SAN JACINTO
REGIONAL WATERSHED MASTER DRAINAGE PLAN

Prepared for:

Harris County Flood Control District
San Jacinto River Authority
Montgomery County
City of Houston

APPENDIX E

FUTURE FLOOD RISK PLANNING ASSESSMENT

San Jacinto Regional Watershed Master Drainage Plan

FUTURE CONDITIONS

Prepared for

Harris County Flood Control District
San Jacinto River Authority
Montgomery County
City of Houston

by

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1.0 Introduction

As part of the San Jacinto Regional Watershed Master Drainage Plan (SJMDP), the project team developed existing conditions hydrologic and hydraulic models of the watershed. These HEC-HMS and HEC-RAS models were then calibrated to the Hurricane Harvey and Memorial Day 2016 storm events and validated using the October 1994 and Tropical Storm Imelda storm events.

To develop future conditions models of the watershed, the calibrated existing conditions models were updated using population growth trends. These future conditions models reflect anticipated changes in population between 2020 and 2070, which are expected to lead to increases in both impervious cover and the timing of basin runoff. This memorandum summarizes the methodologies used to estimate current populations, project future populations, associate change in population with change in land use and hydrologic parameters, and update hydrologic and hydraulic models. Draft future conditions results are also presented and compared with existing conditions results.

2.0 Population Projections

2.1 Population Data Sources

Population estimates used in the SJMDP are based on projections used in the development of Regional Water Plans (RWPs) for each of the state's sixteen water regions. The RWPs are updated every five years and are compiled by the Texas Water Development Board (TWDB) into the Texas State Water Plan (SWP). The 2021 RWPs are currently in development and include projected population, water demand, and water supplies for each decade from 2020 to 2070. The San Jacinto Watershed is located almost entirely within Region H, except for Grimes County in the west, which is part of Region G.

Data for the RWPs is generated and analyzed on the basis of Water User Groups (WUGs), which represent water-providing utilities or collective groups thereof. Typically, the TWDB projects future population for individual WUGs and further subdivides by county and river basin. However, an independent study was completed in 2013 which provided detailed population and water demand projections for five counties in Region H: Harris, Montgomery, Fort Bend, Brazoria, and Galveston. This study, known as the Regional Groundwater Update Project[1] (RGUP), was sponsored jointly by the Harris-Galveston Subsidence District (HGSD), Fort Bend Subsidence District (FBSD), and Lone Star Groundwater Conservation District (LSGCD). The TWDB has used the results of the RGUP in place of TWDB's standard WUG-level projections to represent population and water demands in the RWP and SWP for these five counties.

For regional water planning, the RGUP results were aggregated to the WUG level. However, for the San Jacinto Watershed Study, the original detailed data from the RGUP, where available, has been applied in

[1] Freese and Nichols, Inc., LBG-Guyton, Fugro, Metrostudy, and University of Houston Hobby Center for Public Policy. *Regional Groundwater Update Project.* June 2013. Prepared for HGSD, FBSD, and LSGCD. Available at https://hgsubsidence.org/wp-content/uploads/2013/07/Regional_Groundwater_Update_Project-Report-6-2013.pdf.

the determination of current and future conditions. As a result, this study is based on fine-scale data at the census block level in Harris and Montgomery Counties and coarser WUG-level data in the remaining counties. Boundaries of population data units and subwatersheds within the study area are shown in **Figure 1**.

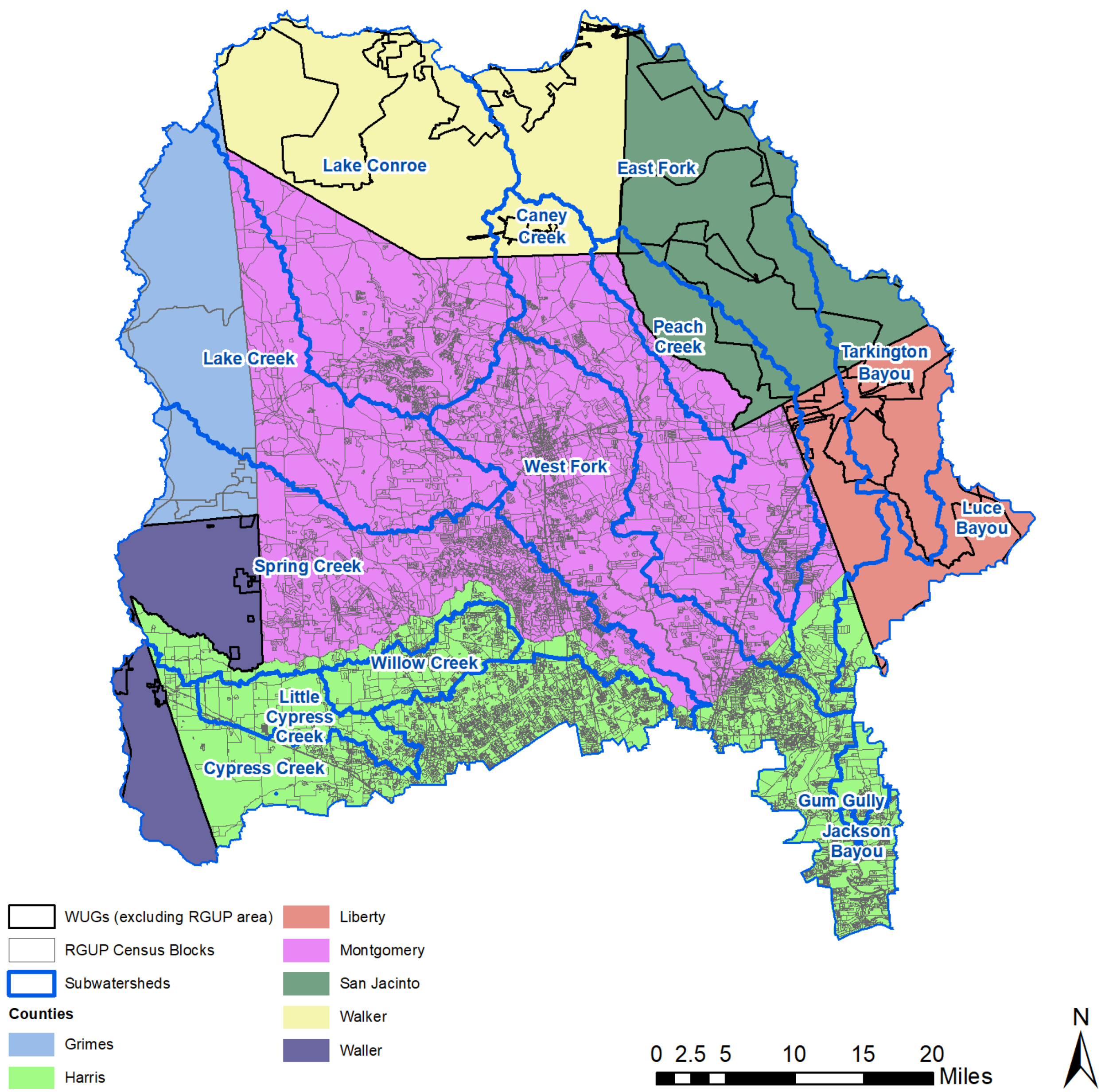


Figure 1. Counties and Population Data Units in the San Jacinto Watershed

2.2 RGUP Population Projection Methodology

The 2013 RGUP population projections are based on 2010 Census data. The RGUP used populations counted in the 2010 Census as a baseline for decadal population projections, which were developed for each census tract and then distributed to individual census blocks. This process considered land use data from the Houston-Galveston Area Council and aerial imagery in order to constrain growth to undeveloped areas. The following sections describe the RGUP's approaches for developing and disaggregating population projections in more detail.

A. Near-Term Projections

RGUP population estimates for 2011 through 2020 represent a "supply driven" forecast based on real estate development and construction activity. Development of near-term growth rates considered historical growth trends in the five-county area, historical household formation rates, apartment data, and interviews with land developers. Single-family and multi-family residential growth patterns were projected separately to account for different development patterns.

B. Long-Term Projections

Long-term growth in the RGUP represents a "demand-driven" model based on employment opportunities. For 2020 through 2070, growth rates were developed using a statistically based forecasting tool that models the location and development of employment centers and land use.

C. Distribution of Tract Projections to Census Blocks

Once population was projected by census tract for each decade through 2070, the RGUP distributed these estimates to census blocks one decade at a time. Distribution to blocks in 2020 accounted for the available area within each tract and expected locations of new or growing subdivisions. After distribution, the RGUP updated remaining undeveloped area. The RGUP repeated a similar process for 2030, accounting for the changes assumed in 2020 and subsequently updating the remaining area available for growth. For 2040 and beyond, the RGUP evenly distributed additional population across the remaining developable area in each tract for each decade.

2.3 TWDB Population Projection Methodology

The TWDB finalized population projections for the 2021 RWPs in February 2018. Populations were projected for each Municipal WUG, which are user groups providing water for residential, commercial, or institutional use. Named municipal WUGs are defined as any utility or water system which provides at least 100 acre-feet per year of water supply on average. Named WUGs also include some Collective Reporting Units of multiple utilities, such as The Woodlands Water Agency in Montgomery County, which includes numerous individual municipal utility districts. In each county, the remaining population not associated with these defined WUGs were grouped into a WUG called "County-Other."

A. Populations of Named WUGs

The TWDB used estimated 2010 populations as the baseline for projecting growth in individual WUGs. Because most WUGs do not align with a single city or other census-designated place, the TWDB considered numerous data sources in estimating baseline populations, including but not limited to:

- TWDB Water Use Survey,
- Texas Commission on Environmental Quality data for Public Water Systems,
- Census household sizes, and
- Census block populations intersected with WUG service area boundaries.

After determining baseline populations, the TWDB applied growth trends from the corresponding WUG in the 2017 SWP where available. Some WUGs were newly delineated in the 2021 RWPs; for these, long-term growth was based on county-level growth projections and the WUG's share of 2010 county population.

B. Populations of County-Other

The TWDB developed county-level population projections for the 2016 RWPs and 2017 SWP, which have not been updated for the 2021 RWPs, as no new census has been completed since that time. Populations in each county for 2011 through 2050 were estimated by the Texas State Data Center and the Office of the State Demographer for multiple migration scenarios. The TWDB extended projections from the Half-Migration scenario to 2060 and 2070 using the average growth trend of the first 40 years. This scenario assumes that future migration will occur at half the rate of that observed in 2000-2010. For counties with projected population declines, the TWDB instead held population constant; no such counties are in the San Jacinto Watershed. After WUG-level populations were updated for the 2021 RWPs as described in the previous section, the TWDB calculated decadal populations in "County-Other" areas as the remaining population in each county.

3.0 Aggregation of Land Use and Population by Subbasin

3.1 Aggregation Process

To project future changes in hydrologic and hydraulic conditions, each subbasin in the existing conditions model of the watershed was updated to reflect future land use data, which was based on the population projections described in **Section 2.0**. As the first step of this process, existing land use data, existing population data, and future population projections were aggregated at the subbasin level for analysis.

To target future development in undeveloped land located in non-floodplain areas, land use data for this study was based on Houston-Galveston Area Council (H-GAC) data gathered in 2018. This land use data was combined with the existing conditions NOAA Atlas 14 1% annual chance event (ACE) floodplain that was generated as part of the SJMDP.

As described in the previous section, detailed population projections from the RGUP were utilized in Harris and Montgomery Counties, with TWDB projections by WUG applied in the remainder of the San Jacinto Watershed. To associate 2018 land use with 2018 population data, the 2018 population in each census block in Harris and Montgomery Counties was interpolated from 2010 Census data and 2020 projections. In the remaining counties, the 2018 population was extrapolated from 2020 and 2030 WUG population projections.

Finally, the 2018 populations, 2018 H-GAC land use with 1% ACE floodplain, and 2070 populations were aggregated by subbasin. Where population data polygons cross subbasin boundaries, the population for each polygon was allocated to each subbasin proportional to the area of overlap.

For each subbasin, existing land use was evaluated to obtain a percent-developed and percent-undeveloped value. The developed categories are transportation, low intensity, medium intensity, high intensity, and developed open space; the undeveloped categories are barren, forested, pasture, and cultivated. The 2018 population per developed acre was then assigned to each subbasin. The 1% ACE floodplain area was also subtracted from the undeveloped area to assign a developable area of each subbasin. Descriptions of each developed category are shown in **Table 1** below.

Table 1. Developed Land Use Categories

Land Use Category	Description	Impervious	DLU (Percent Urbanization)
Transportation	Regional roadways, highways	80%	100%
Low Intensity	Single-family housing, rural neighborhoods	33%	100%
Medium Intensity	Multi- and single-family housing, suburban neighborhoods	65%	100%
High Intensity	Heavily built-up urban centers	85%	100%
Developed Open Space	Managed open space in developed areas for recreation, erosion control, or aesthetic purposes	15%	50%

3.2 Aggregation Results

Exhibits 1 and **2** show the population data units color-coded by 2018 population density and projected 2070 population density, respectively. **Exhibit 3** shows the change in population density aggregated by subbasin. **Exhibit 4** shows 2018 land use color-coded by developed, 1% ACE floodplain, and developable area. The remainder of this analysis takes place at the subbasin level in order to develop future conditions parameters for the HEC-HMS hydrologic model.

Table 2 below summarizes the 2018 population and projected 2070 population by subwatershed.

Table 2. Population Projections by Subwatershed

Subwatershed	2018 Population	2070 Population	Change in Population	% Change in Population
Lake Creek	28,078	100,329	72,251	257%
Spring Creek	287,039	797,494	510,455	178%
Willow Creek	71,385	118,212	46,827	66%
Cypress Creek	451,660	590,617	138,957	31%
Little Cypress Creek	47,791	85,353	37,562	79%
West Fork	334,289	785,126	450,837	135%
Lake Conroe	85,907	228,684	142,777	166%
Luce Bayou	8,817	14,609	5,792	66%
Tarkington Bayou	12,228	17,080	4,852	40%
Caney Creek	80,492	263,111	182,619	227%
Peach Creek	29,005	102,300	73,295	253%
East Fork	44,042	67,866	23,824	54%
Jackson Bayou	4,377	6,221	1,844	42%
Gum Gully	11,830	20,982	9,152	77%

The percentage of each existing development type was also calculated for each subbasin. To give an example, a 100-acre subbasin with 20 acres of total development in the subbasin is considered 20% developed. This development may include 10 acres of low-intensity and 10 acres of medium-intensity development. This equates to a development pattern of 50% low intensity and 50% medium intensity for that individual subbasin. These steps were repeated to capture existing-conditions development patterns for each subbasin in the watershed.

The estimated existing-conditions development patterns, summarized in **Table 3** below, describe the expected proportion of each land use type comprising each unit of future development. This also provides the basis for estimating population distribution per future developed acre as described in **Section 4.0**.

Table 3. Existing Development Patterns by Subwatershed (2018)

Subwatershed	Total Area (ac)	Pct. Dev.	Development Pattern (Pct. of Developed Area)					Avg. Pct. Imp.	Avg. DLU
			Transp.	Low Intens.	Med. Intens.	High Intens.	Devel. Open Space		
Lake Creek	211,803	14%	3%	79%	8%	3%	8%	10.1	18.3
Spring Creek	248,160	39%	3%	72%	13%	3%	10%	17.4	42.4
Willow Creek	35,567	71%	6%	51%	15%	4%	24%	27.7	63.1
Cypress Creek	170,789	53%	3%	45%	28%	7%	16%	26.7	54.3
Little Cypress Creek	33,466	53%	5%	49%	16%	3%	27%	20.4	44.0
West Fork	215,972	44%	7%	61%	15%	7%	10%	30.3	55.3
Lake Conroe	288,151	14%	7%	78%	8%	3%	3%	12.1	21.7
Luce Bayou	53,728	11%	8%	74%	1%	0%	17%	6.3	13.8
Tarkington Bayou	83,611	13%	16%	72%	5%	2%	5%	5.2	11.9
Caney Creek	139,442	26%	7%	82%	4%	2%	6%	15.3	30.2
Peach Creek	101,496	18%	5%	89%	2%	1%	2%	10.7	21.4
East Fork	264,371	11%	10%	79%	4%	1%	6%	6.5	14.4
Jackson Bayou	4,747	42%	9%	63%	9%	7%	12%	20.6	40.6
Gum Gully	11,846	30%	7%	68%	3%	1%	20%	12.1	30.5

3.3 Existing Development Patterns

Developed subbasins were grouped into four areas to form a basis for land use patterns that could be expected in the future: the developed portions of Cypress and Spring Creek subbasins, Lake Houston, Cleveland, and Conroe. The development pattern for each area – that is, the breakdown of the total developed area into its proportions of transportation, low/medium/high intensity development, and developed open space – is presented in **Table 4** below, along with the corresponding 2018 population data averaged over each area. These patterns are also shown in **Exhibit 5**.

Table 4. Existing Development Pattern Groups (2018)

Development Pattern Area	Development Pattern (Pct. of Developed Area)					2018 Population Density (Population per Developed Acre)
	Transp.	Low Intens.	Med. Intens.	High Intens.	Devel. Open Space	
Cypress and Spring	3%	54%	25%	5%	13%	9.22
Lake Houston	5%	63%	14%	7%	11%	6.30
Cleveland	13%	71%	5%	3%	9%	4.05
Conroe	7%	70%	10%	5%	8%	4.63

The table above shows existing development patterns and population density. Each land use was then correlated with a typical population density. The technical documentation for H-GAC's 2018 land use[2] states that low-intensity development "commonly includes single-family housing areas," medium-intensity development "commonly includes multi- and single-family housing areas," and high-intensity development "includes heavily built-up urban centers and large constructed surfaces."

The following section describes the assumptions used to generalize and apply these patterns in order to project anticipated future development.

[2] Houston-Galveston Area Council. *Development of Land Use and Land Cover (LULC) Data for the Houston-Galveston Area Council (H-GAC) Region*. January 2019. Available at http://www.h-gac.com/land-use-and-land-cover-data/default.aspx.

4.0 Future Conditions Assumptions

4.1 Population Density by Land Use

As the first step in forecasting future developed area, assumed population densities were developed for each H-GAC land use categories. The goal for this process was to make generally reasonable assumptions that will produce an average population per future developed acre that generally aligns with the existing population per developed acre values presented in **Table 4** above. Each future developed acre will include a mix of transportation, low-intensity, medium-intensity, high-intensity, and developed open space area. The transportation and developed open space categories were assumed to have no population.

For low-intensity developments, residential lots were assumed to consist of 50% half-acre and 50% quarter-acre lots. According to the US Census Bureau[3], the average persons per household from 2014–2018 was 2.67 for Houston, 2.7 for the Woodlands, 2.65 for Conroe, 2.67 for Cleveland, 2.86 for all of Montgomery County, and 2.88 for all of Harris County. Based on this data, 2.5 people per household was selected as a conservative estimate, which would result in slightly more developed area needed to accommodate a given increase in population. This assumption results in an average of 7.5 people per low-intensity acre of development.

Medium-intensity land use represents a mix of single-family, multi-family, and non-housing areas such as businesses and small shopping centers. As such, a mix of eighth-acre residential lots, multi-family development, and non-housing development was assumed. Eighth-acre residential lots use the same assumption of 2.5 people per household. For multi-family development, an average rate of 55 people per acre was used. In reality, this rate is highly variable as it represents a mix of duplexes, apartments, and multi-story apartments. The goal for setting these assumptions is to set a reasonable range of values that achieve the anticipated population per future developed acre. To allow for variation of medium-intensity population densities between suburban and rural areas, two medium-intensity development patterns were developed, one for suburban and one for rural areas. This is discussed further in the following **Section 4.2**.

It is likely that some population growth will occur in developed areas that redevelop to accommodate a higher population density. However, the level of redevelopment is uncertain and would vary across the watershed. This study assumes that all future population growth will occur in currently undeveloped area. This simplifying assumption yields slightly higher impervious cover and is more conservative than assuming some level of redevelopment. Redevelopment was only assumed where required in order to accommodate population growth in areas that are already highly developed, such as the Cypress Creek and Willow Creek subwatersheds. In these areas, low-intensity and medium-intensity development alone may not accommodate the projected 2070 population, and a small percentage of medium-intensity development was assumed to develop as high-intensity instead. The high-intensity development assumes a population density of 200 people per acre.

[3] US Census Bureau. *QuickFacts: Houston, Texas.* Accessed February 2020. Available at https://www.census.gov/quickfacts/houstoncitytexas.

These assumptions and the resulting population per future developed acre are provided in **Table 5** below.

Table 5. Future Development Pattern Assumptions

Group	Single-Family (2.5 People per House)			Multi-Family (55 People per Acre)	Non-Housing	Population per Future Developed Acre
	1/2-ac Lots	1/4-ac Lots	1/8-ac Lots			
Low-Intensity	50%	50%	-	-	-	7.5
Medium-Intensity (Rural)	-	-	30%	10%	60%	11.5
Medium-Intensity (Suburban)	-	-	50%	20%	30%	21.0
High-Intensity*	-	-	-	-	-	200.0

* High-intensity land use was only used to accommodate population growth in a few highly developed areas that could otherwise not accommodate the projected population growth.

4.2 Future Development Patterns

Two generic future development types, "suburban" and "rural," were created based on the existing development patterns presented in **Table 4**. Both development types are assumed to consist of 5% transportation, 5% high intensity, and 10% developed open space as these values are relatively consistent across the watershed. (Cleveland's developed area is currently 13% transportation, significantly higher than the transportation share for other areas. Because Cleveland is less developed than the other areas, its highways and major roadways make up a higher percentage of its total developed area. This transportation percentage should decrease over time as Cleveland continues to develop, so 5% transportation was assumed to be representative of future development.)

The suburban development type was assumed to consist of 50% low-intensity area and 30% medium-intensity area, similar to the existing Cypress and Spring area shown in **Table 4**. The rural development type was assumed to consist of 65% low-intensity and 15% medium-intensity area, a little denser than the existing Cleveland, Lake Houston, and Conroe areas shown in **Table 4**. These assumptions were combined with the population per future developed acre values developed in **Section 4.1** to produce suburban and rural development patterns shown in **Table 6** below.

To spatially assign the suburban and rural development patterns to future developed areas, each subbasin was categorized as either a suburban or rural development based on aerial imagery and proximity to existing development. In general, areas near The Woodlands, Kingwood, and Lake Conroe were categorized as suburban, and remaining areas were categorized as rural, as shown in **Exhibit 5**.

Table 6. Future Development Patterns

Future Development Type	Development Pattern (Pct. of Developed Area)					Population Density (Population per Future Developed Acre)
	Transp.	Low Intens.	Med. Intens.	High Intens.	Devel. Open Space	
Suburban	5%	50%	30%	5%	10%	10.05
Rural	5%	65%	15%	5%	10%	6.60

As shown in **Table 6** above, these assumptions result in 10.05 people per acre for suburban development and 6.60 people per acre for rural development. These densities are slightly higher than the existing population densities shown in **Table 4**, which matches the expectation that future development in the watershed is likely to be denser than existing development.

This approach provides a way to convert population growth in each subbasin to an expected change in land use within that subbasin. The newly developed area can then be converted to new impervious cover and weighted BDF values for input into HEC-HMS.

4.3 Additional Area Needed for 2070 Development

The 2018–2070 population growth and amount of developable area were aggregated by subbasin as described previously. This data was combined with the population density and land use assumptions presented in **Table 6** to generate a projected area of additional development within each subbasin broken down by land use.

For example, consider a subbasin with an anticipated population growth of 10,000 people by 2070. If this subbasin is expected to develop according to the suburban development pattern, these 10,000 people, which occupy land at a rate of 10.05 people per acre, will require 995 acres of newly developed land. Of these 995 acres, 5% (49.8 acres) would develop as transportation, 50% (497.5 acres) would develop as low-intensity, and so on.

The resulting changes in developed area are summarized by subwatershed in **Table 7** below.

Table 7. Projected Changes in Developed Area, 2018–2070

Subwatershed	Total Area (ac)	2018 Population	2018 Developed Area (ac)	Change in Population 2018–2070	Area (ac) Req'd for Fut. Growth	2070 Developed Area
Lake Creek	211,803	28,078	30,264	72,251	10,947	41,211
Spring Creek	248,160	287,039	96,251	510,455	49,180	145,431
Willow Creek	35,567	71,385	25,140	46,827	3,835	28,975
Cypress Creek	170,789	451,660	89,856	138,957	9,564	99,419
Little Cypress Creek	33,466	47,791	17,625	37,562	3,727	21,352
West Fork	215,972	334,289	94,297	450,837	53,040	147,336
Lake Conroe	288,151	85,907	39,610	142,777	16,126	55,736
Luce Bayou	53,728	8,817	5,669	5,792	673	6,341
Tarkington Bayou	83,611	12,228	10,476	4,852	735	11,211
Caney Creek	139,442	80,492	36,361	182,619	25,285	61,647
Peach Creek	101,496	29,005	18,011	73,295	11,098	29,109
East Fork	264,371	44,042	29,416	23,824	3,401	32,817
Jackson Bayou	4,747	4,377	1,981	1,844	183	2,165
Gum Gully	11,846	11,830	3,519	9,152	911	4,430

As discussed in **Section 4.1**, this study assumes that all future population growth will occur in developable area, that is, currently undeveloped areas outside the floodplain. However, approximately 8% of the subbasins have a smaller developable area than what is required to accommodate future population growth. These subbasins are mainly concentrated in highly populated areas of the Cypress Creek and West Fork subwatersheds. Some level of redevelopment would be required to accommodate the anticipated population growth. In these subbasins, the population density was manually increased by reallocating some of the low-intensity development to medium-intensity development, or in rare cases by reallocating some medium-intensity development to high-intensity residential development at 200 people per acre. The average population density of the manually adjusted subbasins was 19.2 people per acre. The highest three adjusted population densities of 75.9, 45.7, and 42 people per acre are all in highly developed Cypress Creek subbasins.

4.4 Impervious and Development Percentage Calculations

To calculate the impervious and development (DLU) percentages for future conditions in the watershed, the development patterns shown in **Table 6** and were applied to the area required for future development values at the subbasin level. The resulting additional developed area required to accommodate 2070 population totals is summarized by subwatershed in **Table 8**.

Table 8. Additional Development Area by Subwatershed (2070)

Subwatershed	Additional Developed Area (ac)					Total Additional Developed Area (ac)
	Transp.	Low Intens.	Med. Intens.	High Intens.	Devel. Open Space	
Lake Creek	547	7,116	1,642	547	1,095	10,947
Spring Creek	2,459	23,390	15,954	2,459	4,918	49,180
Willow Creek	192	1,739	1,297	225	384	3,835
Cypress Creek	478	4,213	3,241	675	956	9,564
Little Cypress Creek	186	1,856	1,126	186	373	3,727
West Fork	2,652	28,127	14,300	2,657	5,304	53,040
Lake Conroe	806	8,626	4,262	820	1,613	16,126
Luce Bayou	34	378	160	34	67	673
Tarkington Bayou	37	478	110	37	74	735
Caney Creek	1,264	15,127	5,097	1,268	2529	25,285
Peach Creek	555	7,202	1,677	555	1110	11,098
East Fork	170	2,151	570	170	340	3,401
Jackson Bayou	9	92	55	9	18	183
Gum Gully	46	455	273	46	91	911

Each development type shown has a corresponding impervious and development percentage as shown in **Table 1**. Future-conditions impervious and development percentages were calculated by applying these percentages to the additional developed area in **Table 8** and combining the data with existing conditions values. The resulting 2070 development patterns are summarized by subwatershed in **Table 9** below. The resulting changes to percent impervious cover are shown in **Exhibit 6**.

Table 9. Projected Development Patterns by Subwatershed (2070)

Subwatershed	Total Area (ac)	Pct. Dev.	Development Pattern (Pct. of Developed Area)					Avg. Pct. Imp.	Avg. DLU
			Transp.	Low Intens.	Med. Intens.	High Intens.	Devel. Open Space		
Lake Creek	211,803	19%	3%	75%	9%	3%	9%	12.4	23.6
Spring Creek	248,160	59%	4%	63%	19%	4%	10%	27.7	63.3
Willow Creek	35,567	81%	5%	50%	18%	4%	22%	32.7	73.1
Cypress Creek	170,789	58%	3%	45%	29%	7%	16%	29.6	60.0
Little Cypress Creek	33,466	64%	5%	49%	18%	4%	24%	25.0	53.5
West Fork	215,972	68%	6%	58%	19%	7%	10%	42.2	80.3
Lake Conroe	288,151	19%	7%	71%	13%	4%	5%	16.3	30.4
Luce Bayou	53,728	12%	7%	72%	3%	1%	16%	6.9	15.0
Tarkington Bayou	83,611	13%	15%	71%	6%	2%	6%	5.6	12.8
Caney Creek	139,442	44%	6%	73%	11%	3%	7%	22.0	45.5
Peach Creek	101,496	29%	5%	80%	7%	3%	5%	14.9	31.3
East Fork	264,371	12%	9%	77%	5%	2%	6%	7.3	16.2
Jackson Bayou	4,747	46%	9%	62%	11%	7%	12%	22.7	45.0
Gum Gully	11,846	37%	7%	64%	9%	2%	18%	16.0	38.7

4.5 Basin Development Factor (BDF) Calculations

The existing-conditions West Fork, East Fork, Peach Creek, Caney Creek, Luce Bayou, and Tarkington Bayou models were created from scratch as part of the SJMDP and used the Harris County Flood Control District (HCFCD) basin development factor (BDF) method to develop hydrologic parameters. For these models, a fully developed BDF of 12 was assigned to all future development areas except for developed open space, which received a BDF of 6. This represents a conservative assumption in the effect of development on hydrograph timing. BDF values for future development were then combined with existing-conditions BDF values to obtain a single area-weighted BDF value for each subbasin.

The effect on average BDF values throughout the entire watershed was incremental, increasing the average 2018 BDF from 1.35 to 2.17, and increasing the maximum 2018 BDF from 9 to 9.44. The changes in BDF are shown in **Table 10** and **Exhibit 7**. These BDF values were then used to calculate future-conditions time of concentration (TC) and storage (R) parameters for the individual subbasins.

Table 10. BDF Changes by Subwatershed

Subwatershed	2018 BDF	2070 BDF	Change in BDF
Lake Creek	0.32	0.87	0.55
West Fork	4.27	6.21	1.94
Lake Conroe	1.30	2.01	0.70
Luce Bayou	1.05	1.18	0.13
Tarkington Bayou	1.02	1.11	0.09
Caney Creek	1.88	3.60	1.72
Peach Creek	0.63	1.75	1.12
East Fork	0.27	0.41	0.13
Average	**1.35**	**2.17**	**0.82**

The SJMDP existing-conditions Cypress Creek, Spring Creek, Willow Creek, and Jackson Bayou models are based on updated HCFCD effective models. These models use a different methodology for determining TC and R hydrologic parameters. For these models, future conditions TC and R were calculated based on future land urbanization (DLU) and future area affected by detention (DET) values. The DET parameter is used to adjust TC and R parameters in a manner that accounts for detention within a subbasin. Per HCFCD methodology handbooks, DET is described as "the percentage of the subbasin served by onsite detention." This analysis assumes all that all future development will have onsite detention. For each subbasin, the future developed area as described in **Section 4.3** was converted to a percentage and added to the existing value to arrive at a future conditions DET value.

For each subbasin, a detention rate of 0.55 acre-feet per acre was assumed for each acre of future development. (This requirement is recommended as a minimum for all jurisdictions in the watershed. Higher and lower detention rates may be applied throughout the watershed, but the rate of 0.55 acre-feet per acre was selected as a simplifying assumption. Refer to **Sections 5.0** and **6.0** for further discussion of the effect of detention.) The resulting detention volume was then used to calculate a detention rate adjustment factor (C_f) according to Harris County Flood Control District BDF methodology. The TC and R parameters are then multiplied by this C_f factor to reflect the cumulative effect of detention. Per the BDF methodology, this detention rate adjustment is only applied when the subbasin's overall detention rate exceeds 10 acre-feet per square mile, or about 0.016 acre-feet per acre. The resulting TC and R values were then used to create the HEC-HMS and HEC-RAS models of future conditions with detention.

5.0 Hydrologic and Hydraulic Model Results

The HEC-HMS subbasins were updated to reflect the 2070 impervious cover and TC and R values for the 2070 conditions scenario. Simulations were then performed of events ranging from the 50% annual chance event (ACE) to the 0.2% ACE. Resulting inflows to Lake Conroe were routed using current gate operations to provide hydrographs downstream of Lake Conroe Dam. The HEC-RAS hydraulic model simulations were then executed based on these inflows.

Table 11 and **Table 12** summarize the changes in peak flow and runoff volume at the downstream end of each stream during the 1% ACE and 50% ACE events, respectively. **Table 13** summarizes the resulting increases in the 1% ACE and 50% ACE peak water surface elevations (WSE) along each stream. The 1% ACE increases in WSE are depicted on **Exhibits 8–15**.

Table 11 generally shows increases in both peak flow and volume, with two exceptions. One is the slight decrease in peak 1% ACE flow at the downstream end of Lake Creek. This is caused because future development is projected at the downstream end of the Lake Creek subwatershed. This causes runoff from downstream subbasins to peak slightly sooner, which slightly reduces the peak flow just before the confluence with the West Fork. Another counterintuitive is a slight decrease in the total runoff volume at the downstream end of Luce Bayou. This is a result of increased overflow to Cedar Bayou just southwest of the confluence of Luce and Tarkington Bayou. The timing of the higher peak flows and higher WSE at this overflow causes a net decrease in total runoff volume at the downstream end of Luce Bayou.

As mentioned in **Section 4.5**, the HCFCD BDF hydrologic method uses an adjustment factor to account for detained development. This factor is applied to a subbasin's TC and R parameters where detention reaches a threshold of 10 acre-feet per square mile of subbasin area. The average subbasin is 4,620 acres, with an average additional development of 470 acres between now and 2070. At the assumed detention rate of 0.55 acre-ft per developed acre, many subbasins with smaller population projections receive a slightly higher impervious value but do not meet the BDF method threshold for adjusting TC and R parameters. This contributes to the increases in peak flow, volume, and water surface elevations shown in **Tables 11–13**. This analysis could be refined as part of a future study by subdividing each subbasin to delineate specific areas of future development. This would make each future subbasin more homogenous, whether primarily developed or undeveloped, which would make each TC and R value more representative of the entire subbasin. This would also improve the precision of the BDF detention adjustment. This more detailed analysis could potentially reduce the increases shown in **Tables 11–13**.

Table 11. Summary of 1% ACE Peak Flows and Runoff Volumes

Stream	Existing		2070		Difference	
	Peak Flow (cfs)	Runoff Vol. (ac-ft)	Peak Flow (cfs)	Runoff Vol. (ac-ft)	Peak Flow (%)	Volume (%)
Lake Creek	63,815	209,814	63,435	211,102	-0.6%	0.6%
Spring Creek	71,397	443,251	73,713	459,226	3.2%	3.6%
Willow Creek	19,170	66,901	20,008	70,575	4.4%	5.5%
Cypress Creek	29,310	157,590	30,621	163,657	4.5%	3.8%
Little Cypress Creek	16,548	31,639	16,923	32,861	2.3%	3.9%
West Fork D/S of W Lake Houston Pkwy	187,890	1,088,674	190,902	1,113,620	1.6%	2.3%
Luce Bayou	25,285	157,086	25,433	156,566	0.6%	-0.3%
Tarkington Bayou	25,323	103,038	26,206	103,293	3.5%	0.2%
Caney Creek	57,319	247,210	58,320	247,419	1.7%	0.1%
Peach Creek	16,975	57,094	17,288	57,329	1.8%	0.4%
East Fork	124,192	705,725	125,801	709,279	1.3%	0.5%
West Fork U/S of Lake Houston Dam	307,893	1,940,391	310,111	1,969,235	0.7%	1.5%
Jackson Bayou	15,683	19,857	15,774	20,016	0.6%	0.8%
Gum Gully	12,489	15,549	12,567	15,695	0.6%	0.9%

Table 12. Summary of 50% ACE Peak Flows and Runoff Volumes

Stream	Existing		2070		Difference	
	Peak Flow (cfs)	Runoff Volume (ac-ft)	Peak Flow (cfs)	Runoff Volume (ac-ft)	Peak Flow (%)	Volume (%)
Lake Creek	8,048	39,463	8,066	40,504	0.2%	2.6%
Spring Creek	14,334	103,978	16,103	114,861	12.3%	10.5%
Willow Creek	4,655	9,555	5,114	10,591	9.9%	10.8%
Cypress Creek	9,107	38,022	9,807	41,508	7.7%	9.2%
Little Cypress Creek	2,618	7,070	2,820	7,529	7.7%	6.5%
West Fork D/S of W Lake Houston Pkwy	29,930	200,130	33,504	217,687	11.9%	8.8%
Luce Bayou	7,386	45,318	7,458	45,566	1.0%	0.5%
Tarkington Bayou	5,166	28,339	5,307	28,381	2.7%	0.1%
Caney Creek	11,656	49,813	12,554	53,449	7.7%	7.3%
Peach Creek	5,538	22,370	5,581	22,937	0.8%	2.5%
East Fork	22,123	148,147	22,771	152,301	2.9%	2.8%
West Fork U/S of Lake Houston Dam	57,101	472,218	61,785	493,843	8.2%	4.6%
Jackson Bayou	4,472	4,828	4,559	4,959	1.9%	2.7%
Gum Gully	3,552	3,607	3,625	3,720	2.1%	3.1%

Table 13. Summary of Increases in Peak WSE (2018–2070)

Stream	1% ACE Increase		50% ACE Increase	
	Avg. (ft)	Max. (ft)	Avg. (ft)	Max. (ft)
Lake Creek	0.0	0.1	0.0	0.0
Spring Creek	0.2	0.7	0.4	1.0
Willow Creek	0.1	0.3	0.2	0.7
Cypress Creek	0.2	0.4	0.4	1.9
Little Cypress Creek	0.0	0.1	0.1	0.3
West Fork	0.0	0.2	0.5	1.0
Luce Bayou	0.0	0.2	0.0	0.2
Tarkington Bayou	0.1	0.2	0.1	0.2
Caney Creek	0.1	0.2	0.4	0.8
Peach Creek	0.1	0.2	0.1	0.5
East Fork	0.0	0.3	0.0	0.2
West Fork U/S of Lake Houston Dam	-	0.0	-	0.2
Jackson Bayou	0.0	0.1	0.0	0.1
Gum Gully	0.0	0.1	0.1	0.1

As shown in **Table 11**, the average 1% ACE peak WSE increases range from 0.0 to 0.2 feet for all streams. The maximum 1% ACE increases in WSE remain under 0.75 feet. The 1% ACE increase at Lake Houston Dam is 0.04 feet. The average 50% ACE increases are slightly higher, ranging from 0.0 to 0.5 feet. The maximum 50% ACE increases generally remain under 1 foot, except for a 1.9-foot increase on Cypress Creek between Stuebner Airline Rd and Kuykendahl Rd and a 1.0-foot increase on the West Fork downstream of Lake Creek. Both the calibrated existing conditions 50% ACE WSEs and the increases to 50% ACE WSEs described here are generally contained within the channel banks. The 50% ACE increase at Lake Houston Dam is 0.17 feet.

As expected, increases in the 50% ACE event are larger than in the 1% ACE event. Although runoff is not entirely contained within channel banks in the 50% ACE event, the 50% ACE inundation extents reside in a much narrower portion of the stream than the 1% ACE inundation extents. Due to the steeper terrain, this area is more sensitive to increases in peak runoff rates and total runoff volumes.

The increases in water surface elevation are partially a result of the limitations of applying the BDF hydrologic methodology to large subbasins with small developed areas, as explained previously. However, the increases also reflect the increase in runoff volume resulting from additional impervious cover as shown in **Table 11** and **Table 12**. Under existing conditions (2018 land use), the study area of 2,911 square miles includes 779 square miles of developed area, with an average of 14.3% impervious cover. Under future conditions (projected 2070 land use), the study area includes 1,074 square miles of development and an average of 18.8% impervious cover. In other words, 295 square miles of additional developed area are projected to be added over the next 50 years, representing about 10% of the total study area. This future development averages approximately 44% impervious cover based on anticipated land use; therefore, 130 square miles, or 4.4% of the total study area, is projected to change from pervious to impervious cover.

Because the soils within the watershed have a limited infiltration capacity, with an average constant loss of only 0.05 in/hr, even small storms cause undeveloped areas to contribute a significant amount of runoff. Overlaying these low-infiltration soils with impervious cover will cause only an incremental increase in runoff volume. This aligns well with the 1% ACE HEC-HMS results, which show an overall 1.3% increase in runoff volume by 2070. Of the 2.45 million acre-feet of 1% ACE rainfall volume, 2.04 million acre-feet becomes runoff under existing conditions. Under future conditions in 2070, this runoff volume increases to 2.07 million acre-feet. Expressed in terms of the average 15.8 inches of 1% ACE rainfall depth, approximately 13.1 inches of this rainfall currently becomes runoff that reaches Lake Houston; by 2070, this runoff increases to approximately 13.3 inches.

6.0 Conclusions

By 2070, anticipated development is expected to produce increases in peak flow, volume, and peak water surface elevations as shown in **Tables 11–13** and on the attached **Exhibits 8–15**. These increases are based on detailed population projections, development patterns, hydrologic and hydraulic modeling, and assumed onsite detention for local development.

The increases are driven by two hydrologic factors at each subbasin: the total volume of runoff and the timing of that runoff. The total 1% ACE runoff volume is projected to increase by 1.3% between now and 2070, based on anticipated development patterns and impervious area. The TC and R timing parameters for each existing subbasin were adjusted to reflect future development with an assumed detention rate of 0.55 acre-feet per acre. These adjustments were performed at the level of existing subbasins with an average area of 4,620 acres, and this approach may not fully capture localized differences in hydrograph timing. Subdividing each subbasin to delineate specific areas of future development may better quantify the potential impacts of development on the timing of runoff throughout the watershed, but this level of detailed analysis is outside the scope of this study. Generally, the most significant impacts are expected immediately downstream of future development without adequate detention to mitigate the increase in runoff volume.

The anticipated population increases between today and 2070 are generally concentrated in the lower reaches of the upper San Jacinto watershed, closer to Lake Houston. After 2070, development will continue to extend into the remaining 1,409 square miles of developable land and into the upper reaches of the watershed, not only increasing runoff volume but also potentially resulting in more closely aligned hydrograph peaks at stream confluences. A detailed assessment of the fully developed hydrologic condition of the watershed is not included in the scope of this study. However, if future development patterns shown in **Table 6** and are assumed to eventually fill all currently undeveloped area in the watershed, the impervious percentage of each subbasin will increase to between 35% and 50%. Under those conditions, the 1% ACE runoff volume of the entire watershed could increase to 2.15 million acre-feet under fully developed conditions, or 13.9 inches of runoff. This represents a 5.5% increase in runoff volume over existing conditions and a 3.9% increase over 2070 conditions.

Detailed fully developed conditions hydraulic model updates were also not conducted as part of this study. However, the increase in runoff volume can be expected to cause additional increases to peak 1% ACE water surface elevations, in the range of six inches to a foot above what is projected in **Table 13** for 2070. A detailed hydraulic analysis of fully developed conditions may be helpful in determining the mitigation impact of development regulations.

Finally, this analysis only considers the hydrologic effects of anticipated 2070 development that result from increased impervious cover and BDF values. This analysis does not include the potential hydrologic or hydraulic effects of changes in topography such as fill within the 1% ACE floodplain. If future development is allowed to encroach into the floodplain over the next 50 years and beyond, this will cause additional increases in both peak flow rates and peak water surface elevations, if not adequately mitigated.

Attachments:

Exhibit 1. 2018 Population Density

Exhibit 2. 2070 Population Density

Exhibit 3. Change in Population Density by Subbasin, 2018–2070

Exhibit 4. 2018 Developed Area

Exhibit 5. Development Pattern Groups

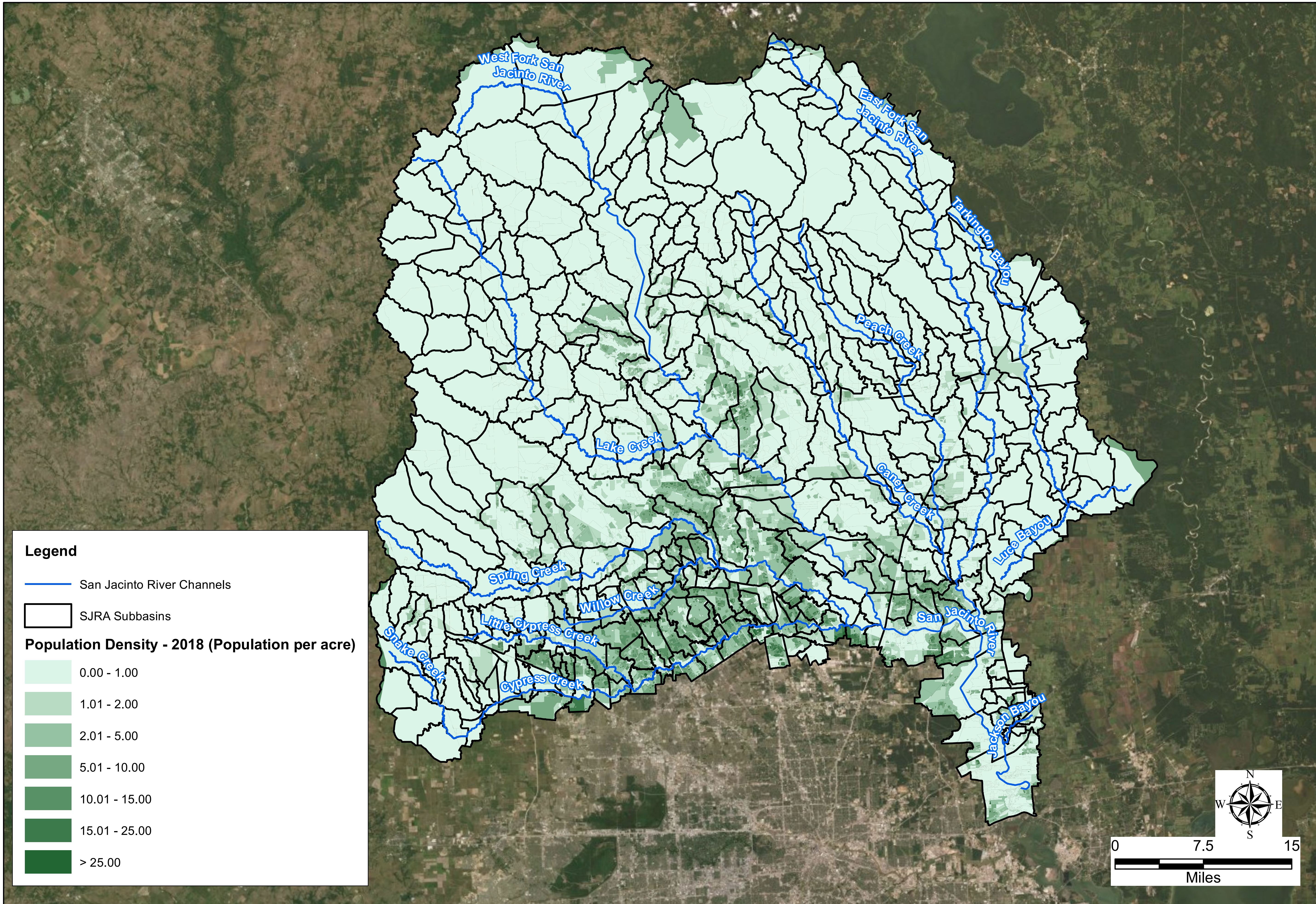
Exhibit 6. Impervious Cover Change by Subbasin, 2018–2070

Exhibit 7. BDF Change by Subbasin, 2018–2070

Exhibits 8–15. Potential Future Change in Peak 1% ACE WSE, 2018–2070

Exhibits 16–29. HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)

Exhibits 30–43. HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)



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DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas South Central
FILE NAME	EX 1 - 2018 Population Density
PREPARED BY	DML

San Jacinto Regional Watershed Master Drainage Plan

2018 Population Density

Future Conditions

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

EXHIBIT

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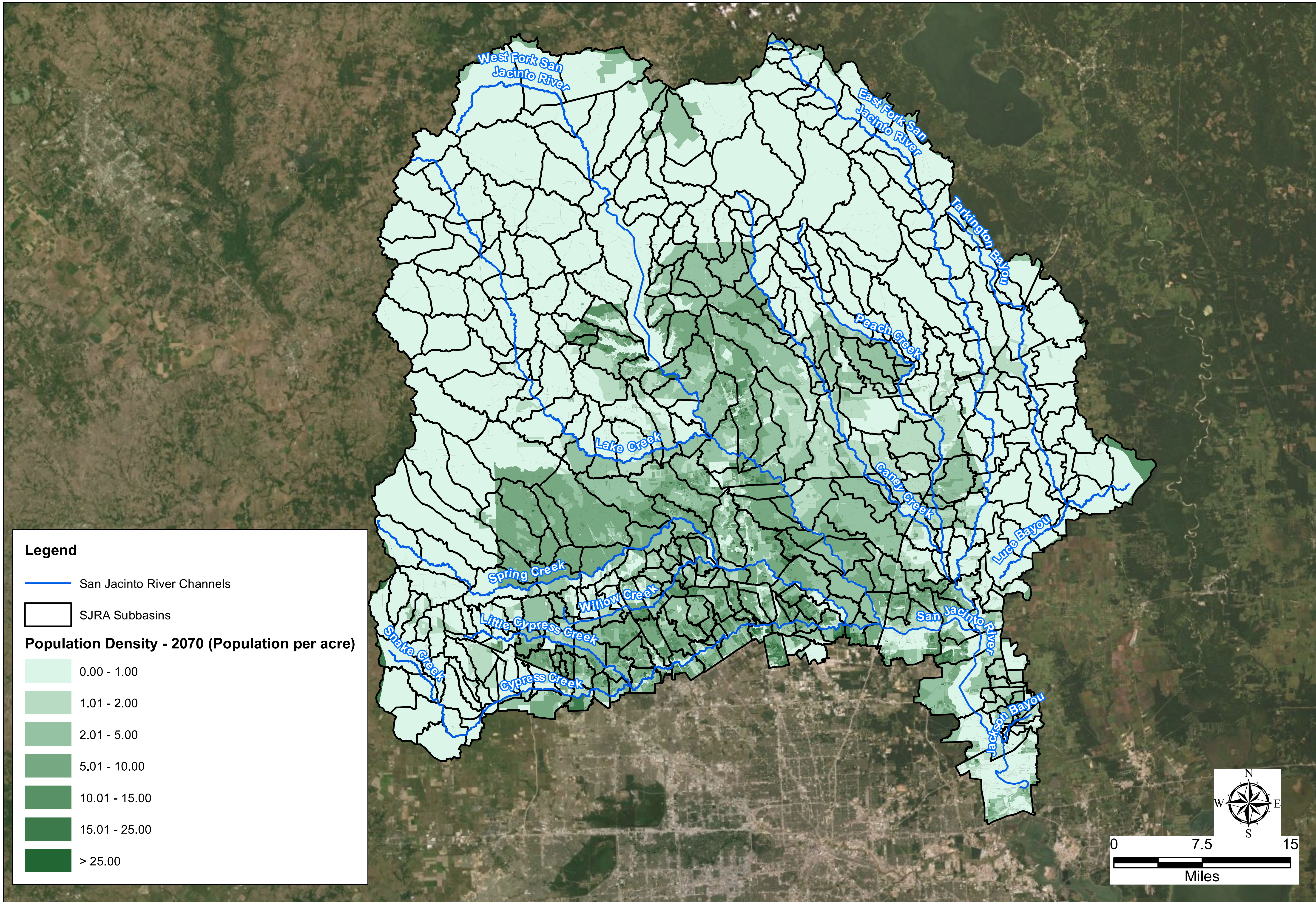

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FILE NAME	EX 2 - 2070 Population Density
PREPARED BY	DML

San Jacinto Regional Watershed Master Drainage Plan

2070 Population Density

Future Conditions

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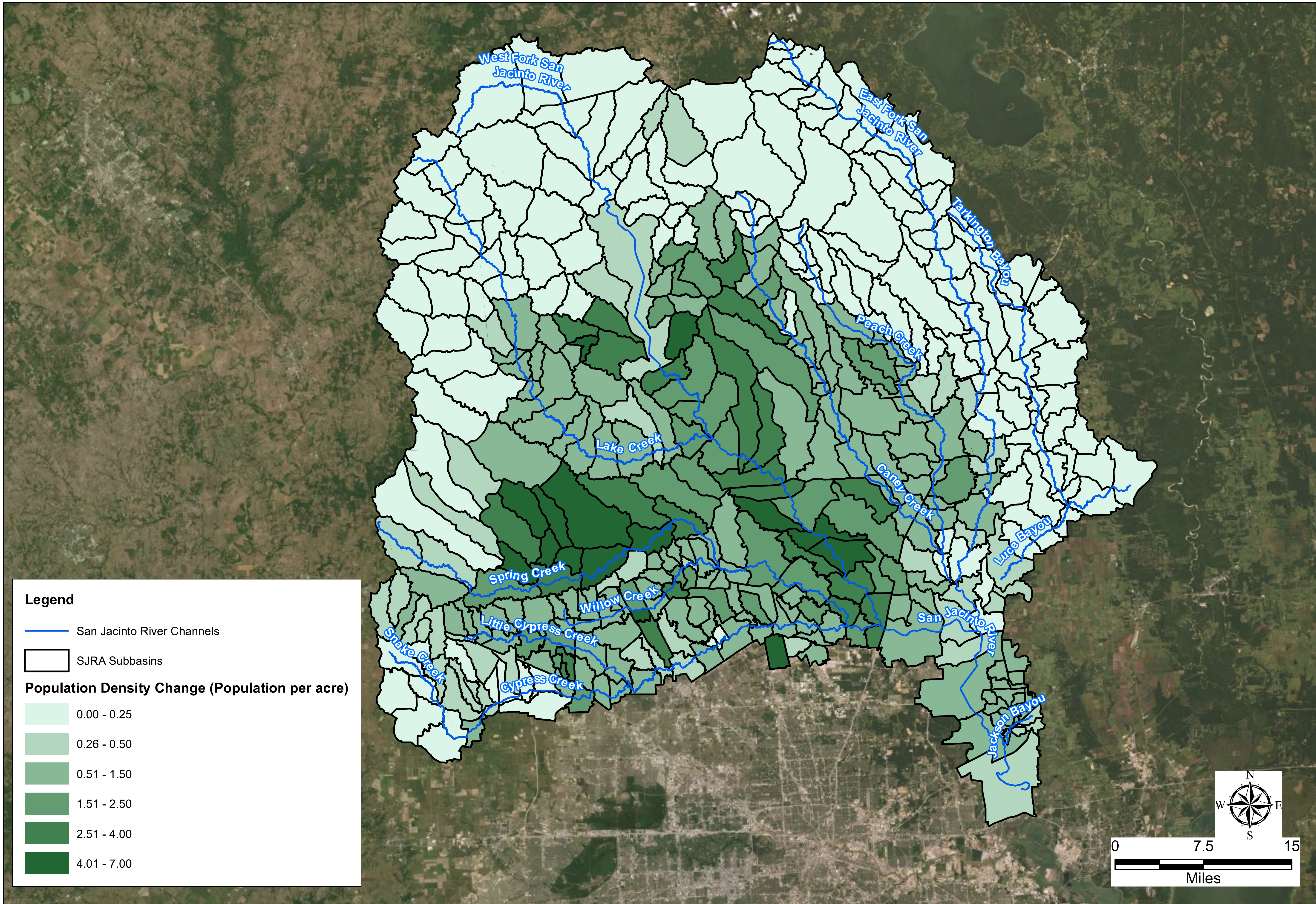

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DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas South Central
FILE NAME	EX 3 - 2020-2070 Population Density Change by Subbasin
PREPARED BY	DML

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Change in Population Density by Subbasin, 2018-2070

Future Conditions

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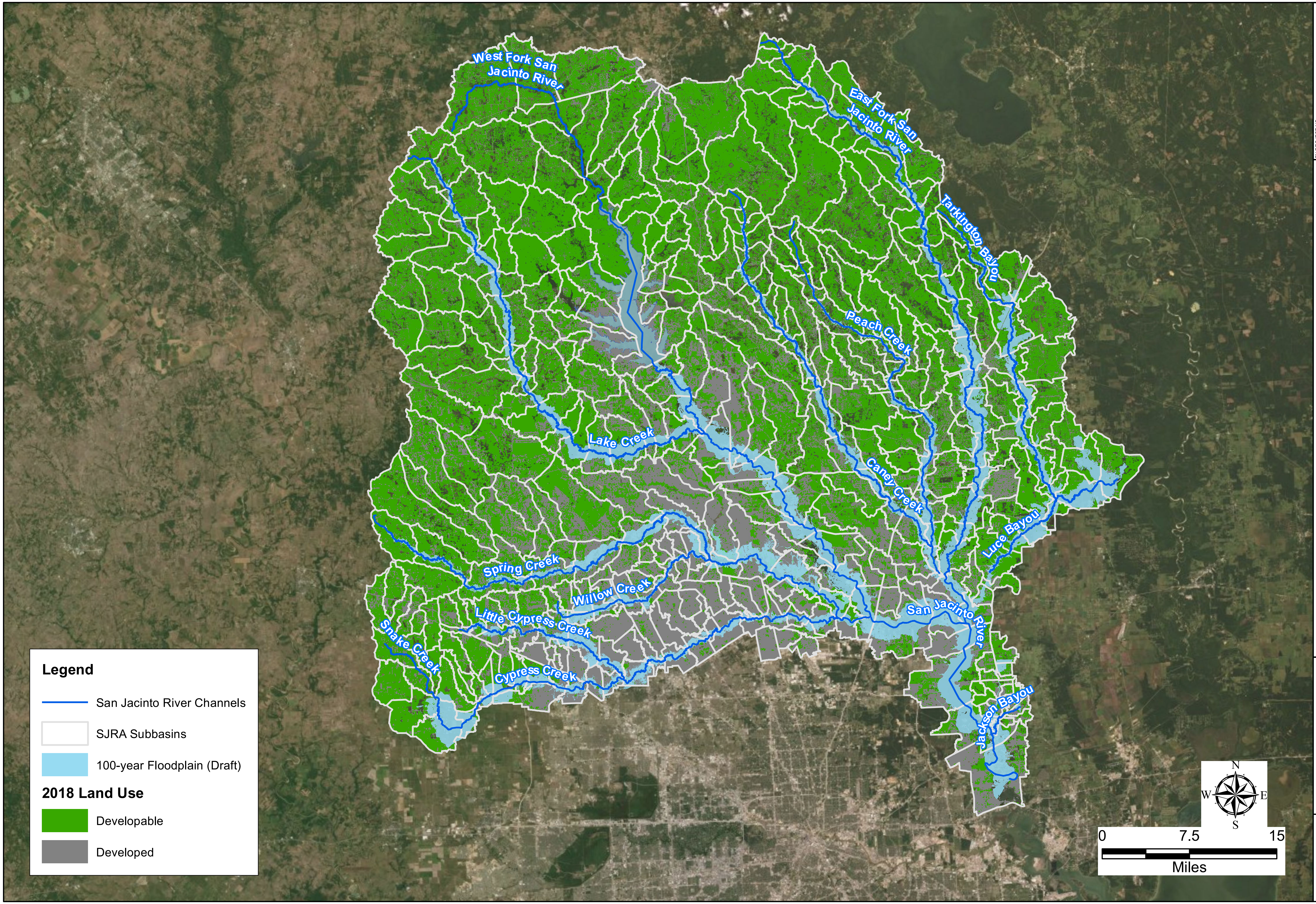

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DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas South Central
FILE NAME	EX 4 - Existing Land Use Map
PREPARED BY	DML

San Jacinto Regional Watershed Master Drainage Plan

2018 Developed Area

Future Conditions

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

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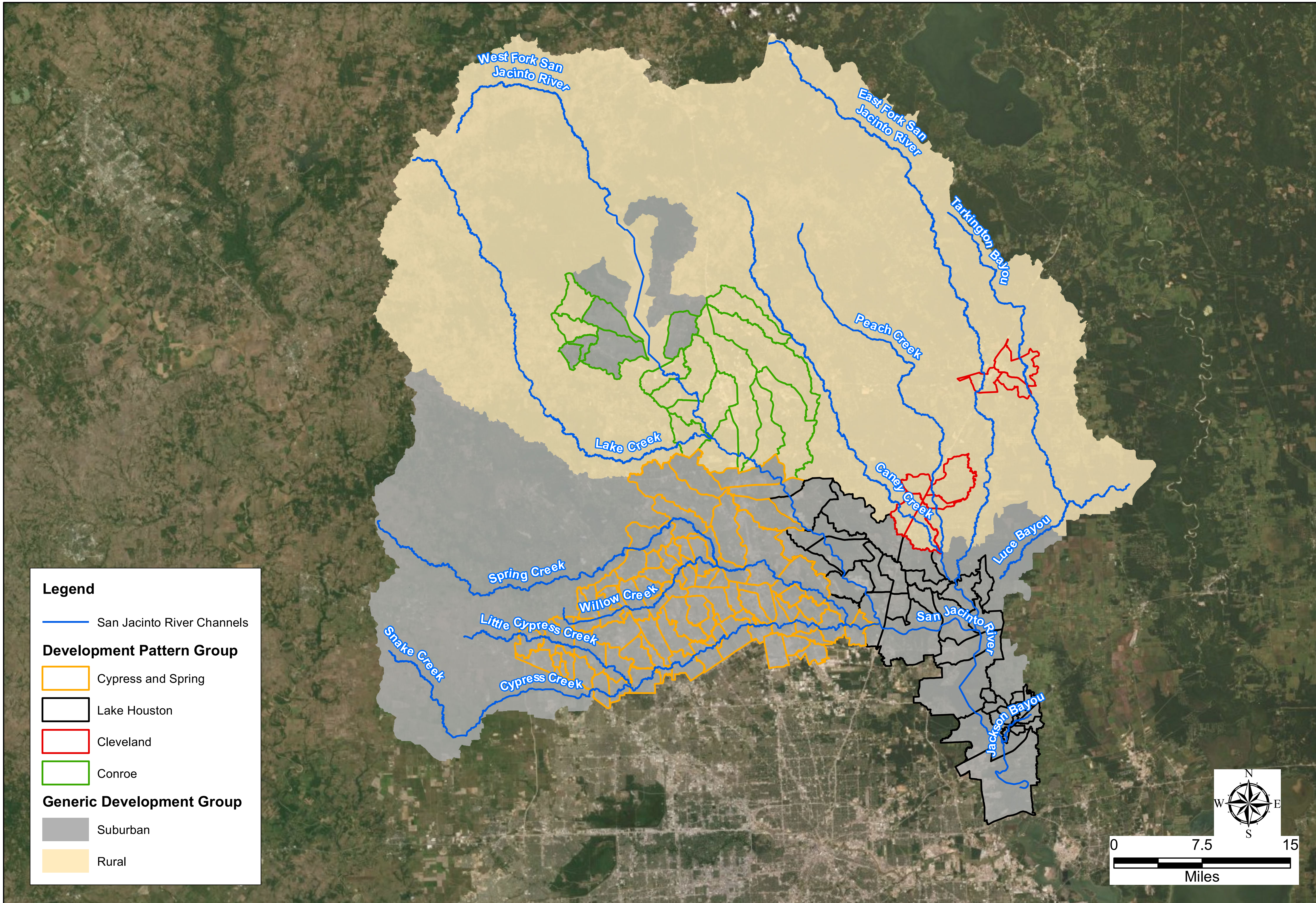

San Jacinto Regional Watershed Master Drainage Plan

Development Pattern Groups

Future Conditions

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

EXHIBIT

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DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas South Central
FILE NAME	EX 5 - Development Pattern Groups
PREPARED BY	DML

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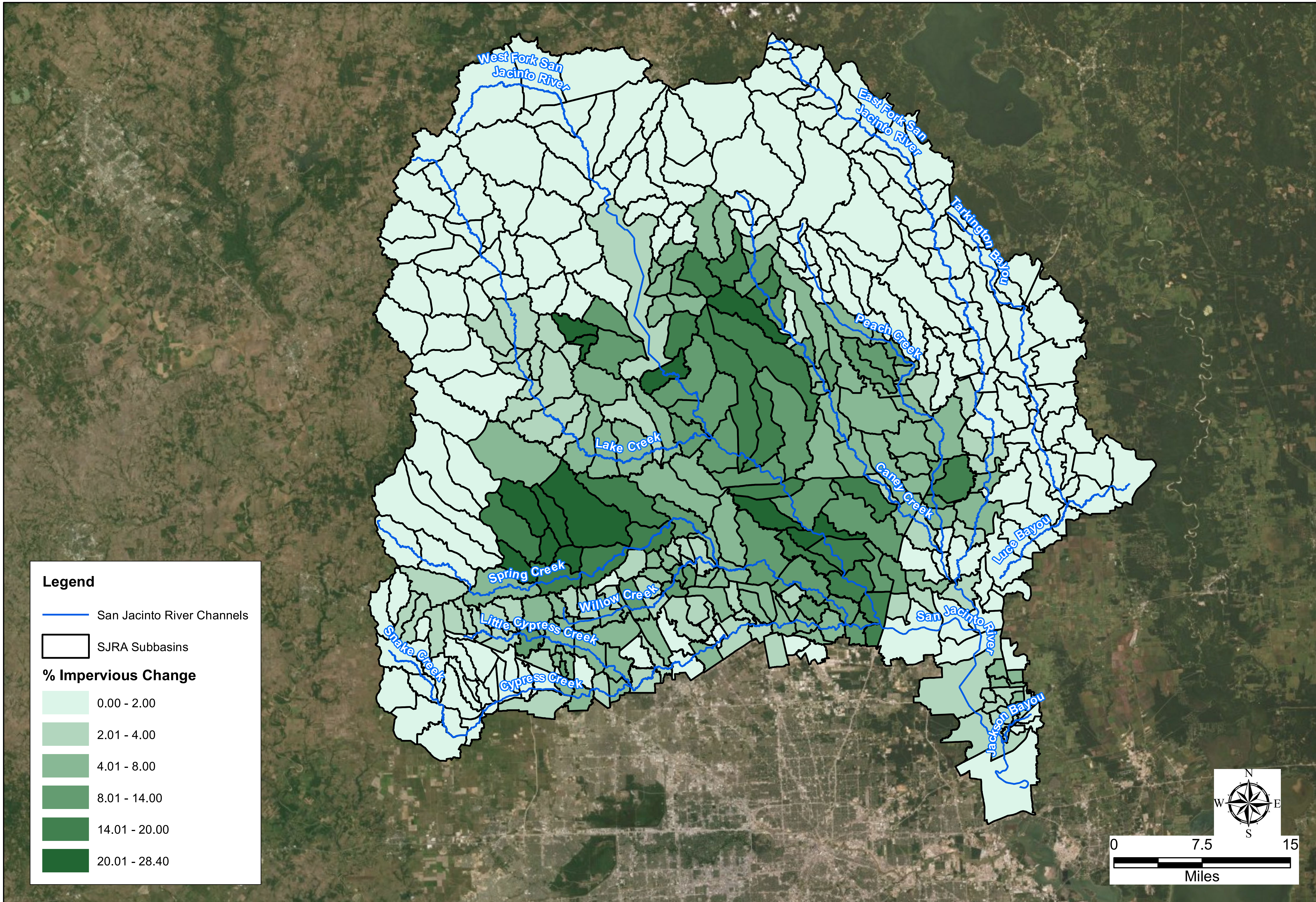

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FILE NAME EX 6 - Impervious Change
PREPARED BY DML

San Jacinto Regional Watershed Master Drainage Plan

Impervious Cover Change by Subbasin, 2018-2070

Future Conditions

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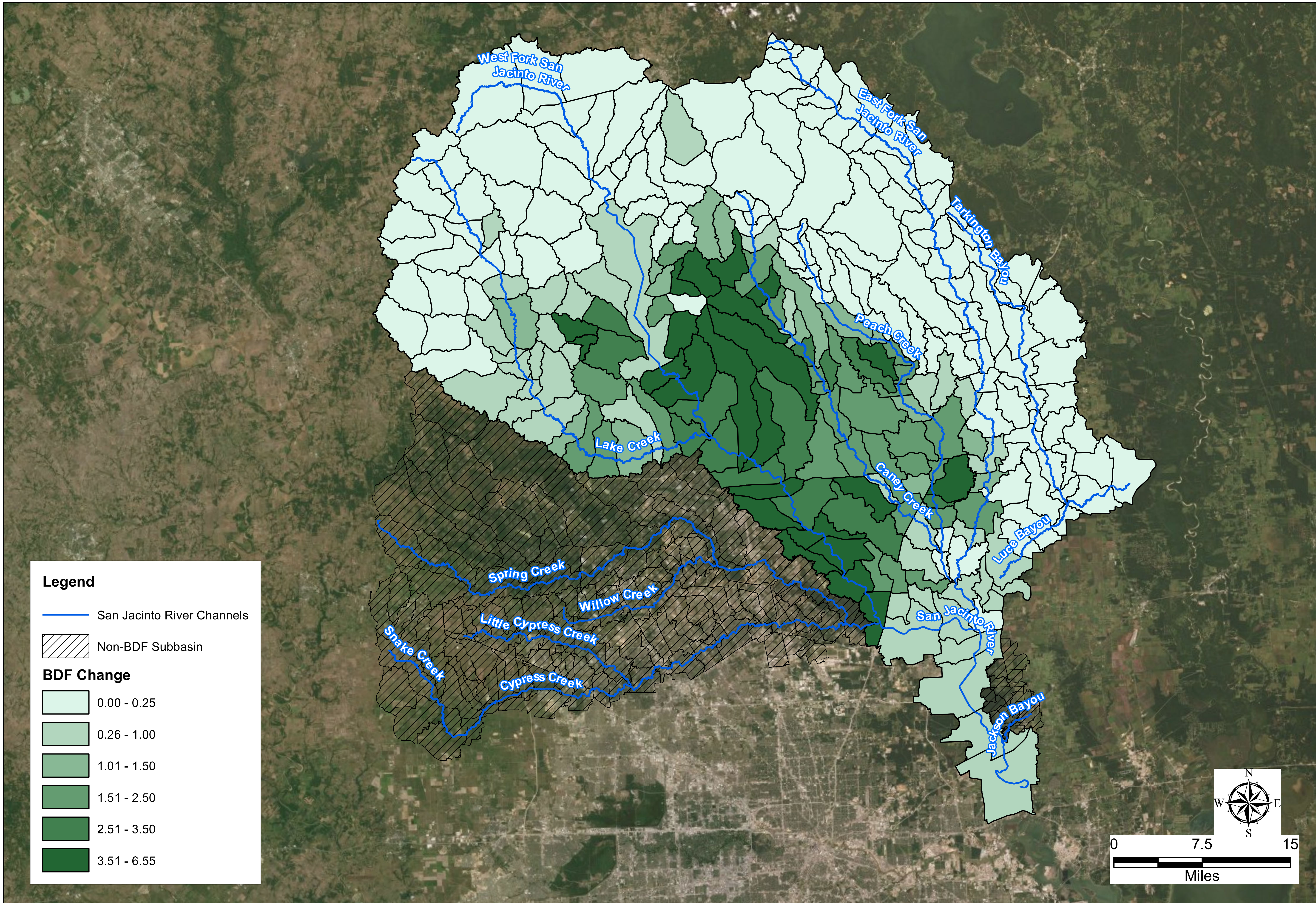

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DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central

FILE NAME EX 7 - BDF Change

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San Jacinto Regional Watershed Master Drainage Plan

BDF Change by Subbasin, 2018-2070

Future Conditions

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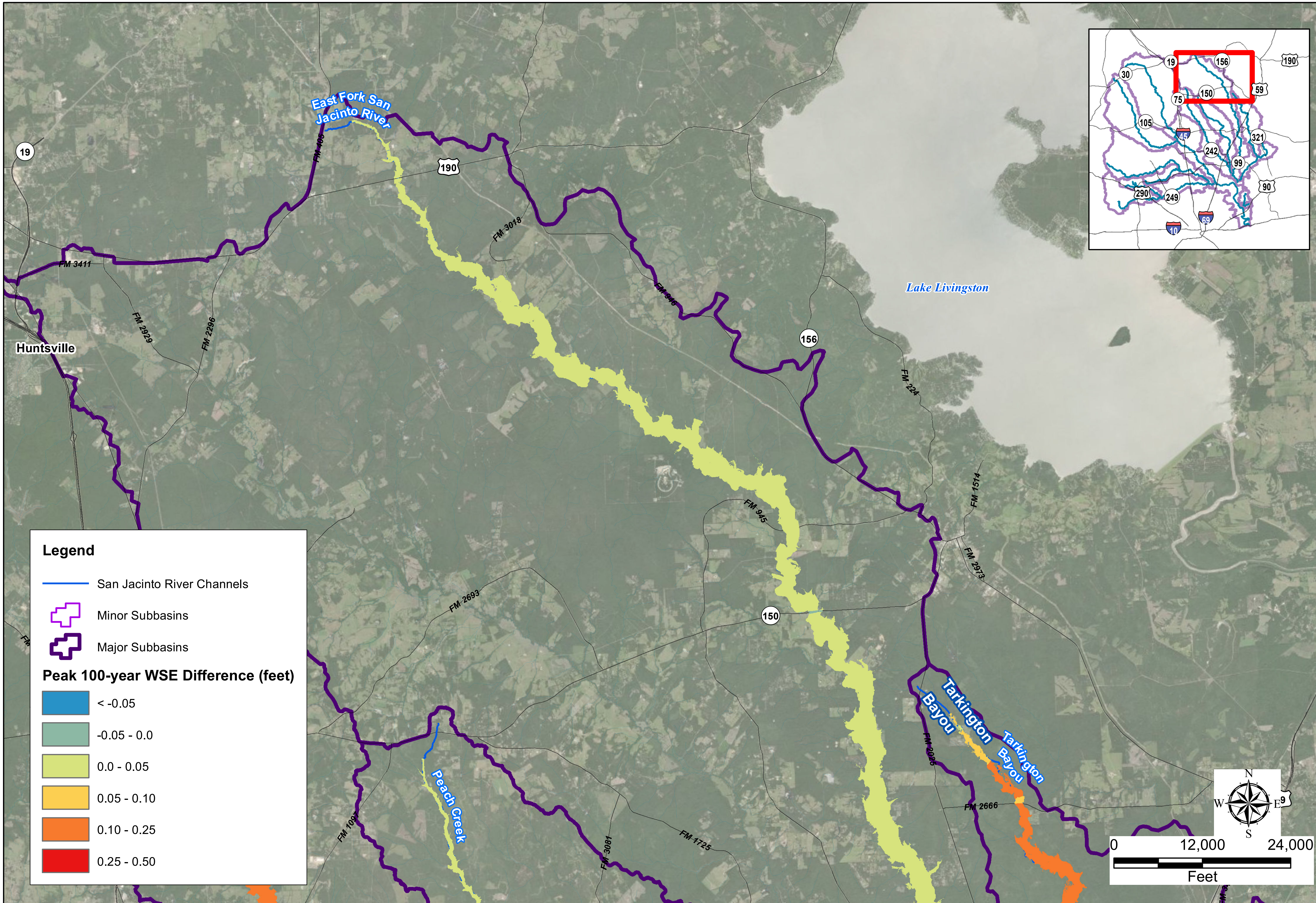

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FILE NAME EX 8 - Change in Peak 1% ACE WSE with Detention, 2018-2070
PREPARED BY DML

San Jacinto Regional Watershed Master Drainage Plan

Change in Peak 100-Year WSE, 2018-2070

Future Conditions

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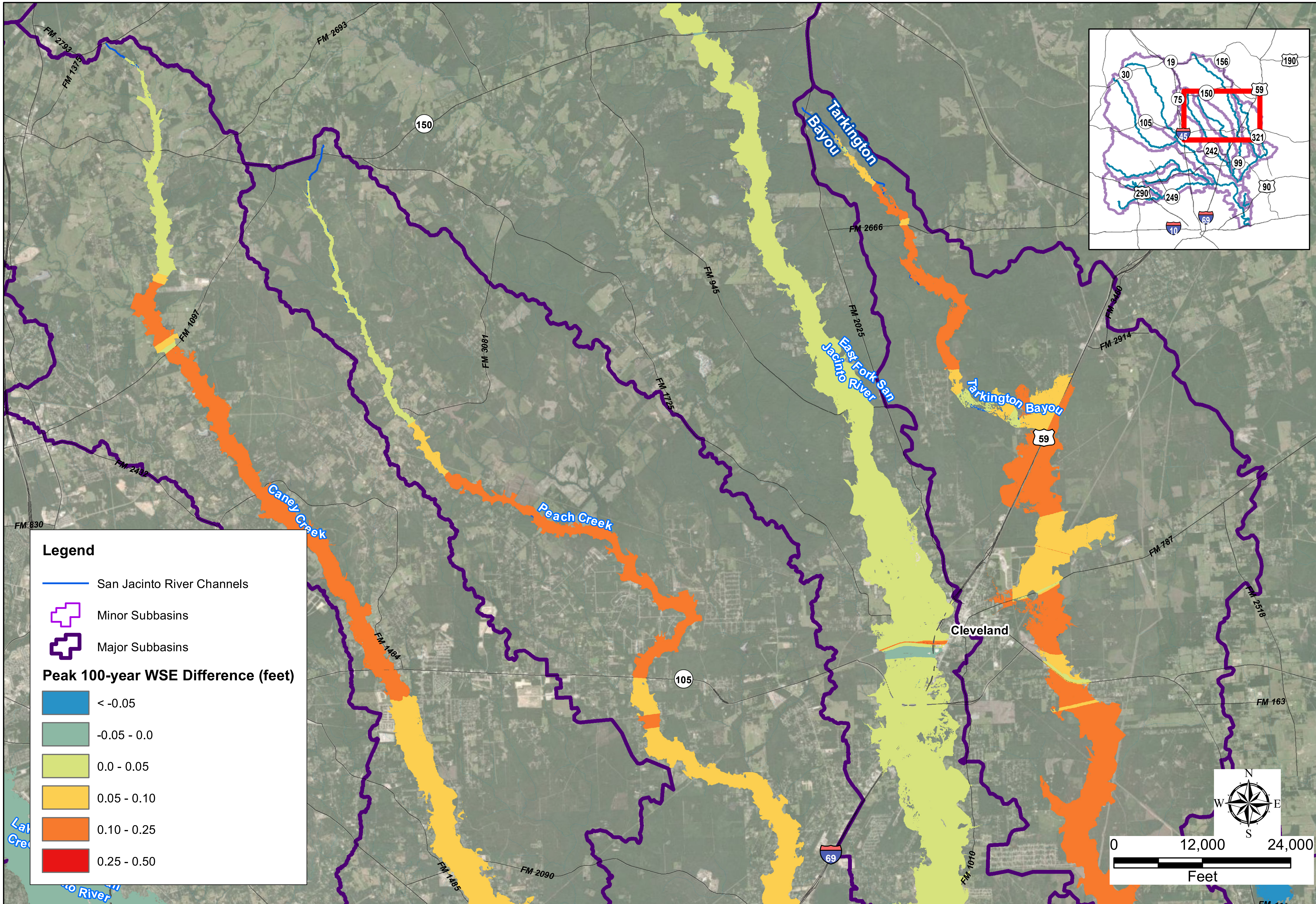

San Jacinto Regional Watershed Master Drainage Plan

Change in Peak 100-Year WSE, 2018-2070

Future Conditions

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

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DATE CREATED	12/8/2020
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas South Central
FILE NAME	EX 8 - Change in Peak 1% ACE WSE with Detention, 2018-2070
PREPARED BY	DML

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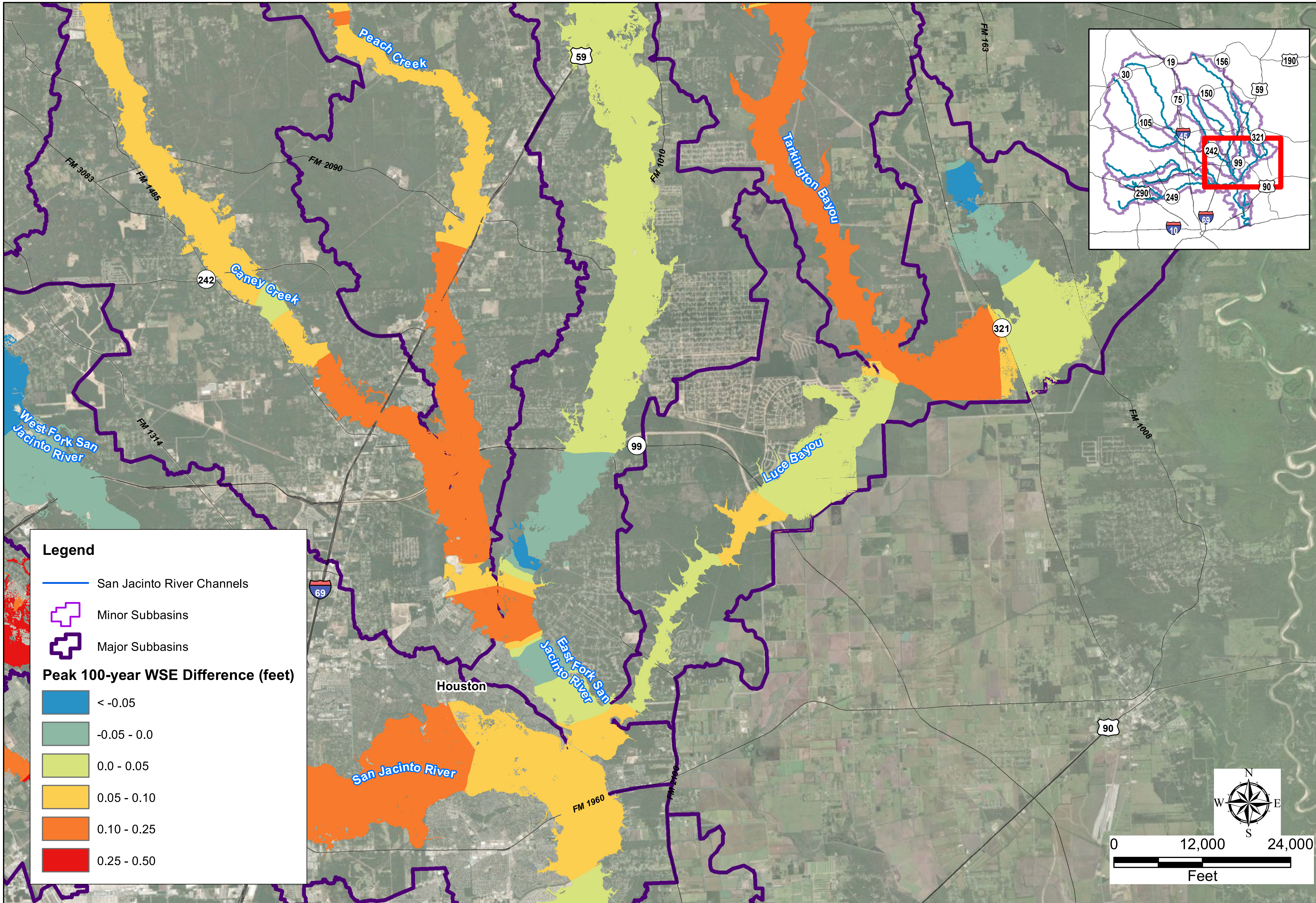

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FILE NAME EX 8 - Change in Peak 1% ACE WSE with Detention, 2018-2070
PREPARED BY DML

San Jacinto Regional Watershed Master Drainage Plan

Change in Peak 100-Year WSE, 2018-2070

Future Conditions

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

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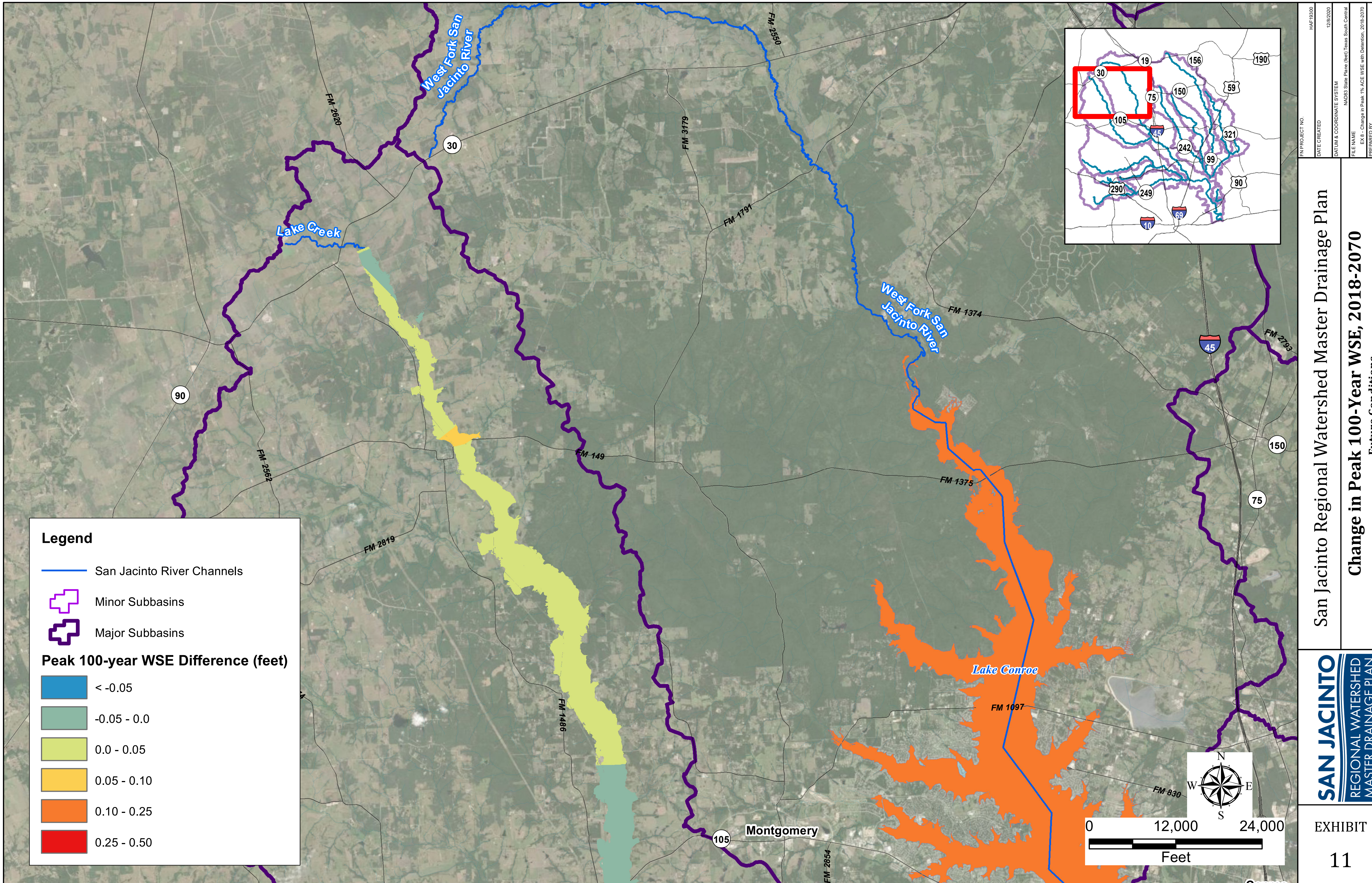

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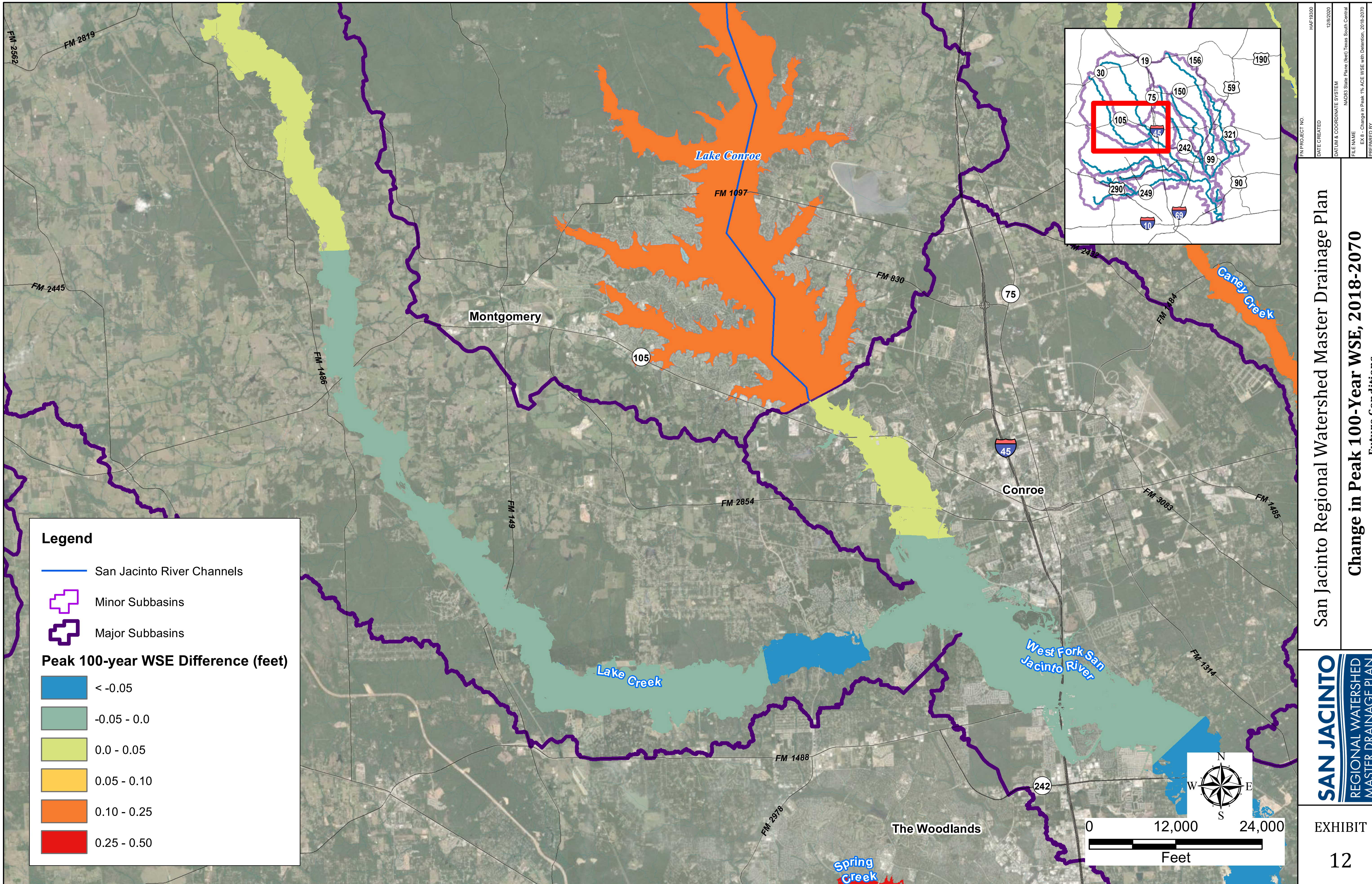

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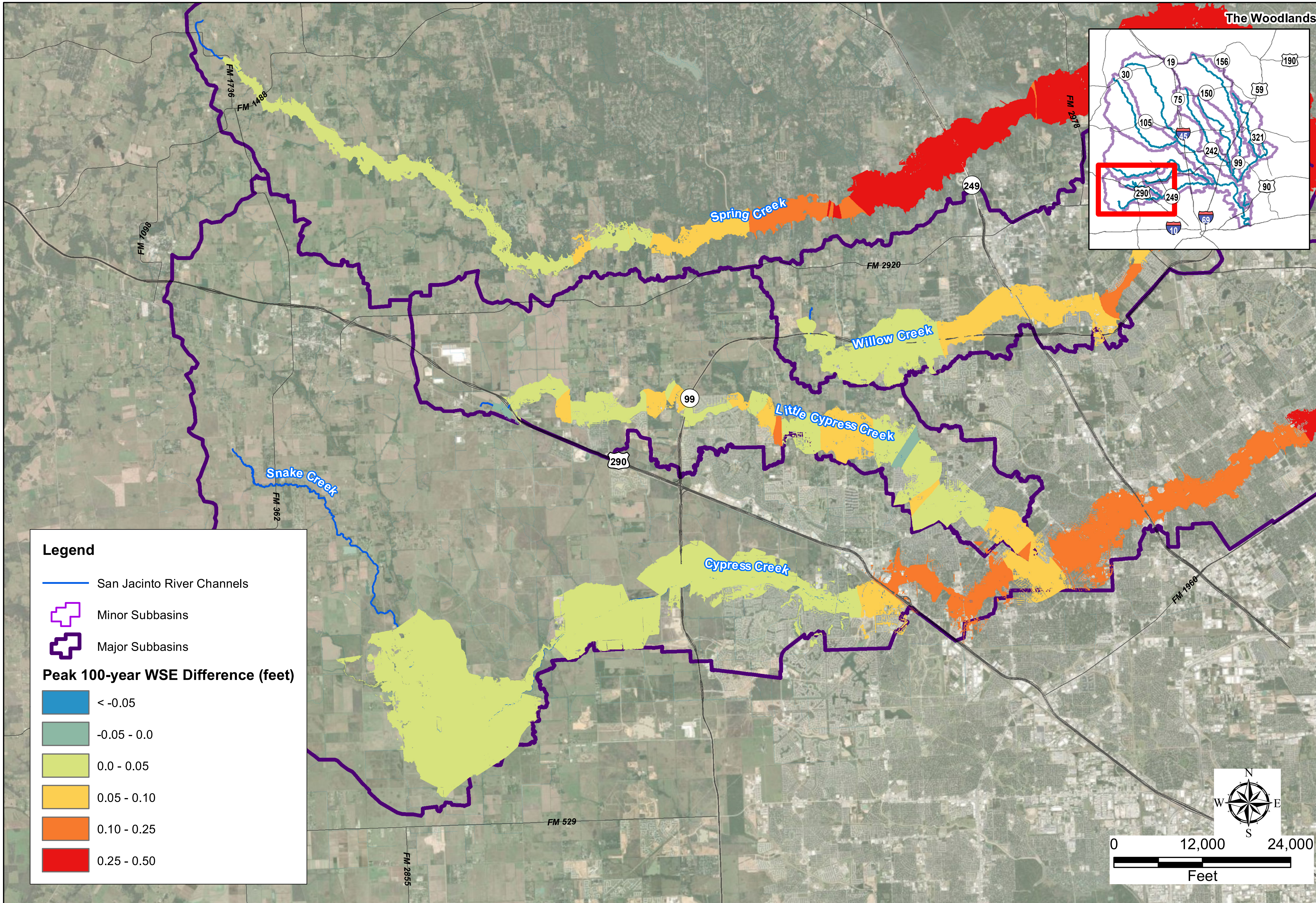

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San Jacinto Regional Watershed Master Drainage Plan

Change in Peak 100-Year WSE, 2018-2070

Future Conditions

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

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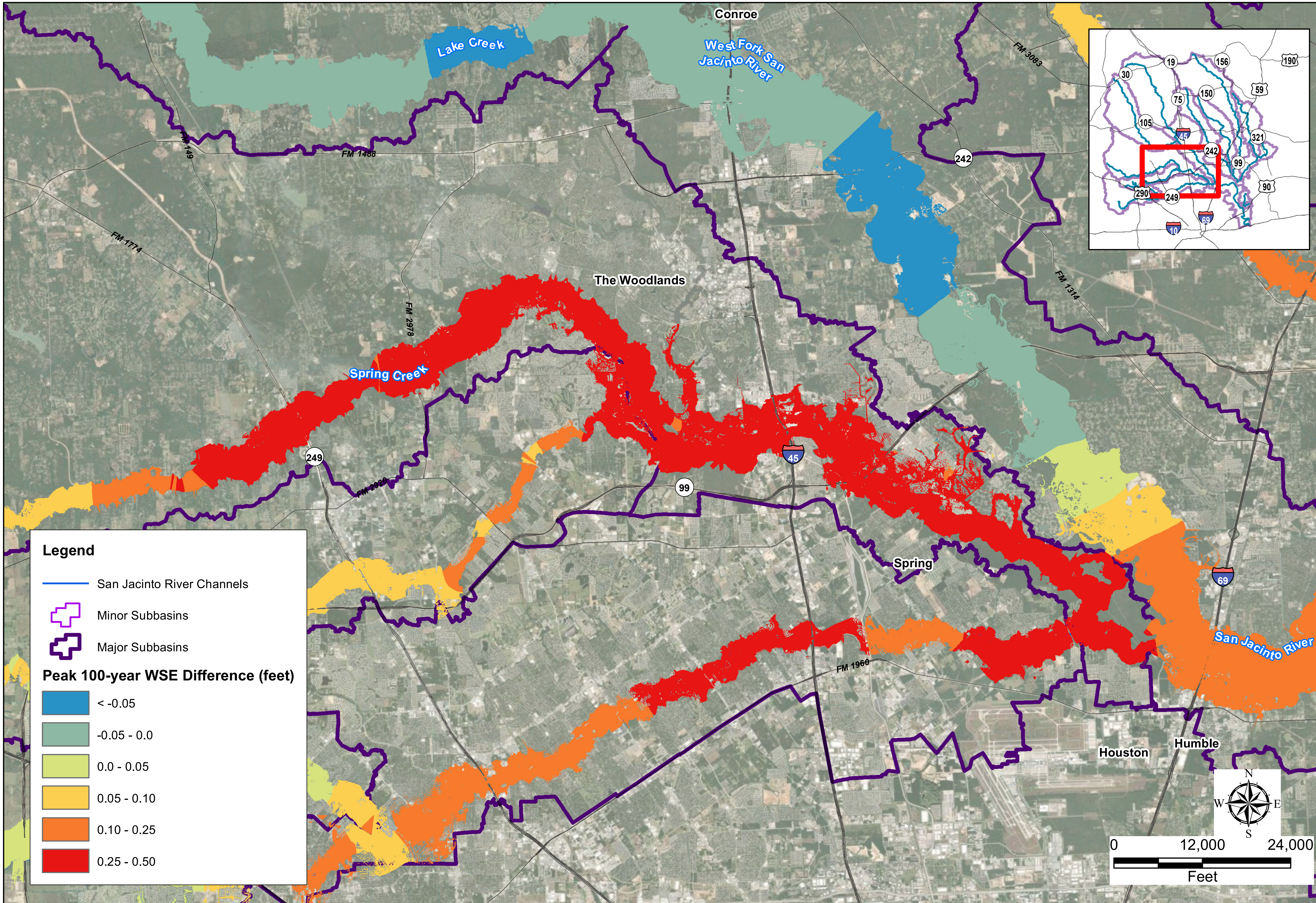

San Jacinto Regional Watershed Master Drainage Plan

Change in Peak 100-Year WSE, 2018-2070

Future Conditions

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

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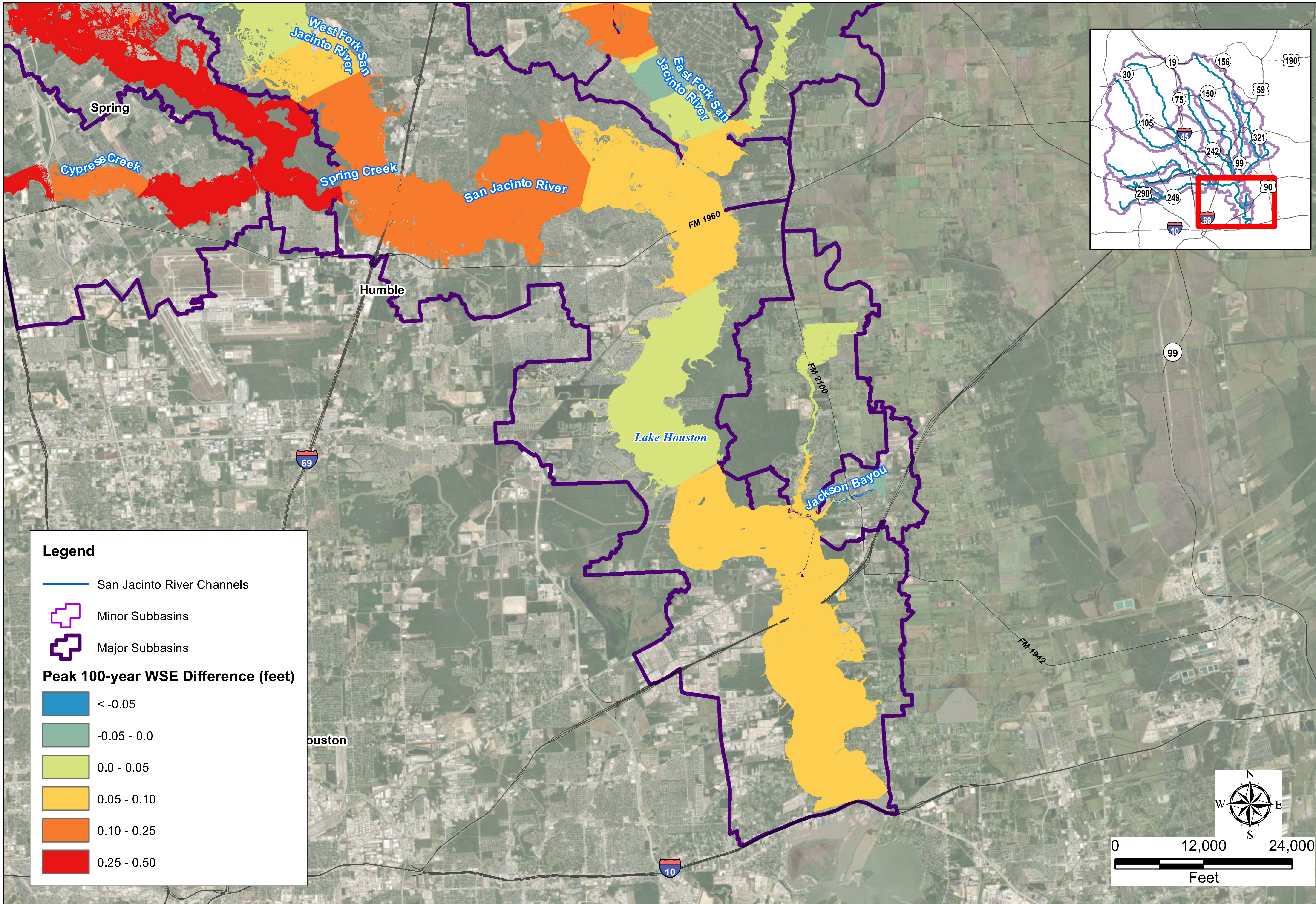

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PREPARED BY	DML

San Jacinto Regional Watershed Master Drainage Plan

Change in Peak 100-Year WSE, 2018-2070

Future Conditions

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

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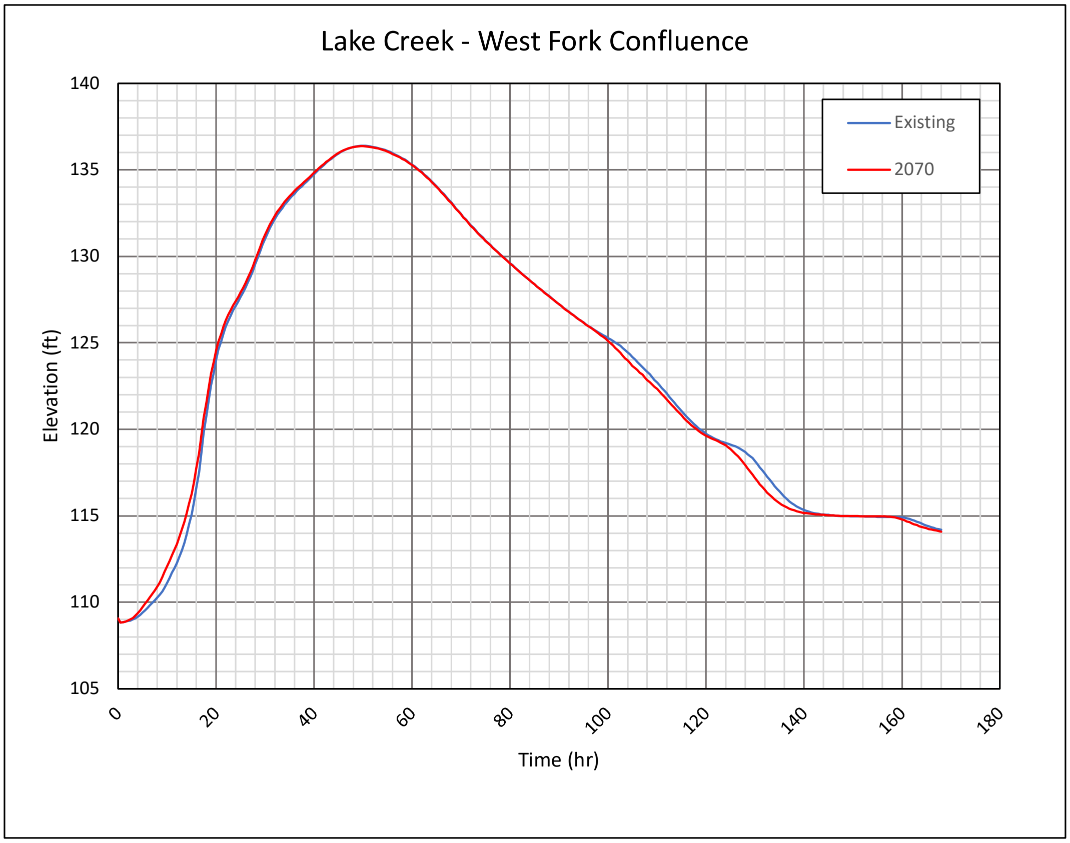
Exhibit 16 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



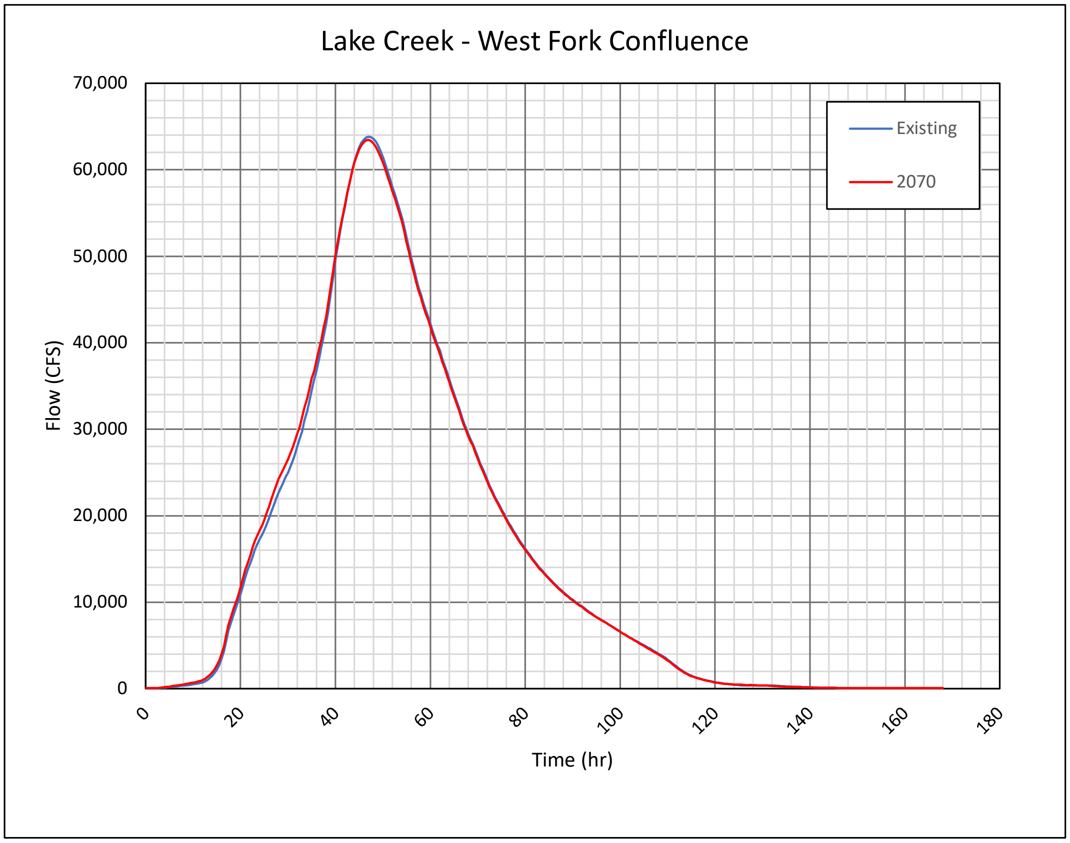
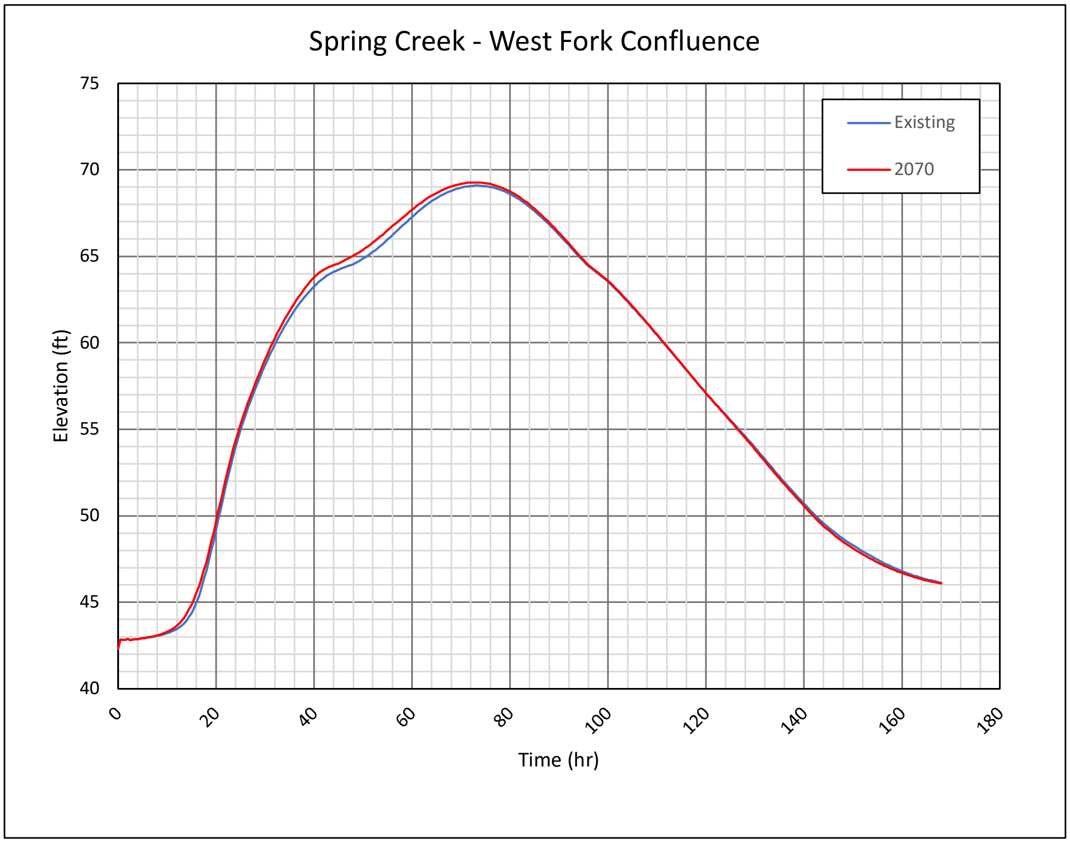


Exhibit 17 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



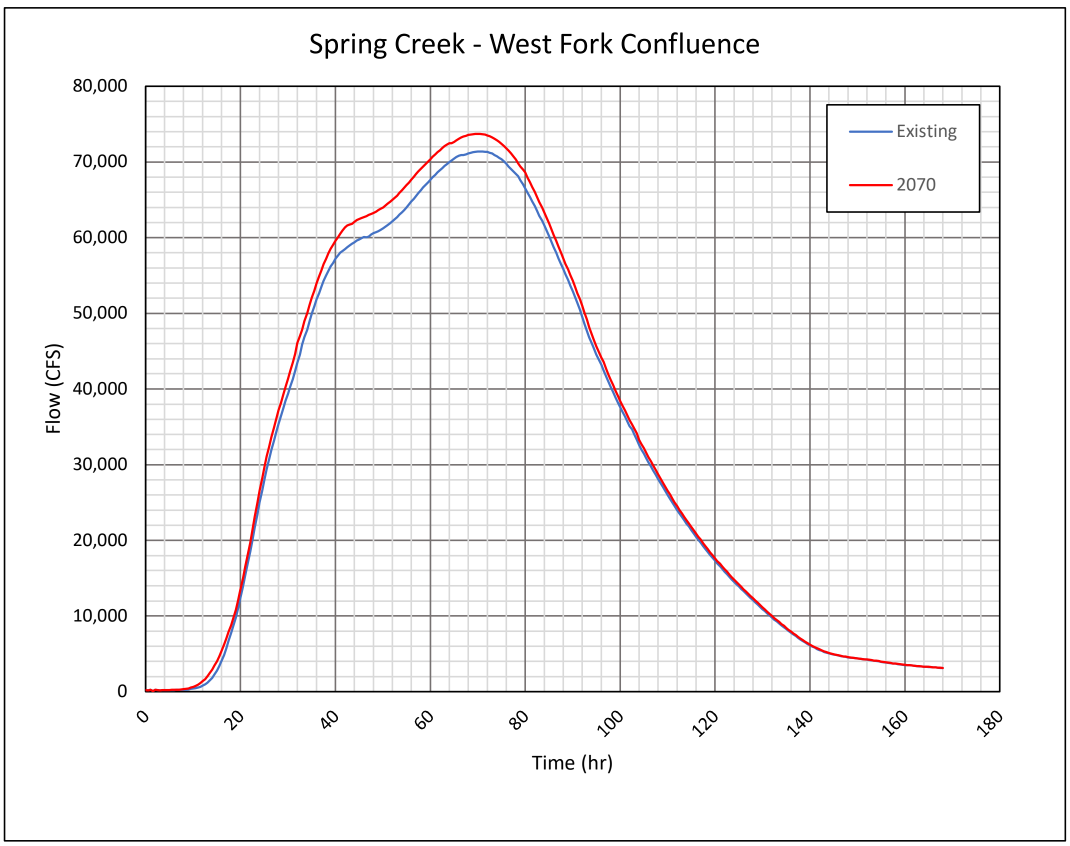
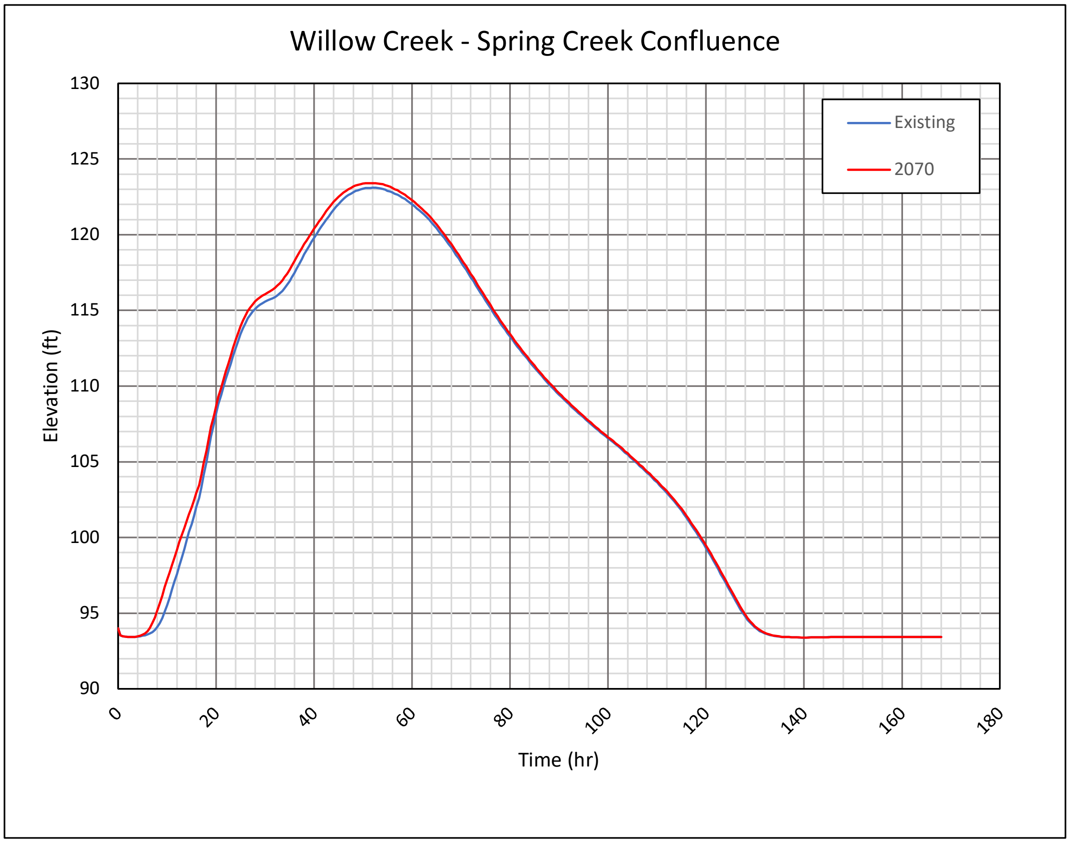


Exhibit 18 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



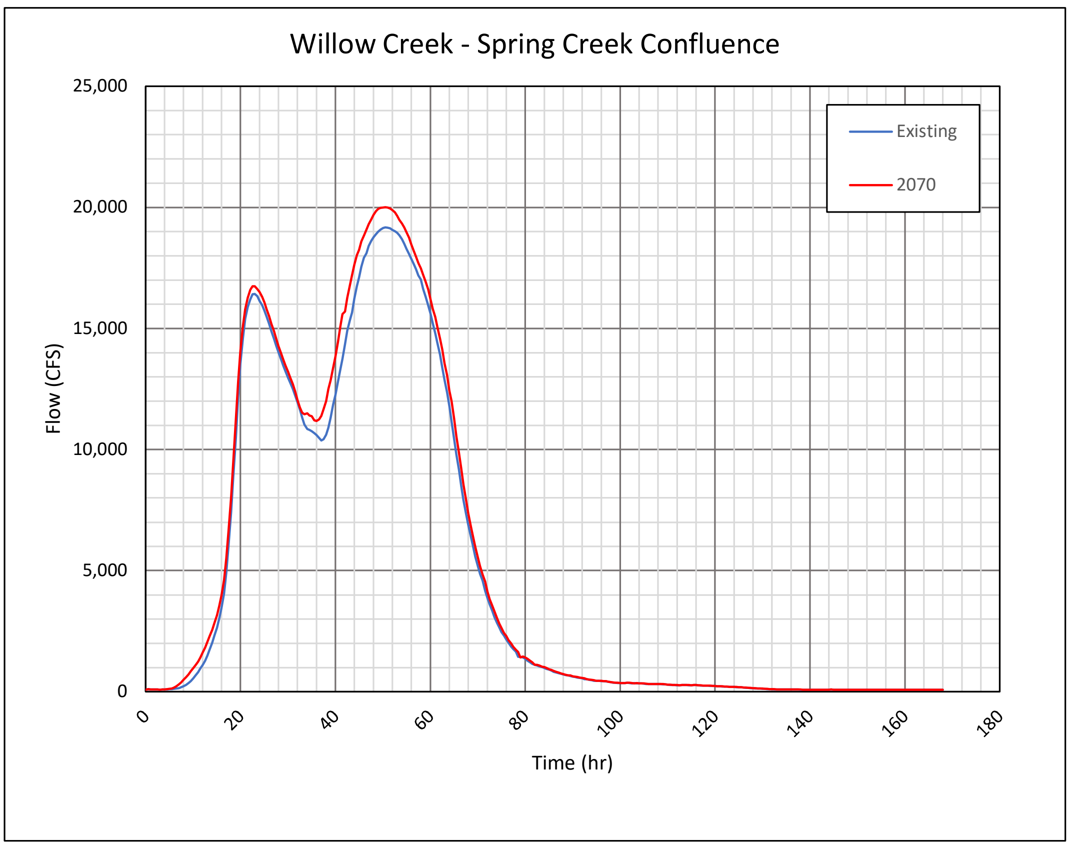
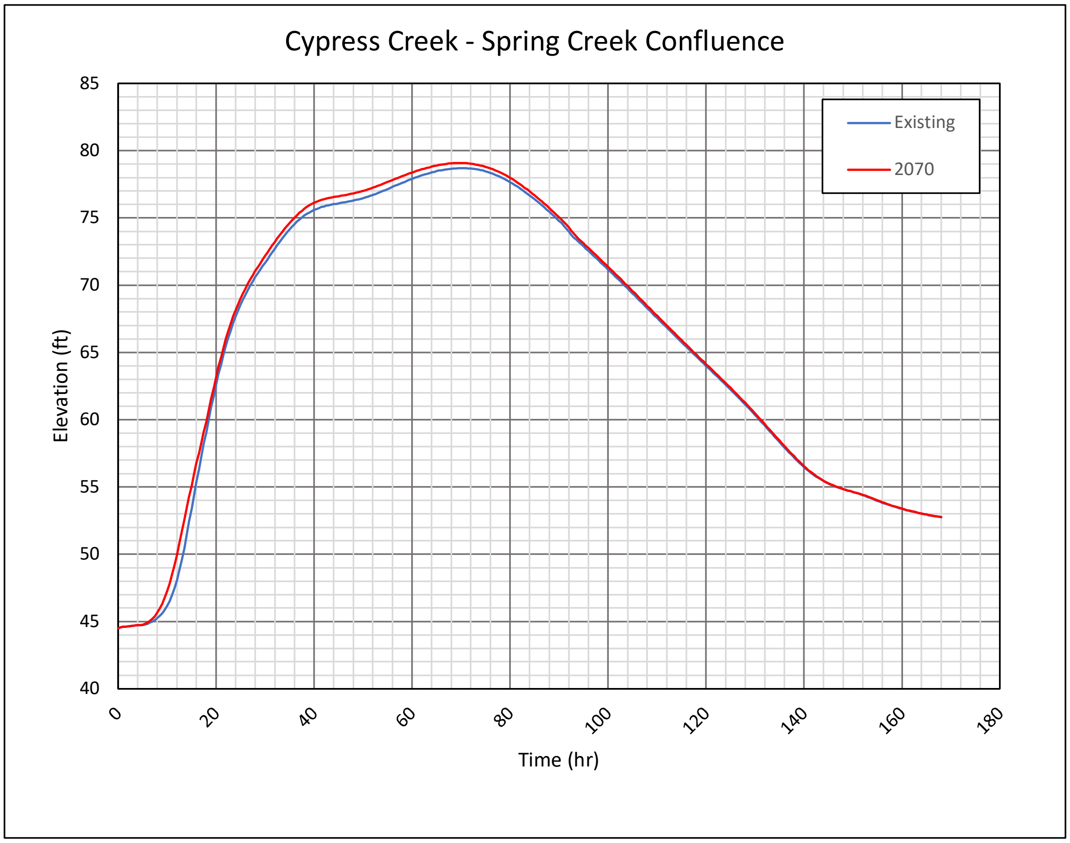


Exhibit 19 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



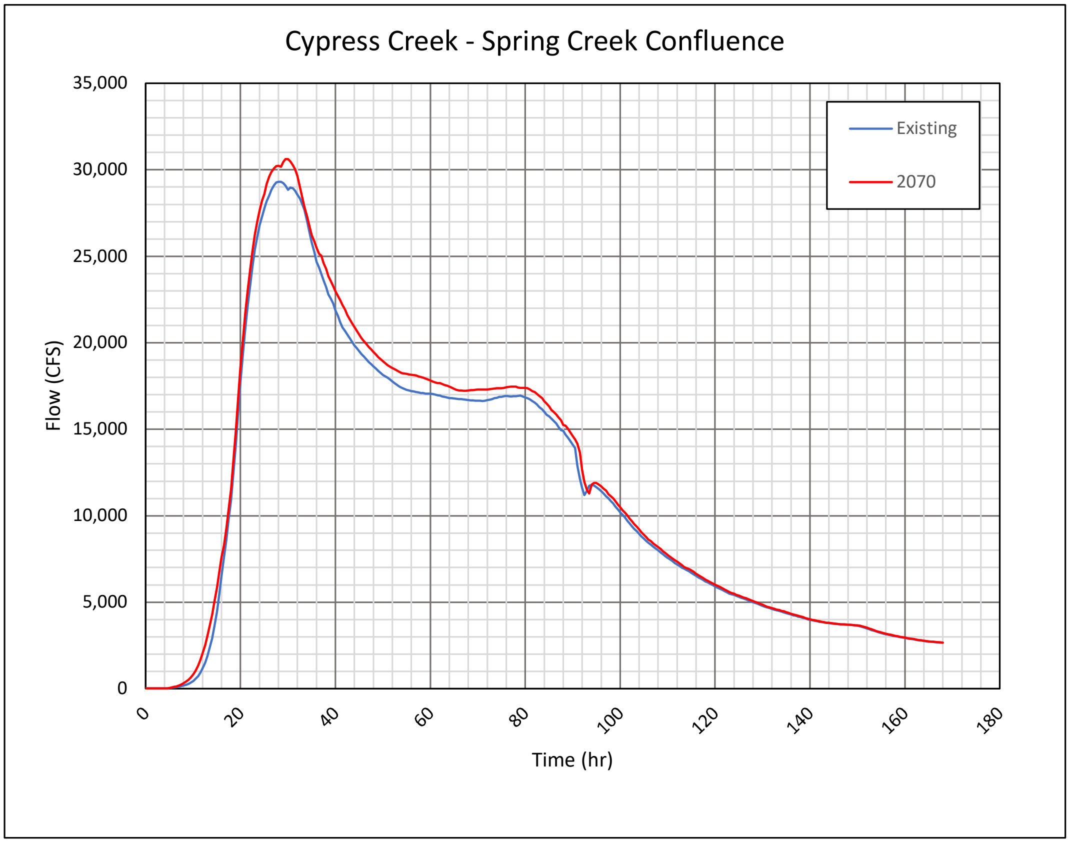
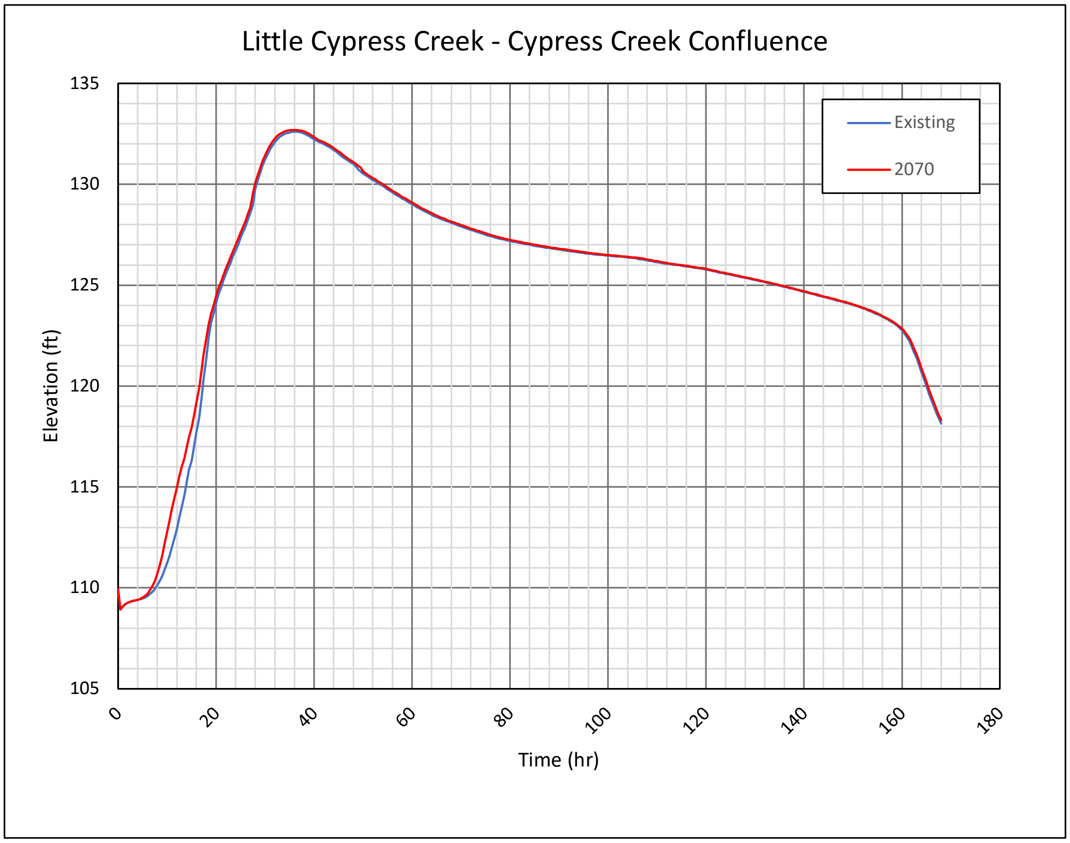


Exhibit 20 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



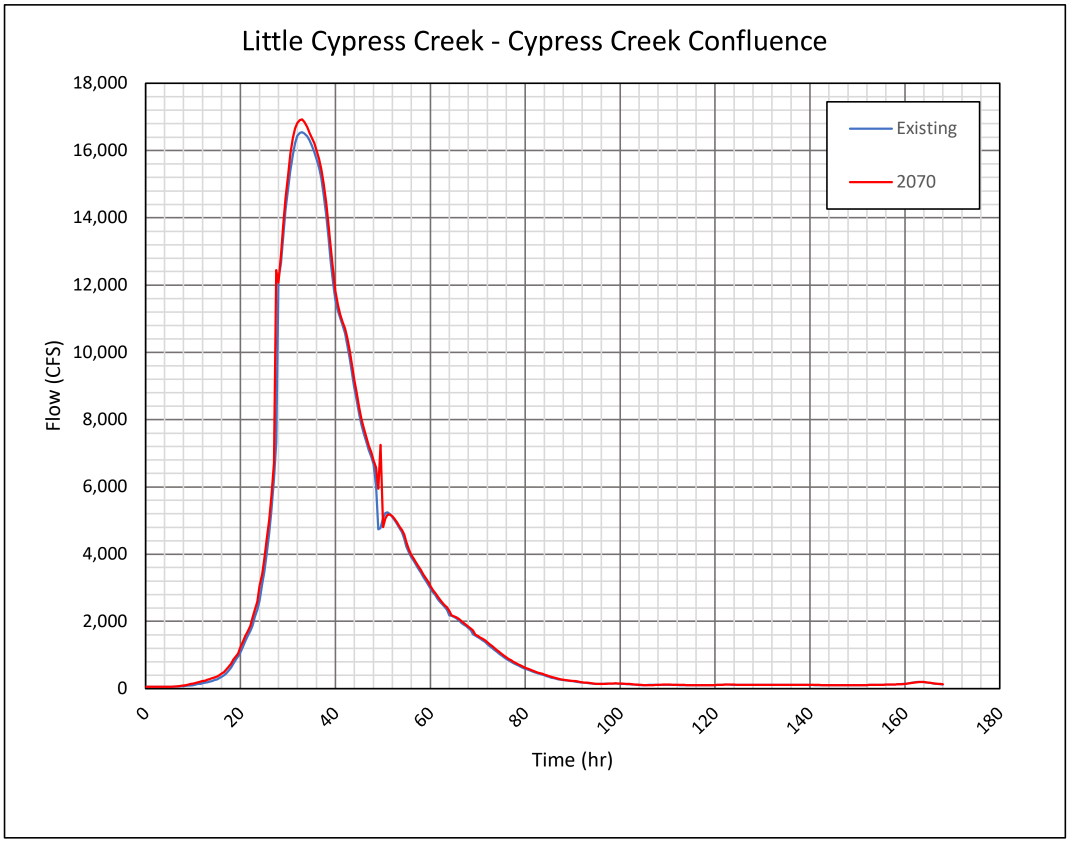
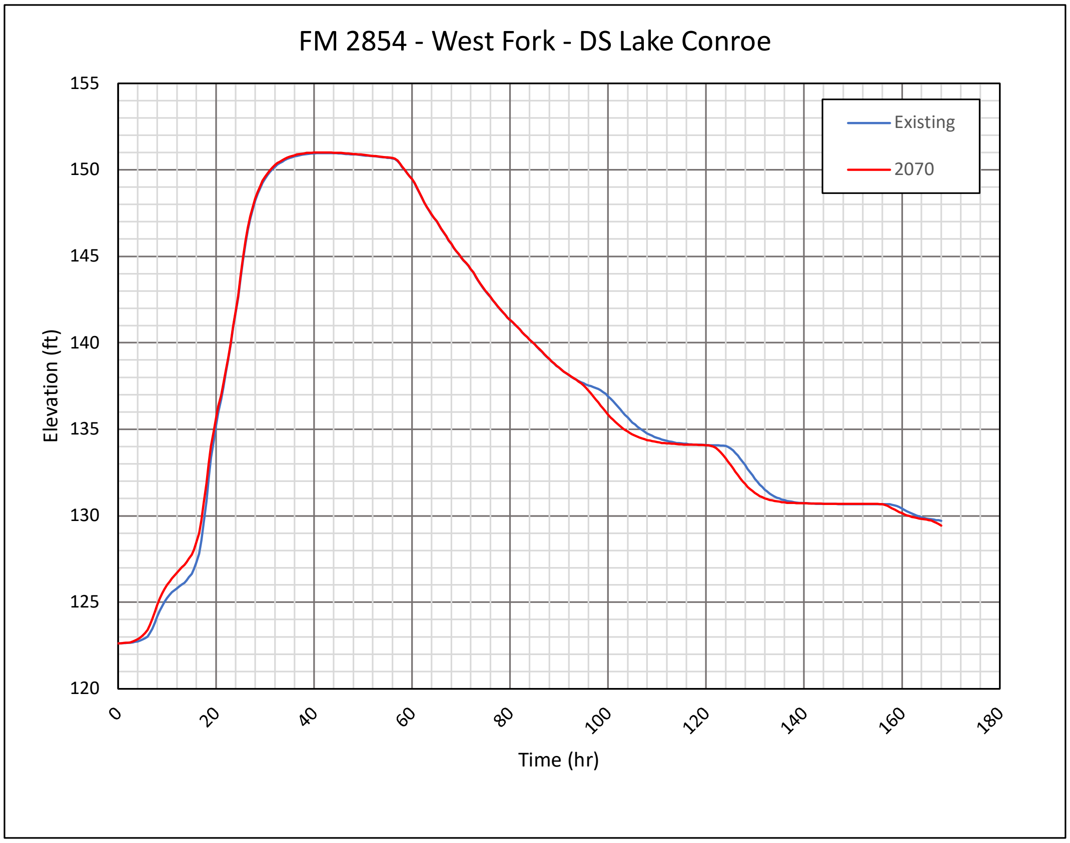


Exhibit 21 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



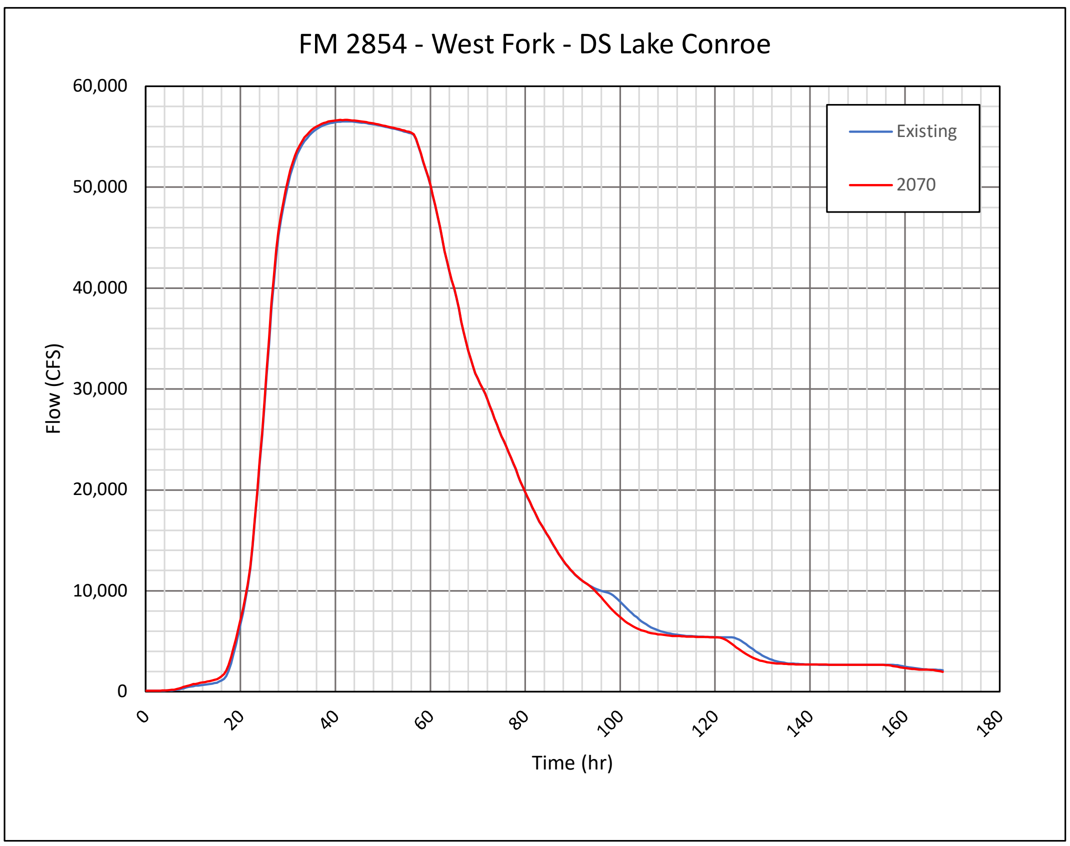
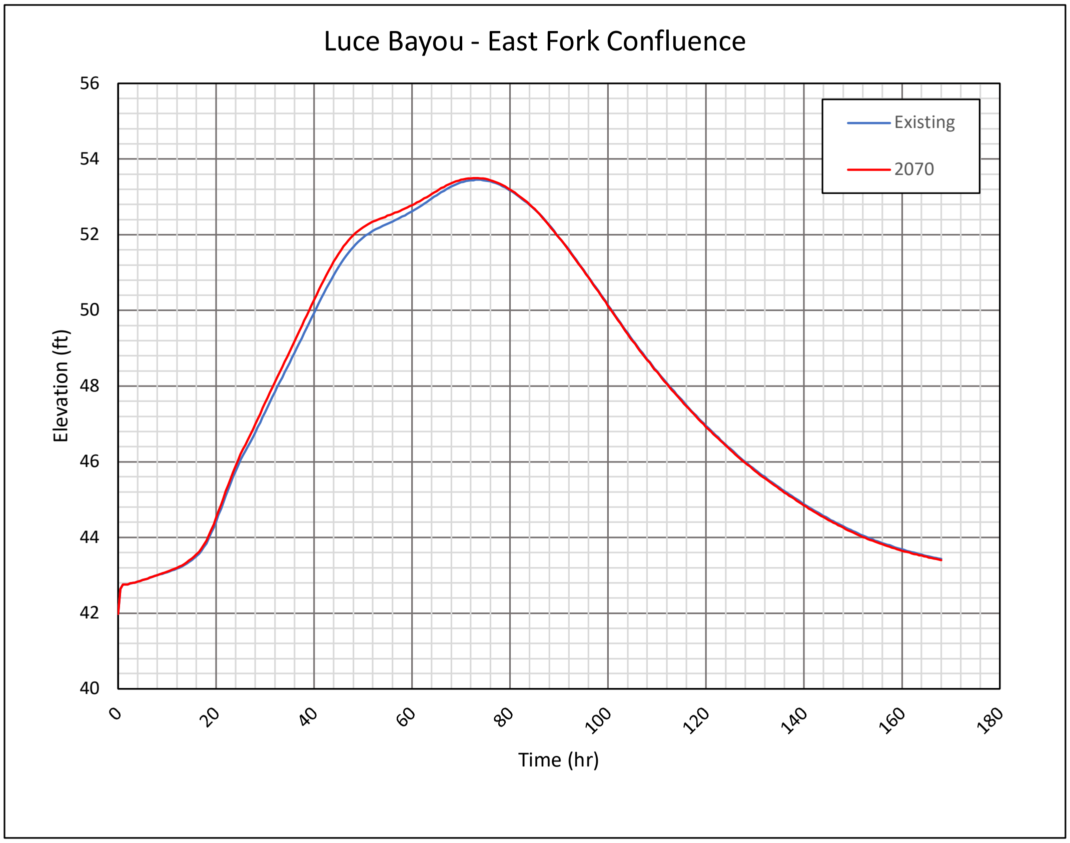
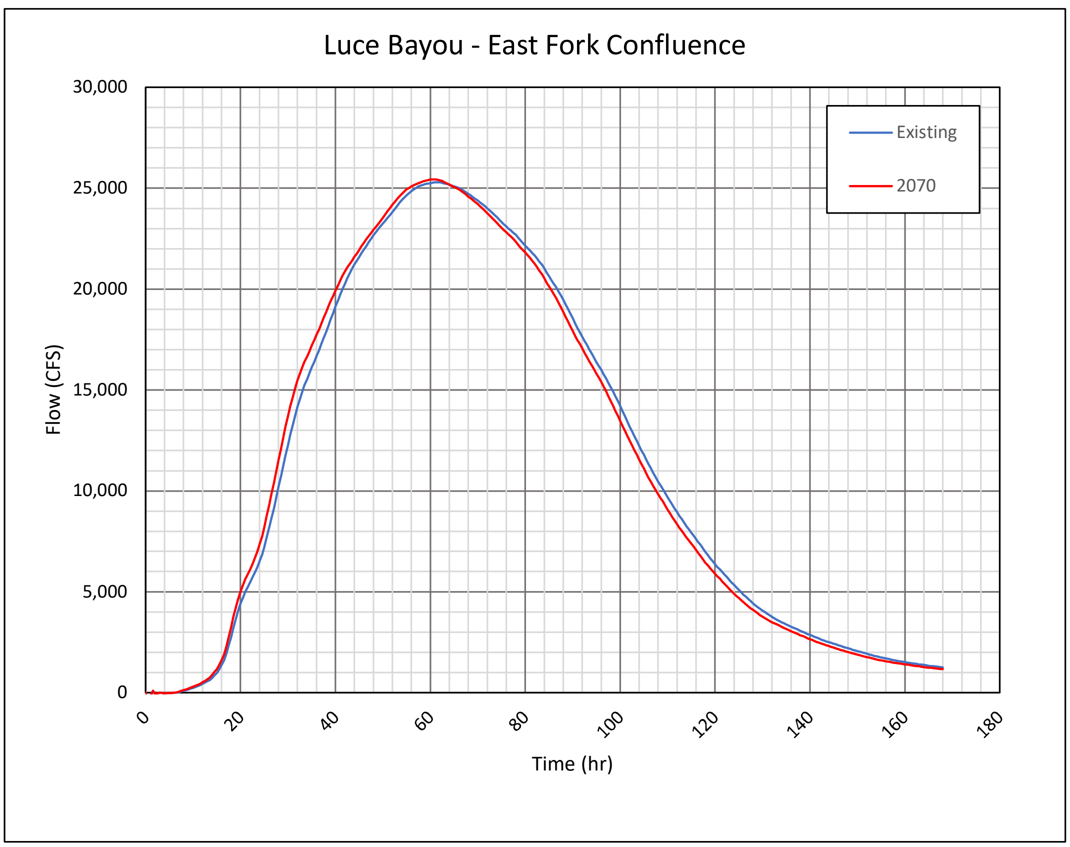


Exhibit 22 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)





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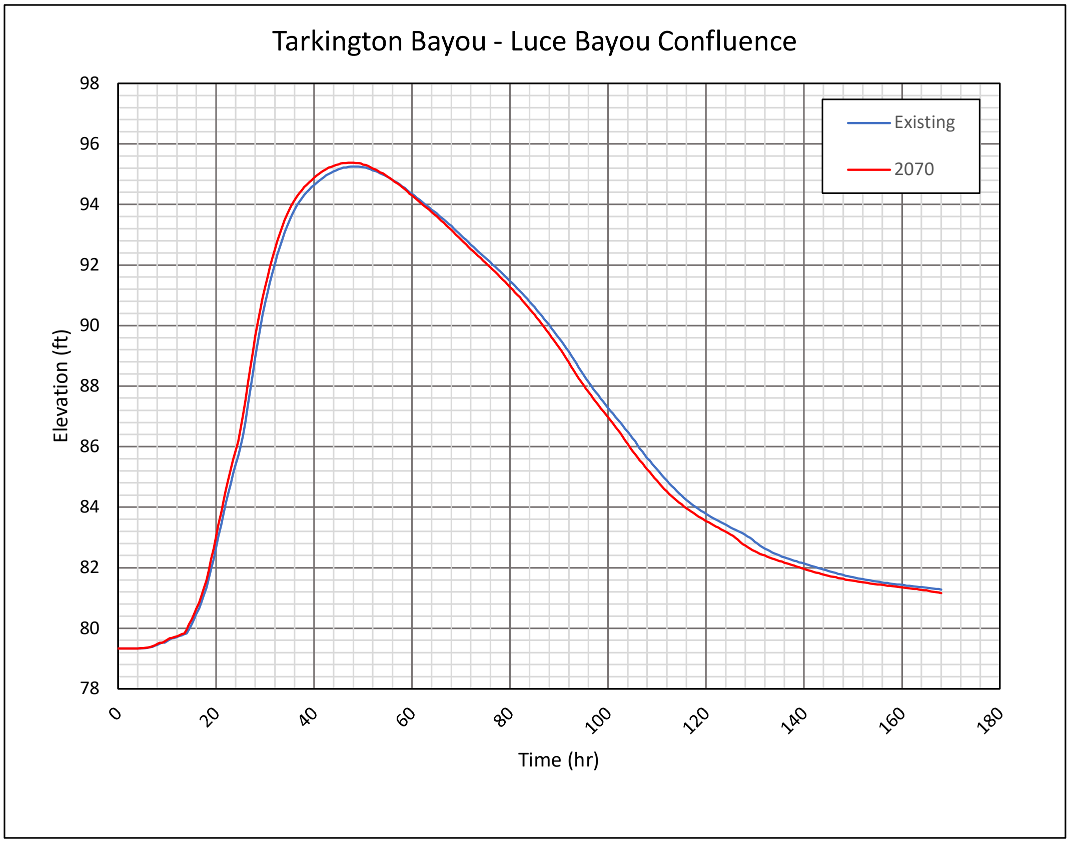


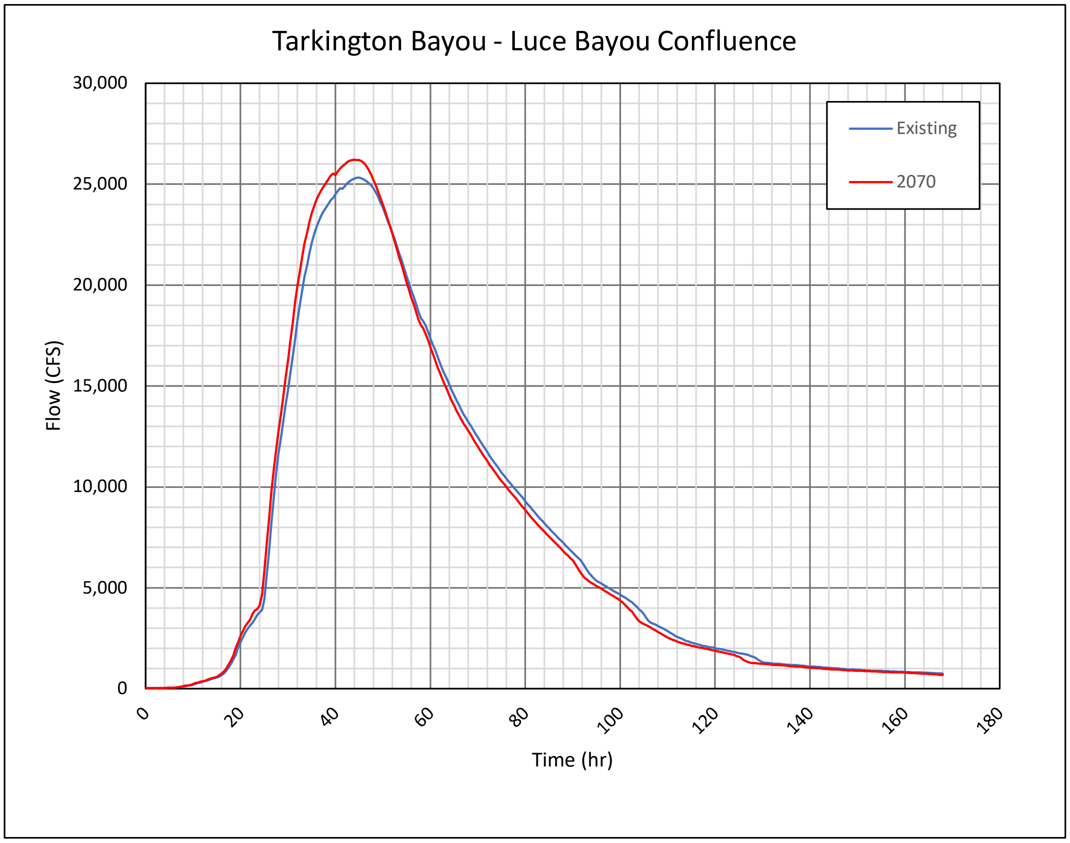
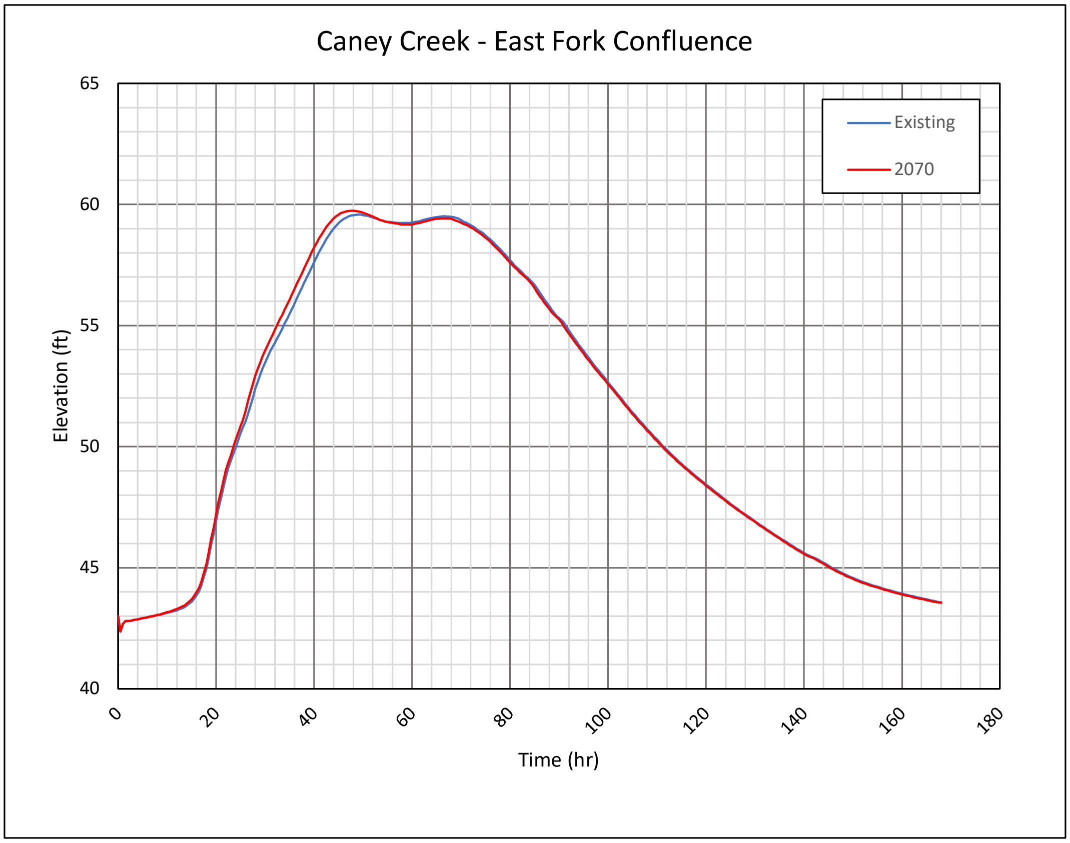


Exhibit 24 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



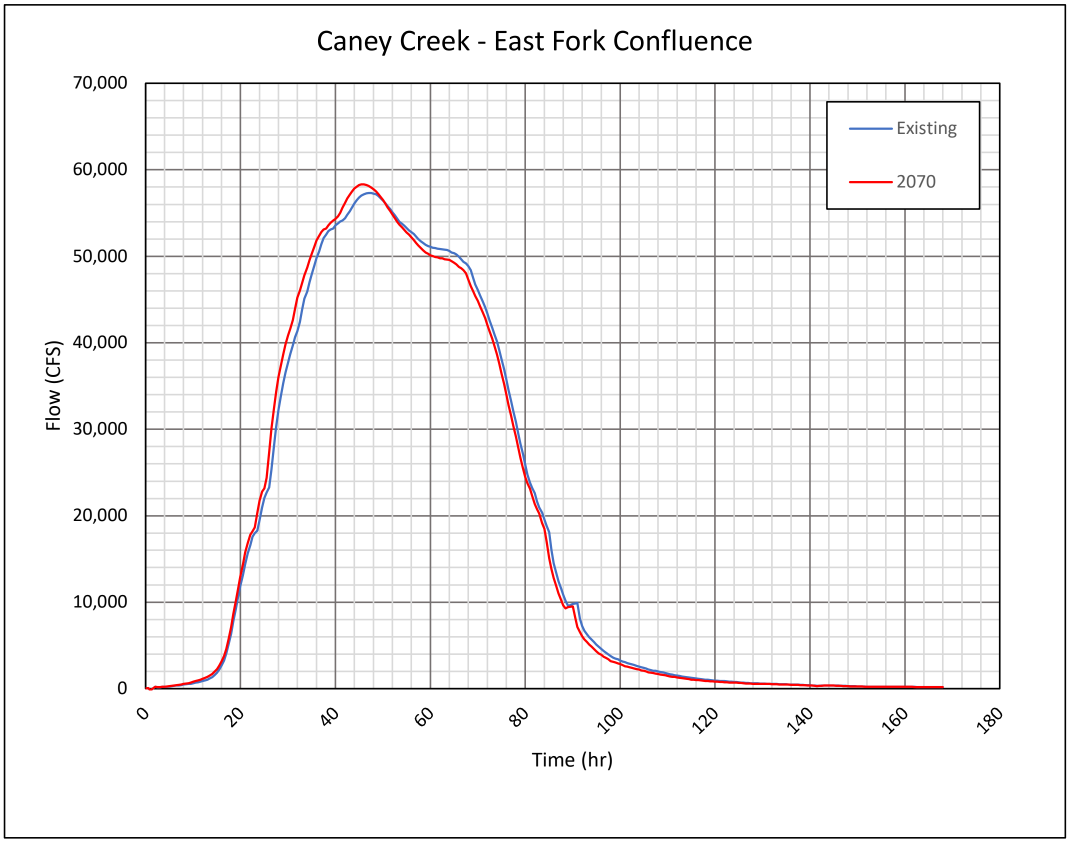
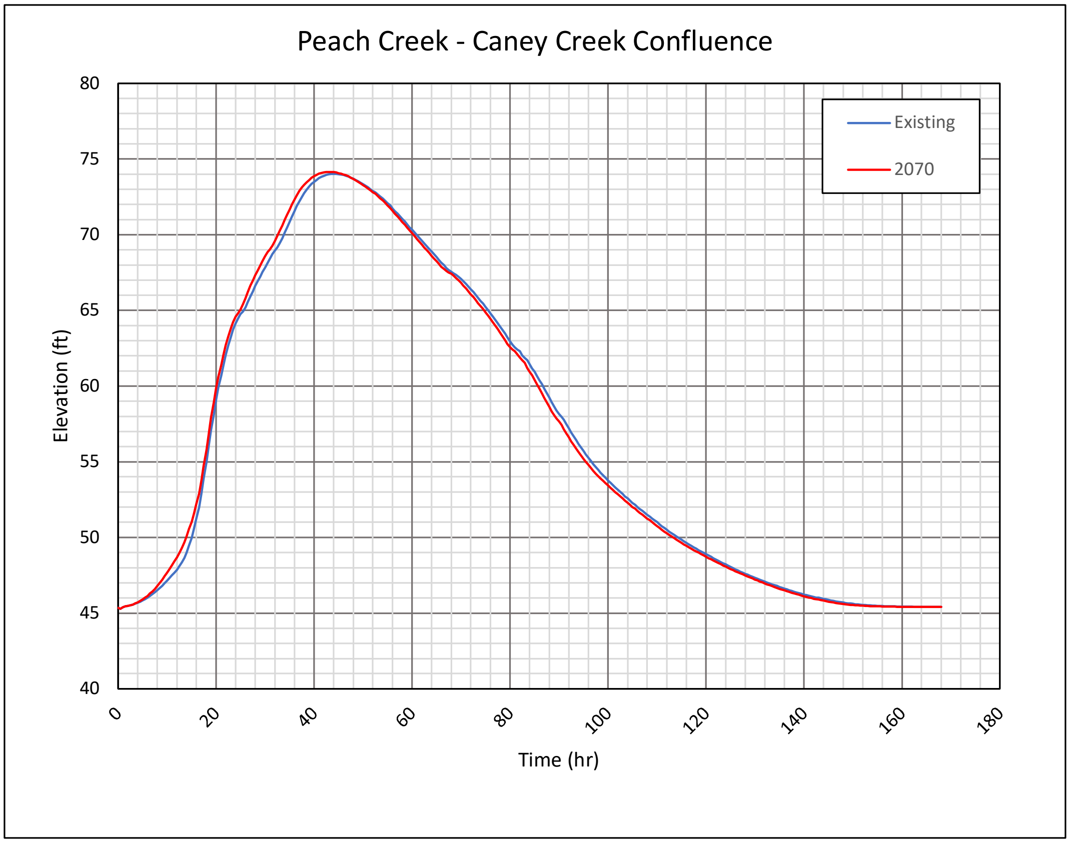


Exhibit 25 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



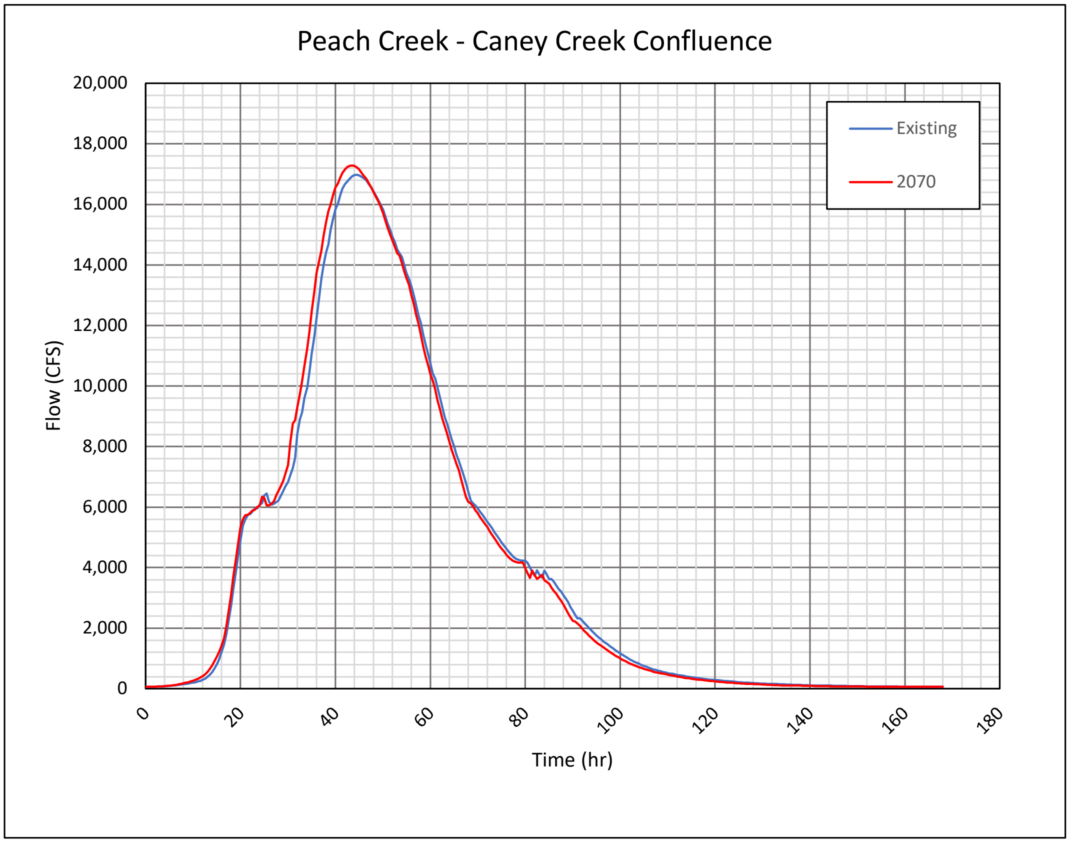
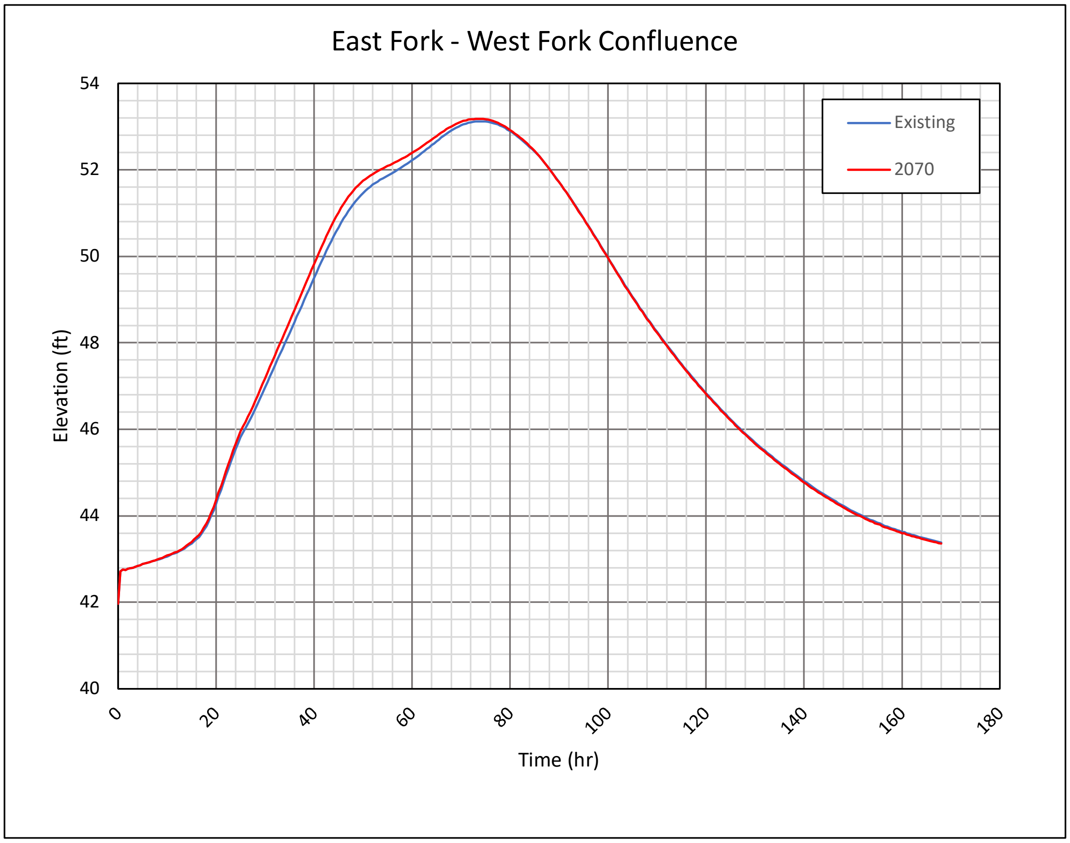


Exhibit 26 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



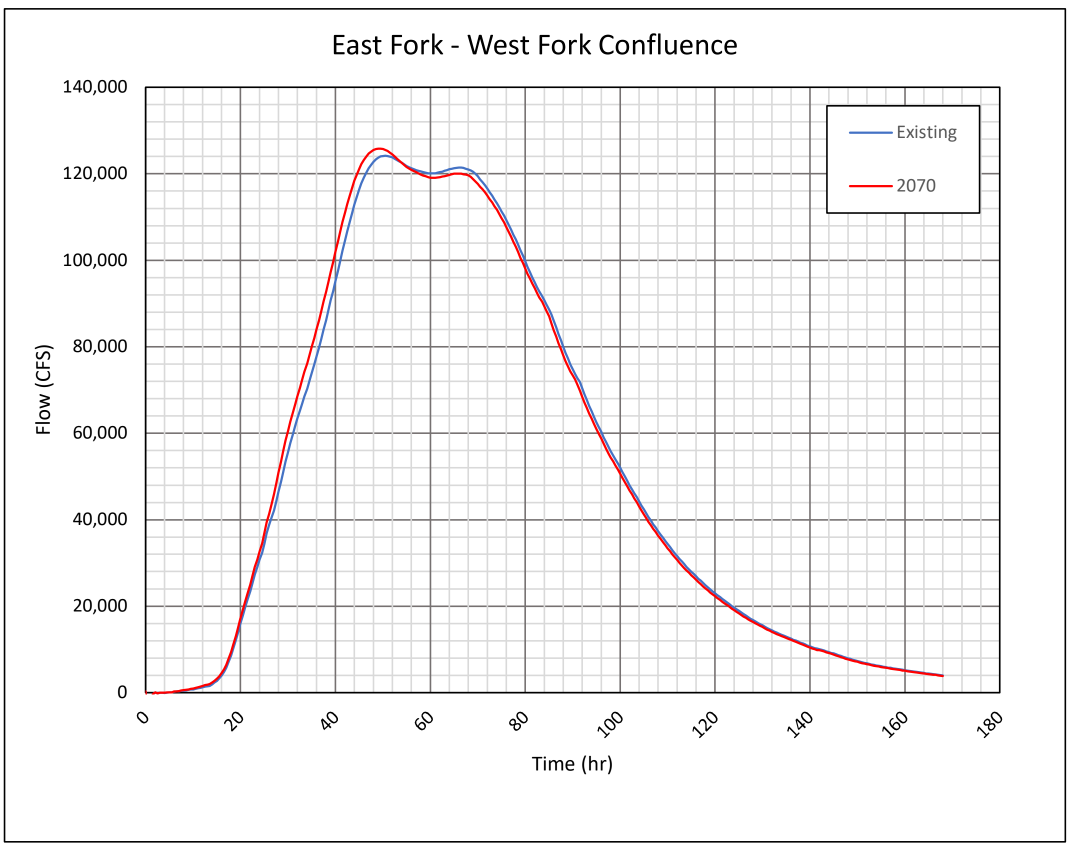
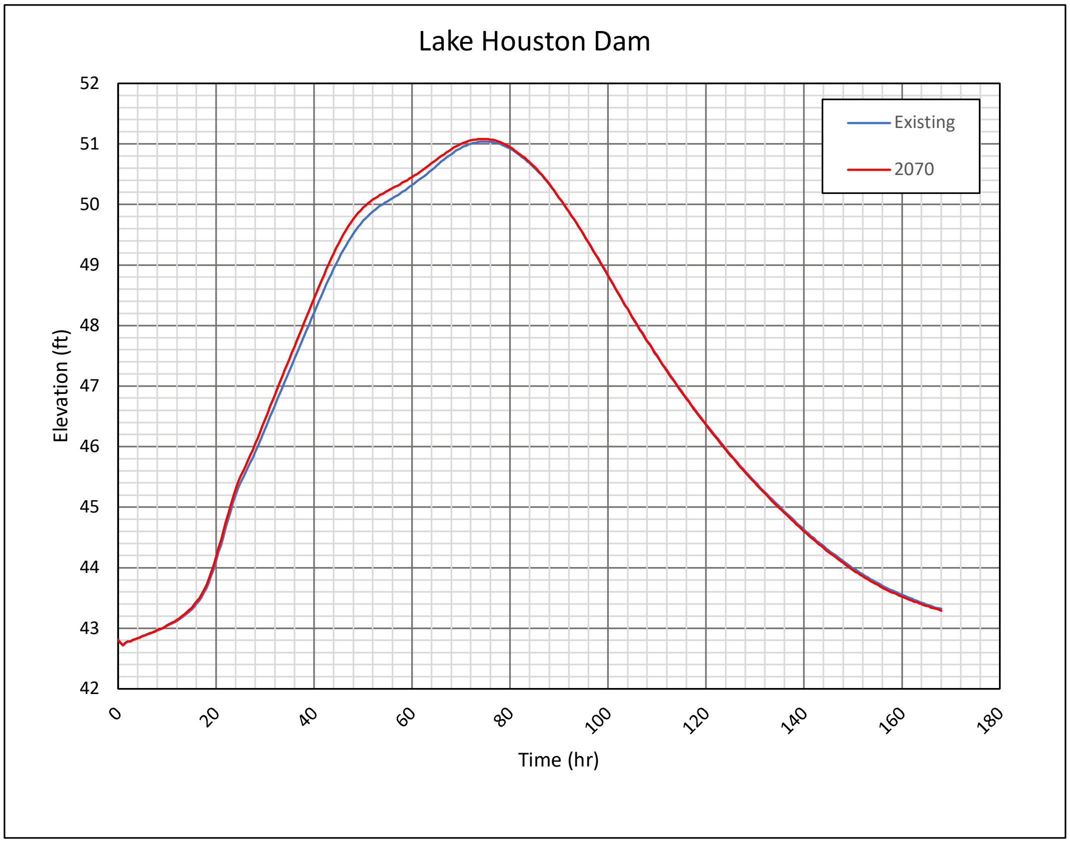


Exhibit 27 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



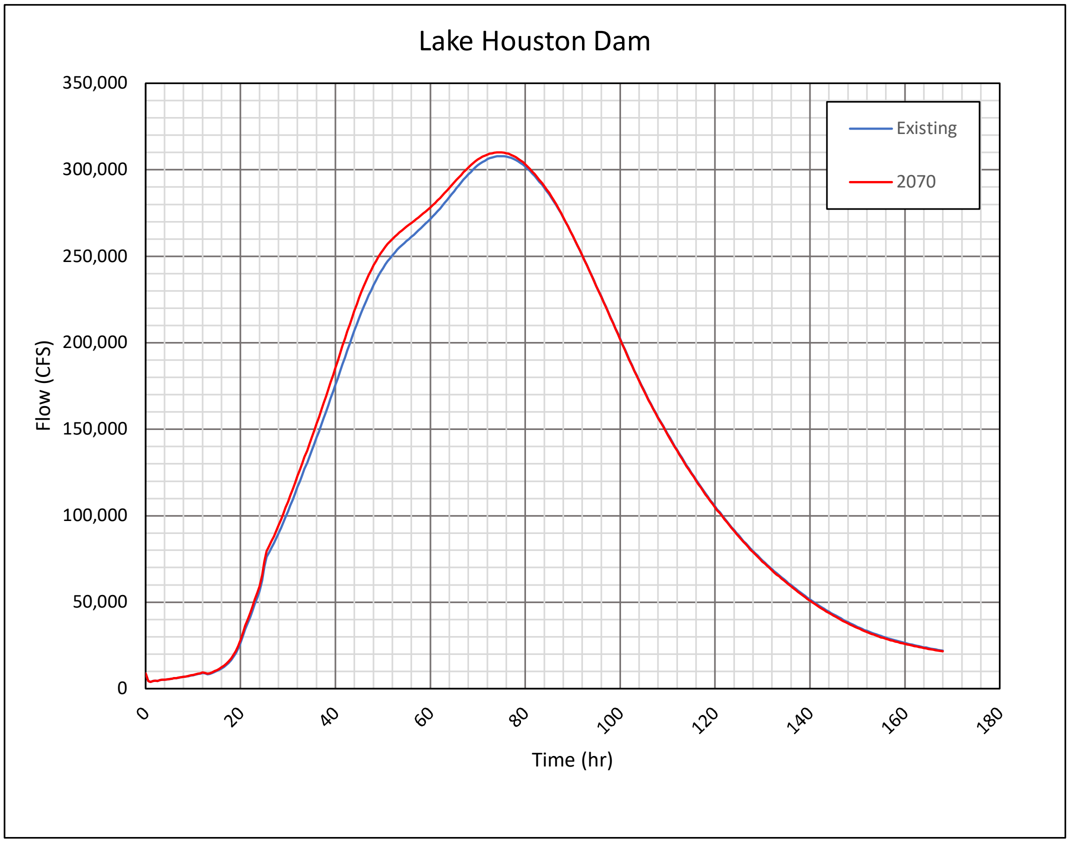
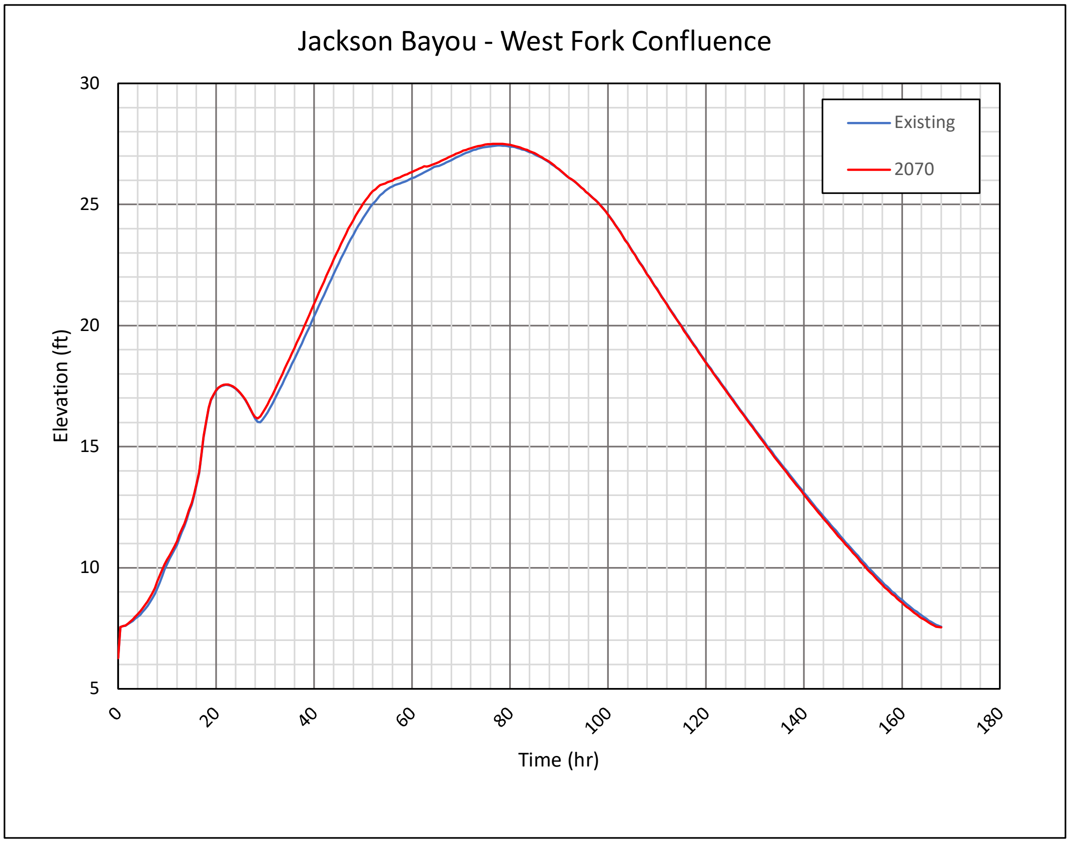


Exhibit 28 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



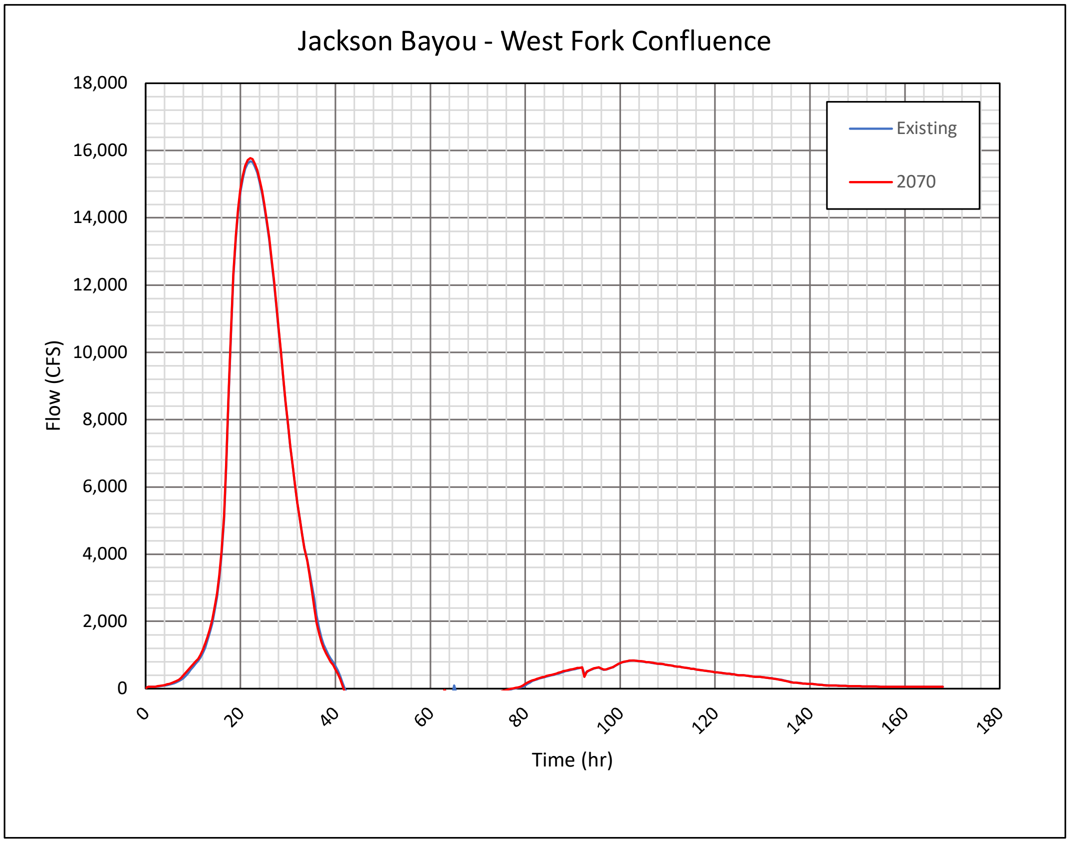
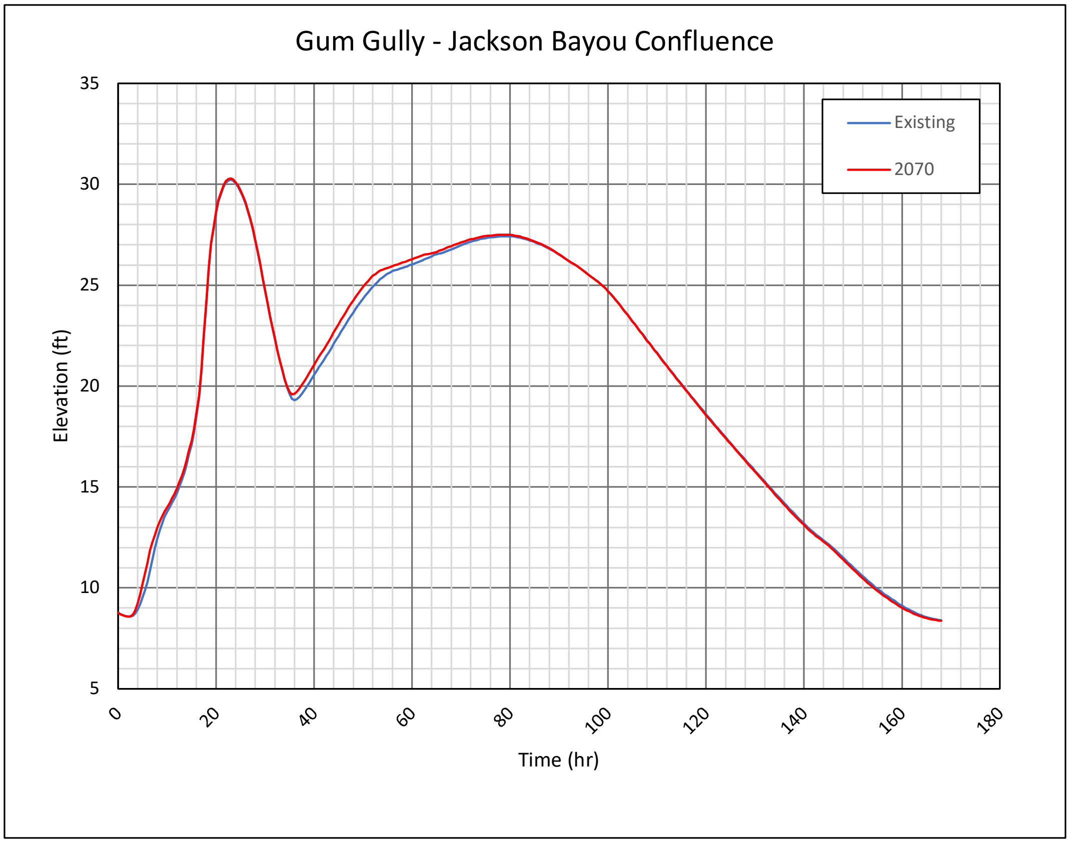


Exhibit 29 – HEC-RAS Flow and Stage Hydrographs at Key Locations (1% ACE)



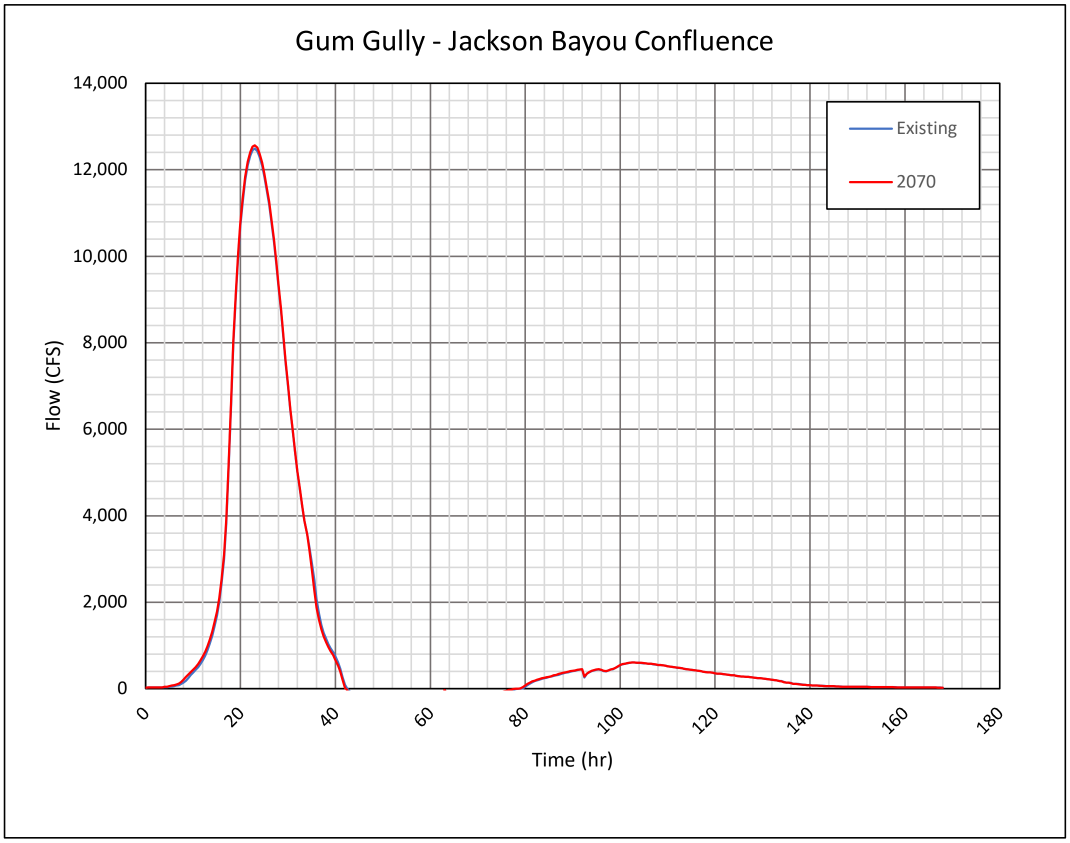
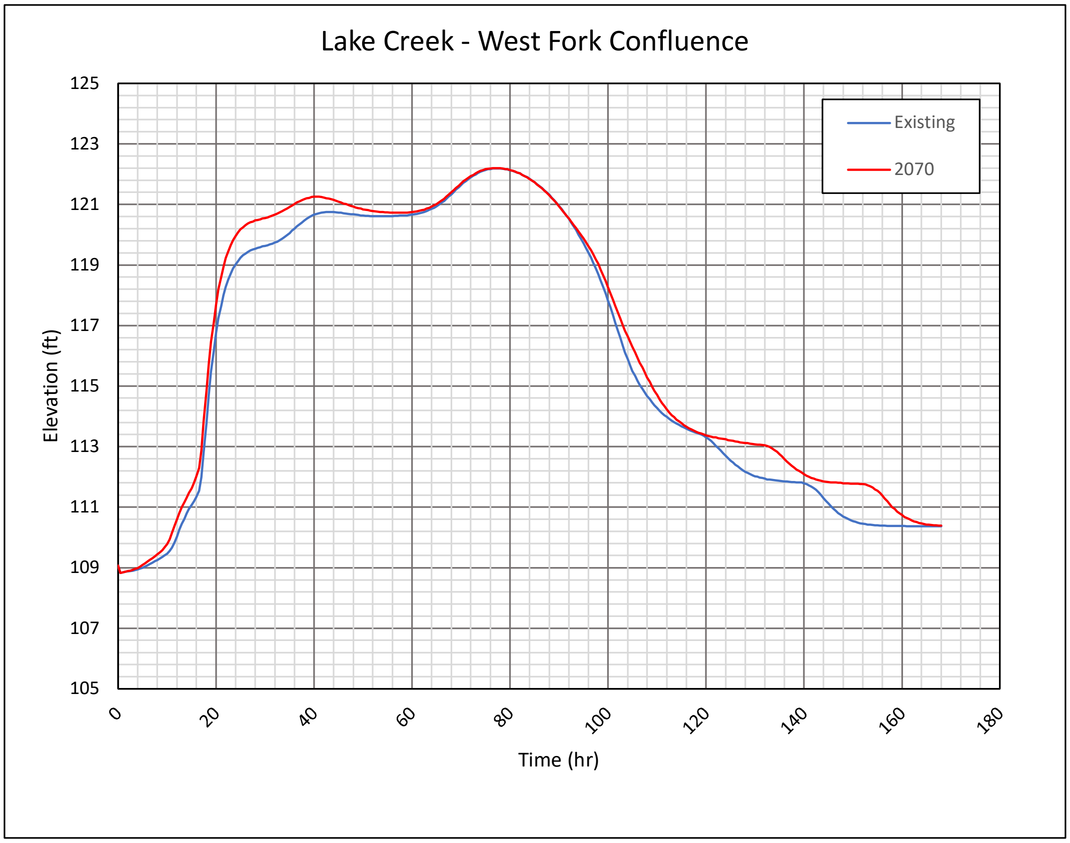


Exhibit 30 – HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)



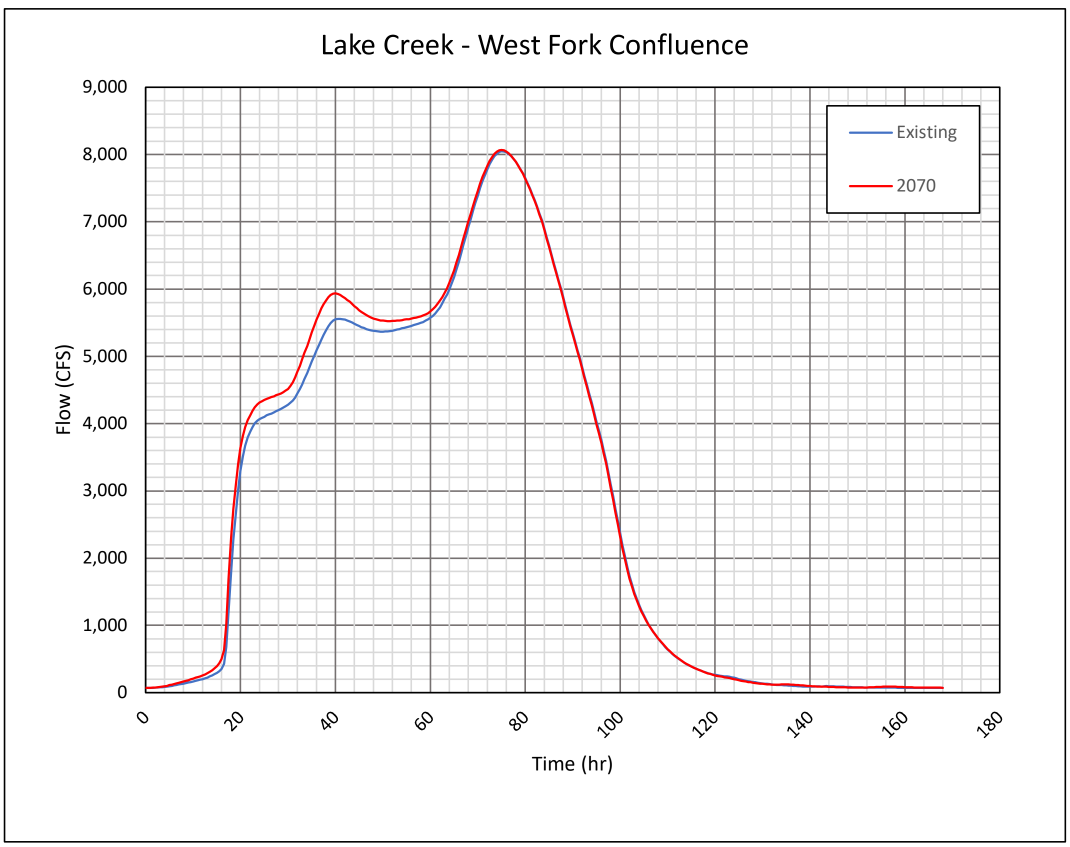
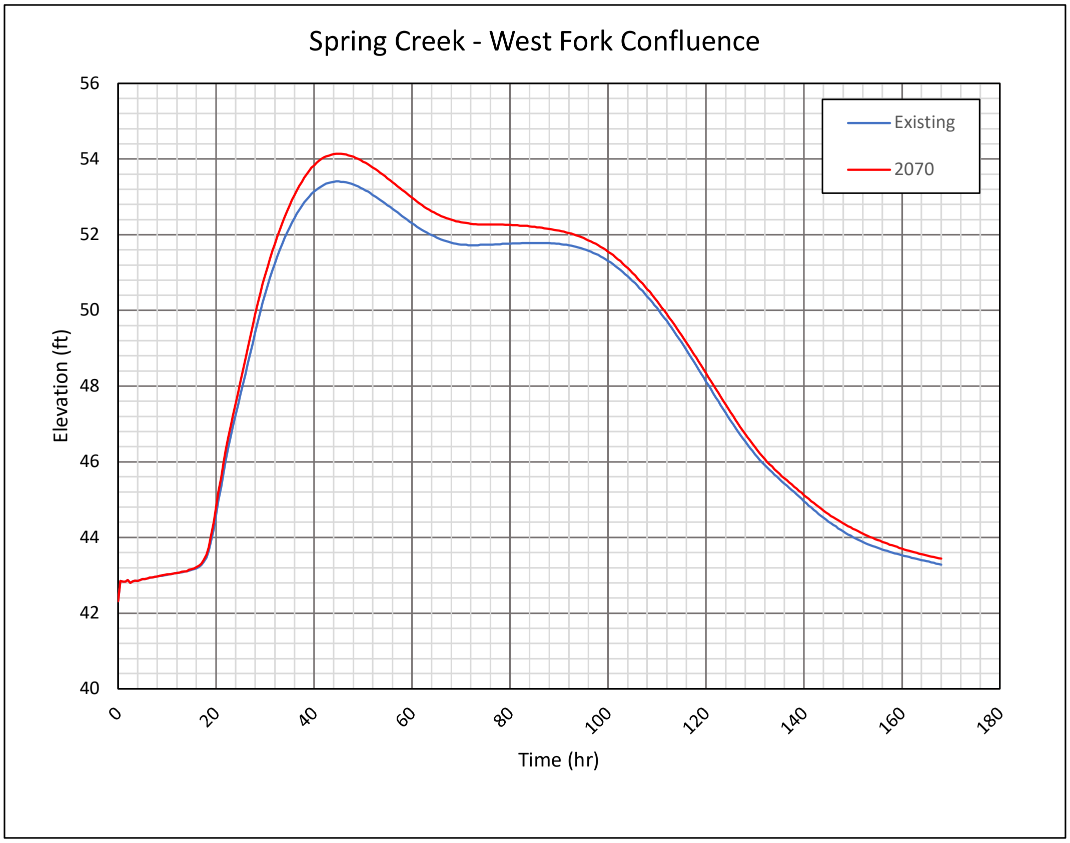
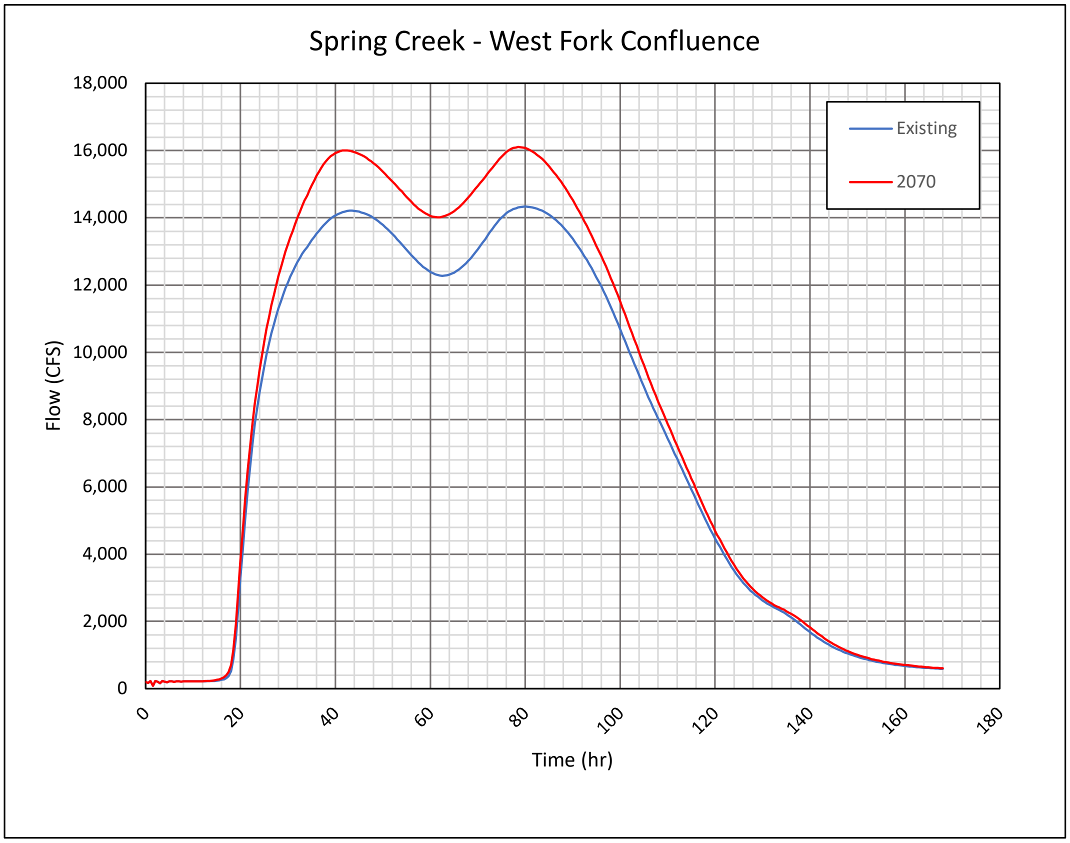


Exhibit 31 – HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)





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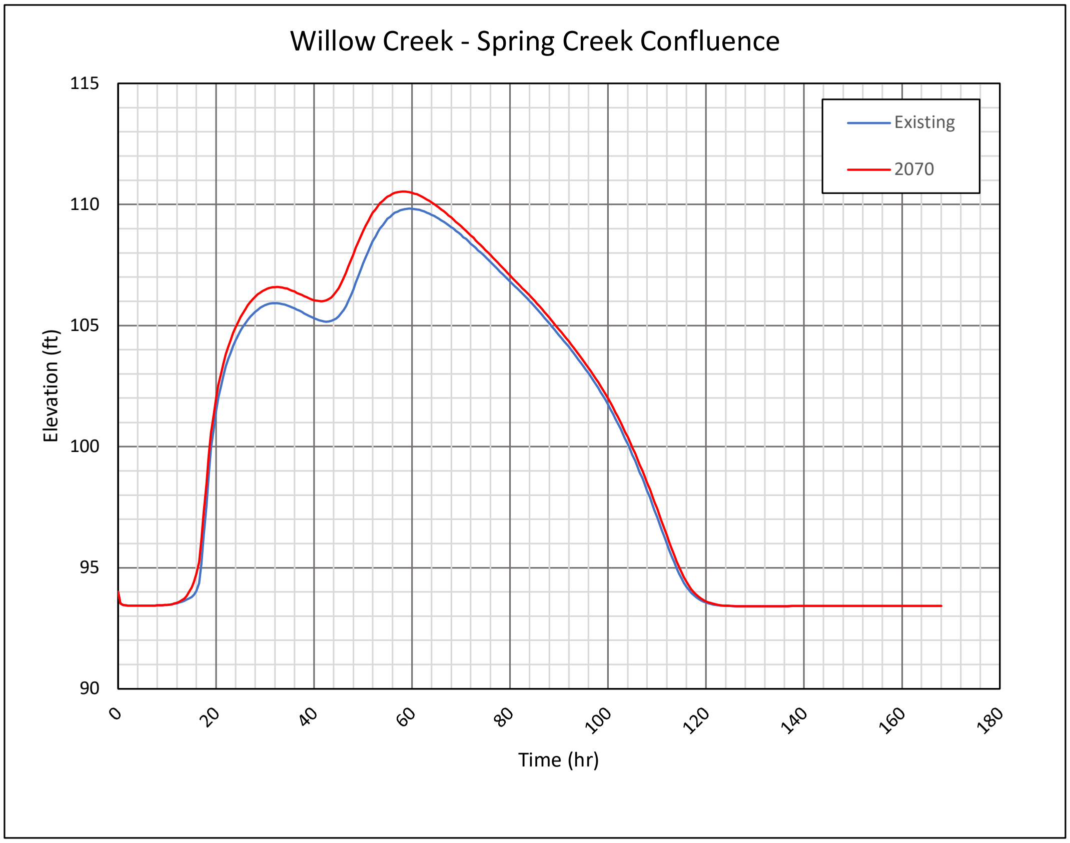

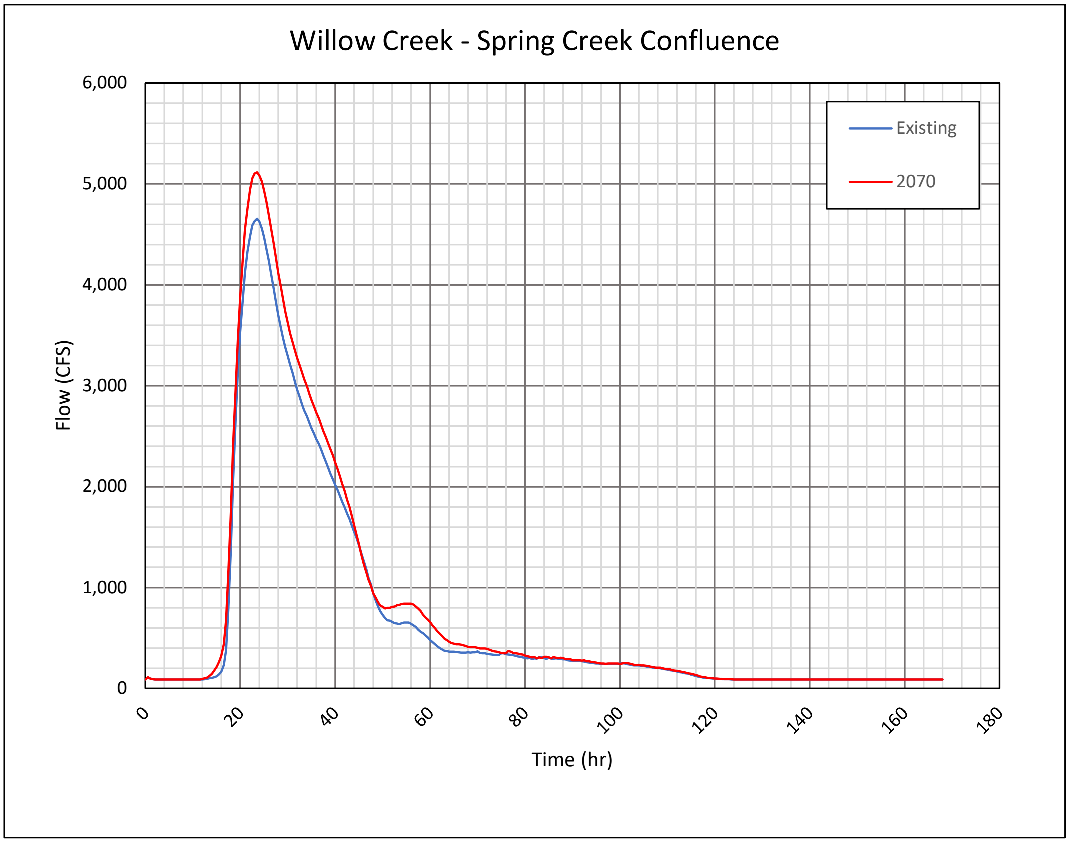

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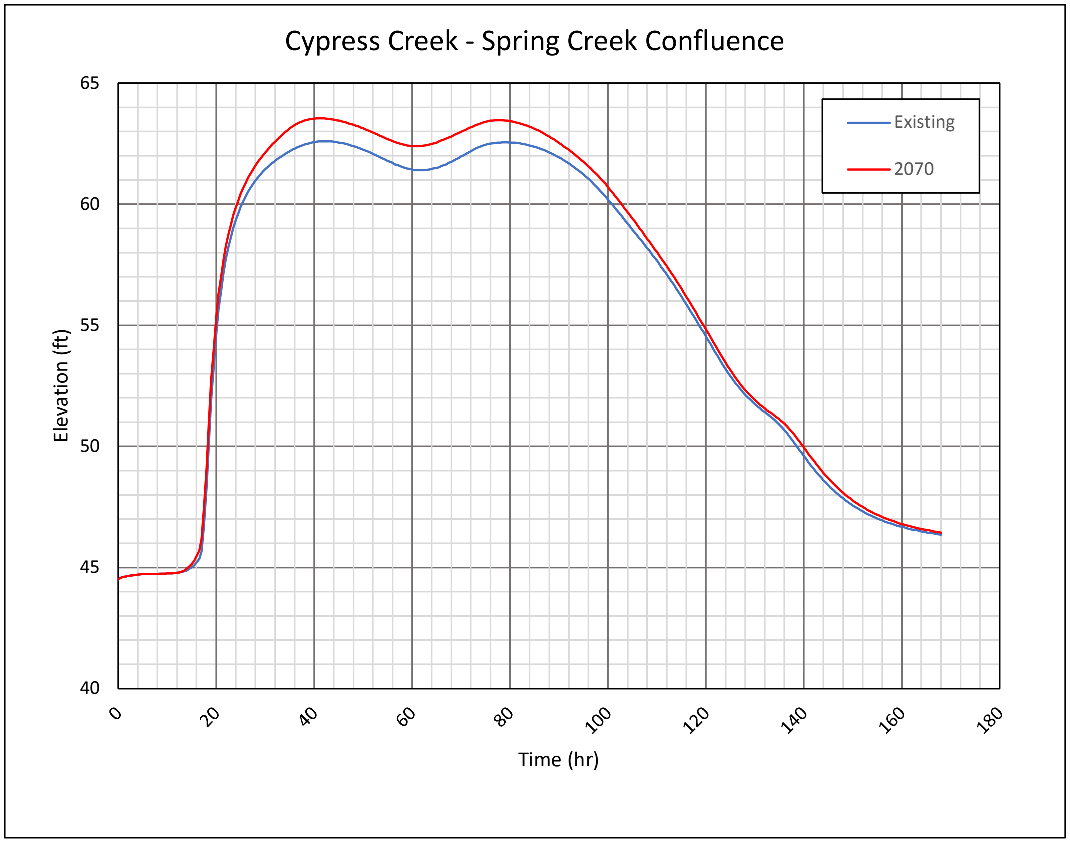


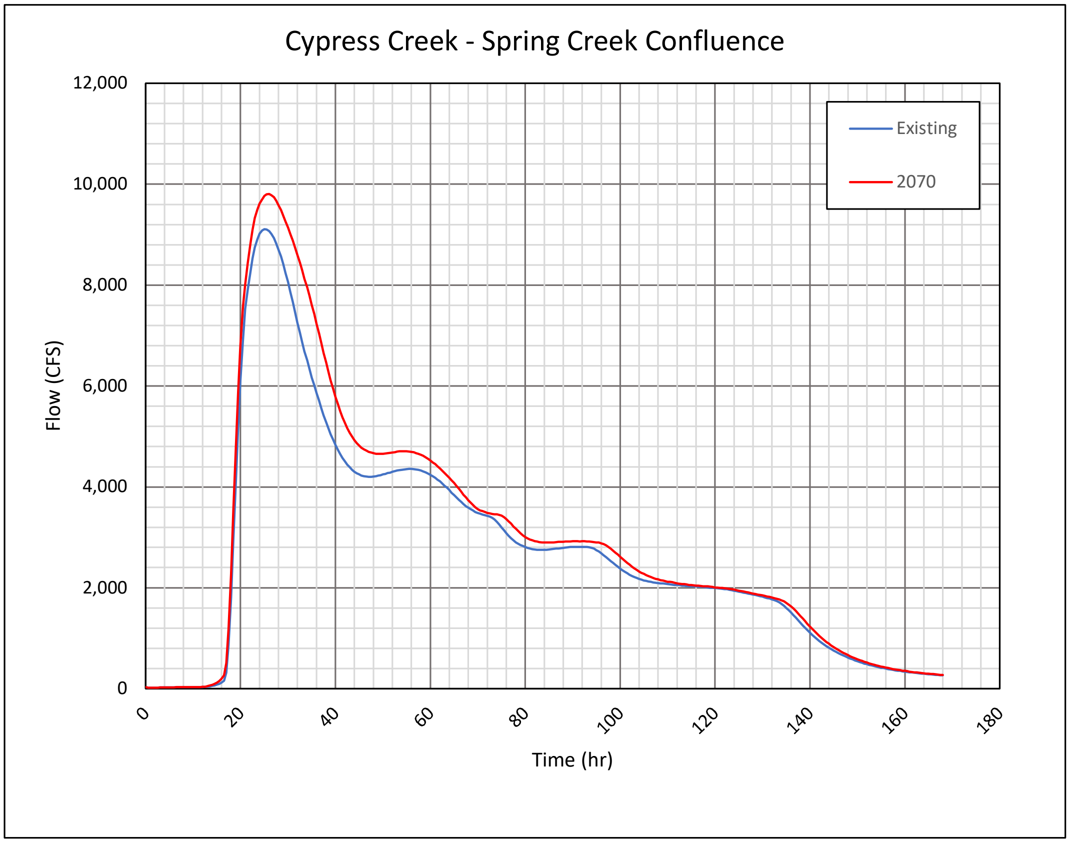
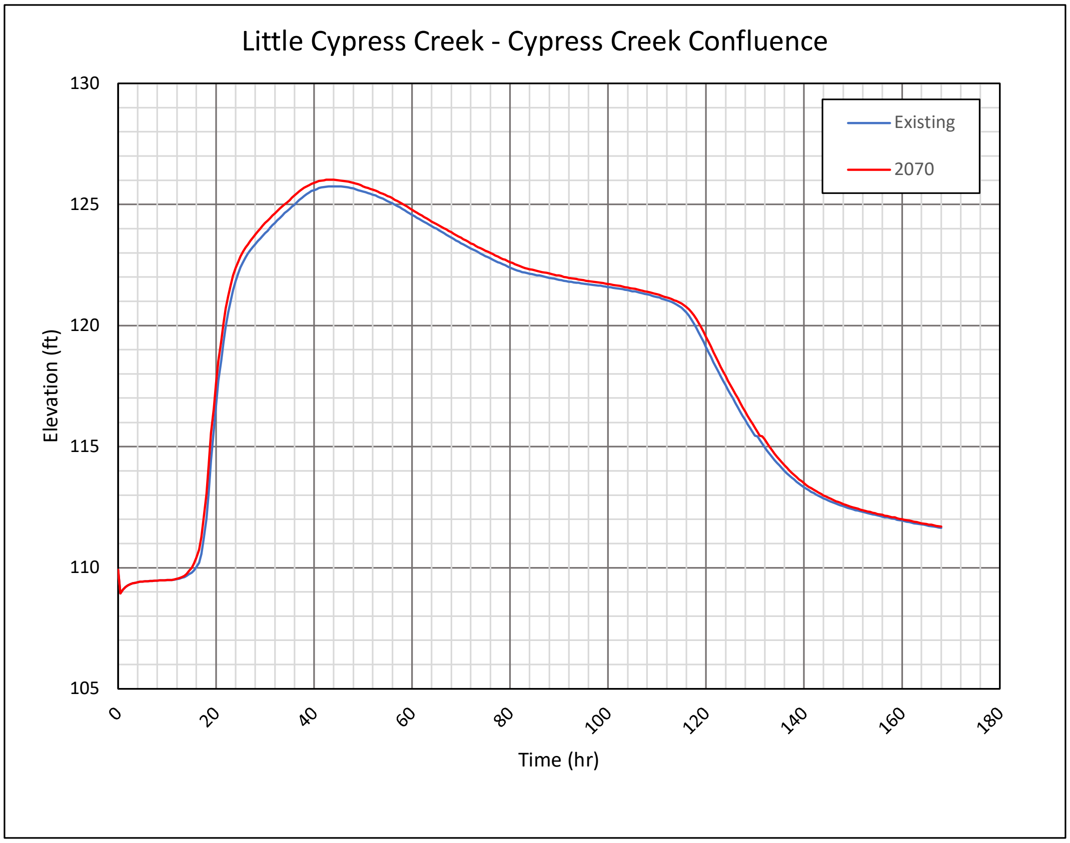


Exhibit 34 – HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)



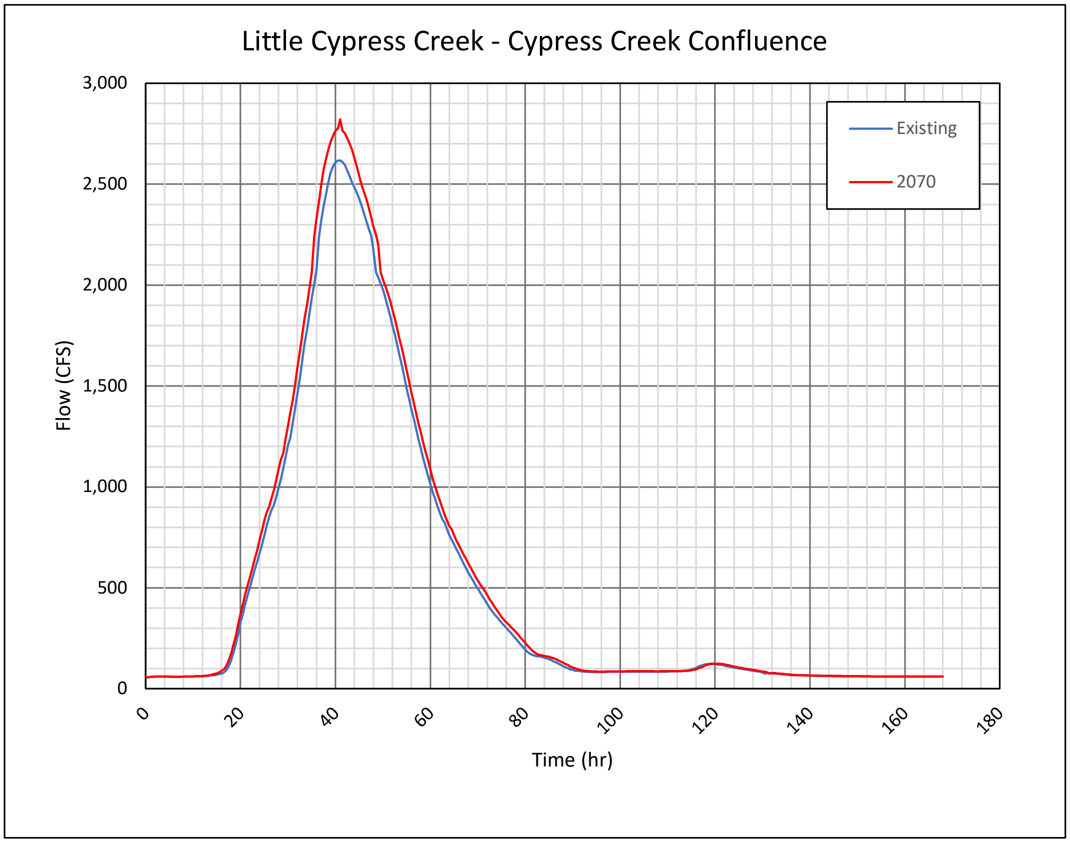
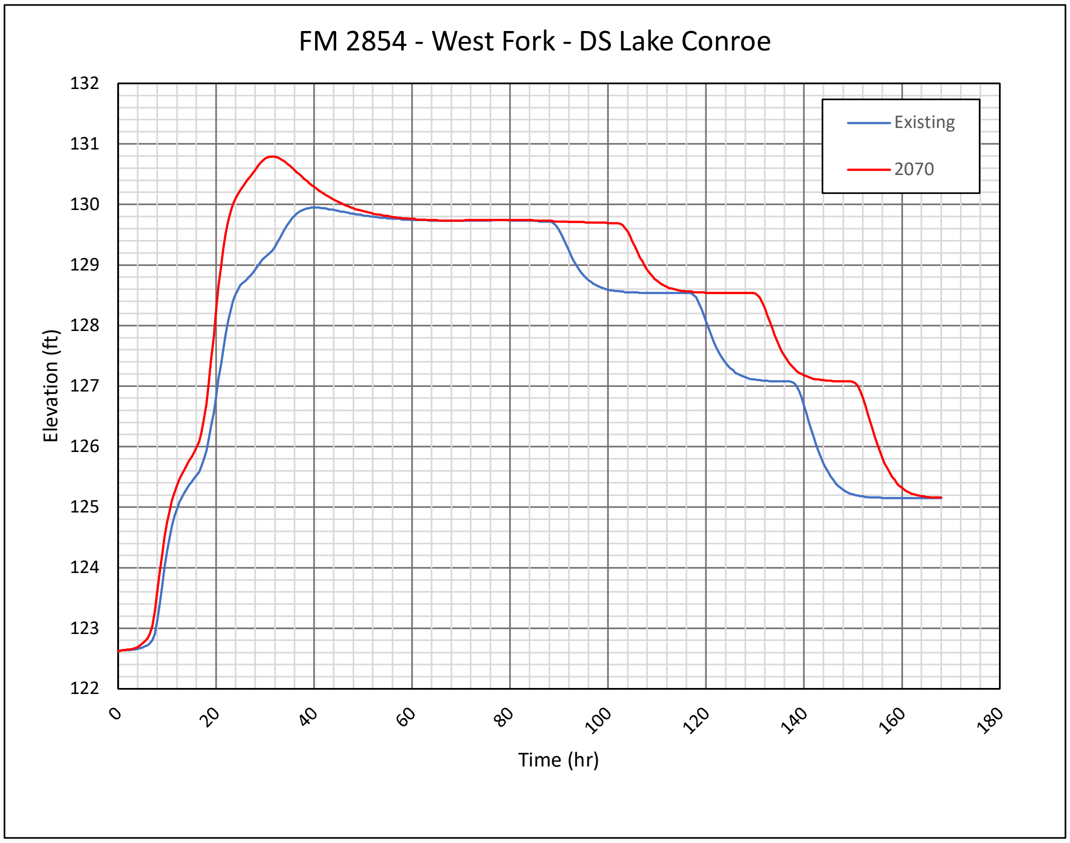


Exhibit 35 – HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)



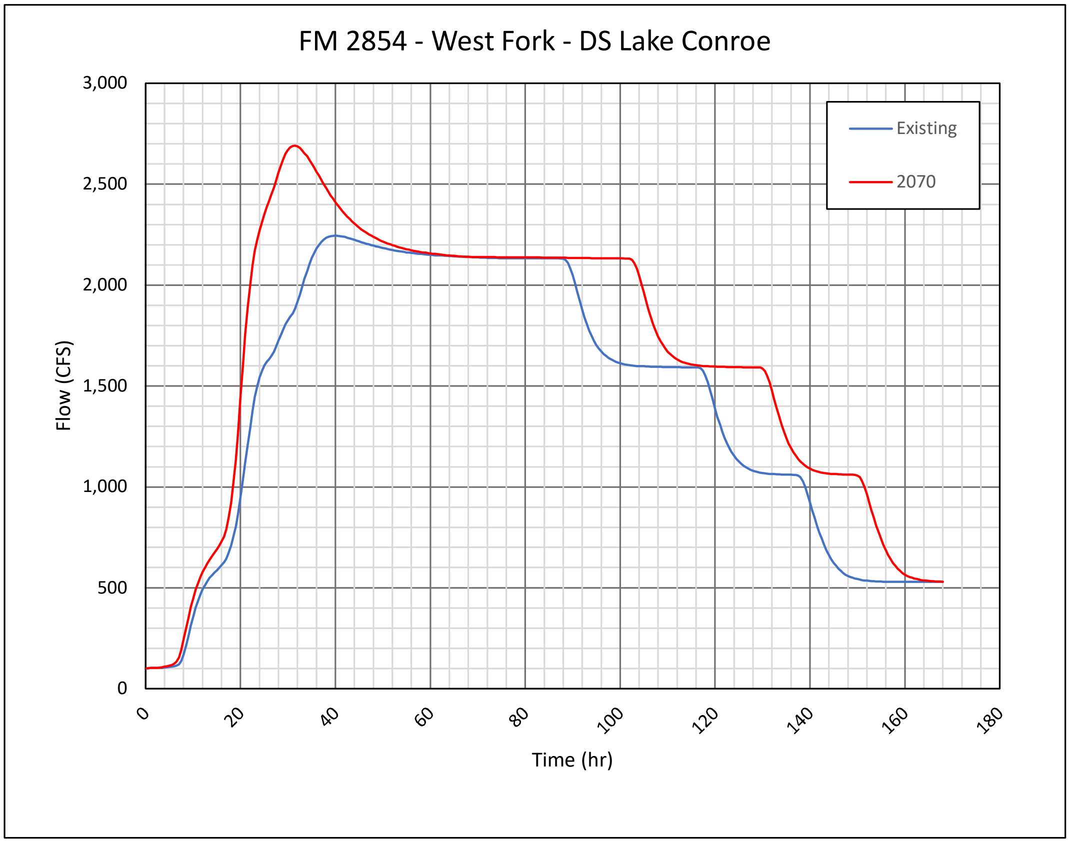
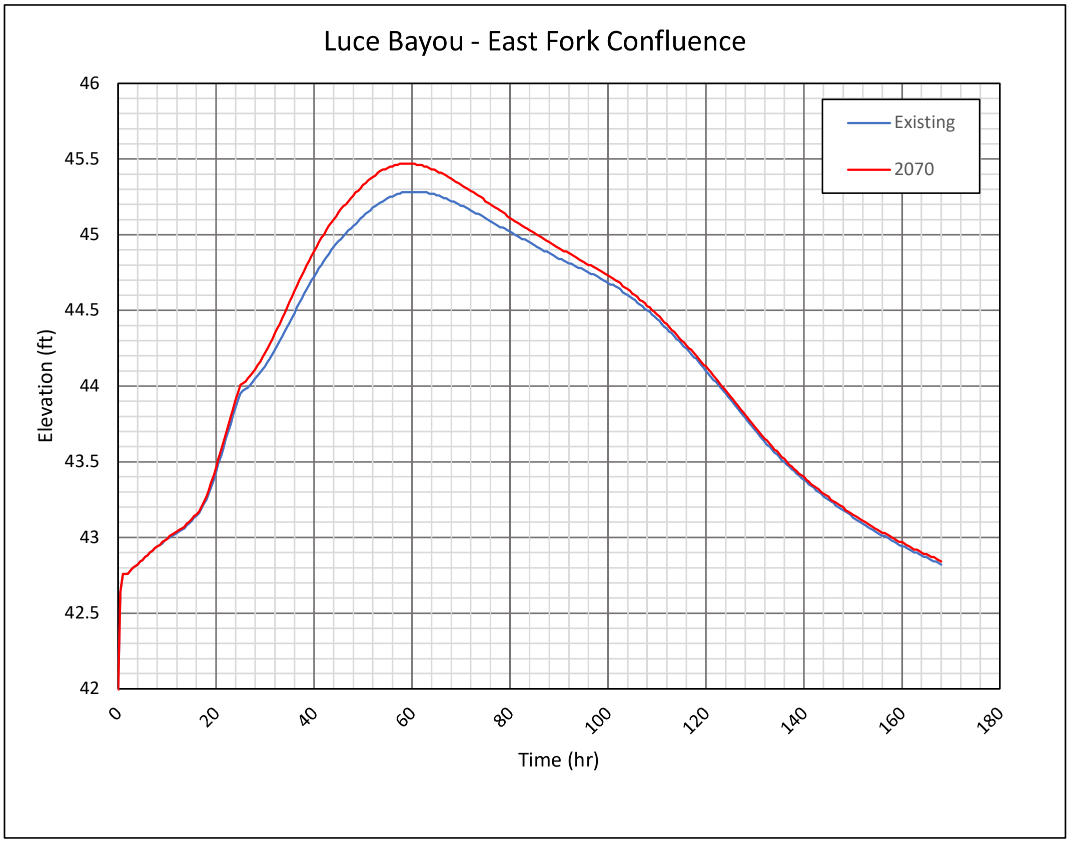
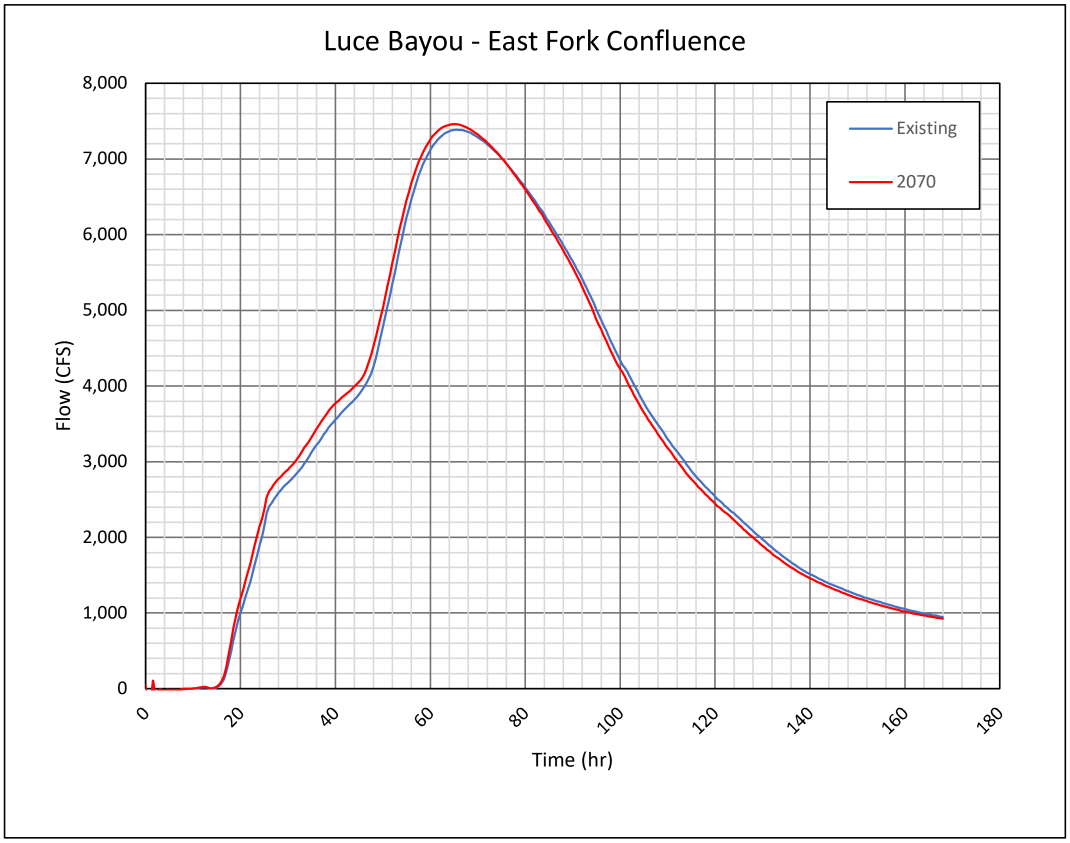


Exhibit 36 – HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)





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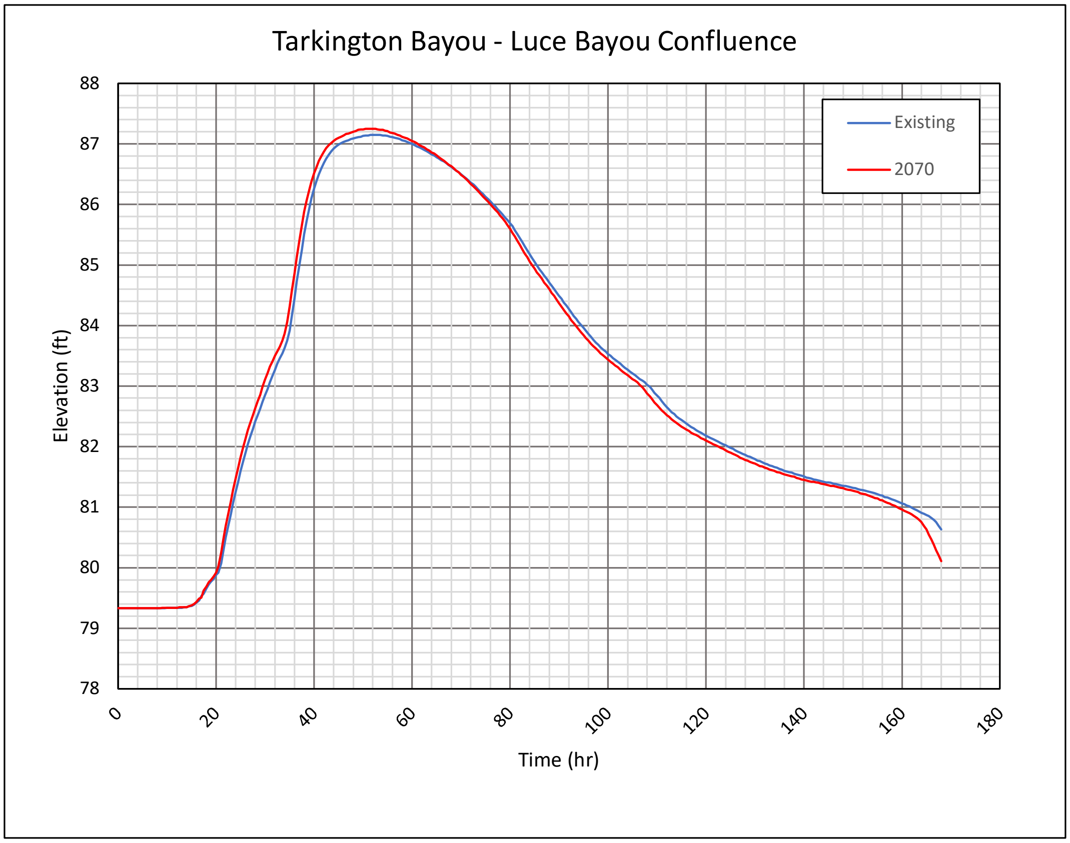


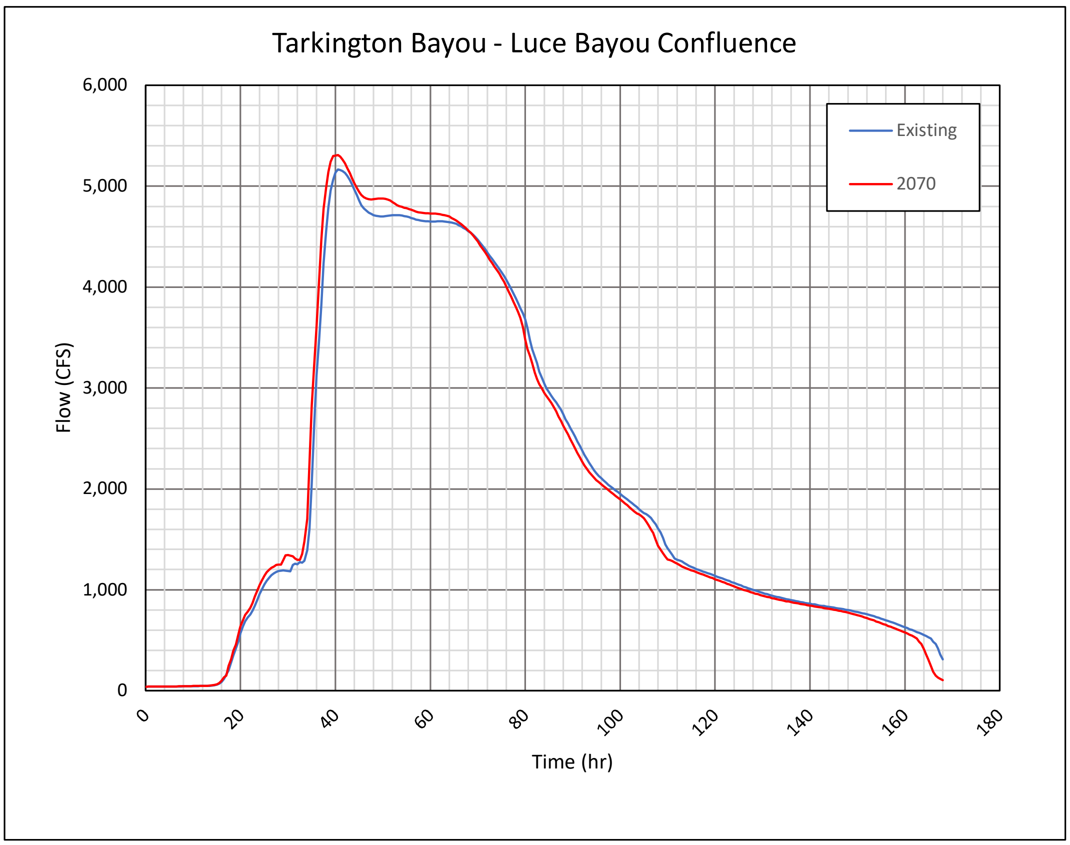
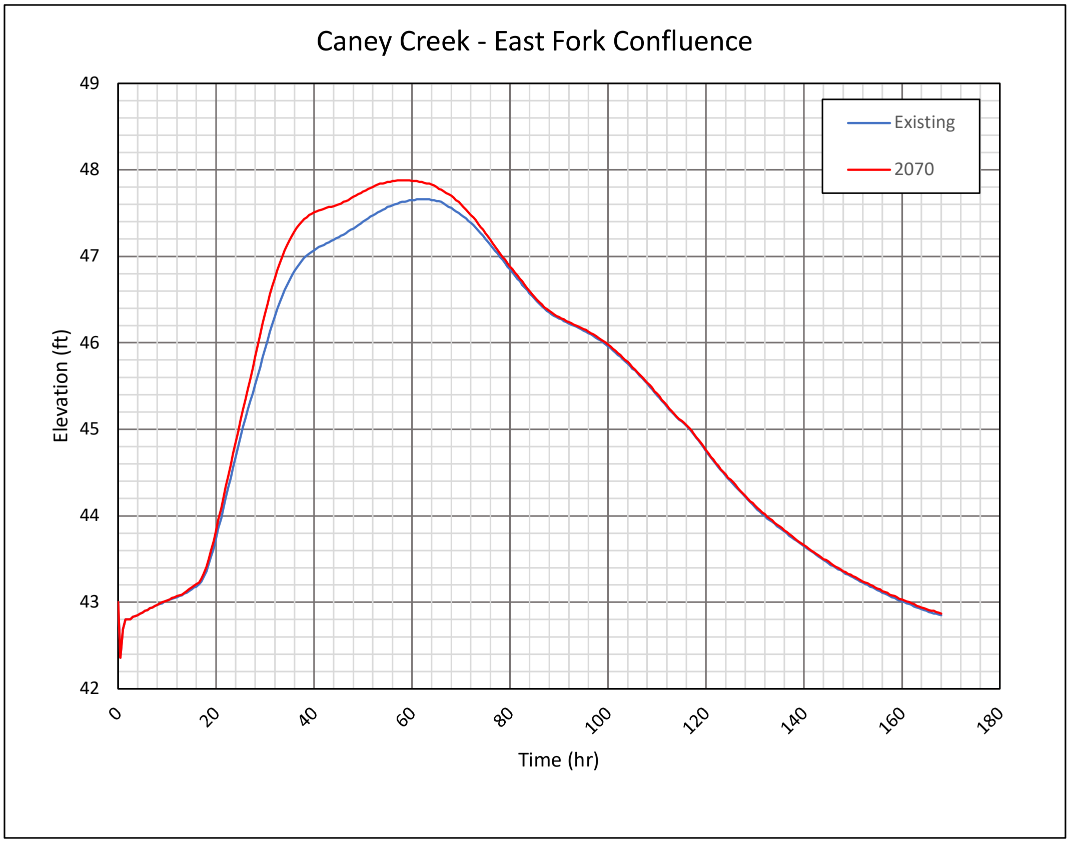


Exhibit 38 – HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)



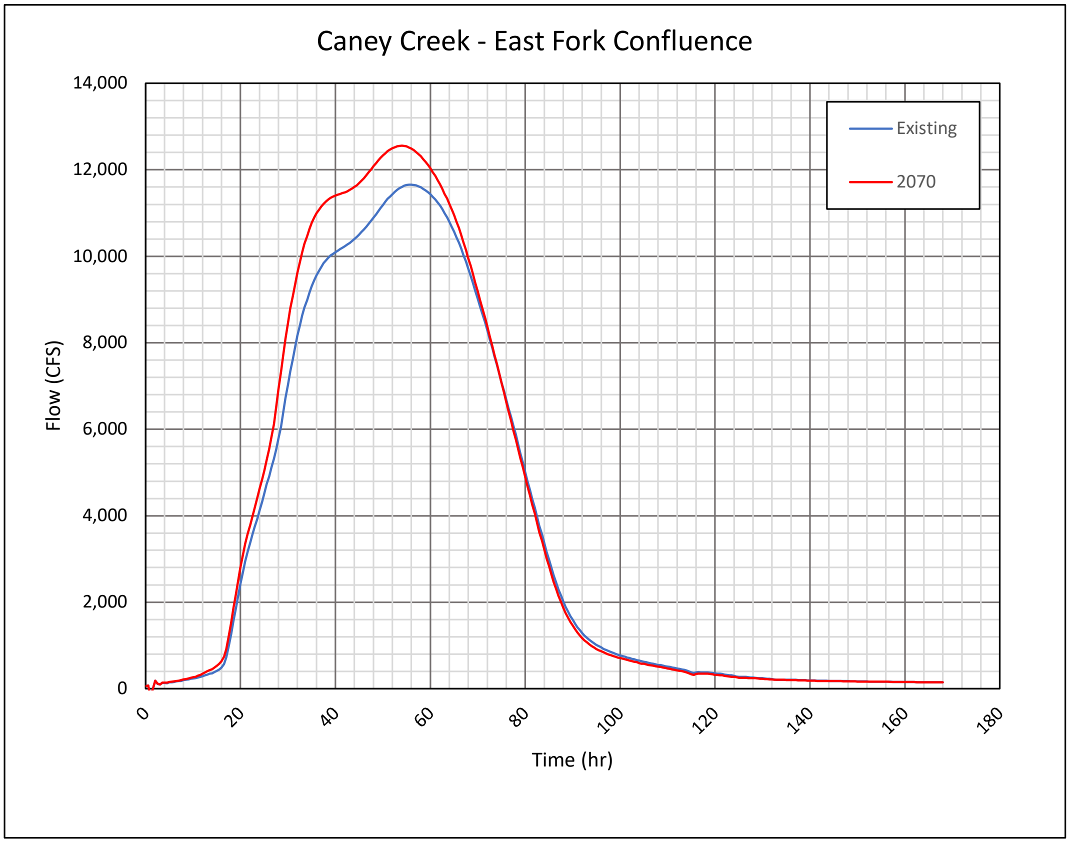
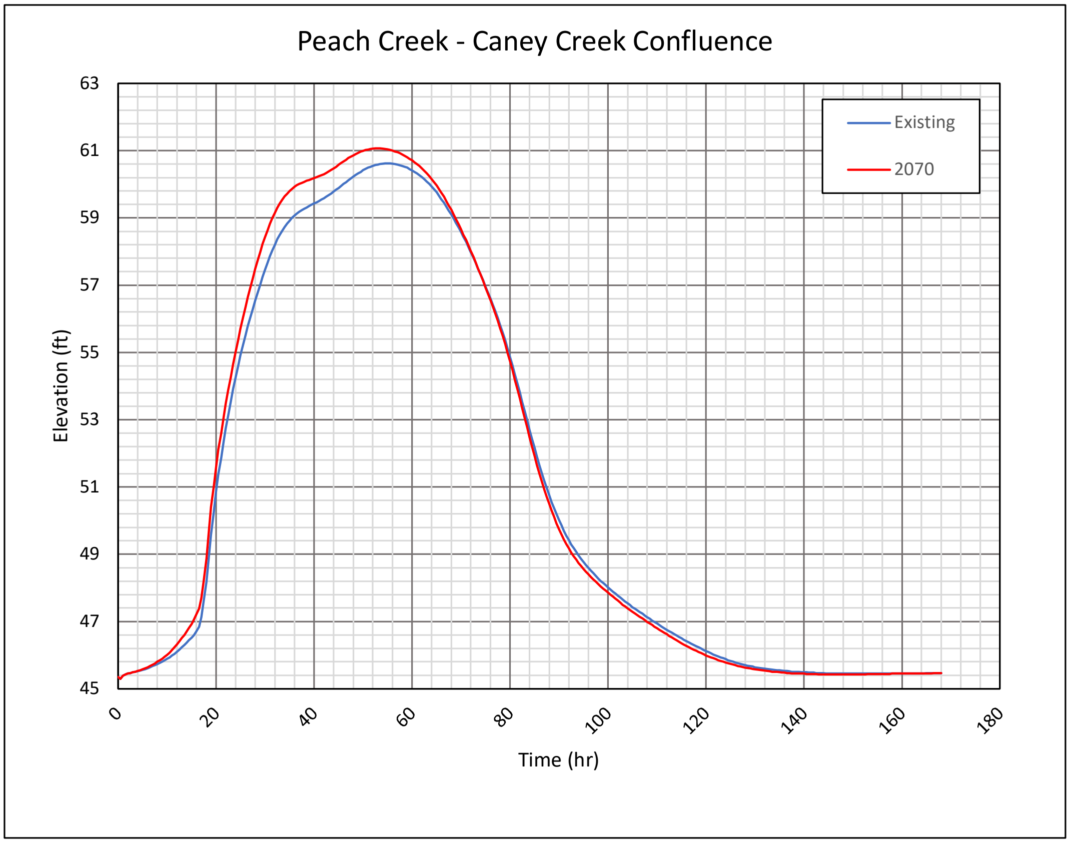
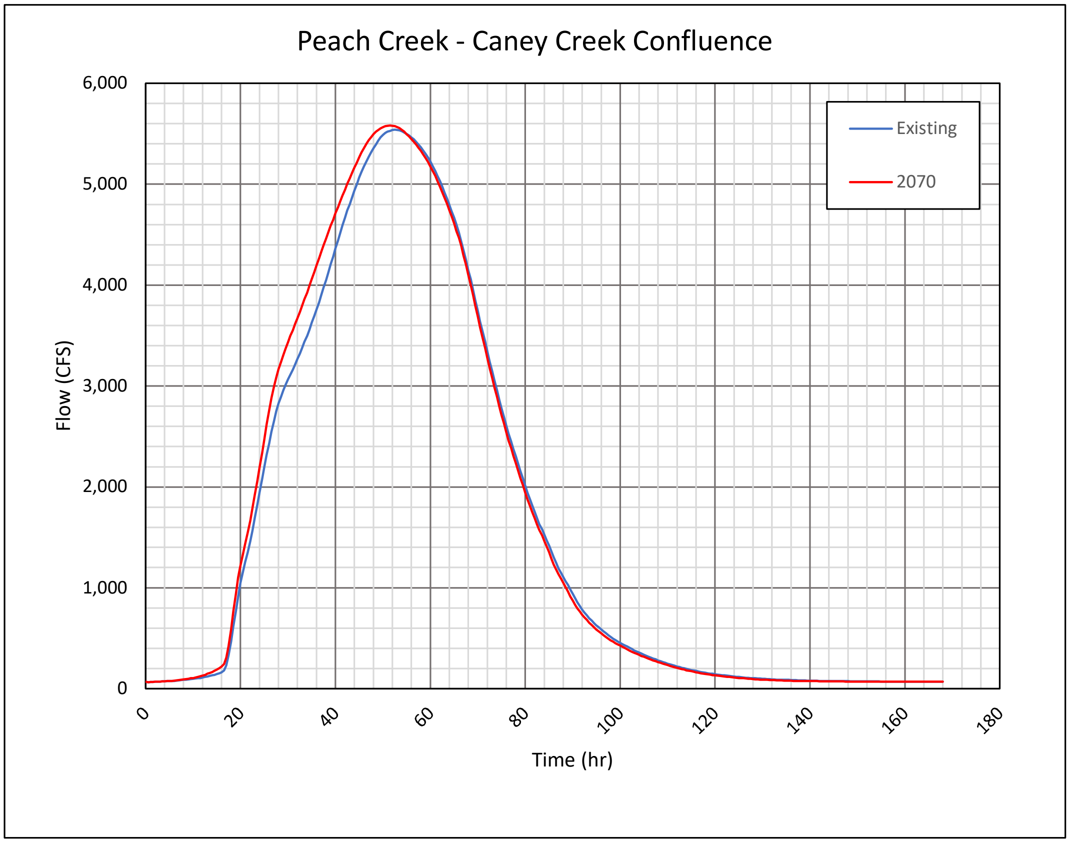


Exhibit 39 – HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)





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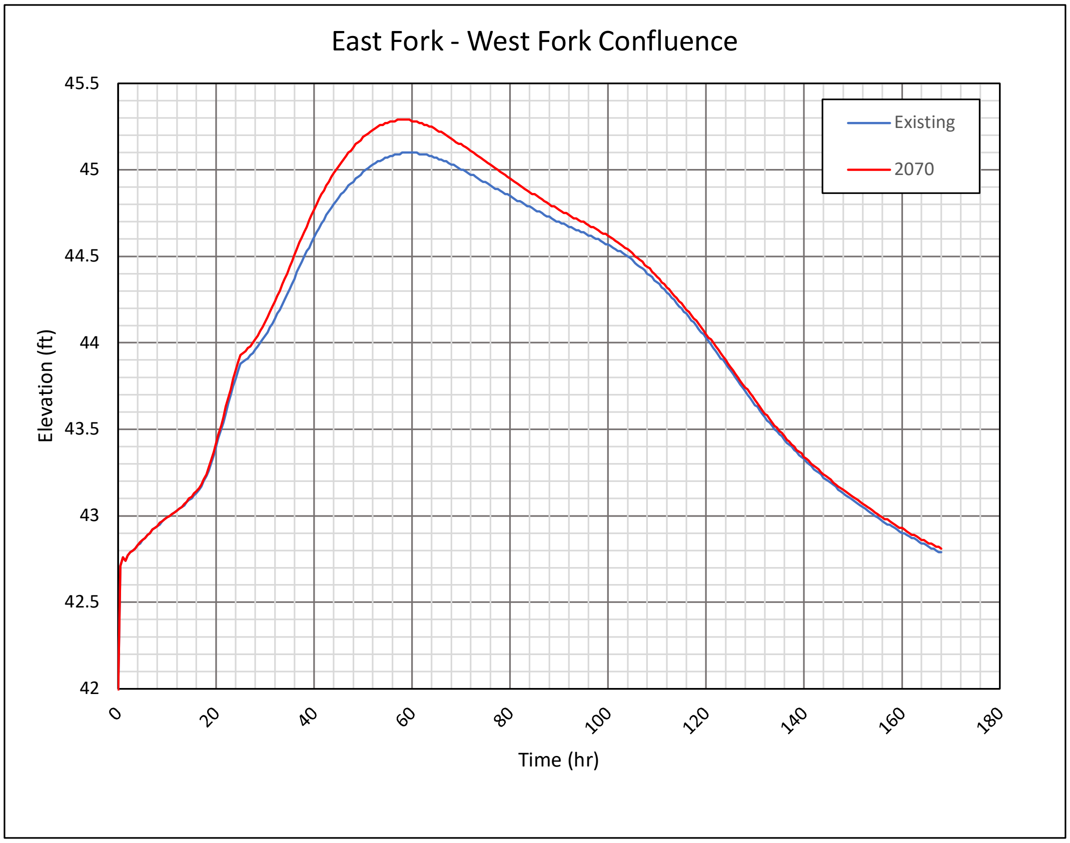


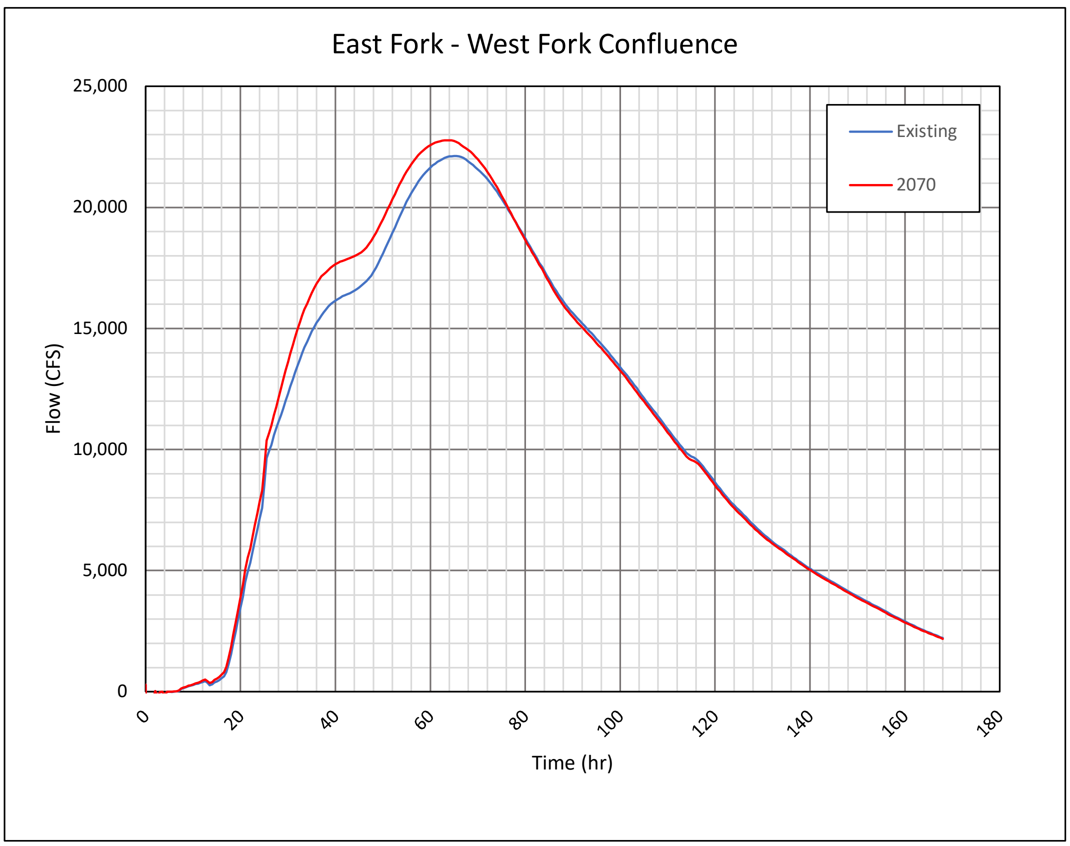
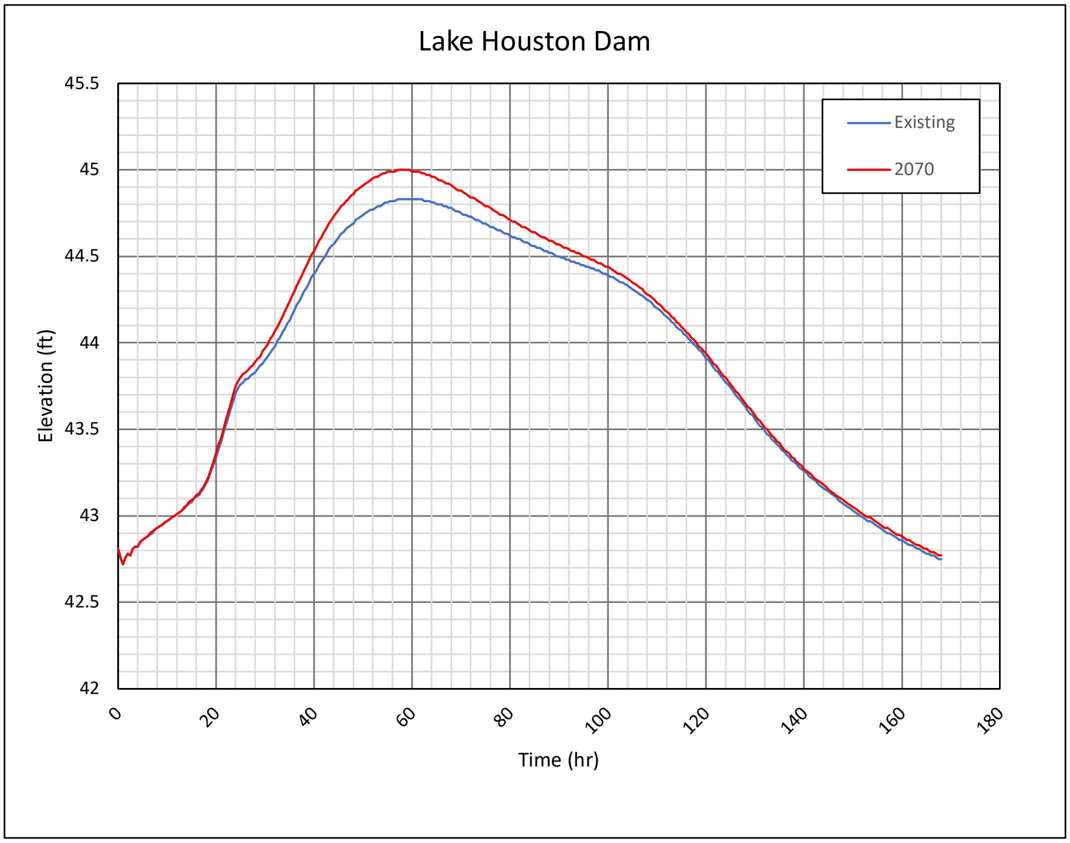


Exhibit 41 – HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)



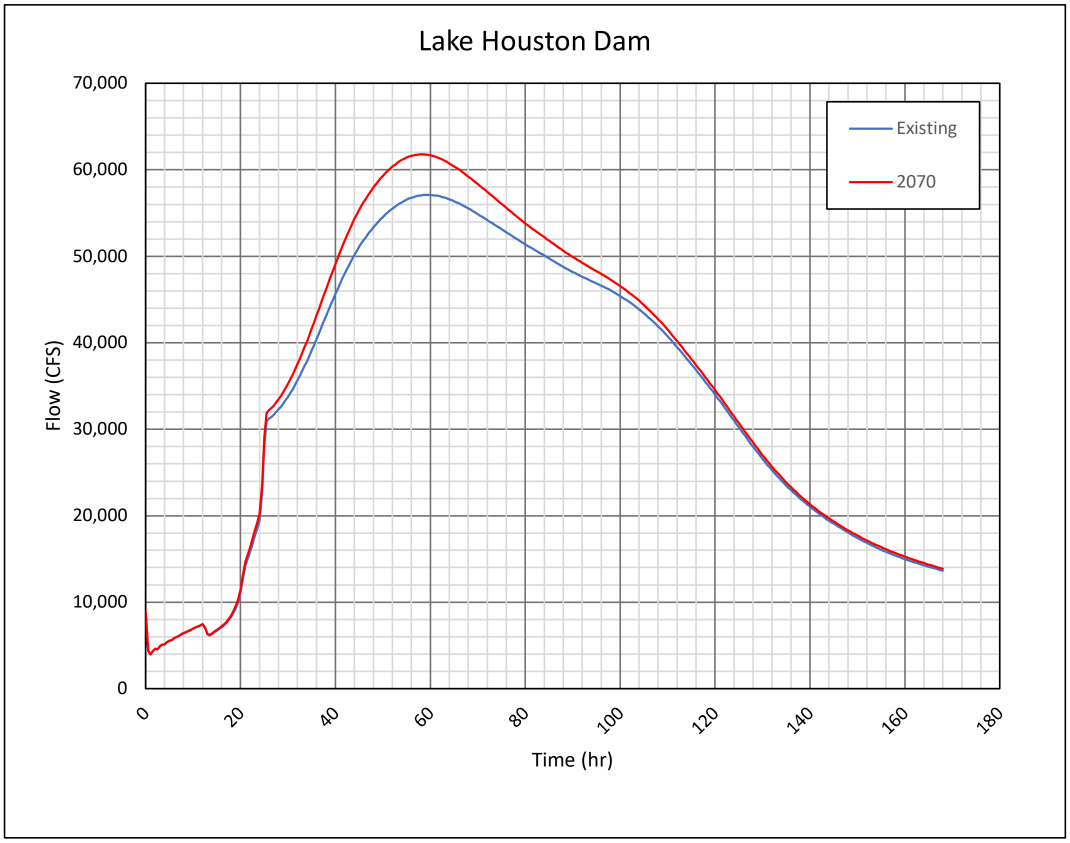
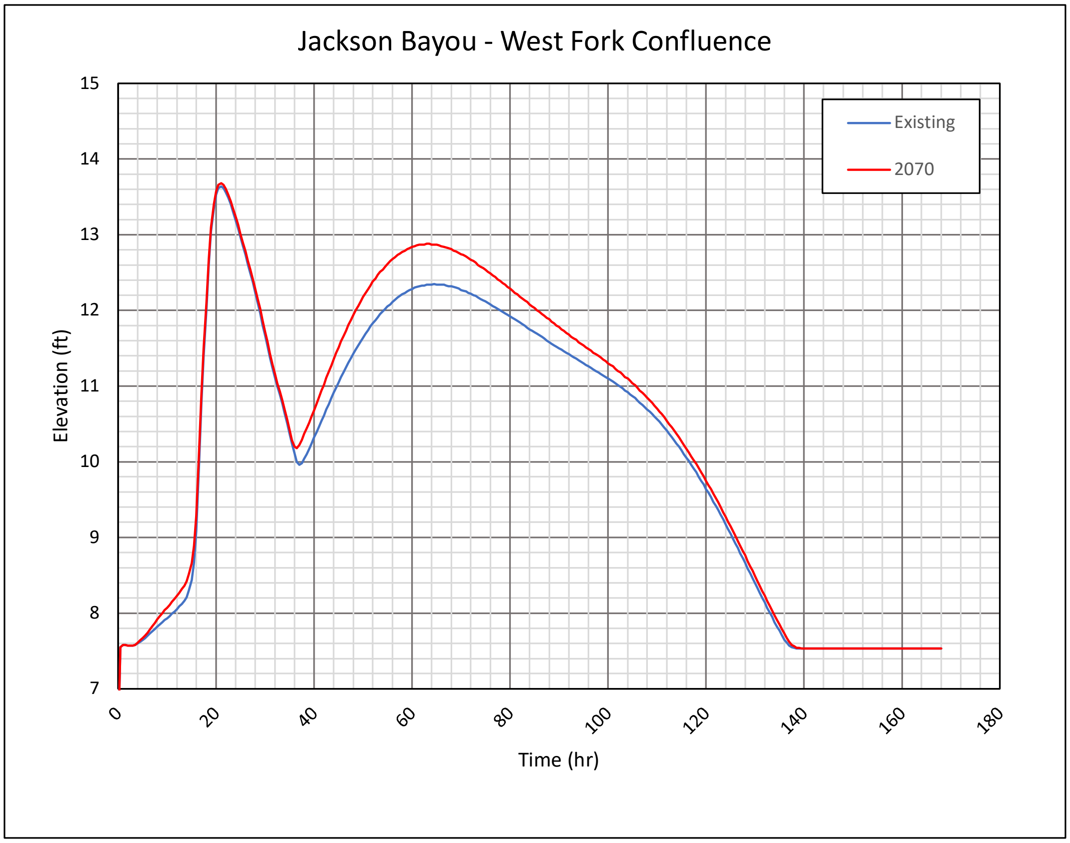


Exhibit 42 – HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)



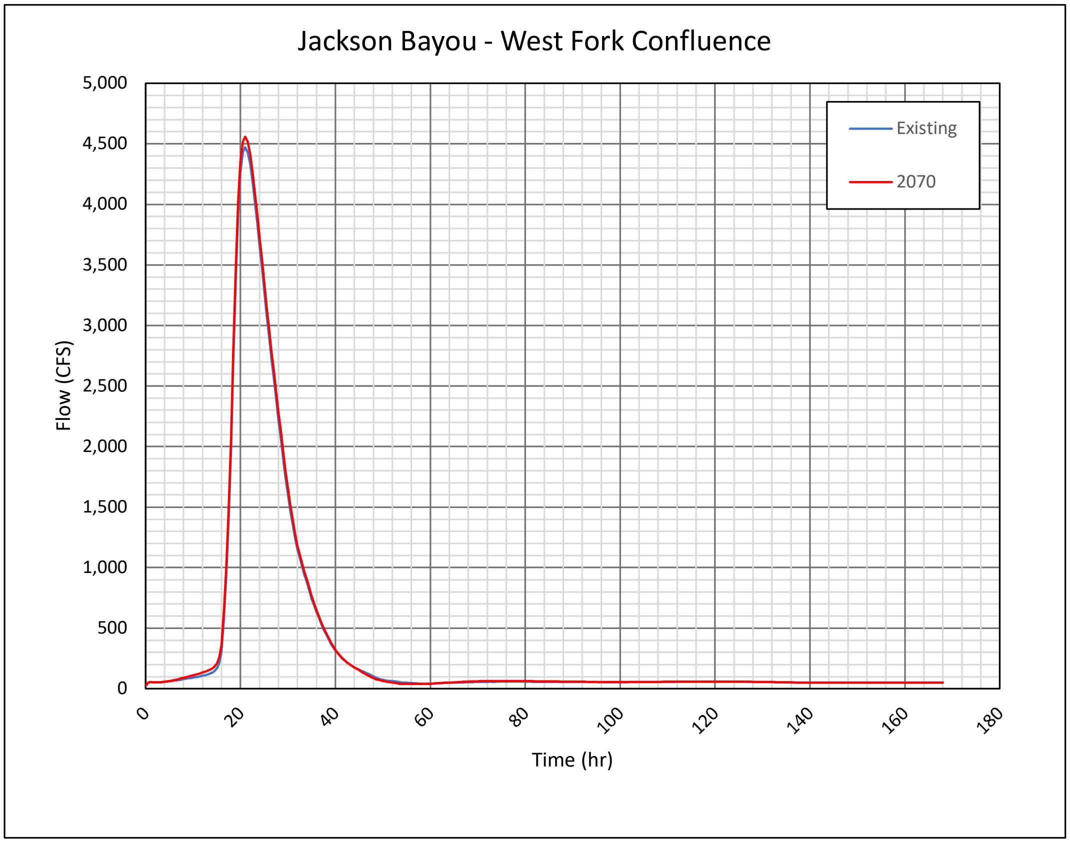


Exhibit 43 – HEC-RAS Flow and Stage Hydrographs at Key Locations (50% ACE)