City of Carrollton

Lower Dudley Branch
Flood Study

3/5/13

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Executive Summary

The Lower Dudley Branch Flood Study uses XPSWMM 2D modeling software to analyze the floodplain formed at the confluence of Timber Creek, Indian Creek, and Dudley Branch with the Elm Fork of the Trinity River in Carrollton, Texas. The study was initiated by the City of Carrollton (the City) in order to more accurately define floodplain elevations in the confluence area and to compare the 2D analysis to the FEMA Effective Base Flood Elevations (BFE's) produced by traditional HEC-RAS modeling.

The study area is shown in **Exhibit A** and is approximately described as being the floodplain area northeast of IH35E, southeast of SH121, and west of Eisenhower Road and the Denton County Reclamation and Road District (DCRRD) levees. The total 2D study area is upwards of 2,000 acres. The project model covers this area as well as extending only the 1D links downstream for approximately 5 miles, to a point downstream of the Belt Line Road Bridge. The project site contains the Indian Creek Golf Course, the newly constructed Denton County Transportation Authority (DCTA) rail line, and multiple ponds, bridges and culverts.

Due to the complex interaction between all four streams that converge in this area, a 2D approach was needed. This low lying area essentially acts as a reservoir during high flow situations and allows overflow from each of these streams to combine before they pass under IH35E. The FEMA Effective HEC-RAS models assume a "normal depth" downstream boundary condition for the tributaries running through this area. The 2D analysis indicates that this assumption may need to be revised due to the way the floodplain fills up and backs up during a high flow event. Once Dudley Branch, Indian Creek, Elm Fork , and Timber Creek enter this "reservoir", they act together to form one contiguous floodplain.

To build this model, data was gathered from a variety of sources. The basis of the hydrology for the model is the FEMA Effective and CDC hydrology. This data was used directly out of the HEC-HMS and HEC-1 models. No new hydrology was created. The basis of the hydraulic modeling is the FEMA Effective and CDC HEC-RAS models. Geometry was taken directly out of these models and imported into the XPSWMM 1D links. Field survey was performed to detail all structures and confirm cross sections in selected locations. The basis of the 2D model was Light Detection And Ranging (LiDAR) data flown specifically for this project and was supplemented by topo survey under bridge decks and in dense tree canopy areas.

After running the 2D model, results were compared to the FEMA Effective floodplain and BFE's. The 2D results showed varying degrees of agreement with the FEMA Effective BFEs. In the vicinity of IH35E and the DCTA rail line (Elm Fork channel) the 2D results are less than 0.5 feet different from FEMA. Upstream along the tributaries, the 2D results differ by 2 to 3 feet. This is attributed to the Elm Fork backwater impacts on the tributaries.

The 2D model also showed three areas of flooding along Frankford Road. The City confirmed that these areas have flooded before in high intensity events. A few proposed solutions were modeled to reduce the flood risk to Frankford Road and adjacent homes.

Section 1 - Introduction

1.1 General

Brown & Gay Engineers, Inc. was hired by the City of Carrollton (the City) to study the floodplain and hydraulic interaction between Timber Creek, Indian Creek, Dudley Branch, and the Elm Fork Trinity River to determine water surface elevations at the confluence of these streams. This confluence is located generally northeast of IH35E and south of SH121 in Carrollton, TX. As shown in **Exhibit A**, the study area is bound by major highways on the north and west, Frankford Road to the south, and dense residential development protected by levees to the east. The study area also contains the Indian Creek Golf Course (ICGC), the new Denton County Transportation Authority (DCTA) regional rail line, and several retention ponds. Ground cover in the study area consists of short grass on the golf course, tall dense native grasses, dense mature tree stands, water, and some light industrial development. The confluence is rather complex in that the topography of the region is low lying and flat which allows all four streams to overflow and combine before exiting the area under IH35E. The current existing model of the Elm Fork Trinity River is the United States Army Corps of Engineers (USACE) Trinity River Corridor Development Certificate (CDC) model. The current models of the tributaries are the Federal Emergency Management Administration (FEMA) Effective HEC-RAS models.

1.2 Purpose

The Lower Dudley Branch Flood Study project was initiated in response to observed high water surface elevations in the area after relatively minor rainfall events. Locations such as the Eisenhower Street Bridge over Dudley Branch were observed to have a greater potential for flooding than indicated in design plans. Further inspection of the effective FEMA HEC-RAS models revealed that some of the model assumptions or parameters may need to be revised. There were some questions as to whether or not the traditional HEC-RAS modeling method used in the FEMA models adequately represented the hydraulic interaction of these streams in the combined floodplain area near the Elm Fork Trinity River. The traditional HEC-RAS modeling methods assume all flow is linear and parallel to the channel bed. This modeling method also does not inherently account for inflow from another watershed. The purpose of this project is to take new look at this area with a modeling technique that might be better suited to capture the hydraulics of the complex interaction of theses streams. Revisions to the effective FEMA models could potentially result in an increase in the effective Base Flood Elevations (BFEs) along Indian Creek and Dudley Branch. The BFEs could be affected due to the mixing of flows in the study area. The existing HEC-RAS models only contain runoff from within each respective watershed and do not consider transfer of flow between the Elm Fork Trinity River, Indian Creek and Dudley Branch. In reality, it is likely that these streams overflow into one another. This means that the effective HEC-RAS models may not accurately represent the amount of flow in the overbanks of these streams in the combined floodplain area, resulting in a lower water surface elevation. The new modeling method used for this project will account for this combined flow as well as multi-directional flow paths in the overbanks in the vicinity of the study area.

1.3 Technical Approach

To re-study the complex confluence, it was decided that an integrated one–dimensional (1D) and two-dimensional (2D) model would be needed. This type of model allows for main channel banks to be modeled in the 1D realm similar to the analyses of a HEC-RAS model while simultaneously allowing this main channel to overflow into a 2D grid where the water can flow in multiple directions and combine with overflow of other streams. The XPSWMM 2D software package was selected for this purpose. XPSWMM 2D uses an integration of the EPASWMM hydraulics engine with the TUFLOW 2D engine to accomplish this capability. The project combines existing FEMA effective floodplain models and CDC floodplain models together with updated survey data to create a 1D/2D XPSWMM model capable of analyzing the complex confluence and combined floodplains of these four streams. In general, the requirement for the project model was to combine all the FEMA and CDC models together into one model and provide connectivity between each channel with the 2D grid. All the geometry related values for the project model such as roughness, culvert entrance and exit losses, bridge parameters, etc. were taken from these existing models. New survey was performed to confirm selected cross sections and detail all cross structures in the area. Detailed topographic data was collected from both light detection and ranging (LIDAR) data flown for the project and supplemental topographical field survey to develop the 2D grid. Other 2D model simulation parameters such as time step, grid cell size and extent were developed for this project using available references such as the TUFLOW user's manual and the XPSWMM 2D software technical support. The model uses the corresponding FEMA and CDC effective hydrology for flows. This hydrology was reviewed and deemed agreeable by the City. No new hydrology was created.

1.4 Scope of Work

A detailed scope of work was approved by the City of Carrollton City Council on September 6, 2011. The following is a summary of all major tasks contained in the contract scope.

1.4.1 Project Management

The project management task was included to perform appropriate non technical duties to manage tasks such as project progress reporting, setting up project meetings, internal team coordination of tasks and needs, project scheduling and invoicing.

1.4.2 Survey

The survey scope item was included to outline the project' survey needs, specifications, and deliverables. This project called for detailed ground survey of cross sections and hydraulic structures as well as detailed topographical survey under all bridges and dense tree canopy to be used in conjunction with LIDAR data for the 2D surface. This scope item also outlines the needs for the LIDAR flown for this project

1.4.3 Data Collection

The data collection task for this project included gathering hydrologic and hydraulic models, as built plans, and site photos. Models required for the project included both hydrologic and

hydraulic for all the streams within the study area. As-built plans were collected and reviewed for all available structures within the study area. Field photos were taken of certain points of interest and compiled into a photo log attached to this report in **Appendix B**.

1.4.4 Hydrology

The hydrology task involved reviewing the hydrologic models collected and extracting runoff hydrographs to be used in the 2D model. It was not scoped to develop any new hydrology.

1.4.5 Hydraulics

The hydraulics portion of the scope outlined all the extents of the project model, the scenarios to be executed, a specified validation storm, and provided deliverables to be developed from model results.

1.4.6 Mapping

The mapping task was included to develop maps of the resulting 2D BFEs and floodplain as well as a comparison of these items to the FEMA effective BFEs and floodplain.

1.4.7 Report

The reporting task outlines all the requirements of the final report discussing the model, its results, and possible recommendations for future action.

1.4.8 QAQC Plan

A QAQC plan was developed and executed throughout the project.

1.5 Criteria

Existing FEMA effective or CDC hydrologic and hydraulic models were used for the basis of the project model. Parameters of the project model were taken from the parameters of these existing models. There were limited situations which required determination of new parameters, such as floodplain n values, spill crest elevations, 1D/2D interface lines, simulation time step, 2D head boundaries, and 2D elevation shape parameters. The NCTCOG iSWM Manual (March 2006), HEC-RAS Hydraulic Reference Manual, or XPSWMM and TUFLOW users manuals were used for guidance for these parameters. Refer to existing effective model Technical Support Data Notebooks (TSDNs) for more details regarding existing HEC-HMS and HEC-RAS model parameters and criteria. The datum to be used for this project is NAVD88 for elevations and NAD 83 Texas State Plane North Central Zone coordinates for horizontal control. The project model, survey, HEC-RAS and HEC-HMS models acquired for the project conform to this datum.

Section 2 - Survey

2.1 Ground Survey

Ground survey was performed for the 1D channel elements in the study area. Project control was set in the field based on one NGS monument, and 6 City of Carrollton monuments. These monuments were observed using GPS and resolved to provide an accurate network used to establish project control. The project control points were then used as the basis for all field work and LIDAR performed for the project. **Appendix A** contains more information on the benchmarks used and project control point data. Channel cross sections were surveyed at a maximum spacing of 1,500 feet along the stream. Since LiDAR was flown for the project, survey sections were limited to the channel banks of the stream. Also, every major structure along each river in the study area was surveyed. Structural surveys required data such as upstream cross sections, culvert and bridge information, and overtopping section data. In addition to this typical survey data, ground topo survey was performed underneath major bridges at I35E, Frankford Rd., and SH121 to be used as a supplement to the LiDAR data that was flown for the 2D surface. This data incorporates ground elevations and slope changes to more accurately reflect the channel and overbanks underneath the bridge decks which are impenetrable by LiDAR. This survey data was then used to build the respective 1D and 2D features in the model. **Appendix A** contains all survey data obtained for the project.

2.2 LiDAR

In order to accurately represent the natural ground surface in the 2D model area, dense and detailed topographical elevation data was needed. Rather than using traditional field survey crew to cover the 2,000+ acres, the use of LiDAR was employed. LiDAR is a remote sensing method which uses laser light to accurately measure distances. This method is applied to developing topographical elevation data by fixing the LiDAR apparatus to an aircraft and flying in an overlapping grid pattern over the site of interest at a known altitude and measuring the distance returns from the laser. This process is performed while simultaneously tracking the spatial location of the returns so that a spatially referenced elevation point group is produced. LiDAR data was flown specifically for this project by Dallas Aerial Surveys, Inc. (DAS). Limits of the LiDAR data acquired for this project more or less follow the shape of the 2D model area shown in **Exhibit A** with a wider coverage area to avoid any conflicts along the edges. More detailed limits and specifications of this data are provided in **Appendix A**. This LiDAR data was flown by helicopter in the Fall of 2011. The LIDAR datum is the control network set in the field for this project. That way all field survey shots and all LIDAR shots match up both horizontally and vertically. The data produced was approximately a 2.5 foot average point spacing over the entire study area. DAS post processed the data to remove false returns and converted the data into an ESRI Multipoint format. This LiDAR data was combined with the additional topo survey data to produce one foot contours for the City's use. This combined LiDAR/topo data was used as the basis of the 2D portion of the model. The development of the 2D surface from this data is described in more detail in Section 5.1.2.

Section 3 - Data Collection

Data collection for this project included acquiring all available as built plans for crossings in the project area, FEMA effective or CDC hydrologic models, and FEMA effective or CDC hydraulic models. Sections 3.1 and 3.2 provide descriptions and sources of all acquired data.

3.1 FEMA and CDC Models

Existing FEMA and CDC models were used as the basis of the new 1D/2D model. Both hydrologic and hydraulic models were acquired and used to extract data. This was done in order to provide a consistent comparison between project model results and existing base flood elevations. Data extracted from these models was applied to the project model with little or no modification. Refer to Section 4 and Section 5 for further discussion regarding any modifications and application of this data.

3.1.1 Hydrologic Models

Four hydrologic models were used to extract inflow hydrographs for each watercourse that flows through the study area. The following list outlines the models used and the sources they originated from.

Dudley Branch HEC-HMS model
(Originally created using version 2.2.2 but run in v3.5)

The HEC-HMS hydrologic model for Dudley Branch was obtained from the City of Carrollton. This model was developed as part of a FEMA watershed update study for the City. This watershed is effectively fully developed. This model contains data for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year storms.

- Created by Halff & Associates in June 2006. Obtained from the City of Carrollton.
    - FEMA Effective model
    - Uses Future (Fully) Developed Land Use watershed conditions
        - TSDN cites this watershed as currently being “fully developed” with flows less than 5% different than “existing conditions”.
    - Rainfall data based on City of Carrollton’s 1988 Master Drainage Study hydrology models

Indian Creek HEC-HMS model
(Originally created using version 2.2.2 but run in v3.5)

The HEC-HMS hydrologic model for Indian Creek was obtained from the City of Carrollton. This model was developed as part of a FEMA watershed update study for the City. This model contains data for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year storms.

- Created by Halff & Associates in June 2006. Obtained from the City of Carrollton.
    - FEMA Effective Model
    - Uses existing watershed conditions

- Rainfall data based on City of Carrollton's 1988 Master Drainage Study hydrology models

Timber Creek HEC-HMS model
(Originally created using version 2.2.2 but run in v3.5)

The HEC-HMS hydrologic model for Timber Creek was obtained from FEMA's Mapping Information Platform (MIP). This model contained data for the 10-, 50-, 100-, and 500-year events.

- Created by a CF3R Joint Venture team of Carter & Burgess and Michael Baker Corporation in March 2005. Obtained from FEMA.
  - FEMA Effective Model
  - Uses existing watershed conditions
  - Rainfall data based on North Central Texas Council of Governments Integrated Storm Water Management (NCTCOG iSWM) Appendix A: Rainfall Tables for North Central Texas.

Elm Fork Trinity River HEC-1 Model

The hydrology data obtained for the Elm Fork Trinity River included HEC-1 models for existing and future conditions for the 10-, 50-, 100- and 500-yr flood frequencies. The HEC-1 computer program was used to generate outputs for the 10-, 50-, 100- and 500-yr flood frequencies for existing conditions as required for the scope of the project.

Detailed hydrographs were not available at desired locations using the default options in the input data. For the purpose of this project, additional hydrographs were generated at five locations in the vicinity of the project area by adding a KO card, which generates time series data at desired locations. In addition, a ZW card was also added to export the time series data into a .DSS file. The data was then exported into a spreadsheet using the HEC-DSSVue computer program. The process was repeated for all the 10-, 50-, 100- and 500-yr flood frequencies to extract hydrographs to be used in the XPSWMM 2D model.

- Created by U.S. Army Corps of Engineers (USACE) as part of the Upper Trinity River Basin Study modeling effort. Obtained from USACE.
  - HEC-1 Model from USACE of Elm Fork watershed. Uses a 15-minute time step which is more precise than FEMA Effective HEC-1 which uses a 1-hour time step.
  - Uses the Baseline scenario which represents existing watershed conditions as of the 1990 USACE Upper Trinity watershed study.
  - Rainfall data based on TP40.

Rainfall Data Sources

These models are based on three different rainfall data sources, as listed above. These rainfall data sources all produce very similar rainfall values for the selected design storms. **Table 1** below compares 24-hour rainfall depths between the three sources for the 10-, 25-, 50-, and 100-year storms.

Table 1: Comparison of 24 Hour Rainfall Depths (in.) for Various Return Frequency Storms

Source	10-Yr	25-Yr	50-Yr	100-Yr
TP40	6.25	7.4	8.4	9.5
NCTCOG iSWM Appendix A	5.52	6.96	7.92	9.36
1988 City of Carrollton	6.4	7.5	8.55	9.5

3.1.2 Hydraulic Models

Hydraulic models for each watercourse in the study area were obtained. Each of these hydraulic models use the corresponding hydrology listed in the previous section for flow data. The following list summarizes the models used and the sources they originated from.

Dudley Branch HEC-RAS model

- Created by Halff & Associates in June 2006. Obtained from the City of Carrollton.
    - FEMA Effective model

Indian Creek HEC-RAS model

- Created by Halff & Associates in June 2006. Obtained from the City of Carrollton.
    - FEMA Effective model

Timber Creek HEC-RAS model

- Created by a CF3R Joint Venture team of Carter & Burgess and Michael Baker Corporation in March 2005. Obtained from FEMA.
    - FEMA Effective Model

Elm Fork Trinity River HEC-RAS Model

- Created by U.S. Army Corps of Engineers (USACE) as part of the Upper Trinity River Basin Study modeling effort. Obtained from USACE.
    - The CDC model by USACE is from September 2011 and is more recent than the FEMA effective model, which has an effective FIS date of June 2005.

3.2 As-Built Plans

Available as-built plans were obtained for most of the stream crossing structures in the project area. Plans were used to verify modeled structures in the project area and survey data collected for the project. The following list summarizes plans acquired and the source they were obtained from.

I35E Bridges – from TXDOT

SH121 Bridges – from TXDOT

Frankford Road Bridge – from TXDOT

DCTA Railroad Bridges – From DCTA staff

Eisenhower Road Bridge – from City of Carrollton

Indian Creek Golf Course grading and pond plans – from City of Carrollton

Frankford Road east of I35E – from City of Carrollton

Elm Fork Trinity River Levee outlet structure – Denton County Reclamation and Road District (DCRRD) was contacted. The district did not have record drawings for the structure. This structure was not modeled therefore no plans were pursued.

Record drawings were not available for the DCRRD levee outlet structure or the Indian Creek Drive culvert.

3.3 Field Visit

A field visit was performed on October 12, 2011. Portions of the project site that were accessible without the use of four wheel drive, a boat, or special access were investigated. For the areas that were inaccessible at this time, photos taken during field survey were utilized to visually assess the area. **Exhibit B** shows locations of photos taken for the project. The photo log is included in **Appendix B.**

Section 4 - Hydrology

4.1 Methodology

Inflow hydrographs are required input to model flood flows in the combined 1D/2D XPSWMM model. Hydrographs were extracted from current FEMA effective or CDC HEC-HMS and HEC-1 models. No new hydrology was developed. The hydrologic models were obtained, reviewed for completeness, and then run to extract hydrographs for input into the XPSWMM 2D model. **Table 2** shows all available hydrology obtained for the project.

Table 2: Available Hydrology

Frequency Storm	Elm Fork	Timber Creek	Indian Creek	Dudley Branch
2-Yr			X	X
5-Yr			X	X
10-Yr	X	X	X	X
25-Yr			X	X
50-Yr	X	X	X	X
100-Yr	X	X	X	X
500-Yr	X	X	X	X

The storm events modeled for this project are the 10-, 50-, 100-, and 500-year events. A coincidental occurrence analysis was applied to the model in order to account for the confluence of the smaller watersheds of Timber Creek, Indian Creek, and Dudley Branch with the larger Elm Fork Trinity River in the study area.

4.1.1 Model Review

All models were reviewed for completeness only to ensure that the necessary data could be extracted from these models and appropriately used in the XPSWMM 2D model. As per the scope of the project, these hydrologic models were accepted as-is due to their acceptance by FEMA as being the current effective hydrologic models supporting the current effective FEMA HEC-RAS floodplain models or being the most up to date CDC models. During the review, appropriate subbasin and outflow hydrographs were identified for use in the XPSWMM 2D model. These discharges were also cross checked with the flows in the effective hydraulic models. A standard hydrology check list was developed and used to document the review of each of the received models. Checklists are provided in **Appendix C**.

4.1.2 Model Errors

Once the models were reviewed, the desired runs were executed to produce the necessary hydrographs. During this process a couple of minor model errors were discovered that prevented the models from running. These were fixed and the models were run. A detailed output showing these errors from HEC-HMS is included in **Appendix E.**

4.1.3 Hydrographs Extracted

After executing all required storm events, the following hydrographs were extracted from their respective models. All hydrographs extracted retained the timing and routing effects produced in HEC-HMS or HEC-1 when input into the XPSWMM 2D model. Refer to **Exhibit C** for hydrograph locations.

Dudley Branch

- Route thru 11 (XS 8767 – 6192)

  Inflow hydrograph. This hydrograph represents flow from the 3.26 sq mi watershed upstream of Rosemeade Parkway. This flow enters the project area through the channel reach just upstream of Eisenhower Street.

- 11

  Subbasin runoff hydrograph. This hydrograph represents rainfall runoff from an area 0.56 sq. mi. in size that enters Dudley Branch at a point downstream of Eisenhower Street. This runoff is generated from the ICGC area and enters the channel near the ICGC detention ponds.

- 12

  Subbasin runoff hydrograph. This hydrograph represents rainfall runoff from an area 0.48 sq. mi. in size that enters the channel downstream of the Indian Creek Golf Course detention ponds. This runoff is generated from the local drainage area between the ICGC and the confluence with Elm Fork Trinity River.

  A drainage area map showing the location of these watersheds is included in the attached **Exhibit C-1,** taken from the Technical Support Data Notebook for the City of Carrollton Floodplain Update Study dated August 14, 2006 by Halff Associates, Inc.

Indian Creek

- Reach 13 (XS9908-4826)

  Outflow hydrograph. This hydrograph represents flow from the 14.67 sq mi watershed upstream of Hebron Parkway. This flow enters the project area from the main fork of Indian Creek that flows west from Hebron Parkway, through the by-pass structure near Island Drive.

- Reach 18 (XS4002-595, Levee Channel)
  Outflow hydrograph. This hydrograph represents flow from the smaller, manmade channel tributary that is north of the main fork. The watershed upstream of this confluence is approximately 0.43 sq mi in size. This particular hydrograph represents flow in a reach of channel between Hebron Parkway and the confluence with the main reach of Indian Creek.

- 20A

Subbasin runoff hydrograph. This hydrograph represents rainfall runoff from an area 0.39 sq. mi. in size that enters the main reach of Indian Creek near its confluence with the Elm Fork Trinity River. This runoff is generated from a portion of ICGC that drains north towards the confluence of Indian Creek and Elm Fork Trinity River.

- 20B
  Subbasin runoff hydrograph. This hydrograph represents rainfall runoff from an area 0.36 sq. mi. that enters the main reach of Indian Creek near its confluence with the northern, minor tributary. This runoff is generated from an area of ICGC and the adjacent neighborhood which discharges into the main reach of Indian Creek upstream of its confluence with the levee channel.

- 20C
  Subbasin hydrograph. This hydrograph represents rainfall runoff from an area 0.1 sq. mi. in size which enters the minor tributary just upstream of its confluence with the main reach of Indian Creek. It is assumed that this runoff is from the residential area located between the levee channel and the main channel of Indian Creek, south of Hebron Parkway.

A drainage area map taken from the TSDN for the City of Carrollton Floodplain Update Study dated August 14, 2006 by Halff & Associates showing locations of these watersheds is included in **Appendix C**.

Timber Creek

- Junction 14 - Mouth

  The outflow hydrograph at this location represents the flow into the study area from Timber Creek. The stream has a contributing drainage area of 20.4 square miles upstream of its confluence with the Elm Fork Trinity River.

Elm Fork Trinity River

- EFAIND - Elm Fork Trinity River Above Indian Creek

  The outflow hydrograph at this location represents the discharge in Elm Fork Trinity River, before the confluence with Indian Creek. The drainage area at this location is 20.8 square miles.

- DENAEF – Denton Creek Above Elm Fork Confluence

  The outflow hydrograph at this location represents the discharge in Denton Creek at the confluence with the Elm Fork Trinity River. The drainage area at this location is 21.4 square miles. A rainfall event on the Elm Fork watershed below Lake Lewisville Dam produces higher peak discharges than the corresponding spillway discharge from the dam, and therefore is the controlling factor for flood discharges in the study area. The contributing area upstream of Lake Lewisville Dam is not included in the USACE HEC-1 model.

- SUB16 – Furneaux Creek Above Elm Fork Confluence

  The outflow hydrograph at this location represents the discharge in Furneaux Creek at the confluence with the Elm Fork Trinity River. The drainage area at this location is 11.5 square miles.

- SUB15 - Elm Fork Trinity River Local Drainage Between IH-35E and Carrollton Gage
  The outflow hydrograph at this location represents the local drainage area for the Elm Fork Trinity River between IH-35E and the Carrollton Gage. The drainage area at this location is 4.5 square miles.

- I35EF – Hutton Branch Inflow Routed from IH-35E to Elm Fork Confluence

  The outflow hydrograph at this location represents the drainage area of Hutton Branch which is routed from IH-35E to the Elm Fork Trinity River confluence. The drainage area at this location is 9.5 square miles.

- SUB19 – Elm Fork Trinity River Local Drainage Between Carrollton Gage and Grapevine Creek

  The outflow hydrograph at this location represents the local drainage area for the Elm Fork Trinity River between the Carrollton Gage and the confluence with Grapevine Creek. The drainage area at this location is 5.5 square miles.

- SUB21 – Grapevine Creek Above South Elm Fork Confluence

  The outflow hydrograph at this location represents the discharge in Grapevine Creek at the confluence with the Elm Fork Trinity River. The drainage area at this location is 13.2 square miles.

4.1.4 Existing Model Results

The total accumulated flow from the Elm Fork above Indian Creek, Indian Creek, Dudley Branch, and Timber Creek inflow hydrographs as computed by the XP-SWMM model will be compared to the peak discharges from the Elm Fork Trinity River HEC-1 model at a single node downstream of the project area for validation purposes.

All hydrographs for the above hydrologic elements are provided in **Appendix C**.

All models were successfully run and produced results consistent with flow values used in the HEC-RAS models. The HEC-RAS flow values have been rounded off, but are within 10% (maximum error) of the peak discharges produced by the hydrographs. **Table 3** below is a summary of the peak discharges from HEC-HMS for each hydrograph extracted.

Table 3: Summary of Peak Flows from Hydrographs

Watershed/Hydrograph Name	HMS Peak Discharges (CFS)				HEC-RAS Peak Flow (CFS)	Difference (%)
	10-Yr	50-Yr	100-Yr	500-Yr	100-Yr	
Dudley Branch						
Route thru 11 (XS 8767 – 6192)	5741	7743	8570	10495	8550	-0.24%
11	1182	1586	1762	2123	N/A	-
12	1043	1386	1535	1841	N/A	-
Indian Creek						
Reach 13 (XS 9908-4826)	8709	13364	15290	20153	15300	0.07%
Reach 18 (XS 4002-595)	814	1111	1234	1499	1300	5.37%
20A	568	818	925	1172	N/A	-
20B	752	1024	1139	1392	N/A	-
20C	242	324	359	435	N/A	-
Timber Creek						
Junction 14-Mouth	6922	11061	13492	18961	13493	0.007%
Elm Fork Trinity River						
EFAIND - Above Indian Creek	5023	9168	11367	16595	10300	9.3%
DENAEF – Denton Creek	8695	16130	19701	29311	N/A	-
SUB16 – Furneaux Creek	8631	12250	14027	20368	N/A	-
SUB15 – Elm Fork Local DA	3400	4886	5620	8181	N/A	-
I35EF – Hutton Branch	10274	13741	15198	20307	N/A	-
SUB19 – Elm Fork Local DA	7163	9864	11211	16185	N/A	-
SUB21 – Grapevine Creek	9703	13842	15856	23022	N/A	-

4.1.5 Hydrograph Loading

Once these hydrographs were extracted from their respective models, they were input into the 1D/2D XPSWMM model as “User Defined Inflow” at a model node as close as possible to

the location that the hydrographs are applied in the existing hydraulic model. **Exhibit C** shows these locations. **Table 4** below summarizes locations of the hydrograph loading.

Table 4: Summary of Hydrograph Loading

Hydrograph Name (Description)	Type of Hydrograph	Model Input Location
EFAIND (Elm Fork Above Indian Creek)	Outflow	Node 25
Junction 14 (Outflow of Timber Creek into model area)	Outflow	Node 119
Reach 18 (Outflow of north channel of Indian Creek into model area)	Outflow	I-Node129
Reach 13 (Outflow of main channel of Indian Creek into model area)	Outflow	I-Node133
20A (Runoff from Subbasin 20A on Indian Creek)	Subbasin Runoff	Node 73
20B (Runoff from Subbasin 20B on Indian Creek)	Subbasin Runoff	I-Node131
20C (Runoff from Subbasin 20C on Indian Creek)	Subbasin Runoff	I-Node128
Route thru 11 (Outflow of Dudley Branch into model area)	Outflow	Node 85
11 (Runoff from Subbasin 11 on Dudley Branch)	Subbasin Runoff	Node 79
12 (Runoff from Subbasin 12 on Dudley Branch)	Subbasin Runoff	Node 63
Sub 16 (Outflow from Furneaux Creek above Elm Fork Confluence)	Outflow	Node 44
DENAEF (Outflow from Denton Creek above Elm Fork Confluence)	Outflow	Node 43
Sub 15 (Local runoff into Elm Fork between I35E and the Carrollton Gauge at Sandy Lake Road)	Subbasin Runoff	Node 49
I35EF (Outflow from Hutton Branch into model area)	Outflow	Node 69
SUB19 (Local runoff into Elm Fork between Carrollton Gauge and Grapevine Creek confluence)	Subbasin Runoff	Node 70
SUB21 (Outflow from Grapevine Creek Above South Elm Fork Confluence)	Outflow	Node 72

Section 5 - Hydraulics

5.1 Methodology

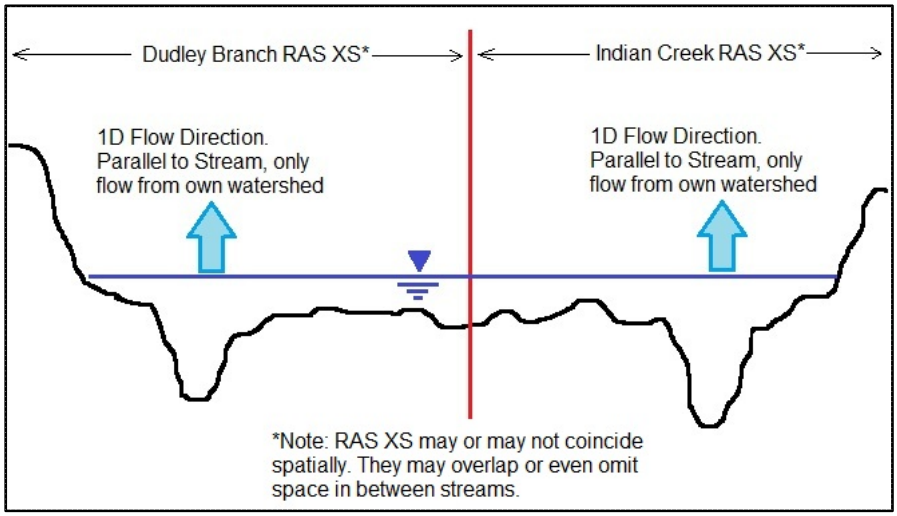
The hydraulic model for this project is a combined 1D "link and node" system with 2D grid elements that are interconnected. This was accomplished using XPSWMM version 13.0 (2011) 2D software, which allows for this type of framework to be utilized. The 1D components are utilized to model open channel flow similar to a traditional HEC-RAS model. The 2D element is a surface representing the natural ground of the channel overbanks and allows for flows that overtop the 1D main channel to combine and move dynamically across the 2D floodplain. This framework allows for 1D computation to occur in the main channel banks of the stream while simultaneously balancing the head in the 2D overbanks when the main channel overflows. Flow across the 2D grid is then allowed to enter or exit the main channel at multiple locations along the river between SH121 and I35E. All flow in the 2D grid is then collected at the downstream boundary of the grid at a single node using 1D/2D connection elements to direct flow back into the 1D channel downstream of I35E. The following sections describe this process in more detail. Refer to **Exhibit D** for a schematic layout of the model.

5.1.1 1D Model Development

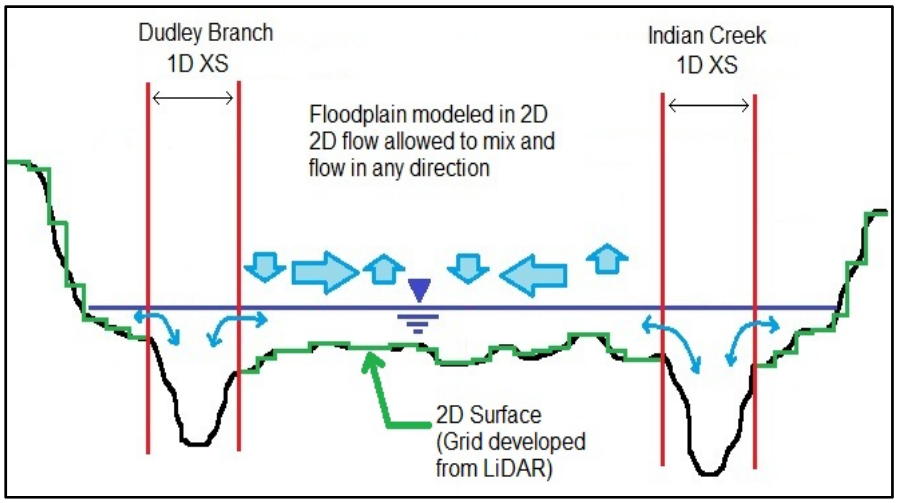
The 1D model components were developed from the acquired existing HEC-RAS models and from field survey performed for the project. Channel cross sections and hydraulic structures were surveyed on all streams within the limits of the 2D area shown on **Exhibit D**. Survey data for the project, including locations of cross sections and structures, is provided in **Appendix A**.

All channels in the project are modeled as 1D links. Within the 2D area shown on **Exhibit D**, the 1D channel cross sections were clipped at the main channel bank stations. These links only convey flow within the main channel. The width of these 1D channels is shown on **Exhibit D** as the blue "2D Inactive Areas". When this main channel capacity is exceeded it is allowed to overflow into the 2D surface. **Figure 1** below conceptually depicts this framework. Outside of the 2D area shown on **Exhibit D**, the 1D channel cross sections extend the full width of the floodplain, as modeled in HEC-RAS.

Figure 1: Concept Sketch of Modeling Approach



Traditional HEC-RAS modeling approach.



In the 2D model, the cross section is clipped at the channel banks and the 2D grid is used for the overbanks

Hydraulic structures such as culverts, bridges, and dams are modeled as 1D links in XPSWMM and were developed based on the acquired HEC-RAS models and project survey data. This new survey data was used in conjunction with existing HEC-RAS models to build these structures in the project model. All structures outside (upstream and downstream) of the 2D area were developed only from the acquired HEC-RAS models. The SH121, I35E Timber Creek relief, and I35E Elm Fork Trinity River relief structures were modeled in the 2D domain.

5.1.2 2D Model Development

The 2D portion of this model represents the natural ground surface of the floodplain (outside of each of the main channels) in the study area. The 2D study area is shown in **Exhibit D.** Portions of the 2D surface located between the main channel banks were then blocked out as "inactive" on the 2D grid. There is no 2D flow allowed on the grid in these areas. This was done in order to prevent double counting of conveyance and storage of the channels. Flow

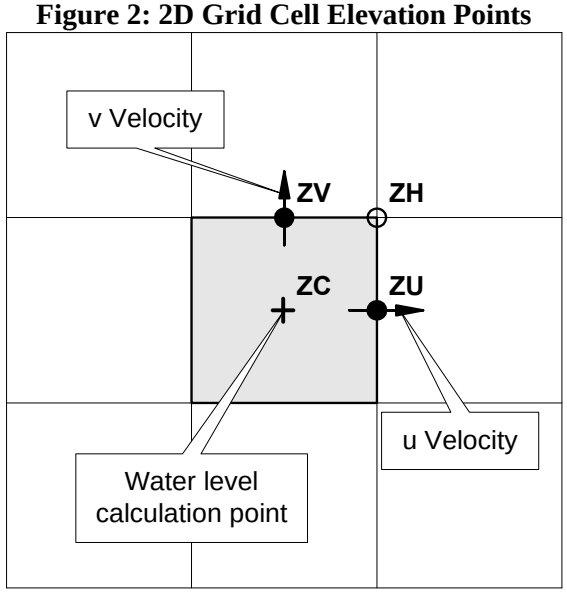
only enters the 2D grid (floodplain) when the 1D main channel section overflows and spills into the 2D grid. Conversely, 2D flow can enter back into the 1D link as the head in the main channel falls back within capacity.

To model 2D flow in XPSWMM, it is necessary to create several different model elements within the 2D domain. For this project the following 2D model elements were created:

XPTIN
This is a TIN feature created within XPSWMM that is used to store elevation data. This is the "surface" in the model that the 2D grid reads to assign elevations for all the cells in the grid.

2D Grid
This is a region of equally sized square cells on which the 2D flow occurs. The user can specify cell size (length of a side) and rotation angle of the cells to align it with features of interest. Each cell in the 2D grid is assigned an elevation at 4 distinct points shown in **Figure 2** below. The source of the elevation data is the XPTIN.

Figure 2: 2D Grid Cell Elevation Points



Source: TUFLOW User Manual: GIS Based 2D/1D Hydrodynamic Modeling. 2010 (Build 2010-10-AB) p. 4-16

Active/Inactive areas
These are polygons which can be used to define areas of the 2D grid as "active" or "inactive". If no polygon is drawn the default is set to "active".

1D/2D Connection lines
These are lines that connect 1D nodes to the 2D grid at vertices along the 2D grid. These vertices can either be along an edge of the 2D grid as a boundary condition or they can be located along an "inactive" polygon to allow flow between the 1D and 2D elements.

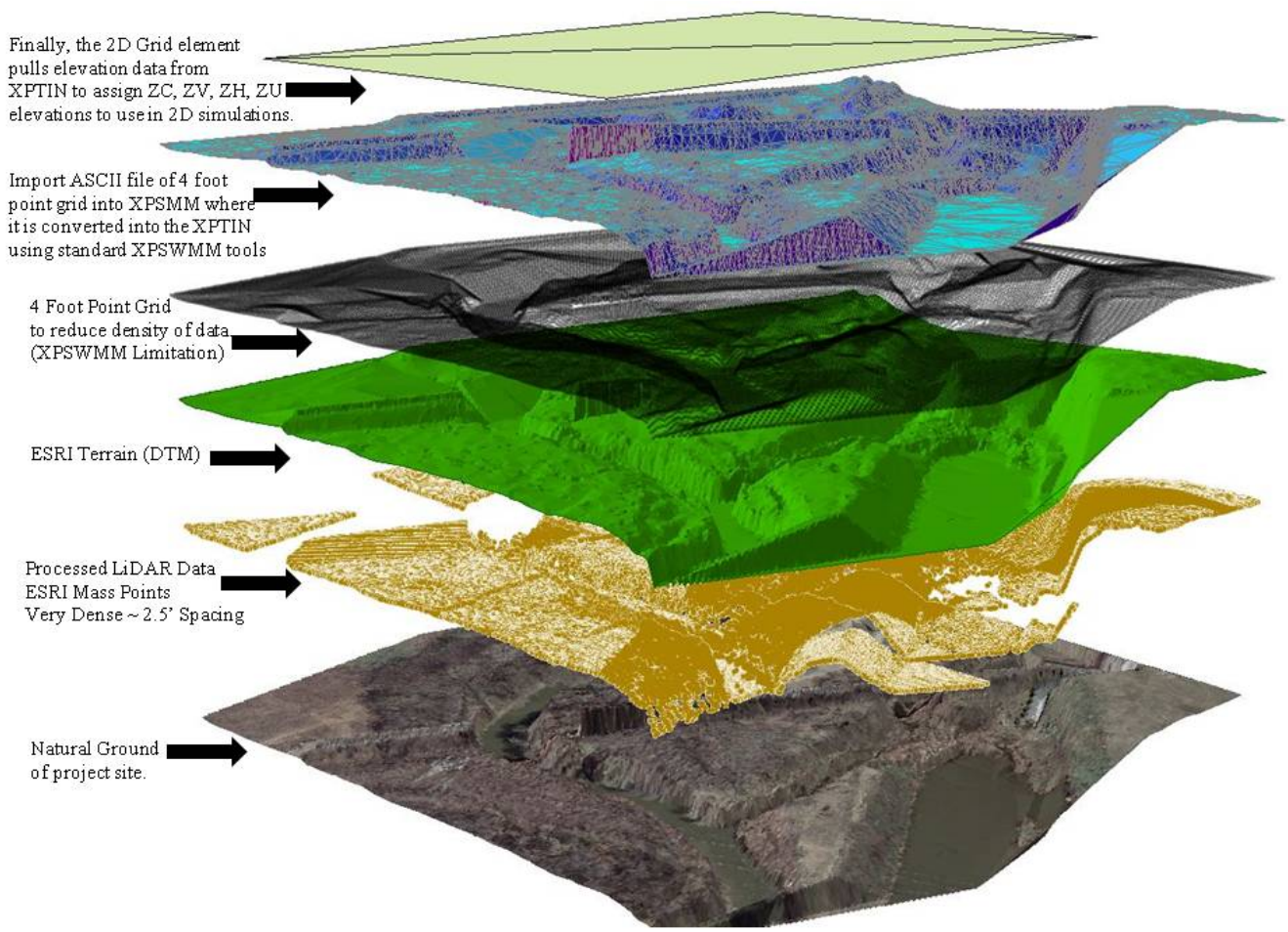
Landuse/Roughness Polygons
These polygons allow the user to specify a particular Manning n value for the area covered by the polygon.

Elevation Shapes
This model feature allows the user to edit 2D grid cell elevations in specific locations. The cells are modified based on the elevations entered by the user.

5.1.2.1 2D Surface (XPTIN) Development

The 2D surface used in this model was developed from LiDAR data that was flown for the project. When the LiDAR flight was finished, DAS post processed the data and produced an ESRI Multipoint shapefile to use in GIS. Then the points were edited to remove bridge decks at I35E, SH121, and the DCTA railroad bridges. The additional topo survey points that were collected underneath these structures were then combined with the remaining LiDAR points to create an ESRI Terrain dataset which contained a continuous flow path for each channel and relief structure. This data could not be directly imported into XPSWMM as it was too large of a dataset. This terrain was then exported as a point grid with a 4-foot spacing to reduce the size and density of the dataset. This 4-foot point group was then imported into XPSWMM to be used as the basis of the XPTIN. This data is converted to the XPTIN within XPSWMM to be used by the 2D grid for elevation data during simulations. As described above, each individual cell of the 2D grid is assigned an elevation from the XPTIN at each of the four locations shown in **Figure 2**. The process is illustrated in **Figure 3** below.

Figure 3: 2D Surface Creation Illustrated by Layer



5.1.2.2 2D Grid

For this project a 2D grid with a cell size of 30-feet was used. Smaller cell sizing than this presented unreasonably long run times without significant improvement in model accuracy. The 30-foot cell size provided appropriate resolution to model the railroad relief, I35E relief and SH121 bridges in the 2D domain. This was done in order to allow overflow from any source and any direction to flow through the structures.

5.1.2.3 Time step

A time step of 2 seconds was used for this model. The TUFLOW User's Manual provides the following guidance on selecting a 2D simulation timestep.

- Should be equally divisible into one minute. (Section A.3 Simulation Time Control Commands, p A-10)
- Are typically in the range of ¼ to ½ of the cell size in meters. For a 10 meter cell size, this would be 2 to 5 seconds. (Section 8.1.1 Timestep, p. 8-3)
- Should satisfy the Courant Condition (Cr < 10) as defined below:

$$C_r = \frac{\Delta t \sqrt{2gH}}{\Delta x} \qquad \text{2-D Square Grid}$$

where

$\Delta t = timestep, s$

$\Delta x = length\ of\ model\ element, m$

$g = acceleration\ due\ to\ gravity, ms^{-\frac{1}{2}}$

$H = depth\ of\ water, m$

(Section 3.6.1 2D Domains (Courant Number), p 3-8)

For the project model:

$\Delta t = 2$ s

$\Delta x = 9.14$ m (30 ft)

$g = 9.81$

$H = 3$ m (9.8 ft) approximate average

$Cr = 1.67$

- The TUFLOW manual also suggests that the timestep should not be arbitrarily reduced to try and "fix" a model instability. There are various reasons cited for this in the TUFLOW manual, but generally the instabilities are a function of hydraulics, not necessarily timestep.

For this model, 2 seconds was the largest time step that gave stable 2D results and met the above recommendations using a 30-foot cell size. A smaller timestep would not produce results of a higher quality and would significantly increase run times of the model.

5.1.2.4 Active & Inactive Areas

Inactive areas were defined along all of the main channels in the model. The polygons cover the length of the channel in the 2D study area and span the width of the main channel banks. This removed the area of the main channels from the 2D simulation. The remainder of the 2D grid was left to the default setting of "active" and is used in the 2D simulation.

5.1.2.5 1D/2D Connections and Boundary Conditions

Connection lines were placed along each of the main channels throughout the 2D study area. Each node within the 2D area is connected to the nearest vertex of the containing inactive area polygon. This allows flow to transfer between the 1D and 2D domains at frequent intervals along the river.

Connection lines were used as the downstream boundary condition of the 2D model. Lines were drawn connecting all the downstream vertices of the 2D grid to a single node in the 1D domain just downstream the 2D study area. This allows the model to compare water surface elevations between the level in the 1D node and levels in the 2D grid at each connection. Flow is allowed to either back up from the 1D channel into the 2D grid or drain from the 2D grid into the 1D link. This provides a uniform head boundary across the downstream edge of the 2D grid.

5.1.2.6 2D Roughness Values

Land use polygons were drawn in the model and assigned a Manning's n value based on ground cover observed in aerial photography. The Manning's n values that were assigned to each polygon were taken from the acquired HEC-RAS models or the HEC-RAS hydraulic reference manual. The SH121, I35E Timber Creek relief and Elm Fork Trinity River relief bridges were modeled in the 2D domain using the surveyed natural ground with a higher Manning's n value to account for turbulence around piers within the bridge. The I35E relief structures use the default Manning's n value listed below due to the dense tree canopy adjacent to them. The SH121 bridge uses a slightly lower Manning's n value due to the lighter vegetation adjacent to it. **Table 5** below lists Manning's n values used in the 2D model.

Table 5: Summary of 2D Manning's n Values

Land Use Description	Manning's n Value
Default - Dense tree canopy with heavy underbrush, from the CDC HEC-RAS model	0.18
Tall Grass, un-mowed fields in floodplain, from CDC HEC-RAS model	0.06
Short Grass, well groomed on the golf course, from Indian Creek HEC-RAS model	0.045
Piers under SH121, from HEC-RAS hydraulic reference manual	0.12
Golf course ponds, from Dudley Branch HEC-RAS model	0.03
Tree stands in golf course, medium density, little to no underbrush, from Indian Creek HEC-RAS model	0.07
Light industrial, predominantly concrete, some landscaping, obstructions from buildings, from Dudley Branch HEC-RAS model	0.01

5.1.2.7 Elevation Shapes

The XPSWMM software package uses "elevation shape" features to adjust 2D grid cell elevations. This option was utilized to ensure that the railroad embankment was appropriately modeled in the 2D area. A "thick" elevation shape with a width of 5 feet was used along with original GIS Terrain data to adjust these 2D cells to elevations consistent with the top of the railroad track. This was necessary because at a 30-foot cell size, it is possible that the model could have assigned elevations to these cells that were lower than the top of the track.

5.1.2.8 GIS Data/Background Layers

Additional GIS data was imported into XPSWMM to assist in building the model. Aerial photographs were used to aid in locating and visualizing model features and for defining roughness polygons. Road features were imported to also assist in locating model features. Cross-section cut lines from the existing FEMA and CDC HEC-RAS models were imported to assist in locating XPSWMM links and selecting the appropriate cross section geometry from the corresponding HEC-RAS model.

5.1.3 Model Validation

In order to validate the XPSWMM 2D model, a scenario was developed to simulate a flood event that occurred in October of 2007 in the City of Carrollton. During this event, which was less than a 10-Year event, the Eisenhower Street Bridge on Dudley Branch came very close to overtopping, according to City of Carrollton engineering staff. Field observations just after the peak of the storm indicated that the water surface elevation on Dudley Branch was about 0.5 feet above the top of the 10' x 9' concrete box culverts of the bridge, as shown in **Photo 1**. For comparison, **Photo 2** shows the bridge during typical operating conditions.

Photo 1: Eisenhower Street Bridge in the October 2007 flood event, after peak flow.

Photo 2: Eisenhower Street Bridge under normal flow conditions.

Rainfall records indicate the October 2007 storm event produced between 2.5 and 4.5 inches of rainfall in 24 hours on October 15, 2007 in and around the City of Carrollton. To get the most representative distribution and intensity of rainfall across the Dudley Branch and Indian Creek watersheds for this particular storm, NEXRAD radar data of this exact storm was obtained from the National Oceanic and Atmospheric Administration's (NOAA) National Climactic Data Center (NCDC) data inventory search. This data consists of roughly 5-minute

radar precipitation readings from the KFWS NEXRAD radar tower in Cleburne, TX. The data was obtained in an ESRI GIS raster grid format consisting of a grid with a cell size of 0.000305 degree x 0.000305 degree (approximately 112 ft x 112 ft). Each grid square contains a value for incremental rainfall. There is one raster grid for each 5 minute interval of the NOAA recording day for October 15, 2007.

The raster data provides varying rainfall over the spatial extents of each watershed as well as over time for the duration of the storm. The subbasins within the Dudley Branch and Indian Creek watersheds, as shown on **Exhibit C1**, were then digitized in GIS. Using GIS and Microsoft Excel tools, the raster data was processed and a rainfall hyetograph was produced for each subbasin shown on **Exhibit C1** within the Dudley Branch and Indian Creek watersheds. These results were verified to be consistent with other nearby rain gauges. Rain gauges used to validate the radar rainfall hyetographs were:

City of Dallas Flood Control Gauge 7955

http://fc.dallascityhall.com/html/fc.html

DFW Airport Rain Gauge KDFW

http://www.wunderground.com/history/airport/KDFW/2007/10/15/DailyHistory.html?req_city=Lewisville&req_state=TX&req_statename=Texas

Love Field Rain Gauge KDAL

http://www.wunderground.com/history/airport/KDAL/2007/10/15/DailyHistory.html

City of Coppell Rain Gauge KTXCOPPE1

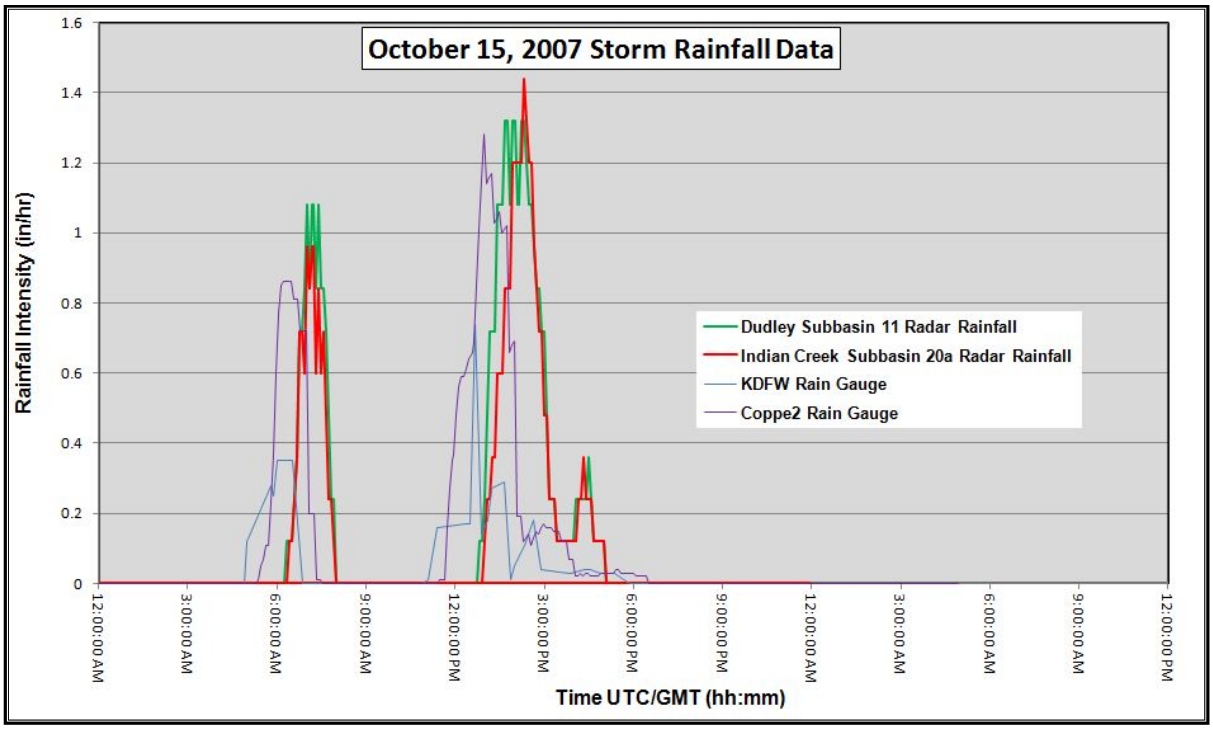
http://www.wunderground.com/weatherstation/WXDailyHistory.asp?ID=KTXCOPPE1&month=10&day=15&year=2007

City of Coppell Rain Gauge KTXCOPPE2

http://www.wunderground.com/weatherstation/WXDailyHistory.asp?ID=KTXCOPPE2&month=10&day=15&year=2007

For comparison, **Figure 4** below shows the radar rainfall data computed for this validation storm for two selected subbasins plotted against rain gauge observations from the KDFW and the Coppe2 weather stations.

Figure 4: Radar Rainfall vs. Nearby Rain Gauge Observations



Since the radar data obtained varies over the extent of the watershed and over time for the duration of the storm, the resulting hyetographs account for movement of the storm through the watershed.

All of the computed hyetographs were then input into the FEMA effective HEC-HMS models that were obtained for the project. The models were run to create inflow hydrographs for the validation storm in the XPSWMM 2D model.

The resulting runoff from HEC-HMS for Dudley Branch produced a peak discharge of 2,750 cfs in the vicinity of the Eisenhower Street Bridge. There is no stream gauge on Dudley Branch in this area to use for comparison. A flow hydrograph for the Elm Fork was determined from USGS stream gage data recorded during the event using the gage located on Elm Fork Trinity River, at Lewisville (ID- 08053000 - Elm Fk Trinity Rv nr Lewisville, TX). The results of the hydraulic model indicate that the Eisenhower Street Bridge is not influenced by Elm Fork backwater conditions and is controlled only by flow on Dudley Branch. Therefore, no hydrographs were developed for Timber Creek for this event as it has no impact on the water surface elevations at the Eisenhower Street Bridge.

The October 2007 discharges for the Elm Fork, Indian Creek, and Dudley Branch were loaded into the XPSWMM model and a maximum water surface elevation of 454.4 ft was computed at the Eisenhower Street Bridge. Survey data for Eisenhower Bridge shows the top of box elevation as 453.6. Which would give an estimated field observed water surface elevation of approximately 454.1 in the photo. The photo was taken after peak flow had occurred, so the exact peak elevation is not known, and is likely to be slightly higher than the photo. The XPSWMM 2D model, using the flows developed from the NEXRAD radar data obtained for this storm, produces hydraulic conditions within approximately 0.3 feet of the observed conditions. Although this is only one location for comparison, these results indicate

that the XPSWMM 2D model developed for this project is valid to use for simulating hydraulic conditions of the study area.

5.1.4 FEMA Floodplain Comparison Scenarios

XPSWMM software package was used to create two base scenarios for the purpose of developing floodplain boundaries for this study. The first scenario was created using 100-yr flow hydrographs for all the inflows in the study area. This is the same way that the CDC model is set up and is a valid comparison of floodplain boundaries in the project area as well as water surface elevations along the Elm Fork. This scenario was titled the "All-100Yr" scenario for this project and is used for the basis of the floodplain delineation for this project as well as the 2D water surface elevations in the vicinity of Elm Fork. Water surface elevations along the tributaries were developed from the "ELM50_ALL100" coincidental occurrence scenario. This process is discussed further in **Section 6.2.5** below.

The second scenario was created using 500-yr flow hydrographs for all the inflows in the study area. This scenario was named the "All 500-Yr" scenario for this project and is included for reference.

5.1.5 Coincidental Occurrence Scenarios

As part of the analysis, Coincidental Occurrence Scenarios were developed to represent the most probable peak flow conditions, based on the guidelines illustrated in the NCTCOG iSWM Design Manual (January 2006) and Texas Department of Transportation Hydraulic Design Manual (TxDOT 2002). **Table 6** below shows drainage area ratios that were established between the Elm Fork Trinity River and its tributaries

Table 6: Area Ratio Computations

Main River		Tributary		Actual Ratio	Ratio Used
Location	Drainage Area (sq mi)	Stream Name	Drainage Area (sq mi)		
Elm Fork Above Indian Creek	1680	Indian Creek	15.95	105:1	100:1
Elm Fork Above Dudley Branch	1697.2	Dudley Branch	4.3	395:1	100:1
Elm Fork Above Timber Creek	1706.7	Timber Creek	20.3	84:1	100:1

Based on the computed area ratios and considering that the drainage area of the Elm Fork is controlled by reservoirs, an area ratio of 100:1 was deemed most suitable for the study area. Coincidental occurrence frequencies were selected from Table 3.2-12 of the ISWM design manual for the 10-, 50- and 100-yr design storms, each with an area ratio of 100:1, as shown in **Table 7**.

Table 7: ISWM Recommended Coincidental Occurrence Scenarios

Design Storm	Area Ratio	ISWM Recommendation	
		Main Stream	Tributary
10-Yr	100:1	5	10
		10	5
50-Yr	100:1	10	50
		50	10
100-Yr	100:1	25	100
		100	25
500-Yr	NA	NA	NA
	NA	NA	NA

As mentioned in **Section 4**, only available hydrologic analyses were used for this study. As such, not all storms were available to meet the ISWM Coincidental Occurrence recommendation. (See **Table 1** for available hydrology) The most appropriate available storm hydrographs were substituted for the missing ISWM recommendations. The intent was to develop a coincidental occurrence scenario for Indian Creek and Dudley Branch to more realistically model these tributaries with a reasonable downstream tailwater condition. Since the hydrology was available and it was included in the project scope, the remaining coincident occurrence events and the "All 500-Yr" scenarios were developed and provided for reference and potential future use. The 100-year coincidental occurrence storm scenario which applies the 50-year storm to the Elm Fork and 100-year storms to the tributaries was used to develop 100-year water surface elevations along the tributaries. **Table 8** shows all modeled scenarios and available storm frequencies used along with the intended use for each.

Table 8: Modeled Scenarios and Storm Frequencies Used

Design Storm	Area Ratio	Available (Used) Frequency				Comments
		Elm Fork	Dudley Branch	Indian Creek	Timber Creek	
10-Yr	100:1	10*	10	10	10	Provided for reference. Can be used in future design and analyses.
		10	5	5	10*	
50-Yr	100:1	10	50	50	50	Provided for reference. Can be used in future design and analyses.
		50	10	10	10	
100-Yr	100:1	50+	100	100	100	Used as the basis of the 2D water surface elevations along the tributaries.
		100	25	25	50+	
All 100-Yr	NA	100	100	100	100	All 100-year is the most similar to the FEMA 100-year analysis along Elm Fork and is used as the basis of 2D water surface elevations along Elm Fork.
All 500-Yr	NA	500	500	500	500	Provided for reference. Can be used in future design and analyses

* 10-yr frequency substituted for 5-yr storm due to available hydrology
\+ 50-yr frequency substituted for 25-yr due to available hydrology

5.2 Model Scenarios Developed

For this study nine different scenarios were developed. There were six coincidental occurrence scenarios developed for various return frequencies, one "All 100-Year" scenario, one "All 500-Year" scenario and one validation scenario (October 2007 event) developed for this study. The default scenario title set by XPSWMM is "Base Scenario" and was not renamed. **Table 9** lists the runs that were performed for this study, the XP model each run is stored in, the scenario name within each model, and the storm used on each stream for each scenario.

Table 9: XPSWMM Models by Scenario

Description	XPSWMM Model Name	Model Scenario Name	Frequency Storm Used			
			Elm Fork	Dudley Branch	Indian Creek	Timber Creek
All 100-Yr	LDB_Base_Scenario_All_100 _NoShift	Base Scenario	100	100	100	100
All 500-Yr	LDB_Base_Scenarios_All500 _NoShift	Base Scenario	500	500	500	500
October 2007 Flood	LDB_Oct2007_Scenario	Base Scenario	Oct 2007 Flood	Oct 2007 Flood	Oct 2007 Flood	
Coincidental Occurrence Scenarios	LDB_All_10	Base Scenario	10	10	10	10
	LDB_ELMTIM_10_DUDIND_ 5	ELM_TIM_10_DUD_IND_5	10	5	5	10
	LDB_ELM_10_TIMDUDIND_ 50	ELM_10_DUD_IND_TIM_50	10	50	50	50
	LDB_Scenario_4	ELM50_ALL100	50	100	100	100
	LDB_Scenario_5	ELM50_ALL10	50	10	10	10
	LDB_Scenarios_6	Base Scenario	100	25	25	50

Section 6 - Model Results

6.1 Summary of Results

In general, the XPSWMM 2D model developed for this project produces water surface elevations similar to those produced by the FEMA effective and CDC HEC-RAS models. As shown in **Table 11** below, the XPSWMM 2D results are generally 0.5 – 2 feet different than those produced by the HEC-RAS models. In the vicinities of SH121, Elm Fork Trinity River, and I35E, the XPSWMM 2D model is within about 0.5 feet of the CDC HEC-RAS model. In the vicinities of Dudley Branch, Indian Creek, and the Indian Creek Golf Course the 2D XPSWMM model results are within 1 to 2 feet of the FEMA effective HEC-RAS models.

These differences are due to some fundamental differences in the conditions that each model simulates, the assumptions associated with those conditions, and methodologies between the current HEC-RAS models and the XPSWMM 2D model.

6.1.1 Limitations of Current HEC-RAS Models

The scope of the current HEC-RAS models is to simulate a steady-state flood event on each individual stream by itself. These models serve to delineate the limits of the regulatory floodplain in reaches with uniform flow that is mostly parallel to the main channel, with no impacts from high tailwater conditions or interaction with overflow from other streams.

Using this modeling approach, there are many assumptions that must be made or that are inherent to the software. Assumptions associated with this type of modeling include:

- Flow is uniform and in a direction parallel to the main channel.
- That all the flow in the cross section acts as a single unit and can be approximated by calculating the average friction slope for the entire cross section.
- The receiving stream only impacts the study channel as a flat backwater.
- That each stream has separate, individual floodplains near confluences. This requires making assumptions about the width of the floodplain and adjustments to cross section width.
- Assuming that there is no volume in the model cross sections previously occupied by floodwaters from another source. (i.e. the entire cross section is free to convey all flow originating from within the studied watershed.)

If overflows from another watershed are considered, then assumptions about flow path, location and flow rate must be made. Estimating overland flow using traditional 1D methods can be difficult to accomplish. As a result of this modeling approach and these assumptions, there are limitations to the hydraulic conditions that these models can simulate. Limitations of this type of model include:

- Does not account for flow from one channel (or floodplain) to another

- Does not account for channel storage
- Does not account for volume in the floodplain
- Does not capture impacts to water surface elevations when the downstream channel is full.
- No accounting for variation in velocity, friction loss, or other head losses within each individual cross section.
- Difficult to appropriately capture physical terrain features in between cross sections
- Can be difficult to appropriately determine cross section extents in a wide, flat, low lying floodplain.
- Defines shared floodplains near confluences as isolated individual floodplains belonging to a single channel.

If these conditions represent the flow conditions of the modeled stream, then this approach is appropriate. This is the case for most common channels with well defined and self contained floodplains. However, in locations where these conditions do not represent the nature of the flow, such as in the vicinity of the low lying confluence of multiple streams, then this modeling approach may not be appropriate.

Additional assumptions and a different modeling approach would be required to use this software to simulate the flow conditions of a complex confluence of multiple streams. The current HEC-RAS models are not set up to simulate a combined confluence with a shared floodplain accepting overflow from adjacent streams.

6.1.2 The Lower Dudley Branch Flood Study Model

The scope of the Lower Dudley Branch Flood Study XPSWMM 2D model was to model the confluence of Timber Creek, Elm Fork Trinity River, Indian Creek, and Dudley Branch as one single shared floodplain system over a range of storm events to more accurately simulate the interaction between these streams. All of these streams empty into the Elm Fork Trinity River in a shared, low lying floodplain in close proximity to each other. None of the existing HEC-RAS models treat this confluence as a single, shared floodplain. The USACE CDC model was the most comprehensive model of this area prior to this study, and the results of this study agree more closely to the CDC HEC-RAS results than the tributaries' HEC-RAS models. This study considers high flows from all four watersheds moving through this area as one event and allows the overflows from each channel to mix and flow, unconfined, over a 2D surface.

The scope and modeling approach of this analysis is different from that of the current HEC-RAS studies in that:

- This combined floodplain is treated as one shared entity and considers flood flows from all four streams in the same event

- The assumed Normal Depth "downstream" conditions of the HEC-RAS models are not applicable.
- Flow is not confined strictly within each channel or cross section.
- 2D model uses unsteady flow, which accounts for floodplain storage volumes
- A 2D floodplain eliminates the need to assume floodplain width within cross sections.

For these reasons and for this scope, a dynamic, unsteady, integrated 1D/2D modeling approach was determined to be the most appropriate approach to simulate these conditions. Advantages of this modeling approach are:

- Allows concurrent modeling of adjacent streams
- Allows for flood waters to leave the 1D channel banks and flow in an "unconfined" direction according to topography in the 2D grid. This flow is subjected to all topographical features in the grid, rather than just those shown in a 1D cross section.
- Flow is allowed to go back and forth between the 1D main channel and 2D floodplain at multiple locations along each 1D link.
- Flow in the 2D floodplain can combine with overflow from adjacent streams. Flow path and quantity of this overflow are shown.
- The 2D grid captures all terrain features in the area.
- 2D flow can also flow at different velocities than the main channel and encounter different head losses independent from the main channel.
- 2D flow is unsteady and dynamic. Total runoff volume, flow timing, floodplain surface storage, and flow attenuation are all considered.
- The 2D floodplain can be used to delineate FEMA floodplain

These advantages are utilized in this model. The confluence simulated in this model consists of four closely spaced streams, so it is advantageous to simulate them all concurrently as one system. Due to the low lying nature of the area, overflows from each channel will combine and mix together. These overflows have significant impacts on the water surface elevations of adjacent streams. These impacts are accounted for in upstream reaches of each tributary in this model. Due to the different timings of each watershed, some volume of the shared floodplain may be occupied by flood water from another stream when the peak flow comes through. The 2D grid in this model simulates this condition. Unsteady flow across the 2D grid is attenuated as it meanders across the terrain and through relief structures not located on the main channel. Both the railroad and IH35E bridges cause a noticeable attenuation of flows in this area. The advantages of a 2D model stand out when modeling a system such as this confluence. However, there are limitations to this modeling approach and is not suitable for all applications. Limitations to this type of model include:

- More complicated than standard 1D HEC-RAS
- Very data intensive when using LIDAR to develop 2D surfaces
- No real advantage over traditional 1D analysis in scenarios where 1D assumptions are appropriate, i.e. most streams with well defined and fully contained floodplains

This 2D model was developed specifically to simulate the flow conditions of this confluence and shared floodplain as one integrated system. No assumptions were made regarding backwater effects, volume stored in the floodplain, or estimating the cross flow between channels. All these components are inherently calculated in the simulation by utilizing this 1D/2D framework. After analyzing results, it becomes evident that this scenario is more indicative of reality for this specific case due to the fact that there are no topographical features separating these four streams in this study area.

Due to these fundamental differences in modeling approaches and set ups, a difference in resulting water surface elevations is to be expected. The results presented in the following section provide a more quantitative assessment of these differences.

6.2 2D Model Results

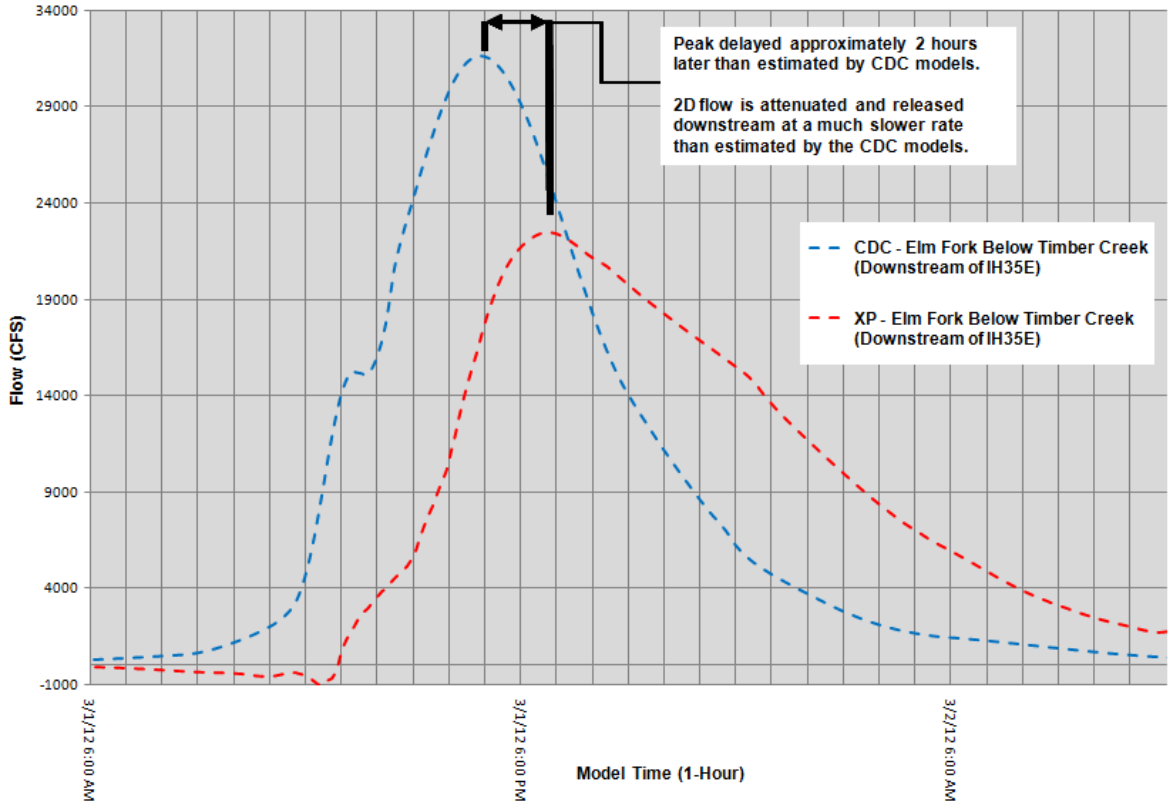
The XPSWMM 2D software was used to review results after model runs were completed. The software comes equipped with various tools to review flow through 1D links, water surface elevations in 1D nodes, 2D flow across a previously defined line, and 2D water surface elevations (or depth) across the 2D grid. Additionally, results can be reviewed directly from the .OUT (1D results) or the .TLF (2D results) text files stored in the same directory as the .XP model file. The following results were produced for this study.

6.2.1 2D Model Flows and Comparison to CDC Flows

The XPSWMM 2D model indicates that a larger attenuation of flood flows occurs upstream of the IH35E bridge than is accounted for in the CDC HEC-1 and HEC-RAS models. The CDC models show a 100-year peak discharge of about 31,600 CFS compared to the XSWMM 2D 100-year peak discharge of about 22,400 CFS. This is due to the assumed timing of hydrograph peaks in the CDC models. The CDC models use a Modified Puls routing method to estimate the attenuation that occurs along the course of the Elm Fork. The 2D model shows more complex flow patterns across the 2D surface. These complex flow patterns increase the travel time of the flow through this area causing a significant flow volume to be impounded behind the IH35E and DCTA railroad bridges and then slowly metered out after the peaks have moved through.

At the upstream end of the study model, the CDC flow and the XPSWMM flows are identical because the CDC flow is the inflow for the XPSWMM model at this location. The attenuation occurs when this inflow combines in the 2D floodplain with inflows from the other streams and drains out downstream through the IH35E bridge. The XPSWMM results show that the peak outflow from the 2D area occurs approximately 2 hours later than is estimated by the CDC models. The total volume is approximately the same, but the peak flows are different. **Figure 5** below shows this attenuation and compares the XPSWMM flow to the CDC model flows.

Figure 5: 2D Flow Routing vs. CDC Flow Routing Through 2D Study Area



This attenuation has impacts all the way through the remaining downstream reaches of this model. Downstream of IH35E there are six more major inflows into the Elm Fork Trinity River channel. The delay observed upstream of IH35E causes the peaks of these remaining hydrographs to interact with the Elm Fork flow differently than in the CDC models.

There is not an appropriate way to compare flows within the 2D model area to the CDC model flows though the 2D area. This is due to the different modeling approaches and the way this data is recorded in each software. The CDC HEC-RAS model contains all the flow within a cross section. The integrated 1D/2D model divides the flow between the main channel banks (1D) and the 2D grid where it is allowed to flow in multiple directions. Measuring the flow in the 1D link accounts only for the flow contained within the main channel banks. This is further complicated by the fact that flow is interchanging between the 1D and 2D domain for the length of each link. It is not an equivalent analysis to compare the total 1D cross section flow to the dynamic flow across the 2D grid.

For these reasons, 2D flow was not measured for purposes of comparing to the CDC flows through this area. **Table 10** below reports peak 100-year flows from 1D links outside the 2D area from the XPSWMM model and compares them to the CDC model flows.

Table 10: 100-Year Peak Flows - XPSWMM vs. CDC Models

CDC Location		CDC Peak Flow	XPSWMM Peak Flow	XPSWMM Location	
Station	Description			Link	Node
EFAIND	Elm Fork Above Indian Creek	11367	11309	125658	25 to 26
EFBIND	Elm Fork Below Indian Creek	22442	N/A*	118732	73 to 31
EFADUD	Elm Fork Above Dudley Branch	19698	N/A*	112617	78 to 77
EFBDUD	Elm Fork Below Dudley Branch	20059	N/A*	110572	36 to 37
EFBTIM	Elm Fork Below Timber Creek	31622	22408	109445	39 to 38
EFDEN	Elm Fork and Denton Creek	42940	25664	101428	44 to 45
EFAGPV	Elm Fork Above Grapevine Creek	39173	23635	84959	66 to 67

* Located within 2D area, comparison not valid.

6.2.2 2D Overflows Between Streams

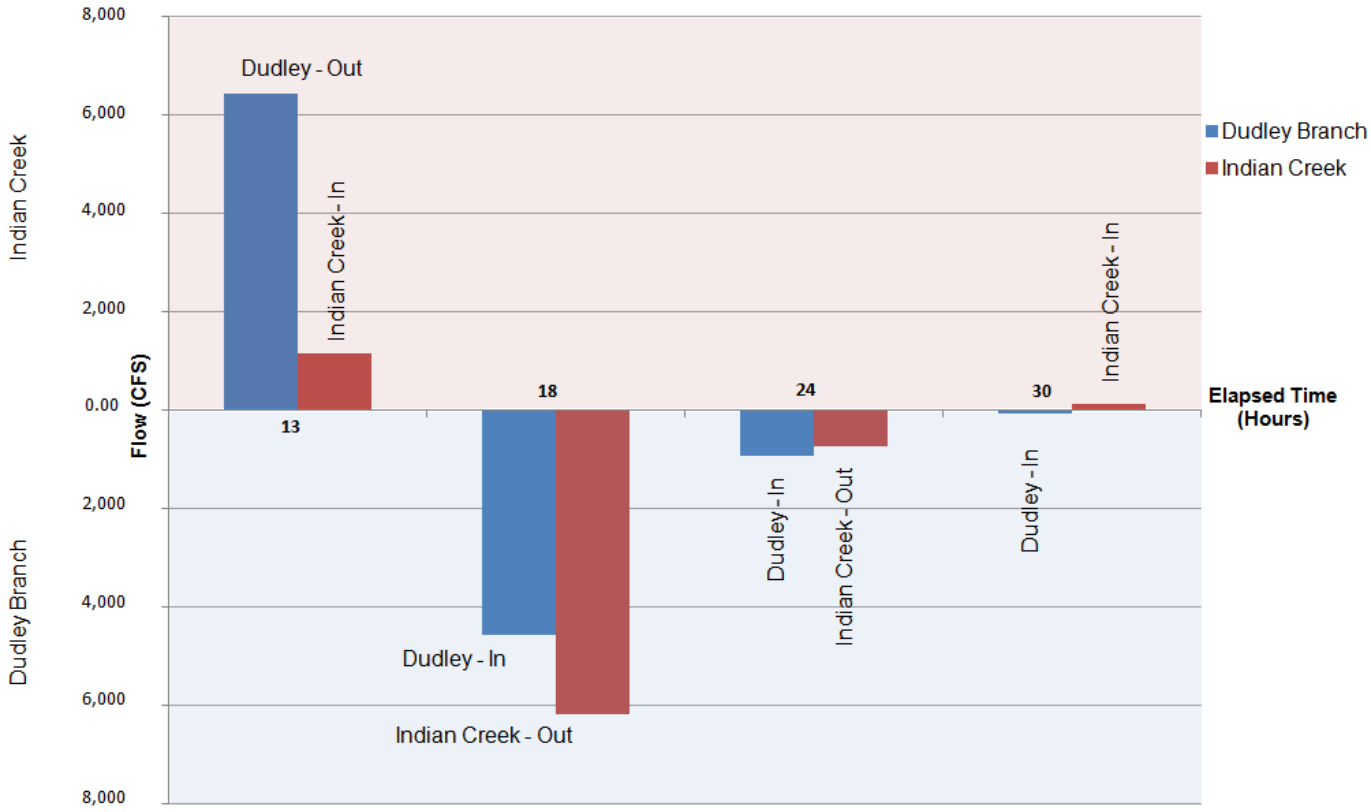
The model results show that all streams overflow in this area and combine in the overland 2D grid. This is quantified by use of the "2D Flow Line" tool in XPSWMM. This tool allows the user to draw a polyline across the 2D grid, run a scenario, and then view a hydrograph of net flow that crosses this line. Location of these lines should be carefully considered prior to placement, as the 2D flow is reported as positive in one direction and negative in another direction. So areas of eddy flow or flow parallel to the polylines can affect the reported results.

A set of three 2D flow lines in the vicinity of the ICGC was utilized to quantify overflow from each channel. There is one line just north of the Dudley Branch channel, upstream of the Elm Fork, one line just south of the Indian Creek Channel, also upstream of the Elm Fork, and one line just east of the Elm Fork between Indian Creek and Dudley Branch.

For the 100-year event, the 2D model shows peak flows of approximately 6,500 CFS leaving Dudley Branch and 6,200 CFS leaving Indian Creek. These are only the peak flow values. The 2D results show that this overflow occurs over some period of time which results in a volume of water filling up the floodplain before the peaks come through. All this flow combines in the vicinity of the ICGC. This additional overflow backs up in this area to create additional volume in the floodplain and causes a backwater effect along the Indian Creek and Dudley Branch tributaries. **Figure 6** below shows the 100-year results from these 2D flow lines. Four individual timesteps were selected to depict which stream was overflowing (labeled "Out") and generally where this overflow went (labeled "In"), with some volume of this overflow being stored in the floodplain.

The figure is divided into two sections according to the source of the overflow. It is important to note that flow crossing one 2D flow line does not necessarily cross the other. There is a volume of floodplain in between these two lines that will fill up, store water and attenuate the flows across this area. Once the peaks move through and the floodplain is full, the stored volume drains off back into each respective channel.

Figure 6: Summary of 2D Flow Lines from XPSWMM 2D Model



The figure shows that there is a significant overflow volume that combines in the shared floodplain between these streams. This combined overflow is one of the main causes of the difference in water surface elevations between the effective HEC-RAS models and the XPSWMM 2D model.

6.2.3 2D Water Surface Elevations and Comparison to CDC & FEMA Models

The results from this analysis were compared to the effective FEMA hydraulic models to determine the difference in water surface elevations at various locations. **Table 11** shows a list of the locations where elevations were compared, along with the difference in water surface elevations. **Exhibit G** shows a comparison between the FEMA Effective and XPSWMM BFE's and floodplains.

Elevations for the locations marked as "Elm Fork CDC HEC-RAS Model" are taken from the CDC HEC-RAS model and the "All 100-yr" 2D model scenario. Elevations on Indian Creek and Dudley Branch are taken from their respective HEC-RAS model and the "ELM50_ALL100" coincidental occurrence 2D model scenario. **Tables 11 A, B,** & **C**, provide the same comparison for the 10-, 50-, and 500-year model results, respectively. These tables are provided in **Appendix D.**

Table 11: Comparison of 100-yr Results to HEC-RAS WSE

	Location (Physical Description)	RAS River Station	XPSWMM WSEL (ft)	HEC-RAS WSEL (ft)	Δ (ft)
Elm Fork CDC HEC-RAS Model	Downstream reach of model	76475	439.22	438.33	0.89
	Upstream of Beltline Bridge	87428	440.91	440.63	0.28
	Upstream of Sandy Lake Bridge	93927	443.82	444.52	-0.7
	Downstream of I35E Bridge	110074	450.89	450.44	0.45
	Upstream of I35E Bridge	110475	451.7*	451.37	0.33
	Downstream of SH121 Bridge North of RR Tracks	122744	453.8*	453.08	0.72
	Downstream of SH121 Bridge South of RR Tracks	122744	453.3*	453.08	0.22
	Upstream of SH121 Bridge North of RR Bridge	122944	453.9*	453.12	0.78
	Upstream of SH121 Bridge South of RR Bridge	122944	453.4*	453.12	0.28
	Indian Creek Entering 2D Area	5329**	457.3	454.41	2.89
	Upstream of Eisenhower Bridge	7065+	459.05	457.78	1.27

* Indicates approximate 2D water surface elevations.
Actual elevations will vary over distance.
** River station from Indian Creek model
+River station from Lower Dudley Branch model.

6.2.4 Differences between HEC-RAS and 2D XPSWMM Results

These results generally agree with the water surface elevations produced by the CDC model of the Elm Fork. A difference of less than a foot between these two data sets, given the previously discussed differences between modeling methods, is not a significant discrepancy. These results agree well because the CDC model cross sections account for the total width of the shared floodplain in this area and all of the inflows from Indian Creek and Dudley Branch. Also, the CDC HEC-1 hydrologic model partially accounts for the floodplain storage upstream of IH35E. The 2D XPSWMM model more comprehensively simulates the interaction of flow in the floodplain and the attenuation caused by the IH35E bridge. In the 2D floodplain, flow is allowed to meander across the surface and fill up the floodplain differently than is modeled in traditional 1D methods. This is consistent with the attenuation shown in **Figure 5**.

These results are similar to the existing HEC-RAS results for the Indian Creek and Dudley Branch models in that they indicate the same general flow patterns, but are 1 to 3 feet higher

in elevation than the HEC-RAS results. These results are reasonable given the differences in scope between the HEC-RAS and XPSWMM models.

The differences in these results are due to the differences in modeling approaches and scopes discussed in **Sections 6.1.1** and **6.1.2** above. The HEC-RAS models use a normal depth for the downstream condition. The 2D model indicates this assumption is not appropriate because these streams are affected by tailwater conditions. Both of these models also have lateral structures in the downstream reaches, near the confluence with Elm Fork, which lets as much as 10,000 cfs leave the system unaccounted for. In the 2D model, this overflow is contained and accounted for within the shared system. The 2D model shows that this overflow has an impact on adjacent streams upstream of the confluence area. In order to divide the shared floodplain into two distinct floodplains, the HEC-RAS model cross sections are subjectively clipped to the assumed floodplain width. This has an impact on the resulting conveyance and storage capacity of the floodplain. The HEC-RAS models simulate a single event on individual watersheds. The XPSWMM 2D model simulates simultaneous events occurring in this area as one system and will yield higher water surface elevations. Using coincidental occurrence scenarios is more conservative than the HEC-RAS approach.

The XPSWMM 2D model was validated as discussed in **Section 5.1.3**. As an additional "order of magnitude" check, the 2D results were back checked by revising the current HEC-RAS models to reflect the hydraulic conditions observed in the 2D model. Conceptually, the HEC-RAS models were adjusted to account for the following observed conditions:

- Flood flow crossing between Indian Creek, Elm Fork, and Dudley Branch.
- Overflow volumes stored within the shared floodplain
- Backwater effects from the elevated tailwater of the Elm Fork.

To adjust these individual HEC-RAS models to more closely simulate the conditions observed in the 2D model, cross section limits were revised, lateral structures were edited, inflows were added to approximate the observed 2D overflows, and the downstream boundary condition was set to the Elm Fork water surface elevation of the 2D model.

After making these revisions to the effective FEMA HEC-RAS models, the model results agreed within about 1 foot of the XPSWMM 2D model results. **Table 12** below shows a comparison of these results at a few selected locations.

Table 12: 100-Year Results - XPSWMM 2D vs. Revised & Effective FEMA HEC-RAS Results

	Physical Location	HEC-RAS River Station	XPSWMM 2D Water Surface (Ft)	Revised HEC-RAS Model Water Surface (ft)	FEMA Effective Model Water Surface (ft)
Indian Creek	Confluence with Elm Fork Trinity River	747	453.9	453.9	448.0
	In the middle of Indian Creek Golf Course	4030	456.0	455.8	452.5
	Where Indian Creek channel discharges into 2D area	5329	457.7	456.6	454.4
Dudley Branch	Confluence with Elm Fork Trinity River	549	451.8	451.8	444.9
	In the middle of Indian Creek Golf Course	2857	452.7	452.9	449.0
	Upstream of Eisenhower Bridge	7065	459.05	458.7	457.8

Exhibits G1 & G2 show HEC-RAS profile results comparing these HEC-RAS model runs to the 2D model results for the 100-year event. The similarities between the revised HEC-RAS model results and the XPSWMM 2D model results further support that the differences between the models suggested above are valid sources for the observed differences. As such, the XPSWMM 2D results are more representative of peak water surface elevations in this area. However, the scenario of having multiple events occurring on all watersheds simultaneously is unlikely. These 2D results better represent the flood risk in this vicinity, under these conditions, than the lower HEC-RAS water surface elevations.

6.2.5 Creation of 100-Yr Base Flood Elevations (BFEs) and Floodplain Boundary

As another comparison to the FEMA models, a set of "base flood elevations" was developed. Published FEMA BFEs are generally straight lines running perpendicular to the flow direction of the channel. This is because of the inherent assumption made by HEC-RAS that all the flow in the floodplain travels in one direction parallel to the channel. This is not the case with resulting 2D "BFE" lines. The 2D results are more similar to contour lines of the resulting 2D results surface than they are to the FEMA published BFEs. As shown on **Exhibit F**, these contours are curved, they are not straight lines. This is because flow is allowed to spread out and flow in multiple directions across the 2D grid. They are still perpendicular to the direction of flow, but the direction of flow is not parallel to the channel.

To create BFE's from the 2D model results, two different scenarios were used. The "All 100-Yr" scenario was used in conjunction with the "ELM50_ALL100" coincidental occurrence scenario outlined in **Table 9**. The "All 100-Yr" scenario was used to represent water surface elevations in the vicinity of the Elm Fork, roughly from just east of the DCTA rail line to IH35E. This scenario is essentially the same event that the CDC HEC-RAS model uses. The "ELM50_ALL100" coincidental occurrence scenario was used to represent the water surface

elevations along Indian Creek and Dudley Branch. This was done to more appropriately reflect the 100-year water surface elevations along Indian Creek and Dudley Branch. While the Elm Fork backwater does impact these tributaries, it is unrealistic to represent these tributaries' 100-year water surface elevations using a simultaneous 100-Year event on the Elm Fork as a downstream tailwater condition. In the 2D domain it is again unrealistic to model simultaneous 100-year flow volumes on both the Elm Fork and the tributaries. Using the coincidental occurrence model with a lesser event on the Elm Fork is more closely aligned with typical engineering practice when studying a smaller tributary discharging into a larger watercourse.

Results from each of these scenarios were exported to GIS. Then 1-foot contours were created from each of these grids in GIS, which represent whole foot BFE's for the 2D study area. **Exhibit F** shows the resulting 100-year BFE data.

The 100-year floodplain boundary was created from the "All-100Yr" 2D water surface elevation grid that was exported in the BFE creation process. The water surface elevation grid was converted from a raster grid to a polygon shapefile using GIS tools. **Exhibit F** shows these 100-year results. No floodways were delineated for this study.

6.3 Indian Creek Impacts

The 2D model shows about a 2 to 3 foot higher water surface elevation in Indian Creek than the current HEC-RAS model. The difference in water surface elevation shown by the XPSWMM model may be attributed to the reasons discussed above. The HEC-RAS models use a "normal depth" downstream boundary condition for this stream. The backwater from the Elm Fork has a significant influence on this steam in this reach. The HEC-RAS models also do not account for mixing of flows between the Indian Creek and Elm Fork or Dudley Branch. The 2D results show that flow from both streams combines with flow from Indian Creek in this area. This is important because in the 1D HEC-RAS models the cross sections are cut relatively wide but only convey the assigned Indian Creek flow. These effects can be seen on **Exhibit G2**.

The primary concern in this area is the potential impact than an increase in BFE would have on the Denton County Reclamation and Road District (DCRRD) Levee relative to freeboard and levee certification. In order to quantify these impacts, a comparison of the levee elevations and XPSWMM water surface elevations is presented in **Exhibit H**. As shown in **Exhibit H**, the DCRRD Levee still maintains over 4 feet of freeboard adjacent to the study area, which is above the minimum required by FEMA.

The 2D results show two areas of potential home flooding. The first area, north of the Indian Creek channel, is along Legacy Trail and Creekside Lane. This area shows approximately 0.5 feet of flooding during the 100-year event and 1-2 feet during the 500-year event. Both events show this flooding to be mainly within the roadway. This flooding does not appear to inundate any homes in this area.

The second area, south of the Indian Creek channel, is located in the Pawnee Trail cul-de-sac. The 2D water surface elevations show approximately 0.5 to 1 feet of water touching the western most lots in the 100-year event and 0.5 to 2 feet of water inundating lots, homes, and

the cul-de-sac in the 500-year event. The results do not indicate any home flooding in the 100-year event, but do indicate potential home flooding during the 500-year event.

6.4 Dudley Branch Impacts and Frankford Road Flooding

The 2D study results indicate that 100-yr water surfaces are about 2 feet higher than current HEC-RAS results show along Dudley Branch where it enters the project area but then begin to converge with the current CDC HEC-RAS model towards the confluence with Elm Fork. The difference in water surface elevation shown by the XPSWMM model may be attributed to the same reasons as discussed above. The FEMA HEC-RAS models use a "normal depth" downstream boundary condition for this stream. The backwater from the Elm Fork does have an influence on the lower portions of this stream, but converges with normal depth near the in-line pond on Dudley Branch upstream of Indian Creek drive. The 2D model indicates that this pond fills up to a level above the adjacent berm first, then overflows across the golf course to the north and west. The 2D model results indicate that this pond does not operate in a "steady state" manner, as it is assumed to do in the HEC-RAS models. Since the pond is in-line with the channel, this elevated water surface causes the main channel to backup towards the Eisenhower Bridge before discharging into the 2D area. The HEC-RAS models also do not account for mixing of flows between the Dudley Branch and Elm Fork or Indian Creek. The 2D results show that flow from both streams combines with flow from Dudley Branch in this area. This is important because in the 1D HEC-RAS models cross sections only convey the assigned Dudley Branch flow. Another probable difference could be attributed to the different solutions between the steady HEC-RAS model and the unsteady XPSWMM model. Both use different algorithms to determine water surface elevations. These effects can be seen in **Exhibit G1**.

The 2D results show one area of potential home flooding if the in-line pond were to overtop. The 2D water surface shows approximately 1.0 foot of inundation in the alley way west of the intersection of Taos Trail and Sundance Circle. The homes at 3201 and 3205 Taos Trail are located on either side of this alley and would be the homes most likely impacted by this inundation. However, the 2D results do not show these homes, or any other homes in this area, becoming inundated in any of the scenarios run.

These results show that there are three areas where the 100-yr flood inundates Frankford Road. Flooding of Frankford Road would significantly impact traffic and connectivity to I35E as well as presenting a public safety hazard. When these results were discovered, City of Carrollton engineering staff confirmed that this area has been known to flood in events as low as a 10-year storm. Conceptual improvements were investigated and briefly modeled to determine if there is a feasible solution to prevent this overtopping. After an initial analysis, it is likely that this overflow can be contained by excavating the channel to widen it and provide more storage volume in this area.

Section 7 - Conclusions and Recommendations

7.1 Conclusions

The water surface elevations computed with 2D XPSWMM are generally within 0.5 - 2 feet of the FEMA Effective BFEs in the Elm Fork floodplain area, with some higher water surface elevations being calculated up each of the tributaries. The 2D XPSWMM model simulates a different set of hydraulic conditions than the Indian Creek and Dudley Branch models, but is similar to the Elm Fork Trinity River CDC model. Modeling this confluence as a shared floodplain between all four streams is more indicative of reality for this area than the conditions assumed in the 1D HEC-RAS models. Mixing of flows and multidirectional flow occur in this area and are very difficult to capture in a 1D model. The XPSWMM 2D model captures this behavior and shows the variation in water surface elevation across the 1D cross sections. **Exhibit G** compares the BFEs visually to show how the assumptions of uniform water surface elevations along a cross section in HEC-RAS are not valid in the study area. The dynamic 2D model also more accurately represents the variation in water surface through the study area by capturing effects of mixing flows between streams, tailwater effects on the tributaries, hydrograph timing, volume, storage, and attenuation that occur along this reach of the Elm Fork. These differences can be seen in **Exhibit G** and **Table 11**. Finally, the ability to generate flow vectors from the 2D model greatly aid in visualizing how flood waters move across the floodplain, especially in backwater areas at the downstream ends of tributaries. The results of the study and benefits highlighted above demonstrate the advantages of the 2D XPSWMM model over the 1D HEC-RAS models.

The 2D model results agreed with the effective BFEs rather well for the majority of the combined floodplain area. However, the model shows some significant differences from the FEMA effective BFEs on both the Indian Creek and Dudley Branch tributaries. These differences can be partially attributed to the FEMA Effective HEC-RAS models use of "normal depth" for their downstream boundary condition rather than a known water surface elevation of the Elm Fork floodplain. The models do not account for the impacts to water surface elevations on the tributaries caused by high tailwater elevations in the Elm Fork floodplain. The tributaries essentially discharge into a large reservoir that will be inundated in an event such as the 100-year event. Another difference between the two models is that the HEC-RAS models do not account for the combining of overflows from all four streams in the shared Elm Fork floodplain. This additional overflow volume fills up portions of the floodplain and adds additional flow to be conveyed by the existing HEC-RAS cross sections. When the HEC-RAS models of Indian Creek and Dudley Branch were revised to incorporate some of these 2D observations, the HEC-RAS results matched the 2D results within 1.0 foot along the tributaries.

The XPSWMM model developed for this study provides more accurate flood elevations for the hydraulic conditions present near the confluence of these streams, and is a valuable tool for the City to evaluate future development and capital projects in the study area. Additionally, the study results have highlighted specific impacts and recommendations for the City to consider.

7.2 Recommendations

The XSWMM 2D model can potentially be used to assess future CIP projects in the area, flooding impacts as a result of future IH35E reconstruction, to assess flood risk to future development adjacent to this floodplain, or to establish a better downstream tailwater elevation for the existing HEC-RAS models. For example, the XPSWMM 2D model showed flooding along Frankford Road. The model was then used to simulate potential improvements to address this flooding.

Based on the higher 2D water surface elevations identified above, multiple scenarios were developed to investigate the cause of the Frankford Road overtopping and determine economically feasible solutions to improve conveyance and divert the flow such that Frankford Road would not be inundated. These scenarios involved removal of the eastern most pond on the ICGC, channel improvements along Dudley Branch downstream to the DCTA railroad crossing, re-constructing the Indian Creek Drive culvert, and a small floodwall along the southeast corner of the golf course immediately adjacent to Frankford Road. The channel improvements and pond removal involve excavating the berm on the southern edge of the pond, excavation to widen the Dudley Branch channel by 100 feet, and encroaching on the large golf course pond to the west of Indian Creek Drive to provide more channel conveyance. Increasing capacity to the Indian Creek Drive culvert and construction of a 1’ tall floodwall were also considered as possible improvements.

Preliminary results of these scenarios indicate a significant reduction in water surface elevation and flooding on Frankford Road is possible with excavation and re-grading along the Dudley Branch channel. Removing the berm on the south end of the pond, widening the channel by approximately 100 feet, and re-grading and realigning this channel between the existing pond location and Indian Creek Drive, reduces the peak 100-year water surface elevation enough to prevent the overtopping. The City owns multiple parcels adjacent to the stream in this area that could potentially be utilized to facilitate the proposed improvements. It is therefore recommended that additional optimization of these alternatives be performed to determine the most cost effective solution to flooding of Frankford Road. **Exhibit I** depicts the conceptual areas considered for improvement.