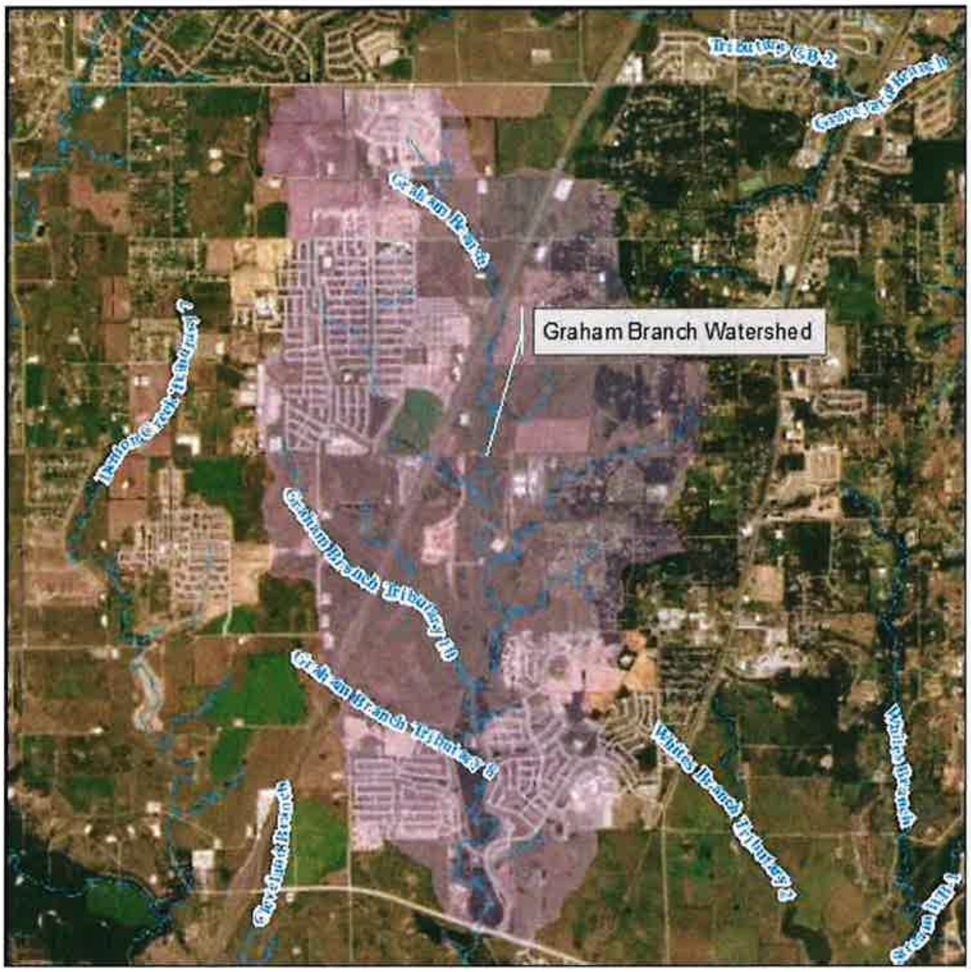
GRAHAM BRANCH

MASTER DRAINAGE STUDY

Argyle, TX



Prepared by:

CARDINAL STRATEGIES

TBPE Firm No. F -11976

Prepared for:

Argyle TEXAS

June 4, 2021

STATE OF TEXAS
THOMAS N. CAFFAREL
103444
LICENSED
PROFESSIONAL ENGINEER

P.E.
6/4/2021

The Town of Argyle – Town Administrator
Attn: Richard Olson
308 Denton Street
Argyle, Texas 76226

Re: Graham Branch Master Drainage Study
Argyle, Texas

Dear Mr. Olson:

Enclosed herewith is the Master Drainage Study for the Graham Branch watershed in order to support future development in the Town of Argyle and adjacent jurisdictions. This report includes comprehensive hydrologic modeling with results for 2009 and 2021 conditions for existing and fully developed flows. This study reviewed recent submittals for development in the Graham Branch watershed, which is further detailed in the report.

Should you have any questions or concerns, please do not hesitate to contact me at (817) 721-6405 to discuss any items related to this Report.

Sincerely,

Thomas Caffarel, P.E. CFM
Principal, Engineering Services Manager
Cardinal Strategies Engineering Services, LLC
TBPE Firm Registration No. F-11976

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EXECUTIVE SUMMARY

The Town of Argyle contracted Cardinal Strategies Engineering Services, LLC (Cardinal) to construct an overall watershed model for Graham Branch. This is the only unstudied watershed within Argyle and development has started to take off within the past eight years. Several different engineers representing several different developments within the watershed have built varying models and the overall flow rates established by each engineer has not always been consistent. Regulating future development submittals will become much easier with a master drainage study and development engineers can use this model as a starting point for evaluating potential impacts associated with their sites. For purposes of this study, the Cardinal 2021 watershed model is representative of all completed and built developments at the start of January 2021. It also includes those developments that have been approved for construction.

Cardinal constructed a couple of models that represent two time periods. First, Cardinal built a model representative of 2009 conditions. TNRIS LiDAR data was used to delineate the watershed and historic images from 2012 were used to determine land usage. The watershed was shown to be predominantly undeveloped in 2012 imagery. The results of this model served as the baseline comparison. Cardinal also set up a hydrologic model to represent the January 2021 conditions which included the following developments inside the Town limits as well as outside. This model did include all notable detention that has been constructed as of January 2021.

- Harvest (Phases 1 - 15)
- McCurley Phase 1 and 2
- Meadows (Phases 1 - 5)
- The Ridge of Northlake
- Avalon
- Heath
- Canyon Falls

Comparisons between the two modeled results show that decreases in peak discharge for the overall watershed are seen at all junctions moving downstream through the watershed. This is confirmation that the regulations being followed are working to reduce or preserve the flood risk for downstream properties. The model should serve as a tool to continue regulating the floodplain as it is a global view of the overall watershed that accounts for the timing of various detention ponds.

1.0 Project Description

1.1. Purpose

The Town of Argyle has identified the Graham Branch Watershed as the only watershed that has not had a master drainage study developed to aid with floodplain management. The purpose of this study is to establish a comprehensive watershed model and report to aid both the Town and developer's engineers in assessing future developments within this watershed. In addition, the Town would like to understand any inadvertent impacts that may have been caused by this rapidly developing watershed to their downstream neighbors in Northlake and Flower Mound.

1.2. Site Location

Graham Branch generally flows from north to south with the upper end of watershed (west of IH-35W) flowing from northwest to southeast. The stream continues from Argyle into Flower Mound and eventually connects with Denton Creek before discharging into Grapevine Lake. This study includes analysis of the Graham Branch Main Stem and all of its Tributaries north of FM 1171 (Cross Timbers Rd). Figure 1 provides the vicinity map.

1.3. FEMA Flood Insurance Rate Map

Graham Branch is currently mapped within FEMA Special Hazard Area, designated Zone A on the Flood Insurance Rate Maps (FIRM) 48121C0505G dated April 18, 2011, as shown in Figure 2.

1.4. Data Collection

Data obtained in support of the Graham Branch Master Drainage study includes:

- Texas Natural Resources Information System (TNRIS) 5m Lidar dated 2009
- TNRIS 1m Lidar dated 2019
- Future Land Use Map from the Town of Argyle
- Future Land Use Map from the Town of Flower Mound
- Future Land Use Map from the Town of Northlake
- NRCS SSURGO soil data collected June 2020
- TxDOT plans for all culvert crossings along IH-35W, FM 407, and FM 1171
- Various development plans and models discussed further below

The Harvest multi-phase development is approximately a 1,200 acre tract located west of IH-35W, bounded on the west by FM 334, and located north-south around Old Justin Rd and FM 407. Graham Branch main stem and several northern tributaries run through the site. Many phases have been constructed, while some are in the proposal phase. Information received for this development includes:

- "Drainage and Detention Analysis for Harvest Development" by Jones & Carter dated March 2021
- "Drainage and Detention Analysis for McCurley Tract" by Jones & Carter dated June 2020
- "Construction of Drainage Facilities for Harvest Phase 3A" by Jones & Carter dated May 2016

- "Construction of Drainage Facilities for Harvest Townside Phase 1" by Jones & Carter dated April 2017
- "Construction of Drainage Facilities for Harvest Townside Phase 2" by Jones & Carter dated November 2018
- "Construction of Drainage Facilities for Harvest Townhomes Phase 1" by Jones & Carter dated March 2020
- "Construction of Drainage Facilities for Harvest McCurley Tract" by Jones & Carter dated February 2021
- HEC-HMS 4.2.1 model with multi-phase basin models and ultimate buildout
- Digital shape files: Longest flow paths, drainage basin delineation, detention area footprints, land use

The Heath Tract proposed development is approximately 330 acres located east of IH-35W, bounded north-south by Sam Davis Rd. and FM 407 respectively. Both Graham Branch main stem and Tributary 14 run through the site. This development is intended to be a community athletic complex as well as both single-family and multi-family residential land use. Information received for this proposed development includes:

- "Flood Study – Graham Branch Heath Tract" by HydroLink Engineering dated March 2021
  "The Ridge at Northlake Ultimate Hydrologic Workmap" by HydroLink Engineering dated September 2018
- HEC-HMS 4.2.1 model with pre-project and post-project basin models for existing and fully-developed conditions
- Digital shape files: Drainage basin delineations (pre- and post-project)

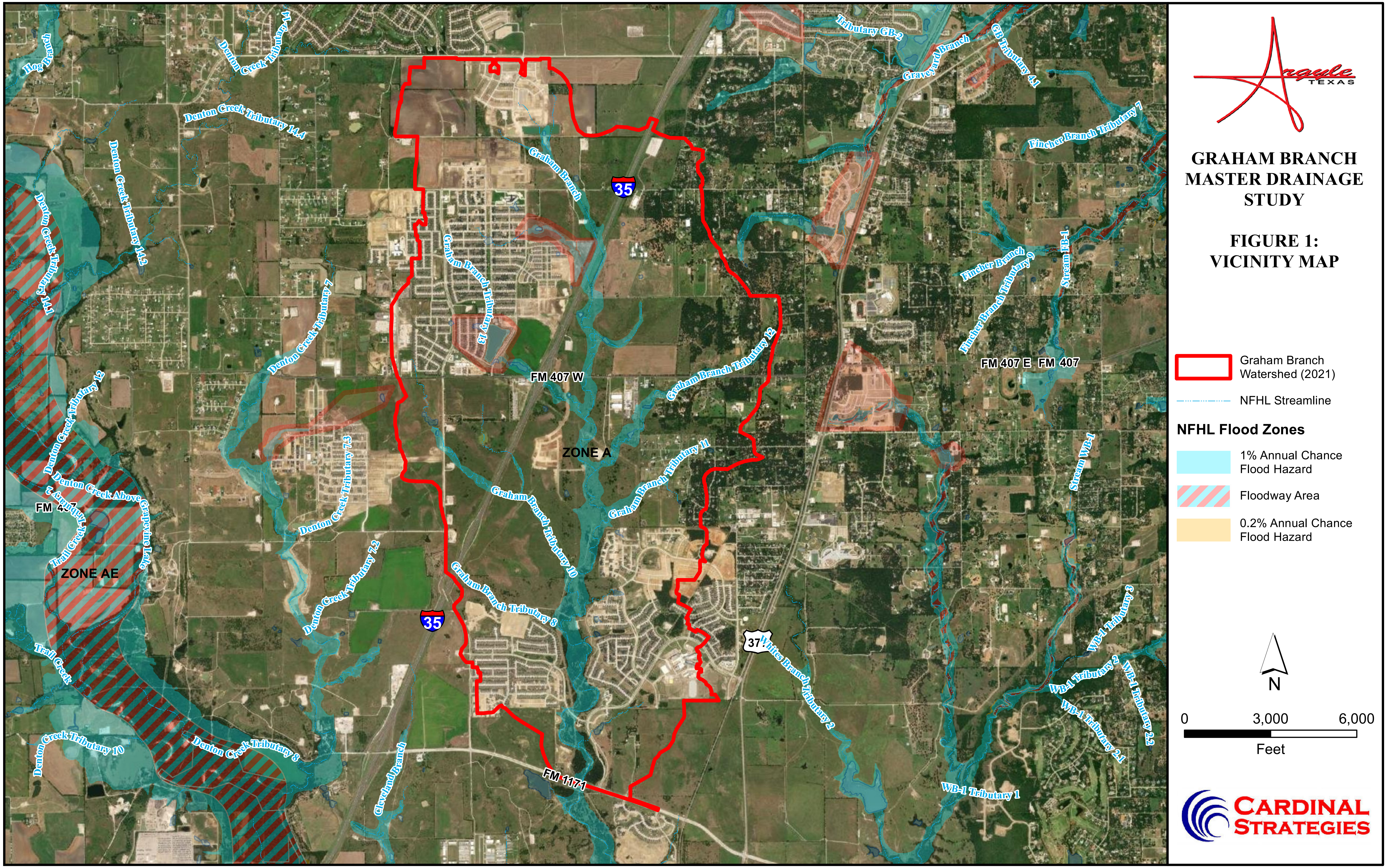
The Avalon proposed development is a multi-phase single-family residential land use that also contains a business park and a church. The approximate 300 acres are located immediately east of IH-35W and south of FM 407, along the Graham Branch main stem. Information for this proposed development includes:

- "Avalon Residential Phase II Downstream Assessment" and "Avalon Residential Phase II Flood Study" from McAdams Engineering dated January 2021
- "Avalon Residential Phase II Downstream Assessment Technical Memo" from McAdams Engineering dated March 2021
- "McCutchin Residential Concept C" from McAdams Engineering dated December 2020
- HEC-HMS 4.6.1 model with pre-project and post-project basin models for existing and fully-developed conditions
- Digital shape files: Longest flow paths, drainage basin delineation (pre- and post-project)

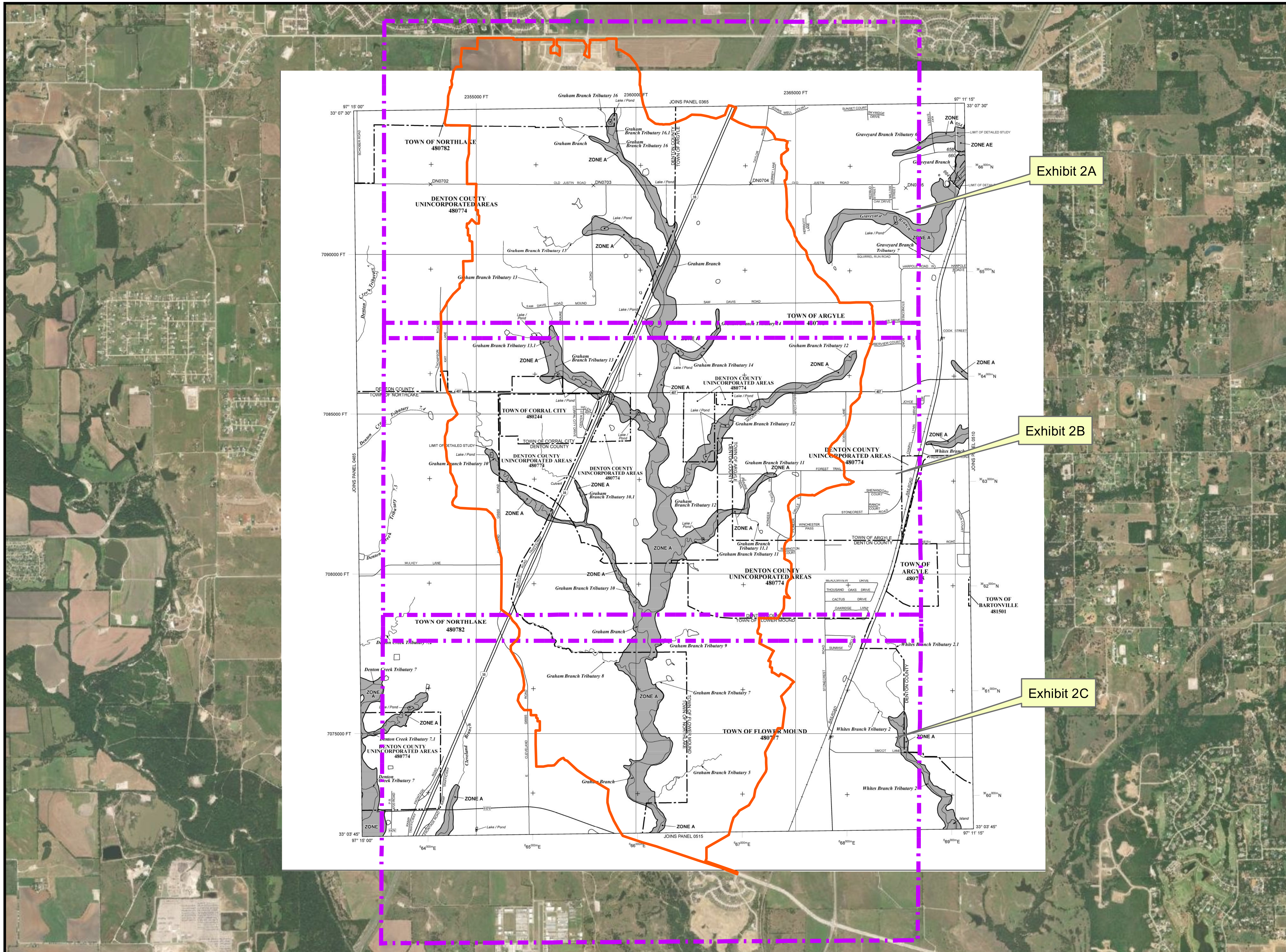
The Canyon Falls development is a multi-phase single-family development located north of FM 1171 Cross Timbers Rd, and bounded east-west by US 377 and IH-35W. Most phases have been constructed, with some in the proposal phase. The site is approximately 1,100 acres and is in the towns of Flower Mound, Northlake, and Argyle ETJ. Information for this development includes:

- "Canyon Falls – Master Infrastructure" construction plans from J. Volk Consulting dated August 2015
- "Canyon Falls – Phase 1 Infrastructure" construction plans from Middleton & Associates dated January 2013
- "Argyle High School Plans" construction plans from Glenn Engineering dated March 2019

The horizontal datum utilized for the project is the NAD83 Texas State Plane North Central Zone FIPS 4202. The vertical datum is NAVD88.



Argyle TEXAS
GRAHAM BRANCH MASTER DRAINAGE STUDY
FIGURE 1: VICINITY MAP
Graham Branch Watershed (2021)
NFHL Streamline
NFHL Flood Zones
1% Annual Chance Flood Hazard
Floodway Area
0.2% Annual Chance Flood Hazard
N
0
3,000
6,000
Feet
CARDINAL STRATEGIES
Hog Branch
Denton Creek Tributary 14
Denton Creek Tributary 14.4
Denton Creek Tributary 14.2
Denton Creek Tributary 14.1
Denton Creek Tributary 7
Denton Creek Tributary 12
Denton Creek Tributary 7.3
Denton Creek Tributary 7.2
Denton Creek Tributary 10
Denton Creek Tributary 8
Denton Creek Above Grapevine Lake
Trail Creek
ZONE AE
FM 407
Graham Branch
Graham Branch Tributary 13
Graham Branch Tributary 12
Graham Branch Tributary 11
Graham Branch Tributary 10
Graham Branch Tributary 8
Clevenland Branch
FM 407 W
FM 407 E
ZONE A
FM 1171
35
37
Tributary GB-2
Graveyard Branch
GB Tributary 4.1
Fincher Branch Tributary 7
Fincher Branch
Fincher Branch Tributary 9
Stream FB-1
Stream WB-1
WB-1 Tributary 3
WB-1 Tributary 2
WB-1 Tributary 2.1
WB-1 Tributary 2.2
WB-1 Tributary 1



GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 2: FIRM MAP

MAP PANEL: 48121C0505G
EFFECTIVEDATE: APRIL 18, 2011

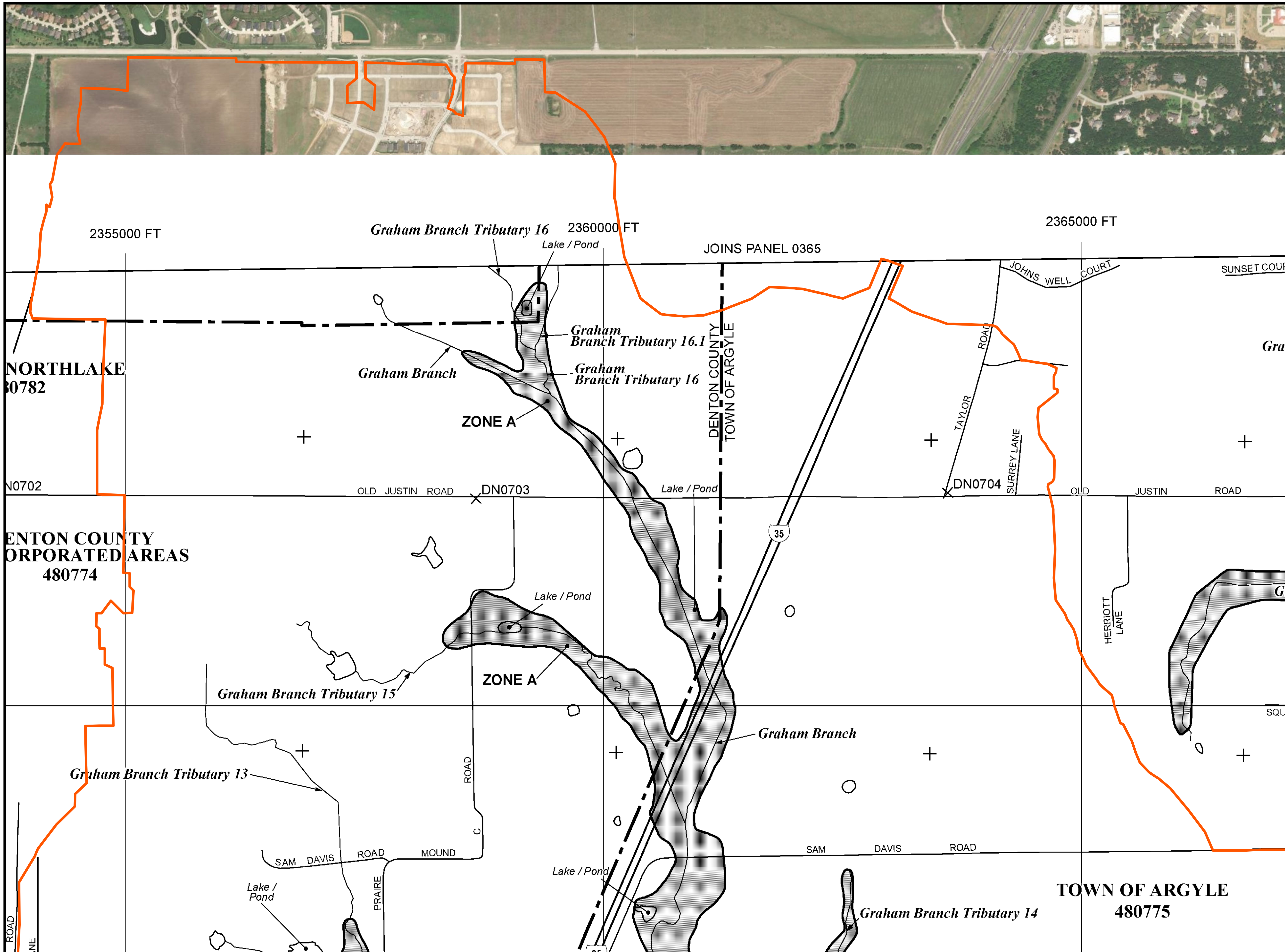
Watershed 2021

Exhibit

N

0 3,000 6,000

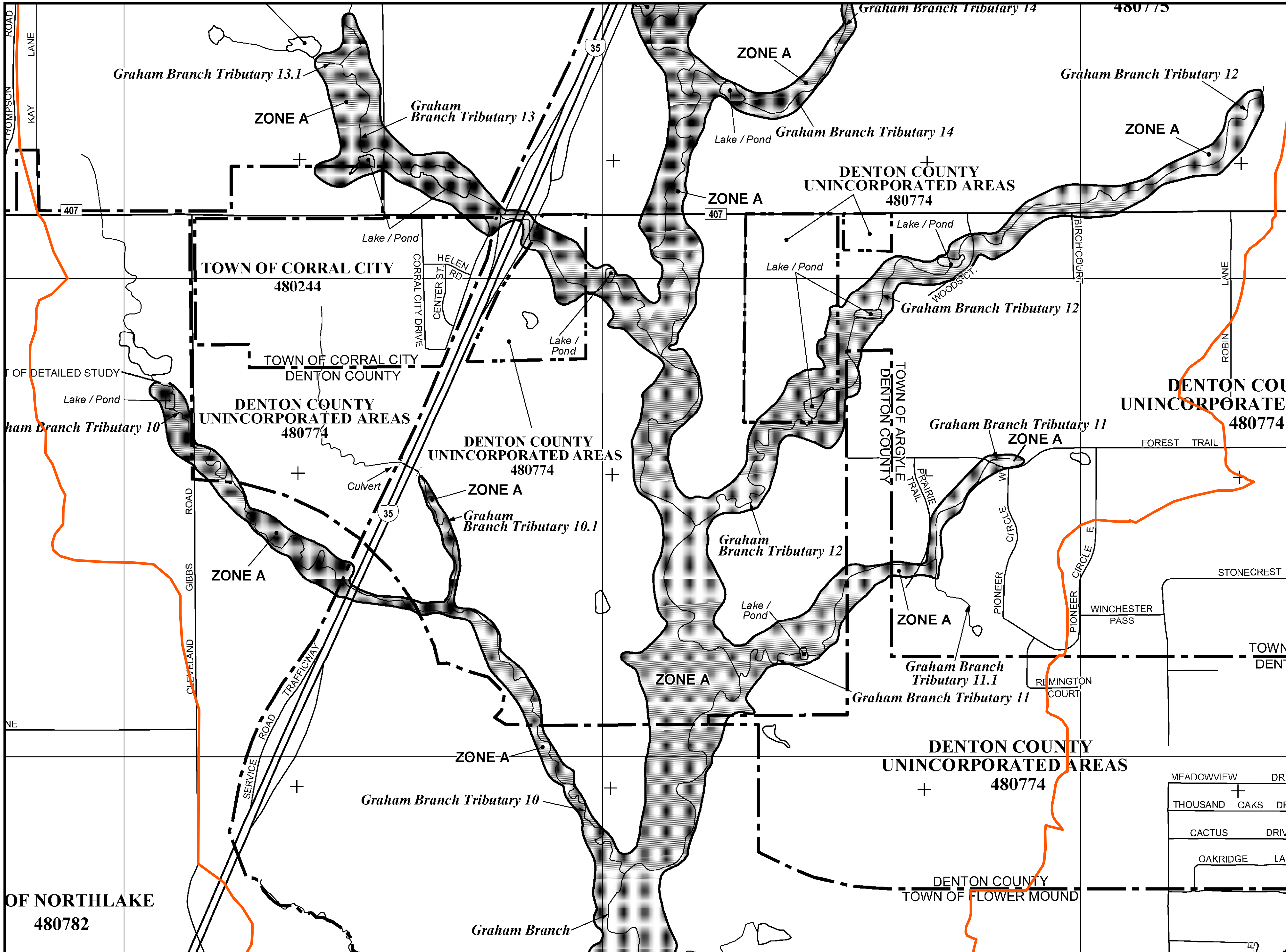
Feet



GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 2A: FIRM MAP (1/3)

MAP PANEL: 48121C0505G
EFFECTIVEDATE: APRIL 18, 2011



GRAHAM BRANCH MASTER DRAINAGE STUDY

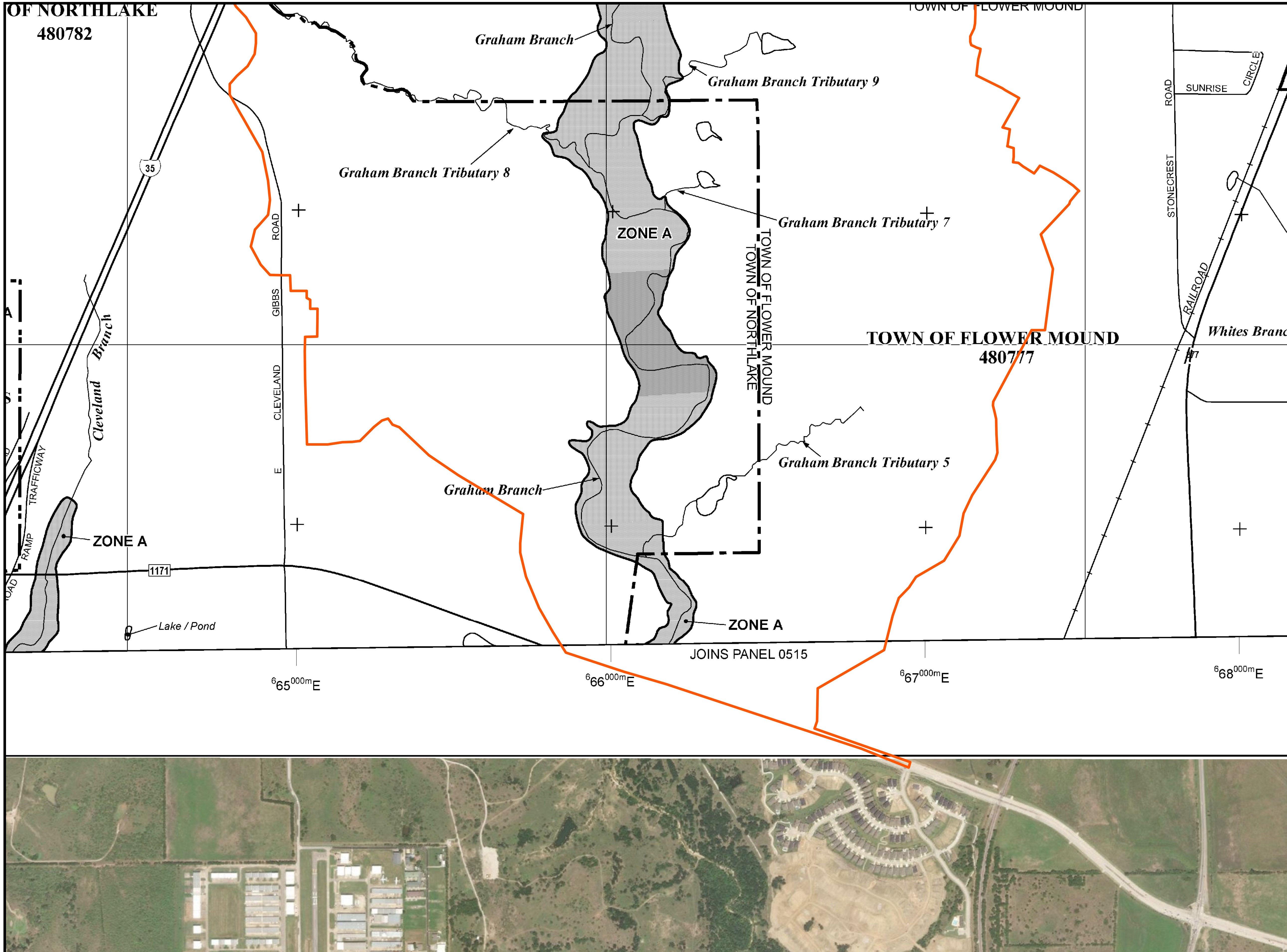
FIGURE 2B: FIRM MAP (2/3)

MAP PANEL: 48121C0505G
EFFECTIVEDATE: APRIL 18, 2011

Watershed 2021

N

0 1,000 2,000
Feet



TEXAS

GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 2C: FIRM MAP (3/3)

MAP PANEL: 48121C0505G
EFFECTIVE DATE: APRIL 18, 2011

Watershed 2021

N

0 1,000 2,000
Feet

CARDINAL STRATEGIES

2.0 Hydrologic Analysis

2.1. Previous Models

While many models were received from the various developments, there were none that were reflective of an undeveloped watershed. From aerial inspection over the past decade, it appears that the earliest phases of the Harvest development would be the place to find a comparable model, but those models were reviewed by the Town of Northlake. Data requests to Northlake were unfulfilled at the time of this report.

2.2. Hydrology (2009)

2.2.1. Modeling Software

Cardinal developed a hydrologic model using the U.S. Army Corps of Engineers' (USACE) HEC-HMS version 4.6.1 software to calculate storm water discharges for the land use conditions reflective of 2009. This is a time when the watershed was predominantly undeveloped. The closest historic imagery that Cardinal was able to locate is from 2012 and when reviewing Google Earth historic images, it appears no significant development occurred between 2009 and 2012 within this watershed.

2.2.2. Basin Delineations

The Graham Branch watershed was delineated by first using the Hydrological Unit Code -12 (HUC-12) basins and making alterations based on more detailed 2009 TNRIS LiDAR topo. Plan sets collected from TxDOT for many of the IH-35W culvert crossings were collected and georeferenced as best as possible for additional comparisons. Site visits and other desktop programs were used to identify where culverts crossed specific roadways. Lastly, Cardinal also used the collected development plans to identify where some strategic basin breaks were desired in an effort to provide for comparison points to the 2021 land use scenario. The 2009 model was broken into 41 different basins at major road crossings, confluences, and other strategic points of interest within the watershed. Figure 3 outlines the basin delineations and Table 1 summarizes the basins' hydrologic parameters.

2.2.3. Curve Numbers

Runoff for each basin was determined through the use of the Soil Conservation Service (SCS) Curve Number Method. Hydrologic soil types for the watershed were determined from the latest data available from the Natural Resources Conservation Service (NRCS) Soil Survey Geographic database (SSURGO). This data was last updated in June 2020 for this area. Hydrologic soil types are classified as A, B, C, or D with Soil Type A being sandy with high infiltration rates and Soil Type D being very clayey with low infiltration rates. The hydrologic soils for the watershed are shown in Figure 4.

Land use maps for 2009 conditions were created from historic aerial photographs. Figure 5 shows the land use used in the 2009 scenario for calculating curve numbers for each basin within the watershed.

Composite curve numbers for each basin were calculated from soil types and land use classifications in accordance with the SCS Curve Number Method. Table 1 summarized the CN for each basin. All calculations are included in Appendix B.

2.2.4. Lag Times

Longest flow paths were identified for each basin using methods described in the United States Department of Agriculture (USDA) TR-55. Sheet flow for undeveloped areas was limited to no more than 300 feet in length. Shallow concentrated flow was generally shown as unpaved for the 2009 conditions and channel flow was identified and assumptions were made as to the channel flow velocities to simplify the calculations. For channels identified as swales with shallow depths, 4 fps was assumed. For open channels a velocity of 6 fps was assumed and closed storm drains were assigned a velocity of 8 fps. The summation of each segment of flow type is the time of concentration and that value was multiplied by 0.6 to define the lag time value in minutes. Table 1 summarizes the total lag time for each basin. All calculations are included in Appendix B.

Table 1 – Hydrologic Parameters (2009)

Drainage Basin	Area (mi²)	Area (acres)	2009 CN	2009 T_c (min)	2009 Lag Time (min)
GB-01	0.317	202.88	77.6	25.5	15.3
GB-02	0.197192	126.20	76.9	23.5	14.1
GB-03	0.5147	329.41	78.8	36.0	21.6
GB-04	0.1413	90.43	80.1	22.7	13.6
GB-05	0.1327	84.93	70.8	17.7	10.6
GB-06A	0.1467	93.89	64.6	26.2	15.7
GB-06B	0.4524	289.54	79.7	15.0	9
GB-07	0.1563	100.03	77.5	37.8	22.7
GB-08	0.1964	125.70	79.7	33.2	19.9
GB-09	0.251	160.64	76	24.3	14.6
GB-10	0.0543	34.75	79	25.3	15.2
GB-11	0.4312	275.97	62.3	22.2	13.3
GB-12	0.1524	97.54	68.3	19.7	11.8
GB-13	0.0852	54.53	77.7	20.7	12.4
GB-14	0.0759	48.58	79.1	27.8	16.7
GB-15	0.0253	16.19	82.1	26.8	16.1
GB-16	0.0969	62.02	86.7	15.7	9.4
GB-17	0.1004	64.26	80.8	23.7	14.2
GB-18	0.2565	164.16	79.9	20.2	12.1
GB-19	0.0523	33.47	79.6	12.5	7.5
GB-20	0.113	72.32	78.4	27.2	16.3
GB-21	0.2434	155.78	80.9	20.2	12.1
GB-22	0.3887	248.77	76.9	26.8	16.1
GB-23	0.1193	76.35	77.8	37.5	22.5
GB-24	0.3103	198.59	80.5	22.2	13.3
GB-25	0.3666	234.62	77.9	37.0	22.2
GB-26	0.1454	93.06	71.6	20.0	12
GB-27	0.0792	50.69	75.3	39.3	23.6
GB-28	0.2086	133.50	77.4	25.2	15.1
GB-29	0.1743	111.55	64.6	15.0	9
GB-30	0.1085	69.44	75.3	25.8	15.5
GB-31	0.2373	151.87	74.8	24.3	14.6
GB-32	0.079	50.56	76.7	32.2	19.3
GB-33	0.0837	53.57	77.9	20.2	12.1
GB-34	0.1567	100.29	78.1	30.0	18
GB-35	0.3267	209.09	73.6	22.0	13.2
GB-36	0.0393	25.15	72.7	19.7	11.8
GB-37	0.1805	115.52	74	20.0	12
GB-38	0.3512	224.77	77	33.2	19.9
GB-39	0.5359	342.98	76.4	31.5	18.9
GB-40	0.1978	126.59	74.3	26.3	15.8

2.2.5. Rainfall Data

Synthetic storm models were created for the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year return periods. These meteorological models were based on rainfall statistics for Denton County provided in the

North Central Texas Council of Governments' (NCTCOG) integrated Storm Water Management (iSWM) manual. These values are reflective of the most recent NOAA Atlas 14 update to the rainfall values. Table 2 captures the depths for the varying storm events.

Table 2 – Estimated precipitation frequency (inches) for Denton County

Duration	Average recurrence interval (years)						
	1	2	5	10	25	50	100
5-min	0.419	0.452	0.584	0.682	0.808	0.901	0.992
15-min	0.836	0.902	1.162	1.356	1.606	1.788	1.967
60-min	1.508	1.627	2.100	2.452	2.907	3.237	3.569
2-hr	1.842	2.000	2.612	3.076	3.690	4.149	4.621
3-hr	2.040	2.223	2.927	3.465	4.189	4.741	5.315
6-hr	2.407	2.635	3.502	4.172	5.085	5.791	6.536
12-hr	2.833	3.106	4.143	4.944	6.033	6.872	7.760
24-hr	3.310	3.630	4.847	5.785	7.056	8.030	9.062

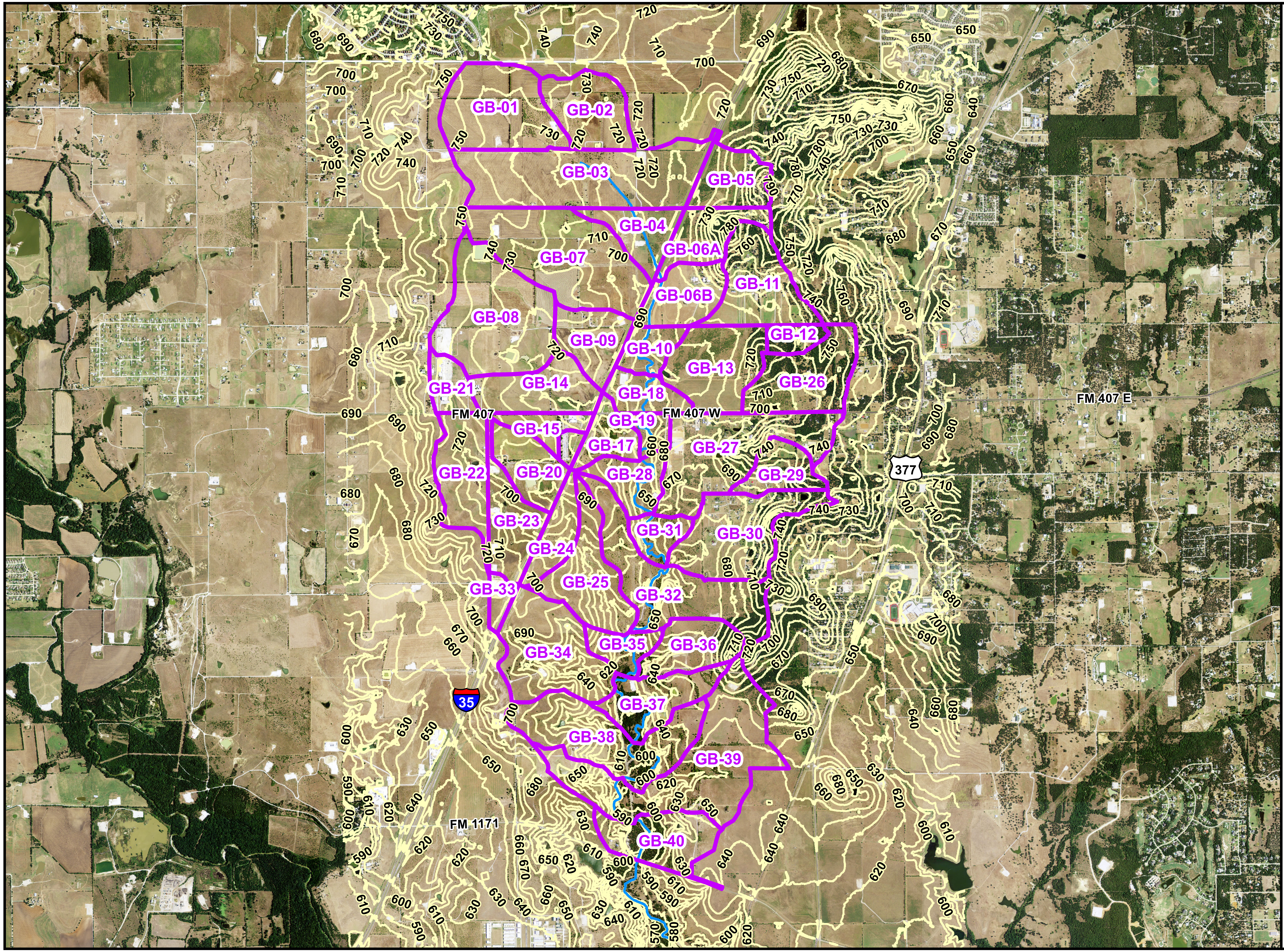
2.2.6. Routing Data

Flow routing was considered in the development of the Graham Branch watershed and Modified-Puls data was prepared for use along the mainstem of Graham Branch. A hydraulic model was developed for the 2009 conditions inclusive of all the roadway crossings to best account for potentially undersized crossings and any type of detention effect they might have. The development of the hydraulic model is discussed later in the report.

Storage-discharge curves were developed from the hydraulic model and specific number of sub-reaches was calculated for each reach. In areas outside of the mainstem, Muskingum-Cunge methodology was utilized with 8-point cross section and other geometric properties defined from the TNRIS LiDAR data. All routing calculations are included in Appendix B, and digital shapefiles containing the measured data can be found in Appendix D.

2.2.7. Special Physical Characteristics

There were no specific detention ponds large enough to warrant modeling in the 2009 scenario. Smaller pocket ponds were not modeled due to the limited impact they would have on the overall watershed response.



Argyle TEXAS

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FIGURE 3: 2009 CONDITION DRAINAGE AREA MAP

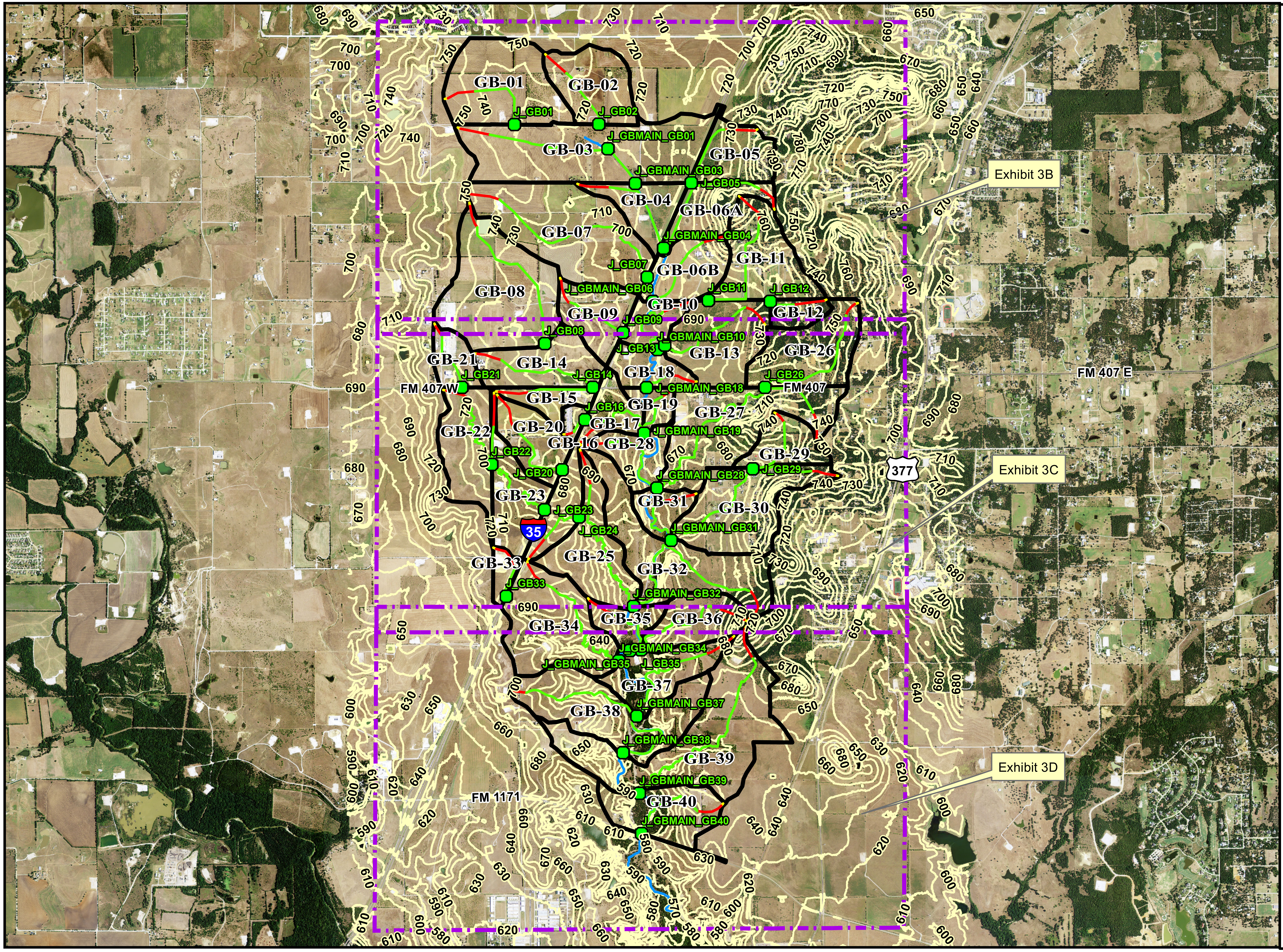
Legend

- 2009 Drainage
- Graham Branch Main Stem
- 2009 TNRIS 10ft Contours

N

0 3,000 6,000
Feet

CARDINAL STRATEGIES



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GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 3A: 2009 CONDITION DRAINAGE AREA MAP

Legend

- Graham Branch Main Stem
- 2009 Junctions

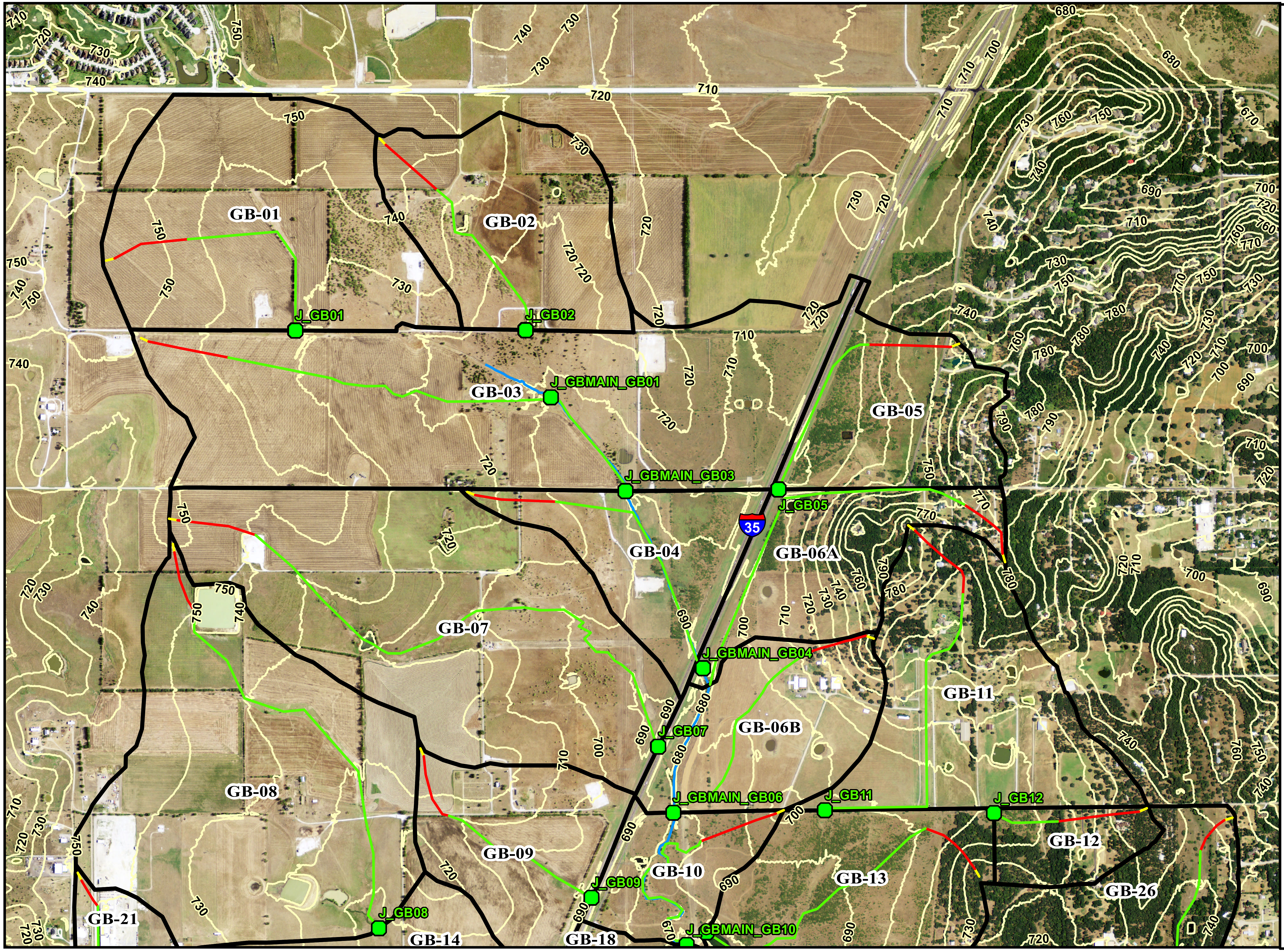
2009 Flow Paths

- Sheet
- Shallow
- Channel
- 2009 Drainage Areas
- Exhibit Areas
- TNRIS 10ft Contours

N

0 3,000 6,000
Feet

CARDINAL STRATEGIES



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GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 3B: 2009 CONDITION DRAINAGE AREA MAP

Legend

- Graham Branch Main Stem
- 2009 Junctions

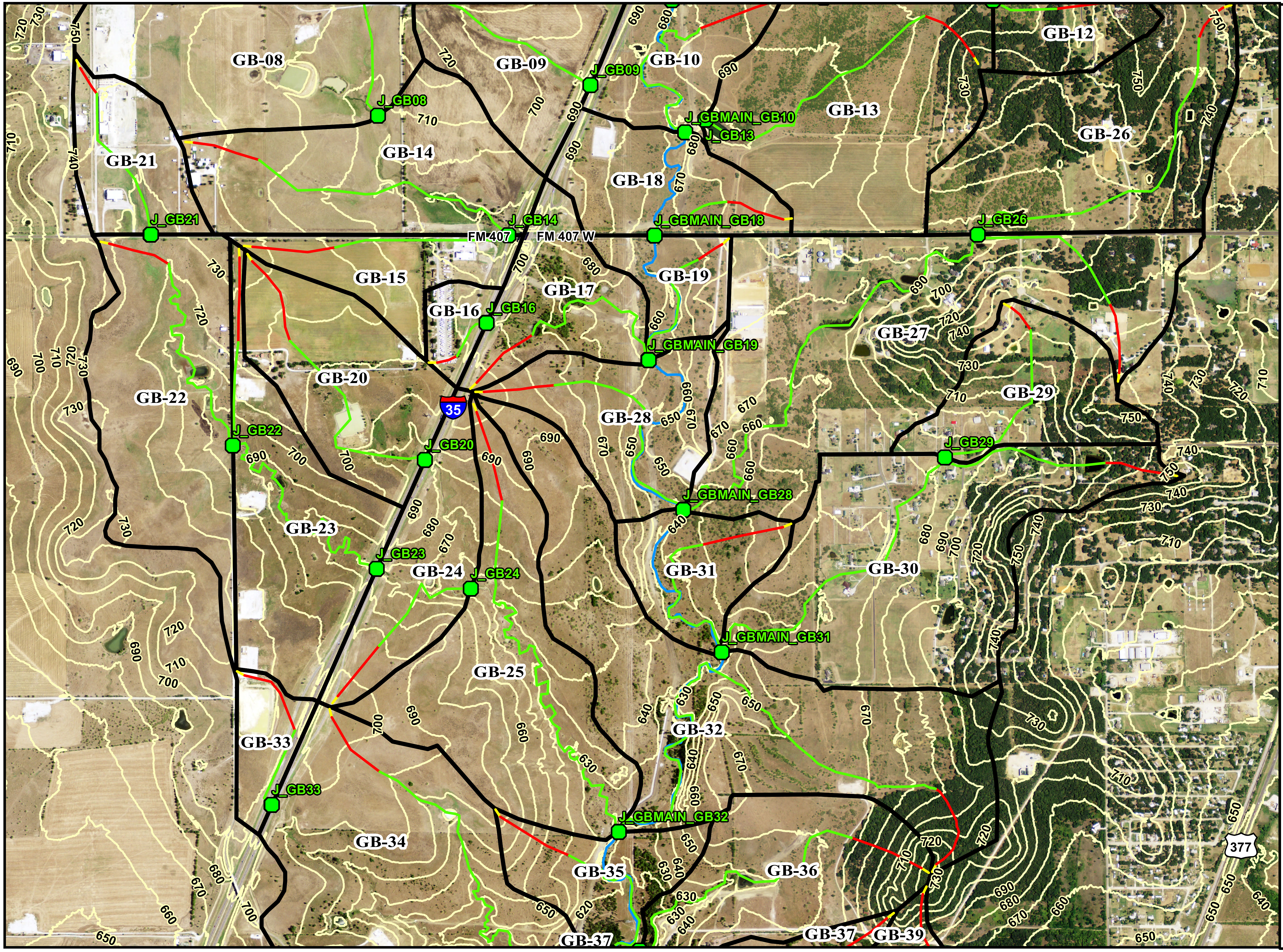
2009 Flow Paths

- Sheet
- Shallow
- Channel
- 2009 Drainage Areas
- 2009 TNRIS 10ft Contours

N

0 1,000 2,000
Feet

CARDINAL STRATEGIES



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GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 3C: 2009 CONDITION DRAINAGE AREA MAP

Legend

- Graham Branch Main Stem
- 2009 Junctions

2009 Flow Paths

- Sheet
- Shallow
- Channel
- 2009 Drainage Areas
- 2009 TNRIS 10ft Contours

N

0 1,000 2,000
Feet

CARDINAL STRATEGIES

Argyle TEXAS

GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 3D:
2009 CONDITION DRAINAGE AREA MAP

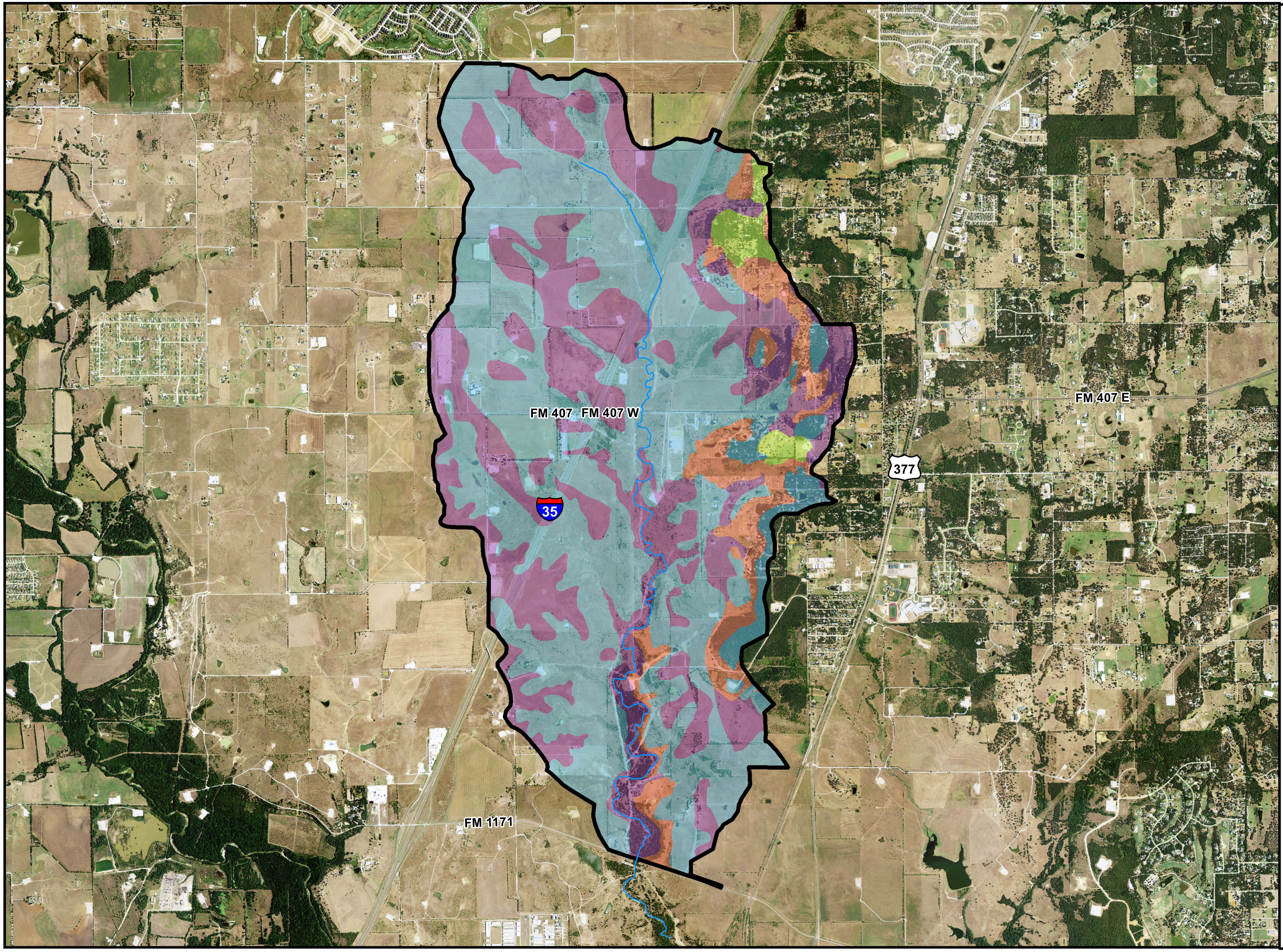
Legend

- Graham Branch Main Stem
- 2009 Junctions
- 2009 Flow Paths
  - Sheet
  - Shallow
  - Channel
- 2009 Drainage
- 2009 TNRIS 10ft Contours

N

0 1,000 2,000
Feet

CARDINAL STRATEGIES



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GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 4: SOILS MAP

Legend

Graham Branch Main Stem

Soil

A

B

C

D

Watershed 2009

N

0 3,000 6,000

Feet

CARDINAL STRATEGIES

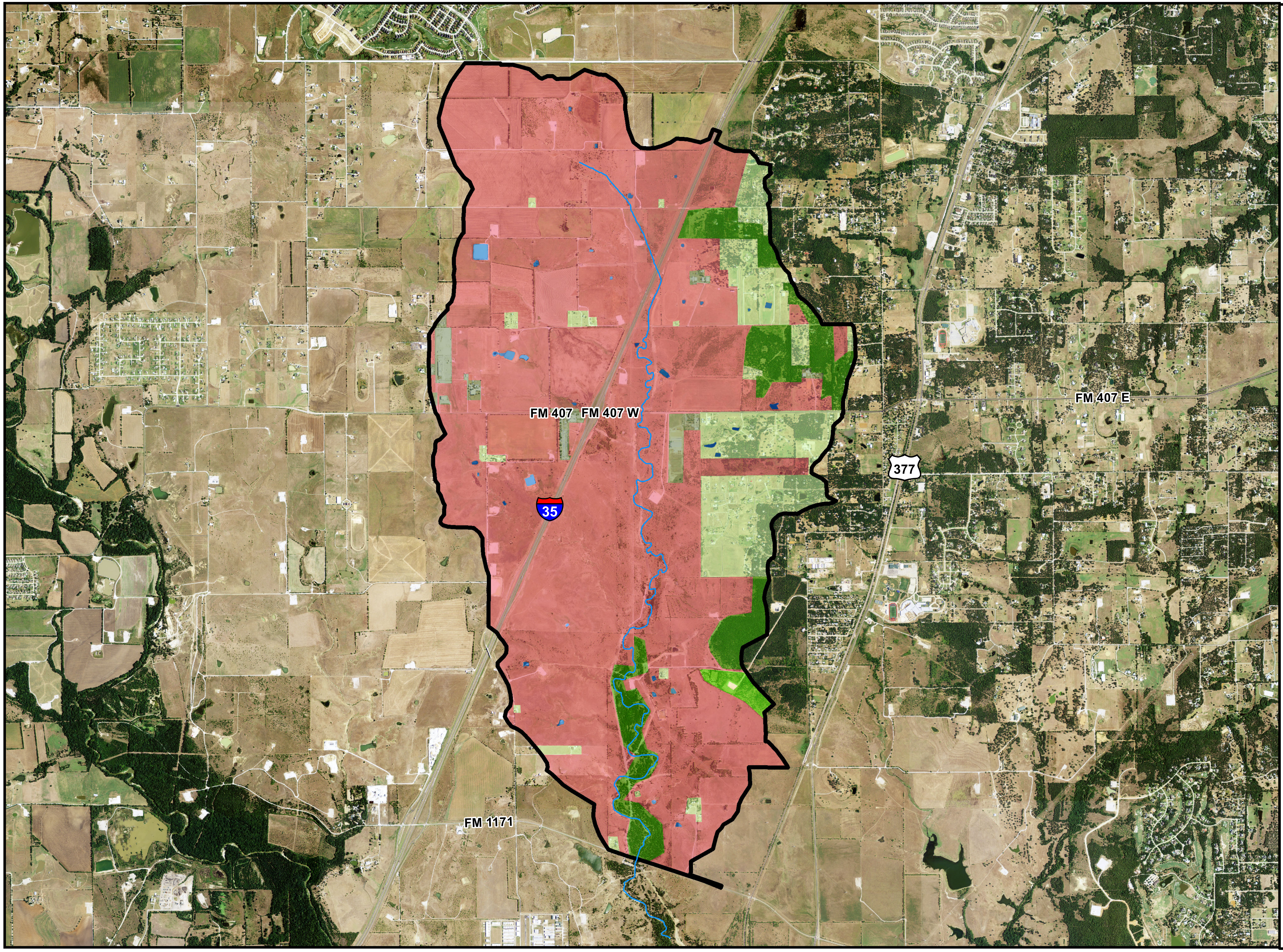

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FIGURE 5: 2009 CONDITION LAND USE EXISTING MAP

Legend

- Graham Branch Main Stem

Land Use

- Gravel
- Industrial
- Lake
- Open Space - Good
- Paved - Roads
- Residential - 2 Acre
- Woods - Good Cover
- Woods - Poor Cover
- Watershed 2009

N

0 3,000 6,000
Feet

CARDINAL STRATEGIES

2.3. Hydrology (2021)

2.3.1. Modeling Software

Cardinal developed a hydrologic model using the U.S. Army Corps of Engineers' (USACE) HEC-HMS version 4.6.1 software to calculate storm water discharges for the land use conditions reflective of 2021. The 2021 basin condition reflects the most up to date approved land developments including any detention ponds. The purpose of including approved land developments in this condition is to assist in the validation of previous studies, and to provide future studies with a more accurate model of what developments exist in the watershed. This will allow the Town of Argyle the opportunity to evaluate future developments on a global scale to understand how proposed detention might affect the timing of the watershed response. In addition, the use of this model for future studies will help to analyze each future site against a consistent approach.

During the development of the hydrologic model, it was observed that there were several instances where developments designed detention ponds located in series. These instances are a special situation where the downstream pond levels can influence the outfall characteristics of connected ponds upstream and alter the typical assumptions used in calculating discharges. This is because the head calculated on the upstream ponds is smaller and generally results in less discharge leaving the upstream ponds. This is a dynamic situation and HEC-HMS is not able to solve for the dynamic situation presented with this type of pond setup. In an effort to dynamically calculate the varying pond elevations and relationships, HydroCAD v4.1.11.0 was utilized to simulate these types of ponds. An outflow hydrograph was generated from HydroCAD and input back into the HEC-HMS model as a source flow in order to allow HEC-HMS to be used as intended.

2.3.2. Basin Delineations

The Graham Branch watershed for 2021 conditions was first delineated using the 2009 condition boundaries described in section 2.2.2. Next, using 2019 TNRIS LiDAR topography, the outer boundary of the watershed was modified in areas that had evidence of development or change. Drainage area maps from construction plans and the latest approved study submittals described in section 1.4 were used to further and more accurately define the outer boundary as well as the individual subbasin break areas. Site visits were conducted in areas of recent construction in order to validate assumptions made based on construction plans or flood study drainage area delineations.

The 2021 model was ultimately broken into 71 different basins at major road crossings, confluences, detention areas, and other strategic points to compare with flood studies for recent developments and for the 2009 condition basin delineations described in section 2.2.2. Figure 6 outlines the basin delineations and Table 3 summarizes the basins' hydrologic parameters.

2.3.3. Curve Numbers

Runoff for each basin was determined through the use of the Soil Conservation Service (SCS) Curve Number Method. Hydrologic soil types for the watershed remained the same as from the 2009 conditions modeling.

Land use maps for 2021 conditions were created using a combination of aerial imagery, construction plans, and the most recent available flood study approved submittals. Figure 7 shows the land use used in the 2021 scenario for calculating curve numbers for each basin within the watershed. Additionally, assumptions for how the watershed might develop in the future were made based on zoning maps from each Town that were available. Figure 8 summarizes the fully-developed land use for the watershed.

Composite curve numbers for each basin were calculated from soil types and land use classifications in accordance with the SCS Curve Number Method. Table 3 summarizes the CN for each basin. All calculations are included in Appendix B. Table 4 summarizes the CN for each fully-developed basin. All calculations are included in Appendix B.

2.3.4. Lag Times

Longest flow paths were identified for each basin using methods described in the United States Department of Agriculture (USDA) TR-55. Sheet flow for undeveloped areas was limited to no more than 300 feet in length. Shallow concentrated flow was shown as paved in developed areas, and unpaved undeveloped areas for the 2021 conditions. Finally, channel flow was identified and assumptions were made as to the channel flow velocities to simplify the calculations. For channels identified as swales with shallow depths, 4 fps was assumed. For open channels, a velocity of 6 fps was assumed and closed storm drains were assigned a velocity of 8 fps. The summation of each segment of flow type is the time of concentration and that value was multiplied by 0.6 to define the lag time value in minutes. Table 3 summarizes the total lag time for each basin. All calculations are included in Appendix B.

For the fully-developed condition, assumptions were made to account for the anticipated decrease in time of concentrations. The general alignment of the flowpath remained the same as previously identified. However, for all basins with sheet flow longer than 100 feet, the sheet flow value was altered to 100 feet. In addition, all 'unpaved' shallow concentrated flow determinations were altered to 'paved' condition. Channel flow calculations remained the same as previously determined. The total time of concentrations were multiplied by 0.6 to define the lag time value in minutes. Table 4 summarizes the total lag time for each basin. All calculations are included in Appendix B.

2.3.5. Rainfall Data

Reference Section 2.2.5. Synthetic storm models were created for the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year return periods. These meteorological models were based on rainfall statistics for Denton County provided in the North Central Texas Council of Governments' (NCTCOG) integrated Storm Water Management (iSWM) manual. These values are reflective of the most recent NOAA Atlas 14 update to the rainfall values.

2.3.6. Routing Data

Flow routing was considered in the development of the Graham Branch watershed and Modified-Puls data was prepared for use along the mainstem of Graham Branch. A hydraulic model was developed for the 2021 conditions inclusive of all the roadway crossings to best account for potentially undersized crossings and any type of detention effect they might have. This model included newly constructed stream crossings and recent developments along the stream. The development of the hydraulic model is discussed later in the report.

Storage-discharge curves were developed from the hydraulic model and specific number of sub-reaches was calculated for each reach. In areas outside of the mainstem, Muskingum-Cunge methodology was utilized with 8-point cross section and other geometric properties defined from the TNRIS LiDAR data. All routing calculations are included in Appendix B, and digital shapefiles containing the measured data can be found in Appendix D.

Table 3 – Hydrologic Parameters (2021)

Drainage Basin	Area (mi^2)	Area (acres)	2021 CN	2021 T_c (min)	2021 Lag Time (min)
AVA_DA01	0.0133	8.50	81.4	13.7	8.2
AVA_DA02	0.0458	29.34	90.9	10.0	6.0
AVA_DA03	0.0430	27.51	91.5	12.2	7.3
AVA_DA04	0.0119	7.59	91.8	7.7	4.6
AVA_MCC01	0.0832	53.26	75.0	25.3	15.2
AVA_NORTH01	0.0968	61.96	79.5	23.7	14.2
AVA_NORTH02	0.0523	33.48	84.2	14.2	8.5
AVA_NORTH03	0.1270	81.31	79.6	27.5	16.5
GB_E01	0.1467	93.86	71.8	24.7	14.8
GB_E02	0.1413	90.44	70.4	26.3	15.8
GB_E03	0.1563	100.04	79.3	15.0	9.0
GB_E04	0.1861	119.13	83.1	24.2	14.5
GB_E05	0.0891	57.02	74.9	21.8	13.1
GB_E06	0.1649	105.55	82.4	17.3	10.4
GB_E07	0.3302	211.36	87.8	32.2	19.3
GB_E08	0.1859	119.00	83.7	19.5	11.7
GB_E09	0.2030	129.90	76.1	23.8	14.3
GB_T_101	0.1454	93.05	78.3	26.3	15.8
GB_T05	0.4166	266.63	87.0	23.8	14.3
GB_T08A	0.0393	25.18	79.1	18.2	10.9
GB_T08B	0.3324	212.76	81.7	33.7	20.2
GB_T09A	0.1336	85.48	89.6	18.0	10.8
GB_T09B	0.1316	84.22	85.1	14.3	8.6
GB_T10A	0.1131	72.41	90.7	28.7	17.2
GB_T10B	0.2086	133.51	76.8	24.7	14.8
GB_T10C	0.1743	111.57	78.6	32.7	19.6
GB_T10D	0.1049	67.13	80.3	25.8	15.5
GB_T10E	0.0803	51.41	77.7	24.5	14.7
GB_T10F	0.0979	62.63	78.4	22.7	13.6
GB_T11A	0.1130	72.30	64.7	16.3	9.8
GB_T11B	0.3103	198.56	75.2	33.2	19.9
GB_T12A	0.2434	155.80	74.5	27.0	16.2
GB_T12B	0.3889	248.88	75.2	37.8	22.7
GB_T14	0.2510	160.66	63.6	27.8	16.7
GB_W01	0.1272	81.43	80.3	20.3	12.2
GB_W02	0.0227	14.52	77.0	15.0	9.0
GB_W03	0.0711	45.49	81.4	18.8	11.3
GB_W04	0.0759	48.59	83.6	28.0	16.8
GB_W05	0.0253	16.19	92.6	15.7	9.4
HARV_MCLY02	0.0540	34.54	89.5	13.7	8.2
HARV_MEAD01N	0.0492	31.49	92.0	17.5	10.5
HARV_MEAD01S	0.0421	26.94	91.3	8.3	5.0
HARV_MEAD02	0.0673	43.08	91.2	13.7	8.2
HARV_MEAD03N	0.0428	27.41	92.0	9.3	5.6
HARV_MEAD03S	0.0352	22.51	92.0	5.3	3.2

Drainage Basin	Area (mi²)	Area (acres)	2021 CN	2021 T_c (min)	2021 Lag Time (min)
HARV_MU01	0.0898	57.48	94.4	25.2	15.1
HARV_NOJR01	0.0269	17.19	91.8	12.3	7.4
HARV_PH01	0.1730	110.71	91.3	13.7	8.2
HARV_PH01_POND	0.0818	52.36	91.3	10.0	6.0
HEATH_01	0.0543	34.73	71.5	20.7	12.4
HEATH_02	0.1642	105.11	77.3	28.8	17.3
HEATH_03	0.0756	48.40	79.6	25.8	15.5
HEATH_04_POND	0.0164	10.50	81.3	8.3	5.0
HEATH_05_ATHL	0.0852	54.55	79.1	31.7	19.0
HEATH_06	0.1004	64.24	80.1	33.2	19.9

Table 4 – Hydrologic Parameters (Fully-Developed)

Drainage Basin	Area (mi²)	Area (acres)	FD CN	FD T_c (min)	FD Lag Time (min)
AVA_DA01	0.0133	8.50	91.4	12.8	7.7
AVA_DA02	0.0458	29.34	91.0	9.8	5.9
AVA_DA03	0.0430	27.51	91.6	12.2	7.3
AVA_DA04	0.0119	7.59	92.0	7.5	4.5
AVA_MCC01	0.0832	53.26	81.9	23.8	14.3
AVA_NORTH01	0.0968	61.96	95.0	22.5	13.5
AVA_NORTH02	0.0523	33.48	94.9	13.3	8.0
AVA_NORTH03	0.1270	81.31	88.3	25.8	15.5
GB_E01	0.1467	93.86	82.5	24.0	14.4
GB_E02	0.1413	90.44	78.2	25.5	15.3
GB_E03	0.1563	100.04	88.9	14.3	8.6
GB_E04	0.1861	119.13	86.5	24.0	14.4
GB_E05	0.0891	57.02	80.6	21.3	12.8
GB_E06	0.1649	105.55	82.7	17.3	10.4
GB_E07	0.3302	211.36	89.1	31.7	19.0
GB_E08	0.1859	119.00	88.5	19.5	11.7
GB_E09	0.2030	129.90	86.1	23.0	13.8
GB_T_101	0.1454	93.05	94.7	25.0	15.0
GB_T05	0.4166	266.63	92.6	23.7	14.2
GB_T08A	0.0393	25.18	95.0	17.2	10.3
GB_T08B	0.3324	212.76	91.1	31.8	19.1
GB_T09A	0.1336	85.48	89.6	17.5	10.5
GB_T09B	0.1316	84.22	89.6	14.3	8.6
GB_T10A	0.1131	72.41	91.0	26.2	15.7
GB_T10B	0.2086	133.51	91.1	23.8	14.3
GB_T10C	0.1743	111.57	94.7	31.8	19.1
GB_T10D	0.1049	67.13	92.6	22.8	13.7
GB_T10E	0.0803	51.41	91.2	22.8	13.7
GB_T10F	0.0979	62.63	90.2	21.7	13.0
GB_T11A	0.1130	72.30	66.0	16.0	9.6
GB_T11B	0.3103	198.56	76.2	33.2	19.9
GB_T12A	0.2434	155.80	78.5	25.3	15.2
GB_T12B	0.3889	248.88	78.7	37.8	22.7
GB_T14	0.2510	160.66	66.4	25.5	15.3
GB_W01	0.1272	81.43	92.5	18.8	11.3
GB_W02	0.0227	14.52	90.3	14.7	8.8
GB_W03	0.0711	45.49	92.4	17.2	10.3
GB_W04	0.0759	48.59	94.8	25.8	15.5
GB_W05	0.0253	16.19	95.6	15.3	9.2
HARV_MCLY02	0.0540	34.54	91.9	13.2	7.9
HARV_MEAD01N	0.0492	31.49	92.0	17.2	10.3
HARV_MEAD01S	0.0421	26.94	91.3	8.3	5.0
HARV_MEAD02	0.0673	43.08	92.0	13.5	8.1
HARV_MEAD03N	0.0428	27.41	92.0	9.2	5.5
HARV_MEAD03S	0.0352	22.51	92.0	5.0	3.0

Drainage Basin	Area (mi²)	Area (acres)	FD CN	FD T_c (min)	FD Lag Time (min)
HARV_MU01	0.0898	57.48	94.4	23.2	13.9
HARV_NOJR01	0.0269	17.19	91.8	11.8	7.1
HARV_PH01	0.1730	110.71	91.3	13.5	8.1
HARV_PH01_POND	0.0818	52.36	91.3	9.8	5.9
HEATH_01	0.0543	34.73	73.1	19.5	11.7
HEATH_02	0.1642	105.11	82.3	17.8	10.7
HEATH_03	0.0756	48.40	92.0	14.7	8.8
HEATH_04_POND	0.0164	10.50	94.7	7.5	4.5
HEATH_05_ATHL	0.0852	54.55	94.7	23.2	13.9
HEATH_06	0.1004	64.24	95.0	15.5	9.3

2.3.7. Special Physical Characteristics

Eight detention areas were modeled in the 2021 scenario. Four of the detention areas consisted of several interconnected ponds in series. HEC-HMS does not adequately assess ponds in series and a dynamic model to account for tailwater and headwater effects during a storm scenario was created using HydroCAD. HydroCAD is a dynamic modeling software that can assess the relationships of each pond, properly accounting for the varying tailwater elevations of one pond and the effects it has on the outflow of another connected pond. The models can be found in Appendix D.

Specific hydrographs were generated in HEC-HMS for the upstream watershed for each detention area. These hydrographs were duplicated in HydroCAD and the interconnected ponds were modeled based on dimensions shown in the construction plans. HydroCAD calculates the actual rating curve for each pond dynamically and Cardinal extended each detention model downstream of each pond in order to generate a hydrograph representing the downstream pond discharge. This hydrograph was generated for each system for each storm event, then modeled as a source input in HEC-HMS. The storm model was for a 48-hour period with a 1 minute time step, in order to match the HMS model. The series data below summarizes the locations of each detention system and source node that was modeled in series outside of HEC-HMS.

Harvest development contains four separately modeled series of interconnected ponds, summarized below. Figure 9 shows the labeled schematics of each series.

HydroCAD

Series 1: Harvest North development, East side

Ridge Pond West -> Ridge Pond East	box culvert
Ridge Pond East -> Pond A:	box culvert
Pond A -> Pond D:	pipe
Pond A -> Graham Branch Main Stem:	2 spillways
Pond D -> Graham Branch Main Stem:	pipe, spillway

Series 2: Harvest North development, West side

Pond C North -> Pond C South:	box culvert, spillway
Pond C South -> Graham Branch Main Stem:	pipe, spillway

Series 3: Harvest Townhomes development

Pond A -> Pond B:	pipe, box culvert
Pond C -> Pond B:	pipe
Pond B -> I35W Culvert:	pipe

Series 4: Harvest Townside development along Graham Branch Tributary 15

Pond A -> Pond B:	box culvert
Pond B -> Trib 15 Inline Detention:	pipe
Trib 15 Inline Detention -> Trib 15 I35W:	pipe
Pond C -> Trib 15 Inline Detention:	pipe
Pond C -> Trib 15 I35W	spillway
Pond B -> Trib 15 I35W	spillway

HEC-HMS

In addition to these ponds in series, there are several detention ponds modeled from the construction plans and/or HEC-HMS models within the watershed. Each of these ponds are included in the HEC-HMS model. These include the following ponds:

- McCurley East (Harvest)
- Harvest Meadows Phase 3 (two ponds)
- Harvest Lake Park Pond
- Heath Tract Pond

Harvest Meadows Phase 3 development

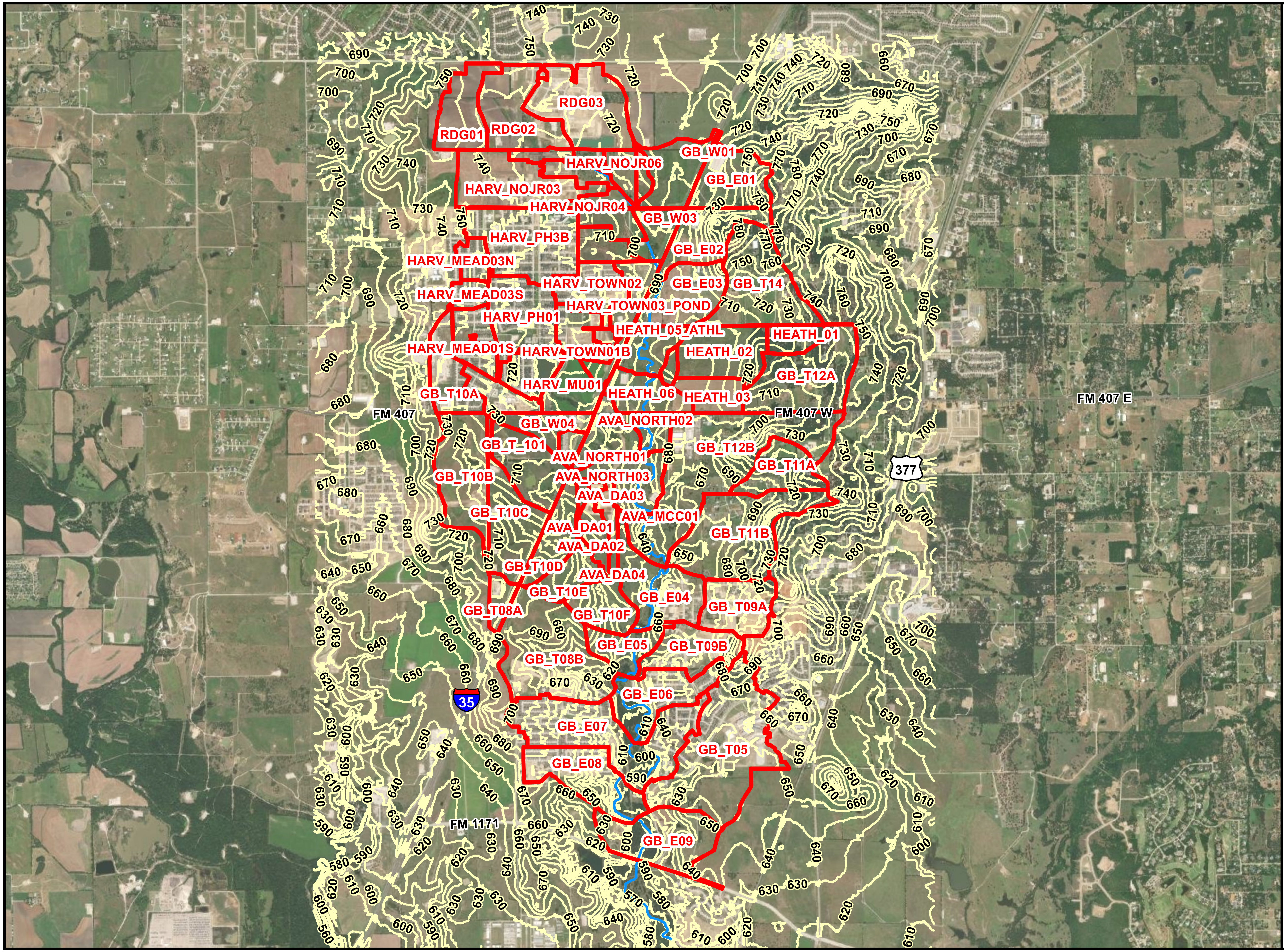
Pond A -> Storm drain:	pipe
Pond B -> Storm drain:	pipe
Storm drain -> Lake Park Pond:	pipe

2.3.8. HydroCAD Calculations

Hydrographs for each storm event were generated in HMS for each basin and reach feeding the ponds in series modeled in HydroCAD. Table 5 below details the hydrologic parameters for each of these basins, which is found the in overall model included in Appendix D. As these watersheds are fully-developed, the parameters are the same for both the 2021 existing condition and the future fully-developed condition.

Table 5 – HydroCAD Basin Hydrologic Parameters (2021 Existing and Fully-Developed)

Drainage Basin	Area (mi^2)	Area (acres)	2021 CN	2021 Lag Time (min)
HARV_MCLY01	0.059	37.9	91.4	11.3
HARV_NOJR02	0.044	28.0	91.4	7.9
HARV_NOJR03	0.213	136.2	91.8	19.8
HARV_NOJR04	0.032	20.2	89.8	9.6
HARV_NOJR05	0.018	11.5	88	5.2
HARV_NOJR06	0.045	28.5	83.7	5.9
HARV_PH3B	0.254	162.6	91	10.5
HARV_TOWN01A	0.061	38.9	91.7	12.3
HARV_TOWN01B	0.031	20.0	94.2	10.5
HARV_TOWN01C	0.009	6.0	92	7
HARV_TOWN01D	0.032	20.4	95.4	9.2
HARV_TOWN02	0.108	69.0	90.9	12.9
HARV_TOWN03_POND	0.065	41.5	85.8	9.9
RDG01	0.128	81.9	91.6	8.5
RDG02	0.185	118.2	91.5	9.5
RDG03	0.235	150.5	87.4	7.3



GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 6: 2021 CONDITION DRAINAGE AREA MAP

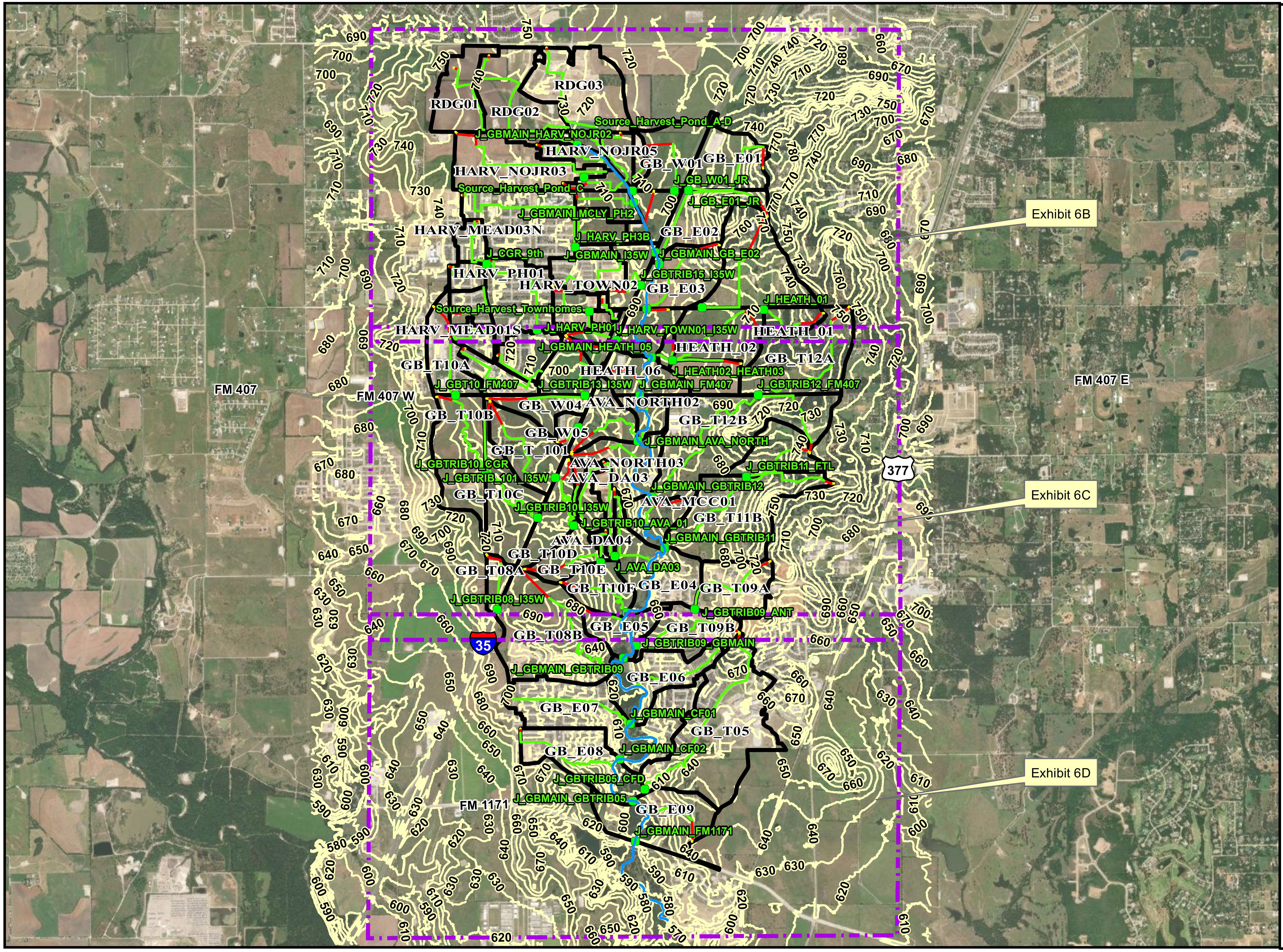
Legend

- 2021 Drainage
- Graham Branch Main Stem
- 2019 TNRIS 10ft Contours

N

0 3,000 6,000
Feet

CARDINAL STRATEGIES



Argyle TEXAS

GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 6A: 2021 CONDITION DRAINAGE AREA MAP

Legend

- Graham Branch Main Stem
- 2021 Drainage Areas
- 2021 Junctions

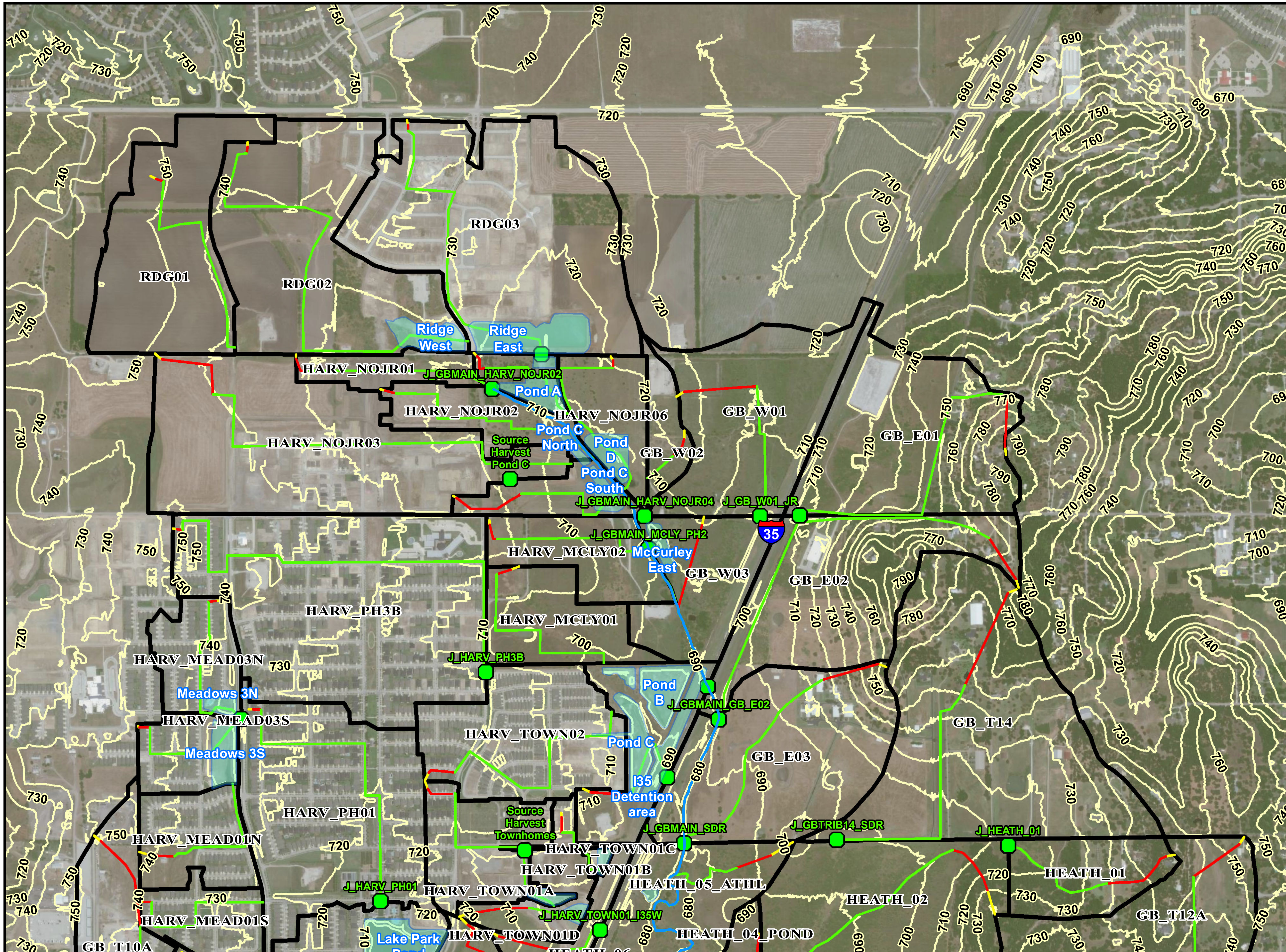
2021 Flow Paths

- Sheet
- Shallow
- Channel
- 2019 TNRIS 10ft Contours
- Exhibit Areas

N

0 3,000 6,000
Feet

CARDINAL STRATEGIES



Argyle TEXAS

GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 6B: 2021 CONDITION DRAINAGE AREA MAP

Legend

- Graham Branch Main Stem
- 2021 Drainage Areas
- Detention Ponds
- 2021 Junctions

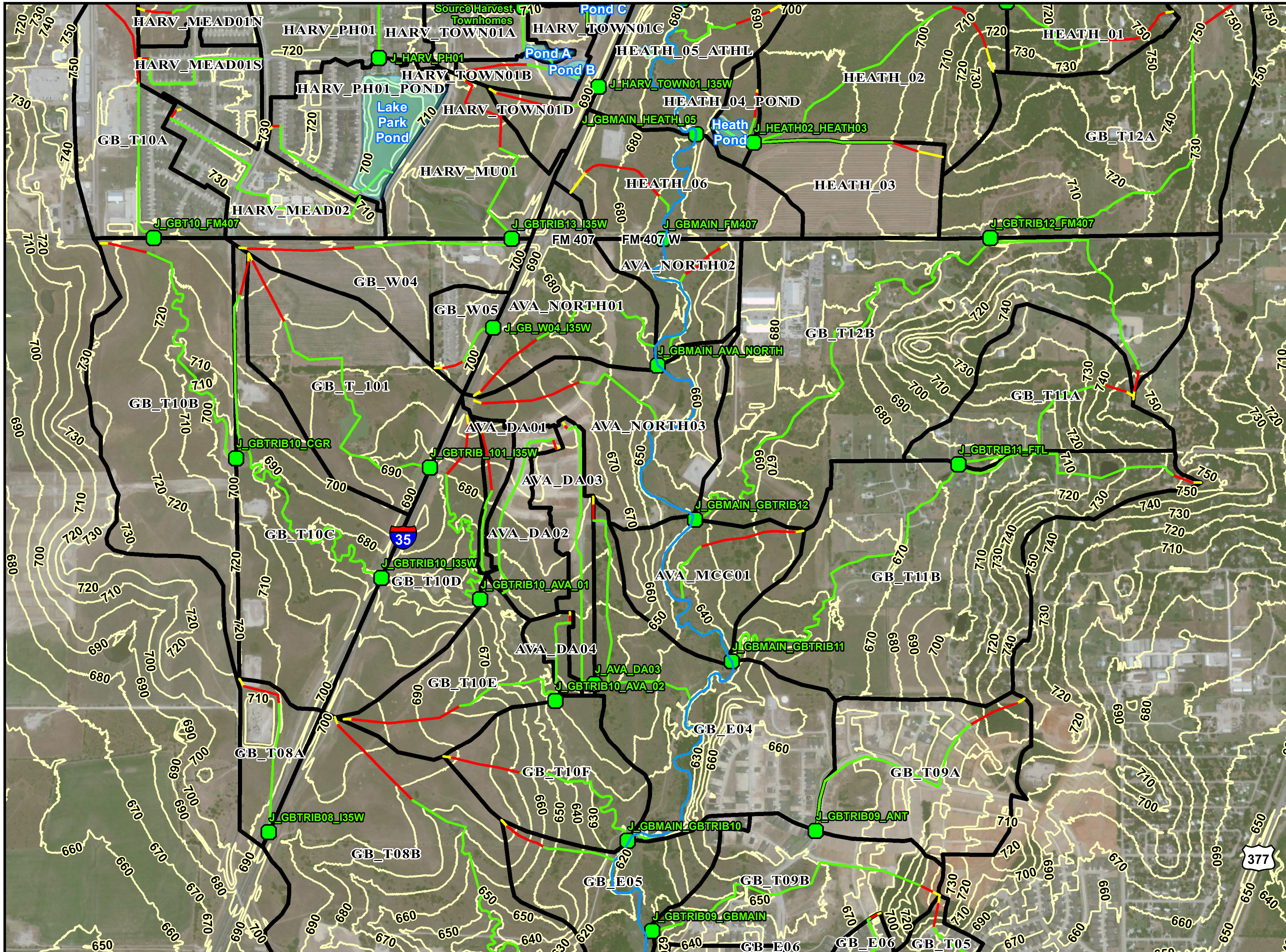
2021 Flow Paths

- Sheet
- Shallow
- Channel
- 2019 TNRIS 10ft Contours

N

0 1,000 2,000
Feet

CARDINAL STRATEGIES



GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 6C: 2021 CONDITION DRAINAGE AREA MAP

Legend

- Graham Branch Main Stem
- 2021 Drainage Areas
- Detention Ponds
- 2021 Junctions

2021 Flow Paths

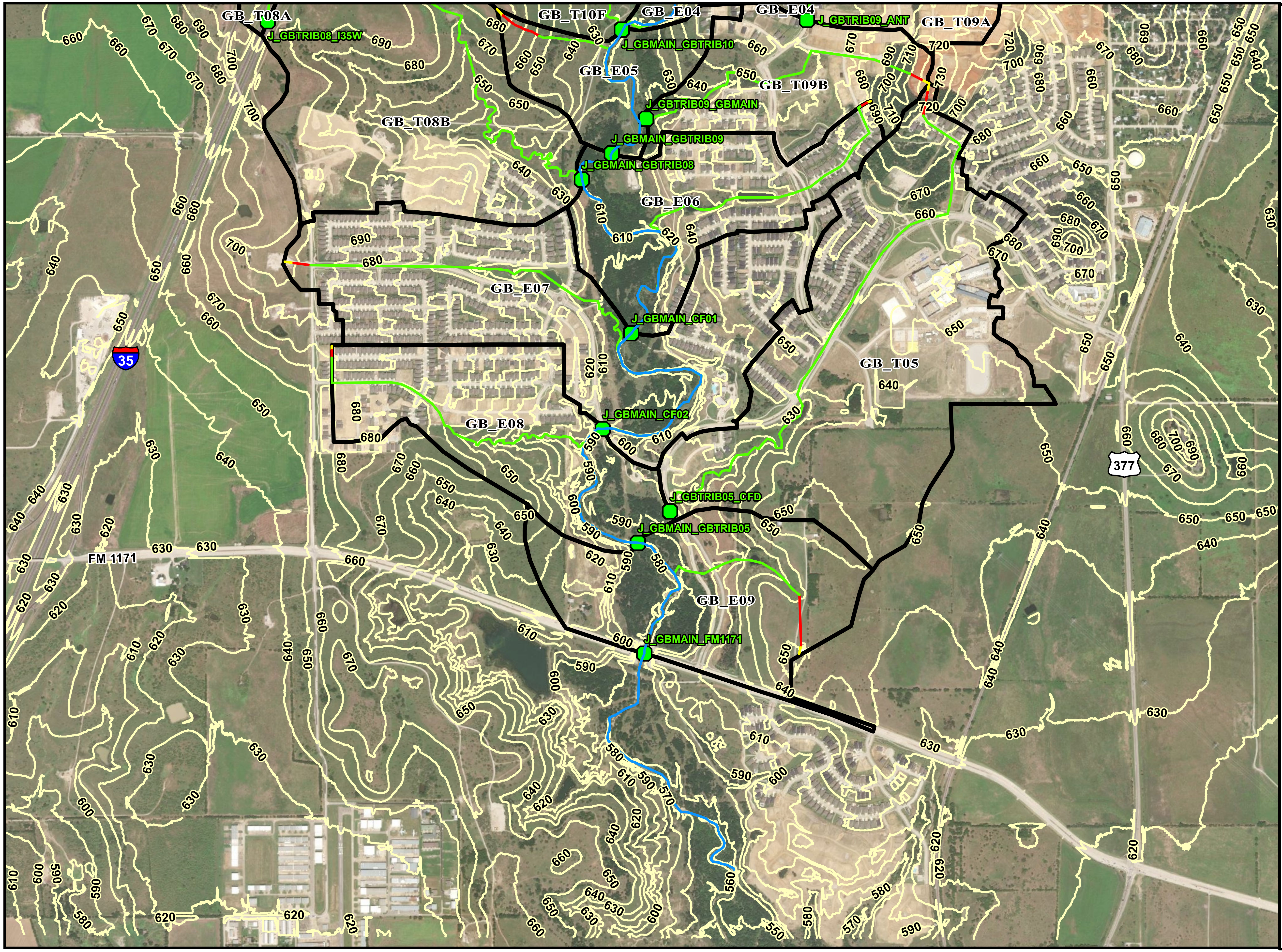
- Sheet
- Shallow
- Channel
- 2019 TNRIS 10ft Contours

N

0 1,000 2,000

Feet

CARDINAL STRATEGIES



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GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 6D: 2021 CONDITION DRAINAGE AREA MAP

Legend

- Graham Branch Main Stem
- 2021 Drainage Areas
- 2021 Junctions

2021 Flow Paths

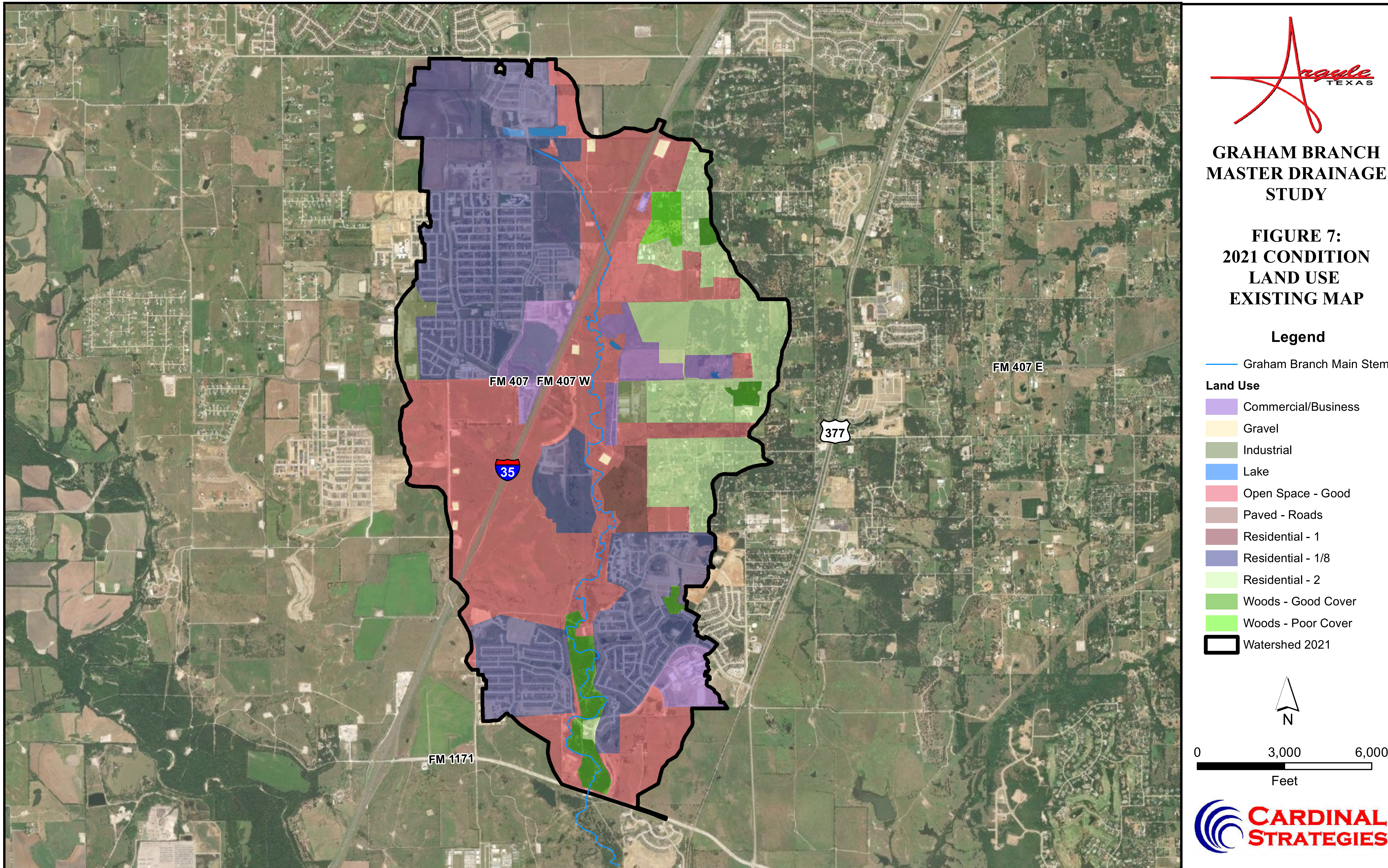
- Sheet
- Shallow
- Channel
- 2019 TNRIS 10ft Contours

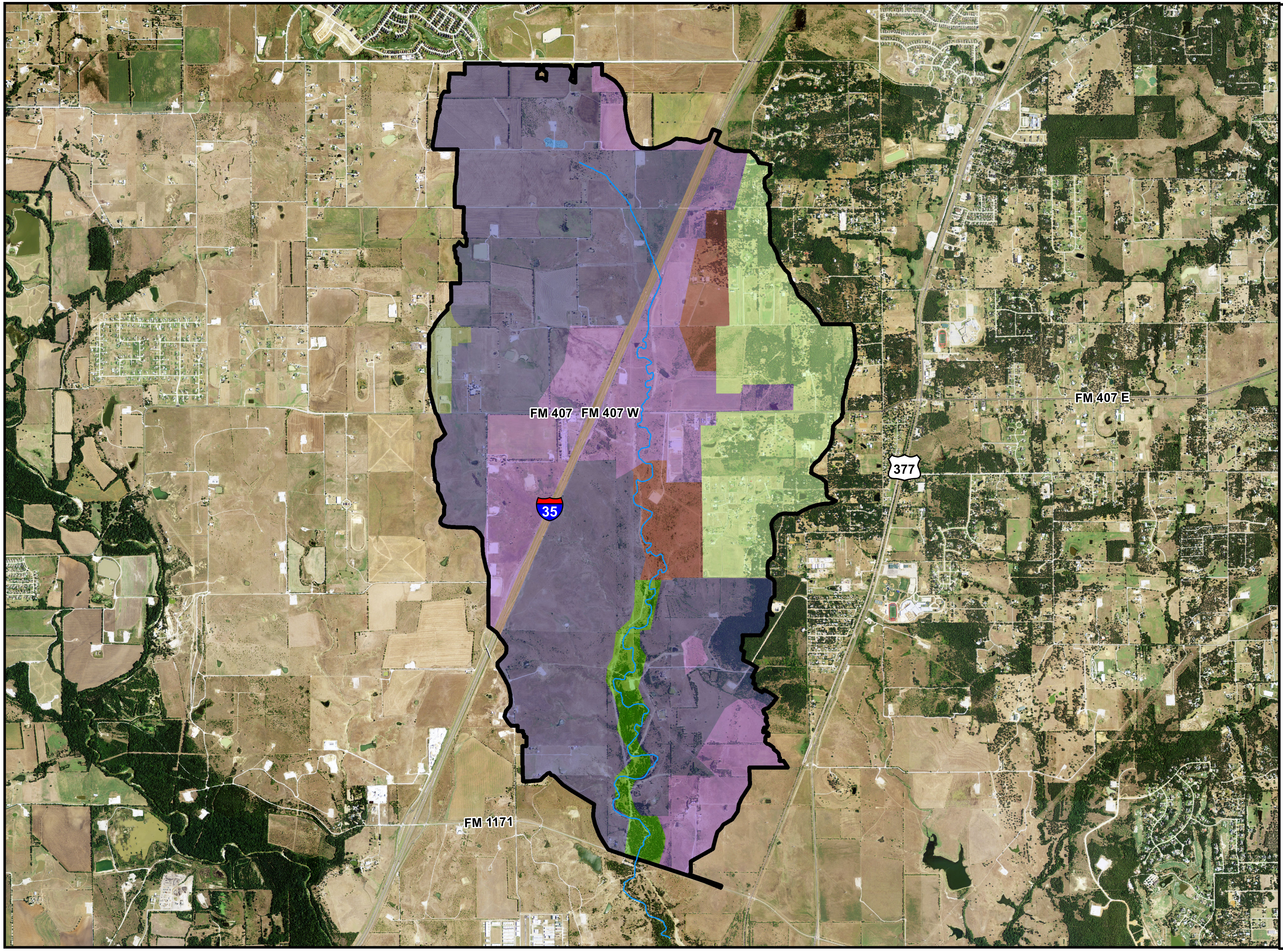
N

0 1,000 2,000

Feet

CARDINAL STRATEGIES


FM 407
FM 407 W
FM 407 E
35
377
FM 1171
Argyle TEXAS
GRAHAM BRANCH MASTER DRAINAGE STUDY
FIGURE 7: 2021 CONDITION LAND USE EXISTING MAP
Legend
Graham Branch Main Stem
Land Use
Commercial/Business
Gravel
Industrial
Lake
Open Space - Good
Paved - Roads
Residential - 1
Residential - 1/8
Residential - 2
Woods - Good Cover
Woods - Poor Cover
Watershed 2021
N
0
3,000
6,000
Feet
CARDINAL STRATEGIES



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GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 8: LAND USE FULLY DEVELOPED MAP

Legend

Graham Branch Main Stem

Land Use

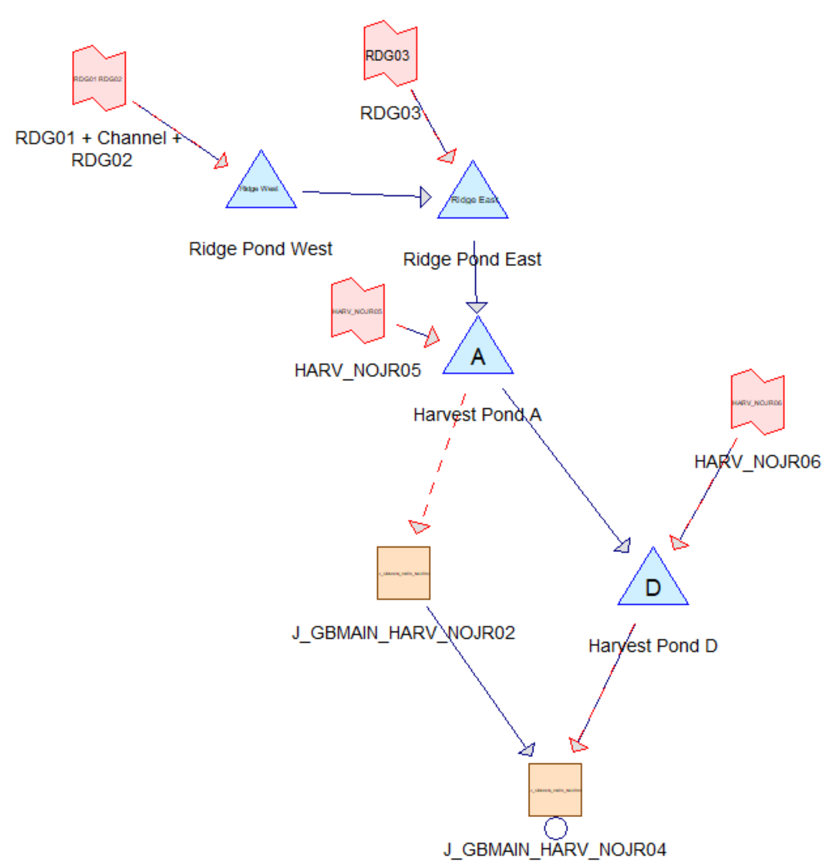
- Commercial/Business
- Industrial
- Lake
- Paved - Roads
- Residential - 1
- Residential - 1/8
- Residential - 2
- Woods - Good Cover
- Watershed 2021

N

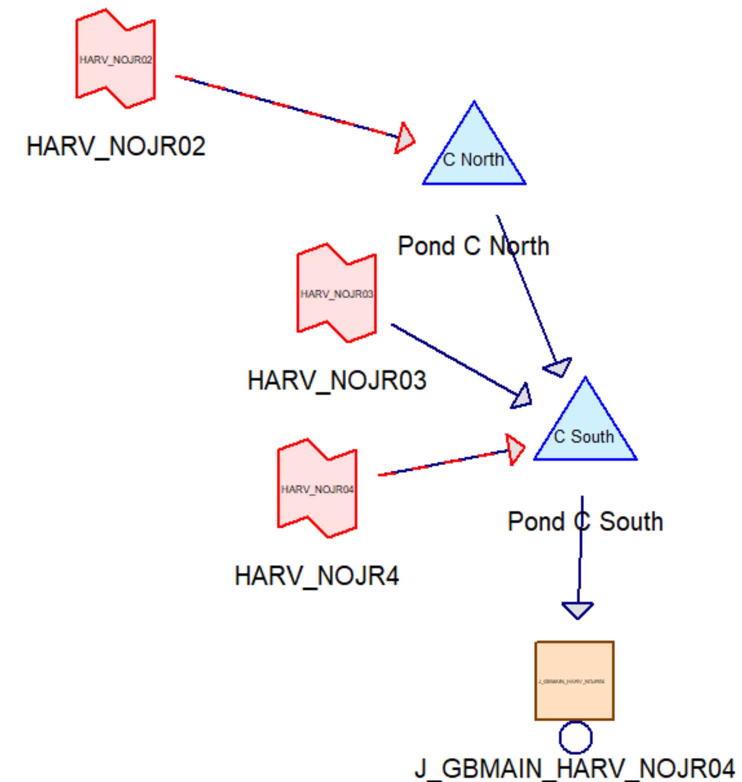
0 3,000 6,000
Feet

CARDINAL STRATEGIES

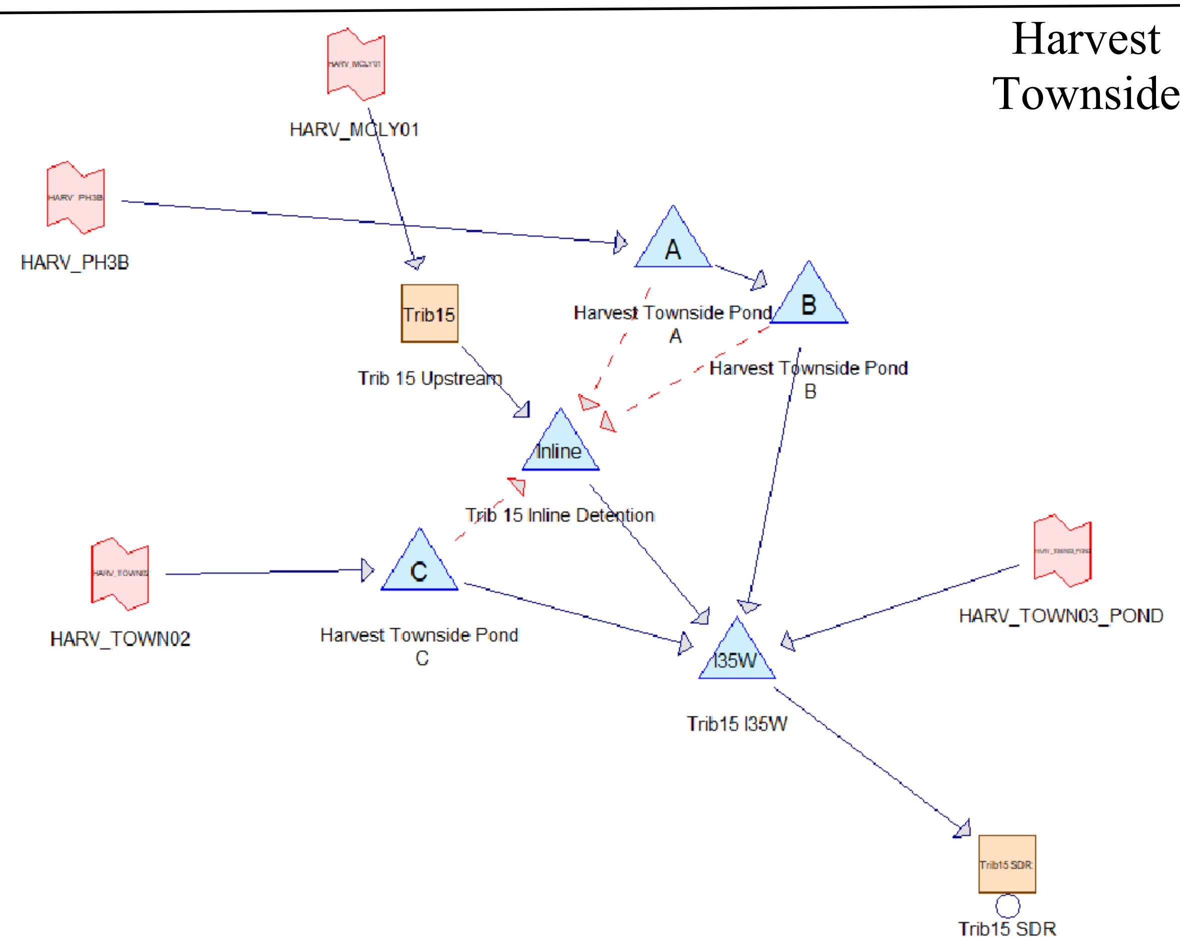
Harvest North Ponds A and D



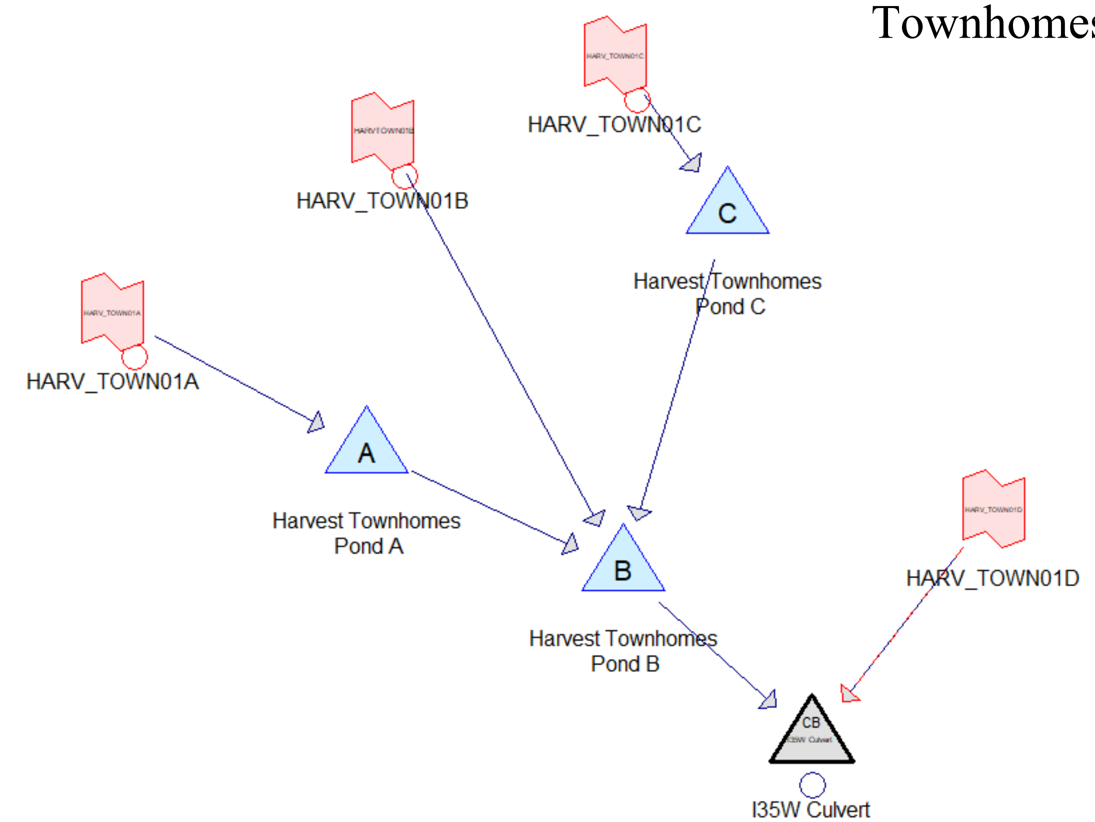
Harvest North Pond C



Harvest Townside



Harvest Townhomes



GRAHAM BRANCH MASTER DRAINAGE STUDY

FIGURE 9: HYDROCAD POND SCHEMATICS

3.0 Hydrologic Results

3.1. 2009 Conditions

Table 6 below summarizes the peak discharges along the Graham Branch Main Stem under the 2009 condition described in Section 2.2.

Table 6 – 2009 Hydrologic Results

HMS Element	Jurisdiction	Flow Rates (cfs)						
		1-YR	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
J_GBMAIN_GB03	Argyle	450.0	533.8	895.7	1180.7	1720.3	2017.0	2289.3
J_GBMAIN_GB04	Argyle	561.5	666.6	1109.9	1502.2	1996.2	2402.7	2823.0
J_GBMAIN_GB06	Argyle	806.3	976.1	1608.0	2176.2	2855.7	3367.3	3956.7
J_GBMAIN_GB10	Argyle	987.2	1208.7	2084.7	2836.6	3806.6	4506.0	5272.8
J_GBMAIN_GB18	Argyle	989.7	1208.6	2095.8	2857.3	3857.6	4572.5	5345.5
J_GBMAIN_GB19	Argyle	1240.1	1573.3	2680.4	3624.1	4914.1	5906.6	6925.1
J_GBMAIN_GB28	Argyle	1368.4	1711.7	3035.0	4114.0	5606.9	6767.5	7989.7
J_GBMAIN_GB31	Argyle	1398.3	1745.1	3149.7	4296.2	5869.4	7105.2	8399.5
J_GBMAIN_GB32	Flower Mound	1611.0	2028.3	3820.7	5281.7	7247.6	8789.9	10369.9
J_GBMAIN_GB35	Northlake	1623.2	2037.5	3836.2	5320.8	7322.7	8883.9	10489.6
J_GBMAIN_GB34	Northlake	1656.7	2074.8	3902.5	5431.9	7508.8	9123.6	10788.5
J_GBMAIN_GB37	Northlake	1654.5	2067.0	3880.9	5412.6	7517.1	9145.0	10832.1
J_GBMAIN_GB38	Northlake	1670.0	2086.1	3918.7	5480.8	7637.1	9309.0	11042.8
J_GBMAIN_GB39	Northlake	1695.5	2114.5	3966.3	5555.5	7756.0	9496.2	11302.1
J_GBMAIN_GB40	Flower Mound	1703.2	2121.5	3966.1	5554.7	7752.3	9477.0	11279.8

3.2. 2021 Existing Conditions

Table 7 below summarizes the peak discharges along the Graham Branch Main Stem under the 2021 condition described in Section 2.3.

Table 7 – 2021 Existing Watershed Hydrologic Results

HMS Element	Jurisdiction	Flow Rates (cfs)						
		1-YR	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
J_GBMAIN_HARV_NOJR02	Argyle	52.6	58	78.6	93.8	113.2	127.3	141.2
J_GBMAIN_HARV_NOJR04	Argyle	297.6	324.2	508.6	759.1	855.8	1089.5	1383.8
J_GBMAIN_MCLY_PH2	Argyle	351	383.3	578.7	792.8	986.4	1201.4	1500.6
J_GBMAIN_I35W	Argyle	441.3	493.8	710.6	894.4	1123.2	1344.6	1575.8
J_GBMAIN_GB_E02	Argyle	582.6	669.2	1023.5	1318.2	1667	1946.3	2255.2
J_GBMAIN_SDR	Argyle	817.3	935.7	1401.9	1765.4	2195	2516.6	2858.4
J_GBMAIN_HEATH_05	Argyle	1108.5	1281.3	1952.1	2521.2	3231.3	3769.7	4540.8
J_GBMAIN_FM407	Argyle	1105.5	1279.9	1974.7	2544.7	3279	3823.1	4692
J_GBMAIN_AVA_NORTH	Argyle	1488.3	1725	2692.6	3476.3	4465.5	5208.2	6250.3
J_GBMAIN_GBTRIB12	Argyle	1678.9	1972.6	3190	4178.8	5439.4	6400.4	7479.9
J_GBMAIN_GBTRIB11	Argyle	1736.1	2053.9	3392.2	4504.3	5925.3	6993.6	8097.9
J_GBMAIN_GBTRIB10	Flower Mound	2002.4	2400.1	4046.7	5421.3	7197.5	8536.3	9779.7
J_GBMAIN_GBTRIB09	Northlake	2028.2	2429.4	4115.2	5526.3	7356.5	8742.1	10018
J_GBMAIN_GBTRIB08	Northlake	2058.8	2464.7	4195	5660.6	7575.6	9030.5	10351
J_GBMAIN_CF01	Northlake	2041.3	2438	4143.5	5610.3	7542	9016.7	10365.9
J_GBMAIN_CF02	Northlake	2050.6	2444.9	4162.6	5651.1	7626.2	9139.4	10522.2
J_GBMAIN_GBTRIB05	Northlake	2089.2	2489.9	4245.1	5768.8	7786.2	9344.6	10803.2
J_GBMAIN_FM1171	Flower Mound	2095.6	2495.8	4246.3	5771.1	7784.8	9345.7	10845.5

3.3. Fully-Developed Conditions

Table 8 below summarizes the peak discharges along the Graham Branch Main Stem under the fully-developed condition described in Section 2.3.

Table 8 – Fully-Developed Watershed Hydrologic Results

HMS Element	Jurisdiction	Flow Rates (cfs)						
		1-YR	2-YR	5-YR	10-YR	25-YR	50-YR	100-YR
J_GBMAIN_HARV_NOJR02	Argyle	53.5	58.9	80	95.5	115.2	129.6	143.7
J_GBMAIN_HARV_NOJR04	Argyle	297.6	324.2	507.7	759.1	854.4	1089.2	1383.1
J_GBMAIN_MCLY_PH2	Argyle	372.2	404.5	596.6	799.2	1001.1	1214	1512.6
J_GBMAIN_I35W	Argyle	544.2	605.9	848.6	1040.9	1242.6	1401.4	1603.7
J_GBMAIN_GB_E02	Argyle	797.5	899.6	1299	1612.4	1971.5	2238.3	2516
J_GBMAIN_SDR	Argyle	1065.9	1202	1705.3	2056.4	2500.9	2827.5	3166.6
J_GBMAIN_HEATH_05	Argyle	1451.7	1644.5	2380	2945.9	3682	4227.1	4793.5
J_GBMAIN_FM407	Argyle	1458.7	1652.6	2405.8	2984.2	3728.6	4297.4	4877.1
J_GBMAIN_AVA_NORTH	Argyle	1900.2	2162.5	3182.6	3976	4971	5767	6554
J_GBMAIN_GBTRIB12	Argyle	2188.7	2505	3793.4	4809.6	6088.4	7065.1	8041.5
J_GBMAIN_GBTRIB11	Argyle	2269.3	2616.3	4045.5	5190.1	6624.5	7711.8	8796.1
J_GBMAIN_GBTRIB10	Flower Mound	2701.9	3143	4928.3	6334.6	8127.6	9484.7	10838.3
J_GBMAIN_GBTRIB09	Northlake	2732.8	3176.6	5011.9	6458.2	8310.4	9714.9	11116.4
J_GBMAIN_GBTRIB08	Northlake	2777.2	3227.9	5130	6635.8	8574.7	10052.4	11524
J_GBMAIN_CF01	Northlake	2751.8	3191.6	5082.2	6595.5	8555.6	10050.7	11540.7
J_GBMAIN_CF02	Northlake	2760.6	3201.9	5112	6650	8653.4	10185.8	11716.4
J_GBMAIN_GBTRIB05	Northlake	2808	3259.2	5211.1	6775	8830.4	10436.6	12035.2
J_GBMAIN_FM1171	Flower Mound	2816.9	3266	5216.2	6778.4	8832.1	10441.3	12093.2

3.4. Comparison of Hydrologic Results

Four hydrologic models are available for comparison purposes and are discussed independently. Only the 100-YR storm event is compared as that is what the design frequency is for flood risk assessment.

3.4.1. Cardinal 2021 Existing Condition vs. Cardinal 2009

Table 9 below summarizes the peak discharge along common locations in the Graham Branch main stem between the 2021 and 2009 conditions in order to evaluate the impacts of the completed and approved developments in the watershed.

Table 9 – Existing Watershed Comparison to Pre-Development Conditions

2009 Model Junction	2009 Model Peak Discharge (cfs)	2021 Model Junction	2021 Model Peak Discharge (cfs)	Difference (cfs)
J_GBMAIN_GB03	2289.3	J_GBMAIN_HARV_NOJR04	1383.8	-905.5
J_GBMAIN_GB04	2814.2	J_GBMAIN_GB_E02	2255.2	-559
J_GBMAIN_GB06	3578.9	J_GBMAIN_SDR	2858.4	-720.5
J_GBMAIN_GB10	5650.9	J_GBMAIN_HEATH_05	4540.8	-1110.1
J_GBMAIN_GB18	5993.3	J_GBMAIN_FM407	4692	-1301.3
J_GBMAIN_GB19	7064.8	J_GBMAIN_AVA_NORTH	6250.3	-814.5
J_GBMAIN_GB28	7647	J_GBMAIN_GBTRIB12	7479.9	-167.1
J_GBMAIN_GB31	8044.2	J_GBMAIN_GBTRIB11	8097.9	53.7
J_GBMAIN_GB32	10614.8	J_GBMAIN_GBTRIB10	9779.7	-835.1
J_GBMAIN_GB34	11008.1	J_GBMAIN_GBTRIB09	10018	-990.1
J_GBMAIN_GB35	10802.4	J_GBMAIN_GBTRIB08	10351	-451.4
J_GBMAIN_GB37	11031.5	J_GBMAIN_CF01	10365.9	-665.6
J_GBMAIN_GB38	11235.4	J_GBMAIN_CF02	10522.2	-713.2
J_GBMAIN_GB39	11484.4	J_GBMAIN_GBTRIB05	10803.2	-681.2
J_GBMAIN_GB40	11450.1	J_GBMAIN_FM1171	10845.5	-604.6

The Cardinal 2021 and 2009 models were developed concurrently using the methodology outlined in Sections 2.2 and 2.3. These models are the only comparison in this report that contains the entire Graham Branch watershed north of FM1171. Therefore, there are more junctions of comparison available along the main stem between these two models than those mentioned in future sections.

Results indicate that the developments have resulted in an overall decrease in peak discharges downstream, likely due to significant detention structures in The Ridge at Northlake, Harvest, and Heath developments.

The first junction of interest, located north of Justin Rd, indicates that the significant detention associated with The Ridge at Northlake and the Harvest North phases results in a large decrease in peak flows at the upstream end of Graham Branch.

3.4.2. Cardinal 2021 Existing Condition vs. Harvest Model

Table 10 below summarizes the peak discharge along common locations in the Graham Branch main stem between the Cardinal 2021 conditions model and the latest hydrologic model for the Harvest development.

Table 10 – Existing Watershed Comparison to Harvest Results

2021 Model Junction	2021 Model Peak Discharge (cfs)	Harvest Junction	Harvest Model Peak Discharge (cfs)	Difference (cfs)
J_GBMAIN_I35W	1575.8	899	1642	66.2
J_GBMAIN_GB_E02	2255.2	Junction-GBM&T15	2848.9	593.7
J_GBMAIN_SDR	2858.4	Junction-GBM&SamDavisRd	2709.5	-148.9
J_GBMAIN_HEATH_05	4540.8	Junction-GBM&T14.2	2808.9	-1731.9
J_GBMAIN_FM407	4692	n/a	n/a	n/a
J_GBMAIN_AVA_NORTH	6250.3	Junction-GBM&T13	4714.3	-1536
J_GBMAIN_GBTRIB12	7479.9	Junction-GBM&T12	5714.4	-1765.5
J_GBMAIN_GBTRIB11	8097.9	Junction-GBM&T11	6128.4	-1969.5

The most recent hydrologic model for the Harvest Development was completed by Jones & Carter in March 2021 using HEC-HMS version 4.2.1. This model captures the upstream drainage areas containing The Ridge at Northlake development, with a downstream limit at the confluence with Tributary 11 which outfalls just north of the drainage areas associated with the Canyon Falls development. Therefore, the junctions for comparison are mostly located in the northern part of the watershed.

Differences between the Harvest and Cardinal models include:

- Rainfall data in the Harvest model has overall higher depths than the Cardinal model based on prior development criteria manuals
- Ponds in series were modeled differently between engineers

The upstream end of the model has similar peak discharges as those modeled in a source output in the Harvest model. The next three junctions in the Harvest model show a small increase in peak discharges when compared to the Cardinal 2021 condition model. Without a report to better understand how the detention ponds were established during the design of the Harvest phases, exact differences can't be fully understood.

3.4.3. Cardinal 2021 Existing Condition vs. Heath Model

Table 11 below summarizes the peak discharge along common locations in the Graham Branch main stem between the Cardinal 2021 conditions model and the latest hydrologic model for the Heath development.

Table 11 – Existing Watershed Comparison to Heath Results

2021 Model Junction	2021 Model Peak Discharge (cfs)	Heath Junction	Heath Model Peak Discharge (cfs)	Difference (cfs)
J_GBMAIN_HARV_NOJR04	1383.8	2-4x4's	2128.6	744.8
J_GBMAIN_I35W	1575.8	I-35W (2)	2294.7	718.9
J_GBMAIN_GB_E02	2255.2	Junction-T15	3997.3	1742.1
J_GBMAIN_SDR	2858.4	3-10x6 RCBs	3725.9	867.5
J_GBMAIN_HEATH_05	4540.8	Junction-Main&T14	4517.6	-23.2
J_GBMAIN_FM407	4692	n/a	n/a	n/a
J_GBMAIN_AVA_NORTH	6250.3	Junction-Main&T13	5803.8	-446.5
J_GBMAIN_GBTRIB12	7479.9	Junction-Main&T12	6948.1	-531.8
J_GBMAIN_GBTRIB11	8097.9	Junction-Main&T11	7113.4	-984.5

The most recent hydrologic model for the Heath Development was completed by HydroLink Engineering in March 2021 using HEC-HMS version 4.2.1. This model is based on an earlier submittal from the Jones & Carter Harvest model. This version does not contain updated detention modeling for Harvest North of Justin Rd.

Similar to the Harvest model, the Heath model captures the upstream drainage areas containing The Ridge at Northlake development, with a downstream limit at the confluence with Tributary 11 which outfalls just north of the drainage areas associated with the Canyon Falls development. Therefore, the junctions for comparison are mostly located in the northern part of the watershed.

Differences between the Heath and Cardinal models include:

- Rainfall data in the Heath model has overall higher depths than the Cardinal model
- Ponds in series were modeled differently between engineers
- Harvest North of Justin Road has a more simplistic basin and single detention area model which does not match what has been approved and designed

Because of the lack of detention modeling in the upstream basins, the peak discharges in the upstream sections of the Heath model are larger than the Cardinal model. Differences in peak discharges south of Sam Davis road can be attributed to different detention modeling and therefore timing of peaks in the watershed, but generally show the same trends as the Cardinal model.

3.4.4. Cardinal 2021 Existing Condition vs. Avalon Model

Table 12 below summarizes the peak discharge along common locations in the Graham Branch main stem between the Cardinal 2021 conditions model and the latest hydrologic model for the Avalon development.

Table 12 – Existing Watershed Comparison to Avalon Results

2021 Model Junction	2021 Model Peak Discharge (cfs)	Avalon Junction	Avalon Model Peak Discharge (cfs)	Difference (cfs)
J_GBMAIN_HARV_NOJR04	1383.8	n/a	n/a	n/a
J_GBMAIN_I35W	1575.8	Junction-Q|R	2585	1009.2
J_GBMAIN_GB_E02	2255.2	n/a	n/a	n/a
J_GBMAIN_SDR	2858.4	Junction-O|P	4438.1	1579.7
J_GBMAIN_HEATH_05	4540.8	Junction-M|N	5715.8	1175
J_GBMAIN_FM407	4692	n/a	n/a	n/a
J_GBMAIN_AVA_NORTH	6250.3	Junction-J|K	7627	1376.7
J_GBMAIN_GBTRIB12	7479.9	Junction-G|L	9105.3	1625.4
J_GBMAIN_GBTRIB11	8097.9	Junction-H|I	9732.5	1634.6
J_GBMAIN_GBTRIB10	9779.7	Junction-A|B	11851	2071.3

The most recent hydrologic model for the Heath Development was completed by McAdams Engineering in January 2021 using HEC-HMS version 4.6.1. This model is based on an earlier submittal from McAdams for the Avalon Phase 1 development. Of note, this model does not contain any modeling of upstream detention or proposed detention.

The Avalon model captures the upstream drainage areas containing The Ridge at Northlake development, with a downstream limit at the confluence with Tributary 10 which outfalls in Graham Branch main stem in the northern portion of the Canyon Falls development. This model has the most downstream comparison point of any previous models developed by others.

Differences between the Avalon and Cardinal models include:

- Rainfall data in the Avalon model has overall higher depths than the Cardinal model
- No detention included in Avalon model

Because of the lack of detention modeling, the peak discharges in the Avalon model are larger than the Cardinal model, though generally the flows follow a similar trend in both models.

Table 13 – Rainfall Data from Previous Models

Duration	Average Recurrance Interval (years)			
	2	10	25	100
5-min	0.5	0.67	0.77	0.94
15-min	0.98	1.38	1.6	1.98
1-hr	1.67	2.5	2.96	3.77
2-hr	2.02	3.1	3.7	4.76
3-hr	2.22	3.45	4.14	5.37
6-hr	2.58	4.08	4.98	6.54
12-hr	3	4.8	5.88	7.8
1-day	3.36	5.52	6.96	9.36

4.0 Hydraulic Routing

A hydraulic model was constructed as part of this analysis for routing purposes to better understand and evaluate the storage effects within Graham Branch and the effect it has on the calculated peak discharge in order to properly assess flood risk. The hydraulic model was built using HEC-RAS v5.0.7 and cross sections were spaced roughly between 200 and 500 feet apart.

4.1. Topography and Crossings (2009)

For the 2009 routing model, the same TNRIS data used for the hydrology delineations was used for cutting cross sections for the hydraulic model. A combination of site visits and field measurements along with collected plans from TxDOT for various crossings was used to develop the overall model. The model extends from approximately 3,600 feet downstream of FM 1171 to the headwaters west of IH35W. The model includes the following crossings:

1. Old Justin Road
2. IH35W
3. Sam Davis Road
4. FM 407
5. FM 1171

4.2. Topography and Crossings (2021)

For the 2021 routing model, the latest version of TNRIS LiDAR data was used to cut cross sections for the hydraulic model. Utilizing the same crossings as the 2009 model, one additional crossing was added to the model:

1. Westbridge Drive

The limits of the overall routing model remained the same as the 2009 model.

All routing storage-discharge relationships are included in Appendix C along with cross sections for each condition.

5.0 Conclusion

Comparisons of the current watershed inclusive of all approved developments to a pre-developed watershed show that decreases in peak discharge are observed. This model utilizes the most current rainfall data and should be the most complete model for that overall watershed. Several comparisons were made to previous development submittals, but many were not a fair comparison for various reasons. This master drainage study confirms that the regulations being followed are working to reduce flood risk as development of this watershed continues. It will be important that the Town of Argyle utilizes an overall model to better evaluate timing impacts of proposed detention throughout the watershed to ensure peak discharges are not inadvertently adversely impacted.