Corridor Development Certificate

Upper Trinity River, Texas
Hydrologic and Hydraulic Model Update
in Partnership with the
North Central Texas Council of Governments

May 2013

US Army Corps
of Engineers
Fort Worth District

Executive Summary

General

The 1988 Record of Decision (ROD) and subsequent development of the "Upper Trinity River Feasibility Study" (UTRFS) by the United States Army Corps of Engineers (USACE) established the framework and criteria that became the 1st Edition of the Corridor Development Certificate (CDC) Manual in 1991. Since then, many projects have been granted a CDC permit, three new CDC manuals have been published, development in the upper Trinity River watershed has grown at a much higher rate than previously projected, and advances in hydrologic and hydraulic modeling have occurred. Thus the need for an updated set of hydrologic and hydraulic models arose in discussions with the members of the North Central Texas Council of Governments (NCTCOG).

Model Development

Baseline and future land use coverage was obtained from the NCTCOG for use in updating the percent urbanization and percent imperviousness hydrologic model parameters, as was previously done in the development of the UTRFS hydrology models. This information was used in conjunction with the Dallas-Fort Worth (DFW) area urban curves to develop the sub-area parameters utilized in this study.

More than 80 CDC projects are incorporated into the updated CDC hydraulic model. A large majority of these, close to 70, were incorporated into the CDC hydraulic model as part of this study. The work consisted of incorporating site specific project data into a much larger regional model. This model update required a recalculation of valley storage for use in the routings within the hydrologic model. The revised HEC-RAS hydraulic model developed in this study has the ability to run multiple geometry files and plans, therefore one HEC-RAS model now exists for both storage and conveyance calculations.

The revised storage routings produced from the HEC-RAS model that included the more than 80 CDC projects yielded unexpected shifts in the hydrograph timing as well as the overall shape of the hydrographs. Although the CDC criteria regarding valley storage was met by all the projects that did not have a variance, the redistribution of the storage was shown to have an effect on peak discharges. The HEC-1 hydrologic models were converted to HEC-HMS by importing the HEC-1 data, insuring hydrologic connectivity, and updating the meteorological data containing the rainfall for each flood frequency. The resultant calculated discharges were then tabulated for comparison to the HEC-1 results. The conversion of the upper Trinity River model from HEC-1 to HEC-HMS results in differences of less than 1 percent. The Elm Fork detailed model (15 minute time step) generates a larger difference between the hydrologic models due to the updated pump station calculations in HEC-HMS. The HEC-HMS Elm Fork model produces lower discharges due to decreased discharges from the three pump stations represented in the model.

The peak discharges from HEC-HMS were entered into the HEC-RAS model to develop water surface elevations throughout the study area. As expected, the increased discharges result in increased water surface elevations at most locations. The updated CDC discharges are tabulated and included in this report as well as a summarization and comparison of the resultant 100-year and Standard Project Flood water surface elevations at selected locations.

Conclusions

The updated future conditions hydrology models for the upper Trinity River watershed produced increased peak discharges due to the projected urbanization within the watershed. However, the Elm Fork experienced a decrease in peak discharges in the upper reaches for the 100-year flood and an overall decrease for the Standard Project Flood. This is primarily due to the storage routing in the Elm Fork and increased urbanization that changed the timing of the hydrographs.

This study illustrates how proposed CDC projects have met the CDC criteria for no loss of valley storage for the 100-year flood and no more than 5 percent loss for the Standard Project Flood but have redistributed the compensatory valley storage within the project reach. This resulted in adverse changes to the shape and timing of the hydrographs. This illustrates the need for further discussion regarding the valley storage requirements of the CDC program.

The increased discharges along the Clear Fork, West Fork, Elm Fork, and Main Stem of the Trinity River resulted in increases in the calculated water surface elevations, as expected.

A comprehensive list of CDC applications that have been processed from the beginning of the CDC program in the 1990s to November 2012 has been created. The intention is for the NCTCOG and USACE to maintain this database in the future.

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1.0 Introduction

The upper Trinity River watershed has experienced significant continual growth since the development boom of the 1980s, which was the basis for the 1988 Regional Environmental Impact Statement Trinity River and Tributaries Record of Decision (ROD) by the United States Army Corps of Engineers (USACE). The ROD established criteria for the analysis of permit applications that included no rise in the 100-year or Standard Project Flood (SPF) water surface elevations, 0% and 5% loss of valley storage for the 100-year and SPF respectively, and no increase or creation of erosive velocities.

In response to the ROD, the Trinity River Steering Committee and the Flood Management Task Force (FMTF) were formed, both facilitated by the North Central Texas Council of Governments (NCTCOG). The Steering Committee directed the FMTF to develop a process and manual based on the criteria outlined in the ROD. In 1991, the 1st Edition of the Corridor Development Certificate (CDC) Manual was published.

In 1998, the 2nd Edition of the CDC Manual was published which established the review fund and Cost Recovery Fee which provided a funding stream for continual development of the CDC process and models. The 3rd Edition of the CDC manual, published in 2002, incorporated comments and revisions to the 2nd Edition. The 4th Edition was published in 2010 addressing technological advances and outdated items, and also increased the Cost Recovery Fee.

Through four CDC Manual editions, minor updates to the CDC Models have occurred. However, the land use assignments were never completely revised to existing and revised future projections in the hydrologic model. The hydraulic model had also never been revised on a comprehensive scale that included all the CDC permitted and constructed projects along the corridor. Thus, the need for revised models arose to account for the increase in development since the development of the model in the 1990s.

2.0 Study Purpose

The purpose of this study was to update the upper Trinity River hydrology model to the 2005 (baseline) land use and projected 2055 (future) land use as well as update the HEC-RAS hydraulic model to reflect the CDC permitted and constructed projects. The current CDC Manual 4th Edition, dated June 2010, includes West Fork and Clear Fork 100-year and SPF discharges based on hydrology updated in 2009 as part of the USACE Central City project in Fort Worth. The HEC-1 upper Trinity River watershed model included revised sub-area parameters along the Clear Fork and upper West Fork. The land use values, however, were the same as the previous manual editions. The baseline land use was circa 2000 and the future projection was to the year 2040. The HEC-RAS model had never been fully updated to this point. Several CDC projects had been incorporated, but many CDC projects remained which needed to be included in the model.

3.0 Study Area

For the hydrologic analysis, the upper Trinity River watershed, from its headwaters to the confluence of Five Mile Creek near the IH 20 bridge in Dallas, was evaluated during this study. This area covers about 6,275 square miles and includes the majority of the Dallas-Fort Worth Metroplex. Terrain in this watershed varies in elevation from about 1,200 feet National Geodetic Vertical Datum (NGVD) at the headwaters of the West Fork of the Trinity River just northeast of Olney, Texas, to about 380 feet NGVD at the confluence of Five Mile Creek. A general watershed map is included as Plate 1.

Of the five U.S. Army Corps of Engineers (USACE) flood control reservoirs in the study area, three (Benbrook Lake, Lewisville Lake, and Grapevine Lake) were impounded in the early 1950s. Impoundments in the other two USACE reservoirs (Joe Pool Lake and Ray Roberts Lake) were initiated in January 1986 and June 1987, respectively. Additional major USACE flood control projects in the study area include the Fort Worth Floodway and Dallas Floodway levee/channel improvement systems.

The two largest non-federal lakes in the study area, both of which are situated on the West Fork of the Trinity River, are Lake Bridgeport and Eagle Mountain Lake. Lake Bridgeport is located just west of Bridgeport in Wise County. Eagle Mountain Lake is located in northwestern Tarrant County, just upstream from the much smaller Lake Worth, which is owned by the City of Fort Worth. Eagle Mountain Lake has two sets of outlet gates and an emergency spillway, but since it has no dedicated flood control storage, large releases are required during flooding periods. Smaller lakes within the upper Trinity watershed include: Lake Amon Carter, located on Big Sandy Creek south of Bowie in southwestern Montague County; Lake Weatherford, located on the Clear Fork of the Trinity River northeast of Weatherford in Parker County; Lake Arlington, located on Village Creek in western Arlington in Tarrant County; and Mountain Creek Lake, located on its namesake in Grand Prairie in western Dallas County.

For the hydraulic analysis, the HEC-RAS CDC model incorporates the Clear Fork from the confluence with the West Fork to Lake Benbrook Dam (12.43 miles), the West Fork from the confluence with the Elm Fork to Lake Worth Dam (58.08 miles), the Elm Fork from the confluence with the West Fork to Lewisville Dam (29.04 miles), and the Trinity River main stem from Dowdy Ferry Road in southeast Dallas to the West/Elm Fork confluence (23.25 miles).

4.0 Hydrology

The current CDC hydrology model is a HEC-1 model originally developed as part of the “Upper Trinity River Feasibility Study” and is the model used to calculate the peak discharges for the standard frequency storms and Standard Project Flood impacting development projects within the upper Trinity River corridor. The current baseline HEC-1 model utilizes circa 2000 land use developed by USACE in cooperation with the NCTCOG. The future conditions HEC-1 model calculates discharges for a projected 2040 land use developed in cooperation with the NCTCOG participating partners. In this study, the hydrology model has been updated to a revised baseline of 2005 and a projected 2055 land use, the Modified Puls routing from the updated hydraulic model has been incorporated, and the HEC-1 model has been converted to HEC-HMS.

4.1 Overview

The current HEC-1 hydrology model of the upper Trinity River is divided into 110 sub-areas and utilizes a 1-hour computation time step in order to be responsive to the timing of each major tributary’s runoff contribution to the total flood hydrograph, and also to obtain detailed flow information (flood hydrographs) at all major points of interest on the Clear Fork, West Fork, Elm Fork, and the main stem of the Trinity River. Each reservoir having flood control storage was assumed to be at conservation pool level at the start of the hypothetical, frequency related storms/floods and at a level corresponding to that at which one-third of the full flood control pool (except at Lewisville Lake which was started at 89 percent full) would already be occupied at the start of the USACE Standard Project Flood. All reservoirs without flood control storage were assumed to be at normal (conservation pool) levels at the start of all frequency storm/flood events. Lake Bridgeport, Eagle Mountain Lake, Lake Worth, and Lake Arlington were assumed to reside at a level corresponding to 2, 3, 2, and 3-feet, respectively, above normal (conservation pool) level at the start of the SPF event.

The current detailed HEC-1 hydrology model of the Elm Fork is divided into 37 sub-areas and utilized a 15-minute computation time interval to be responsive to the timing of each major tributary's runoff contribution to the total flood hydrograph, and also to obtain detailed flow information (flood hydrographs) at all major points of interest on the Elm Fork of the Trinity River. Although the 1-hour upper Trinity River model includes the Elm Fork, the Elm Fork 15-minute model is a more detailed model that includes the uncontrolled drainage area downstream of Lewisville Dam and Grapevine Dam to the mouth of the Elm Fork.

4.2 Methodology

The CDC hydrology model was revised to reflect updated land uses and routings through the Clear Fork, West Fork, Elm Fork, and Main Stem of the Trinity River. The sub-area areas remained the same, but the Snyder's time to peak (T_p), percent imperviousness, and storage routing were revised to reflect the increase in development through the corridor. The following sections detail the methodology behind the updates to the HEC-1 model.

4.2.1 Uniform Rainfall Methodology

The hypothetical precipitation for the 2-, 5-, 10-, 25-, 50-, 100- and 500-year frequency storms was adopted from the UTRFS. The Standard Project Storm (SPS) was also adopted from the UTRFS, except for the critical storm centering at Lake Worth. The SPS for the Lake Worth centering was assumed to have a total rainfall amount equal to 46 percent of the Probable Maximum Storm (PMS) rainfall amount. This SPS was adopted for use in the Corridor Certificate Manual 4th Edition in December 2009.

4.2.2 Design Storm Methodology

4.2.2.1 Design Storm Overview

A Design Storm analysis was completed in July 2012 as part of the Dallas Floodway Feasibility Study (DFFS) to calculate the flow at the Trinity River at Dallas Gage for storms having recurrence intervals of 2, 5, 10, 25, 50, 100, and 500-years. Design storms were developed for each rainfall frequency based on regional historical rainfall data. The calculated discharges at the Dallas Gage for each design storm were used in defining the Dallas Gage discharge frequency curve. The parameters that were evaluated in constructing the design storms were the storm duration, depth-duration, depth-area relationship, spatial distribution, and temporal distribution.

The uniform distribution rainfall pattern is no longer valid when a catchment's drainage area is greater than 400 square miles. For the West Fork and Trinity River Main Stem, the design storm is a more appropriate synthetic rainfall method since their drainage areas are larger than 400 square miles. For the Clear Fork and Elm Fork, the uniform rainfall distribution method is appropriate and was used in this update.

4.2.2.2 Storm Duration

The time of concentration for the uncontrolled subarea above the Trinity River at Dallas Gage was found to be less than 24 hours. The time of concentration for other key discharge points was also found to be less than 24 hours. Based on this and historical knowledge that the runoff hydrograph reaches the Dallas Gage within 24 hours, a storm duration of 24 hours was used for the design storms. Some sensitivity testing has been done to show that longer storm durations do not affect the peak discharges in this watershed. This is due to the low intensity of the rainfall being added to the storm.

4.2.2.3 Development of Depth-Duration Data

The TP-40 24-hour depth-duration data was used for each of the design storms. Table 4-1 lists the point rainfall amounts that were used for each design storm.

Table 4-1. TP-40 Point Rainfall for Each Design Storm Frequency Simulation

TP-40 24-Hour Point Rainfall for Design Storm Frequencies						
Return Period (year)	2	5	10	25	50	100
TP-40 (in)	4.0	5.33	6.43	7.54	8.55	9.55

4.2.2.4 Historical Storms

Available storm data for the Texas and Oklahoma region was collected. The focal point of the data collection was to find an appropriate generalized set of depth-area relationships for the region. The majority of the data collected came from a study by the US Army Corps of Engineers, War Department "Storm Rainfall in the United States – Depth-Area-Duration Data" (1945). Other storm data collected included that from the USACE Extreme Storm Team and the "Site-Specific Probable Maximum Precipitation Study for the Tarrant Regional Water District", dated March 2011, prepared for the Water District (TRWD) by Applied Weather Associates, LLC.

Depth-area relationships have been published by the U.S. Weather Bureau in Technical Paper Number 40 (TP-40), based upon data from climatic gaging station networks ranging upwards to 400 square miles in coverage extent. Extrapolation of these relationships far beyond 400 square miles is not recommended as stated in TP No. 40. Since most of the points of concern along the Trinity River have watersheds larger than 400 square miles, extended depth-area relationships were developed to cover these areas.

4.2.2.5 Depth-Area Reduction Factors

In order to develop the rainfall file for the Multiple Parameter Visualization Tool (MPVT) program, supplemental calculations were needed. First the depth-area reduction factors were calculated from historical storm data. The reduction factors represent the percent reduction of each historical storm's precipitation amount from the point rainfall to each area. For example, the historical storm at Weatherford, TX, 25 April 1922, is shown in Table 4-2.

Table 4-2. Example Reduction Factor Calculation

Weatherford Texas 25 April 1922 24 Hour Peak Precipitation Over a Given Area						
10 (mi^2)	100 (mi^2)	200 (mi^2)	500 (mi^2)	1,000 (mi^2)	5,000 (mi^2)	10,000 (mi^2)
8.9 in	8.3 in	8.2 in	8.0 in	7.6 in	5.1 in	4.0 in
Reduction Factor	0.933	0.921	0.899	0.854	0.573	0.449

Depth-area reduction factors were calculated for all of the historical storms. Low and high band reduction factors were calculated from 60 of the historical storms. Only storms that had point rainfall amounts in the range of the TP-40 24-hour 2-year to 100-year rainfall amounts were used to calculate the reduction factors. This created a precipitation range from 5” -11” for the reduction factors. Figure 4-2 displays the reduction factor bands for the 5”-11” rainfall bands along with the HMR-52 reduction factors and the TP-40 Figure 15 depth-area curve extrapolated to 10,000 square miles. Figure 4-2 shows the same bands clipped at the 1,000 square mile point on the x-axis.

The depth-area curve that was used for the design storms was developed based on the median reduction factors at each given area. The depth-area curve was calibrated to match the 100-year flows in the baseline Trinity River hydrology model with the 2000 land use and routing. The adopted curve followed the general shape of the HMR-52 depth-area curve and the historical storm data better than the TP-40 Figure 15 curve as can be seen in Figures 4-1 and 4-2.

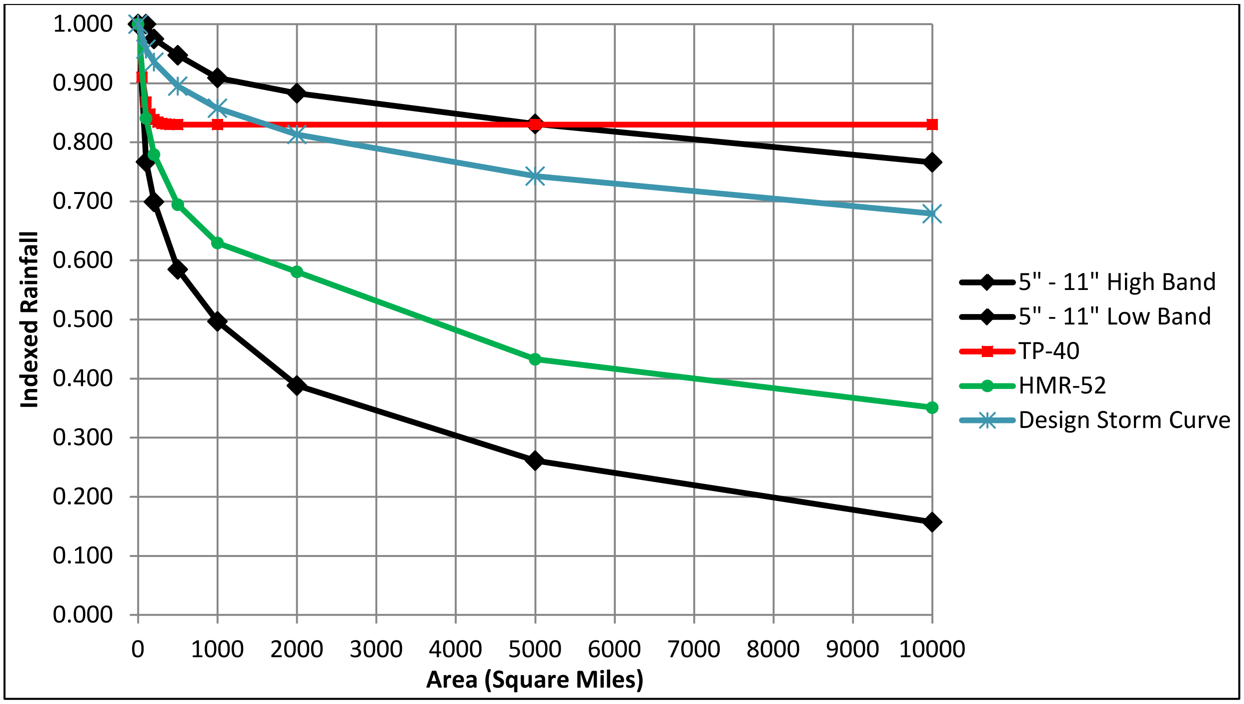


Figure 4-1. Historical Storm Depth-Area Reduction Factors for 5”-11” Bands

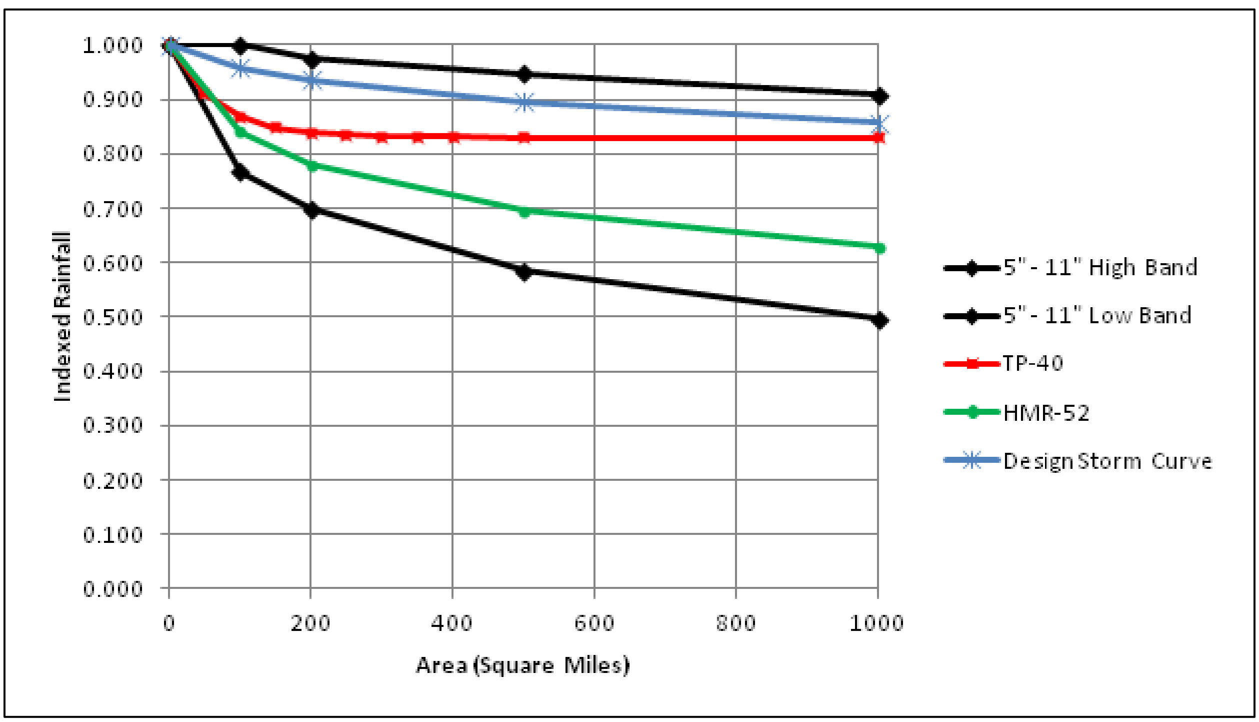


Figure 4-2. Depth-Area Reduction Factors for 5”-11” Bands (less than 1000 sq.mi.)

4.2.2.6 Storm Centering

The isohyetal pattern was developed for the spatial distribution of the TP-40 24-hour point rainfall amounts. The elliptical isohyetal pattern has a ratio of major to minor axis of 2.5 to 1 and is the pattern used in standard practice. For this update, two different storm centerings were used and are shown in Figures 4-3 and 4-4. Figure 4-3 shows the rainfall isohyetal pattern that produces the peak flow on the West Fork of the Trinity River above the Clear Fork. Figure 4-4 shows the rainfall images created from the isohyetal patterns that produce the peak flows on the West Fork Trinity River from the confluence of the West Fork and Clear Fork to the Trinity River at Dallas Gage.

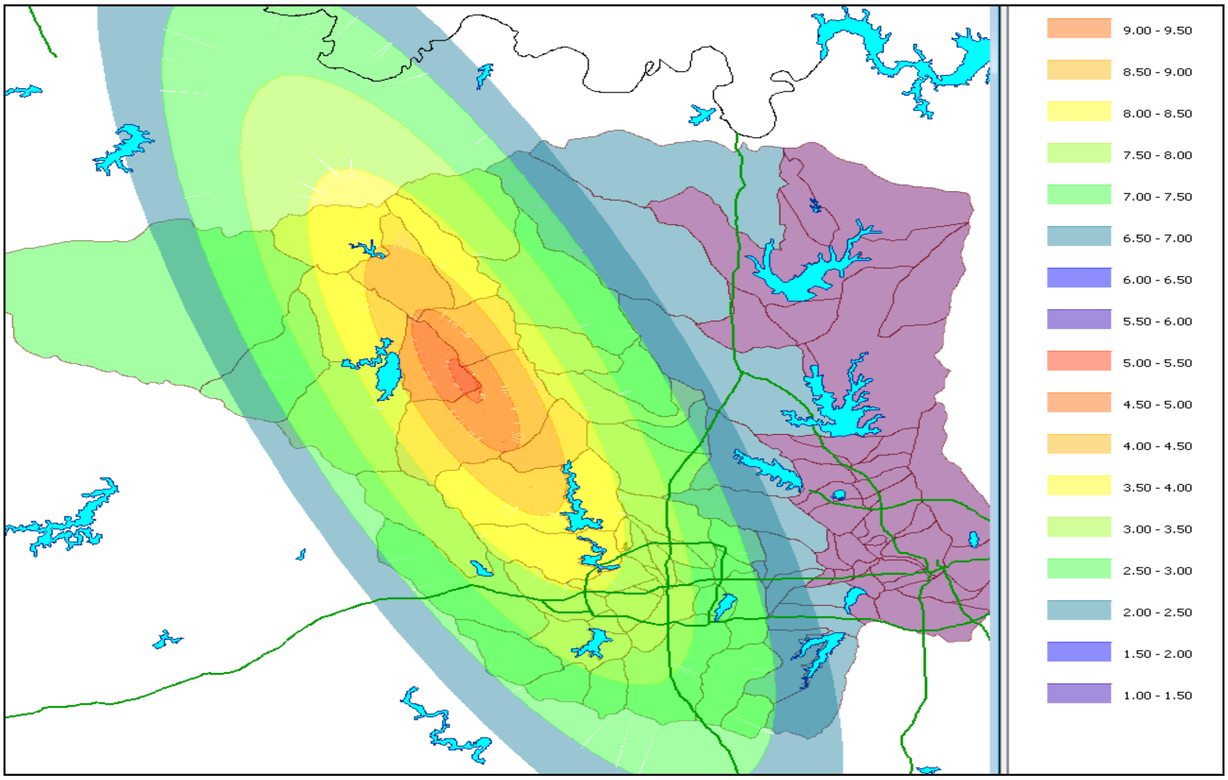


Figure 4-3. Storm Centering for West Fork Peak Flow above the Clear Fork

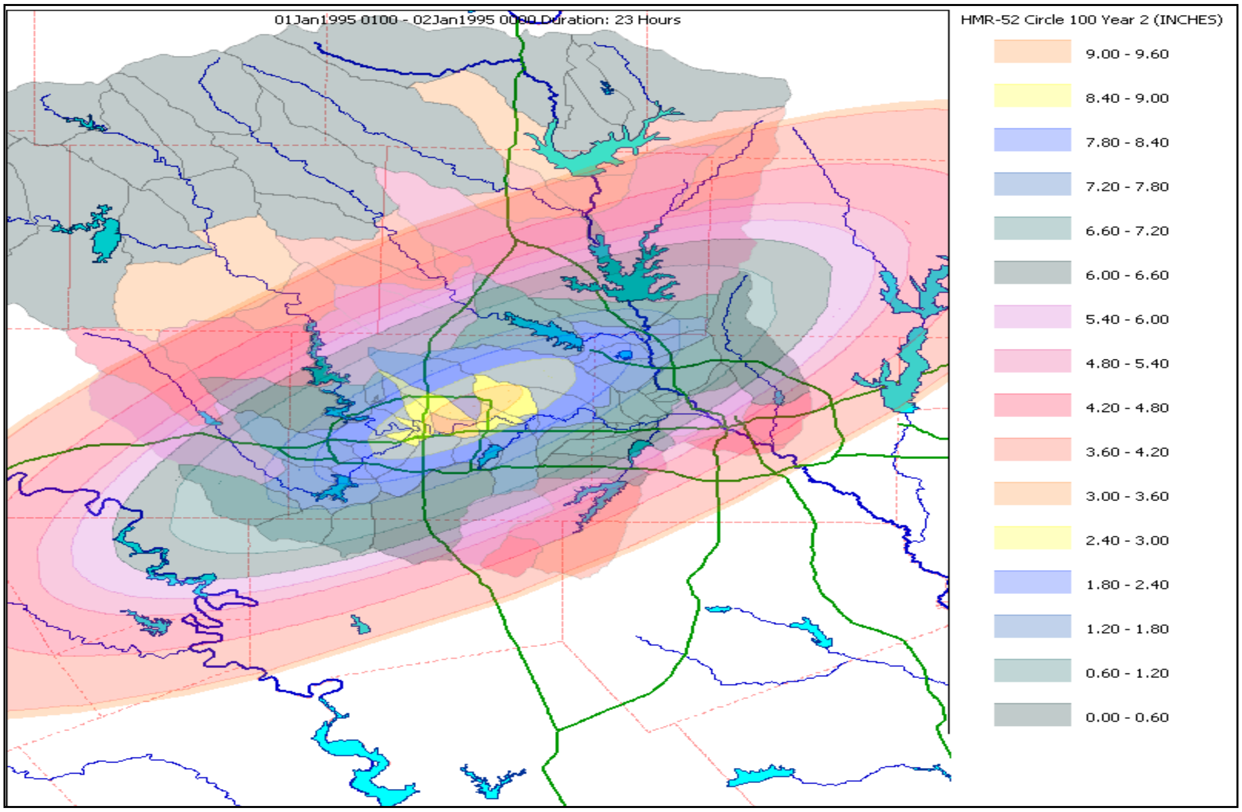


Figure 4-4. Storm Centering for Dallas Peak Flow

4.2.2.7 Storm Transposition Method

Simulations were run over multiple areas of the unregulated drainage areas upstream of the Dallas Gage to determine the storm centering. The rainfall TIN created from the TP-40 100-year 24-hour point rainfall was used as the standard during this process. The optimal centering from previous studies was used as a starting point for optimizing the flow at the Dallas Gage. The elliptical pattern simulations were run at every half-minute in a grid around the starting point while additionally rotating the elliptical in increments of 15^{o} degrees between the 0^{o} and 90^{o} at every point.

With the centering and rotation of the elliptical isohyetal pattern found using the rainfall TIN created from the TP-40 100-year 24- hour point rainfall, additional testing was completed to determine if there would be different storm centerings for the other frequency storm events. Using the elliptical storm centering and rotation as the starting point, the different frequency rainfall amounts were tested over a grid to determine if a higher flow could be calculated at the Dallas Gage. For the 25, 50, 100, and 500 year recurrence intervals, the centering and rotation of the elliptical were the same. For the 2, 5, and 10 year recurrence interval the storm centering was slightly closer to the Dallas Gage along the West Fork of the Trinity River. However, because the greatest difference in the peak flow for the 2, 5, and 10 year storms was less than 3%, the storm centering and rotation of the 100-year rainfall amount was used for all design storms.

4.2.2.8 Development of Temporal Distribution

The MPVT program requires an hourly distribution of the design storm to develop the basin average precipitation from the rainfall TIN. The standard distribution used in the study was developed from the

Standard Balanced Frequency Storm distribution from HEC-HMS. This provided an hourly distribution over the 24 hour storm that centered the peak six hours of precipitation on the 12th hour of the storm. Figure 4-5 shows the three temporal distributions tested in the previous DFFS study. Based on the findings of the DFFS study, the balanced temporal distribution denoted by the blue line in Figure 4-5, was used.

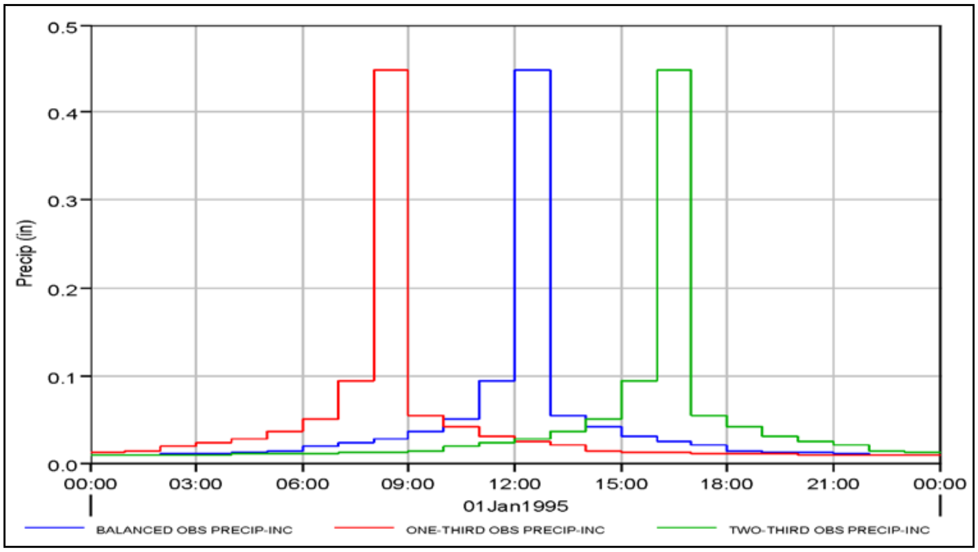


Figure 4-5. HEC-HMS Temporal Distribution for a Balanced, Front, and Back Loaded Distribution

4.2.3 Initial Abstractions and Infiltration Rates

The rainfall loss values for the frequency events were adopted from the UTRFS. The loss rates for the SPF event varied regionally and were identical to those used in the "Upper Trinity River Reconnaissance Study September 1992".

4.2.4 Land Use Processing

The current HEC-1 baseline hydrology model for the upper Trinity River and the Elm Fork detailed model utilizes circa 1995 land use that was partially updated to circa 2000. The percent urbanization and percent imperviousness of each sub-area was determined from the land use type within the sub-area and assigned a corresponding value. Table 4-3 is a list of land uses utilized in the upper Trinity River and Elm Fork HEC-1 models developed in the 1990s.

Table 4-3. USACE Land Use Classifications (1995)

Land Use Category	Title	Percent Urbanization	Percent Imperviousness
1	Low Density Residential	30	25
2	Medium Density Residential	80	41
3	High Density Residential	90	47
4	Multi-family Residential	95	70
5	Mobile Home Parks	40	20
6	Central Business District	95	95
7	Strip Commercial	90	90
8	Shopping centers	95	95
9	Institutional – School, Churches	50	40
10	Industrial	95	90
11	Transportation, Major Highways	80	35
12	Communication	50	35
13	Public Utilities	70	60
14	Strip Settlement	20	10
15	Parks and Developed Open Space	10	6
16	Developing	20	15
17	Cropland	5	3
18	Grassland	0	0
19	Woodland, forest	0	0
20	Water Bodies	100	100
21	Barren Land, Gravel Pits	0	0

The 2005 (baseline) land use coverage was obtained from the NCTCOG as individual county coverage. The NCTCOG land use data utilizes a land use code that corresponds to a state land use category. Although most of the land use codes were similar to those developed by USACE in 1995 (residential, commercial, industrial, etc), there were different land use codes and descriptions than those previously developed by USACE. Specifically, the single family residential value is not broken down into low, medium, and high density as in the USACE values. For this reason, a new table was created which correlates the NCTCOG land use codes to the USACE land use categories and corresponding percent imperviousness and percent urbanization. Table 4-4 below details the correlation.

Table 4-4. USACE Assigned Percent Impervious and Percent Urbanized

Land Use Code	Description	Examples of Use	Assigned Percent Urbanized	Assigned Percent Impervious
111	single family	Single family detached units and duplexes	80	41
112	multi-family	Apartments, condominiums, residential hotels, converted apartments and townhouses (single family attached)	95	70
113	mobile home	Mobile homes inside mobile home parks and free-standing units outside parks	40	20
114	group quarters	Nursing homes, group homes, college dormitories, jails, military base personnel quarters	70	60
121	office	Generally include and administration functions including corporate and government offices, banks	90	90
122	retail	Retail trade and services, such as department stores, repair shops, supermarkets, restaurants	95	95
123	institutional	Churches, governmental facilities, museum, education, hospitals, medical clinics, libraries and military bases	50	40
124	hotel/motel	Hotels and motels	95	95
131	industrial	Manufacturing plants, warehouses, office showrooms	95	90
141	transportation	Railroads, radio and television communication stations, truck terminals	30	15
142	roadway	Roadway and right-of-ways	80	35
143	utilities	Sewage treatment and power plants, power line easements, pump stations, water treatment plants and water systems	70	60
144	airport	Airport terminals	40	20
145	parking garage	Parking garages	95	95
146	runway	Airport runways	100	100

Table 4-4 Continued. USACE Assigned Percent Impervious and Percent Urbanized

Land Use Code	Description	Examples of Use	Assigned Percent Urbanized	Assigned Percent Impervious
147	large stadium	Large stadiums	95	95
160	mixed use	Areas that contain both commercial (office and retail) and residential uses either in the same facility or in very close proximity	95	90
171	parks/recreation	Public and private parks, golf courses, cemeteries, public and private tennis courts and swimming pools, amusement parks	10	6
172	landfill	Sanitary landfills, land applications, and similar waste management facilities	10	5
173	under construction	Land that has undergone site preparation and construction has begun	20	15
181	flood control	Major flood control structures including levies and flood channels	0	0
300	vacant	Vacant land	0	0
306	parking CBD	Parking in Central Business Districts	100	100
308	expanded parking	Parking areas adjacent to or near large event venues and other large parking lots	100	100
500	water	Water	100	100

The single family residential values were chosen to be medium density residential as a median between the available values of low density and high density.

The baseline land use coverage obtained from the NCTCOG was utilized in an ArcMap platform along with the upper Trinity River basin and detailed Elm Fork basin layouts. The land use coverage was clipped to the boundaries of the watersheds. Plates 2 and 3 are baseline land use maps for the upper Trinity River basin and Elm Fork basin, respectively. Each individual sub-area was then clipped to form its own individual shape file then converted to grid format for calculations. Each grid was converted to square feet to determine the amount of each land use code within each sub-area. The individual land uses were used along with the assigned percent impervious and percent urbanization to develop a composite value for each. Areas outside the extents of the NCTCOG coverage retained the previous study's values unless significant urbanization could be verified using aerial photography. The baseline values were then compared against the previous model to verify the baseline calculated percent impervious and percent urbanization either remained the same or increased over the circa 2000 land uses.

The 2055 (future) land use coverage was obtained from the NCTCOG as city-wide, rather than county-wide, GIS files. NCTCOG had solicited the ultimate land use from its member cities for planning purposes and for use in this study update. The future land use coverage was overlaid on the upper Trinity River basin and Elm Fork basin files and clipped to the limits of each. Plates 4 and 5 are future land use maps for the upper Trinity River basin and Elm Fork basin, respectively. Each individual sub-area was then clipped to form its own individual shape file and then converted to grid format for calculations. Each grid was converted to square feet to determine the amount of each land use code within each sub-area. The individual land uses were used along with the assigned percent impervious and percent urbanization to develop a composite value for each. Due to the future land use being compiled from individual cities and not county-wide, there were large gaps in coverage throughout the watersheds. Areas outside the extents of the NCTCOG coverage retained the previous study's values. The revised future values were then compared with the previous model to verify the future calculated percent impervious and percent urbanization - these either remained the same or increased over the circa 2040 land uses. Tables 4-5 and 4-6 are summaries of the baseline and future calculated percent urbanization and percent impervious for each sub-area in the upper Trinity River and Elm Fork, respectively.

Table 4-5. Upper Trinity River Urbanization and Imperviousness (2005 and 2055)

Sub-basin ID	Baseline		Future		Sub-basin ID	Baseline		Future	
	% Urb	% Imp	% Urb	% Imp		% Urb	% Imp	% Urb	% Imp
1	0.33	0.20	0.33	0.20	23	18.31	11.18	35.38	21.13
2	2.43	1.31	2.43	1.31	24	4.45	2.62	18.70	12.85
3	6.56	3.54	6.56	3.54	25	3.69	2.23	18.28	12.46
4	5.00	4.00	5.2	4.17	26	17.01	9.11	48.53	26.47
5	Lake Bridgeport				27	12.52	7.73	55.01	30.73
6	8.67	6.61	14.98	11.85	28	Benbrook Lake			
7	5.08	2.91	5.08	2.91	29	44.25	44.25	44.25	44.25
8	Lake Amon Carter				30	62.63	41.16	72.55	13.50
9	3.00	2.00	3.00	2.00	31	69.17	69.17	69.17	69.17
10	5.31	3.29	5.31	3.29	32	69.82	69.82	69.82	69.82
11	4.80	3.30	4.81	3.30	33	69.84	69.84	69.84	69.84
12	6.59	4.21	11.57	7.24	34	26.03	26.03	26.03	26.03
13	5.80	4.07	5.80	4.07	35	Marine Creek Lake			
14	15.73	10.62	59.60	34.40	36	52.89	52.89	52.89	52.89
15	19.34	11.81	21.06	14.86	37	67.00	67.00	67.00	67.00
16	Eagle Mountain Lake				38	14.03	7.44	23.04	59.00
17	21.88	15.68	54.81	33.90	39	59.65	59.65	59.65	59.65
18	22.89	13.43	53.34	29.93	40	44.84	44.84	44.84	44.84
19	Lake Worth				41	23.30	14.99	58.22	36.07
20	56.73	36.14	66.88	46.73	42	38.66	29.71	57.29	42.39
21	4.00	3.01	8.40	5.56	43	30.88	19.30	69.31	43.17
22	Lake Weatherford				44	60.48	45.55	72.26	61.50

Table 4-5 Continued. Upper Trinity River Urbanization and Imperviousness (2005 and 2055)

45	72.86	41.96	79.07	45.58
46	Lake Arlington			
47	54.90	33.99	68.16	41.63
49	41.26	32.17	61.85	41.12
50	62.63	41.16	72.55	46.64
51	47.85	36.84	67.77	51.82
52	69.00	51.52	77.16	58.10
53	59.45	39.44	64.73	43.40
54	45.90	34.52	53.94	36.65
55	49.46	31.06	73.91	50.72
56	49.70	37.76	62.32	49.72
57	30.72	25.11	44.79	35.10
58	14.03	7.44	23.04	16.52
59	34.55	19.89	69.02	38.68
60	12.00	8.00	63.38	46.73
61	23.30	14.99	58.22	40.44
62	Joe Pool Lake			
63	42.52	28.01	64.03	44.93
64	60.48	45.55	72.26	53.66
65	33.46	22.98	37.05	22.84
66	Mountain Creek Lake			
67	38.40	31.03	44.76	86.52
68	74.81	47.94	77.35	55.00
69	1.03	0.79	1.03	25.37
70	3.00	2.00	3.00	75.25
71	3.59	2.42	7.53	66.38
72	4.58	2.92	17.93	12.57
73	6.34	3.67	19.32	11.16
74	9.07	6.52	60.96	36.31
75	10.62	7.66	63.48	44.25
76	28.61	18.50	56.83	39.74
77	Grapevine Lake			

78	36.79	27.34	60.47	46.73
79	4.00	2.50	6.82	3.99
80	10.81	6.90	65.04	36.48
81	2.79	2.64	2.79	2.64
82	2.00	2.00	9.91	6.46
83	2.15	1.87	2.15	1.87
84	Ray Roberts Lake			
85	14.27	8.42	44.83	23.57
86	16.20	10.89	39.65	31.09
87	10.00	5.00	42.30	29.67
88	6.50	4.16	54.63	35.32
89	Lewisville Lake			
90	28.07	20.74	37.57	25.47
91	30.67	21.42	43.58	30.42
92	57.71	35.94	64.71	41.64
93	54.86	38.95	65.45	40.94
96	60.73	46.26	69.12	48.76
95	53.20	42.34	68.31	55.78
96	70.79	54.52	79.93	61.17
97	48.13	38.16	75.71	66.93
98	67.35	50.89	78.26	57.91
99	86.52	49.03	86.76	49.19
100	55.00	42.45	61.96	50.66
101	25.37	21.69	25.37	21.69
102	75.25	52.16	83.98	59.59
103	66.38	45.74	74.46	48.64
104	White Rock Lake			
105	63.27	39.35	69.33	43.62
106	65.78	40.72	71.15	44.87
109	3.00	3.00	3.00	3.00
110	4.58	4.56	4.58	4.56
111	4.00	3.00	4.00	4.00

Table 4-6 Continued. Elm Fork Urbanization and Imperviousness (2005 and 2055)

Sub-basin ID	Baseline % Urb	Baseline % Imp	Future % Urb	Future % Imp
1	17.45	17.15	17.45	17.15
2	55.10	38.50	72.04	46.92
3	19.16	17.45	59.74	44.73
4	3.50	3.31	59.08	43.12
5	9.78	7.45	9.78	7.45
6	15.40	11.50	65.20	46.50
7	27.92	19.91	49.43	33.11
8	29.40	22.52	61.33	38.96
9	23.03	14.47	77.60	49.01
10	27.99	26.12	39.69	36.11
11	56.83	33.79	70.53	40.44
12	51.91	29.17	69.19	47.49
13	62.76	39.06	70.89	45.23
14	49.35	43.39	72.18	53.90
15	39.50	32.44	40.21	32.44
16	63.04	42.99	73.18	49.35
17	24.95	18.25	71.88	56.02
18	41.24	31.17	68.77	50.83
19	44.14	35.17	57.16	46.36
20	70.48	52.57	76.19	54.80

Sub-basin ID	Baseline % Urb	Baseline % Imp	Future % Urb	Future % Imp
21	53.68	44.82	76.65	61.41
22	Bachman Lake			
23	62.82	42.45	70.58	47.08
24	29.64	27.85	32.82	28.88
25	77.72	69.02	85.15	75.01
26	77.85	49.50	80.44	49.60
27	32.72	31.48	77.16	64.09
28	29.97	27.85	58.94	49.83
29	70.32	54.44	79.74	59.44
30	48.34	39.37	87.71	78.72
31	52.85	40.58	70.38	52.69
32	43.16	41.72	84.13	76.14
33	56.25	50.42	69.99	60.26
34	48.60	42.08	71.35	59.28
35	77.87	51.47	84.80	54.68
36	77.03	47.54	86.49	50.79
37	44.12	39.89	60.41	49.35
38	61.36	59.52	79.36	67.75
39	70.26	66.93	81.21	72.65
40	64.47	49.94	73.55	56.38

The upper Trinity River HEC-1 model utilizes the Snyder's unit hydrograph lag time (time-to-peak) that was developed for each urban sub-area using methodology described in "Synthetic Hydrograph Relationships, Trinity River Tributaries, Fort Worth-Dallas Urban Area" by T. L. Nelson, 1970. These mathematical relationships, which are referred to as Urbanization Curves, are available for both Cross Timbers sandy loam and Blackland Prairie clay dominated watersheds in the general vicinity of the Dallas-Fort Worth Metroplex. The geographical characteristics of each sub-area, including the length of the major stream (L), the distance from the sub-area outflow point to the location of the sub-area centroid (L_{ca}), the weighted slope (S_{st}) of the major stream, and the percent urbanization comprise the data used in the equations to determine the Snyder's lag time for the two general extremes of soil type. The Snyder's lag for each sub-area was then generated mathematically from the Cross Timbers Sandy Loam and Blackland Prairie Clay Urbanization Curves through direct interpolation, based on the percentage of each soil type within that sub-area. Appendix A contains the sub-area parameters from the land use calculations and applied urban curves. For reference, Appendix B contains the sub-area parameters used in the models prior to this update effort.

4.2.5 Storage Routings

The UTRFS utilized the Modified Puls routing method along the reaches downstream of Lake Worth, Benbrook Lake, Grapevine Lake, and Lewisville Lake. The valley storage versus discharge relationships were originally developed using an HEC-2 backwater model. The Modified Puls routing method was also used along the reach of Denton Creek below Grapevine Lake.

The Muskingum routing method was generally used along the reaches upstream from Lake Worth, Benbrook Lake, and Lewisville Lake. The Muskingum routing method and number of routing steps (in both the Muskingum and Modified Puls routing methods) were calibrated by reproducing the historical flood hydrographs of May-June 1989, April-May 1990, and December 1991.

This CDC Model update included incorporating projects that have been granted CDC permits into the HEC-RAS hydraulic model of the Clear Fork, West Fork, Elm Fork, and Main Stem. The addition of approximately 70 projects facilitated the need for revised storage routing through the reaches within the hydrologic model. The storage/discharge relationship was entered into the HEC-1 model at the routing card corresponding to a reach within the HEC-RAS model. The development of the HEC-RAS storage model is described in Section 5 “Hydraulics” in this report.

4.2.6 Calibration

The UTRFS was calibrated to historical storms of May - June 1989, April - May 1990, and December 1991. These three calibration events produced a very good reproduction of the peak discharges resulting from the storm events. Gage frequency analysis was utilized as a calibration technique for the hypothetical storm reproduction with good results.

Due to the update of the land use to 2005 and updated routing from the permitted projects in the upper Trinity River corridor, calibration to a storm occurring since 2005 was needed to verify calculated discharges from the HEC-1 model. Unfortunately, the entire north Texas region has experienced a longer than average period of dry weather resulting in limited rain events of a magnitude large enough for calibration.

Tropical Storm Hermine made landfall on September 7, 2010 near Matamoros, Mexico and continued inland on a NNW direction producing extremely heavy rainfall over areas of central Texas. In the upper Trinity River basin, point rainfall amounts exceeding 10-inches, greater than a 100-year 24-hr rainfall total, were seen. However, due to extremely dry conditions in the watershed, peak runoff amounts equal to that of the 10-year storm were produced. Although not a significant rain event, the rainfall was used in the calibration process to determine the validity of the HEC-1 model. Figure 4-6 below is a graphical representation of the storm calibration at the Trinity River at the Commerce Street gage (DALT2).

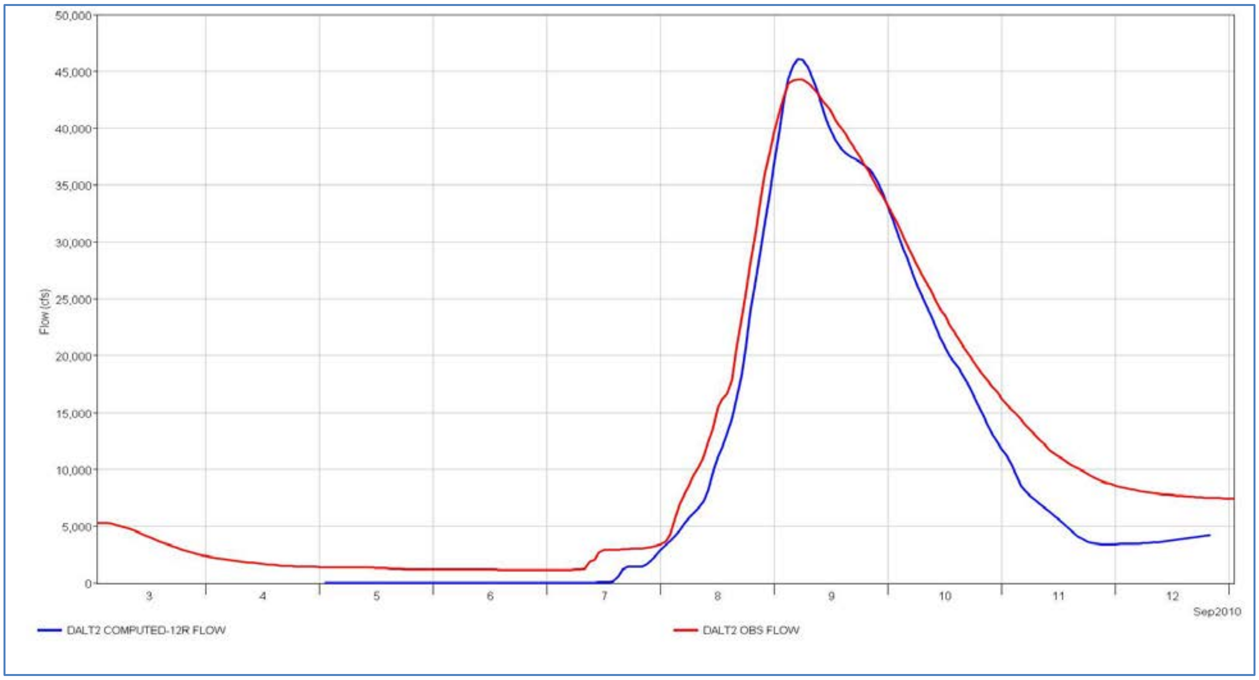


Figure 4-6. Tropical Storm Hermine DALT2 Calibration

The gage frequency analysis utilizing gages along the Trinity River resulted in a negative skew deeming them unreliable for calibration. Although the reason for the negative skew is not known at this time, it is believed to be a result of the drier than normal weather pattern since the mid-1990s. The decreased intensity of the storms over the last 20 years tends to result in a bowing effect of the frequency curve and results in frequency storms much lower than typically seen in the watershed.

4.2.7 HEC-1 to HEC-HMS Conversion

The UTRFS and subsequent CDC hydrology models were all produced utilizing the USACE HEC-1 computer program. Since the creation of the UTRFS, there have been significant advancements in the technology available for the modeling of watersheds. One such advancement is the USACE Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) which provides the user with a graphical interface which can be linked to GIS files for visual interpretation of a watershed layout as well as numerous advancements in the methodology utilized in several routines. One example is the addition of pumps enabling the modeler to utilize outflow calculations from sluice gate operations based on the same hydraulic calculations utilized in hydraulic modeling of culverts.

The HEC-1 models, the upper Trinity River 1-hour and Elm Fork 15-minute, were converted to HEC-HMS by importing them into the HEC-HMS program. The watershed boundaries were added as GIS files for graphical representation of the watersheds. The sub-basins, reaches, reservoirs, and combine points had to be rearranged to accurately reflect the watershed. The HEC-1 imported variables were then checked for accuracy to insure the correct basin parameters and routing parameters were imported. A key difference between the HEC-1 and HEC-HMS models utilized for this study is the ability of HEC-HMS to have multiple meteorological modules whereas, in HEC-1, each storm frequency and SPS storm centering is a separate model. The meteorological data for the standard frequency storms and the SPS storms were entered into the HEC-HMS model and the program was run. The results were tabulated and compared. Table 4-7 compares the results between the two programs for future conditions discharges for the 100-year and SPF at key locations.

Table 4-7. HEC-1 to HEC-HMS Future Conditions Comparison

Location Description	100-Year			SPF		
	HEC-1	**HEC-HMS**	**% Diff.**	**HEC-1**	**HEC-HMS**	**% Diff.**
West Fork above Clear Fork	35,519	35,654	0.38	63,356	63,345	-0.02
West Fork below Clear Fork	70,443	70,361	-0.12	135,783	135,870	0.06
West Fork above Elm Fork	105,089	105,759	0.63	233,269	234,162	0.38
Elm Fork at Sandy Lake Road	48,065	48,179*	0.24	87,800	88,001*	0.23
Elm Fork above West Fork	45,760	44,695*	-2.38	99,300	94,100*	-5.53
Trinity River at Dallas Gage	131,156	132,053	0.68	293,730	294,663	0.32
Trinity River below Five Mile Creek	132,726	133,439	0.53	299,109	300,283	0.39

*Discharges for Elm Fork are from the 15-minute detailed HEC-HMS model and utilize better pump station calculations.

4.3 Results

Increased urbanization in the upper Trinity River watershed, particularly around the Dallas-Fort Worth Metroplex area, has resulted in an increase in runoff within the basin. In some locations, the baseline 100-year discharge, calculated using the best available land use available at the time of model development, has increased as much as 36 percent due to urbanization. The projection of the urbanization to 2055, by the NCTCOG member cities, increases the runoff within the watershed even further. However, the Elm Fork experiences a decrease in both the 100-year and SPS due to additional valley storage in the upper portion of the watershed. The 100-year in the Elm Fork reverts back to an increase below Sandy Lake Road. Table 4-8 is a comparison of the 100-year and SPF calculated discharges for the 2040 (4th Edition "Future") HEC-1 and the 2055 (Future) HEC-HMS at key locations within the watershed.

Table 4-8. Future Conditions Discharge Comparison (HEC-HMS)

Location Description	100-Year Discharge			SPF Discharge		
	2040	2055	Diff. (cfs)	2040	2055	Diff. (cfs)
West Fork above Clear Fork	35,400	35,100	-300	57,700	63,300	5,600
Clear Fork above West Fork	39,800	48,300	8500	84,000	93,000	9,000
West Fork below Clear Fork	58,700	69,400	10700	124,400	135,900	11,500
West Fork below Big Fossil Creek	89,700	91,400	1700	182,600	181,900	-700
West Fork below Village Creek	100,700	110,400	9700	204,700	217,400	12,700
West Fork at Belt Line Road	92,300	106,300	14000	210,400	223,000	12,600
West Fork above Elm Fork	92,800	103,100	10300	222,700	234,200	11,500
Elm Fork below Dudley Branch*	22,400	15,600	-6800	66,600**	66,600**	0
Elm Fork at Sandy Lake Road*	51,500	48,200	-3300	99,200	88,000	-11,200
Elm Fork below Farmers Branch*	46,400	47,800	1400	99,400	88,700	-10,700
Elm Fork above West Fork*	42,700	44,700	2000	106,200	94,100	-12,100
Trinity River at Dallas Gage	119,800	128,600	8800	277,000	294,700	17,700
Trinity River below Five Mile Creek	126,900	129,000	2100	281,100	300,300	19,200

*Discharges for Elm Fork are from the 15-minute detailed model.
**Peak flow controlled by spillage from Lewisville Lake.

The 2040 land use utilized in the calculation of the discharges published in the CDC Manual 4th Edition was an extension of the same projected land use from the 1st Edition CDC Manual. The projected urbanization was an estimate by the NCTCOG members of their expected 50-year growth. Since the initial development of the CDC Manual, urbanization has progressed more to the north and east. Some sub-area's 2005 land uses approached, or in some cases surpassed, the projected 2040 land uses of the previous study. Mary's Creek, sub-area 30 in the hydrologic model, is one such watershed. The 2040 "Future" percent urbanized and percent imperviousness were 28.1 and 18.0, respectively. The 2005 "Baseline" percent urbanization and percent imperviousness are 13.5 and 8.32, respectively. Subsequently, the 2055 "Future" percent urbanization and percent imperviousness are projected to be 60.7 and 36.67, respectively. Figure 4-7 is an aerial photograph of the Mary's Creek sub-area from circa 1995 and Figure 4-8 is from circa 2005. This is helpful in understanding the development that has occurred since 1995. Figures 4-9 and 4-10 are the 2005 land use and 2055 land use, respectively.

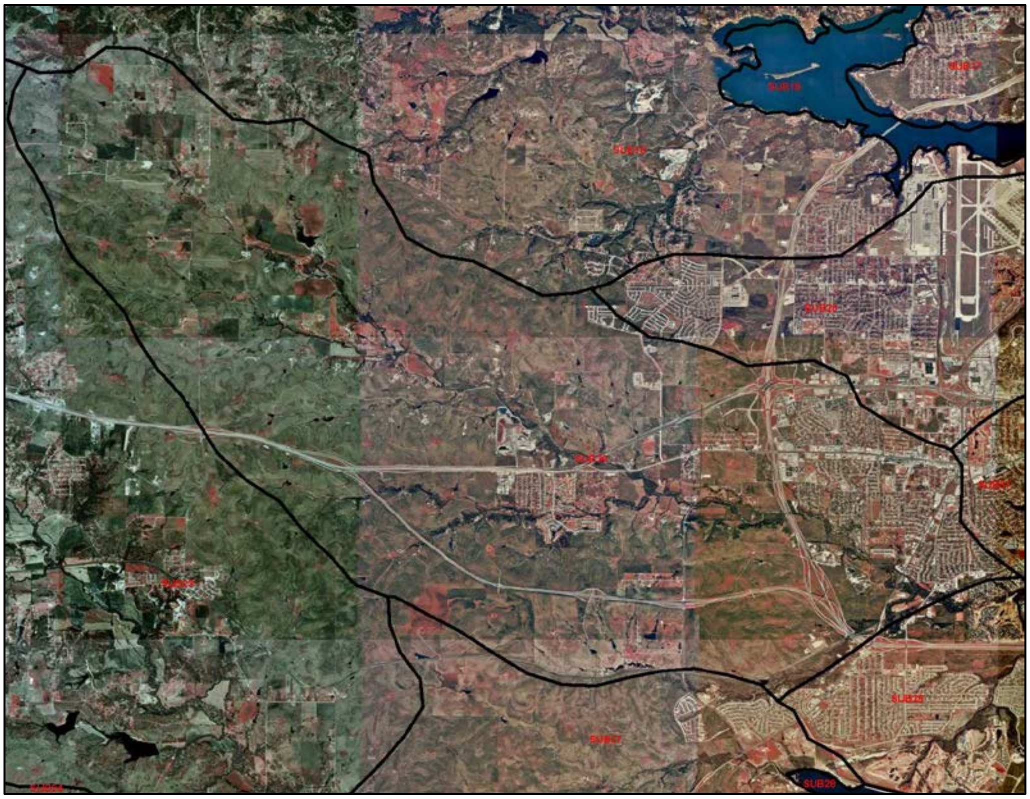


Figure 4-7. Mary's Creek Aerial circa 1995

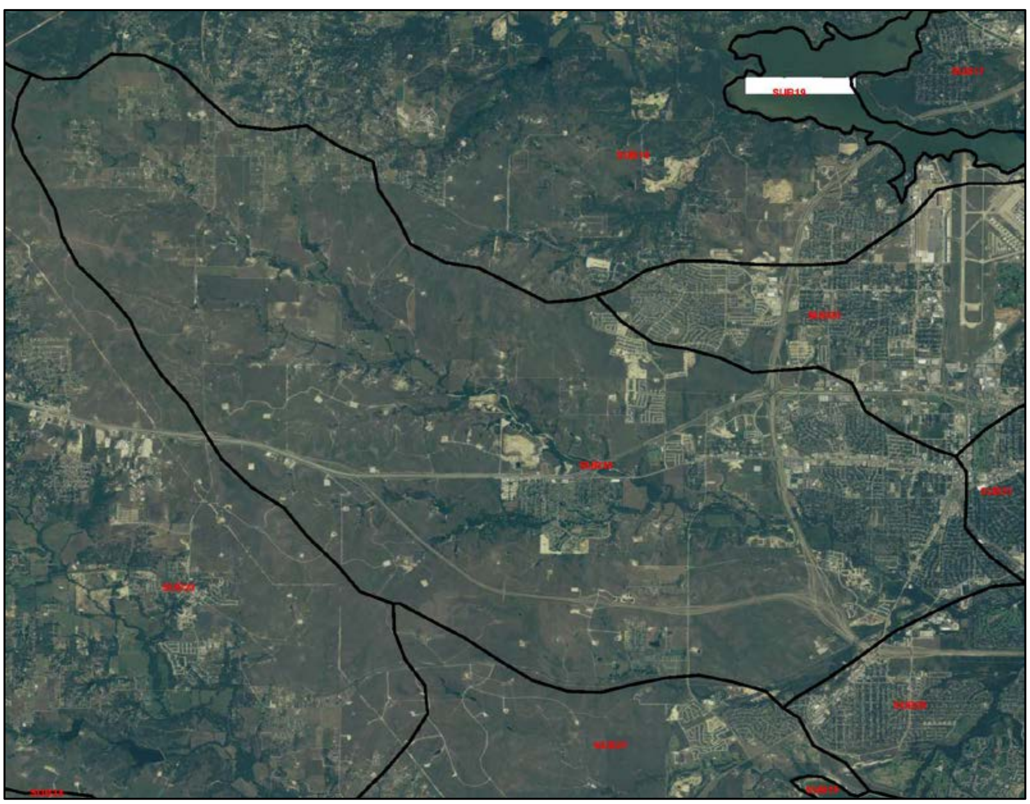


Figure 4-8. Mary's Creek Aerial circa 2005

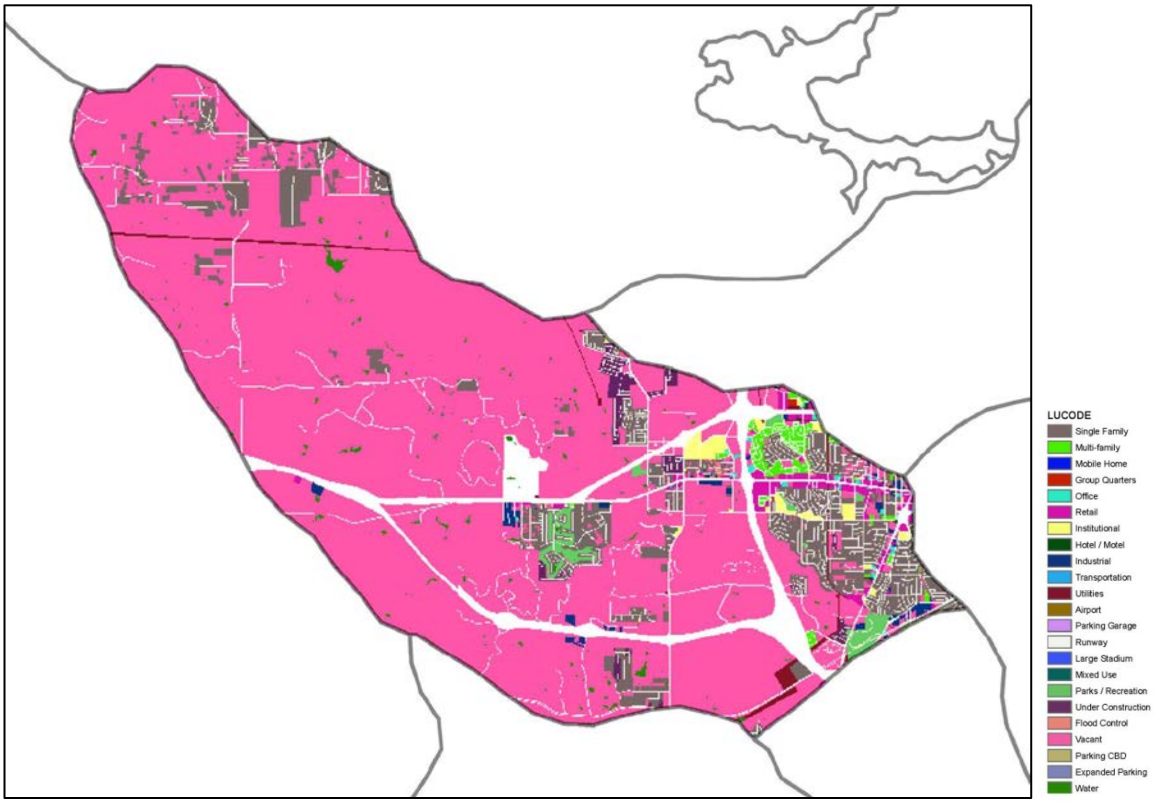


Figure 4-9. Mary's Creek 2005 Land Use

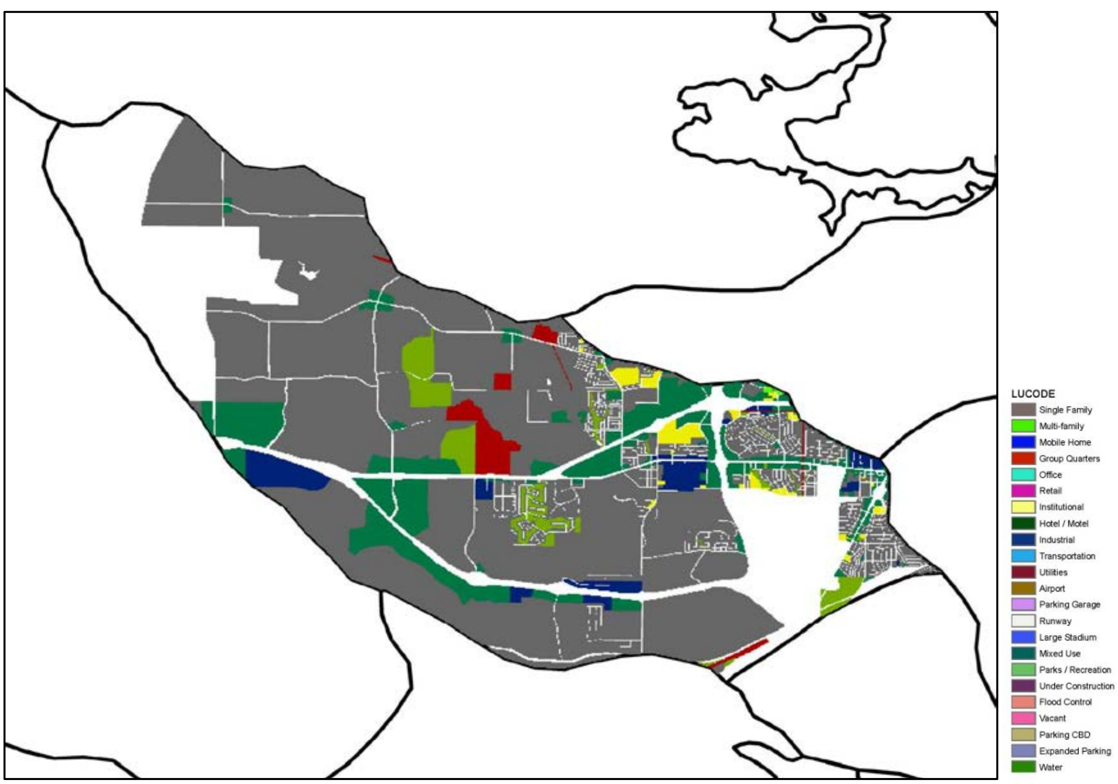


Figure 4-10. Mary's Creek 2055 Land Use

According to the figures above, and the representative percent urbanization and percent imperviousness, the Mary's Creek drainage area is projected to be primarily single family residential by the year 2055. Other sub-areas exhibiting the same trends include Village Creek, Big Fossil Creek, Little Fossil Creek, and sub-areas adjacent to and below Eagle Mountain, Joe Pool Lake, and Grapevine Lake.

The updated valley storage from the revised HEC-RAS hydraulic model has an impact on the calculated discharges as well. The Common Regional Criteria set forth in the CDC Manual requires a proposed project to have no loss of valley storage for the 100-year flood and no more than 5 percent loss of valley storage for the SPF. Projects are submitted to, and reviewed by, the USACE to insure they meet the criteria regarding valley storage. However, the updated hydrologic model tends to be very sensitive to slight changes in the storage curves input for Modified Puls routing. Figure 4-11 is a graphical comparison of an original upper Trinity River storage (1990s) versus the CDC updated storage from this study exhibiting very little, if any, variation. Figure 4-12 represents how the valley storage requirement is met, but the shape of the storage curve is different from the original UTRFS.

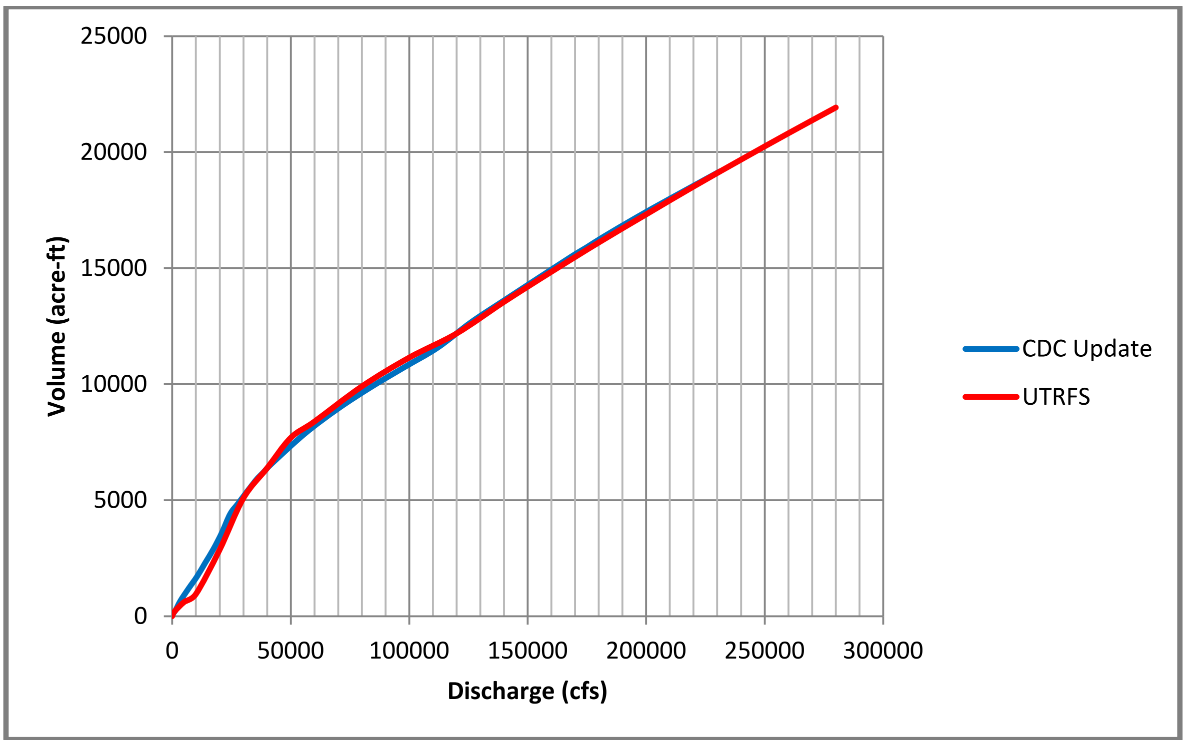


Figure 4-11. Typical Valley Storage Example

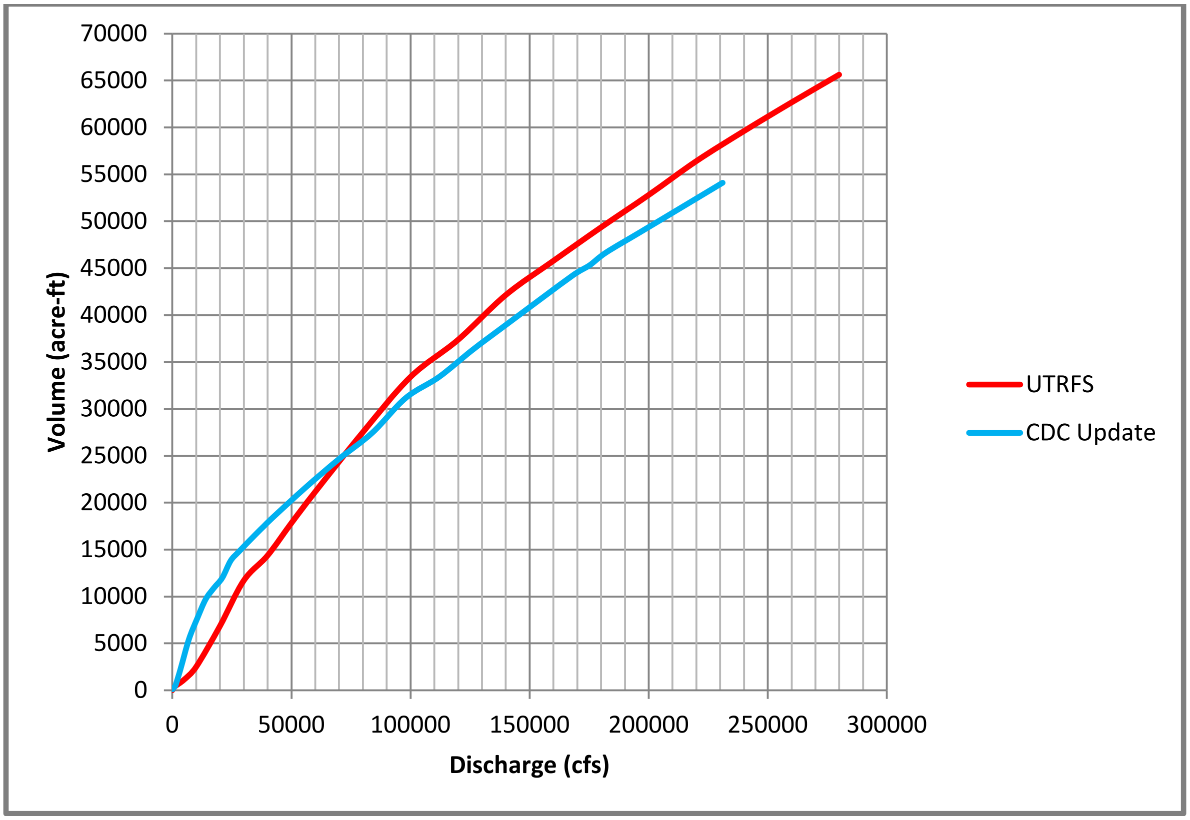


Figure 4-12. Redistribution of Storage Example

The resultant Future 2055 calculated discharges (100-year and SPF) have been tabulated and included with this report as Appendix C. For reference, the Future 2040 calculated discharges published in the CDC Manual 4th Edition are included as Appendix D.

5.0 Hydraulics

5.1 General

The purpose of the hydraulics portion of this study, as stated in the Project Management Plan (PMP), *"… is to update the current CDC hydrologic and hydraulic models."* The current regional CDC Model is maintained by the USACE Fort Worth District and is distributed upon request. The CDC Model has been periodically updated by the USACE, however never on a comprehensive basis. The objective of the work under the PMP is to update the CDC Model, utilizing available data and resources, to develop a CDC Model consistent with the present day CDC program and upper Trinity River floodplain permit conditions.

The USACE role in the CDC Process is the performance of a Technical Review of the CDC applications. The CDC applications are submitted to the USACE by member communities, and reviewed by the USACE. The results of the review are stated in a letter submitted from the USACE to the member communities and the NCTCOG. The CDC applications are reviewed using the respective CDC Manuals in effect at the time of submittal. The CDC Manuals used throughout the CDC process are as follows:

- CDC Manual 1st Edition May 1991
- CDC Manual 2nd Edition August 1997
- CDC Manual 3rd Edition September 2002
- CDC Manual 4th Edition June 2010

The Common Regional Criteria hydrologic and hydraulic criteria stated in each of the manuals were used to evaluate the impacts of the proposed CDC projects.

5.2 Data Collection

Most of the hydraulic data for the CDC projects that were incorporated into the CDC Model came from the USACE Water Resources Branch files. The Water Resources Branch maintains a collection of the CDC applications and associated technical hydraulics reports. The majority of the CDC projects incorporated into the CDC Model originated from this source. Data for several CDC projects came from engineering firms that were originally responsible for the hydraulic design of each project. Data for one CDC project came from the city of Fort Worth staff.

The CDC project submittals generally consisted of the CDC application forms, a technical hydraulics analysis, tables, maps, figures, and an electronic copy of the pertinent data in formats from either 5¼-inch and 3½-inch floppy disks or CDs, depending on the age of the CDC application. The CDC applications ranged in date from the early 1990s to present. The electronic data from the CDC applications had been uploaded to the Water Resources Branch servers for easy access.

5.3 Methodology

The process of incorporating specific CDC projects into the CDC Model consisted of the following steps:

- Opening of the regional CDC Model (using HEC-RAS version 4.1.0)
- Opening of the specific CDC project model (using HEC-RAS version 4.1.0)
- Identifying and isolating the specific river reach/cross-sections that contain the CDC project data

- Transferring, by either direct copying or by text editor, the pertinent CDC project data into the CDC Model
- Creating cross-section descriptions in the CDC Model to identify each project
- Including pertinent CDC project information on the tracking spreadsheet (see paragraph 5.4).

5.4 Tracking Spreadsheet

A comprehensive list of CDC applications that have been processed from the beginning of the CDC program in the 1990s to November 2012 has been created. The spreadsheet includes the CDC project name/CDC number, the status of project construction, identifies whether the project has been incorporated into the CDC Model, and identifies exempted CDC projects. The spreadsheet was created from an existing Water Resources Branch tracking spreadsheet along with CDC application information from the NCTCOG. The spreadsheet was distributed to the participating CDC members for verification and for the inclusion of additional information. The CDC members provided useful information such as the identification of CDC projects that have either been abandoned or expired. The resultant spreadsheet represents a snapshot of the CDC process up to the present day. The intention is for the NCTCOG and USACE to maintain this spreadsheet in the future. See Table 5.4 CDC Tracking at the end of this section.

5.5 Modeling Issues

More than 80 CDC projects are incorporated into the updated CDC Model. A large majority of these, close to 70, were incorporated into the CDC Model as part of this study. The work consisted of incorporating site specific project data into a much larger regional model. The nature of this work created unique modeling issues that are discussed herein.

- Several CDC projects were developed using newly generated site topographic data which was used to develop new cross-sections. Consequently, the geometric information represented in the CDC Model is not consistent throughout, i.e. original Upper Trinity River 1991 topographic data used in the development of the models in the 1990s combined with recent topographic data.

- The age of several of the CDC projects were older than 10 years. The hydraulic models for these projects were developed in HEC-2 (and then converted to HEC-RAS as part of this study). The HEC-2 computational procedure is slightly different from HEC-RAS, therefore there is not a consistency between these programs.

- Many of the CDC projects were developed using earlier versions of the HEC-RAS program. The different versions of the HEC-RAS program produce differences in water surface profiles due to changes in computational procedures, therefore there is not a perfect consistency of the older CDC models and the current HEC-RAS version 4.1.0.

5.6 Model Structure

The CDC Model developed in this study consists of one project file and three plans that encompass the entire upper Trinity River corridor. Each plan represents a specific set of geometric data and flow data. The CDC Model was originally developed in the 1990s in HEC-2 and consisted of two plans since there are different floodplain characteristics that occur during the rare flood events (500-year and SPF) as compared to the more frequent flood events (2-year to 100-year). The development of two separate HEC-2 models was the best approach at the time to represent these different conditions. This two plan structure was maintained as the HEC-2 model was converted to HEC-RAS in the late 1990s. In this study an additional plan for the upper West Fork and Clear Fork was developed.

The organization of the CDC Model plan structure is as follows:

Plans	River Reach	Flood Events
p01, g01, f01	West Fork downstream of 206218, Elm Fork, Trinity River main stem	2-year to 100-year
p02, g02, f02	West Fork downstream of 206218, Elm Fork, Trinity River main stem	500-year and SPF
p03, g03, f03	West Fork upstream of 206218 and Clear Fork	2-year to SPF

A description of the major modeling aspects of the hydraulic analysis is included in paragraphs 5.7 - 5.9. These paragraphs highlight the major modeling work that has been accomplished as part of this study and by other work associated with upper Trinity River projects.

5.6.1 Modeling Notes

a. The basic modeling assumptions used in the development of the original CDC model were similar to the hydraulic models developed for the Trinity River and Tributaries Regional Environmental Impact Statement – 1988. These are as follows:

- Levees are vertically extended, therefore no conveyance and storage is accounted for behind the levees

- Landfills are assumed to full build-out conditions.

b. The peak discharges used in the CDC Model, which were generated from the upper Trinity River HEC-HMS model, were rounded for use in the HEC-RAS model as follows:

- 4 figures … nearest 100 cfs
- 5 figures … nearest 500 cfs
- 6 figures … nearest 1000 cfs

c. All split flows were balanced using the energy gradient (EG).

d. The CDC Model in this study was developed using HEC-RAS 4.1.0.

5.7 Main Stem Trinity River

5.7.1 General

This paragraph describes the modeling work that has been performed for the Trinity River main stem during the past 10 years. The work was not part of this specific CDC Model update, but is included here to provide information on the development of the model since the early 2000s.

Since the completion of the CDC Model in the late 1990s, an updated hydraulic model for existing conditions on the Trinity River and the Dallas Floodway was determined to be advantageous for the detailed analysis required of the Dallas Floodway Feasibility Study as well as analysis for the numerous other projects within the Dallas Floodway that are planned by the local sponsor and others. The needs for an updated model within the Dallas Floodway were based on a number of factors, (1) primarily due to the data requirements for modeling the proposed Trinity Parkway riverside alternatives by the North Texas Tollway Authority and (2) the recreational amenities planned by the City of Dallas under the "Balanced Vision Plan" within the Dallas Floodway. Also, the channel widening and levee fill project completed by the City of Dallas in the mid-1990s was not reflected on the 1991 topographic data on which the original models were based. This river channel project was reflected in the current models but the data was input to the model from construction plans and not from actual survey data. In addition, recent river channel topographic data and bathymetry was needed for low flow analysis. Therefore, additional topographic survey data for the Dallas Floodway levees and the Trinity River channel within the floodway was obtained in order to update the Initial HEC-RAS CDC model within the Dallas Floodway.

The revised HEC-RAS model revision for the Dallas Floodway was limited to the reach of the Trinity River between the Union Pacific Railroad Bridge near SH 310 (cross-section 89108) and the confluence of the West Fork and the Elm Fork Trinity River (cross-section 148136). The model was developed through a joint effort by the USACE and A/E services using recent survey data, additional cross-section locations, and updated bridge model data. The development of the updated bridge model input was performed by the USACE as well as periodic reviews of the model update development to ensure accuracy and consistency with the proposed Trinity Parkway model. The major data revisions of the revised existing conditions model update were:

- One-foot contour interval topographic survey was developed in 2003 for both the East and West Dallas Floodway Levees extending from the DART Rail Line Bridge (cross-section 108380) to the Union Pacific Railroad Bridge (cross-section 121623) to capture changes to the levees due to the City of Dallas river channel widening and levee fill project.

- One-foot contour topographic survey for the existing river channel with bathymetry was developed in 2003 extending from the DART Rail Line Bridge (cross-section 108380) to the confluence of the West Fork and the Elm Fork (cross-section 148136) to capture changes due to the river channel widening and levee fill project and any geomorphic and sedimentation changes to the river channel.

- A composite 1-foot contour topographic digital terrain model was compiled to include the new survey data described above so that model cross-section data could be derived from the new survey data for the full floodway width. The terrain model includes the 1991 2-foot contour survey of the floodplain between the channel banks and the toe of the levees for the reach from the DART Rail Line Bridge and the confluence of the Elm Fork and the West Fork.

- The revision includes updated bridge model input for all bridges in the Dallas Floodway and in the Dallas Floodway Extension (DFE) Project reach on the main stem Trinity River.

- The revision includes the addition of approximately 200% more cross-section locations within this reach than the previous CDC Model and the update of the previous cross-sections within the Dallas Floodway on the Trinity River main stem from the DART Rail Line Bridge to the confluence of the West Fork and the Elm Fork with the composite terrain data described above.

- The revision includes the updating of valley cross-sections in the DFE reach from the Union Pacific Railroad Bridge near SH 310 to the DART Rail Line Bridge with 1999 and 2004 1-foot topographic mapping data.

- The revised existing HEC-RAS model cross sections from the DART Rail Line Bridge to the confluence of the Elm Fork and the West Fork were derived from a composite digital terrain model (DTM) that was created by combining the 1991 topographic data for the floodplain between the river channel and the levees with a new 1-foot contour survey of the river channel with bathymetry and a 1-foot contour survey of the levees. The new survey of the river channel extends from the DART Rail Line Bridge upstream to the confluence of the West Fork and the Elm Fork of the Trinity River. The new survey of the East and West levees extends from the DART Rail Line Bridge upstream to the Union Pacific Railroad (cross-section 121623). The levee survey extends laterally from the toe of the levees up to and including the crest. All of the cross-sections within the reach from the DART Rail Line Bridge to the confluence were replaced with cross-sections derived from this newly created DTM. However, all of the original cross-section locations (cross-section stations) were retained. Generally, two additional cross-sections were added by evenly dividing the distance between the original cross-section locations within this reach. The original Manning's roughness coefficients used in the previous CDC Model were retained for the revised existing model update. The roughness values used within the Dallas Floodway are 0.055 for the overbanks and 0.035 for the river channel from Houston Street to the confluence of the West Fork and the Elm Fork. The roughness values used in the reach from the DART Rail Line Bridge to Houston Street are 0.055 for the overbanks and 0.030 for the river channel. The lower roughness value for the river channel in this reach is due to the river channel widening project.

- The revised existing model update also includes the update of all of the original cross-sections in the Dallas Floodway Extension project reach from just downstream of the Union Pacific Railroad Bridge (cross-section 89108) upstream to the DART Rail Line Bridge. These cross-sections were derived directly from plotted maps in part from the 1-foot contour topographic data compiled in 1999 for the DFE Project. The 1-foot contour topographic data compiled in 2004 for the Lamar Street Levee sump study was also used in the areas from the river channel north to the Lamar Street Levee. All of the original cross-section locations (cross-section stations) were retained. Seventeen new cross-section locations were added in this reach. The Manning's roughness coefficients used in the previous CDC Model were retained and interpolated for the newly added cross-sections.

5.7.2 Dallas Floodway Extension

The Dallas Floodway Extension Project (DFE) is a USACE federal flood control project. The DFE is comprised of three major structural components: the Lamar Street Levee, the Cadillac Heights Levee, and the Chain of Wetlands. The Chain of Wetlands is divided into the Upper Chain of Wetlands and Lower Chain of Wetlands segments. The DFE is located downstream of the existing Dallas Floodway project. The DFE also includes the construction of trail systems, environmental restoration, and mitigation features. The CDC Model includes all of the authorized DFE Project features, though only the Lower Chain of Wetlands project component and Cell D of the Upper Chain of Wetlands have been constructed.

5.7.3 Bridges

The proposed Sylvan Street bridge is incorporated into the CDC Model. The existing channel bridge remains. The two bridge structures at the East Levee and the West levee were removed.

5.8 Elm Fork

5.8.1 Development of Model

There were several large CDC projects along the Elm Fork that were incorporated into CDC Model. The major change in the Elm Fork occurred as part of the President George Bush Turnpike (PGBT) project. Part of the project design included a split flow for the rare flood events. This split flow is included in plan p02 and geometry g02 and represents the 500-year flood and SPF conditions. Two split flow reaches were created, PGBT East and PGBT West, between cross-sections 87000 – 98000.

Other large CDC projects that were incorporated into the CDC Model were:

- Irving Flood Control District #1 Levee (Northwest Levee) improvements
- DART bridge
- California Crossing bridge
- Modifications to the landfills in Lewisville

5.8.2 Bridges

Several Elm Fork bridges were updated. The original CDC Model was developed in HEC-2 and these bridges were modeled by grouping some of the bridge piers due to the ground point limitation in the HEC-2 program. The HEC-RAS program allows for a larger number of individual bridge piers to be represented. All of the individual bridge piers for each of these bridges were represented in the model. The bridges updated in this way are:

- SH 183
- Spur 482/Storey Lane
- Valley View Lane

Also, the right relief bridges for the Southern Pacific Railroad and Belt Line Road were modified to correct ineffective flow boundaries through both bridges.

5.9 Upper West Fork Trinity River and Clear Fork Trinity River

5.9.1 Development of HEC-RAS Model

This section describes the work that has been performed for the upper West Fork and a portion of the Clear Fork as part of the USACE Central City project model. The work was not part of this CDC Model update, but is included herein to provide information of the analysis. The HEC-RAS model developed in the Central City project is incorporated in the CDC Model developed for this study. This section was part of the USACE Technical Paper presented to NCTCOG on 8 September 2009 - several modifications have been made for this report for clarification.

A new upper Trinity River HEC-RAS model was developed by the USACE-Fort Worth District in 2008 as part of the engineering analysis for the Fort Worth Central City Project, which is a USACE project that consists of the creation of a flood bypass channel, levee, floodwalls, urban lake, canals, and environmental features. The Central City project is part of the Trinity River Vision, which is a master plan for the river and tributaries throughout greater Fort Worth. The primary purpose of the hydraulic analysis was to provide a hydraulic model that represents the most recent characteristics of the rivers and floodplain by using the most current hydraulic design tools for the majority of the West Fork Trinity River and Clear Fork Trinity River within the Central City Project area. Figure 5-1 is an overview of the major Central City features.

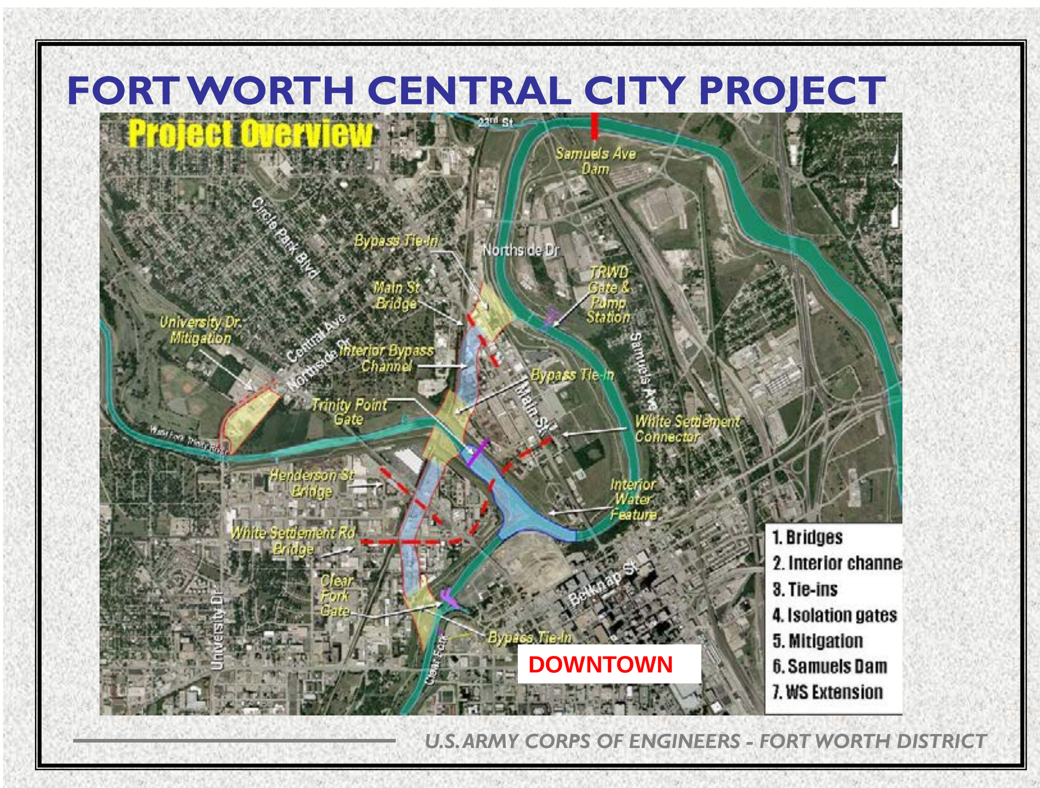


Figure 5-1. Fort Worth Central City project

Note that for this CDC Model work only the completed portions of the Central City project, the two valley storage areas downstream of Samuels Avenue within the Fort Worth Floodway, were incorporated into the CDC Model.

As part of the development of the hydraulic model, new topographic and bathymetric information was developed. A new hydraulic model has the following advantages compared to the then current CDC Model (which was developed in the 1990s):

New HEC-RAS Model	Then Current CDC Model
New two-foot contour interval topography developed from January 2005 aerials	Two-foot contour topography developed from 1991 aerials
New river bathymetry developed in November 2006	Bathymetry not part of 1991 mapping – estimated from 1975 USACE field survey
Model developed in HEC-RAS with more detail in cross-sections and bridge data	Model developed in HEC-2 and later converted to HEC-RAS. HEC-2 limited in amount of data points used to represent cross-sections and bridges.
Model is geo-referenced	Model not geo-referenced

5.9.2 Mapping

New photogrammetric mapping and bathymetry was developed for most of the Central City project area. All of the survey was located within the city of Fort Worth. Each was developed as separate survey products – the data was merged to create a seamless data file for use in the hydraulic analysis. The aerial mapping extent is shown in Figure 5-2. The limit of the original aerial survey is indicated in pink – the survey extent on the West Fork is downstream of Beach Street to SH 183, and the extent on the Clear Fork is from the West Fork/Clear Fork confluence to IH 30. Additional survey areas were added on the West Fork downstream to East 1st Street, and on the Clear Fork upstream to West Rosedale Street.

The mapping consisted of generation of two-foot contours from January 2005 aerial photography. The orthophotography resolution is 6-inches. The mapping also included generation of planimetric features (roads, structures). The DTM points and breaklines were also generated as part of the contract work.

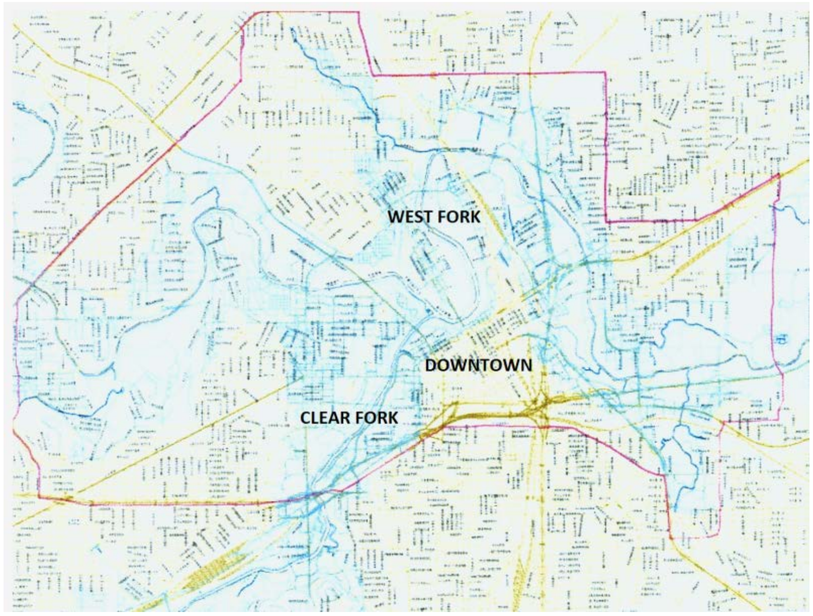


Figure 5-2. Aerial mapping limits (shown in pink)

Horizontal control was based on Texas State Plane Grid Coordinate System, NAD 83 State Plane Zone 4202. Vertical control was based on NAVD-88. The horizontal control and vertical control complied with Corps of Engineers, 3rd Order, Class II standards as outlined in EM 1110-1-1000.

Bathymetry survey was performed by Hydrographics Consultants, Ltd. Field work was completed from 6-17 November 2006. For narrow sections of the river, cross-sections were taken on 100-foot intervals with a centerline. For wider sections of the river, the survey consisted of a centerline profile and two along bank profiles either side of the centerline profiles which were equally spaced between the river bank and the centerline profile, and two reciprocating sinusoidal cross-lines.

All surveys met the requirements and procedures for performing Class I, dredge payment, surveys as provided by the USACE document EM 1110-2-1003, “Hydrographic Surveying.” Horizontal control was based on Texas State Plane Grid Coordinate System, NAD 83 State Plane Zone 4202. Vertical control was based on NAVD-88. The horizontal control and vertical control complied with Corps of Engineers, 3rd Order, Class II standards as outlined in EM 1110-1-1000. The limits of the bathymetric survey are indicated in pink - the extent on the West Fork is downstream of Beach Street to SH 183, and the Clear Fork from the West Fork/Clear Fork confluence to Lancaster Avenue bridge - see Figure 5-3 and Figure 5-4.

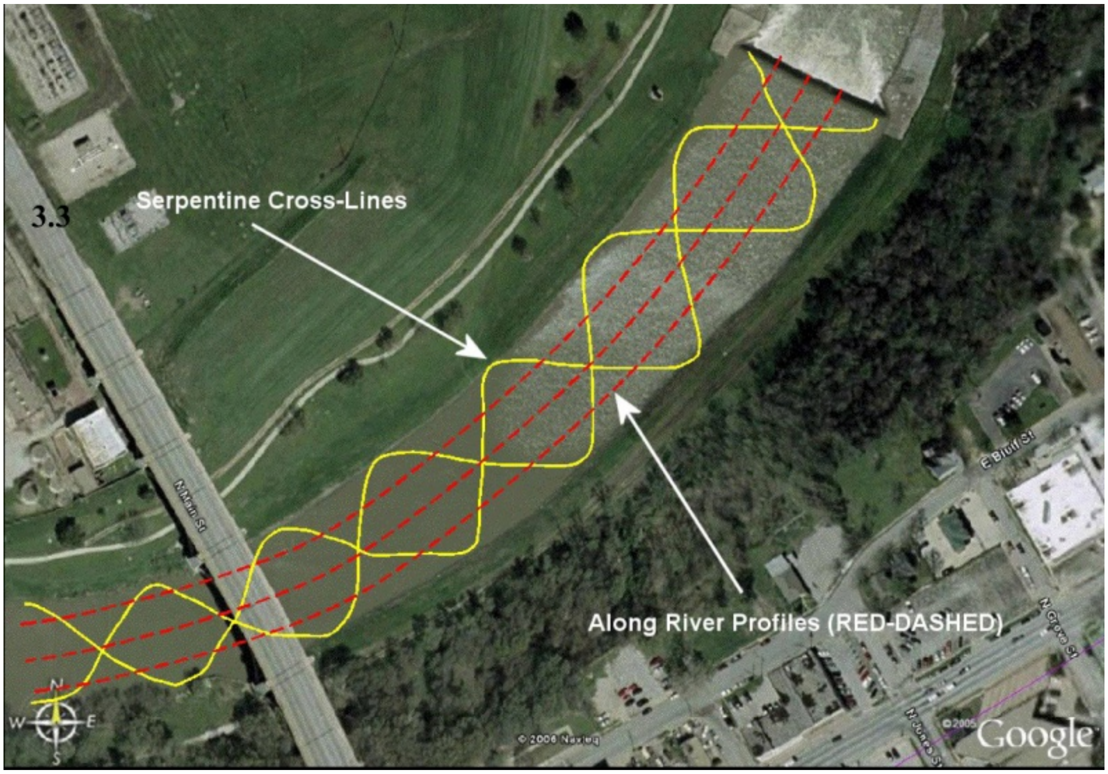


Figure 5-3. Survey acquisition pattern for the wide portions of the river

Figure 5-4. Bathymetry limits (shown in pink)

5.9.3 Model Details

The extent of the HEC-RAS model is as follows:
West Fork: downstream of East 1st Street to Lake Worth Dam
Clear Fork: West Fork/Clear Fork confluence to Benbrook Dam.

The HEC-GeoRAS program was used to create the structure of the HEC-RAS Model. HEC-GeoRAS is an ArcGIS extension specifically designed to process geospatial data for use with HEC-RAS. The tools allow users to create a HEC-RAS import file containing geometric attribute data, such as cross-section cut lines, river bank stations, flow paths and reach lengths, and roughness coefficients, from an existing Digital Terrain Model (DTM). The mapping product was converted to a TIN (Triangulated Irregular Network).

The following is a listing of the major aspects of the new HEC-RAS Model:

- The new HEC-RAS model has more cross-sections than the current HEC-RAS CDC Model.
- Additional detail in the cross-section geometry due to the limit of ground points (500 in HEC-RAS, 100 in HEC-2)
- Additional detail in the representation of bridges due to the greater limit of points in HEC-RAS than HEC-2. This was especially noticeable for the large railroad bridges where the piers were individually represented. The current CDC Model has many of the bridge piers grouped together.
- Original bridge plans and USACE bridge surveys used to develop bridge modeling data.
- The downstream limit of the model is cross-section 206218 on the West Fork (just downstream of East 1st Street). The starting boundary condition was developed from the current CDC Model rating curve at this location.
- The BNSF Trinity Park Railroad relief bridge was remodeled from field measurements.
- The lower Northside Drive bridge was remodeled from field measurements.
- The Union Pacific Railroad bridge (upstream of IH 35) was remodeled from field survey data
- The UP and BNSF railroad bridges downstream of Samuels Avenue were remodeled from field measurements.
- All channel dams were converted to in-line weirs.
- Incorporated TRWD field survey data of several channel dams.
- Added new University Drive bridge on West Fork.
- Remodeled the reach at Colonial Golf Course to account for storage.

- Remodeled Nutt Dam and City Dam No.2 hydraulic data (spillway approach height and design head) using the original USACE design data for each structure.

- Incorporated changes to the Fort Worth Floodway since the completion of the 1991 mapping: construction of 4th Street Dam, construction of Beach Street Dam, dredging/reshaping of the West Fork by TRWD, Radio Shack project, and the Pier 1 project.

- Added cross-section descriptions.

- Changed blocked obstructions to ineffective flow to account for storage.

- Redefined effective flow limits on upper West Fork.

- Redefined effective flow limits on upper Clear Fork near Overton Park channel.

- Redefined channel stations at Meandering Road, Carswell Access Road, University Drive, and Rogers Road.

- Due to the new definition of the West Fork and Clear Fork river centerline, the channel stations are slightly different in the new HEC-RAS model from the current CDC Model.

- The new HEC-RAS model represents the new topography/bathymetry to the limits noted above. Upstream of these upper limits, the current CDC Model geometry is used (along with the modifications stated above).

- Note that the new HEC-RAS model has one geometry file to run with all of the discharges (from the 2-year flood to SPF), as compared to the then current CDC Model which has separate High Flow and Low Flow plans and geometries. This was done to simplify the analysis. Additional comparative analysis was performed to ensure that combining the High Flow and Low Flow plan geometries produced the same water surface profiles as the High Flow and Low Flow plan geometries do separately.

5.9.4 Calibration of the HEC-RAS model

5.9.4.1 General

Information that can be useful in the development of a backwater numerical model includes surveyed high watermarks from a flood event, stream gage rating curves, and flow measurements. There are three USGS stream gages within the Central City HEC-RAS model area: West Fork at Beach Street Gage (located at Beach Street), West Fork at Fort Worth Gage (located upstream of Nutt Dam), and the Clear Fork at Fort Worth Gage (located upstream of City Dam No. 2). There is a scarcity of high watermarks within the Fort Worth Floodway - the only high watermark measurements of significant flow since the project has been completed in the 1970s are those recorded at various flood events by the USGS at the three gages. The 1990 flood was the largest flood event within the Fort Worth Floodway since its completion.

The new Central City topography and bathymetry was used in the generation of cross-sections in the HEC-RAS model. Bridge surveys, bridge plans, USACE channel surveys, and field measurements were used to complete the input data requirements. The original Fort Worth Floodway design roughness values were used to represent the overbank and river channel conditions within the limits of the project. The Fort Worth Floodway is a maintained system - the roughness values of the channel and overbanks may vary as maintenance operations are performed throughout the year, e.g. mowing, brush control/removal, etc. Using the original design roughness values is a logical assumption based on experience modeling the river and knowledge of the Fort Worth Floodway, especially considering that the measured discharges at the gages represent project conditions at specific points in time.

5.9.4.2 Calibration/Verification/Validation

The modeling process requires three steps to develop a data set that produces good, meaningful results that adhere to accepted engineering principles and theories, logic, and engineering experience - these three steps are calibration, verification, and validation. As part of the calibration/verification process, the outputs of the HEC-RAS model were compared to the three USGS gage rating curves and the stage/flow measurements of several flood events, obtained by the USGS, where applicable. Comparison of this data compares favorably to the HEC-RAS model outputs - no adjustment to the model (change of roughness values) was performed on the West Fork and Clear Fork reaches within the limit of the Fort Worth Floodway. Note that adjustments were made to the HEC-RAS model during this process in the reach downstream of Beach Street, which is downstream of the Fort Worth Floodway. The USACE is confident, based on engineering experience, that the parameters defined in the HEC-RAS model are valid for larger discharges, and supports the extension of the calibration/verification range model to the rarer floods events.

The following portion of this calibration section includes tables and rating curves comparing the HEC-RAS model outputs to the respective gage data. The HEC-RAS flows indicated in the following tables were generated in the 2008 analysis of the upper portion of the Trinity River watershed in the Fort Worth area.

These three USGS measurements were recorded at the upper Northside Drive bridge. The HEC-RAS discharges listed in the above table are from the 2009 Trinity River basin revised HEC-1 hydrology model. These are Future Conditions discharges (note: 12,100 cfs = 2 year flood, 18,700 cfs = 5 year flood, 25,900 cfs = 10 year flood). These discharges are used as a comparison since they are closer to the measured discharges than the Existing Conditions (year 2000) discharges.

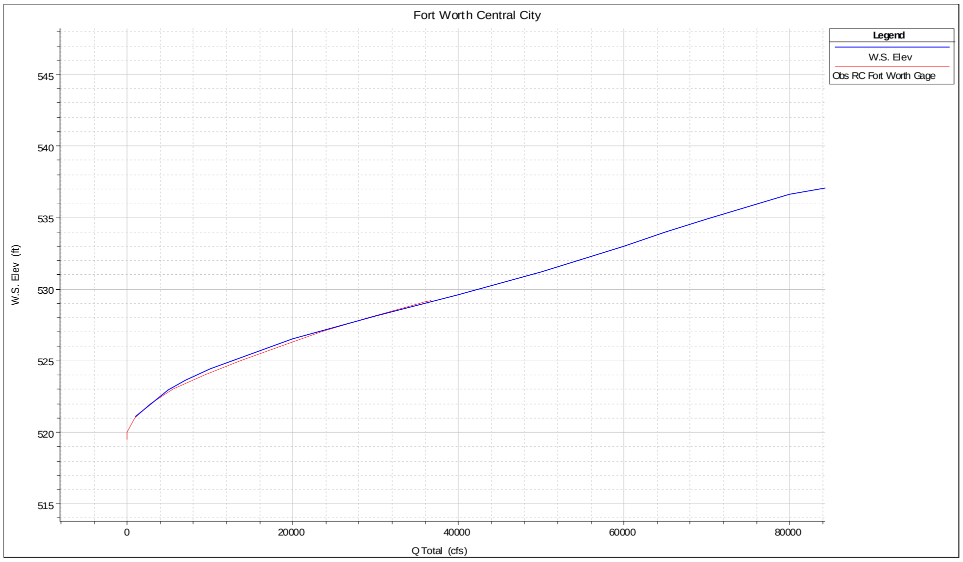


Figure 5-5. West Fork Trinity River at Fort Worth (Gage 08048000) Comparison of HEC-RAS Model (Blue) and Gage Rating Curve (Red)

Table 5-1. West Fork Trinity River at Fort Worth (Gage 08048000)					
Table of Gage Data and HEC-RAS Results					
	Date of Measurement	Flow (cfs)	Gage Height (feet)	Water Surface Elevation (feet)	Velocity (fps)
	18 May 1989	13,400	5.70	524.94	4.86
HEC-RAS Model		12,100	-	524.94	3.55
	2 May 1990	25,200	8.07	527.13	5.77
HEC-RAS Model		26,000	-	527.51	4.70
	9 June 2004	17,100	6.31	525.55	4.75
HEC-RAS Model		18,700	-	526.29	3.98

Table 5-2. Clear Fork Trinity River at Fort Worth (Gage 08047500)					
Table of Gage Data and HEC-RAS Results					
	Date of Measurement	Flow (cfs)	Gage Height (feet)	Water Surface Elevation (feet)	Velocity (fps)
	4 May 1990	6,240	12.60	545.51	5.20
HEC-RAS Model		7,200	-	545.90	4.66

The USGS measurement was recorded at the Vickery Street bridge. This was the largest flow measured at the gage within the past 20 years. The HEC-RAS flow listed in the above table is from the 2008 analysis of the Trinity River basin revised HEC-1 hydrology model. This is the Existing Conditions (year 2000) flow (note: 7,200 cfs = 2 year flood).

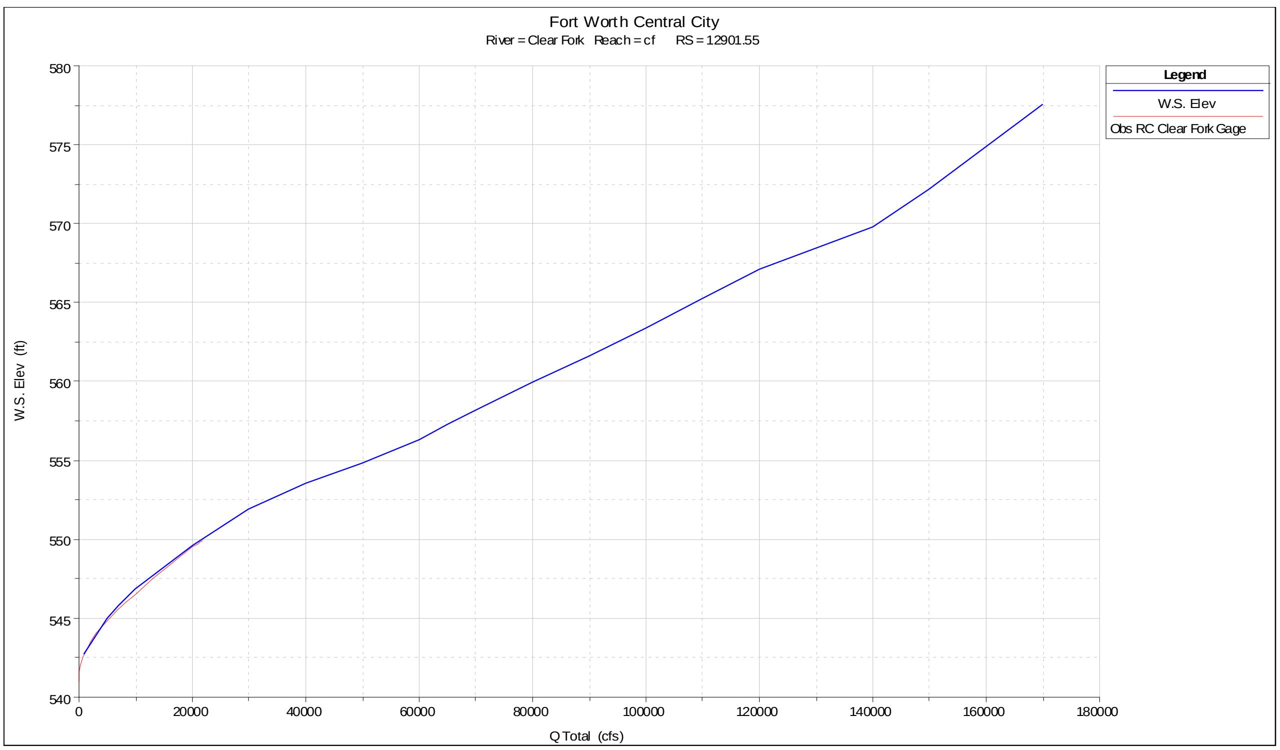


Figure 5-6. Clear Fork Trinity River at Fort Worth (Gage 08047500) Comparison of HEC-RAS Model (Blue) and Gage Rating Curve (Red)

Table 5-3. West Fork Trinity River at Beach Street (Gage 08048543)					
Table of Gage Data and HEC-RAS Results					
	Date of Measurement	Flow (cfs)	Gage Height (feet)	Water Surface Elevation (feet)	Velocity (fps)
	10 June 2004	16,400	28.05	506.75	2.60
HEC-RAS Model		17,300	-	506.27	2.82

The HEC-RAS flow listed in the above table is from the recent Trinity River basin revised HEC-1 hydrology model. This is the Existing Conditions (year 2000) flow (note: 17,300 cfs = 2 year flood).

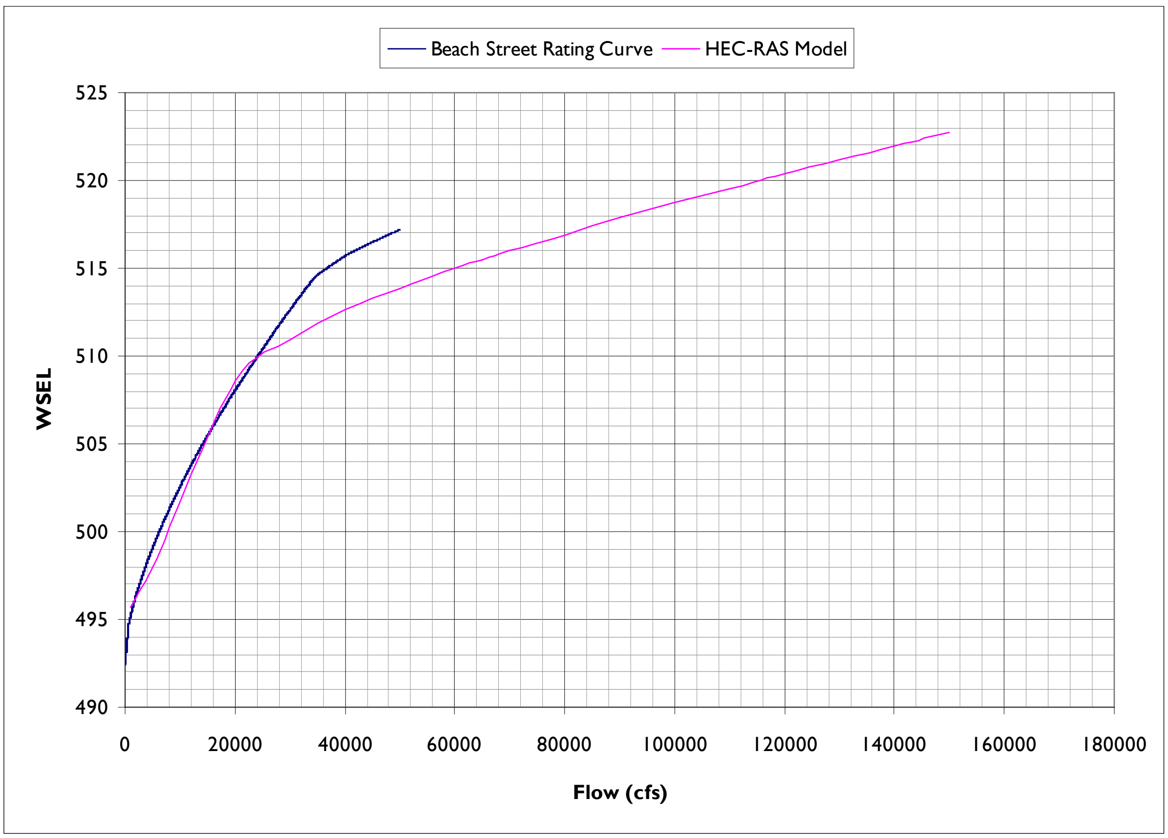


Figure 5-7. West Fork Trinity River at Beach Street (Gage 08048543) Comparison of HEC-RAS Model (Pink) and Gage Rating Curve (Blue)

The HEC-RAS model compares favorably with the gage rating curve for in-channel discharges (up to 24,000 cfs). This was achieved by increasing the West Fork river channel roughness values downstream of the modified channel to East First Street. However, modification of the HEC-RAS model to produce a better match to the gage rating curve for the out-of-channel higher discharges proved to be problematic. To achieve a better curve match, changes to the floodplain roughness values in the HEC-

RAS model, contrary to accepted published sources and experience, would be necessary. These changes were not implemented and the HEC-RAS model was completed with parameters determined as representative and appropriate of the floodplain conditions from Beach Street to East 1st Street.

5.10 West Fork Trinity River

5.10.1 Development of Model

Several projects in the vicinity of Belt Line Road in the Grand Prairie/Irving area were incorporated into the model – these projects include Belt Line West Reclamation, Hunter-Ferrell Road, and the Belt Line Road Extension. This lower reach of the West Fork consists of new topographic data and a revised split flow analysis within the Bear Creek area.

The SH 161 bridge was incorporated in the model upstream of split flow reach.

The Viridian project was incorporated into the model. This project is located in Arlington in the left overbank between SH 360 and FM 157. Two split flows were incorporated at SH 360 through the south relief bridge and through FM 157. The Ballpark Way bridges associated with the Viridian project were removed from the model per the City of Arlington instructions.

5.10.2 Split Flow Analysis at Belt Line Road in Grand Prairie and Irving

The area in the vicinity of Belt Line Road in Grand Prairie and Irving was remodeled. There are several CDC projects in the general area that were incorporated in the CDC Model: Belt Line West Reclamation, Hunter-Ferrell Road, Palace Parkway Hotel Addition, 28 Acre Site, SH 161, and the Belt Line Road Extension. The split flow reach that extends from upstream of MacArthur Boulevard, around the GPMURD Levee, along the Bear Creek floodplain north of Wildlife Parkway was reanalyzed using data from these projects. The Belt Line West reclamation used 1999 2-foot contour interval topography and 2001 NCTCOG topography and replaced the Lone Star Jockey Club project, located upstream of Belt Line Road, that was in the previous CDC Model.

The split flow analysis consisted of two reaches: the main West Fork river channel (wf2) and the Bear Creek split flow area (wfs). A detailed model of wfs was used which was generated for the Belt Line West Reclamation project. The split flow balances the energy gradient (EG) at the upstream end of both reaches at Hardrock Road, where flow spills over the roadway from the West Fork floodplain and enters the Bear Creek overflow area. For the 100-year flood, the discharge of 106,000 cfs at West Fork Below Big Bear Creek (WFBBRC) was used throughout the spilt flow reach. No intervening flows were included in the analysis. The results of the analysis show the distribution of flows as follows: 91,500 cfs in the West Fork (wf2) and 14,500 cfs in the Bear Creek spilt flow area (wfs).

5.11 Storage Model

5.11.1 Model Development – Upper Trinity River Feasibility Study (UTRFS) 1990s

The "Upper Trinity River Regional EIS (1988)" focused on the issue of floodplain storage and included several scenarios depicting loss of valley storage in the upper Trinity River floodplain. For the UTRFS, separate storage models were specifically developed to account for available floodplain storage. Previous river model studies did not account for storage in this way.

The CDC Model developed by the USACE in the UTRFS, and used to evaluate CDC applications, is essentially a conveyance model. The geometric cross-section data represents the effective flow limits for a range of flood event discharges (2-year to SPF). As part of the development of the CDC Model in the UTRFS, separate HEC-2 storage models for each river reach were developed in order to quantify floodplain storage in the upper Trinity River watershed. These storage models were used to compute routing data for use in the upper Trinity River HEC-1 watershed model. The HEC-2 program did not have the capability to model both conveyance and storage in the same model, therefore separate conveyance and storage models were necessary. The cross-sections were specifically developed to account for floodplain storage by representing full floodplain storage beyond the effective flow limits of the conveyance model. The cross-sections accounted for low areas, gravel pits, etc. that were not part of floodplain conveyance. Both the HEC-2 conveyance and storage models utilized the same cross-section locations and split flow areas.

The steps in the development of the CDC Model in the UTRFS were as follows:

(1) Permitted projects were incorporated into the conveyance model.

(2) A full range of discharges (low to high) that were to be evaluated in the HEC-2 storage models were run in the conveyance model.

(3) The resulting water surface elevations at each cross-section for each discharge (rating curve) were incorporated into the same cross-sections using the same discharges in the storage model by use of a utility program developed by the USACE. A special HEC-2 program that could accommodate 500 GR points was used for the storage model. This allowed for the use of the original contractor-generated cross-sections. The majority of these cross-sections consisted of more than 100 points and represented the floodplain topography in great detail.

(4) The resulting storage routing data was incorporated into the HEC-1 model.

(5) Peak discharges for eight flood events incorporated into the CDC Model (the HEC-2 conveyance model).

5.11.2 Updated CDC Model (2012)

In this study update, one unified HEC-RAS model was developed to account for both conveyance and storage. The HEC-RAS program has the capability to model both conveyance and storage at the same time. The CDC Model cross-sections were extended by use of the original digitized cross-section data used in the UTRFS described in the paragraph 5.11.1. A typical cross-section graphical representation is shown in Figure 5-8 below.

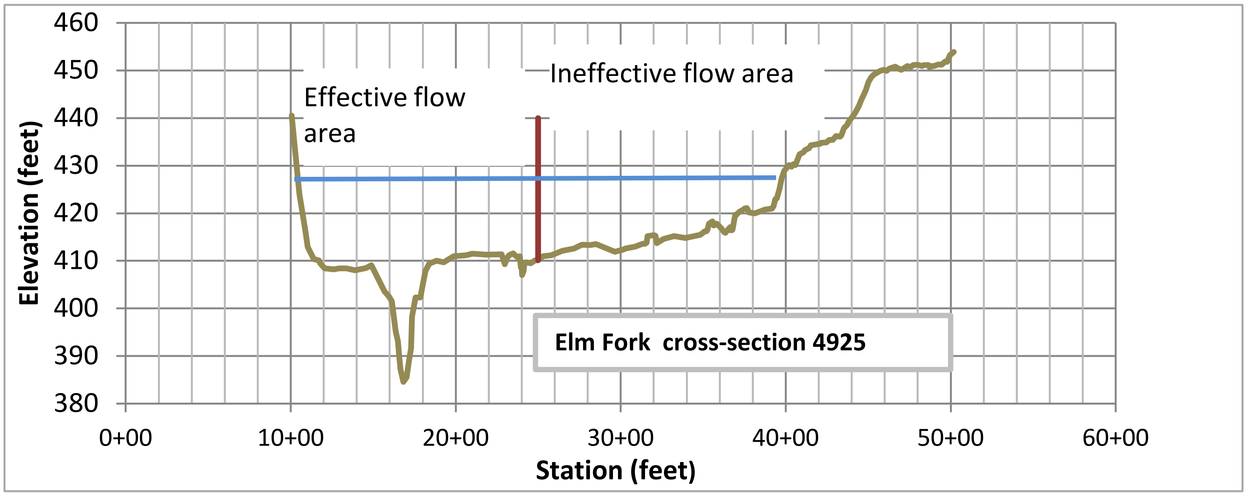


Figure 5-8. Typical cross-section.

The development of the storage models included the following items:

- Cross-sections in the lower Elm Fork and lower West Fork were extended as well as many other areas of the model to replicate the storage models used in the UTRFS study and account for storage areas.

- The ineffective flow areas that were originally represented in the UTRFS CDC Model by use of ground points were replaced with ineffective flow areas where possible. This caused storage to be counted while maintaining the water surface profile.

- Mountain Creek storage from the West Fork to Mountain Creek Dam was computed separately and added in the lower West Fork routing reach. This model was supplied to the USACE by the City of Grand Prairie. The model was developed as a Flood Protection Plan for the city of Grand Prairie in 2009.

- A separate storage model was utilized for the Trinity River main stem which specifically accounted for floodplain storage in the Trinity River floodplain.

- Storage for several of the CDC projects was computed outside of the HEC-RAS program by use of surface/volumetric programs. Many of the project storage areas are complex shapes that the HEC-RAS program cannot completely model, therefore, as the CDC Manual allows, other means to compute storage have been utilized. These methods show that the 100-year and SPF storage requirements have been met, however it is difficult to replicate the exact storage that these methods compute in the HEC-RAS model representation of the proposed project.

- The same storage relationships at the West Fork/Elm Fork confluence and the West Fork/Clear Fork confluence that were used in the UTRFS were used in this study. An estimate of the percent flow contribution of the Elm Fork and West Fork that forms the total peak flows below the West Fork/Elm Fork confluence was developed based on previous hydrology and was used to determine flows and corresponding water surface elevations for the Elm Fork and West Fork.

- The Elm Fork storage model developed in this study includes the split flow reach (efs1) located downstream of Royal Lane. This split flow reach was originally developed after the conveyance and storage models were finalized in the UTRFS, therefore it was not used for the computation of storage routing data at that time.

- The starting water surface elevations (boundary condition) in the HEC-RAS model at the downstream end of the study area (Trinity River main stem) were determined from a rating curve at cross-section 25457 (see Figure 5-9 below). The rating curve was generated from the USACE Trinity River LRD-1 models in the 1970s, updated in the 1990s, that model the Trinity River from Dallas to Houston.

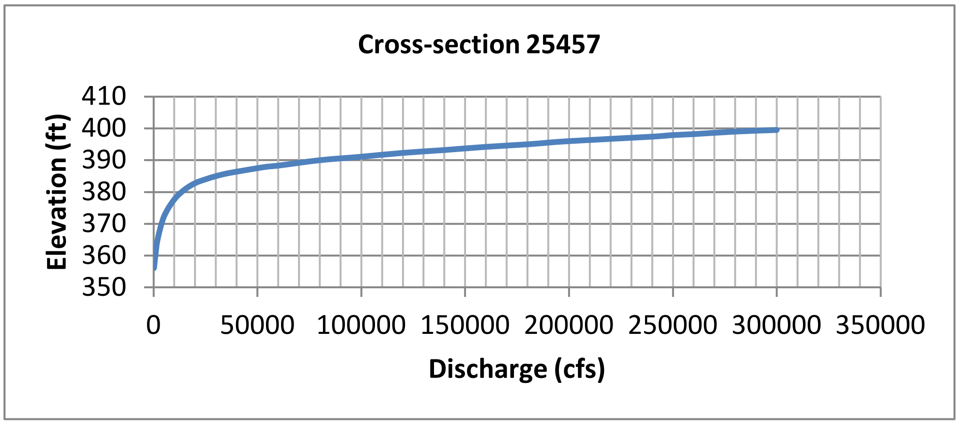
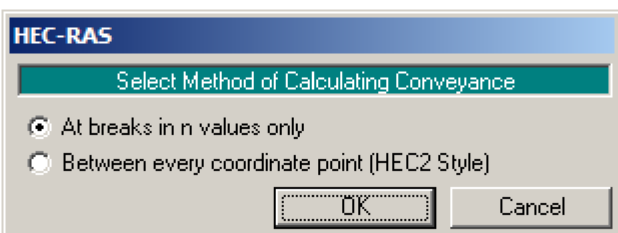
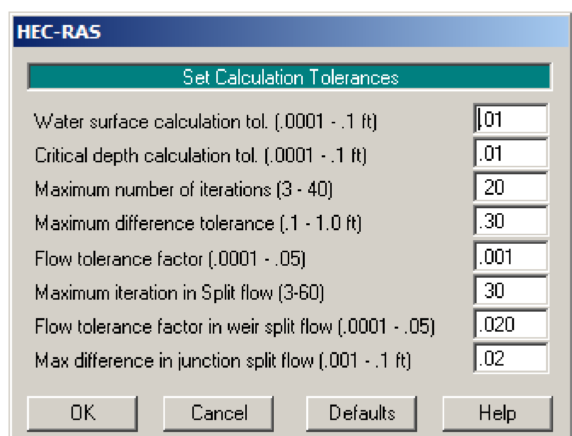


Figure 5-9. Cross-section 25457 Rating Curve

5.11 CDC Model Settings

The following are the default parameters used in the HEC-RAS computations.





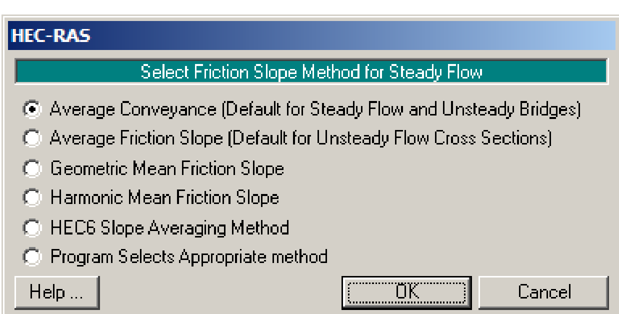


TABLE 5-4. CDC TRACKING

ARLINGTON

CDC Application			Status								
Year	Project Name	CDC Number	CDC Granted		Granted With Variance	Exemption Granted	Project Constructed			Project in CDC Model	
			Yes	No			Yes	No		Yes	No
1994	Metroworld	ARL 110394-01	✓					✓	See Viridian project.		✓
1997	North Arlington Recreation Center	ARL 100397-01	✓				✓				✓
1997	Links at Water Chase	ARL 031397-01	✓				✓			✓	
1997	Lakes of Arlington	ARL 091797-01	✓					✓	See Viridian project.		✓
2000	SH 360 Erosion Control	ARL 012400-01	✓			✓	✓				✓
2002	Trinity River Regional Park at Collins Street	ARL 070802-02	✓				✓				✓
2002	Preston Estates Convenience Store	ARL 070102-01	✓			✓	✓				
2005	SVC Park Highlands	ARL 071405-01	✓				✓			✓	
2007	John F. Kubala WTP Expansion	ARL 120607-01	✓			✓	✓				✓
2007	Viridian Project	ARL 062007-01	✓					✓	Under construction.	✓	
2010	City of Arlington Landfill Project	ARL 021910-01	✓					✓		✓	
2011	Greenman Well Site	ARL 021511-01	✓				✓			✓	

CARROLLTON

CDC Application			Status								
Year	Project Name	CDC Number	CDC Granted		Granted With Variance	Exemption Granted	Project Constructed		Comments	Project in CDC Model	
			Yes	No			Yes	No		Yes	No
1995	12.63,7.78 Ac. Tract for industrial office site	CAR 030695-01	✓					✓			✓
1996	Dallas Gun Club	CAR 021696-01		✓				✓	Project abandoned.		✓
1996	Four Parcel Pratt Tract	CAR 091996-01	✓				✓		No data available.		✓
1997	Coyote Ridge Golf Club	CAR 110497-01	✓				✓			✓	
1997	NW of IH-35 and Trinity Mills Road	CAR 030397-01	✓					✓	No data available.		✓
1998	PGBT - IH35E to east of Dickerson Pkwy	CAR 092898-01	✓				✓			✓	
1999	Belt Line and Luna	CAR 080299-01	✓					✓	Project abandoned.		✓
2002	Indian Creek Golf Course	CAR 040202-01	✓				✓			✓	
2002	PGBT - Segment IV (I-35 to I-635)	CAR 012102-01	✓				✓			✓	
2004	T.C. Rice, Jr. Athletic Complex	CAR 062504-01		✓				✓	Project abandoned.		✓
2005	Western Extrusions Corporation	CAR 103105-01	✓				✓		See CAR 040507-01.		
2007	McInnish Park Athletic Complex	CAR 100307-01	✓			✓	✓				✓
2007	Western Extrusions Corporation	CAR 040507-01	✓				✓		Outside conveyance area.		✓
2009	Elm Fort WTP Pre-Sedimentation Basins	CAR 062309-01	✓					✓		✓	
2010	Gateway Distribution Warehouse	CAR 122210-01	✓			✓	✓				✓
2011	Luna Road #2 LP	CAR 032511-01	✓					✓		✓	
2011	Luna Road LP	CAR 032511-02	✓					✓		✓	

COPPELL

CDC Application			Status								
Year	**Project Name**	**CDC Number**	**CDC Granted**		**Granted With Variance**	**Exemption Granted**	**Project Constructed**		**Comments**	**Project in CDC Model**	
			Yes	**No**			**Yes**	**No**		**Yes**	**No**
1995	Sandy Lake Road and McInnish Park	COP 082295-01	✓				✓				✓
1996	Sandy Lake Road Property	COP 073096-01	✓					✓	Project abandoned.		✓
1999	Windsor Estates	COP 070199-01	✓				✓			✓	
2001	Estates of Denton Creek	COP 092301-01	✓					✓			✓
2010	1550 E. Belt Line Road	COP 082310-01	✓					✓		✓	
2012	River Oaks Assisted Living and Memory Care	COP050812-01	?	?	?	?	?	?		✓	

DALLAS											
CDC Application			**Status**								
Year	**Project Name**	**CDC Number**	**CDC Granted**		**Granted With Variance**	**Exemption Granted**	**Project Constructed**		**Comments**	**Project in CDC Model**	
			Yes	**No**			**Yes**	**No**		**Yes**	**No**
1994	Sandy Lake Road	DAL 071294-01	✓				✓			✓	
1996	Cell Tower #276	DAL 031396-01	✓				✓		No data available.		✓
1996	Rosebriar River Crossing, LP	DAL 081996-01	✓				✓		No data available.		✓
2000	DEA Laboratory Facility	DAL 021800-01	✓				✓			✓	
2000	Trinity River Boat Ramps	DAL 121500-01	✓				✓			✓	
2000	Simpson Stuart Road	DAL 072100-01	✓				✓			✓	
2000	Frasier Dam Modifications	DAL 021200-01	✓		✓		✓		See DAL 021201-01.		✓
2001	Dallas Floodway Extension	DAL 070601-01	✓		✓		✓		Portion of project constructed.	✓	
2001	Frasier Dam Modifications	DAL 021201-01	✓		✓		✓			✓	
2001	B & B Lakes Office Site	DAL 050901-01	✓				✓			✓	
2003	Oncor Sargent Road Substation	DAL 060603-01	✓				✓			✓	
2004	Trash King Transfer and Recycling Station	DAL 110504-01		✓				✓	Application withdrawn.		
2005	Hampton/Inwood Bridge	DAL 122205-01	✓			✓	✓			✓	
2005	Woodall Rogers Freeway Extension	DAL 051805-01	✓				✓			✓	
2006	Railroad Bridge at Richards Branch	DAL 051006-01	✓			✓	✓				✓
2006	DAF Building	DAL 052406-01	✓			✓	✓				✓
2007	Moore Park Gateway Phase 1	DAL 061307-01	✓				✓			✓	

DALLAS

CDC Application			Status								
Year	**Project Name**	**CDC Number**	**CDC Granted**		**Granted With Variance**	**Exemption Granted**	**Project Constructed**		**Comments**	**Project in CDC Model**	
			Yes	**No**			**Yes**	**No**		**Yes**	**No**
2007	EF-7 Elm Fork Relief Sewer Replacement	DAL 060507-01	✓			✓	✓				✓
2008	California Crossing at Elm Fork	DAL 071508-01	✓					✓	Pending construction.	✓	
2008	Trinity River Standing Wave at Moore Park	DAL 090508-01	✓				✓			✓	
2008	UPRR Bridge 260.18, Ennis Subdivision	DAL 091008-01	✓				✓			✓	
2009	Santa Fe Trestle Trail	DAL 010909-01	✓				✓			✓	
2009	Elm Fork Flood Control	DAL 022309-01		✓				✓	On hold.		✓
2009	DWU EB/WB Interceptor	DAL 052209-01	✓					✓	Under construction.	✓	

DALLAS COUNTY											
CDC Application			**Status**								
Year	**Project Name**	**CDC Number**	**CDC Granted**		**Granted With Variance**	**Exemption Granted**	**Project Constructed**		**Comments**	**Project in CDC Model**	
			Yes	**No**			**Yes**	**No**		**Yes**	**No**
1999	Meyers Road	DC 072699-01		✓				✓	Application abandoned.		✓
2003	Meyers Road	DC 040803-01	✓					✓	CDC extended. ROW being acquired.	✓	

FARMERS BRANCH											
CDC Application			**Status**								
Year	**Project Name**	**CDC Number**	**CDC Granted**		**Granted With Variance**	**Exemption Granted**	**Project Constructed**		**Comments**	**Project in CDC Model**	
			Yes	**No**			**Yes**	**No**		**Yes**	**No**
2002	Mercer Crossing/Manhattan Tract	FB 071002-01		✓				✓	Application abandoned.		✓

FORT WORTH											
CDC Application			**Status**								
Year	**Project Name**	**CDC Number**	**CDC Granted**		**Granted With Variance**	**Exemption Granted**	**Project Constructed**		**Comments**	**Project in CDC Model**	
			Yes	**No**			**Yes**	**No**		**Yes**	**No**
1996	West Side Lions Little League	FW 081296-01	✓				✓			✓	
1996	4th Street Low Water Dam	FW 121296-02	✓				✓			✓	
1997	Randol Mill Road - Phase 1 & 2	FW 021297-01	✓				✓			✓	
1998	Beach Street Low Water Dam	FW 112598-01	✓			✓	✓			✓	
1998	The Lodge at River Park	FW 020698-01	✓			✓					✓
1999	Gateway Project	FW 082399-01	✓				✓			✓	
1999	Fort Worth TS/MRF	FW 042399-01	✓				✓		No data available.		✓
1999	Links at Water Chase	FW 070799-01	✓				✓			✓	
2000	Go-Kart Maintenance Facility	FW 052600-01		✓				✓	Project abandoned.		✓
2000	Dyer Addition	FW 070700-01	✓				✓			✓	
2000	Lakeview Addition	FW 020400-01	✓				✓		Outside conveyance area.		✓
2002	Radio Shack Corp Headquarters	FW 080602-01	✓				✓			✓	
2003	Riverpark Addition	FW 111303-01		✓				✓	See FW 020105-01.		✓
2003	Riverbend West Trussway Addition	FW 050103-01	✓				✓			✓	
2004	Proposed Gas Well at Duck Lake No. 1	FW 122804-01	✓				✓			✓	
2005	Bell Station Addition	FW 121505-01	✓				✓			✓	
2005	Riverpark Addition (mod of FW 111303-01)	FW 020105-01	✓				✓			✓	

FORT WORTH											
CDC Application			Status								
Year	Project Name	CDC Number	CDC Granted		Granted With Variance	Exemption Granted	Project Constructed		Comments	Project in CDC Model	
			Yes	No			Yes	No		Yes	No
2005	Village Creek WWTP TR Pipeline Crossing	FW 010505-01	✓			✓	✓				✓
2005	RA and R Soccer Rugby Fields at Gateway	FW 092205-01	✓			✓	✓				✓
2006	Wal-Mart at University and Jacksboro	FW 101906-01		✓				✓	Application abandoned.		✓
2007	Rocking River M Equestrian Center	FW 022307-01	✓				?			✓	
2008	Central City	FW 090808-01	✓						Only constructed portion in model.	✓	
2009	Clear Fork Main Street Bridge	FW 110209-01	✓				✓		Under construction.	✓	
2009	WF-6 and WF-14 Interceptor Relief Project	FW 102809-01	✓			✓	✓				✓
2009	SH 121/Southwest Parkway	FW 111809-01	✓						Under construction.	✓	
2009	Union Pacific Railroad Bridge 248	FW 072209-01	✓				✓			✓	
2010	7th Street Bridge Replacement	FW 062310-01	✓		✓			✓		✓	
2010	Lancaster Pedestrian Bridge	FW 040910-01	✓						Under construction.	✓	
2011	Quicksilver Resources Pad Site	FW 022811-01	✓				✓			✓	
2011	Expansion Goodman A Gas Well Pad Site	FW 121411-01	✓				?	?		✓	
2012	XTO – Bass Arlington Well Pad Site	FW 041812-01	✓				✓			✓	

GRAND PRAIRIE											
CDC Application			Status								
Year	Project Name	CDC Number	CDC Granted		Granted With Variance	Exemption Granted	Project Constructed		Comments	Project in CDC Model	
			Yes	No			Yes	No		Yes	No
1995	TRA Influent Junction Box and Pipe Rehab.	GP 050795-01	✓			✓	✓				✓
1995	Riverside Development	GP 041795-01	✓				✓			✓	
1997	I-30 Sowell Tract	GP 072497-01	✓					✓	Project abandoned.		✓
1998	Grand Prairie Ford Site	GP 040198-01	✓				✓		No data available.		✓
1999	Great Southwestern Development	GP 120299-01	✓					✓	See GP 121400-04.		✓
2000	TRA Relief Interceptor WF-1 for CWWTP	GP 042800-02	✓				✓			✓	
2000	Great Southwestern Development	GP 121400-04	✓				✓			✓	
2000	I-30 Sowell Tract	GP 072400-03		✓				✓	Application abandoned.		✓
2000	TRA Relief Interceptor WF-11B	GP 011000-01	✓			✓	✓				✓
2003	Grand Prairie Park and Ride	GP 120903-01	✓					✓	Project relocated outside regulatory zone.		✓
2003	Heydarian Project	GP 120103-01		✓				✓	Application abandoned.		✓
2004	Junction Box 1F	GP 121304-01	✓				✓		Outside effective area.		✓
2004	SH 161	GP 011404-01	✓						Under construction.	✓	
2005	Auto Recyclers	GP 052505-01		✓				✓	Application abandoned.		✓
2007	TRA - West Fork Interceptor 11B	GP 101007-01	✓				✓			✓	
2007	Lone Star Gas Well	GP 051707-01	✓			✓	✓				✓

GRAND PRAIRIE

CDC Application			Status								
Year	Project Name	CDC Number	CDC Granted		Granted With Variance	Exemption Granted	Project Constructed		Comments	Project in CDC Model	
			Yes	No			Yes	No		Yes	No
2008	28 Acre site	GP 020108-01	✓					✓		✓	
2008	Access Road to Pad Site – Equitable Invest.	GP 021908-01	✓				✓				✓
2008	Belt Line West Reclamation	GP 080808-01	✓					✓	Under construction.	✓	
2008	Enterprise Rent-A-Car	GP 100908-01	✓			✓	✓				✓
2008	S & J Stable	GP 102808-01	✓			✓	✓				✓
2009	Palace Parkway Hotel Addition	GP 022409-01		✓				✓	Project abandoned.		✓
2009	On-Site Storage System	GP 100609-01	✓			✓		✓	Construction scheduled 2/2013.		✓
2009	Grand Lakes West Building "A"	GP 101309-01	✓			✓	✓				✓
2010	Palace Parkway	GP 091010-01	✓					✓		✓	
2010	Elmore Site	GP 060210-01	✓			✓	?	?			✓
2010	IH 30 Frontage Road Ramp Relocations	GP 093010-01	✓			✓			Under construction.		
2011	Levee Improvement at Junction Box 1F	GP 040811-01	✓			✓	✓				✓

IRVING											
CDC Application			Status								
Year	Project Name	CDC Number	CDC Granted		Granted With Variance	Exemption Granted	Project Constructed		Comments	Project in CDC Model	
			Yes	No			Yes	No		Yes	No
1995	Doss, Farrow, Sibley Floodplain Reclamation	IRV 061595-01		✓				✓	Application abandoned.		✓
1996	Birds Fort Trail Park	IRV 121896-01	✓				✓		No data available.		✓
1996	Running Bear Park Levee Work	IRV 081596-01	✓				✓		No data available.		✓
1997	O'Connor Blvd. Improvement	IRV 110697-01	✓		✓		✓		No data available.		✓
1997	Bear Creek Sanitary Sewer Segment V	IRV 110697-02	✓			✓	✓				✓
1997	Bronco Fields	IRV 021197-01	✓				✓		No data available.		✓
1999	Running Bear Park	IRV 092499-01	✓				✓		No data available.		
1999	Running Bear Creek Park Phase 2	IRV 092499-02	✓				✓		No data available.		✓
1999	TRE Bridge Over Elm Fork	IRV 092399-01	✓				✓			✓	
2000	TRA Elm Fork Relief Interceptor	IRV 030200-01	✓			✓	✓				✓
2000	Farrow Addition	IRV 030300-01	✓				✓			✓	
2001	University of Dallas Floodplain Reclamation	IRV 050301-01	✓					✓	Under construction.	✓	
2004	Belt Line Road	IRV 120304-01	✓		✓		✓			✓	
2005	Wood Creek Estates	IRV 021705-01	✓				✓				
2005	Pete & Mac's Pet Resort	IRV 080305-01	✓			✓	?	?			✓
2005	North Hills School Addition Phase 1	IRV 101405-01	✓				✓			✓	

IRVING											
CDC Application			Status								
Year	Project Name	CDC Number	CDC Granted		Granted With Variance	Exemption Granted	Project Constructed		Comments	Project in CDC Model	
			Yes	No			Yes	No		Yes	No
2007	SH 114 Improvements	IRV 012607-01	✓					✓	Under construction.	✓	
2007	Hunter Ferrell Road Improvements	IRV 081607-01	✓					✓	Under construction.	✓	
2008	O'Conner Substation	IRV 012908-01	✓				✓			✓	
2008	DART Bridge Elm Fork	IRV 110308-01	✓				✓			✓	
2009	IFCD -1 Levee Repair and Seepage Control	IRV 082109-01	✓					✓	Under design.	✓	
2010	Campion Trail Bridges over the Elm Fork	IRV 021110-01		✓				✓	Application pending.		✓
2010	Spur 348 at Las Colinas Blvd. in Irving	IRV 031110-01	✓			✓	✓				✓
2011	EF Relief Inter. Segment CAC-11Rehab.	IRV 090111-01	✓			✓		✓	Pending.		✓
2011	Trailer Storage at 1460 Walton Walker Blvd.	IRV 081211-01	✓				✓			✓	
2012	Elm Fork Relief Interceptor Segment EF-2	IRV 121312-01	✓			✓		✓	Pending.		✓

LEWISVILLE												
CDC Application			Status									
Year	Project Name	CDC Number	CDC Granted		Granted With Variance	Exemption Granted	Project Constructed		Comments	Project in CDC Model	
			Yes	No			Yes	No		Yes	No
1996	SH121 Lewisville Bypass	LEW 011796-01	✓				✓				
1996	50 Acre, Pratt Tract	LEW 062496-01	✓				✓				✓
1996	Phase IB, Section 4 Water Pipeline	LEW 031996-01	✓			✓	?	?			✓
1997	Waste Management Slurry Wall	LEW 091297-01	✓				✓		No change in land contours.		✓
1998	Thompson Tract	LEW 090398-01	✓				✓		No data available.		✓
1999	Boat City Addition	LEW 101199-01	✓				✓		No data available.		✓
2000	Waste Management Scale Site	LEW 051600-01	✓				✓		Project relocated within landfill footprint.		✓
2001	Lewisville Water Storage Tanks	LEW 052401-01	✓				✓			✓	
2002	Vista Ridge Golf Center	LEW 050102-01	✓				✓			✓	
2002	Waste Management Excavation	LEW 102202-02	✓				✓		See LEW 121416-01. Under construction.	✓	
2004	Trinity Place Project	LEW 042104-02	✓				✓			✓	
2004	Lewisville Landfill	LEW 012804-01	✓				✓		See LEW 121416-01. Under construction.	✓	
2005	IH 35E HOV lanes	LEW 090805-01	✓			✓	?	?			✓
2005	Elm Fork Trunk Sewer	LEW 042705-01	✓			✓	✓				✓
2005	Lewisville Athletic Complex	LEW 110305-01	✓				✓			✓	
2005	Elm Fork Retail Storage Supercenter	LEW 110705-01	✓			✓	✓				✓
2006	Waste Management Systems Landfill	LEW 121406-01	✓						Under construction.	✓	
2011	Camelot Landfill	LEW 063011-01	✓					✓		✓	

5.12 Results of Analysis

The CDC Model results for the 100-year flood and SPF water surface elevations from this study, compared to the CDC Manual 4th Edition June 2010 100-year flood and SPF water surface elevations, for selected points in the study area are shown in Table 5-5.

Table 5-5. Water Surface Elevation Comparison

Location/Cross-section	100-year Flood			SPF		
	2013 Study	CDC Manual 4th Edition 2010	Difference (feet)	2013 Study	CDC Manual 4th Edition 2010	Difference (feet)
Clear Fork						
Hulen Street [24191]	569.7	567.17	2.5	577.1	575.78	1.3
University Drive [16054]	559.9	557.89	2.0	566.1	564.52	1.6
Lancaster Avenue [6085.75]	545.4	543.20	2.2	556.5	554.69	1.8
Henderson Street [1396.94]	541.6	539.15	2.5	553.5	551.58	1.9
West Fork						
SH 183 [288551.7]	554.1	554.01	0.1	563.7	561.86	1.8
University Drive [261868]	542.9	540.81	2.1	555.2	552.96	2.2
North Main Street [252580.2]	536.4	534.67	1.7	546.5	544.70	1.8
Northside Drive [244071]	530.3	528.30	2.0	541.7	540.09	1.6
Beach Street [218297]	517.0	516.39	0.6	523.0	522.68	0.3
IH 820 [178377]	501.7	501.48	0.2	507.7	508.52	-0.8
Precinct Line Road [154404]	486.1	485.85	0.2	491.1	490.54	0.6
Trammel-Davis Road [127873]	480.5	480.04	0.5	487.8	486.52	1.3
SH 360 [80913]	465.4	464.12	1.3	472.1	471.13	1.0
NW 19th Street [61158]	452.8	452.08	0.7	458.1	457.75	0.4
Belt Line Road [44153]	441.2	440.04	1.2	447.7	447.09	0.6
Macarthur Boulevard [28749]	437.0	436.09	0.9	444.6	443.63	1.0

Table 5-5 (continued). Water Surface Elevation Comparison

Location/Cross-section	100-year Flood			SPF		
	2013 Study	CDC Manual 4th Edition 2010	Difference (feet)	2013 Study	CDC Manual 4th Edition 2010	Difference (feet)
West Fork						
Loop 12 [9617]	427.5	426.59	0.9	439.4	438.06	1.3
Elm Fork						
SH 121 [147301]	461.1	461.68	-0.6	464.2	464.74	-0.5
IH 35E [110174]	450.0	450.44	-0.4	452.9	452.97	-0.1
Sandy Lake Road [93212]	444.2	444.52	-0.3	448.5	449.45	-1.0
Belt Line Road [87339]	440.2	440.62	-0.4	445.8	446.77	-1.0
Royal Lane [58532]	433.2	432.71	0.5	441.2	440.92	0.3
Northwest Highway [48712]	431.2	430.51	0.7	440.9	440.49	0.4
Loop 12 [29320]	427.6	426.73	0.9	439.2	438.37	0.8
SH 183 [14411]	425.8	424.75	1.0	438.3	437.05	1.3
Irving Boulevard [4760]	424.8	423.93	0.9	437.6	436.07	1.5
Trinity River Main Stem						
Westmoreland Road [140646]	422.3	421.51	0.8	435.5	433.97	1.5
Commerce Street [120693]	417.6	416.83	0.8	430.3	429.01	1.3
IH 30 [118611]	417.0	416.28	0.7	429.6	428.38	1.2
Houston Street [116185]	416.1	415.42	0.7	428.4	427.18	1.2
IH 35E North [114116]	415.6	414.90	0.7	427.4	426.34	1.1
ATSF Railroad [108276]	413.8	413.26	0.5	424.9	423.90	1.0
SH 310 [90458]	407.5	407.17	0.3	417.5	416.54	1.0

6.0 Conclusion

The updated future conditions hydrology models for the upper Trinity River watershed produced increased peak discharges due to the projected urbanization within the watershed. However, the Elm Fork experienced a decrease in peak discharges in the upper reaches for the 100-year flood and an overall decrease for the Standard Project Flood. This is primarily due to the storage routing in the Elm Fork and increased urbanization that changed the timing of the hydrographs.

This study also illustrates how proposed CDC projects have met the CDC criteria for no loss of valley storage for the 100-year flood and no more than 5 percent loss for the Standard Project Flood but have redistributed the compensatory valley storage within the project reach. This resulted in adverse changes to the shape and timing of the hydrographs. This illustrates the need for further discussion regarding the valley storage requirements of the CDC program.

The increased discharges along the Clear Fork, West Fork, Elm Fork, and Main Stem of the Trinity River resulted in increases in the calculated water surface elevations, as expected. In some areas the increase was approximately 2-feet. Other locations experienced only minor changes in water surface elevation. The Elm Fork experienced both increases and decreases in water surface elevation.

A comprehensive list of CDC applications that have been processed from the beginning of the CDC program in the 1990s to November 2012 has been created. The intention is for the NCTCOG and USACE to maintain this spreadsheet in the future.

Appendix A

Table A-1. 2005 and 2055 Sub-area Parameters - Upper Trinity River

Sub-Basin	Area (sq. mile)	Baseline Urbanization (%)	Baseline Imperviousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbanization (%)	Future Imperviousness (%)	Future t_{pR} (hours)
1	683.00	0.33	0.2	100	18.32	0.35	0.33	0.2	18.32
2	149.25	2.43	1.31	100	9.23	0.35	2.43	1.31	9.23
3	97.78	6.56	3.54	100	10.16	0.35	6.56	3.54	10.16
4	160.97	5	4	100	7.40	0.35	5.24	4.17	7.39
5	20.00				**			0	
6	71.17	8.67	6.61	100	6.71	0.66	14.98	11.85	6.46
7	97.46	5.08	2.91	100	5.69	0.66	5.08	2.91	5.69
8	2.34				**			0	
9	69.90	3	2	100	8.93	0.66	3	2	8.93
10	90.10	5.31	3.29	100	9.15	0.66	5.31	3.29	9.15
11	73.20	4.8	3.3	100	7.14	0.66	4.81	3.3	7.14
12	209.83	6.59	4.21	97	8.73	0.66	11.57	7.24	8.50
13	55.65	5.8	4.07	75	4.92	0.66	5.8	4.07	4.92
14	47.52	15.73	10.62	20	1.66	0.66	59.6	34.4	1.27
15	127.45	19.34	11.81	100	7.00	0.66	21.06	14.86	6.93
16	14.38				**			0	
17	13.60	21.88	15.68	30	0.82	0.70	54.81	33.9	0.64
18	74.84	22.89	13.43	50	4.24	0.70	53.34	29.93	3.52
19	5.56				**			0	
20	20.99	56.73	36.14	60	3.55	0.70	66.88	46.73	3.24
21	107.11	4	3.01	100	8.51	0.70	8.4	5.56	8.28
22	1.89				**			0	
23	142.38	18.31	11.18	100	12.54	0.70	35.38	21.13	11.30
24	62.47	4.45	2.62	89	6.35	0.70	18.7	12.85	5.82
25	33.61	3.69	2.23	80	5.74	0.70	18.28	12.46	5.25
26	33.94	17.01	9.11	24	2.62	0.70	48.53	26.47	2.16
27	39.11	12.52	7.73	80	2.22	0.70	55.01	30.73	1.71
28	5.89				**			0	
29	8.45	44.25	27.65	50	1.44	0.70	49.9	31.7	1.39
30	54.70	13.5	8.32	10	3.90	0.60	60.7	36.67	3.10
31	24.56	69.17	41.94	40	1.70	0.70	77.91	48.04	1.61
32	3.96	69.82	55.49	40	0.94	0.70	77.77	66.97	0.86
33	0.40	69.84	54.28	40	0.87	0.70	79.37	66.02	0.79

Table A-1 Continue. 2005 and 2055 Sub-area Parameters - Upper Trinity River

Sub-Basin	Area (sq. mile)	Baseline Urbanization (%)	Baseline Imperviousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbanization (%)	Future Imperviousness (%)	Future t_{pR} (hours)
34	8.91	26.03	15.52	5	1.02	0.70	67.22	39.13	0.79
35	0.38				**			0	
36	13.71	52.89	33.84	0	1.24	0.70	69.87	53.59	1.11
37	10.89	67	46.69	40	1.85	0.70	76.54	60.72	1.67
38	37.33	59	36.85	10	2.53	0.70	68.96	44.55	2.31
39	18.25	59.65	38.93	40	1.86	0.70	62.62	43.51	1.75
40	18.45	44.84	33.51	5	2.26	0.70	72.75	57.85	1.90
41	54.70	36.07	22.94	1	3.62	0.70	67.42	45.4	2.98
42	11.30	38.66	29.71	30	3.05	0.70	57.29	42.39	2.72
43	114.76	30.88	19.3	50	5.87	0.70	69.31	43.17	4.64
44	14.42	61.5	39.64	60	1.36	0.70	74.27	48.47	1.22
45	10.38	72.86	41.96	100	1.64	0.70	79.07	45.58	1.58
46	3.44				**			0	
47	48.63	54.9	33.99	90	5.36	0.70	68.16	41.63	4.94
49	1.79	41.26	32.17	30	1.42	0.70	61.85	41.12	1.25
50	27.29	62.63	41.16	60	2.90	0.70	72.55	46.64	2.81
51	29.47	47.85	36.84	70	4.88	0.70	67.77	51.82	4.32
52	21.60	69	51.52	65	3.47	0.70	77.16	58.1	3.29
53	2.85	59.45	39.44	10	0.78	0.70	64.73	43.4	0.76
54	4.12	45.9	34.52	5	1.40	0.70	53.94	36.65	1.33
55	83.16	49.46	31.06	90	8.56	0.70	73.91	50.72	7.37
56	9.64	49.7	37.76	80	3.18	0.70	62.32	49.72	2.94
58	33.00	14.03	7.44	0	2.92	0.70	23.04	16.52	2.81
59	68.00	34.55	19.89	85	5.62	0.70	69.02	38.68	4.55
60	77.08	12	8	7	2.59	0.70	63.38	46.73	1.89
61	42.25	23.3	14.99	8	1.44	0.70	58.22	40.44	1.16
62	11.67				**			0	
63	30.58	42.52	28.01	5	2.30	0.70	64.03	44.93	2.02
64	17.84	60.48	45.55	5	1.33	0.70	72.26	53.66	1.24
65	10.35	33.46	22.98	5	1.04	0.70	37.05	22.84	1.04
66	4.23				**			0	
67	9.00	38.4	31.03	5	1.27	0.70	44.76	32.02	1.25

Table A-1 Continued. 2005 and 2055 Sub-area Parameters - Upper Trinity River

Sub-Basin	Area (sq. mile)	Baseline Urbaniza-tion (%)	Baseline Impervi-ousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbaniza-tion (%)	Future Impervi-ousness (%)	Future t_{pR} (hours)
68	9.23	74.81	47.94	75	2.38	0.70	77.35	48.44	2.34
69	110.00	1.03	0.79	100	7.00	0.70	2.79	2.64	14.28
70	164.00	3	2	91	7.00	0.70	9.91	6.46	
71	58.00	3.59	2.42	54	3.96	0.70	4.58	4.56	7.67
72	68.00	4.58	2.92	12	3.91	0.70	2.15	1.87	8.04
73	61.32	6.34	3.67	23	4.84	0.70	4	3	
74	36.86	9.07	6.52	5	4.90	0.70	3	3	
75	102.44	10.62	7.66	0	6.73	0.70		0	
76	83.01	28.61	18.5	80	2.75	0.70	44.83	23.57	5.40
77	11.37				**		6.82	3.99	15.50
78	23.63	36.79	27.34	25	3.56	0.70	65.04	36.48	6.60
79	295.00	4	2.5	74	15.78	0.79	42.3	29.67	7.00
80	55.34	10.81	6.9	24	9.13	0.79	54.63	35.32	
81	275.10	2.79	2.64	50	14.28	0.79	39.65	31.09	
82	92.80	2	2	25	*	0.79		0	
110	33.80	4.58	4.56	100	7.67	0.79	37.57	25.47	3.05
83	145.60	2.15	1.87	86	8.04	0.79	43.58	30.42	2.06
111	53.28	4	3	74	*	0.79	64.71	41.64	4.10
109	45.56	3	3	100	*	0.79	65.45	40.94	1.55
84	45.86				**		1.03	0.79	7.00
85	37.60	14.27	8.42	80	6.46	0.79	3	2	7.00
87	75.50	10	5	21	8.54	0.79	7.53	4.65	3.90
88	236.71	6.5	4.16	50	*	0.79	17.93	12.57	3.60
86	221.61	16.2	10.89	50	*	0.79	19.32	11.16	4.50
89	46.24		0		**		60.96	36.31	3.60
90	19.95	28.07	20.74	15	3.11	0.70	63.48	44.25	4.90
91	15.93	30.67	21.42	0	2.23	0.70	56.83	39.74	2.31
92	24.98	57.71	35.94	80	4.28	0.70		0	
93	19.51	54.86	38.95	0	1.64	0.70	60.47	46.73	3.08
94	12.81	60.73	46.26	0	1.28	0.70	69.12	48.76	1.23
95	15.22	53.2	42.34	5	2.07	0.70	68.31	55.78	1.89
96	13.70	70.79	54.52	0	1.18	0.70	79.93	61.17	1.12

Table A-1 Continued. 2005 and 2055 Sub-area Parameters - Upper Trinity River

Sub-Basin	Area (sq. mile)	Baseline Urbanization (%)	Baseline Imperviousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbanization (%)	Future Imperviousness (%)	Future t_{pR} (hours)
97	24.12	48.13	38.16	0	1.88	0.70	75.71	66.93	1.57
98	21.62	67.35	50.89	0	1.09	0.70	78.26	57.91	1.01
99	12.59	86.52	49.03	0	1.01	0.70	86.76	49.19	1.01
100	5.12	55	42.45	40	0.74	0.70	61.96	50.66	0.68
101	2.95	25.37	21.69	0	1.50	0.70	25.37	21.69	1.50
102	6.03	75.25	52.16	0	0.81	0.70	83.98	59.59	0.76
103	98.25	66.38	45.74	0	3.52	0.70	74.46	48.64	3.39
104	1.75		0		**			0	
105	32.99	63.27	39.35	0	2.39	0.70	69.33	43.62	2.30
106	22.43	65.78	40.72	5	1.98	0.70	71.15	44.87	1.92
107	12.10	37.13	26.95	5	1.62	0.70	45.54	32.78	1.54
108	60.72	42.33	26.6	0	2.79	0.70	51.32	32.99	2.63

Table A-2. 2005 and 2055 Sub-area Parameters - Elm Fork

Sub-Basin	Area (sq. mile)	Baseline Urbaniza-tion (%)	Baseline Impervi-ousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbaniza-tion (%)	Future Impervi-ousness (%)	Future t_{pR} (hours)
1	1.27	17.45	17.15	0	0.38	0.70	17.45	17.15	0.38
2	6.55	55.1	38.5	50	1.85	0.70	72.04	46.92	1.66
3	0.68	19.16	17.45	0	0.62	0.70	59.74	44.73	0.48
4	4.50	3.5	3.31	0	1.24	0.70	59.08	43.12	0.88
5	1.64	9.78	7.45	0	1.65	0.70	9.78	7.45	1.65
6	2.45	15.4	11.5	0	0.99	0.70	65.20	46.50	0.73
7	3.72	27.92	19.91	0	1.15	0.70	49.43	33.11	1.01
8	9.89	29.4	22.52	0	1.53	0.70	61.33	38.96	1.26
9	5.56	23.03	14.47	0	1.56	0.70	77.60	49.01	1.12
10	1.20	27.99	26.12	0	0.69	0.70	39.69	36.11	0.64
11	4.04	56.83	33.79	0	0.98	0.70	70.53	40.44	0.90
12	9.41	51.91	29.17	87	2.45	0.70	69.19	47.49	2.20
13	11.19	62.76	39.06	82	2.55	0.70	70.89	45.23	2.43
14	4.57	49.35	43.39	62	2.20	0.70	72.18	53.90	1.91
15	4.48	39.5	32.44	0	1.54	0.70	40.21	32.44	1.53
16	11.45	63.04	42.99	0	1.57	0.70	73.18	49.35	1.48
17	10.00	24.95	18.25	38	1.48	0.70	71.88	56.02	1.11
18	11.40	41.24	31.17	20	2.22	0.70	68.77	50.83	1.87
19	5.49	44.14	35.17	0	0.75	0.70	57.16	46.36	0.70
20	9.45	70.48	52.57	0	1.05	0.70	76.19	54.80	1.02
21	13.23	53.68	44.82	5	1.68	0.70	76.65	61.41	1.46
23	3.22	62.82	42.45	0	0.66	0.70	70.58	47.08	0.63
24	1.02	29.64	27.85	0	1.48	0.70	32.82	28.88	1.45
25	3.61	77.72	69.02	10	0.68	0.70	85.15	75.01	0.65
26	2.28	77.85	49.5	0	0.57	0.70	80.44	49.60	0.56
27	1.66	32.72	31.48	90	1.06	0.70	77.16	64.09	0.81
28	2.85	29.97	27.85	0	1.05	0.70	58.94	49.83	0.88
29	11.25	70.32	54.44	0	1.25	0.70	79.74	59.44	1.18
30	14.56	48.34	39.37	0	1.76	0.70	87.71	78.72	1.39
31	4.55	52.85	40.58	0	1.14	0.70	70.38	52.69	1.02
32	1.35	43.16	41.72	0	0.88	0.70	84.13	76.14	0.68
33	9.00	56.25	50.42	0	1.84	0.70	69.99	60.26	1.69

Table A-2 Continued. 2005 and 2055 Sub-area Parameters - Elm Fork

Sub-Basin	Area (sq. mile)	Baseline Urbaniza-tion (%)	Baseline Impervi-ousness (%)	Percent Sand (%)	Baseline t_{Pr} (hours)	C_p	Future Urbaniza-tion (%)	Future Impervi-ousness (%)	Future t_{pR} (hours)
34	2.33	48.6	42.08	2	0.21	0.70	71.35	59.28	0.18
35	10.93	77.87	51.47	0	1.19	0.70	84.80	54.68	1.14
36	12.59	77.03	47.54	0	1.08	0.70	86.49	50.79	1.02
37	1.56	44.12	39.89	0	0.52	0.70	60.41	49.35	0.47
40	5.07	64.47	49.94	40	0.98	0.70	73.55	56.38	0.92

Appendix B

Table B-1. 1995 and 2040 Sub-area Parameters - Upper Trinity River

Sub-Basin	Area (sq. mile)	Baseline Urbanization (%)	Baseline Imperviousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbanization (%)	Future Imperviousness (%)	Future t_{pR} (hours)
1	683	0.33	0.2	100	18.00	0.35	0.33	0.2	18.00
2	149.25	2.43	1.31	100	9.00	0.35	2.43	1.31	9.00
3	97.78	6.56	3.54	100	8.00	0.35	6.56	3.54	8.00
4	160.97	3.97	2.05	100	6.00	0.35	3.97	2.05	6.00
5	20				**				**
6	71.17	7.57	4.06	100	7.00	0.66	7.57	4.06	7.00
7	97.46	5.08	2.91	100	6.00	0.66	5.08	2.91	6.00
8	2.34				**				**
9	69.9	2.4	1.4	100	10.00	0.66	2.4	1.4	10.00
10	90.1	5.31	3.29	100	9.00	0.66	5.31	3.29	9.00
11	73.2	1.47	0.87	100	7.00	0.66	1.47	0.87	7.00
12	209.83	1.6	0.98	97	9.00	0.66	1.6	0.98	9.00
13	55.65	3.08	2.38	75	5.00	0.66	3.08	2.38	5.00
14	47.52	7.65	5.84	20	3.00	0.66	22.81	16.39	3.00
15	127.45	6.63	4.82	100	8.00	0.66	21.06	14.86	8.00
16	14.38				**				**
17	13.6	21.88	14.64	30	0.82	0.70	32.11	21.9	0.77
18	74.84	9.03	6.77	50	4.82	0.70	22.58	16.18	4.43
19	5.56				**				**
20	20.99	56.73	36.14	60	3.55	0.70	60.23	38.65	3.47
21	107.11	1.3	1.03	100	8.00	0.70	1.3	1.03	8.00
22	1.89				**				**
23	142.38	3.36	2.12	100	13.00	0.70	19.06	13.02	13.00
24	62.47	1.77	1.07	89	6.00	0.70	18.7	12.85	6.00
25	33.61	1.45	0.75	80	5.00	0.70	18.28	12.46	5.00
26	33.94	4.77	2.52	24	3.00	0.70	19.57	12.82	3.00
27	39.11	3.23	1.88	80	2.37	0.70	19.6	13.21	2.14
28	5.89				**				**
29	8.45	30.38	17.08	50	1.63	0.70	41.66	24.54	1.52
30	54.7	13.5	7.85	10	3.90	0.60	28.1	18	3.60
31	24.56	69.17	41.94	40	1.70	0.70	77.91	48.04	1.61
32	3.96	69.82	55.49	40	0.94	0.70	72.45	57.93	0.93
33	0.4	69.84	54.28	40	0.87	0.70	70.4	54.7	0.87

Table B-1 Continued. 1995 and 2040 Sub-area Parameters - Upper Trinity River

Sub-Basin	Area (sq. mile)	Baseline Urbanization (%)	Baseline Imperviousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbanization (%)	Future Imperviousness (%)	Future t_{pR} (hours)
34	8.91	9.48	5.93	5	1.16	0.70	23.85	15.92	1.06
35	0.38				**				**
36	13.71	52.89	33.84	0	1.24	0.70	60.38	39.11	1.19
37	10.89	67	46.69	40	1.85	0.70	71.07	49.89	1.80
38	37.33	59	36.85	10	2.53	0.70	64.97	40.9	2.44
39	18.25	59.65	38.93	40	1.86	0.70	68.46	45.28	1.76
40	18.45	42.12	29.64	5	2.35	0.70	51.99	36.73	2.21
41	54.7	24.29	15.2	1	3.97	0.70	37.51	24.25	3.65
42	11.3	28.69	19.72	30	3.39	0.70	40.52	27.88	3.15
43	114.76	15.52	10.26	50	6.73	0.70	29.12	19.73	6.18
44	14.42	61.5	39.64	60	1.36	0.70	66.57	43.29	1.31
45	10.38	72.86	41.96	100	1.64	0.70	79.07	45.58	1.58
46	3.44				**				**
47	48.63	48	29.07	90	5.51	0.70	66.6	39.67	4.91
49	1.79	36.42	23.09	30	1.53	0.70	45.08	29.42	1.45
50	27.29	59.11	38.02	60	3.05	0.70	72.55	46.64	2.81
51	29.47	47.83	34.85	70	4.97	0.70	67.25	50	4.40
52	21.6	69	51.26	65	3.47	0.70	77.16	58.1	3.29
53	2.85	59.45	39.44	10	0.78	0.70	64.73	43.4	0.76
54	4.12	45.9	30.97	5	1.40	0.70	53.94	36.65	1.33
55	83.16	37.34	20.44	90	9.10	0.70	48.5	27.69	8.48
56	9.64	37.42	26.85	80	3.44	0.70	46.37	33.13	3.25
58	33	8.59	6.47	0	3.08	0.70	23.04	16.52	2.81
59	68	10.49	7.12	85	6.51	0.70	24.79	16.94	5.95
60	77.08	9.07	6.08	7	2.72	0.70	23.74	16.24	2.48
61	42.25	8.74	5.73	8	1.62	0.70	24.77	16.43	1.47
62	11.67				**				**
63	30.58	33.87	20.26	5	2.49	0.70	46.52	28.97	2.30
64	17.84	56.64	39.75	5	1.39	0.70	63.35	44.73	1.34
65	10.35	24.32	14.22	5	1.13	0.70	37.05	22.84	1.04
66	4.23				**				**
67	9	36.36	26.19	5	1.32	0.70	44.76	32.02	1.25

Table B-1 Continued. 1995 and 2040 Sub-area Parameters - Upper Trinity River

Sub-Basin	Area (sq. mile)	Baseline Urbanization (%)	Baseline Imperviousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbanization (%)	Future Imperviousness (%)	Future t_{pR} (hours)
68	9.23	74.81	46.75	75	2.38	0.70	77.35	48.44	2.34
69	110	1.03	0.79	100	7.00	0.70	1.03	0.79	7.00
70	164	1.01	0.9	91	7.00	0.70	1.01	0.9	7.00
71	58	2.13	1.81	54	4.00	0.70	2.13	1.81	4.00
72	68	0.71	0.59	12	4.00	0.70	17.93	12.57	4.00
73	61.32	1.08	0.95	23	5.00	0.70	18.45	13.03	5.00
74	36.86	5.8	3.94	5	5.00	0.70	22	15.19	5.00
75	102.44	4.25	2.63	0	7.00	0.70	21.46	14.72	7.00
76	83.01	13.7	9.22	80	4.00	0.70	27.73	18.75	4.00
77	11.37				**				**
78	23.63	24.28	15.09	25	4.02	0.70	57.35	35.08	3.27
79	295	1.7	1.62	74	16.00	0.79	1.7	1.62	16.00
80	55.34	4.4	2.77	24	9.50	0.79	21.06	14.27	9.50
81	275.1	2.79	2.64	50	14.28	0.79	2.79	2.64	14.28
82	92.8	1.46	1.36	25	*	0.79	1.46	1.36	*
110	33.8	4.58	4.56	100	7.67	0.79	4.58	4.56	7.67
83	145.6	2.15	1.87	86	8.04	0.79	2.15	1.87	8.04
111	53.28	2.22	1.92	74	*	0.79	2.22	1.92	*
109	45.56	2.56	2.53	100	*	0.79	2.56	2.53	*
84	45.86				**				**
85	37.6	1.07	0.95	80	7.00	0.79	18.18	12.85	7.00
87	75.5	1.46	1.13	21	9.00	0.79	1.46	1.13	9.00
88	236.71	4.58	3.11	50	*	0.79	20.91	14.4	*
86	221.61	11.1	7.45	50	*	0.79	25.78	17.56	*
89	46.24				**				**
90	19.95	23.78	16.38	15	3.33	0.70	37.57	25.47	3.05
91	15.93	19.34	12.34	0	2.43	0.70	62.05	37.48	1.86
92	24.98	25.51	15.54	80	5.24	0.70	37.91	23.64	4.85
93	19.51	45.44	28.56	0	1.76	0.70	65.45	40.94	1.55
94	12.81	52.08	36.99	0	1.37	0.70	69.12	48.76	1.23
95	15.22	42.33	28.44	5	2.27	0.70	64.99	44.93	1.97
96	13.7	67.94	50.95	0	1.21	0.70	79.93	61.17	1.12

Table B-1 Continued. 1995 and 2040 Sub-area Parameters - Upper Trinity River

Sub-Basin	Area (sq. mile)	Baseline Urbanization (%)	Baseline Imperviousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbanization (%)	Future Imperviousness (%)	Future t_{pR} (hours)
97	24.12	48.13	29.74	0	1.88	0.70	66.53	40.54	1.68
98	21.62	67.35	48.12	0	1.09	0.70	78.26	57.91	1.01
99	12.59	86.52	49.03	0	1.01	0.70	86.76	49.19	1.01
100	5.12	55	41.5	40	0.74	0.70	60.02	45.29	0.72
101	2.95	75.92	56.24	0	1.12	0.70	76.8	57.04	1.11
102	6.03	75.25	52.16	0	0.81	0.70	83.98	59.59	0.76
103	98.25	61.57	40.1	0	3.67	0.70	74.46	48.64	3.39
104	1.75				**				**
105	32.99	63.27	39.35	0	2.39	0.70	69.33	43.62	2.30
106	22.43	65.78	40.72	5	1.98	0.70	71.15	44.87	1.92
107	12.1	37.13	26.95	5	1.62	0.70	45.54	32.78	1.54
108	60.72	42.33	26.6	0	2.79	0.70	51.32	32.99	2.63

Table B-2. 1995 and 2040 Sub-area Parameters - Elm Fork

Sub-Basin	Area (sq. mile)	Baseline Urbaniza-tion (%)	Baseline Impervi-ousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbaniza-tion (%)	Future Impervi-ousness (%)	Future t_{pR} (hours)
1	1.27	8.95	7.2	0	0.40	0.70	8.95	7.20	0.40
2	6.55	46.53	30.27	50	2.01	0.70	71.42	47.96	1.72
3	0.68	12.98	10.4	0	0.65	0.70	59.74	44.73	0.49
4	4.50	1.96	1.81	0	1.28	0.70	59.55	43.46	0.89
5	1.64	0.35	0.24	0	1.79	0.70	0.35	0.24	1.79
6	2.45	16.46	10.26	0	1.00	0.70	65.46	45.38	0.74
7	3.72	5.62	4.23	0	1.35	0.70	40.69	25.50	1.08
8	9.89	20.41	13.08	0	1.65	0.70	65.63	40.29	1.24
9	5.56	38.82	21.94	0	1.44	0.70	79.56	44.60	1.12
10	1.20	17.79	12.89	0	0.75	0.70	17.79	12.89	0.75
11	4.04	44.81	26.2	0	1.07	0.70	72.07	40.31	0.90
12	9.41	13.94	7.83	87	3.08	0.70	57.85	39.43	2.34
13	11.19	34.35	21.31	82	3.04	0.70	70.91	46.20	2.42
14	4.57	43.29	32.83	62	2.35	0.70	72.48	54.13	1.96
15	4.48	24.49	18.24	0	1.71	0.70	47.61	32.11	1.48
16	11.45	49.17	30.73	0	1.73	0.70	68.63	42.69	1.54
17	10.00	13.58	8.24	38	1.66	0.70	57.62	39.64	1.26
18	11.40	31.96	20.79	20	2.45	0.70	31.56	39.70	2.04
19	5.49	30.76	22.6	0	0.83	0.70	57.44	39.74	0.70
20	9.45	63.65	45.58	0	1.01	0.70	75.65	53.43	0.94
21	13.23	47.73	31.74	5	1.78	0.70	66.55	46.26	1.58
23	3.22	31.79	20.08	0	0.81	0.70	53.25	30.92	0.71
24	1.02	10.29	7.4	0	1.69	0.70	30.59	24.55	1.49
25	3.61	62.29	52.09	10	0.77	0.70	77.17	63.47	0.70
26	2.28	84.3	54.07	0	0.55	0.70	85.92	55.35	0.55
27	1.66	38.07	33.18	90	1.01	0.70	75.67	61.86	0.80
28	2.85	22.42	26.31	0	1.12	0.70	46.00	38.42	0.97
29	11.25	70.37	51.29	0	1.26	0.70	79.66	59.28	1.19
30	14.56	55.22	30.84	0	1.71	0.70	71.86	40.89	1.54
31	4.55	54.05	37.54	0	1.15	0.70	68.66	46.54	1.04
32	1.35	34.49	19.1	0	0.94	0.70	78.71	42.92	0.71
33	9.00	5074	43.25	0	1.93	0.70	71.66	62.64	1.70

Table B-2 Continued. 1995 and 2040 Sub-area Parameters - Elm Fork

Sub-Basin	Area (sq. mile)	Baseline Urbaniza-tion (%)	Baseline Impervi-ousness (%)	Percent Sand (%)	Baseline t_{pR} (hours)	C_p	Future Urbaniza-tion (%)	Future Impervi-ousness (%)	Future t_{pR} (hours)
34	2.33	62.95	50.52	2	0.20	0.70	78.66	64.81	0.18
35	10.93	83.02	53.39	0	1.16	0.70	84.80	54.68	1.15
36	12.59	86.1	50.53	0	1.03	0.70	86.49	50.79	1.03
37	1.56	43.79	34.59	0	0.52	0.70	62.96	51.43	0.47
40	5.07	62.69	43.26	40	1.03	0.70	73.34	51.28	0.96

Appendix C

Table C-1. Future 2055 Summary of Discharges (100-year and SPF)

Location	Contributing Drainage Area (sq. mile)	100-Year Peak Discharge (cfs)	SPF Peak Discharge (cfs)
West Fork below Eagle Mountain Dam	1970.00	35,500	54,600
West Fork below Lake Worth Dam	2064.00	35,100	56,700
West Fork above Clear Fork	2084.99	35,100	63,300
Clear Fork above Mary's Creek	437.45	11,600	71,800*
Clear Fork below Mary's Creek	492.15	48,500	95,700
Clear Fork at Interstate Highway 30	516.71	50,100	94,700
Clear Fork above West Fork	520.67	48,300	93,000
West Fork below Clear Fork (at Fort Worth Gage)	2605.77	69,400	135,900
West Fork above Marine Creek	2606.06	69,200	135,800
West Fork below Marine Creek	2629.06	71,500	139,600
West Fork above Sycamore Creek	2639.95	68,200	143,300
West Fork below Sycamore Creek	2677.28	83,500	164,600
West Fork above Big Fossil Creek	2695.53	77,800	154,100
West Fork below Big Fossil Creek	2768.77	91,400	181,900
West Fork above Village Creek	2780.07	89,000	179,200
West Fork below Village Creek	2971.70	110,400	217,400
West Fork above Walker Branch	2973.49	107,700	214,500
West Fork below Walker Branch	3000.78	109,000	219,800
West Fork at FM 157	3000.78	108,500	219,000
West Fork at State Highway 360	3000.78	107,400	217,000
West Fork above Johnson Creek	3030.25	108,800	220,700
West Fork below Johnson Creek	3051.85	109,000	222,700
West Fork at Belt Line Road (at Grand Prairie Gage)	3054.70	106,300	223,000
West Fork above Big Bear Creek	3058.82	99,200	217,200
West Fork below Big Bear Creek	3151.62	105,500	241,700
West Fork above Mountain Creek	3151.62	102,500	228,300
West Fork below Mountain Creek	3455.62	103,600	234,500
West Fork above Elm Fork	3473.70	103,100	234,200
Elm Fork above Prairie Creek	1661.27	1**	1**
Elm Fork below Prairie Creek	1667.82	1**	1**
Elm Fork above Stewart Creek	1668.50	1**	1**
Elm Fork below Stewart Creek	1673.00	21,000***	66,600***
Elm Fork above Midway Branch	1674.64	21,000***	66,600***
Elm Fork below Midway Branch	1677.09	21,000***	66,600***
Elm Fork above confluence of Indian Creek	1680.81	21,000***	66,600***

Table C-1 Continued. Future 2055 Summary of Discharges (100-year and SPF)

Location	Contributing Drainage Area (sq. mile)	100-Year Peak Discharge (cfs)	SPF Peak Discharge (cfs)
Elm Fork below confluence of Indian Creek	1696.26	21,000***	66,600***
Elm Fork below Dudley Branch (IH35)	1701.50	21,000***	66,600***
Elm Fork below Timber Creek (at IH35)	1726.67	30,300	66,600***
Elm Fork below Timber Creek (at IH35 lower crossing)	1748.07	49,400	86,900
Elm Fork at Sandy Lake Road (at Carrollton Gage)	1764.00	48,200	88,000
Elm Fork below Hutton Branch	1773.45	45,400	82,200
Elm Fork above Grapevine Creek	1778.94	45,300	82,600
Elm Fork below Grapevine Creek	1792.17	47,200	85,100
Elm Fork below Cell B sluice	1795.78	47,300	85,400
Elm Fork below Cooks Branch	1798.06	47,200	85,700
Elm Fork below Irving FCD sluice	1801.28	47,400	86,000
Elm Fork below Cell A sluice	1803.96	47,600	87,300
Elm Fork below Farmers Branch	1815.21	47,800	88,700
Elm Fork above Hackberry Creek	1818.06	46,900	87,900
Elm Fork below Hackberry Creek	1838.52	48,100	92,000
Elm Fork above Joe's Creek	1849.85	45,000	91,100
Elm Fork below Joe's Creek	1860.78	45,000	91,800
Elm Fork above Bachman Branch	1862.34	44,600	91,800
Elm Fork below Bachman Branch	1874.93	45,400	94,000
Elm Fork above West Fork	1880.00	44,700	94,100
Trinity River below Elm Fork/West Fork confluence	6037.88	129,400	296,200
Trinity River at the Dallas Gage (Commerce Street)	6040.83	128,600	294,700
Trinity River above confluence with White Rock Creek	6046.86	128,600	283,600
Trinity River below confluence with White Rock Creek	6179.85	123,900	302,200
Trinity River below the Below Dallas Gage (Loop 12)	6202.28	130,200	301,700
Trinity River above confluence with Five Mile Creek	6214.38	130,000	300,100
Trinity River below confluence with Five Mile Creek	6275.10	129,000	300,300

* Controlling outflow from Benbrook Lake spillway
** During the 50-year flood and rare flood events, the Lewisville Lake outlet works is closed. Therefore, a nominal discharge of 1 cfs is used upstream of the Lewisville Lake spillway channel.
*** Controlling outflow from the Lewisville Lake spillway

Appendix D

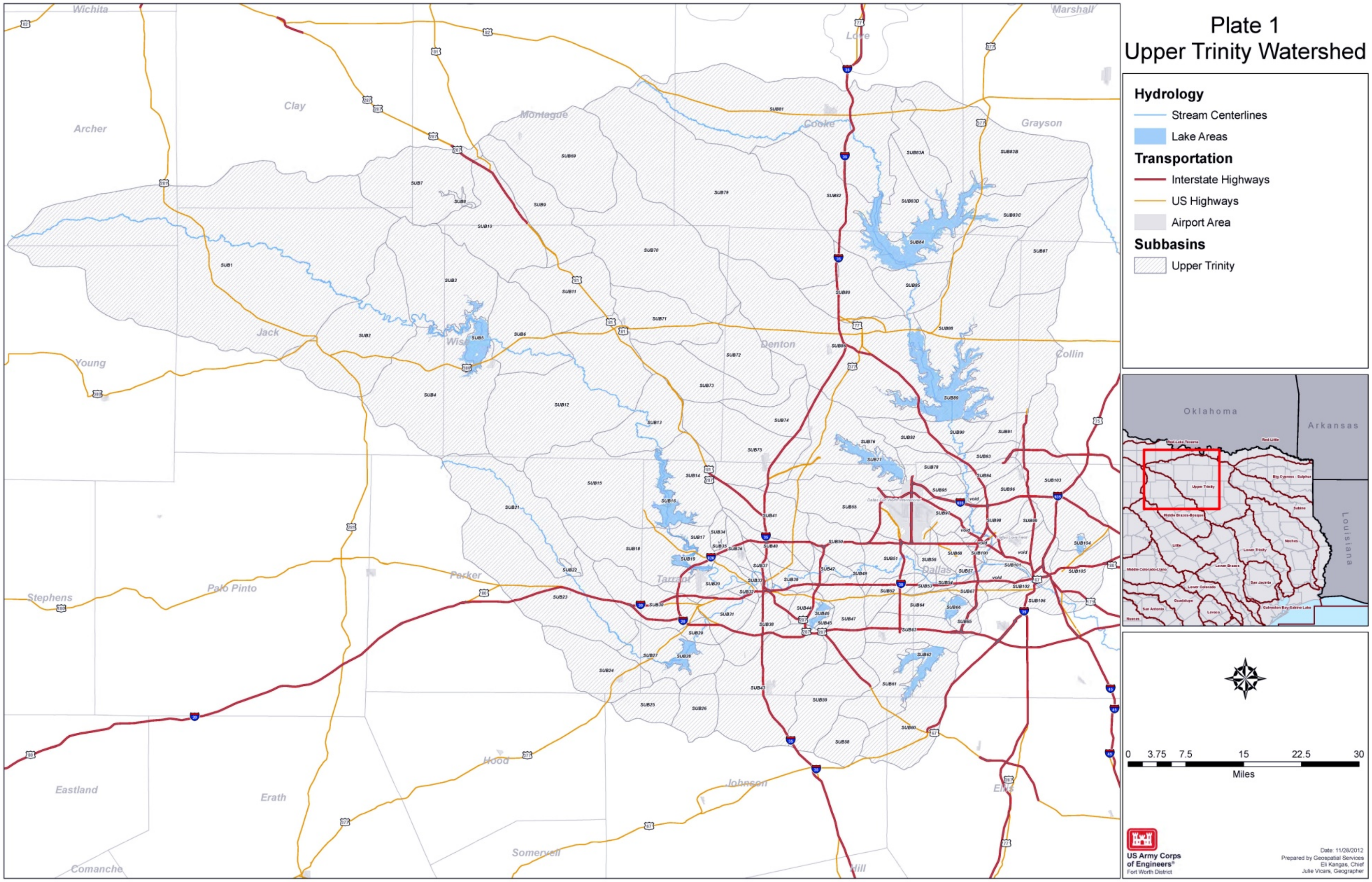
Table D-1. Future 2040 Summary of Discharges (100-year and SPF)

Location	**Contributing Drainage Area (sq. mile)**	**100-Year Peak Discharge (cfs)**	**SPF Peak Discharge (cfs)**
West Fork below Lake Worth Dam	2064.00	35,400	52,200
West Fork above Clear Fork	2084.99	35,400	57,700
Clear Fork above Mary's Creek	8.45	13,000*	71,800*
Clear Fork below Mary's Creek	63.15	38,500	71,800*
Clear Fork at Interstate Highway 30	87.71	40,100	85,400
Clear Fork above West Fork	91.67	39,800	84,000
West Fork below Clear Fork (at Fort Worth Gage)	2176.77	58,700	124,400
West Fork above Marine Creek	2177.06	58,200	124,100
West Fork below Marine Creek	2200.06	60,000	130,600
West Fork above Sycamore Creek	2210.95	60,000	135,000
West Fork below Sycamore Creek	2248.28	77,700	155,700
West Fork above Big Fossil Creek	2266.53	70,700	146,700
West Fork below Big Fossil Creek	2339.77	89,700	182,600
West Fork above Village Creek	2351.07	84,800	178,700
West Fork below Village Creek	2542.70	100,700	204,700
West Fork above Walker Branch	2544.49	97,500	202,400
West Fork below Walker Branch	2571.78	99,200	208,400
West Fork at FM 157	2571.78	98,400	206,800
West Fork at State Highway 360	2571.78	93,900	204,600
West Fork above Johnson Creek	2601.25	92,700	208,100
West Fork below Johnson Creek	2622.85	92,800	210,100
West Fork at Belt Line Road (at Grand Prairie Gage)	2625.70	92,300	210,400
West Fork below Big Bear Creek	2722.62	96,700	231,300
West Fork above Mountain Creek	2722.62	92,300	217,500
West Fork below Mountain Creek	3026.62	93,500	223,500
West Fork above Elm Fork	3044.70	92,800	222,700
Elm Fork above Prairie Creek	1.27	1**	1**
Elm Fork below Prairie Creek	7.82	1**	1**
Elm Fork above Stewart Creek	8.50	1**	1**
Elm Fork below Stewart Creek	13.00	21,000***	66,600***
Elm Fork above Midway Branch	14.64	21,000***	66,600***
Elm Fork below Midway Branch	17.09	21,000***	66,600***
Elm Fork above confluence of Indian Creek	20.81	21,000***	66,600***

Table D-1 Continued. Future 2040 Summary of Discharges (100-year and SPF)

Location	Contributing Drainage Area (sq. mile)	100 - Year Peak Discharge (cfs)	SPF Peak Discharge (cfs)
Elm Fork below confluence of Indian Creek	36.26	24,600	66,600***
Elm Fork below Dudley Branch (IH35)	41.50	22,100	66,600***
Elm Fork below Timber Creek (at IH35)	66.67	35,600	66,600***
Elm Fork below Timber Creek (at IH35 lower crossing)	88.07	49,600	92,700
Elm Fork at Sandy Lake Road (at Carrollton Gage)	104.00	51,500	99,200
Elm Fork below Hutton Branch	113.45	45,400	89,800
Elm Fork above Grapevine Creek	118.94	45,100	90,100
Elm Fork below Grapevine Creek	132.17	46,600	93,300
Elm Fork below Cell B sluice	135.78	46,900	95,100
Elm Fork below Cooks Branch	138.06	46,700	95,300
Elm Fork below Irving FCD sluice	141.28	46,500	97,300
Elm Fork below Cell A sluice	143.96	46,500	98,300
Elm Fork below Farmers Branch	155.21	46,400	99,400
Elm Fork above Hackberry Creek	158.06	45,100	99,300
Elm Fork below Hackberry Creek	178.52	45,600	101,900
Elm Fork above Joe's Creek	189.85	42,900	102,500
Elm Fork below Joe's Creek	200.78	42,900	103,200
Elm Fork above Bachman Branch	202.34	42,500	103,200
Elm Fork below Bachman Branch	214.93	43,100	106,200
Elm Fork above West Fork	220.00	42,700	106,200
Trinity River below Elm Fork/West Fork confluence	5608.88	120,300	278,500
Trinity River at the Dallas Gage (Commerce Street)	5611.83	119,800	277,000
Trinity River above confluence with White Rock Creek	5617.86	117,800	265,900
Trinity River below confluence with White Rock Creek	5750.85	127,500	285,200
Trinity River below the Below Dallas Gage (Loop 12)	5773.28	127,400	284,700
Trinity River above confluence with Five Mile Creek	5785.38	126,900	281,000
Trinity River below confluence with Five Mile Creek	5846.10	126,900	281,100

* Controlling outflow from Benbrook Lake spillway
** During the 50-year flood and rare flood events, the Lewisville Lake outlet works is closed. Therefore, a nominal discharge of 1 cfs is used upstream of the Lewisville Lake spillway channel.
*** Controlling outflow from the Lewisville Lake spillway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Upper Trinity Watershed
Hydrology
Stream Centerlines
Lake Areas
Transportation
Interstate Highways
US Highways
Airport Area
Subbasins
Upper Trinity
Oklahoma
Arkansas
Louisiana
0
3.75
7.5
15
22.5
30
Miles
US Army Corps of Engineers
Fort Worth District
Wichita
Clay
Archer
Montague
Cooke
Grayson
Jack
Wise
Denton
Collin
Young
Stephens
Palo Pinto
Parker
Tarrant
Dallas
Eastland
Erath
Hood
Johnson
Ellis
Somervell
Comanche
Hill

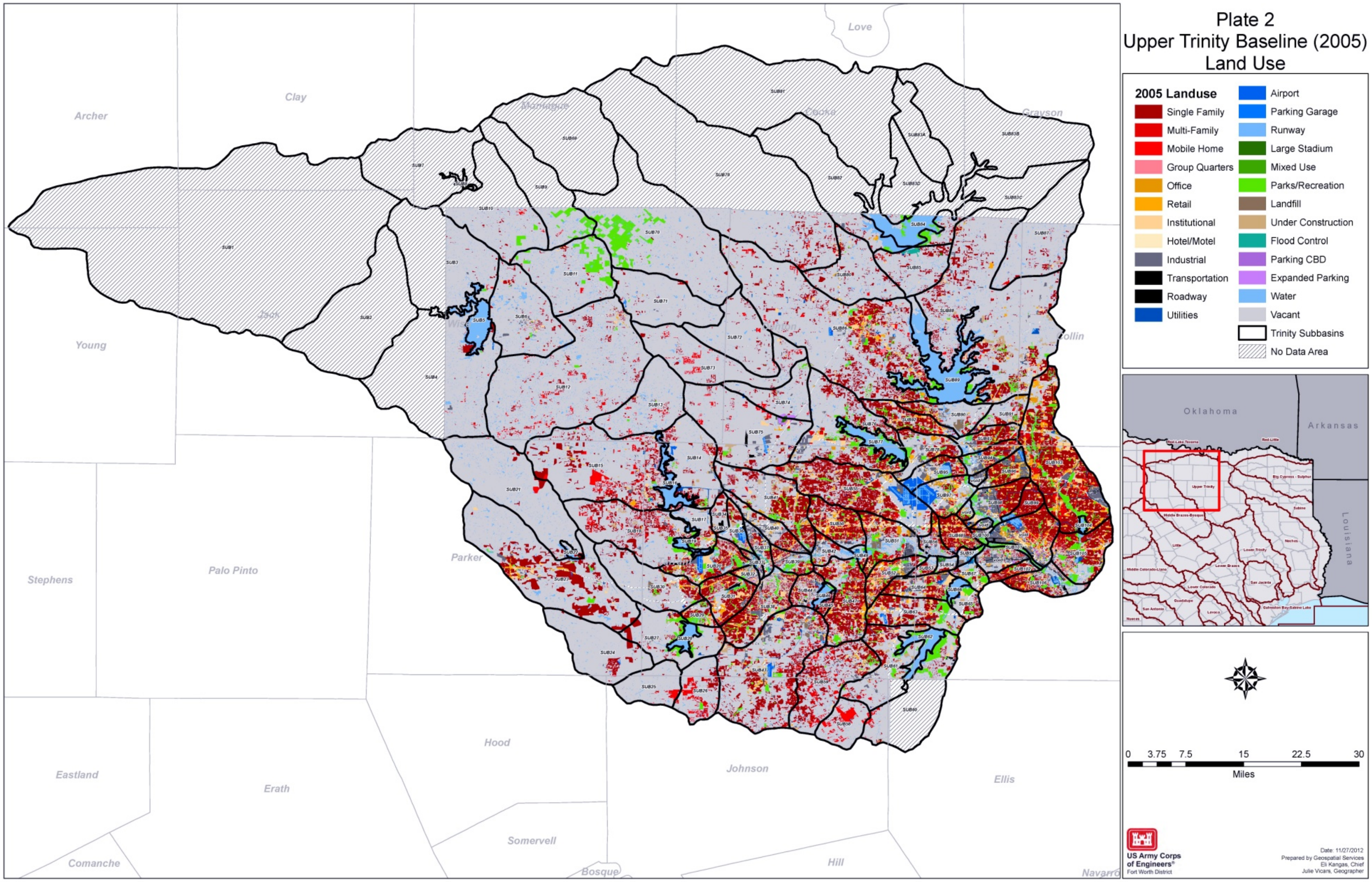
Plate 2
Upper Trinity Baseline (2005)
Land Use
2005 Landuse
Single Family
Multi-Family
Mobile Home
Group Quarters
Office
Retail
Institutional
Hotel/Motel
Industrial
Transportation
Roadway
Utilities
Airport
Parking Garage
Runway
Large Stadium
Mixed Use
Parks/Recreation
Landfill
Under Construction
Flood Control
Parking CBD
Expanded Parking
Water
Vacant
Trinity Subbasins
No Data Area
Oklahoma
Arkansas
Louisiana
0 3.75 7.5 15 22.5 30
Miles
US Army Corps of Engineers
Fort Worth District
Date: 11/27/2012
Prepared by Geospatial Services
Eli Kangas, Chief
Julie Vicars, Geographer
Archer
Clay
Love
Montague
Cooke
Grayson
Young
Jack
Wise
Collin
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Parker
Eastland
Erath
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Johnson
Ellis
Somervell
Comanche
Bosque
Hill
Navarro

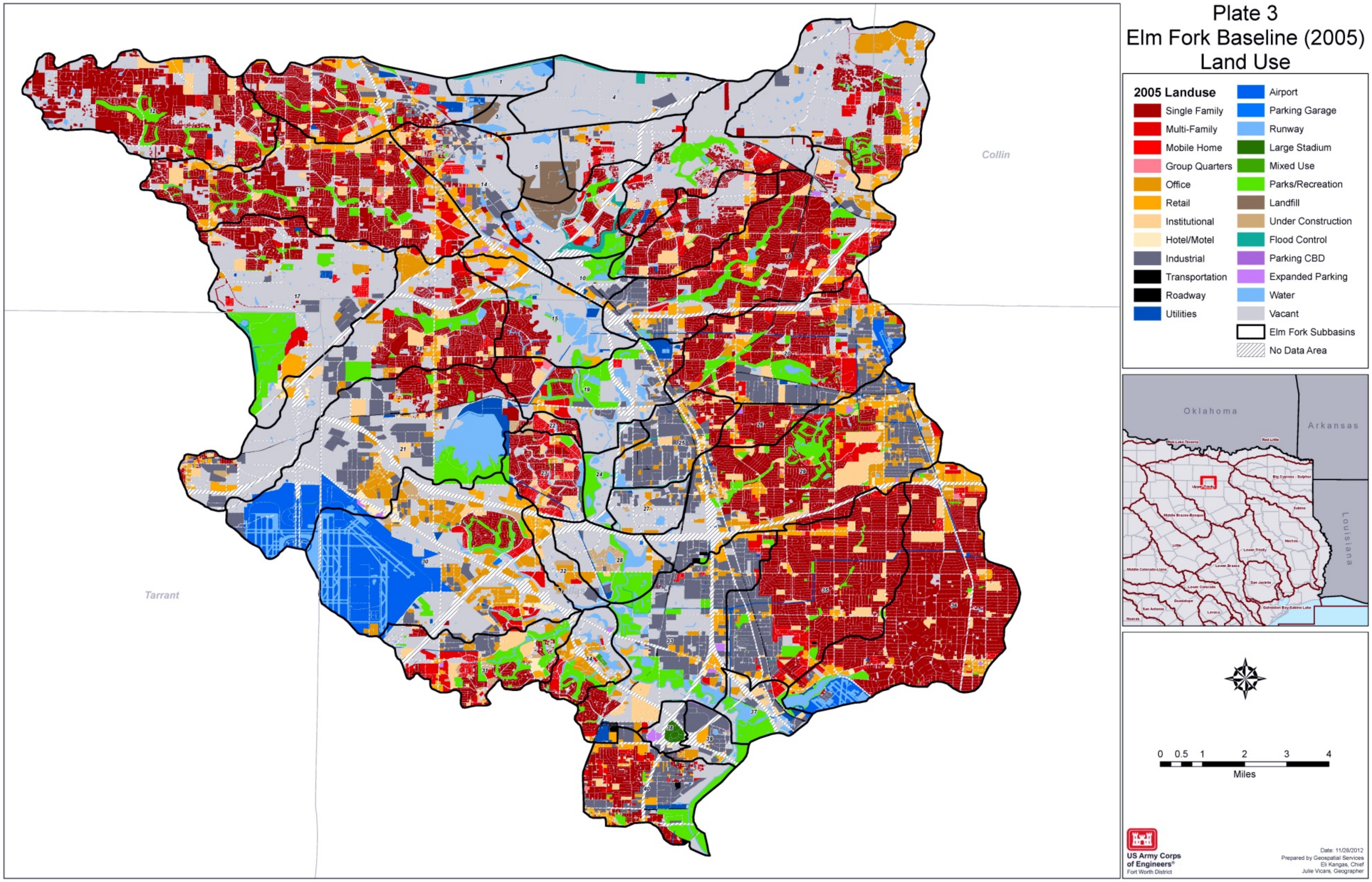
Plate 3
Elm Fork Baseline (2005)
Land Use
2005 Landuse
Single Family
Multi-Family
Mobile Home
Group Quarters
Office
Retail
Institutional
Hotel/Motel
Industrial
Transportation
Roadway
Utilities
Airport
Parking Garage
Runway
Large Stadium
Mixed Use
Parks/Recreation
Landfill
Under Construction
Flood Control
Parking CBD
Expanded Parking
Water
Vacant
Elm Fork Subbasins
No Data Area
Collin
Tarrant
Oklahoma
Arkansas
Louisiana
0 0.5 1 2 3 4
Miles
US Army Corps of Engineers
Fort Worth District
Date: 11/28/2012
Prepared by Geospatial Services
Eli Kangas, Chief
Julie Vicars, Geographer

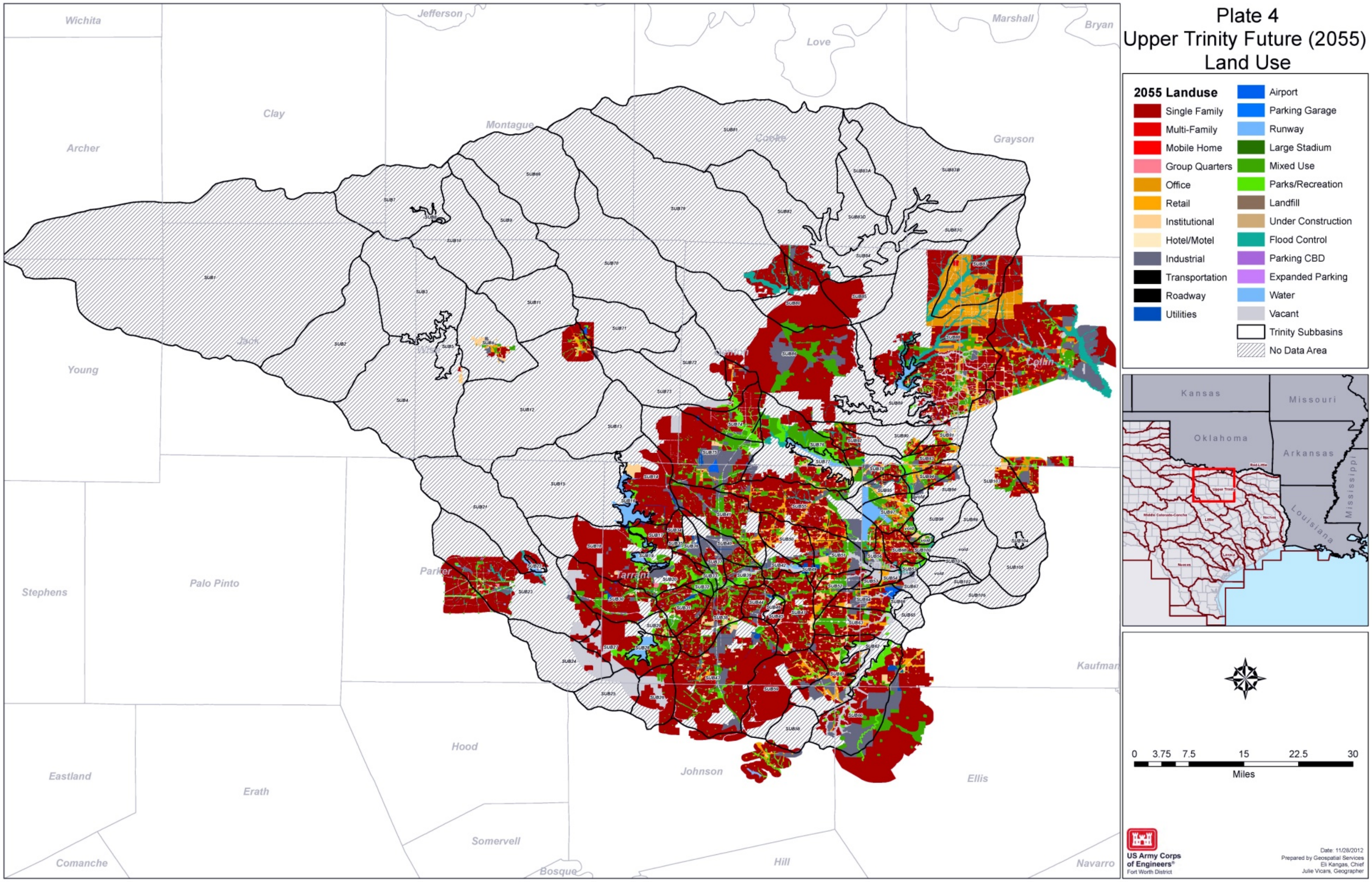

Plate 4
Upper Trinity Future (2055)
Land Use
2055 Landuse
Single Family
Multi-Family
Mobile Home
Group Quarters
Office
Retail
Institutional
Hotel/Motel
Industrial
Transportation
Roadway
Utilities
Airport
Parking Garage
Runway
Large Stadium
Mixed Use
Parks/Recreation
Landfill
Under Construction
Flood Control
Parking CBD
Expanded Parking
Water
Vacant
Trinity Subbasins
No Data Area
Kansas
Missouri
Oklahoma
Arkansas
Louisiana
Mississippi
0 3.75 7.5 15 22.5 30
Miles
US Army Corps of Engineers
Fort Worth District
Date: 11/28/2012
Prepared by Geospatial Services
Eli Kangas, Chief
Julie Vicars, Geographer
Wichita
Jefferson
Marshall
Bryan
Love
Clay
Montague
Cooke
Grayson
Archer
Young
Jack
Wise
Denton
Collin
Stephens
Palo Pinto
Parker
Tarrant
Kaufman
Hood
Johnson
Eastland
Erath
Ellis
Somervell
Comanche
Bosque
Hill
Navarro

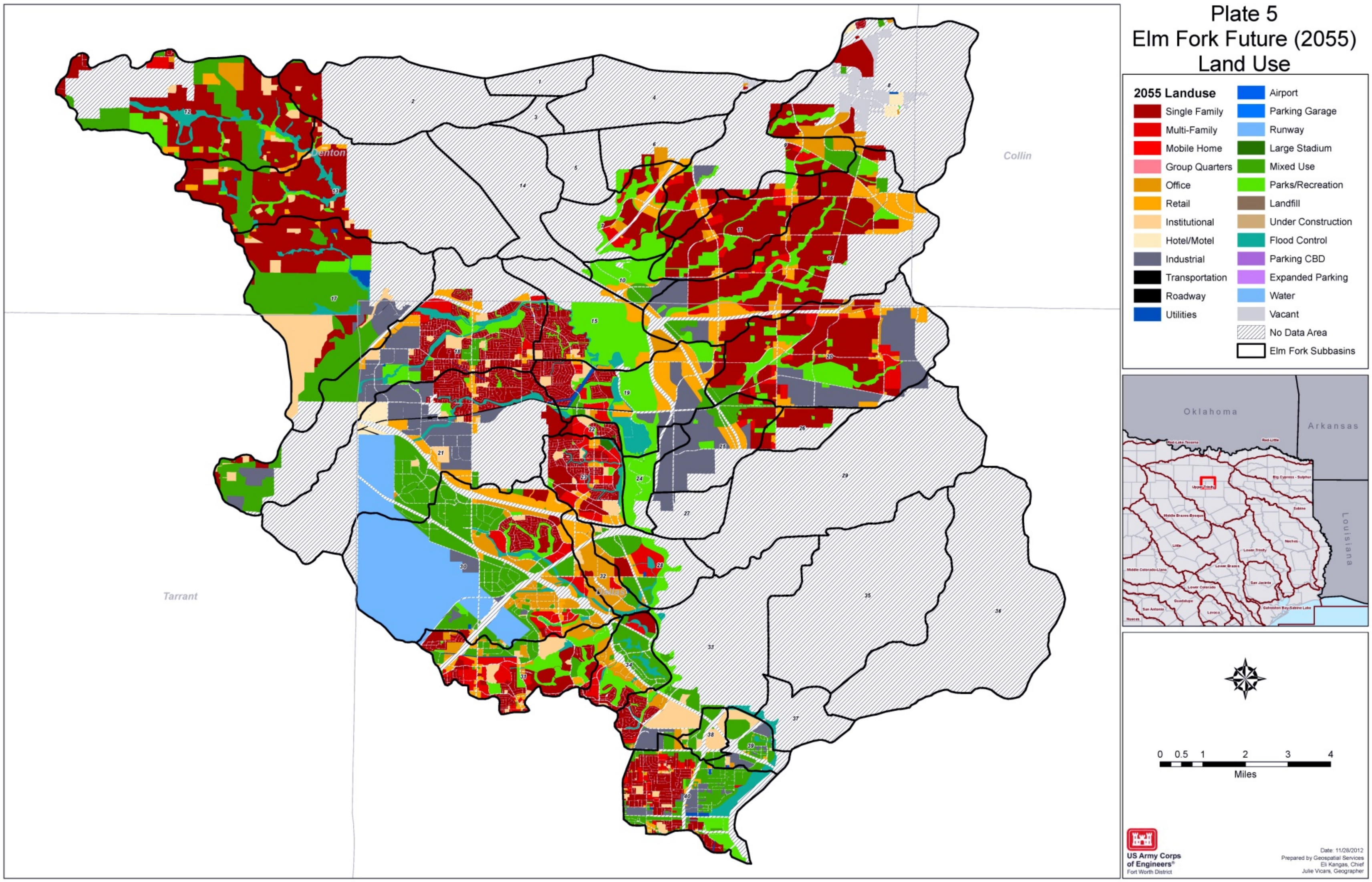
Plate 5
Elm Fork Future (2055)
Land Use
2055 Landuse
Single Family
Multi-Family
Mobile Home
Group Quarters
Office
Retail
Institutional
Hotel/Motel
Industrial
Transportation
Roadway
Utilities
Airport
Parking Garage
Runway
Large Stadium
Mixed Use
Parks/Recreation
Landfill
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Oklahoma
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Collin
Tarrant
Denton
0 0.5 1 2 3 4
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