved	4.7
210	MH004864	Z3	406	0.021	Paved	2.3
210	MH004864	Z3	354	0.028	Unpaved	2.2
211	MH004863A	Z4	509	0.038	Paved	2.1
211	MH004863A	Z4	191	0.036	Unpaved	1.0

ID	XPSWMM Node ID	Catchment Name	Flow Length (ft)	Slope (fraction)	Paved/Unpaved	$T_{shallow}$ (mins)
212	MH004863	Z5	1,189	0.030	Paved	5.7
213	MH013049A	Z6	297	0.015	Paved	2.0
213	MH013049A	Z6	75	0.035	Unpaved	0.4
214	MH013049	Z7	325	0.024	Paved	1.7
215	MH010581	Z8	879	0.051	Paved	3.2
215	MH010581	Z8	297	0.059	Unpaved	1.3
216	MH010573B	Z9	1,358	0.035	Paved	6.0

Table 15. LB Catchments Total Travel Times.

ID	XPSWMM Node ID	Catchment Name	T_{total} (mins)
1	MH004695A	10	6.0
2	MH005493A	100	7.6
3	MH005383A	101	7.3
4	MH005384A	102	6.0
5	MH004729A	103	6.0
6	MH004730A	104	6.0
7	MH004707A	105	6.0
8	MH004701	106	6.0
9	MH004728	107	6.0
10	MH004715	108	6.0
11	MH004714	109	7.7
12	MH004717	110	6.0
13	MH005493	111	6.0
14	MH005487	112	6.5
15	MH004691	113	6.0
16	MH004719	114	6.0
17	MH004035A	115	6.0
18	MH014695A	116	6.0
19	MH005907	117	6.0
20	MH014100	118	6.0
21	MH004699	119	6.0

ID	XPSWMM Node ID	Catchment Name	T_{total} (mins)
22	MH004708	120	7.0
23	MH005908	121	6.0
24	MH005834A	122	6.0
25	MH004697	123	7.2
26	MH005834	124	6.0
27	MH004690	125	6.0
28	MH004709	126	6.0
29	MH005321	127	7.4
30	MH005910	128	9.6
31	MH005328	129	6.0
32	MH005329	130	6.6
33	MH005486B	131	6.0
34	MH012101C	132	8.0
35	MH005308	133	6.0
36	MH005320	134	6.7
37	MH005327	135	6.0
38	MH005322	136	6.0
39	MH005323	137	6.0
40	MH005326	138	6.0
41	MH005325A	139	6.0
42	MH005325	140	6.0
43	MH005333	141	6.0
44	MH005330	142	6.0
45	MH005334	143	6.0
46	MH005337	144	6.0
47	MH005332	145	6.0
48	MH005335	146	6.0
49	MH005336	147	6.0
50	MH005331	148	6.0
51	IF005415	149	6.0
52	IN037719A	150	6.0
53	MH005315	151	6.9

ID	XPSWMM Node ID	Catchment Name	T_{total} (mins)
54	MH012101	152	6.0
55	IF009284	153	6.2
56	MH005311	154	6.0
57	MH005317	155	6.0
58	MH005312	156	6.0
59	MH005316	157	6.0
60	MH005309	158	6.0
61	MH012100	159	6.8
62	MH012108	160	6.0
63	IF005415	161	6.0
64	MH008289A	162	6.0
65	MH008290B	163	6.0
66	MH008274	164	7.2
67	MH008278	165	6.0
68	MH008279	166	6.0
69	MH008282	167	6.0
70	MH008276	168	10.7
71	MH008275	169	6.0
72	MH013460	170	6.0
73	LB1	171	6.0
74	LB4	172	6.0
75	MH005911	173	6.0
76	MH005377A	174	6.0
77	MH005379A	175	6.0
78	MH012993A	176	6.0
79	MH005918	177	6.0
80	MH005917E	178	6.0
81	MH005917J	179	6.0
82	MH005917B	180	6.0
83	MH005917A	181	7.7
84	MH004705B	182	6.0
85	MH005382	183	6.0

ID	XPSWMM Node ID	Catchment Name	T_{total} (mins)
86	LB10	184	6.0
87	MH014510	185	6.0
88	LB11	186	6.0
89	MH005380	188	6.0
90	MH004734	189	6.4
91	MH005381	190	6.1
92	MH012429C	57	6.0
93	MH004036	58	7.2
94	MH004037	59	12.1
95	MH008122	60	6.0
96	MH012429B	61	6.0
97	MH012429A	62	6.0
98	MH004726	63	6.0
99	MH004723B	64	10.5
100	MH004859	65	10.3
101	FR1	66	7.9
102	MH004710	67	6.0
103	MH004713	68	6.0
104	MH007597	69	6.3
105	MH004727A	70	6.0
106	MH013005	71	12.1
107	MH004704	72	6.0
108	MH004733	73	6.0
109	MH004022	74	6.0
110	MH004732	75	6.0
111	MH004707	76	6.0
112	MH004702	77	7.6
113	MH004686	78	7.9
114	MH005490	79	13.7
115	MH005640	80	6.0
116	MH012430	81	6.0
117	MH008130C	82	6.0

ID	XPSWMM Node ID	Catchment Name	T_{total} (mins)
118	MH008130B	83	6.0
119	MH008130	84	6.0
120	MH012436	85	14.7
121	MH004039	86	8.2
122	MH012496	87	8.4
123	MH004041	88	12.7
124	MH005489B	89	11.1
125	MH012435	90	8.3
126	MH005489B	91	6.0
127	MH004689C	92	6.0
128	MH004688	93	8.5
129	MH005494	94	6.0
130	MH005909	95	6.0
131	MH004687	96	6.0
132	MH007596	97	6.2
133	MH004686	98	6.0
134	MH005492A	99	11.9
135	A1	A1	8.7
136	A13	A13	7.1
137	A15	A15	9.1
138	A2	A2	14.2
139	A25	A25	6.0
140	A8	A8	10.8
141	A9a	A9a	7.2
142	B1	B1	10.6
143	B5	B5	7.7
144	C1	C1	6.0
145	C8	C8	6.0
146	MH005492	CEM	32.1
147	D1	D1	15.7
148	D4	D4	7.4
149	D5	D5	8.1

ID	XPSWMM Node ID	Catchment Name	T_{total} (mins)
150	H3a	H3a	8.2
151	IB1	IB1	12.0
152	IB2	IB2	6.2
153	IC1	IC1	6.0
154	IC2	IC2	6.0
155	IC3	IC3	6.0
156	IC4	IC4	6.0
157	ID1	ID1	6.0
158	M1	M1	8.9
159	M2	M2	7.7
160	OW	OW	6.0
161	MH010575A	X1	6.7
162	MH004929	X2	6.0
163	MH004925	X3	6.0
164	MH004927C	X4	6.0
165	MH004927B	X5	6.0
166	MH004927	X6	6.0
167	MH005511A	X7	6.0
168	MH005511	X8	6.0
169	CR-1	X9	7.0
170	MH005512A	Y1	8.2
171	MH005868	Y10	7.1
172	MH005867	Y11	14.2
173	MH005181	Y12	13.0
174	MH005181D	Y13	6.0
175	MH005181C	Y14	7.5
176	MH005181B	Y15	7.2
177	IN009216D	Y16	12.7
178	IN009216C	Y17	6.8
179	IN009216A	Y18	6.0
180	MH005181A1	Y19	11.7
181	MH005458	Y2	6.0

ID	XPSWMM Node ID	Catchment Name	T_{total} (mins)
182	MH005179	Y3	6.1
183	MH005177	Y4	6.1
184	MH012969F	Y5	7.6
185	MH012969D	Y6	6.0
186	MH012969C	Y7	6.0
187	MH012969A	Y8	6.5
188	MH005180	Y9	12.9
189	MH004864C	Z1	6.0
190	MH004916	Z10	6.0
191	MH010573A	Z11	6.0
192	MH004920	Z12	6.0
193	MH004862D	Z13	6.0
194	MH004862C	Z14	6.0
195	MH004862B	Z15	6.0
196	MH004862A	Z16	6.0
197	MH004862A	Z17	6.0
198	MH004904	Z18	6.0
199	MH004860	Z19	6.0
200	MH004864A	Z2	6.0
201	MH004908	Z20	6.0
202	MH004860C	Z21	6.0
203	MH004861A	Z22	6.0
204	MH004866	Z23	6.0
205	MH004907	Z24	6.0
206	MH004921C	Z25	6.0
207	MH004898B	Z26	6.0
208	MH004900B	Z27	6.0
209	MH004903	Z28	6.8
210	MH004864	Z3	6.0
211	MH004863A	Z4	6.0
212	MH004863	Z5	6.3
213	MH013049A	Z6	7.0

ID	XPSWMM Node ID	Catchment Name	T_{total} (mins)
214	MH013049	Z7	6.0
215	MH010581	Z8	6.0
216	MH010573B	Z9	6.5

3.3.4 Hydraulics

Hydrology and hydraulics were simulated simultaneously in the XPSWMM models. The models were configured in 1D-2D mode wherein runoff generation is simulated in 1D and conveyed to the stormwater inlets. The stormwater inlets are connected to the 2D terrain allowing for excess water to spill to the 2D terrain when the capacity of the stormwater system is exceeded. XPSWMM uses physically based methods to simulate hydraulics of the flooded water in the 2D terrain. The 2D terrain in the XPSWMM models are based on Lidar data acquired by Digital Aerial Solutions, LLC for the US Geological Survey (USGS) for portions of 21 counties over north, central, and west Texas between January 26, 2019, and July 12, 2019. Data products including Lidar Point Cloud and DEM are publicly available for download from the Texas Natural Resources Information System (TNRIS). The Central Arlington Heights (CAH) and Linwood-Bailey (LB) watersheds are covered by this project. The DEM for the study area at a spatial resolution of 1-meter was generated by Tetra Tech using the Lidar Point Cloud in ArcGIS using the following procedure.

1) Lidar Point Cloud in “laz” format were converted to “las” format using the “pylas” module in the Python programming language.
2) The “las” files were subsequently converted to 1-meter resolution DEMs using the “LAS Dataset to Raster” tool in ArcGIS for the “Bare-Earth Ground” class. The DEMs for the individual tiles (shown in Figure 1) were combined using the “Mosaic to New Raster” tool in ArcGIS.

As discussed above, the XPSWMM models are based on the City’s InfoWorks ICM models for the LB watershed. The following changes from the InfoWorks ICM model are implemented in the LB XPSWMM model.

1) Stormwater inlets are not modeled in the City’s InfoWorks ICM model for the LB watershed. Stormwater inlets were added to the LB XPSWMM model throughout the watershed based on an analysis of the locations of the stormwater inlets relative to the nodes already present in the model (shown in Figure 38). The majority of the stormwater inlets in the LB watershed are classified as “curb” inlets. At each junction, all inlets were combined together and represented as a single transverse weir. The length of the weir at each junction is equal to the sum of the “window length” and height is the average of “window height” reported for each inlet.

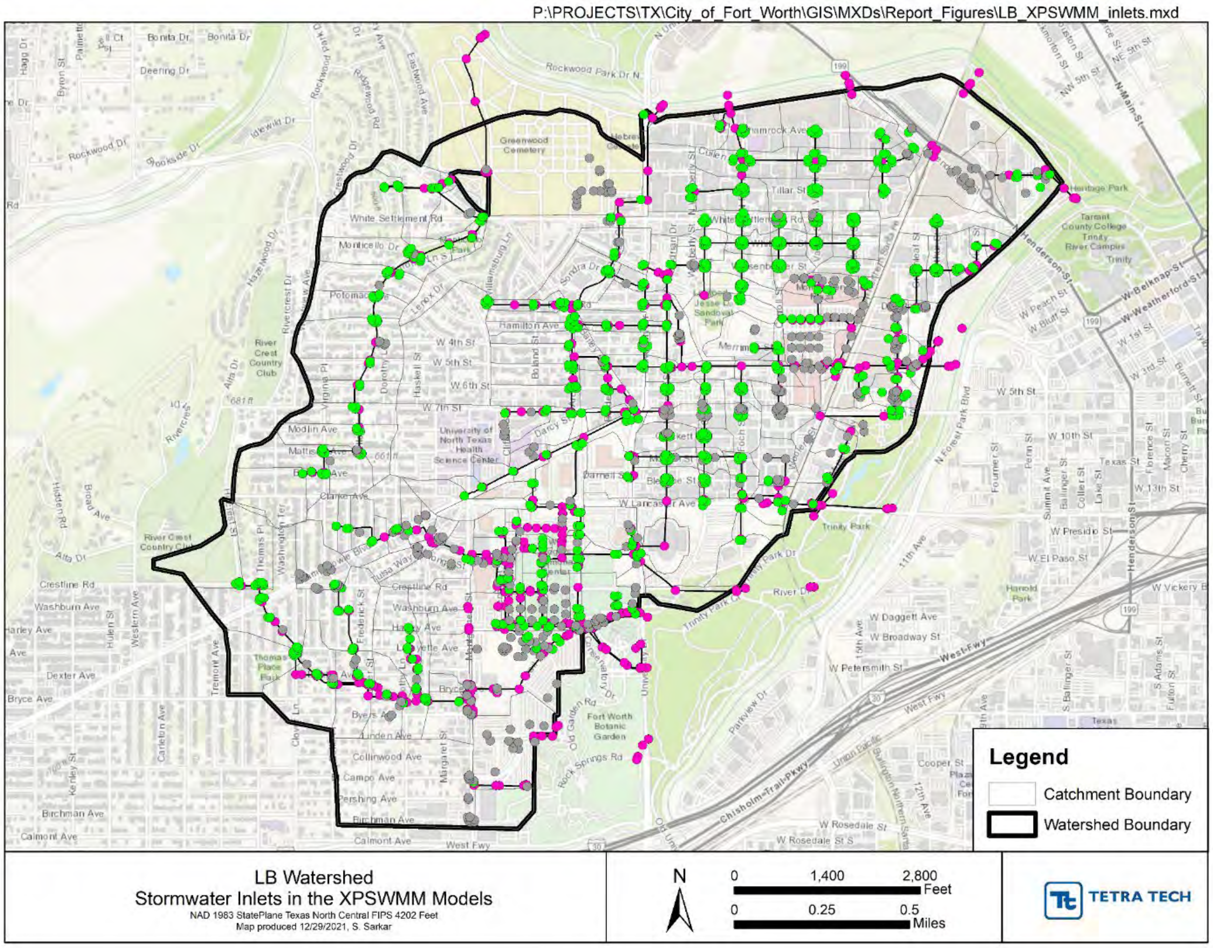

Figure 38. Stormwater Inlets in the XPSWMM Model for LB Watershed.

The 2D grid was specified at a 15-ft resolution. Sub-Grid Sampling (SGS) was enabled in the XPSWMM models with the “Exact” depth interpolation and sampling distance of 3-ft. The XP2D Extreme engine was used for 2D simulations.

Land use specific Manning’s n values were based on the Harris County Flood Control District (HCFCD, 2018) suggestions for flood routing within a 2D domain (summarized in Table 8). The Manning’s n values adopted for the LB XPSWMM models are shown in Figure 18. The City’s building footprints layer was used to define inactive 2D areas in the XPSWMM models.

Table 16. HCFCD 2D Domain Manning’s n Value Recommendations (HCFCD, 2018).

Land Classification	Manning’s n		
	Minimum	Recommended	Maximum
Open Water	0.01	0.02	0.03
Developed High Intensity	0.02	0.03	0.06
Developed Med Intensity	0.06	0.18	0.20
Developed Low Intensity	0.06	0.16	0.20

Land Classification	Manning's n		
	Minimum	Recommended	Maximum
Developed Open Space	0.04	0.06	0.10
Barren Lands	0.06	0.20	0.30
Forest/Shrubs	0.18	0.25	0.30
Pasture/Grasslands	0.15	0.22	0.30
Cultivated Crops	0.10	0.17	0.30
Wetlands	0.03	0.08	0.10
Building	10.00	10.00	10.00
Pavement	0.015	0.02	0.025

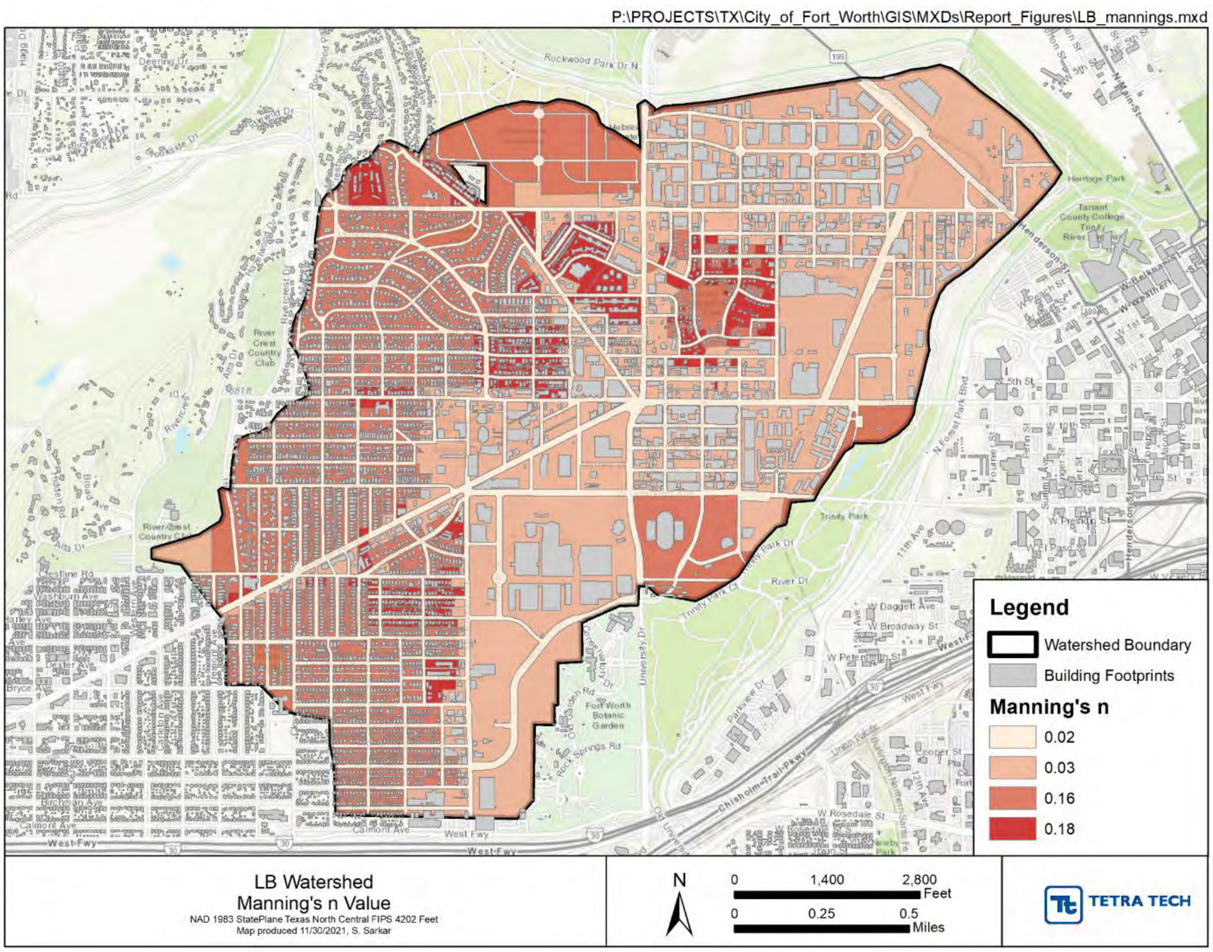

Figure 39. Manning's n Values for the LB Watershed.

Based on analysis of the movement of flooded water on the 2D terrain in the XPSWMM models, 2D outfalls were specified along the northern and eastern edges of the LB watershed.

3.3.5 Results and Discussion

Runoff volumes simulated by the XPSWMM models at the watershed scale for the three impervious Scenarios and design storms are summarized in Table 9.

Table 17. Simulated Runoff Depths and Volumes for the LB Watershed.

Scenario #	Cumulative Runoff Depth (in)			Cumulative Runoff Volume (ac-ft)		
	1-yr 24-hr	5-yr 24-hr	100-yr 24-hr	1-yr 24-hr	5-yr 24-hr	100-yr 24-hr
1	2.140	3.629	7.910	344.9	585.0	1275.1
2	2.326	3.850	8.175	374.9	620.6	1317.8
3	2.522	4.066	8.412	406.5	655.5	1356.1

The depths and extents of inundation simulated by the XPSWMM models for the impervious Scenarios and design storms are shown in Figure 19 to Figure 27. The change in inundation extents and depths for Scenarios 3 and 2 compared to Scenario 1 are shown in Figure 28 to Figure 33. The results of the H&H modeling for the Scenarios in terms of key indicators are summarized in Table 10 and actual flooding incidents are shown in Table 19.

Table 18. XPSWMM Results Summary for the LB Watershed.

Indicator	1-year 24-hour			5-year 24-hour			100-year 24-hour		
	Scn 1	Scn 2	Scn 3	Scn 1	Scn 2	Scn 3	Scn 1	Scn 2	Scn 3
Acres of inundation	122.4	229.0	513.5	135.0	242.8	523.5	149.1	253.3	530.8
Depth range of inundation on private properties (ft)	8.02	8.41	8.78	9.75	9.99	10.23	12.27	12.38	12.49
Average increase in private property inundation depth (ft)	-	0.018	0.036	-	0.021	0.035	-	0.013	0.021
Maximum increase in private property inundation depth (ft)	-	1.46	2.85	-	0.52	1.06	-	0.25	0.34
Depth range of inundation on roads (ft)	5.82	8.09	10.56	6.45	8.30	10.66	6.53	8.45	10.67
Average increase in inundation depth on roads (ft)	-	0.024	0.049	-	0.030	0.042	-	0.017	0.028
Average length of time inlets are surcharging (mins)	380.0	505.5	584.9	327.4	461.5	591.3	423.6	529.3	592.2
Number of flood prone properties*	522	573 (533)	623 (618)	882	917 (870)	948 (933)	1315	1323 (1245)	1330 (1317)

*The number is parenthesis represents the number of flood prone properties with increased inundation depths.

Table 19. Table of Actual Reported Flood Incidents since 2000 for the LB Watershed.

Reported Flooding Type	Count in LB
Structure	20
Vehicle	33
Rescue	7
Road Overtop	53
Other (Fire Response and General Investigation)	5
FEMA Classified Repetitive Loss Structure	3

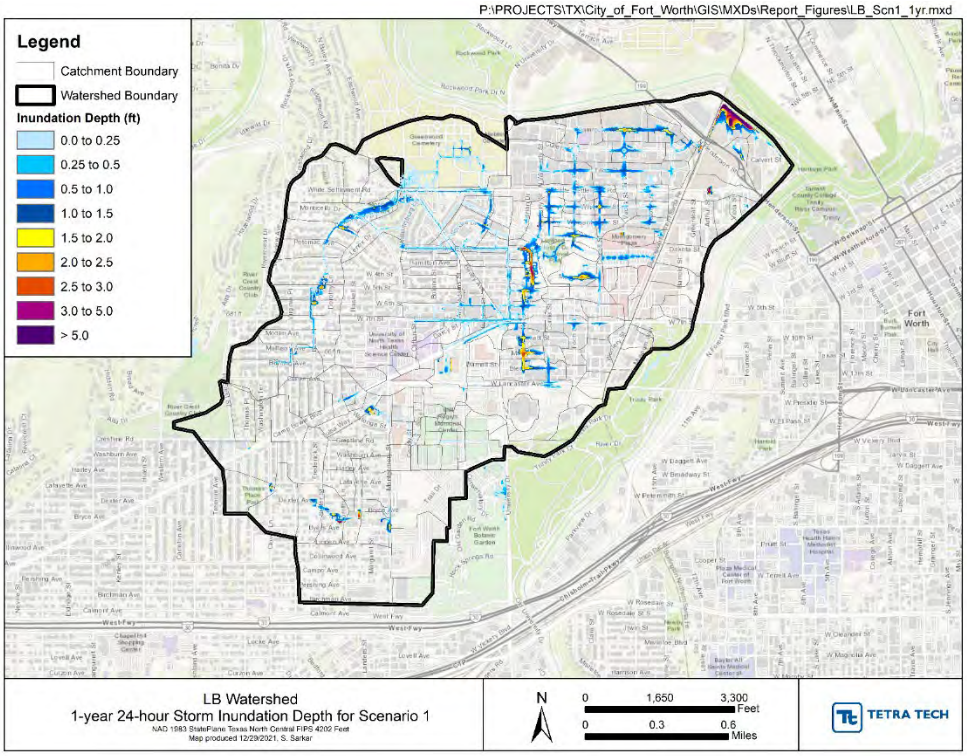

Figure 40. Inundation Depth and Extent for 1-year 24-Storm for LB Watershed Scenario 1.

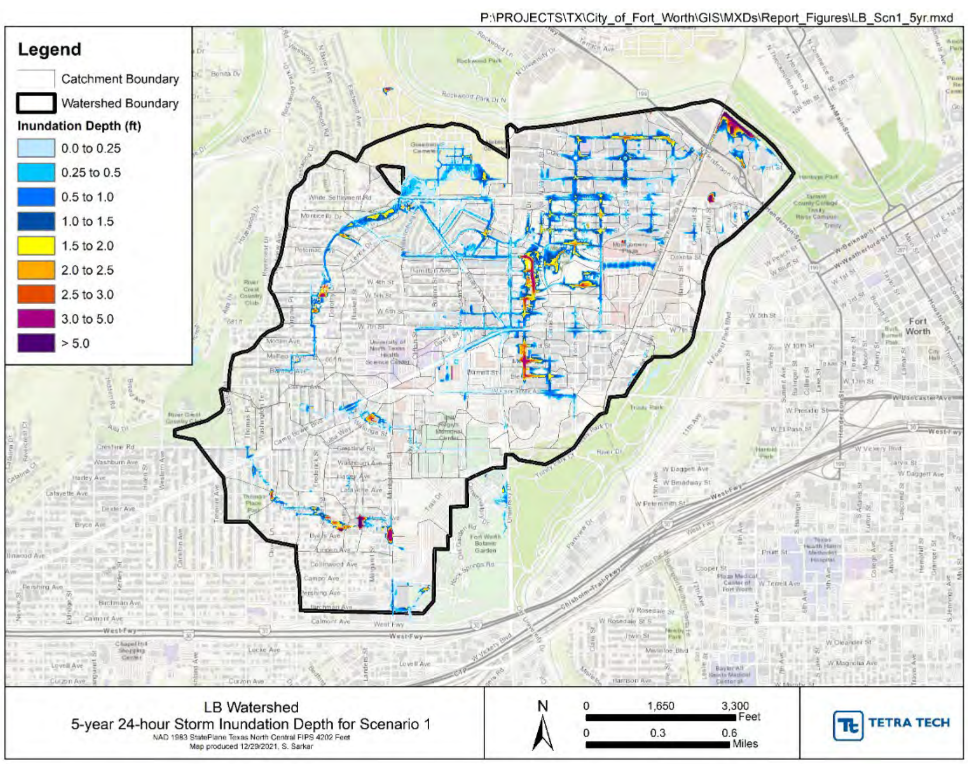

Figure 41. Inundation Depth and Extent for 5-year 24-Storm for LB Watershed Scenario 1.

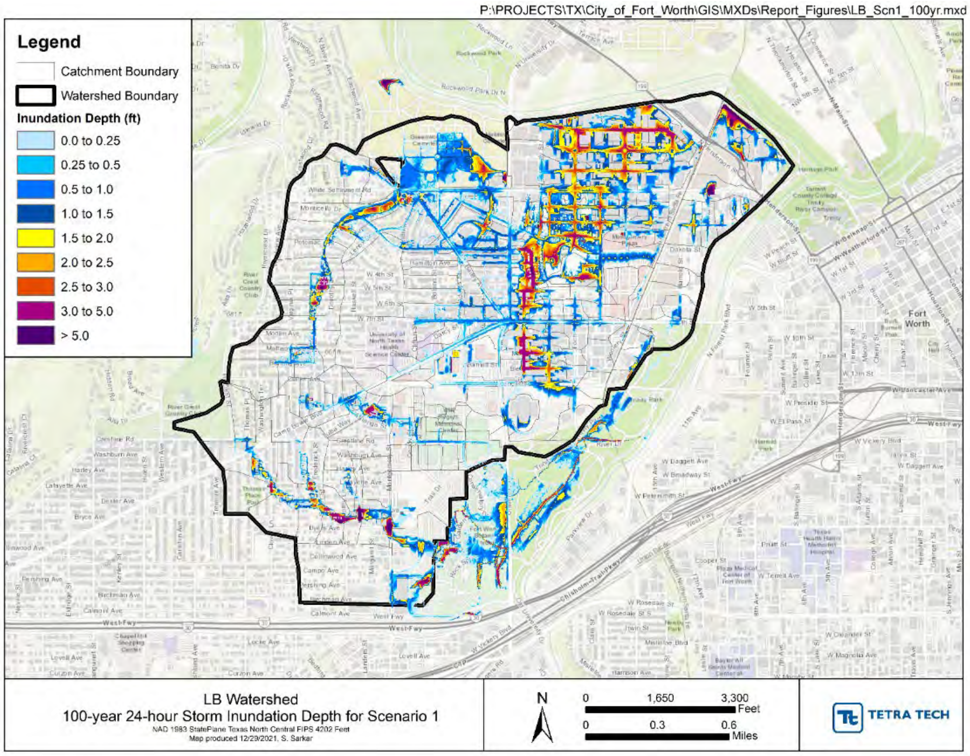

Figure 42. Inundation Depth and Extent for 100-year 24-Storm for LB Watershed Scenario 1.

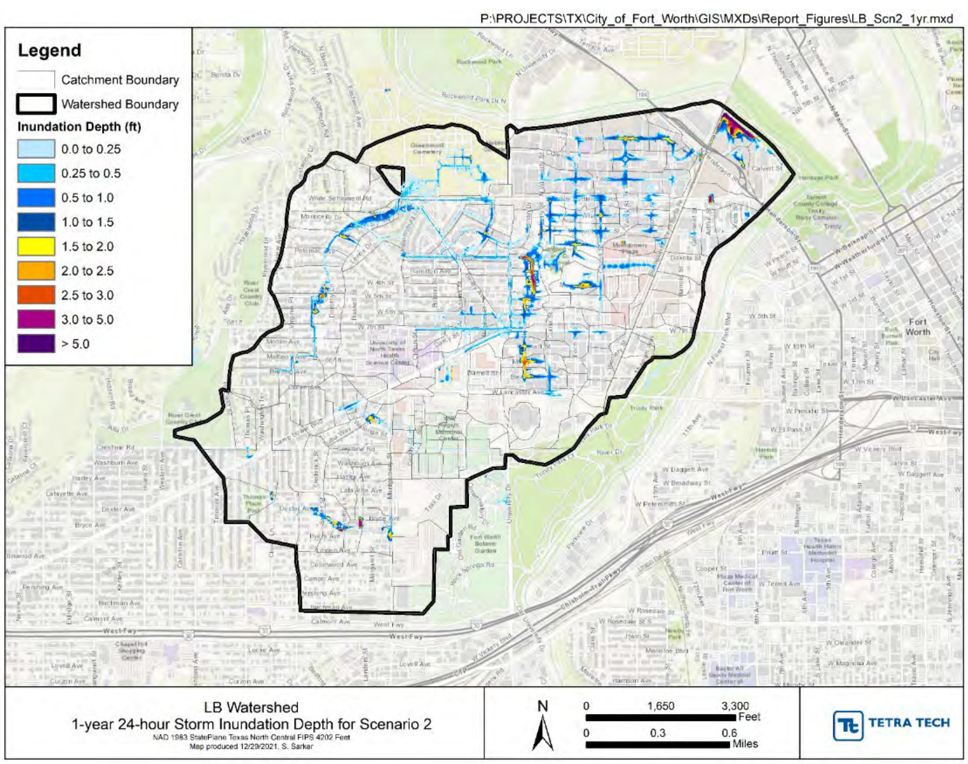

Figure 43. Inundation Depth and Extent for 1-year 24-Storm for LB Watershed Scenario 2.

P:\PROJECTS\TX\City_of_Fort_Worth\GIS\MXDs\Report_Figures\LB_Scn2_5yr.mxd

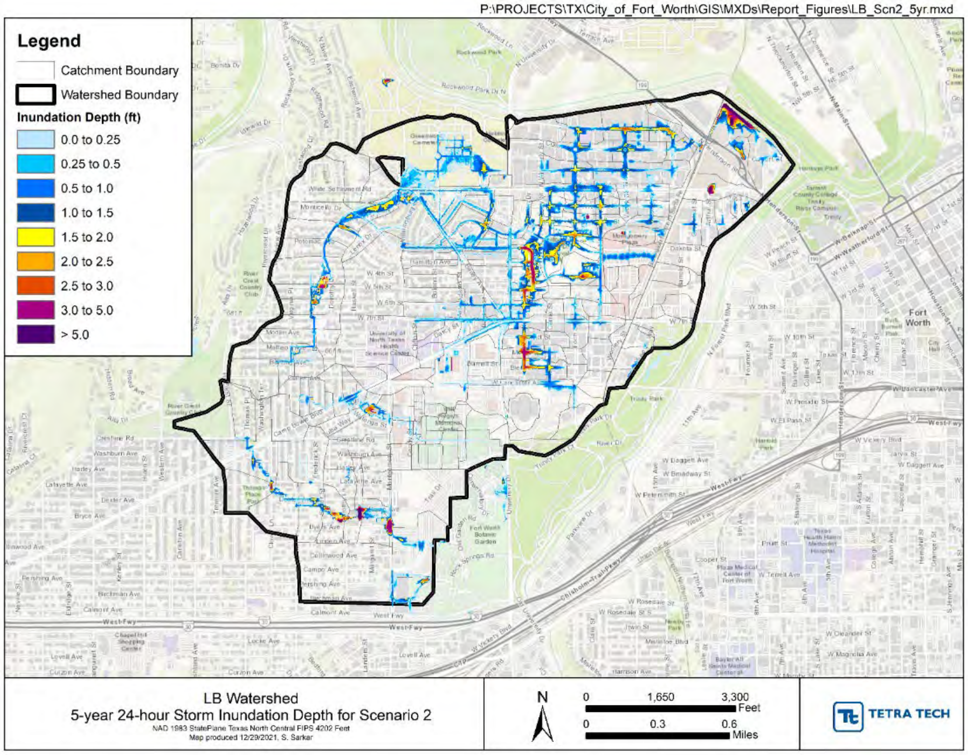

Figure 44. Inundation Depth and Extent for 5-year 24-Storm for LB Watershed Scenario 2.

P:\PROJECTS\TX\City_of_Fort_Worth\GIS\MXDs\Report_Figures\LB_Scn2_100yr.mxd

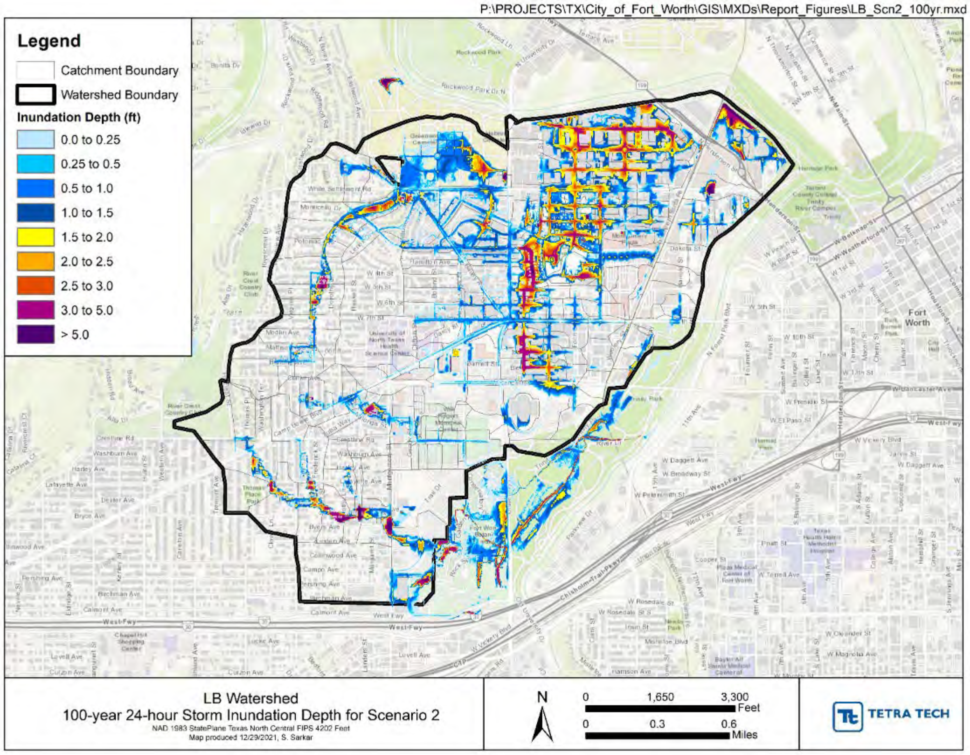

Figure 45. Inundation Depth and Extent for 100-year 24-Storm for LB Watershed Scenario 2.

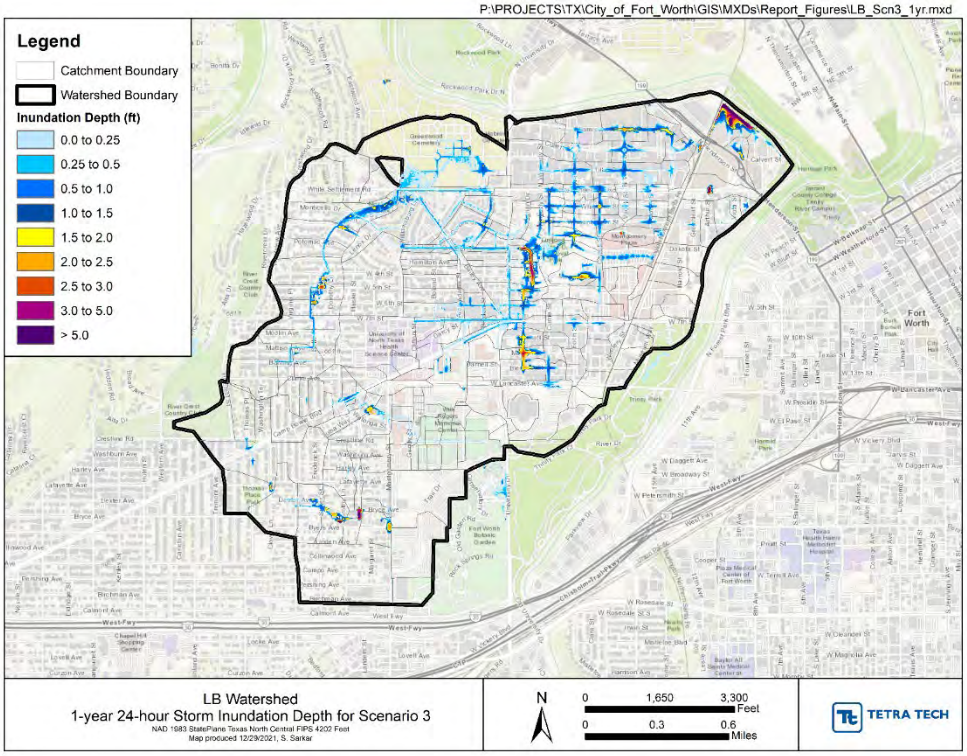

Figure 46. Inundation Depth and Extent for 1-year 24-Storm for LB Watershed Scenario 3.

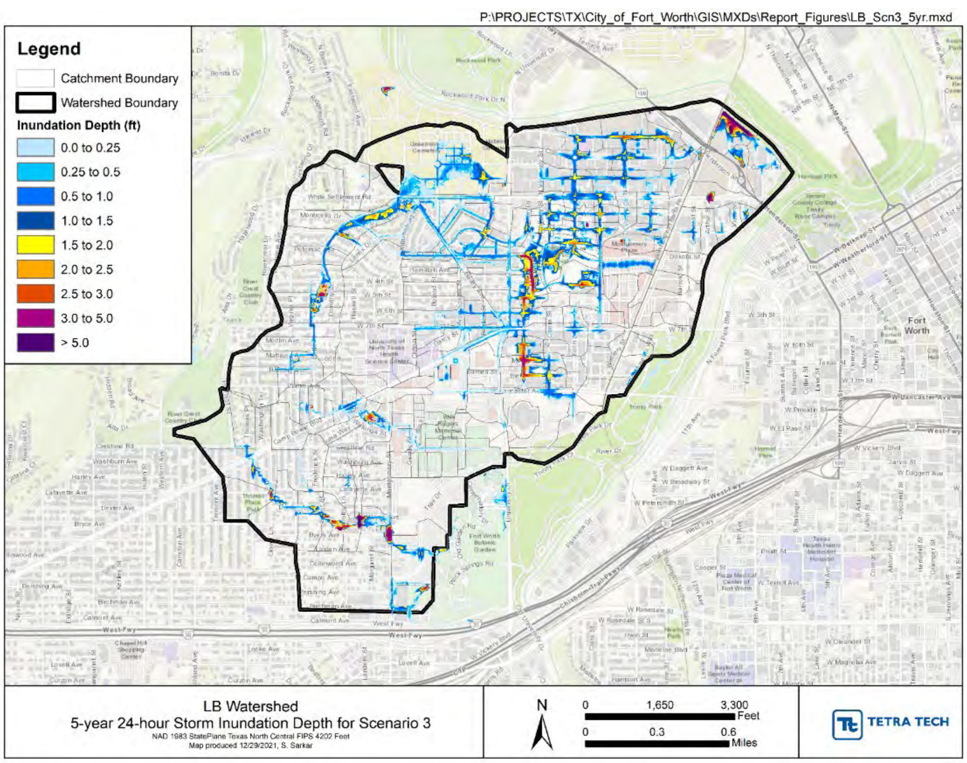

Figure 47. Inundation Depth and Extent for 5-year 24-Storm for LB Watershed Scenario 3.

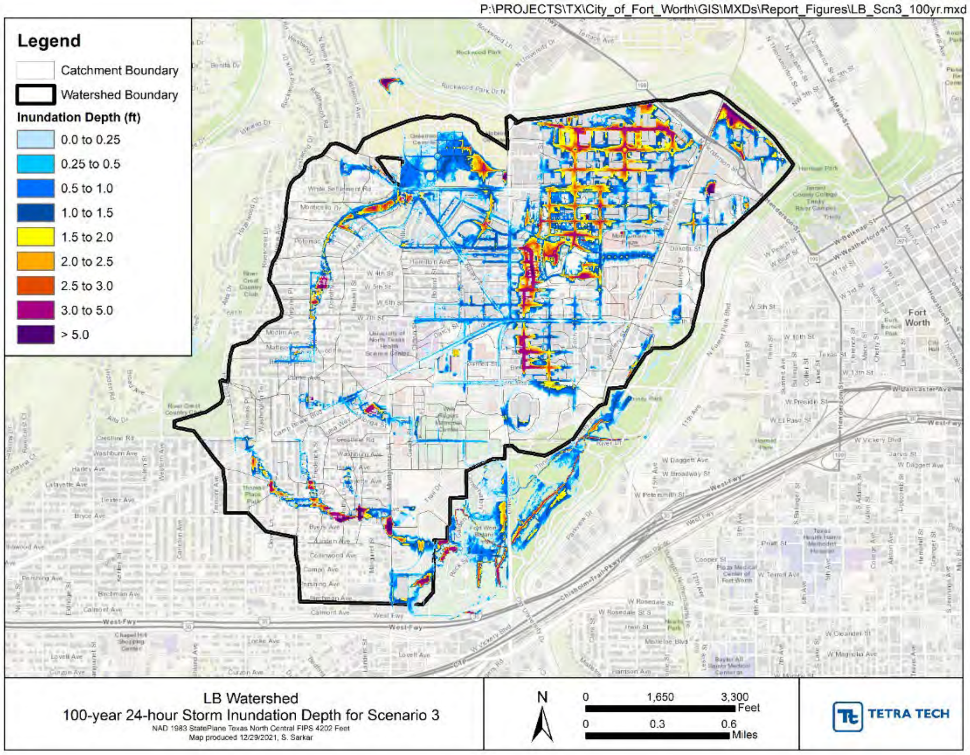

Figure 48. Inundation Depth and Extent for 100-year 24-Storm for LB Watershed Scenario 3.

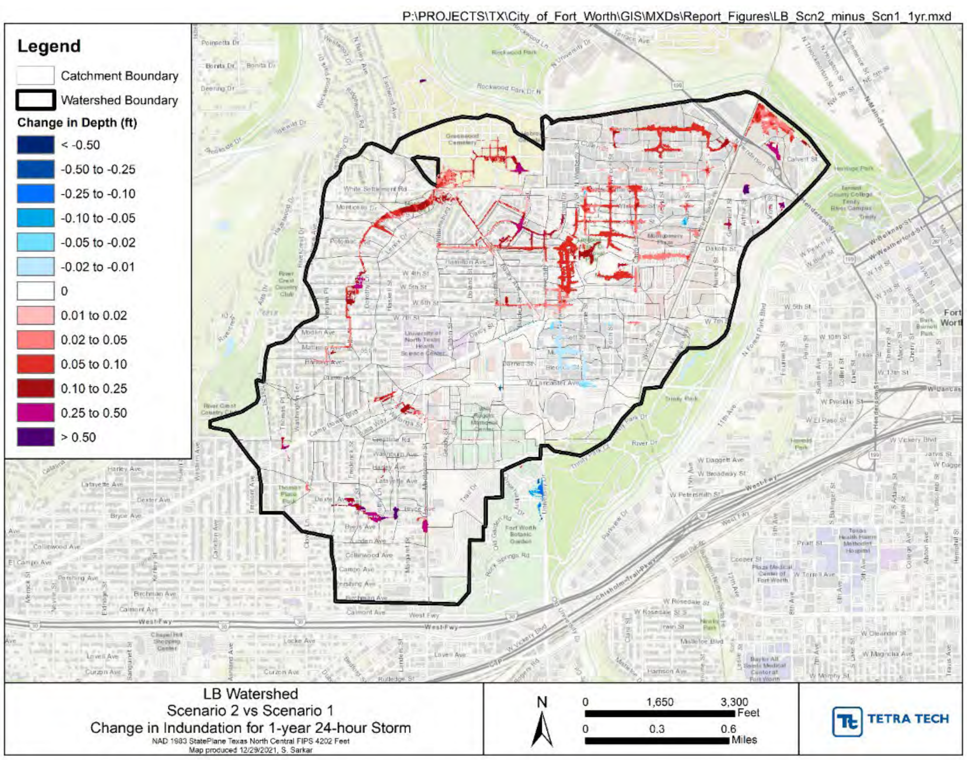

Figure 49. Change in Inundation Depth and Extent for 1-year 24-Storm for Scenario 2 vs Scenario 1.

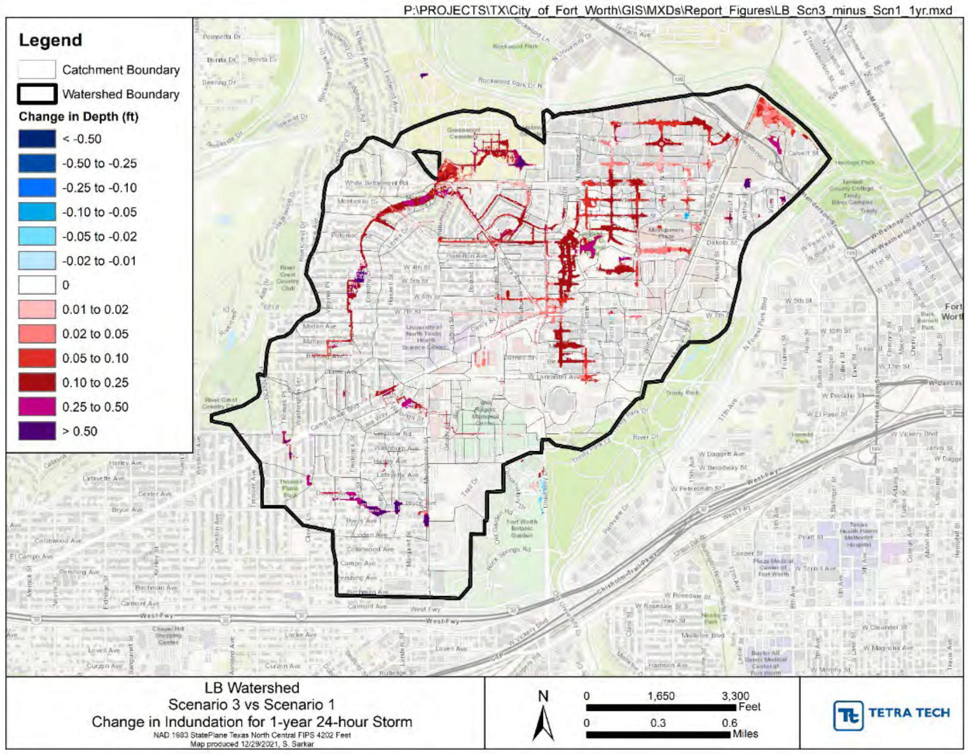

Figure 50. Change in Inundation Depth and Extent for 1-year 24-Storm for Scenario 3 vs Scenario 1.

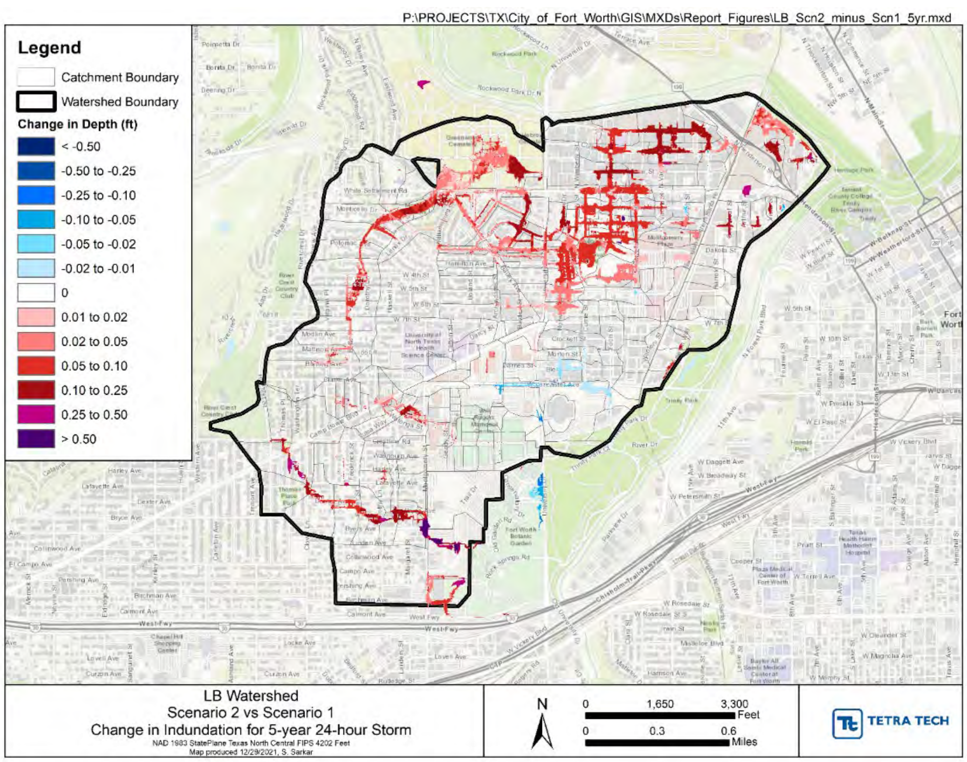

Figure 51. Change in Inundation Depth and Extent for 5-year 24-Storm for Scenario 2 vs Scenario 1.

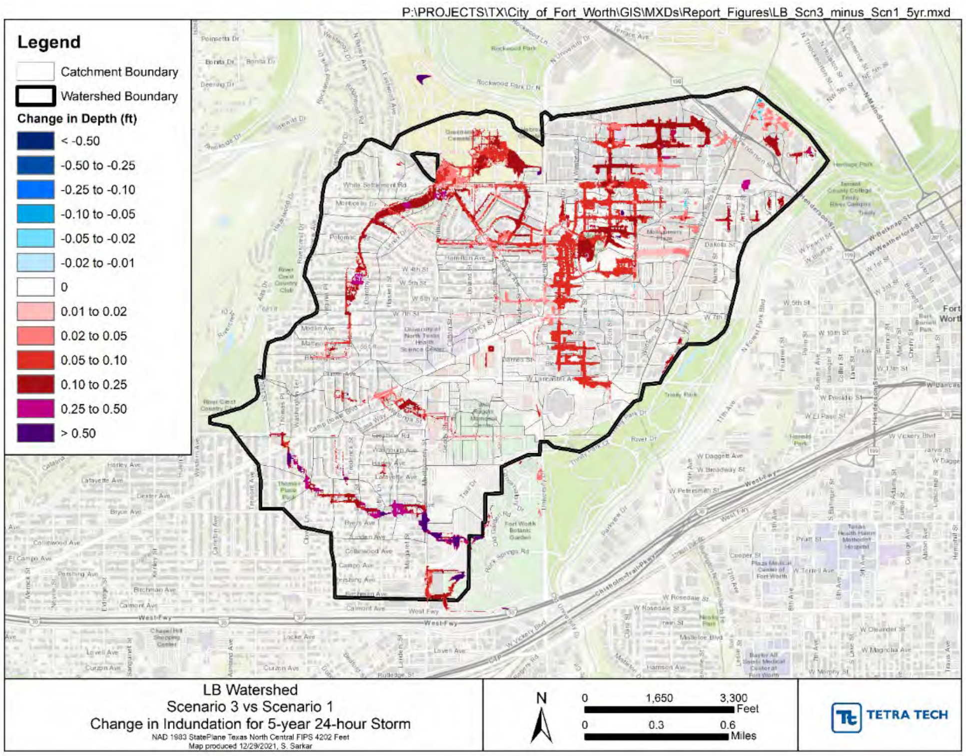

Figure 52. Change in Inundation Depth and Extent for 5-year 24-Storm for Scenario 3 vs Scenario 1.

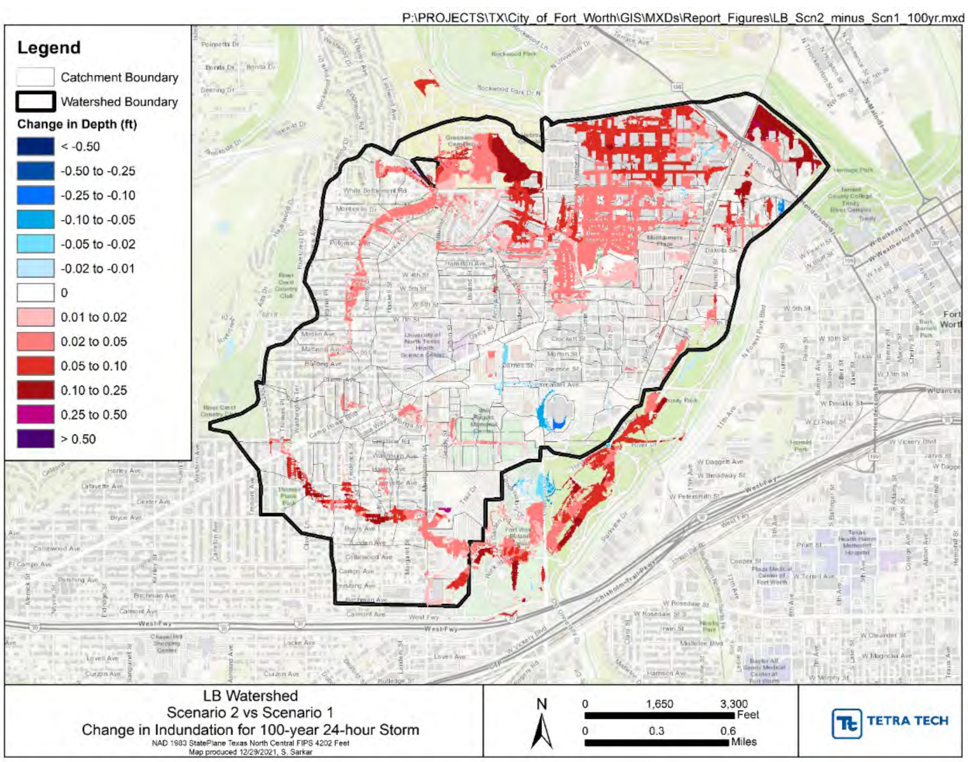

Figure 53. Change in Inundation Depth and Extent for 100-year 24-Storm for Scenario 2 vs Scenario 1.

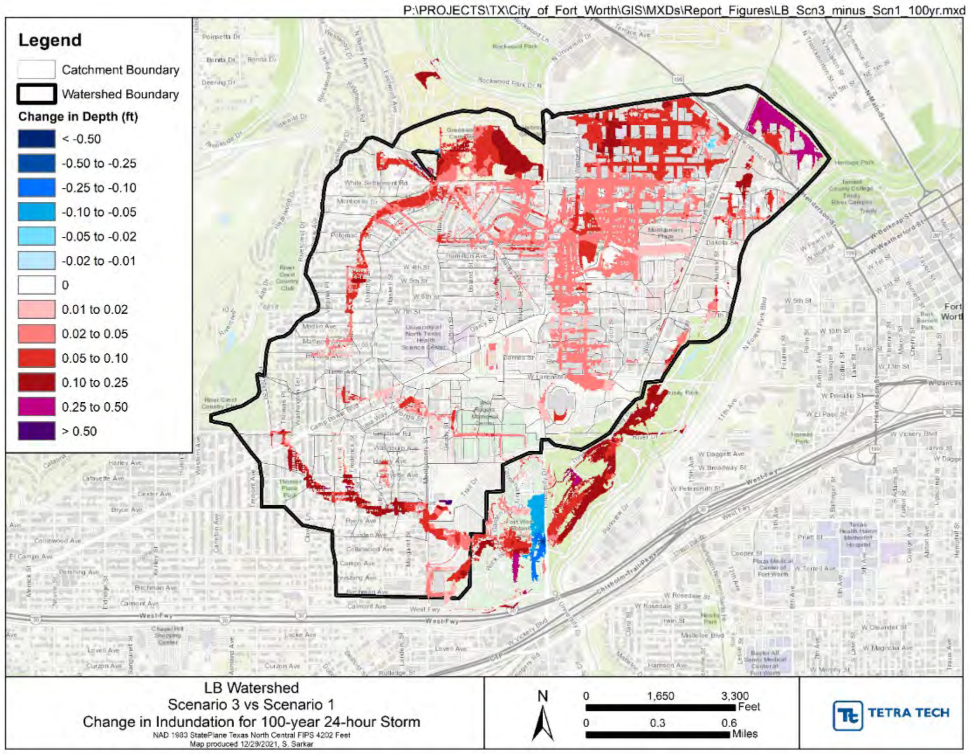

Figure 54. Change in Inundation Depth and Extent for 100-year 24-Storm for Scenario 3 vs Scenario 1.

Resources

NCTCOG: North Central Texas Council of Governments, 2020. iSWM Technical Manual - Hydrology.

CFW: City of Fort Worth, 2015. City of Fort Worth Stormwater Criteria Manual.

HCFCD: Harris County Flood Control District, 2018. Two-Dimensional Modeling Guidelines.