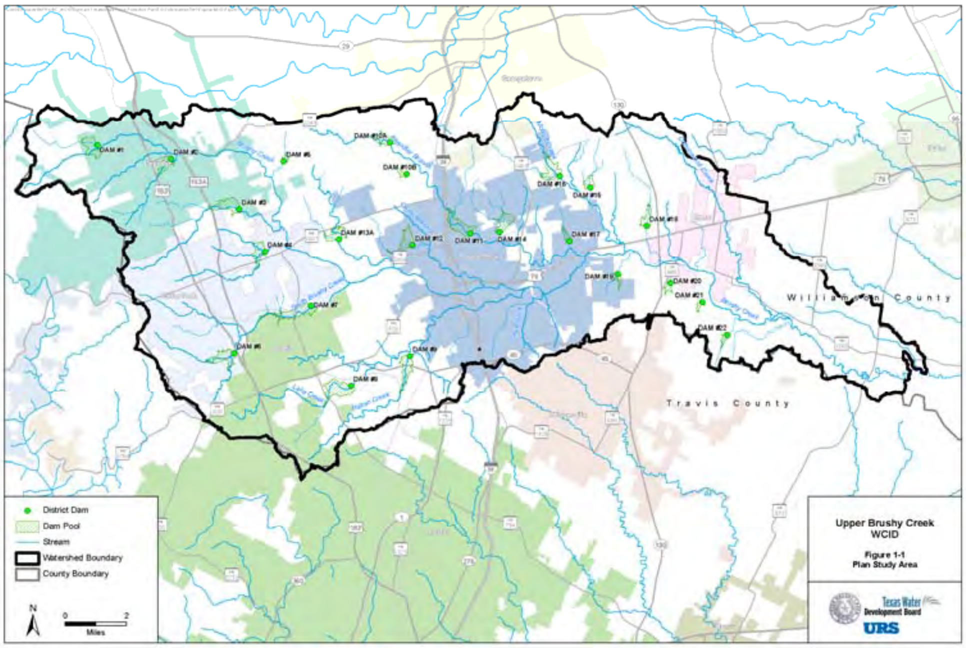
FINAL
Upper Brushy Creek Watershed Flood Protection Plan



Williamson County, Texas
June 2016

Prepared by:
URS
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Texas Water Development Board

FINAL
Upper Brushy Creek Watershed Flood Protection Plan

Prepared for:
Upper Brushy Creek
Water Control & Improvement District
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June 2016

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EXECUTIVE SUMMARY

Background

The Upper Brushy Creek Watershed Control and Improvement District (District) is located in Williamson County within an area that encompasses portions of the cities of Austin, Cedar Park, Hutto, Leander, and Round Rock (see Figure ES-1). The original district was formed by the Texas Legislature in 1956 to provide flood and erosion control within the Brushy Creek Watershed. The primary focus of the District has been operation and maintenance of 23 dams (see Figure ES-1) constructed with federal support (U.S. Department of Agriculture) in the 1950s and 1960s. The current mission of the District is to maintain and improve flood control structures within the Brushy Creek Watershed within the District boundaries and take appropriate measures to protect public safety as well as economic infrastructure of the District, in consultation and cooperation with other governmental entities.

In furtherance of this mission, in 2011 the District applied for and received a flood protection planning grant from the Texas Water Development Board (TWDB) to develop an Upper Brushy Creek Watershed Flood Protection Plan (FPP). The study area includes approximately 187 square miles in the Upper Brushy Creek Watershed and contains approximately 139 river miles of creeks with drainage areas greater than 1 square mile. The five cities (Austin, Cedar Park, Hutto, Leander, and Round Rock) and Williamson County have endorsed the need for the FPP and have been active participants in preparation of the FPP, through participation with the two lead agencies in a Technical Advisory Committee (TAC). The TAC was formed specifically for providing input and review to the watershed flood protection planning process.

Plan Purpose and Organization

The purpose of the FPP is to identify existing creek flooding concerns, prioritize those concerns, propose potential alternatives for the mitigation of the highest priority concerns, develop concept designs and cost estimates for selected alternatives, and provide benefit analyses of each alternative. The FPP therefore provides flood mitigation alternatives, each with an associated concept design, cost, and benefit (relative to other alternatives). This information is provided for the benefit of the stakeholders (cities and county) within the District for consideration in development of capital improvement plans by each stakeholder. Additional benefits to stakeholders include:

- Development of improved watershed hydrologic (runoff prediction) models, consistent with current development and available recently improved topographic data; and
- Development of improved watershed hydraulic (flood elevation prediction) models, consistent with current development and available recently improved topographic data.

The FPP models are planned to form the basis for revised Federal Emergency Management Agency (FEMA) regulatory floodplain maps and are developed per *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix C: Guidance for Riverine Flooding Analyses and Mapping* (FEMA, Appendix C, 2009). This mapping process is being financially supported by FEMA, TWDB, and the District and will be completed after completion of this FPP.

The FPP organization includes the following sections, each documenting a step in the FPP development.

Section 2, Hydrologic Modeling Methodology. Hydrologic modeling predicts the temporal pattern of runoff (flow rate versus time) for a given storm (rainfall versus time). This section provides details of the software used, parameter development methodology, and model calibration method.

Section 3, Hydraulic Modeling Methodology. Hydraulic modeling predicts the water surface elevation (and associated floodplain extent) associated with the peak flow rates derived per hydrologic modeling. This section provides details of the software used, parameter development methodology, methodology for assigning flows to cross-sections, model boundary conditions, and model calibration.

Section 4, Hydrologic Model Analysis and Results. This section provides documentation of hydrologic modeling: data sources used in parameter derivation, tabular and spatial (map) summaries of parameter values throughout the watershed, graphical summary of model structure, map of model flow prediction points, model calibration results, and tabular results for the series of scenarios modeled.

Section 5, Hydraulic Model Analysis and Results. This section provides documentation of hydraulic modeling: data sources used in parameter/ cross-section geometry derivation, model summary output data, model flood extents maps, and details of model calibration.

Section 6, Flood Hazard Assessment. This section provides documentation of the procedure used to obtain TAC consensus approval for the FPP hazard assessment method. The section also provides details and results of the risk assessment method applied to habitable structures, the aggregation of habitable structures into damage centers, the aggregation of damage centers into Priority Areas (PAs), and the ranking of PAs in terms of hazard. Similarly, the section also provides details and results of the risk assessment method applied to in-line structures (road crossings of flood extents: bridges, culverts, etc.).

Section 7, Flood Mitigation Alternatives. This section provides documentation for: 1) the identification of flood mitigation structural alternatives to address flooding within the identified PAs; 2) the methodology used in concept design and cost estimation of these alternatives; 3) the methodology used to estimate benefits of alternatives; 4) presentation of those benefits; and 5) qualitative discussion of project prioritization for consideration by stakeholders in development of local jurisdiction (county, city) capital improvement plans.

Summary of Hydrologic Modeling

The hydrologic modeling was used to develop a predicted flow versus time (hydrograph) relationship at 574 points along the streamlines within the Study Area for a wide range of statistical storms, varying from the routine 50% annual exceedance probability (AEP) storm through the 1% AEP storm to the very rare 0.2% AEP storm. These three storms are sometimes referred to as the 2-year, 100-year, and 500-year average return period storms. Figure ES-2 showing the Leander area provides an example of the size of subwatersheds considered in the model. The District watershed presents a number of challenges to flow prediction, including:

- Storms are historically of significantly higher intensity in the western half of the watershed than in the eastern half;
- The watershed is developing at a fast pace, which makes quantification of subwatershed pavement area a rapidly evolving estimate;
- Portions of the watershed have existing quarries, which are large depressions that strongly affect runoff volume; and
- The watershed encompasses five cities and a county, each of whom specify particular technical methods for hydrologic analysis.

To address these issues, hydrologic modeling methods were proposed, reviewed, and revised with ultimate consent of the TAC prior to modeling being performed. Importantly, the models were calibrated so that predicted volume of runoff and predicted time of flow peak matched historic storms. Two major storms that had caused significant flooding were chosen for calibration: the large, regional Tropical Storm Hermine from September 2010 and a June 2007 intense thunderstorm event. The District dams collected continuous rainfall data and stage data throughout each of these two events. The records from 11 of the District's dams were used in the calibration.

The flow estimates presented in the FPP represent a major improvement in accuracy over the models in use prior to the FPP, notably:

- Modeling considered development up to 2011, while previous modeling represented a development condition from the early 1970s.
- Modeling was calibrated at 11 points within the watershed; i.e., the models' predictions are demonstrated to be consistent with physical data collected during the most significant storms in the watershed in the past decade.
- Modeling used rainfall depths and spatial distribution from a 2004 publication; previous modeling used a 1962 reference. The significance is that the statistics in the new reference considered more than double the duration of rainfall data and a much more dense spatial distribution of gages than considered in the old dataset.
- Watershed boundaries, quarry capacities, etc. were based upon vastly more accurate topographic data collected using state-of-the-art methods (LiDAR) in 2006 and 2012.

Summary of Hydraulic Modeling

The hydraulic modeling performed developed water surface elevations (WSEs) for over 210 stream miles and included over 3,800 hydraulic model cross-sections. Figure ES-3 shows the streamlines for which detailed models were developed. WSEs were estimated for each of the statistical storm scenarios (50%, 10%, 4%, 2%, 1% and 0.2% AEP floods for existing conditions, and 4% and 1% AEP floods for ultimate [full] development conditions) considered in the hydrologic modeling.

As with the hydrologic modeling, hydraulic modeling methods were proposed, reviewed, and revised with ultimate consent of the TAC prior to modeling being performed. Again, models were calibrated so that predicted WSEs matched historic high water marks (HWMs) collected during historic events, notably Tropical Storm Hermine (September 2010) over the full watershed and the July 2012 large storm over the Lake Creek/Rattan Creek watershed. The Lake Creek watershed was identified as having significantly greater rainfall losses (i.e., more rain goes into the ground) than other District watersheds, and the hydrologic model had to be revised to achieve a model match between predicted WSEs and numerous measured HWMs.

The hydraulic models presented in the FPP represent a major improvement in hydraulic accuracy and community utility over hydraulic models in use prior to the FPP, notably:

- Most importantly, floodplain extents were based upon vastly more accurate topographic data collected: 1) using state-of-the-art methods (LiDAR) in 2006 and 2012; and 2) via extensive ground surveys in 2011-2012 (survey of 415 bridges/ culverts, 267 other cross-sections);
- Existing hydraulic models, many developed over 20 years ago, had poor or non-existent documentation , making their utility in estimating impacts of proposed projects on WSE complex and problematic; and
- Detailed models were developed for 29 miles of stream that were previously mapped as FEMA Zone A (i.e., regulatory floodplains mapped without a hydraulic model).

Summary of Hazard Assessment

The FPP includes a study to quantify relative flood risk level within the watershed, so that flood mitigation measures can be identified within the FPP that address the areas within the District of highest flood risk. The hydraulic model results provided for all modeled reaches of the watershed a predicted WSE for each modeled statistical flood scenario. Watershed-wide, over 600 structures (likely to be occupied) were found to be within the 0.2% AEP flood, and over 350 of those structures were found to be within the 1% AEP flood. The latter flood is analogous, but not equal to the regulatory flood, as models will not be finalized until formally submitted to FEMA after a future cycle of stakeholder and FEMA review.

The consensus hazard assessment method was developed over a series of TAC meetings. The basic method is similar to that used by the City of Austin and includes developing a Flood Score (FS) from the hydraulic model results for each habitable structure. The FS equation associated with individual habitable structures is documented in Section 6 of the FPP. Adjacent structures and their FSs were aggregated into Damage Centers (DCs); then DCs were aggregated into PAs. Figure ES-4 shows the distribution of DCs through the watershed and the associated PAs. The boundaries of the PAs were approved by consensus and reflect a judgment that the risk to structures within the entire PA would likely be addressed by the same flood mitigation project or suite of projects. FS were estimated for each structure, then aggregated by DC and PA.

The 13 PAs were prioritized during a TAC meeting in which stakeholders considered aggregate FS and a series of qualitative factors. A sensitivity study was performed to estimate changes associated with altering relative importance assigned between FS and qualitative factors, and order of ranking was generally minimally altered between various weighting scenarios. The priority of PAs from highest to lowest were 3, 2, 6, 9, 13, 11, 10, 12, 5, 8, 7, 4, and 1.

The estimated priority of a PA had no effect on consideration of the PA within the remainder of the study. Each PA was considered an area of significant risk and flood mitigation alternatives were considered to address each PA.

A similar hazard assessment process was followed for assigning relative flood risk to road crossings over modeled flood extents within the watershed. A FS equation was developed and applied, and a table quantifying FS for watershed road crossings was developed for the higher FS crossings in each watershed jurisdiction (Table ES-1).

Summary of Flood Mitigation Alternatives

Flood mitigation alternatives were developed watershed-wide to address the flood risks associated with each of the PAs. A series of meetings was held with each stakeholder (five cities and one county) to discuss feasibility and worthiness for further study of each proposed alternative. The resulting suite of flood mitigation alternatives is depicted in Figure ES-5. The types of alternatives proposed included in-line and off-line flood retarding structures (dams), new channel diversions, and existing channel improvements. Crossing-specific alternatives to address high flood risk associated with road crossings were not developed unless that alternative also resulted in substantive risk reduction in a PA.

A concept design and cost estimate were developed for each alternative deemed feasible in Figure ES-5. Individual project site plans, tables of rough project dimensions, and concept design discussions are included in Exhibit S of the FPP. The site plans in Exhibit S depict project locations, extent of the physical project, and where relevant, extent of the flood pool associated with dams. These sites have been chosen to produce desired flood risk reductions, but the site locations can be moved within the general area and produce similar flood benefits. Features depicted in an Exhibit T site map are not fixed in location and will likely move if the associated project is selected for further level of design. Estimated construction costs, not including real estate costs, are included for each alternative in Exhibit T.

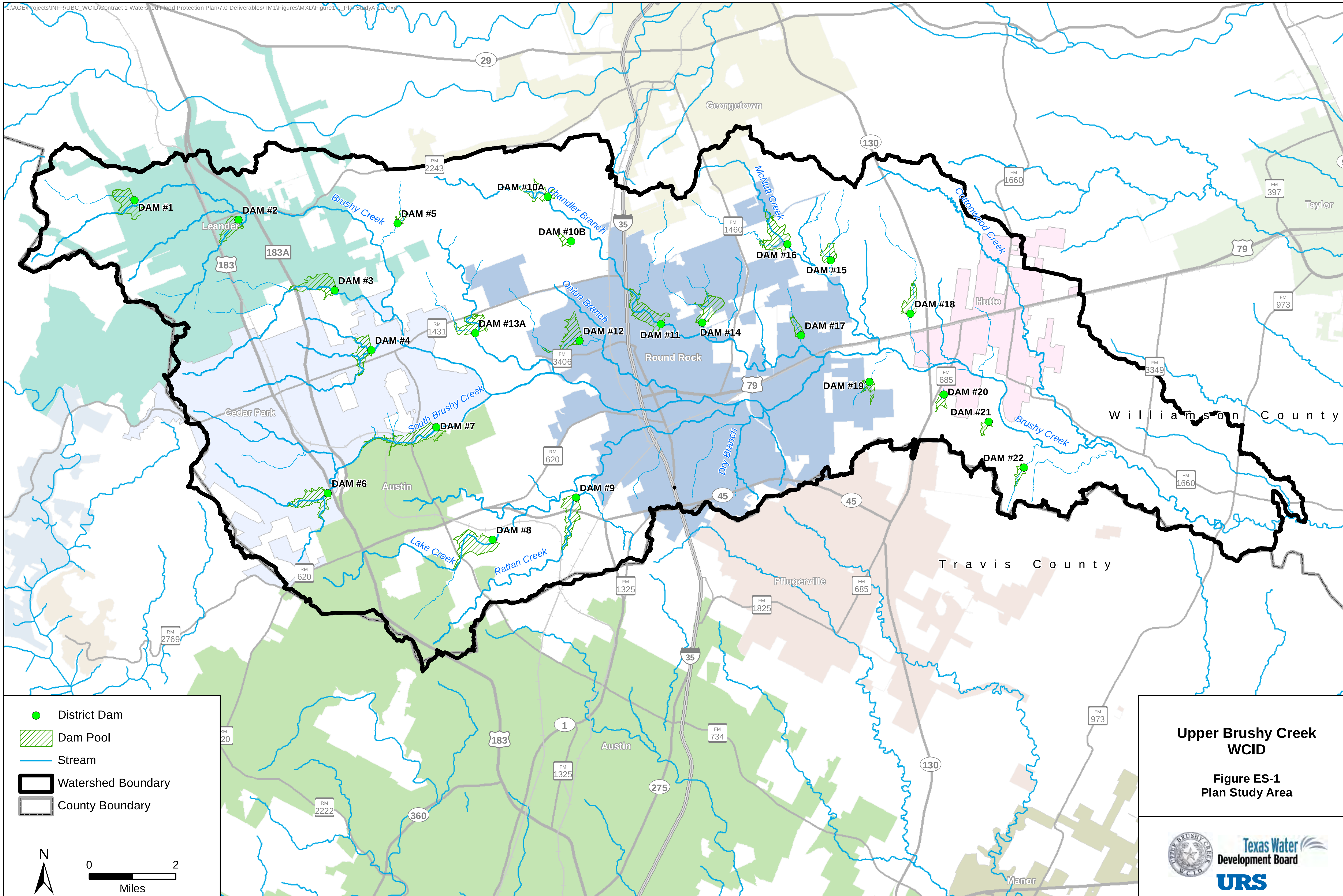
The benefits of each project in terms of FS reduction (per the consensus FS equation) were quantified by running the FPP hydrologic models with the added project and estimating changes in flood depth at each currently flooded habitable structure throughout the watershed (not just structures within PAs). Flood retarding (dam) projects designed primarily to reduce flood risk in PAs along the Brushy Creek main stem were assumed to be constructed along furthest upstream tributaries first. If a project also materially reduced risk at a road crossing previously identified as high risk, that was noted.

In upstream locations where an alternative primarily improved one PA (e.g., PAs 1, 2, and 3 in Figure ES-4), a comparison was made between the benefits and costs associated with competing or partially competing alternatives. In downstream locations where multiple alternatives were considered for risk reduction along a specific tributary and the downstream Brushy Creek main stem, the benefits and costs of these competing (or partially competing) alternatives were compared.

Table ES-1. Roadways Overtopped in 50-Year Flood

ISID	Roadway Name	Location	Type	Total Flood Score	Flood Depth 50-Year	Flood Depth 100-Year	Flood Depth 500-Year	Velocity 50-Year	Velocity 100-Year	Velocity 500-Year
City of Austin										
IS372	Mellow Meadows	Lake Creek R2	Single Access Road	6.1	0.8	1.4	2.8	1.9	2.6	3.5
IS371	San Felipe Blvd	Rattan Creek	Minor Collector	8.2	0.8	1.5	2.9	2.1	3.1	4.1
City of Cedar Park										
IS360	Cardinal Ln	Cluck Creek	Single Access Road	19.9	1.5	1.8	2.6	2.7	3.0	3.6
IS357	Cedar Park Dr	Cluck Creek	Minor Collector	21.9	1.6	1.9	2.4	2.7	2.9	3.4
IS354	RR 1431/W Whitestone Blvd	Cluck Creek	Major Arterial	21.8	1.4	1.5	1.8	2.5	2.6	2.8
City of Hutto										
IS68	Coyote Trail	Brushy Creek Trib9	Local	7.9	2.0	2.3	2.8	3.0	3.1	3.4
IS66	CR 110	McNutt Creek Trib3	Minor Arterial	40.6	2.1	2.5	3.0	3.3	3.6	3.8
IS65	CR 110	McNutt Creek Trib3	Minor Arterial	24.6	1.6	1.8	2.1	2.6	2.7	3.0
IS63	CR 110	McNutt Creek Trib2 R2	Minor Arterial	16.6	1.2	1.4	1.8	2.5	2.7	3.0
IS62	CR 112	McNutt Creek Trib1	Minor Collector	10.5	0.9	1.3	1.9	2.3	2.7	3.3
IS69	CR 135	Brushy Creek Trib9	Single Access Road	10.6	1.2	2.1	3.0	2.2	3.0	3.6
IS169	CR 199	Cottonwood	Local	9.3	5.3	6.1	5.6	1.3	1.3	2.3
City of Leander										
IS39	Emerald Isle Dr	Blockhouse Trib2	Minor Collector	6.9	0.7	0.8	1.0	1.8	2.0	2.2
IS249	FM 2243	S Fork Brushy	Major Arterial	7.7	1.1	1.4	1.8	2.2	2.2	2.5
IS54	Los Vista Dr	Mason Creek Trib1	Minor Collector	11.5	1.0	1.1	1.3	2.2	2.3	2.6
IS252	Ridgmar Rd	Brushy Creek	Local	56.8	7.8	8.7	11.0	5.6	5.7	5.8
IS251	RR 2243	Brushy Creek	Major Arterial	37.1	2.3	2.5	3.3	2.9	3.2	3.8
City of Round Rock										
IS158	A W Grimes Blvd Northbound	Brushy Creek	Major Arterial	128.1	5.7	7.6	11.5	4.5	5.2	6.4
IS318	Burnet St S	Lake Creek R1	Local	5.6	1.8	3.4	7.1	2.9	4.2	5.8
IS254	Chisholm Trail Rd	Brushy Creek	Minor Collector	176.8	6.1	7.1	10.6	5.8	6.3	6.5
IS377	Deep Wood Dr	Lake Creek R1	Minor Collector	85.4	4.2	6.5	9.5	4.3	3.8	4.5
IS7	Greenlawn Blvd	Dry Branch Trib1	Major Arterial	15.6	1.3	1.5	2.0	2.1	2.4	2.8
IS64	Harrell Pkwy	Chandler Branch Trib5 R1	Local	4.7	1.5	1.7	2.1	2.5	2.7	3.0
IS15	Nash St W	Lake Creek Trib6	Local	12.2	2.9	3.2	3.7	3.3	3.5	3.9
IS375	Oak Ridge Dr	Lake Creek R1	Minor Collector	34.9	2.2	4.2	8.1	3.4	4.7	4.9

ISID	Roadway Name	Location	Type	Total Flood Score	Flood Depth			Velocity		
					50-Year	100-Year	500-Year	50-Year	100-Year	500-Year
IS4	Oxford Blvd	Dry Branch Trib1	Local	5.2	1.5	2.1	2.9	2.9	3.3	3.5
IS10	Purple Sage	Lake Creek Trib6	Local	6.5	1.8	2.1	2.5	2.8	3.0	3.4
IS274	Railroad Crossing	Onion Branch R1	Railroad	25.3	1.6	2.0	2.7	2.7	3.0	3.2
IS159	Red Bud Ln	Brushy Creek	Major Arterial	13.9	1.4	2.2	6.7	2.6	3.3	5.6
IS376	Round Rock W Dr	Lake Creek R1	Minor Collector	24.7	1.7	4.1	8.1	3.3	4.4	6.3
IS48	Twin Ridge Pkwy	Brushy Creek Trib5A	Minor Collector	6.6	0.8	1.3	1.8	2.0	2.5	2.9
Williamson County										
IS304	Brushy Bend	Brushy Creek	Local	82.1	10.7	12.0	15.1	6.1	6.1	5.9
IS310	CR 110	McNutt Creek R1	Minor Arterial	63.0	3.0	4.0	5.9	3.7	4.3	5.3
IS173	CR 110	McNutt Creek Trib2A	Minor Arterial	43.8	2.3	2.6	3.1	3.3	3.5	3.7
IS83	CR 129	Brushy Creek	Local	19.8	4.0	5.0	7.0	4.2	4.7	5.8
IS162	CR 137	Brushy Creek	Minor Arterial	108.0	4.4	6.1	9.5	5.0	5.8	7.1
IS125	CR 176	Brushy Creek Trib4 R2	Local	11.2	2.9	3.0	3.5	3.0	3.2	3.5
IS217	CR 177	Brushy Creek	Local	38.6	10.4	11.0	12.5	2.8	2.9	3.4
IS277	CR 179	Brushy Creek	Minor Collector	230.7	7.3	8.0	10.2	6.0	6.2	6.4
IS117	FM 1325	Rattan Creek Trib1 R2	Major Arterial	23.6	1.6	2.1	2.9	2.5	3.1	3.8
IS308	FM 1660	Cottonwood	Major Arterial	19.7	1.5	1.9	2.5	2.4	2.9	3.4
IS89	Hairy Man Rd	Brushy Creek	Major Arterial	73.2	5.7	6.8	9.9	4.3	4.2	5.5
IS130	Lemens Ave	Dam 18 R2	Local	6.6	1.8	2.0	2.4	2.8	3.0	3.0
IS248	Mesa Rd	N Fork Brushy R1	Single Access Road	6.7	0.7	0.7	0.9	1.8	1.8	2.0
IS306	Old TX 180 Dirt Road	Post Oak	Local	5.5	1.8	2.0	2.5	2.6	2.7	3.1
IS313	Railroad Crossing	Chandler Branch R3	Railroad	41.4	2.1	2.3	2.8	3.1	3.3	3.6
IS334	Railroad Crossing	Blockhouse R2	Railroad	6.3	1.0	1.3	1.8	1.5	1.8	2.3
IS365	Skyview St	Spanish Oak R2	Single Access Road	70.0	3.1	3.4	4.3	3.9	4.1	4.5
IS155	Spanish Oak Trail	Brushy Creek	Local	52.4	9.3	10.4	13.6	4.4	4.4	4.4
IS186	Tonkawa Trail	Dry Fork	Local	4.8	1.6	1.8	2.3	2.4	2.6	3.1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DAM #14
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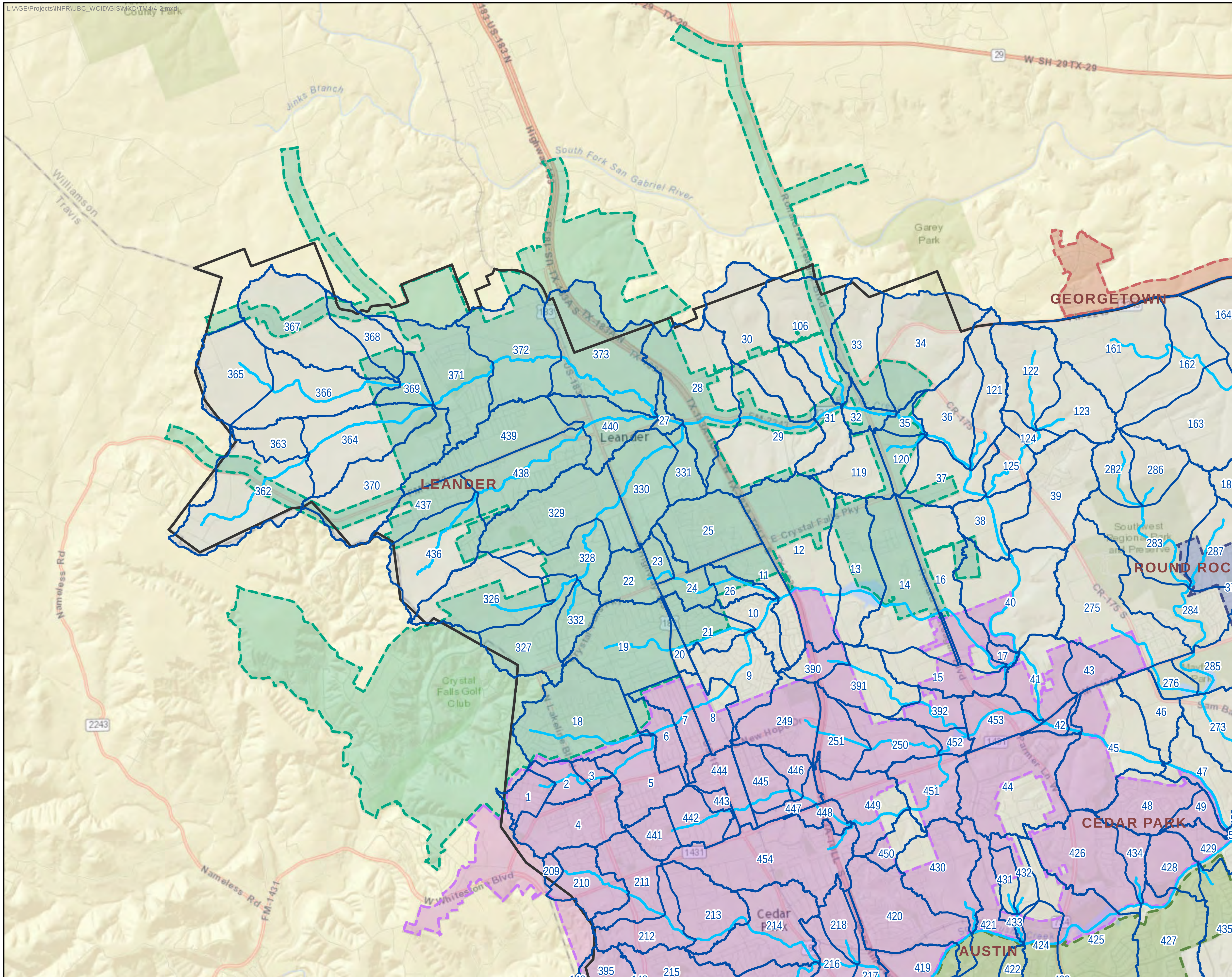
DAM #16
DAM #17
DAM #18
DAM #19
DAM #20
DAM #21
DAM #22
Brushy Creek
South Brushy Creek
Chandler Branch
Onion Branch
McNutt Creek
Cottonwood Creek
Dry Branch
Lake Creek
Rattan Creek
Georgetown
Leander
Cedar Park
Round Rock
Hutto
Taylor
Austin
Pflugerville
Manor
Williamson County
Travis County
District Dam
Dam Pool
Stream
Watershed Boundary
County Boundary
N
0
2
Miles
Upper Brushy Creek WCID
Figure ES-1
Plan Study Area
Texas Water Development Board
URS



Upper Brushy Creek WCID

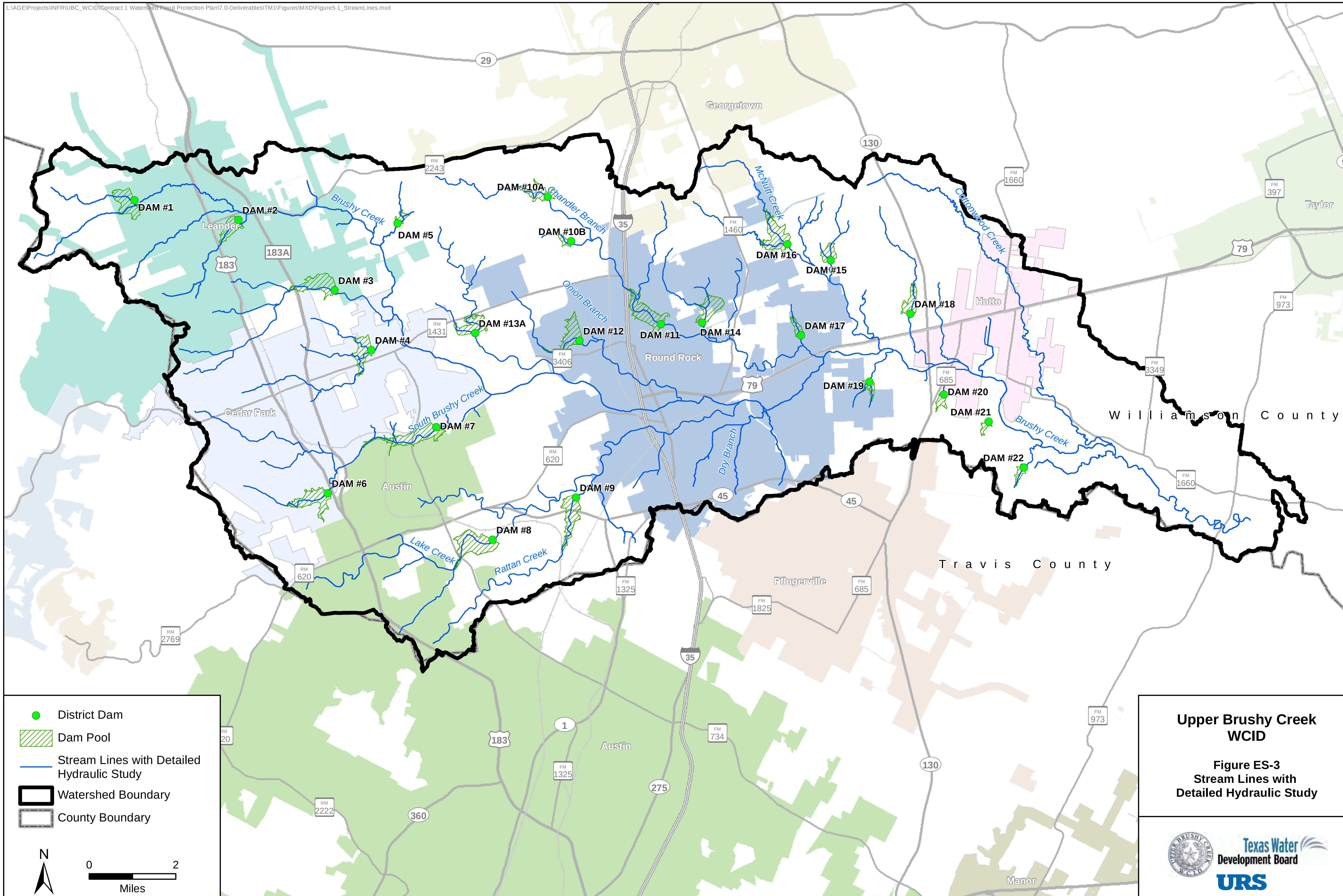
HMS Model Watershed Areas Leander

9/29/2014

Figure ES-2

Texas Water Development Board

URS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DAM #12
DAM #13A
DAM #14
DAM #15
DAM #16
DAM #17
DAM #18
DAM #19
DAM #20
DAM #21
DAM #22
Brushy Creek
South Brushy Creek
Chandler Branch
Onion Branch
McNutt Creek
Cottonwood Creek
Dry Branch
Lake Creek
Rattan Creek
Leander
Cedar Park
Georgetown
Round Rock
Hutto
Taylor
Austin
Pflugerville
Manor
Williamson County
Travis County
29
130
95
79
35
45
183
183A
1
275
360
RM 2243
RM 1431
RM 620
RM 2769
RM 2222
FM 1660
FM 397
FM 1460
FM 973
FM 3349
FM 3406
FM 685
FM 1325
FM 1825
FM 734
District Dam
Dam Pool
Stream Lines with Detailed Hydraulic Study
Watershed Boundary
County Boundary
N
0
2
Miles
Upper Brushy Creek WCID
Figure ES-3
Stream Lines with Detailed Hydraulic Study
Texas Water Development Board
URS

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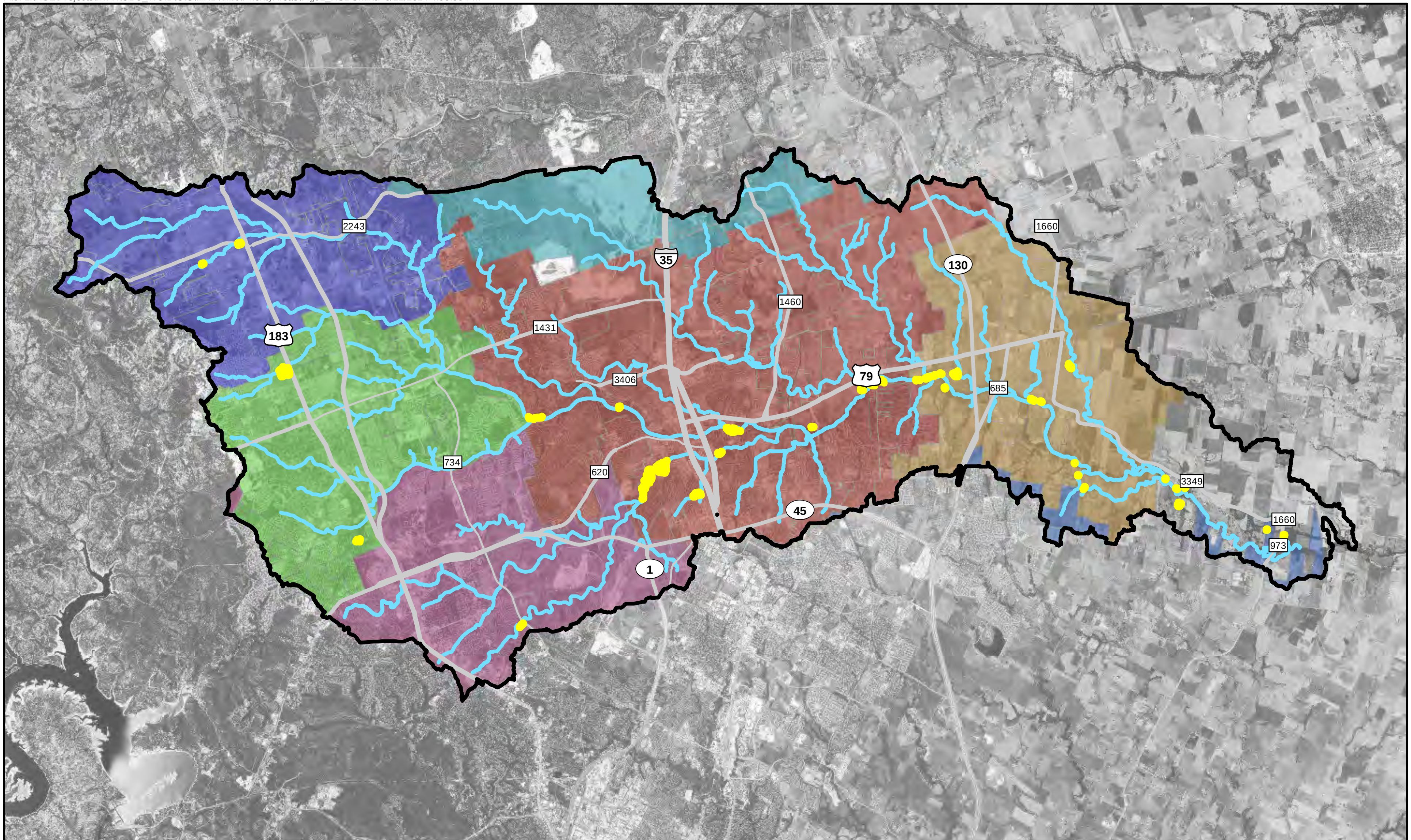


N

0 1.6 3.2 Miles

Texas Water Development Board

URS

Legend

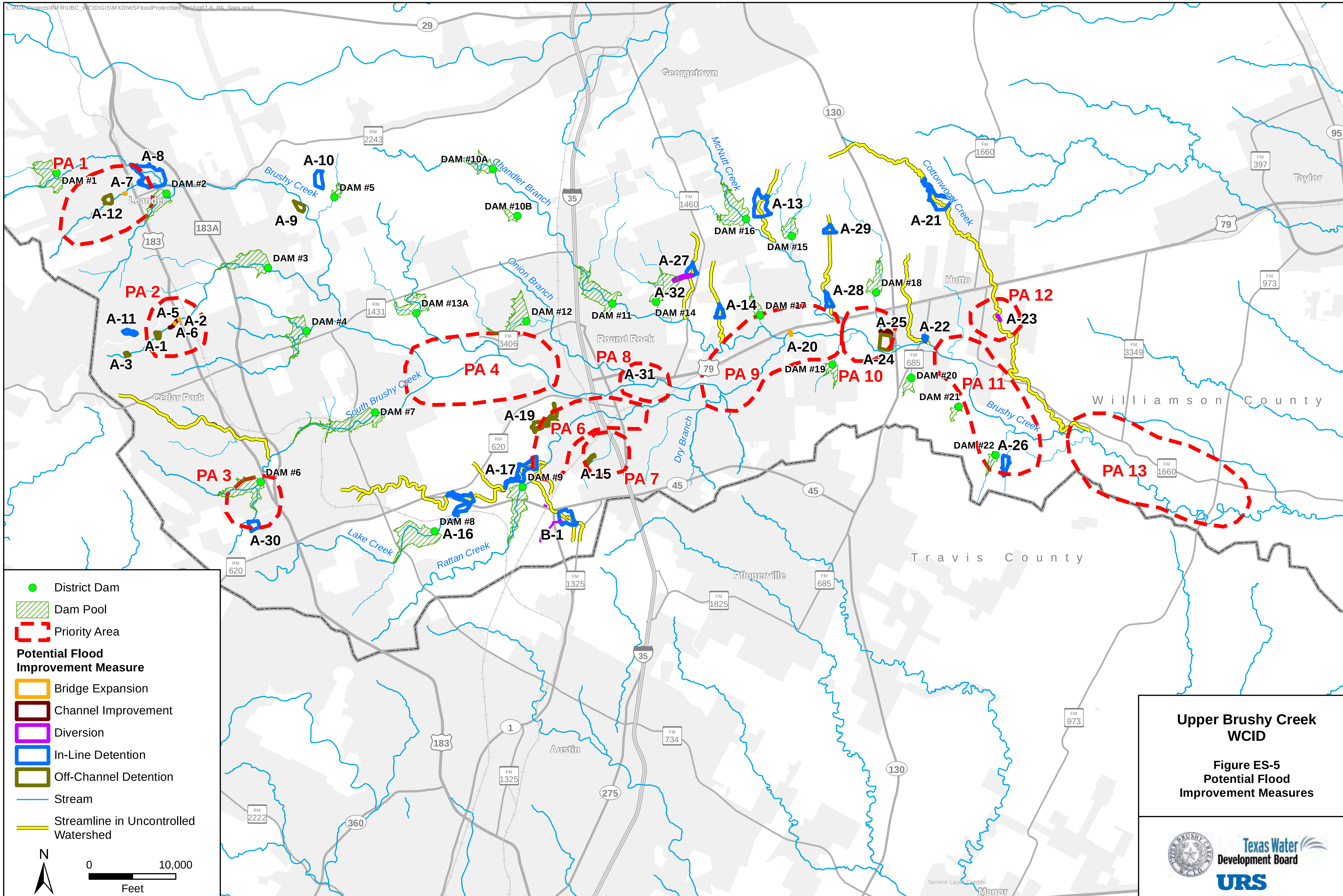
Habitable Structures Damage Center

Stream

Upper Brushy Creek WCID

Habitable Structures Damage Centers

Date: 5/12/2014	Figure ES-4



Upper Brushy Creek WCID
Figure ES-5
Potential Flood Improvement Measures
District Dam
Dam Pool
Priority Area
Potential Flood Improvement Measure
Bridge Expansion
Channel Improvement
Diversion
In-Line Detention
Off-Channel Detention
Stream
Streamline in Uncontrolled Watershed
N
0
10,000
Feet
Texas Water Development Board
URS
PA 1
PA 2
PA 3
PA 4
PA 6
PA 7
PA 8
PA 9
PA 10
PA 11
PA 12
PA 13
A-1
A-2
A-3
A-5
A-6
A-7
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A-10
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B-1
DAM #1
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DAM #18
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Brushy Creek
South Brushy Creek
Chandler Branch
Onion Branch
McNutt Creek
Cottonwood Creek
Dry Branch
Lake Creek
Rattan Creek
Georgetown
Leander
Cedar Park
Round Rock
Hutto
Taylor
Pflugerville
Austin
Manor
Williamson County
Travis County

1.0 UPPER BRUSHY CREEK WATERSHED FLOOD PROTECTION PLAN

1.1 Background

The Upper Brushy Creek Watershed Control and Improvement District (District) is located in Williamson County, Texas within an area that encompasses portions of the cities of Austin, Cedar Park, Hutto, Leander, and Round Rock (see Figure 1-1). The original district was formed by the Texas Legislature in 1956 to provide flood and erosion control within the Brushy Creek Watershed. The primary focus of the District has been operation and maintenance of 23 dams (see Figure 1-1) constructed with federal support (U.S. Department of Agriculture) in the 1950s and 1960s. The current mission of the District is to maintain and improve flood control structures within the Brushy Creek Watershed within the District boundaries and take appropriate measures to protect public safety, as well as economic infrastructure of the District, in consultation and cooperation with other governmental entities.

In furtherance of this mission, in 2011, the District applied for and received a flood protection planning grant from the Texas Water Development Board (TWDB) to develop an Upper Brushy Creek Watershed Flood Protection Plan (FPP). The study area includes approximately 187 square miles in the Upper Brushy Creek Watershed and contains approximately 139 river miles of creeks with drainage areas greater than 1 square mile. The five cities (Austin, Cedar Park, Hutto, Leander, and Round Rock) and Williamson County have endorsed the need for the FPP and have been active participants in its preparation, through participation with the two lead agencies in a Technical Advisory Committee (TAC). The TAC was formed specifically for providing input and review to the watershed flood protection planning process.

In this section, the overall structure of the FPP is described, and the initial project efforts in the identification of watershed flooding issues of concern are presented.

1.2 FPP Purpose and Organization

The purpose of the FPP is to identify existing creek flooding concerns, prioritize those concerns, propose potential alternatives for the mitigation of the highest priority concerns, develop concept designs and cost estimates for selected alternatives, and provide benefit analyses of each alternative. The FPP therefore provides flood mitigation alternatives, each with an associated concept design, cost, and benefit (relative to other alternatives). This information is provided for the benefit of the stakeholders (cities and county) within the District for consideration in development of capital improvement plans by each stakeholder. Additional benefits to stakeholders include:

- Development of improved watershed hydrologic (runoff prediction) models, consistent with current development and available recently improved topographic data; and
- Development of improved watershed hydraulic (flood elevation prediction) models, consistent with current development and available recently improved topographic data.

The FPP models are planned to form the basis for revised Federal Emergency Management Agency (FEMA) regulatory floodplain maps and were developed per *Guidelines and*

Specifications for Flood Hazard Mapping Partners, Appendix C: Guidance for Riverine Flooding Analyses and Mapping (FEMA Appendix C, 2009). This mapping process is being financially supported by FEMA, TWDB, and the District and will be completed after completion of this FPP.

The FPP is organized into the following sections, each documenting a step in the FPP development.

> Section 2, Hydrologic Modeling Methodology. Hydrologic modeling predicts the temporal pattern of runoff (flow rate versus time) for a given storm (rainfall versus time). This section provides details of the software used, parameter development methodology, and model calibration method.
>
> Section 3, Hydraulic Modeling Methodology. Hydraulic modeling predicts the water surface elevation (and associated flood plain extent) associated with the peak flow rates derived per hydrologic modeling. This section provides details of the software used, parameter development methodology, methodology for assigning flows to cross-sections, model boundary conditions, and model calibration.
>
> Section 4, Hydrologic Model Analysis and Results. This section documents the hydrologic modeling: data sources used in parameter derivation, tabular and spatial (map) summaries of parameter values throughout the watershed, graphical summary of model structure, map of model flow prediction points, model calibration results, and tabular results for the series of scenarios modeled.
>
> Section 5, Hydraulic Model Analysis and Results. This section documents the hydraulic modeling: data sources used in parameter/cross-section geometry derivation, model summary output data, model flood extents maps, and details of model calibration.
>
> Section 6, Flood Hazard Assessment. This section documents the procedure used to obtain TAC consensus approval for the plan hazard assessment method. It also provides details and results of the risk assessment method applied to habitable structures, the aggregation of habitable structures into damage centers, the aggregation of damage centers into Priority Areas (PAs), and the ranking of PAs in terms of hazard. Similarly, the section provides details and results of the risk assessment method applied to in-line structures (road crossings of flood extents: bridges, culverts, etc.).
>
> Section 7, Flood Mitigation Alternatives. This section documents: 1) the identification of flood mitigation structural alternatives to address flooding within the identified PAs; 2) the methodology used in concept design and cost estimation of these alternatives; 3) the methodology used to estimate benefits of alternatives; 4) presentation of those benefits; and 5) qualitative discussion of project prioritization for consideration by stakeholders in development of local jurisdiction (county, city) capital improvement plans.

1.3 Identification of Flooding Issues

To provide a basis for initial discussion (in 2011), URS performed brief analyses using existing data relating to these flood issues within the District:

- Dam backwater elevations versus structures;
- Road crossings versus frequency of flooding; and
- Structures in current regulatory floodplain.

URS prepared figures that relate to each of these issues. Additionally, URS conducted interviews with stakeholders prior to commencing analysis to identify key features such as detention/retention structures and new developments as well as areas of historical flooding. This section documents the initial phase of planning. All of the information presented below was assembled prior to the development of watershed hydrologic and hydraulic models (documented in Sections 2 through 5) and provides the baseline understood flooding issues at the time of start of planning.

1.3.1 Dam Backwater Elevations Versus Structures

Figure 1-2 shows dams owned by the District and divides them into three categories:

- Type A. Dams where there are structures upstream located within the flood pool (i.e., located within a contour set at the auxiliary spillway elevation);
- Type B. Dams where there are structures within the emergency flood pool (i.e., located within the area bounded by a contour set at the auxiliary spillway elevation and a contour set at the lowest top-of-dam crest elevation); and
- Type C. Dams where no structures are currently located within a contour set at the lowest top-of-dam crest elevation.

All dam elevations are based on NRCS as-built plans available on the District website.

1.3.2 Road Crossings Versus Frequency of Flooding

Figure 1-3 shows road crossings within stream reaches recently modeled by FEMA and identifies a rough frequency of overtopping associated with each structure.

1.3.3 Structures in Current Regulatory Floodplain

Figure 1-4 identifies structures in the current regulatory 100-year return period (1% Annual Exceedance Probability [AEP]) floodplain.

1.4 Stakeholder Interviews

During initial meetings with Stakeholders from each city within the district as well as Williamson County, preliminary watershed delineations were reviewed, and areas that stakeholders perceived as requiring particular attention were identified. Topics discussed with each stakeholder included:

- Watershed delineations;
- Discrepancies between past and proposed delineations;
- Additional detention/retention to consider;
- Significant storm sewers;
- Linear structures;
- High water marks; and
- Areal reduction.

The dates for each meeting held were:

Stakeholder	Meeting Date
City of Austin	12/12/2011
City of Cedar Park	12/8/2011
City of Hutto	12/15/2011
City of Leander	12/7/2011
City of Round Rock	12/6/2011
Williamson County	12/15/2011

1.4.1 City of Austin

The identified areas of particular concern listed below for the City of Austin are shown on Figure 1-5.

A. In addition to the District dams to be included in the model, the City of Austin identified the following detention structures to potentially include in the hydrologic analysis:

   1) SH45 Main Pond; and

   2) SH45 North Branch Pond.

B. Additional detail should be included in the modeling of significant structures at Tamayo Drive and Los Indios Trail.

C. At the intersection of TX 45, McNeil Road, and a railroad line, flows are diverted into a quarry, which fills and discharges uncontrolled flows to the north into Rattan Creek. For extreme flows, there is the likelihood that the railroad and/or McNeil Road may overtop.

1.4.2 City of Cedar Park

The identified areas of particular concern listed below for the City of Cedar Park are shown on Figure 1-6.

A. In addition to the District dams to be included in the model, the City of Cedar Park identified the following detention structures to potentially include in the hydrologic analysis:
   1) Twin Lakes;
   2) Bagdad Pond;
   3) LISD Pond;
   4) Wal-Mart Pond;
   5) Cedar Park Medical Center Pond; and
   6) Cedar Park Town Center Ponds.

B. Localized flooding within the Rivera subdivision.

C. Localized flooding within the Ranchettes 4 subdivision.

D. Flooding from Cluck Creek in the Ranchettes 2 subdivision (a small number of homeowners were flooded).

E. A large number of homes within Ranchettes 6 and 6A subdivisions are located within the effective 100-year floodplain for Block House Creek.

F. There is no defined channel where Post Oak Creek passes through Lakewood Country Estates.

1.4.3 City of Hutto

The identified area of particular concern listed below for the City of Hutto is shown on Figure 1-7.

A. FM 685 overtopped at Brushy Creek during Tropical Storm (TS) Hermine.

1.4.4 City of Leander

The identified issues listed below for the City of Leander are shown on Figure 1-8.

A. In addition to the District dams to be included in the model, the City of Leander identified the detention structure at Horizon Park Blvd./Gateway.

B. The First Baptist Church of Leander suffered damage from TS Hermine in 2010.

C. County Road 273 experiences frequent road closure due to backwater from NRCS Dam No. 2.

D. The Old Towne Village Detention structure was blown out by a flood event in 2004.

E. The low-water crossing at West Broade St. flooded in a major event in 2004.

F. The low-water crossing on Maple Creek Dr. upstream of NRCS Dam No. 1 has had to be closed due to flooding.

1.4.5 City of Round Rock

Identified areas of particular concern listed below for the City of Round Rock are shown on Figure 1-9.

A. In addition to the District dams to be included in the model, the City of Round Rock identified the following detention structures to potentially include in the hydrologic analysis:
   1) La Frontera;
   2) Stone Oak Inline Structure;
   3) Randall's Town Center;
   4) South Creek;
   5) Terra Vista;
   6) Eagles Nest; and
   7) Lake Forest.

B. The 620 Quarry requires detailed consideration during modeling to ensure any storage accounted for in the model is realistic. The City of Round Rock would also like to determine if a drainage easement is needed to preserve the existing storage in the quarry to prevent future downstream flooding.

C. The McNeil Quarry and the SH45/Mopac interchange need to be reviewed to determine complex split flow characteristics in this location. URS and the City of Round Rock will coordinate on the modeling of this location to ensure flow characteristics are accurately modeled.

D. For east of town, discrepancies in LIDAR elevations were observed in the preliminary HEC-RAS models.

1.4.6 Williamson County

Identified areas of particular concern listed below for Williamson County are shown on Figure 1-10.

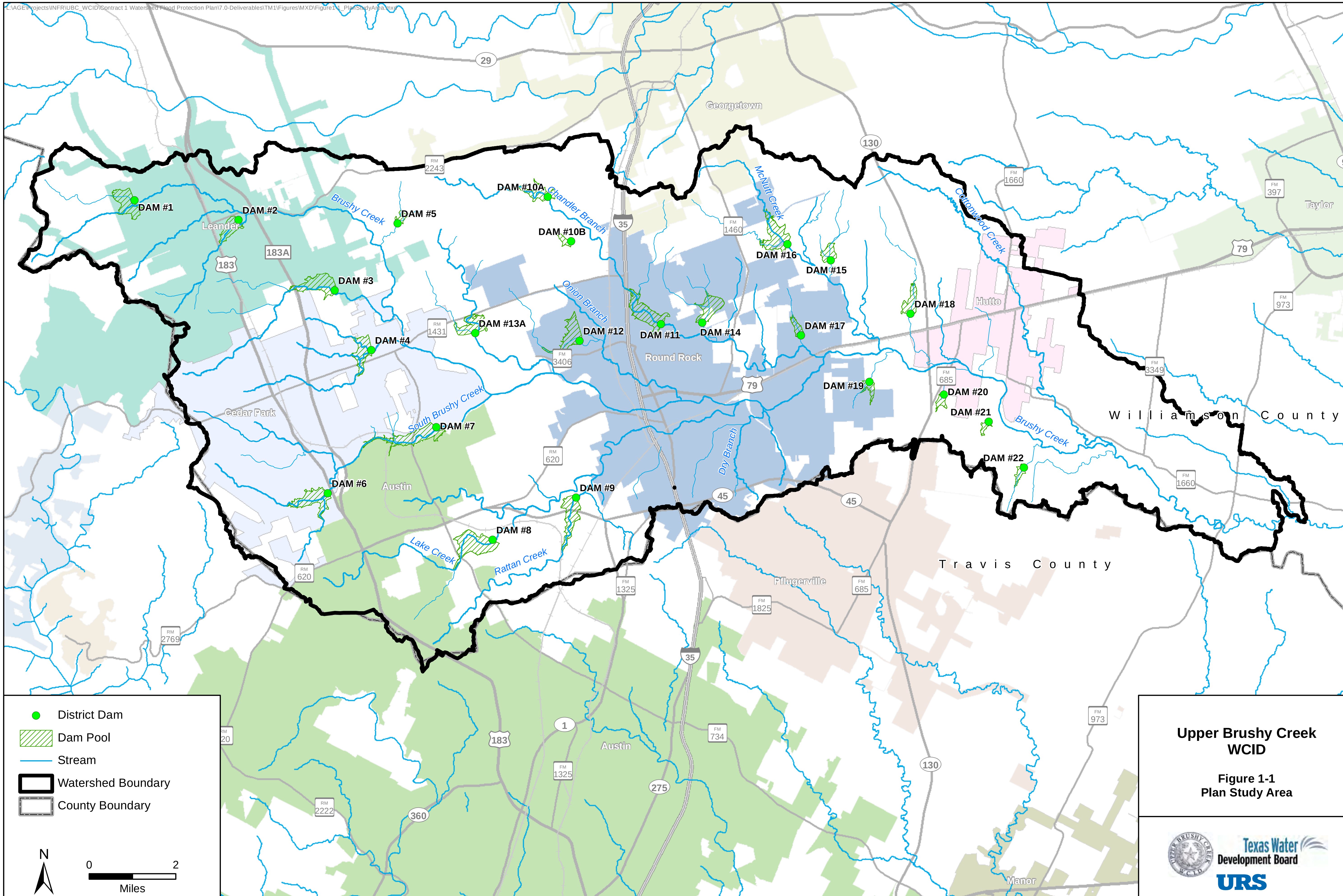
A. Houses along County Road 123 are in the Brushy Creek floodplain.

B. Regular flooding of the low-water crossing at County Road 123 and Brushy Creek Main Stem.

C. A potential additional useful flow node location at Hutto Road and McNutt Fork 1.

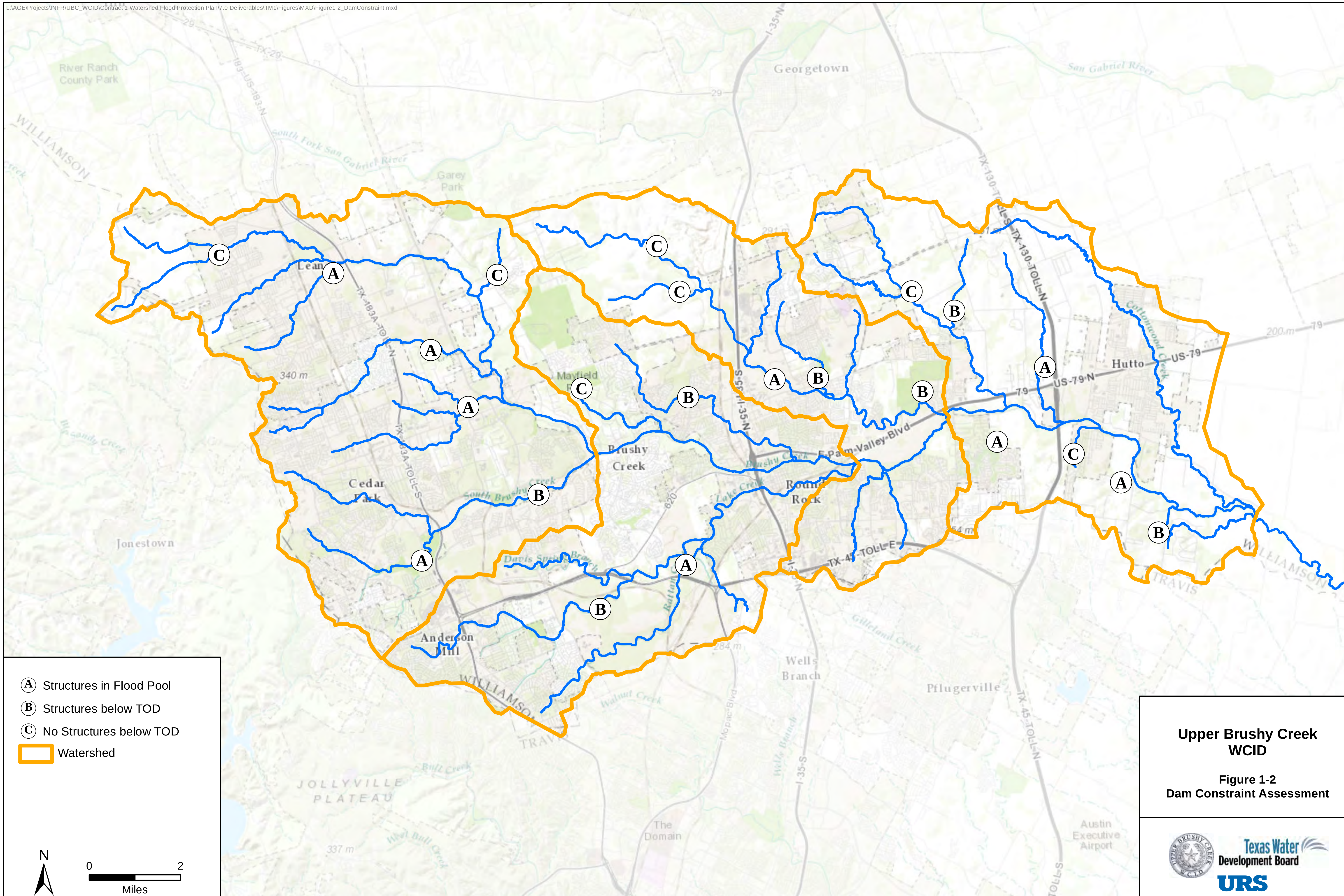
D. A potential additional useful flow node location at Limmer Loop and Brushy Creek Fork 3. Teravista Ponds should be reviewed and included in the model, if appropriate.

E. Flooding occurred during TS Hermine and a 2007 storm event along the South Fork of Brushy Creek near West Broade. Photographs and approximate high water mark elevations were provided by Williamson County.



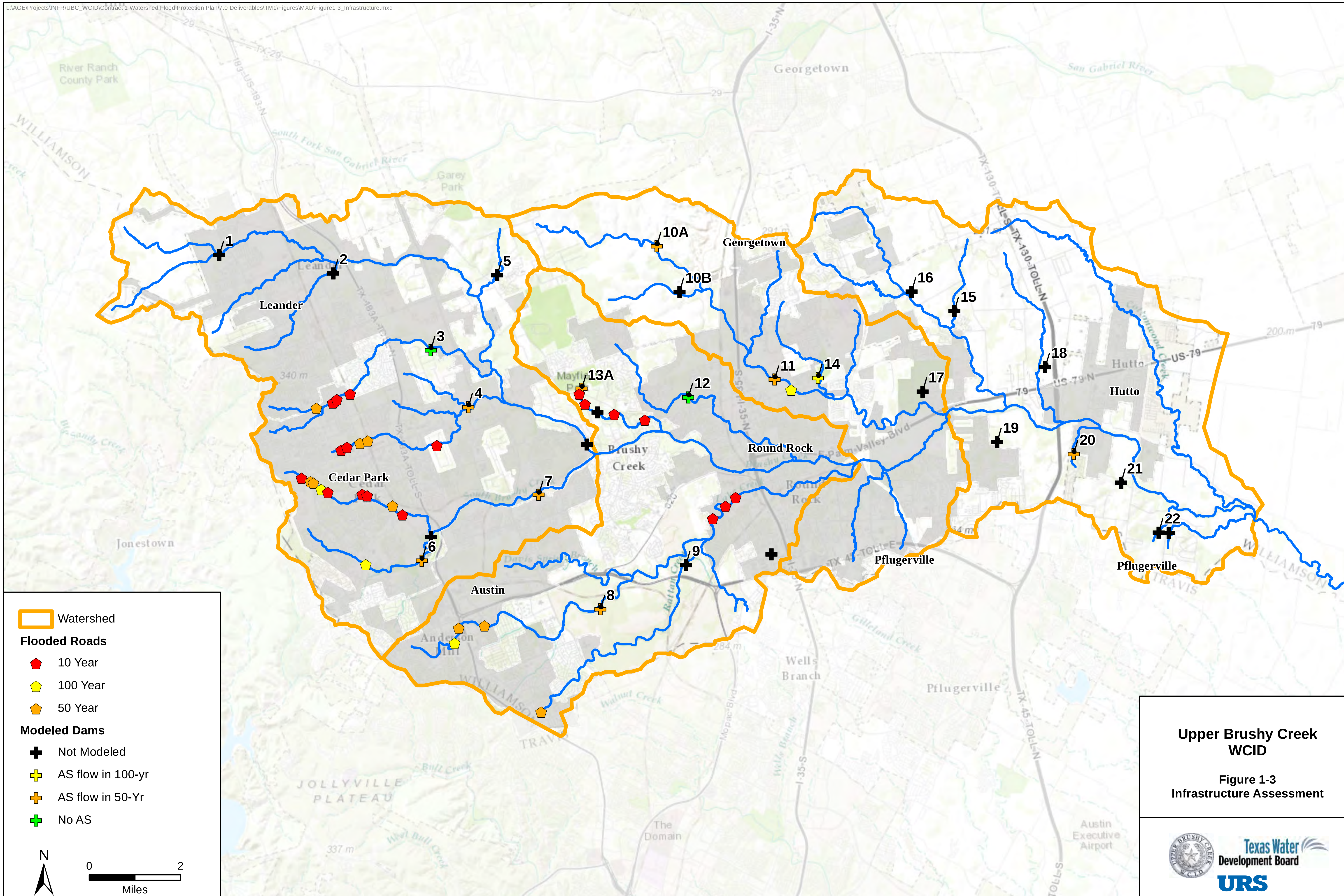
Upper Brushy Creek WCID

Figure 1-1
Plan Study Area



Upper Brushy Creek WCID

Figure 1-2
Dam Constraint Assessment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Upper Brushy Creek WCID
Figure 1-3
Infrastructure Assessment
Watershed
Flooded Roads
10 Year
100 Year
50 Year
Modeled Dams
Not Modeled
AS flow in 100-yr
AS flow in 50-Yr
No AS
N
0
2
Miles
Texas Water Development Board
URS
1
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3
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8
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10A
10B
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13A
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16
17
18
19
20
21
22
Leander
Cedar Park
Georgetown
Round Rock
Brushy Creek
Hutto
Pflugerville
Austin
Anderson Mill
Jonestown
River Ranch County Park
Garey Park
Wells Branch
The Domain
Austin Executive Airport
JOLLYVILLE PLATEAU
WILLIAMSON
TRAVIS
South Fork San Gabriel River
San Gabriel River
Gilleland Creek
Walnut Creek
Bull Creek
West Bull Creek

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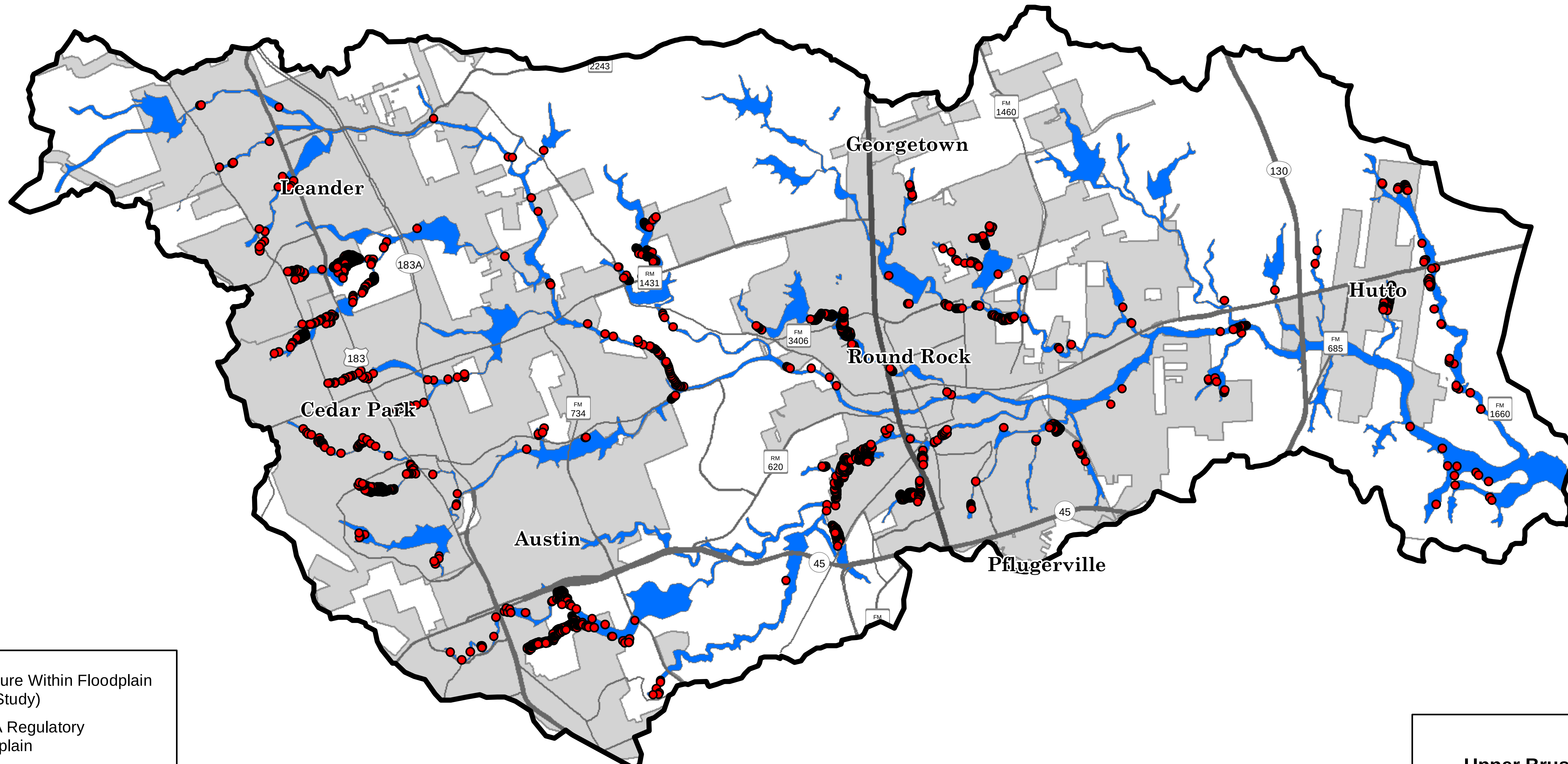


Structure Within Floodplain (Pre-Study)

FEMA Regulatory Floodplain

1590 Structures Within Pre-Study Regulatory Floodplain

N

0 2

Miles

Upper Brushy Creek WCID

Figure 1-4
Floodplain Structure Assessment

Texas Water Development Board

URS

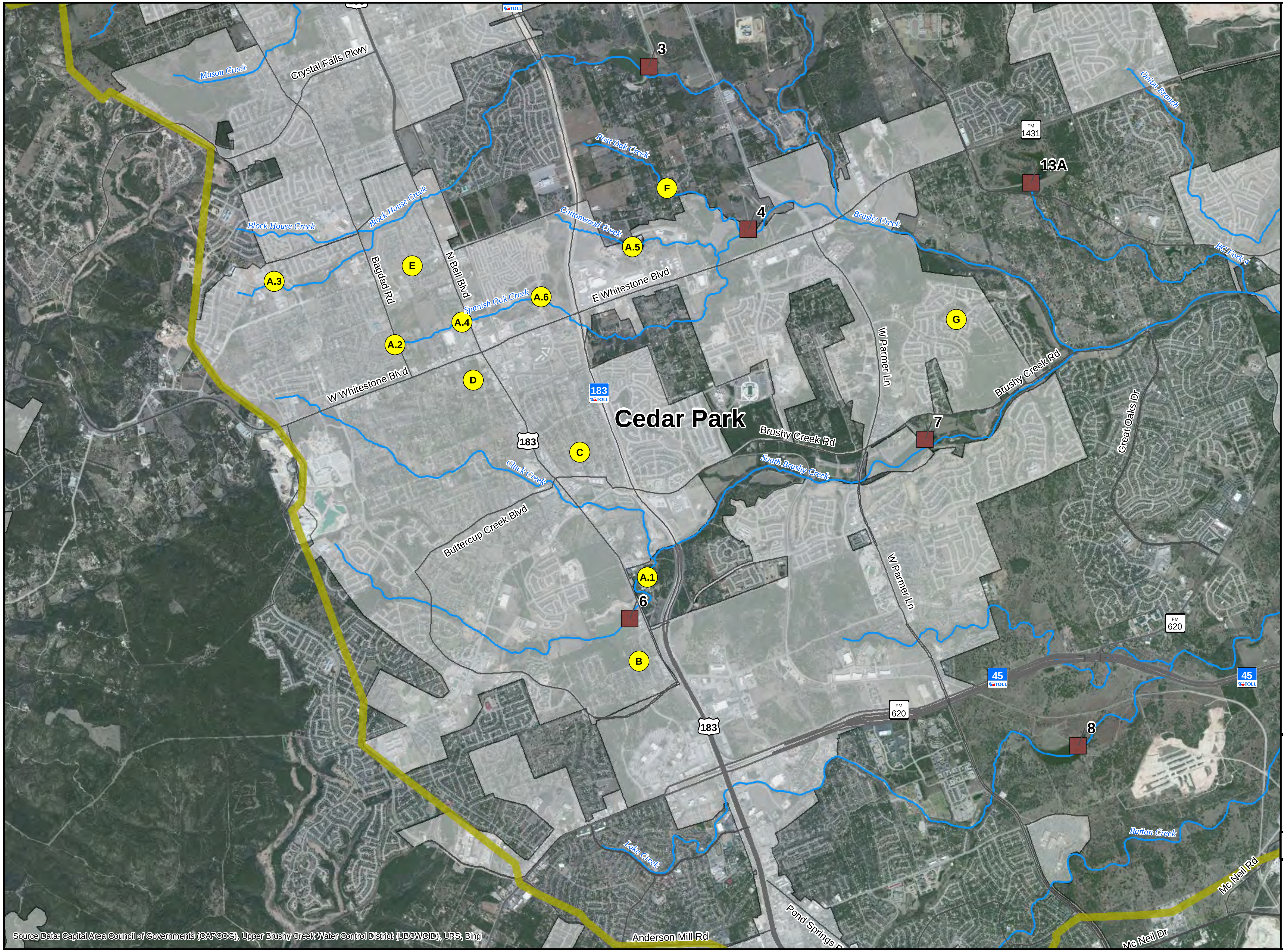
Upper Brushy Creek WCID

City of Austin
Identified Areas
for Particular Concern

Date: 3/18/2012	Figure 1-5

Texas Water Development Board

URS



Legend

- A Identified Issue
- District Dam
- Stream
- City Boundary
- Upper Brushy Creek WCID Taxing Boundary

OVERVIEW MAP

N

0 2,000 4,000

SCALE IN FEET

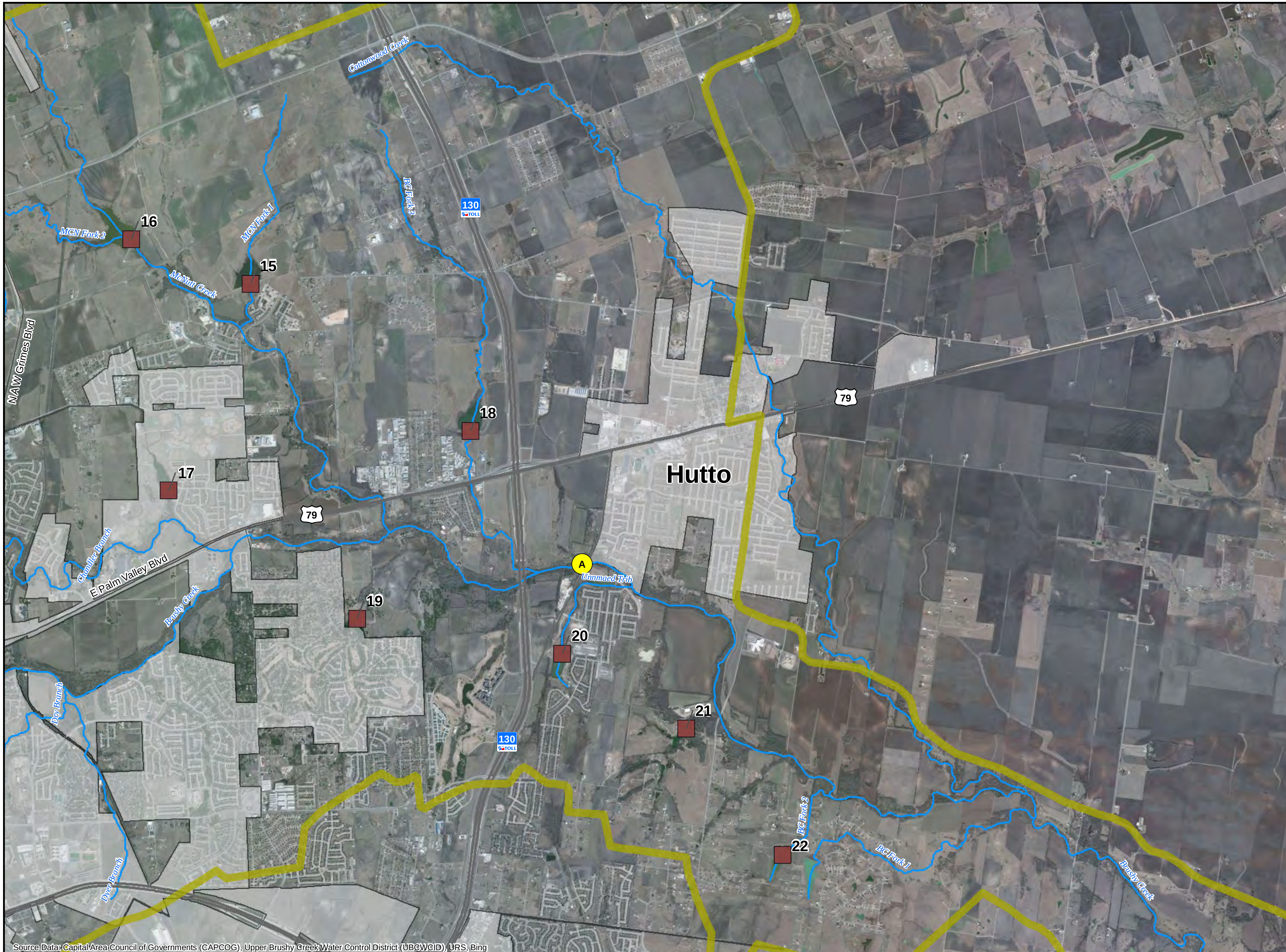
Upper Brushy Creek WCID

City of Cedar Park
Identified Areas
for Particular Concern

Date: 3/18/2012	Figure 1-6

Texas Water Development Board

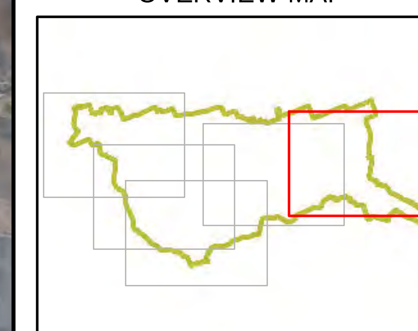
URS



Legend

- A Identified Issue
- District Dam
- Stream
- City Boundary
- Upper Brushy Creek WCID Taxing Boundary

OVERVIEW MAP



N

0 2,000 4,000

SCALE IN FEET

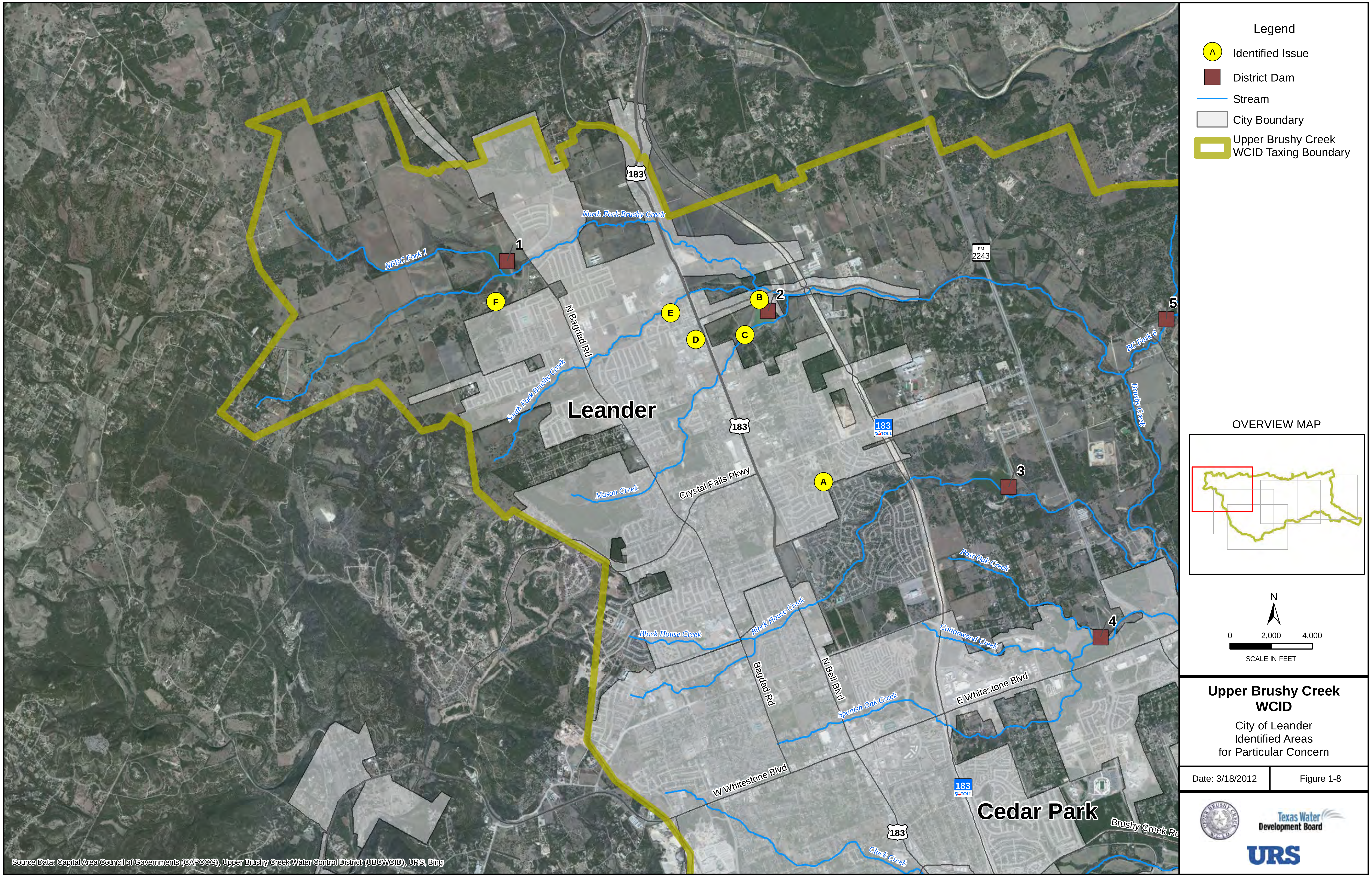
Upper Brushy Creek WCID

City of Hutto
Identified Areas
for Particular Concern

Date: 3/18/2012	Figure 1-7

Texas Water Development Board

URS



Upper Brushy Creek WCID

City of Leander
Identified Areas
for Particular Concern

Date: 3/18/2012 | Figure 1-8

Texas Water Development Board
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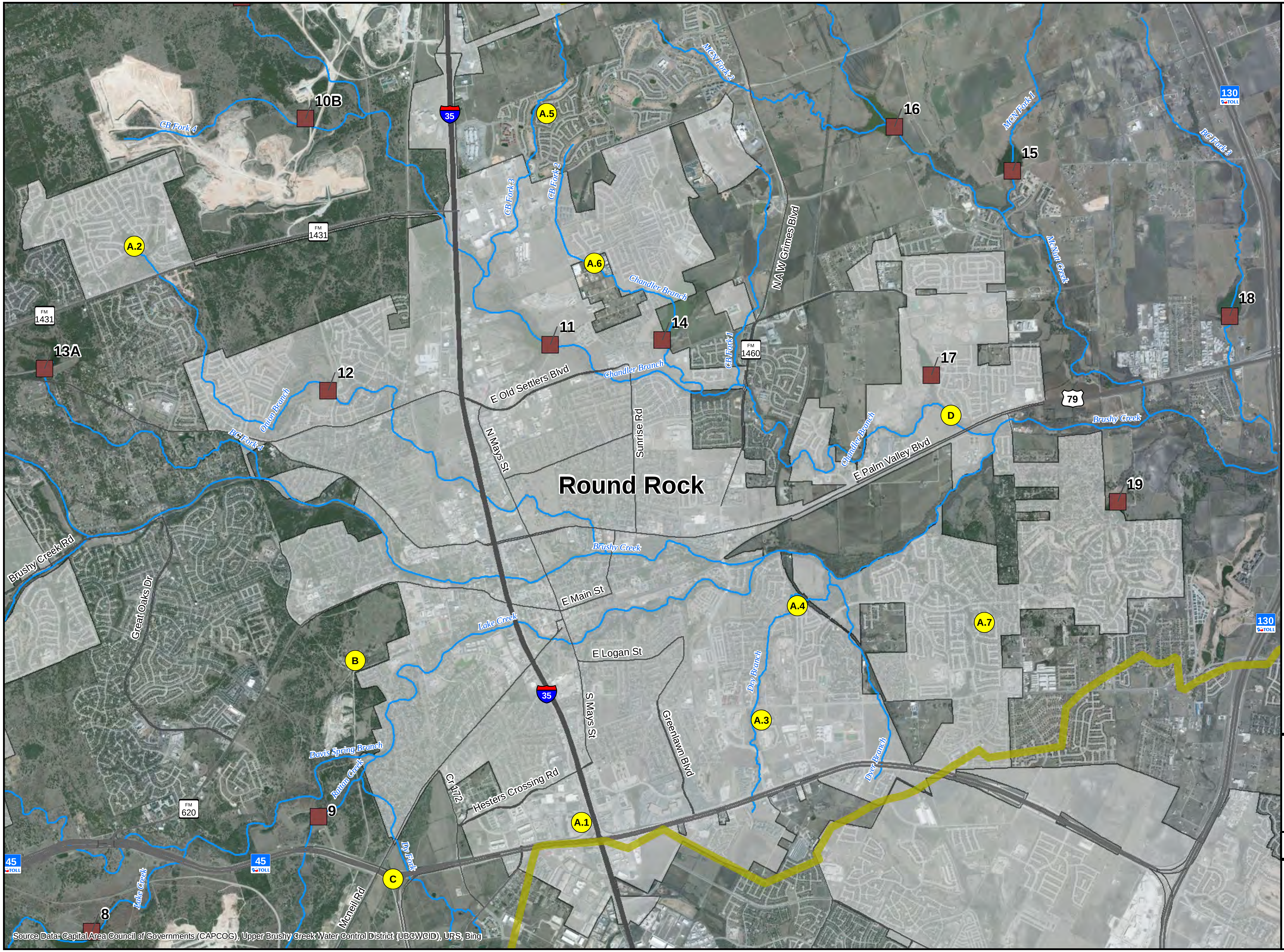

Legend

- A Identified Issue
- District Dam
- Stream
- City Boundary
- Upper Brushy Creek WCID Taxing Boundary

OVERVIEW MAP

N

0 2,000 4,000

SCALE IN FEET

Upper Brushy Creek WCID

City of Round Rock
Identified Areas
for Particular Concern

Date: 3/18/2012 | Figure 1-9

Texas Water Development Board

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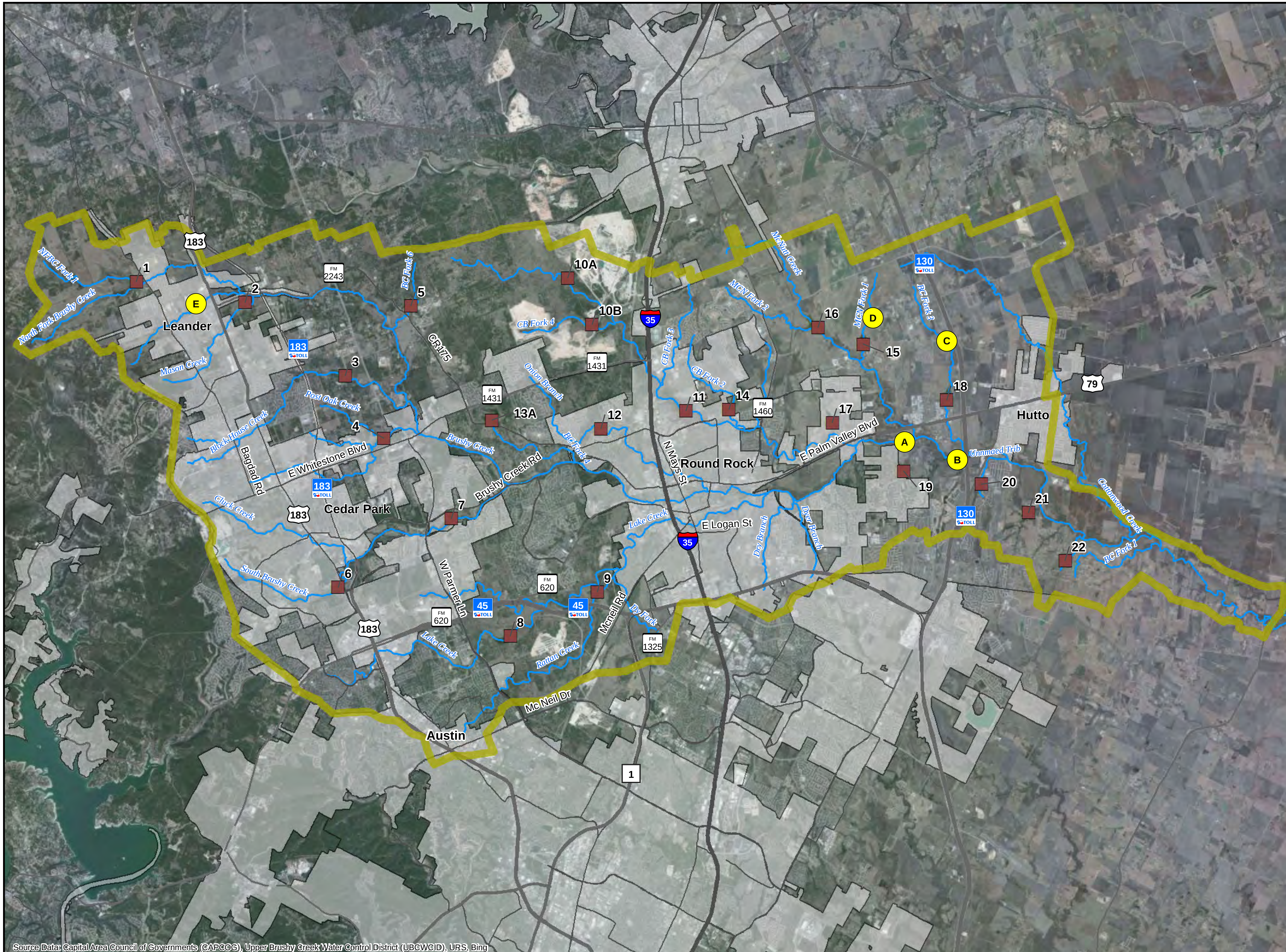


Legend

- A Identified Issue
- District Dam
- Stream
- City Boundary
- Upper Brushy Creek WCID Taxing Boundary

N

0 1 2

SCALE IN MILES

Upper Brushy Creek WCID

Williamson County
Identified Areas
for Particular Concern

Date: 3/14/2012	Figure 1-10

Texas Water Development Board

URS

Chapters 2 - 6 not provided
to reduce online file size

7.0 FLOOD MITIGATION ALTERNATIVES

7.1 Task Summary

Previous sections have addressed:

- Hydrologic modeling;
- Hydraulic modeling; and
- Risk assessment/ identification of PAs to be addressed by future flood mitigation measures.

The FPP goals, as noted in Section 1, include identification of flood mitigation measures that address priority flooding issues within the watershed. This plan focuses on structural improvements (dams, channels, bridge crossings) which can be included in stakeholder (city, county) capital improvement plans. This section includes information which can be used by these stakeholders to prioritize and budget for these improvements within the larger context of their project funding. This section also demonstrates benefits associated with each project in terms of mitigation within regional flood concern PAs. This will facilitate coordination and cooperation between stakeholders when benefits of a flood mitigation measure are substantial within multiple jurisdictional boundaries, or when achieving the desired benefit means a flood mitigation measure needs to be built in an upstream jurisdiction to mitigate flooding concerns in a downstream jurisdiction.

This FPP does not address non-structural improvements (public education, refinements in providing early warning, regulatory changes, etc.). The District and TWDB recognize the importance of these measures, and local stakeholders are encouraged to consider such measures in the context of stormwater planning within each of their relevant individual jurisdictions. The District has been very proactive in facilitating early warning of floods within the District boundaries by: 1) having installed real-time stage and rainfall gages on 22 District dams and several flow gages on streams within the District, and 2) posting gage readings in real time on the District website.

Section 7 details development and assessment of structural flood mitigation alternatives within the study watershed. The tasks documented within this section include:

- Development of alternatives to address flooding in PAs;
- Sizing and costing of each alternative;
- Estimation of benefits in terms of a FS reduction for each alternative and combination of alternatives; and
- Prioritization of alternatives.

7.2 Development of Alternatives

This section describes the development of regional or local structural alternatives for the mitigation of flooding within the 13 PAs. Non-structural alternatives (e.g., home buyouts) or structure-specific measures (e.g., house-specific finished floor raises or floodproofing) are not addressed here.

Flooding within the Upper Brushy Creek Watershed is largely controlled by existing dams maintained by the District (see Figure 7-1). These dams, all located on tributaries to the Brushy Creek main stem, each perform a major function: each dam detains most (if not all) of the 1% AEP flood (100-year flood) within its flood pool, reducing peak floods entering the flood pool to minor flow levels passed through a low level outlet. The flooding within 13 PAs identified in the flood risk assessment analysis (see Figure 7-1) can all be mitigated by one of more of the following regional or local projects:

- Construction of in-line detention (i.e., the full stream line is intercepted) within a watershed not currently controlled by a District dam;
- Improvement of undersized or inefficient drainage structures at a road crossing;
- Construction of off-channel detention to reduce peak flows within an adjacent stream line; or
- Channel improvements and construction of diversion channels.

Opportunities for siting these types of structures were identified, per the following method.

7.2.1 Identification of Undersized/ Inefficient Road Crossing Drainage Structures

Hydraulic model profiles identify PA damage centers located within the backwater of a downstream bridge/culvert, where bridge/culvert modification could potentially reduce upstream flooding. Three structures appeared to potentially negatively impact flood levels in PAs in a substantive manner: U.S. 183 and Peach Tree Lane crossings of Blockhouse Creek (PA2 in Figure 7-1) and Red Bud Lane crossing of Brushy Creek (PA10 in Figure 7-1).

7.2.2 Identification of Potential Sites for In-Line Detention

The watershed HEC-HMS model results were reviewed to identify Brushy Creek tributaries that lacked flood detention structures (i.e., those stream lines not controlled by District dams). Figure 7-2 provides a summary of 100-year (existing condition) flow rate increases along roughly 32 miles of creek length through the study area. This figure shows:

- 100-year flow increasing from 5,600 cfs to over 56,000 cfs through this creek length; and
- For each major tributary, there is an incremental jump in peak flow rate as each tributary adds flows to the main stem. The larger incremental jumps (from upstream to downstream) are associated with Onion Branch (2,400 cfs); Lake Creek (6,000 cfs); Dry Branch (4,000 cfs); Chandler Branch (6,000 cfs), McNutt Creek (5,000 cfs), and Cottonwood Creek (9,000 cfs)

Figures 7-3, 7-4, and 7-5 provide similar diagrams of 100-year flows within Chandler Branch, McNutt Creek, and Lake Creek, each of which are partially controlled by District dams.

For each of these tributaries:

- The topography was reviewed for a potential flood-retarding structure site on a stream line (i.e., a state-regulated dam would be built across the stream, configured in a manner similar to existing District dams);
- The approximate maximum flood detention volume for that site was estimated;
- The effect of this detention on watershed flood flows was estimated; and
- If the available detention was found to significantly reduce flood flows, the site was retained for presentation to and consideration by the District and TAC stakeholders.

Figures 7-2 through 7-5 show the reductions initially estimated to be potentially achievable with construction of detention along these uncontrolled tributaries.

7.2.3 Identification of Potential Sites for Off-Channel Flood Detention

In certain subbasins of the watershed, e.g., where the watershed is highly urbanized or where there are no apparent opportunities for significant flood reduction by interception of tributary flow, off-channel detention was considered. Off-channel detention differs from "Regional Detention" (on-channel) described above in that:

- A stream line is not completely blocked by a dam;
- A low, non-regulatory, three-sided embankment basin is built adjacent to the stream, with flood pool storage augmented by excavation; and
- A diversion channel from the stream to the basin has the channel engaging (i.e., intercepting flow) only in major floods.

This type of structure has the advantage of scalping peak flows significantly in the immediate area downstream of the point of diversion and storage, with a relatively small flood pool. The significant cost associated with controlling the state regulatory dam safety flood is avoided. The structures, however, yield progressively less significant reductions in flow peak as flow proceeds downstream. Benefits from structures sited adjacent to the upper reaches of Brushy Creek (where a small off-channel basin can significantly reduce peaks) are insignificant in the lower reaches of the main stem.

Three PAs were identified to have very limited options for flood mitigation by regional detention, and off-channel detention sites were investigated for each:

- PA1 (Leander);
- PA2 (Cedar Park); and
- PA4 (Round Rock).

7.2.4 Identification of Potential Sites for Mitigation Channels

The hydraulic model flood profiles for the channel adjacent to and immediately downstream of PAs were reviewed to look for opportunities where channel improvements or diversions could potentially lower flood WSELs. In particular, these situations were noted:

- Channels that had been narrowed historically by substantial fills into the natural floodplain;
- PAs located on the outer bank of a channel bend, with undeveloped land within the area adjacent to the inner bank: i.e., an opportunity for diversion of a portion of high-stage flows across the bend; and
- Locations where a short diversion channel could divert flood flows into the flood pool of an existing District dam. This option was only considered where substantive 100-year flood pool capacity was available at the existing dam (i.e., the 100-year flood level was well below the dam's auxiliary spillway).

7.2.5 Selection of Sites for Analysis

The tentatively identified sites for stream crossing improvements, regional detention, and off-channel detention were presented to stakeholders in a series of individual meetings with each stakeholder (City of Round Rock, City of Austin, City of Hutto, City of Leander, City of Cedar Park, Williamson County) during the period October 16 to 25, 2013. Each of these meetings included a review of each site, with the rationale for site selection and a description of potential benefits of the site for flood mitigation. Sites were deleted, added, or generally relocated per discussions with stakeholders. Sites selected for analysis during these meetings were not intended to reflect exact structure locations, but were intended to be representative locations, which under analysis, would result in representative structure sizes, costs, and associated flood mitigation benefits of a structure in the vicinity of the selected site.

The sites selected for analysis during these meetings are presented in Figure 7-6 and are summarized in Table 7-1.

7.3 Description of Alternatives Development Methodology

The detailed methodology for development of alternatives varied by type of mitigation method considered. Each method included these general tasks:

- Identification of site constraints (e.g., maximum elevations of dam backwaters that would not impinge on existing structures);
- Sizing of structure to achieve maximum flood mitigation benefit within site constraints;
- Layout of basic structure configuration on existing topography to estimate rough materials quantities; and
- Concept design-level cost estimation.

7.3.1 In-Line Detention Structures

7.3.1.1 Estimation of Constraints

The types of constraints that were estimated varied depending on the type of project being analyzed. In all, the constraints included:

- *Total runoff volume during the 1% AEP storm.* This volume was estimated by use of the existing HEC-HMS watershed model. The existing model subwatershed was truncated to the location of the dam site and run to estimate this volume. This volume was the preferred flood pool volume for the site.
- *Upstream storage structures.* In some cases, alternative sizes for proposed detention upstream/downstream on the same tributary (e.g., proposed sites A-16 and A-17, and proposed sites A-29 and A-30) were considered to identify the best combination of structure sizes.
- *Thalweg elevation at proposed dam sites.* This elevation determined, once the dam elevation for needed storage was estimated, whether the dam would be regulated per TCEQ dam safety regulations.
- *Primary maximum WSEL allowable before structural or roadway flooding.* This elevation set the maximum allowable 100-year WSEL in the dam backwater (with or without flow through the auxiliary spillway).
- *Secondary and tertiary maximum WSELs allowable before structural or roadway flooding.* These are alternative constraints should the primary constraint be addressed by flood protection, relocation, buyout, etc.
- Potential flood pool volume for the primary through tertiary elevation constraints were each estimated and compared to preferred flood pool volume.

The constraints for each in-line structure site are shown in Table 7-2.

7.3.1.2 Sizing of In-line Structures

The siting and sizing of the embankments and associated spillways were performed using a simplified design methodology for all sites except sites A-16 and A-17. For these two sites, a more detailed analysis of each site and sizing of spillways was performed.

Simplified Concept Design

In the simplified design, the following procedures were followed, and basic design assumptions were made:

- A dam embankment trace was sited consistent with site topography.
- An elevation-volume relationship for the storage volume impounded by the dam embankment was developed from most current LiDAR.
- The sediment pool (and associated principal spillway elevation) was estimated using engineering judgment at each site, depending on site topography. In each case, the principal spillway was several feet above the toe of the upstream embankment.
- The principal spillway was sized to be a 30-inch- or 60-inch-diameter pipe, whichever size best fit site performance goals.

- The auxiliary spillway elevation and width were set such that the 100-year flood elevation (with or without auxiliary spillway flow) stayed below the defined site constraining elevation in Table 7-2.
- The top of dam was set at the auxiliary spillway elevation plus 5 feet to provide an emergency pool for safe passage of the dam safety regulatory flood. This is a conservative (i.e., high estimate) differential for small watershed dams. In some cases, where top of dam elevation was constrained, initial PMF analyses were performed that allowed the top of dam to be set at a lower elevation.
- SITES (small watershed dam design software) was run to set final spillway elevations and dimensions.
- The resulting embankment configuration was laid out in Civil 3D with assumed upstream and downstream embankment slopes of 3 horizontal to 1 vertical. Materials quantities were derived from this analysis.

In particular, an assumption was made that for these small watershed structures, auxiliary spillway channels would be sufficiently wide and flat to preclude breach of the grass surface and subsequent headcutting though the auxiliary spillway crest, leading to dam failure. This condition would require a major (costly) structure (sheetpile wall, drilled piers) to prevent this occurrence. As existing, similar or larger district dams lack such structures, this appears to be a reasonable assumption.

<u>Concept Design of Sites A-16 and A-17</u>

Sites A-16 and A-17 required significantly more detail in concept design than the other sites, for the following reasons:

- The watershed to be controlled by these new structures was substantially larger (over 10 square miles) than other proposed sites;
- The site constraints greatly restrained design, as existing structures and environmental concerns limited flood pool volume to significantly less than the preferred 100-year flood volume;
- The two sites and their associated flood backwaters are primarily located within the property of a single landowner, and as an incentive to the landowner, the flood pools were sized to include added runoff from upstream development; and
- Because of the close proximity of the impounded creek (Lake Creek) and an adjacent creek (Rattan Creek), the hydrologies of the two creeks were intertwined in the state dam safety flood, with auxiliary spillway discharge from the existing Dam 9 spilling into Lake Creek, while auxiliary spillway discharge from the proposed A-17 discharges into Rattan Creek.

These two sites required more detailed analyses than were performed for the other sites, notably:

- The HEC-HMS model was adjusted to assume "ultimate development" (per the City of Austin definition) of the site owner's full property extent upstream of the dam sites;

- A wide variety of principal spillway sizes and configurations and auxiliary spillway sizes and configurations were considered in the analysis of each dam; and alternatives were considered for construction of one dam or both dams;
- A detailed PMF analysis was performed; and
- Sizing of a labyrinth weir was estimated using current methods, the projected PMF flows, and identified site constraints.

Dam A-17 is presented in Exhibit S in two variations, as a smaller dam (A-17) intended to be constructed in tandem with Dam A-16, and as "Site A-17 Expanded," which is be constructed without Dam A-16.

7.3.1.3 Estimated Construction Cost of In-Line Structures

The estimated costs for each in-line structure were based upon the following methods and assumptions:

- Materials quantities for cuts and fill for the embankment and concrete volume for the labyrinth spillways were developed, as noted above, in Civil 3D. Unit costs for structural concrete were per a recent rehabilitation design performed by URS for Calaveras Creek Site 10 (Bexar County). Unit costs for excavation and embankment fill were taken from the 12-month moving average low bid values provided by TxDOT, updated March 31, 2014.
- Costs for principal spillway installation and other project elements were average costs per URS' recent NRCS structure design experience.
- The following contingency costs were added based upon initial construction costs: 30% for construction contingency, 10% for design contingency, 5% for permitting, 8% for construction oversight, and 5% for geotechnical work.
- The latter four contingencies were applied to construction cost after application of the 30% construction contingency.
- Land cost is not included.

7.3.2 Off-Channel Detention Structures

7.3.2.1 Estimation of Constraints

The primary constraints at each site were: 1) the available surface area for the off-channel detention, 2) the lowest feasible bottom elevation, and 3) the maximum allowable water surface elevation (set by the need to have a positive slope from the point of diversion). These three allowed for estimation of the maximum storage volume available at each site. Table 7-3 provides these factors for the proposed off-channel detention structures and for the project to expand in-line detention within the existing Leander High School (LHS) ponds, which was designed in a similar manner as the off-channel structures, because this design also involved an embankment of non-regulatory height.

7.3.2.2 Sizing of Off-Channel Structures

These structures were sized per the following method:

- A hydrograph was developed from the watershed plan HEC-HMS model for the point of diversion into the storage;
- A stage-discharge relation for the HEC-RAS cross-section at the point of diversion was extracted from the watershed plan HEC-RAS model;
- A spreadsheet estimating flow into a lateral weir adjacent to the stream was developed;
- The weir elevation and length were varied by trial and error until the volume of flood water withdrawn from the peak of the stream flow hydrograph equaled the available storage volume at the off channel site; and
- The off-channel storage was assumed to have a low-level outlet for costing purposes, but flow from this outlet was assumed to be too minor to add back into the stream hydrograph downstream of the storage. A high-flow bypass spillway would be needed to control return of extreme flood flows back to the stream.

7.3.2.3 Construction Costs

The estimated costs for each off-channel structure (and the LHS pond expansion) were based upon similar methods to those described for in-line structures. Cost for the lateral weir returning flow to the stream is not included in the estimate.

7.3.3 Road Crossing Improvements

The project constraints, concept design methodology, and cost estimation for construction for road crossing improvements necessarily had to be tailored specifically to each of the three project sites. These are discussed in the individual project descriptions in Exhibit S.

A common methodology was used for all three sites within alternatives analysis for estimating flood depths at structures upstream of each crossing, and this method is described below.

Estimating Finished Floor Elevations (FFEs). FFEs were estimated using the spatial analyst tool to calculate the average 2012 LiDAR elevation under each structure's footprint. These average elevations were then increased by 0.5 foot to account for an average foundation thickness, yielding a final FFE for each habitable structure included in the analysis. If modifications to a bridge produced water surface elevations below this FFE estimate, the habitable structure was considered removed from the floodplain.

Interpolating Depths at Structures. Rather than generate a new flood depth grid for each modification, the HEC-RAS cross-section output elevations were used to interpolate water surface elevations at structures between cross sections. To interpolate the water surface elevation at each habitable structure, the stationing of each structure was estimated along the stream line. This station was used to linearly interpolate the water surface elevation between bounding cross sections for the 2-, 10-, 25-, 50-, 100-, and 500-year storm events. The estimated

FFE was then subtracted from this water surface elevation to estimate the depth of flooding and the FS for each habitable structure.

7.3.4 Channel Improvements and New Diversions

The project constraints, concept design methodology and cost estimation for construction of improved and new channels necessarily had to be tailored specifically to each of the three project sites. These are discussed in the individual project descriptions in Exhibit S.

7.4 Summary of Alternatives Designs

7.4.1 In-Line Detention Structures

Table 7-4 provides a summary of the basic dimensions and estimated costs for the new in-line detention structure alternatives. A description and site layout for each of these structures is provided in Exhibit S.

7.4.2 Off-Channel Detention Structures

Table 7-5 provides a summary of the basic dimensions and estimated costs for the new off-channel detention structure alternatives. A description and site layout for each of these structures is provided in Exhibit S.

7.4.3 Road Crossing Improvements

Table 7-6 provides a summary of the basic dimensions and estimated costs for the new road improvement alternatives. A description and site layout for each of these structures is provided in Exhibit S.

7.4.4 Channel Improvements/New Diversions

Table 7-7 provides a summary of the basic dimensions and estimated costs for the channel improvement alternatives. A description and site layout for each of these structures is provided in Exhibit S.

7.5 Summary of Benefits Analysis

7.5.1 Procedure for Estimating Project Benefits

Benefits provided by projects were estimated as either reduction in Habitable Structure Flood Score, or prevention of a priority In-line Structure Damage Center (ISDC, i.e. road crossing) from overtopping.

7.5.1.1 Procedure for Estimating Changes in Flood Score Due to Projects

To estimate improvements in the FS associated with the construction of each of the projects, the following tasks were performed:

- Each structure within the existing condition 0.2% AEP (500-year) flood was assigned an FFE. This task was performed in the risk assessment process described in Section 6.
- Each structure was assigned to the nearest HEC-RAS cross-section.
- Each structure, per the FPP hydraulic analysis performed for Section 6, has a depth over FFE versus flow rate for 2-, 5-, 10-, 25-, 50-, 100-, and 500-year existing floods and 100-year ultimate flood. These were based upon depth grids that account for topographic changes between cross-sections. This provides a rating curve (depth of flooding above FFE versus flow) at each structure.
- Given the above, a revised FS associated with a particular alternative would be estimated by:
    - Estimating the flow changes throughout the watershed HEC-HMS model associated with the flood improvement alternative;
    - Assigning changed flows to each hydraulic model cross-section per the method described in Section 5;
    - Each structure would be assigned the flow rates associated with its assigned HEC-RAS cross-section;
    - The revised FS at each structure would be estimated by:
        - Taking the new 50-, 100-, and 500-year flow rates and using the structure-specific rating curve to get revised depth of flooding over FFE at each structure; and
        - Using the FS equation documented in Section 6 to estimate a revised FS; and
    - The total reduction in FS associated with each alternative would be aggregated by summing the watershed-wide improvements in FS associated with each structure.

7.5.1.2 Procedure for Estimating Benefits to In-Line Structure Damage Centers

As part of the procedure to estimate flood risks associated with ISDCs, Table 6-9 was developed with 100 priority ISDCs (road crossings). For each of these ISDCs, the flow overtopping the crossing during the 50-year (2% AEP) and 100-year (1% AEP) floods were extracted from HEC-RAS model results. Given this table, the procedure to estimate when an alternative lowered flows below an overtopping threshold is as follows:

- The overtopping flow for each event for each ISDC was subtracted from the total flow at each ISDC for each event to estimate the “threshold” flow at which the ISDC would not overtop for each event;
- Predicted 50- and 100-year flood flows associated with each alternative were assigned to each ISDC; and
- If the predicted flow at an ISDC for an alternative was less than the threshold flow for an event, the alternative was credited with preventing overtopping of that ISDC during that event.

7.5.2 Benefits Associated with Combinations of Detention Structures

The in-line structures are designed to detain most if not all of the 1% AEP (100-year) flood and are expected to have measurable benefits for a significant reach downstream, to include, when built together with other projects, the Brushy Creek main stem. A series of combinations of alternatives were modeled and FS estimated. These combinations were chosen from the large number of potential combinations, using the following insights:

- PA6 along Lake Creek was unique within the District in that it had large numbers of structures at risk (i.e., had a large FS) and was associated with a tributary that lacked regional detention on a significant portion of the watershed. One or two projects had the ability to significantly reduce FS.
- Other PAs with large FS sited along the main stem of Brushy Creek could not have the FS feasibly reduced to the same extent as PA6 because of the lack of available sites that would control as significant a portion of the uncontrolled full Brushy Creek watershed. The necessary strategy for addressing these PAs is to add detention at multiple sites where smaller tributaries are currently uncontrolled.
- Detention sited to address PAs located well upstream along tributaries (e.g., PA2 along Blockhouse Creek, PA7 along Lake Creek Tributary 6) are located so far upstream from the PAs along the Brushy Creek main stem as to have minimal benefits as part of a regional plan to reduce flows in Brushy Creek. Detention to address these isolated upstream PAs are evaluated individually and discussed in the next section.

The conclusion from these insights was that the few projects that addressed PA6 were clearly going to have the greatest impact in FS reduction. Since these projects also potentially provided significant reduction to flow in Brushy Creek below the Lake Creek junction, these projects serve to reduce FS at PAs below the junction.

The logic for the assembly of regional detention structure combinations therefore followed this logic:

- The Lake Creek detention projects would be constructed first;
- The next detention sites would be constructed along the furthest upstream tributaries within the watershed, since the benefits of each were expected to extend downstream through the full length of the Brushy Creek main stem (further upstream stream projects had the greater length of benefits along Brushy Creek). For this reason, projects were added to alternatives in this order:
    - Projects on tributaries of Chandler Creek;
    - Projects on tributaries of McNutt Creek; and
    - Projects on tributaries of Cottonwood Creek.

Table 7-8 provides a summary of each alternative considered, the projects that make up each alternative, and the tributary watershed with increased detention associated with each alternative. The reductions in flow profile associated with the alternatives in Table 7-8 are presented in

Figures 7-7 through 7-11 for Lake Creek, Chandler Branch, McNutt Creek, Cottonwood Creek, and Brushy Creek main stem, respectively. These alternatives and the associated FS are summarized in Table 7-9 for both the entire watershed and individual PAs.

The aggregate numbers of structures with floodplain improvements are provided for the individual scenarios in Table 7-10, for the three floods used in calculating FS. For instance, Alternative 1, in the 100-year flood, reduces the base flood elevation of 44 structures by over a foot.

The numbers of structures in 50-, 100-, and 500-year flood plains are shown in Table 7-11, for each of the modeled scenarios. The structures are counted in the entire watershed and within the individual PAs.

7.5.3 Benefits Associated with Other Alternatives

Table 7-12 shows the FS for Blockhouse Creek (PA2) under existing conditions and with the proposed detention projects affecting that creek. Table 7-12 also shows that the proposed project for South Brushy Creek (PA3) provides minimal improvement in FS.

Table 7-13 shows flood depth reductions associated with proposed projects on Blockhouse Creek for three different flood levels. Table 7-14, in comparison to Table 7-13, provides a summary for Blockhouse Creek of the numbers of structures currently within the floodplain adjacent to the creek.

The channel alternatives A5, A25, and A31 were found to have FS reductions of 36, 0.5, and 3.4, respectively. The channel alternative A23 was found to have minimal benefits.

The road crossing project A2 was found to have a FS reduction of 32.7.

7.5.4 Benefits associated with Flood Improvements at Road Crossings

Table 7-15 provides a summary of the results of the analysis described in Section 7.5.1.2. The suite of plan alternatives addresses overtopping at these structures for these events.

For the 50-year flood, Oak Drive (Lake Creek) is removed from the floodplain by A17 expanded alone. Alternatives 1 through 8 remove Red Bud Lane (Brushy Creek) and Burnet St. South (Lake Creek) from the floodplain. Alternatives 1, 7, and 8 remove CR164 (Cottonwood Creek) from the floodplain. Alternative 8 removes FM 2243 (South Brushy Creek) from the floodplain.

For the 100-year flood, Oak Drive (Lake Creek) is removed from the floodplain by A17 expanded with either Dam 9 Diversion project. Alternatives 1, 7, and 8 remove CR164 (Cottonwood Creek) and Hwy 79 (Cottonwood Creek) from the floodplain. Alternative 8 removes FM 2243 (South Brushy Creek) from the floodplain.

7.6 Project Prioritization

The projects presented in this plan, if implemented, will be funded and implemented under a wide variety of mechanisms. It is expected that individual projects will be incorporated into capital improvement planning of the individual stakeholders (five cities, one county). In this section, a common approach is applied to prioritizing all projects within the planning region. This approach has not been defined to conform to capital project prioritization methods used by the individual stakeholders.

Benefits in terms of FS reduction have been estimated by project in Section 7.5, and cost per project is documented in Exhibit T. Given this information, projects are prioritized generally by a common yardstick: the cost per unit FS reduction, or the cost of the project divided by the difference between the current condition FS minus the post-project condition FS. This yardstick is applied somewhat differently between: 1) the series of detention projects that are conceived to work in tandem to reduce flooding on lower creek main stems, and 2) the remaining projects that are targeted to address flooding issues in the immediate vicinity of each project.

Table 7-16 provides a summary of costs by project used in prioritization. The documentation for these costs is provided in Exhibit T.

7.6.1 Prioritization of Detention Projects

The cost per unit reduction in FS for each alternative is shown in Table 7-17. Note that the alternatives were designed to progressively add detention from upstream to downstream within the Brushy Creek Watershed. Table 7-17 also provides a cost per unit reduction in FS for the incremental new FS reduction associated with the addition of new detention relative to a defined "base" case. For example, when Site A-16 is added to the Dam 9 Diversion project (Option 1), the cost per unit FS reduction for the two projects combined is $202,000 per unit reduction, while the cost per unit FS reduction for the incremental reduction associated with the addition of Site A-16 is $376,000. This allows for prioritization of competing projects that control the same watershed. Results per watershed are discussed below.

7.6.1.1 Controls in Lake Creek Watershed

The choice between the two options for the Dam 9 Diversion project hinges on this discussion:

- Option 1 (which diverts more flow into the Dam 9 flood pool) reduced peak flow in Rattan Creek by 200 to 300 cfs more than Option 2, with associated additional reductions in FS; and
- Option 2 (which avoids construction of a costly additional diversion channel into the Dam 9 flood pool) is much more cost effective ($79,000 per unit FS reduction versus $92,000 per FS reduction).

Given that the added diversion channel (C5) associated with Option 1 has potential significant issues affecting feasibility (see Exhibit S), Option 2 appears to be the most favorable of the two options.

The choice between the options for control of Davis Spring (A16, A17, A16 and A17, or A17 Expanded) is relatively straightforward, with A17 Expanded providing equivalent benefits for less cost.

The choice between which of the two major improvements to construct first and whether to construct the second improvement after the first hinges on this discussion:

- Dam 9 Diversion Option 2 (hereafter just called Dam 9 Diversion) is much less expensive than A17 Expanded and is sited with fewer environmental permitting and cost uncertainties. The project appears feasible to design and construct in the short term, while the cost of A17 and its site complexities make it more feasible in the long term.
- Dam 9 Diversion resolves a long-standing drainage issue where existing flood protection is provided by temporary structures (quarry and temporary levee).
- A17 Expanded alone (per Table 7-10) appears to have very similar benefits in terms of numbers of houses with flood depths that are lowered as the same project with the Dam 9 Diversion added. Per Table 7-11, however, following construction of A17, 33 houses remain in the 100-year floodplain. This number is reduced to 14 with the addition of the Dam 9 Diversion. The depth reductions associated with the 19 houses removed by the addition of the Dam 9 Diversion range from less than 0.1 foot (for 10 houses) to between 0.1 and 0.4 foot (for nine houses).
- Per Table 7-15, the two projects (A17 Expanded and Dam 9 Diversion) are required to remove Oak Creek Blvd. from overtopping during the 100-year flood.

7.6.1.2 Controls in Chandler Branch Watershed

Alternatives 2 and 3 address new controls in the Chandler Branch Watershed. Both achieve the same incremental additional FS reduction, but Alternative 2 is more cost effective.

7.6.1.3 Controls in McNutt Creek Watershed

Alternatives 4, 5,and 6 address new controls in the McNutt Creek Watershed. Alternatives 5 and 6, which add on to Alternative 4, provide minimal new reduction in FS and have very high incremental costs.

7.6.1.4 Controls in Cottonwood Creek Watershed

Alternative 1 adds new controls in the Cottonwood Creek Watershed. Alternative 7, which adds new controls for McNutt Creek to Alternative 1, has a very high incremental cost for minor improvement.

7.6.1.5 Controls in Upper Brushy Creek Main Stem

Alternative 8 is the only alternative that addresses FS above the junction of Lake Creek with Brushy Creek. The alternative results in a small FS reduction at an incremental cost similar to Alternative 1 or 4.

7.6.1.6 Summary

Per the discussion above, the most cost-effective prioritizing of alternatives associated with combined regional detention are, in order:

- Site A-17 Expanded with or without Dam 9 Diversion and associated project elements (Site B-1), with construction of Dam 9 Diversion preceding A17 by several years;
- Alternative 2 (Sites A-14 and A-32);
- Alternative 4 (Site A-13); and
- Alternative 1 (Site A-21).

Table 7-18 provides a prioritization of regional projects per the discussion above.

7.6.2 Prioritization of Other Projects

The cost per unit reduction in FS for alternatives not associated with region-wide combined detention is shown in Table 7-19. Each of these projects is concept designed to perform alone. In terms of cost effectiveness, these projects can be prioritized as follows:

- Site A-2 is clearly the most effective improvement to Blockhouse Creek flooding within PA2.
- Site A-15 achieves significant reduction in FS, but the cost is not yet estimated.
- Site A-11 is also designed to improve flooding in PA2. The site may provide significant incremental added reduction in FS above that provided by Site A-2, but these two projects have not been assessed in combination.

The other projects in Table 7-19 appear to have high costs for minor improvements or high relative costs when compared to competing projects.

Table 7-20 provides a prioritization of standalone projects per the discussion above.

Table 7-1. Identified Potential Mitigation Actions

ID	Actions	Priority Areas to be Mitigated
A-1	Off-channel detention	2
A-2	Bridge crossing improvement	2
A-3	Expansion of existing detention storage	2
A-4	Secondary Spillway at Dam 6	3
A-5	Channel improvement	2
A-6	Bridge crossing improvement	2
A-7	Bridge crossing improvement	1
A-8	New in-line storage	4, 8, 9, 10, 11,13
A-9	Off channel storage US of CR177	4, 8, 9, 10, 11,14
A-11	Expansion of existing detention storage	2
A-12	Off-channel detention	1
A-13	New in-line storage	10, 11
A-14	New in-line storage	9, 10
A-15	New in-line storage	7
A-16	New in-line storage	6
A-17	New in-line storage	6
A-19	New in-line storage	6
A-20	Bridge crossing improvement	9
A-21	New in-line storage	12
A-22	New in-line storage	11
A-23	New diversion channel	12
A-24	Off-channel detention	10, 11
A-25	Channel expansion	10, 11
A-26	Upgrade existing dam	11, 13
A-27	New in-line storage	9, 10
A-28	New in-line storage	10, 11
A-29	New in-line storage	10, 11
A-30	New in-line storage	2
A-31	Channel Improvement	8
A-32	New diversion channel	9, 10

Table 7-2. Summary of Site Constraints

New Dam	1% AEP (100-Year) Water Surface Elevation Constraint	Top-of-Dam Elevation Constraint	
	Constraint	Constraint	Constraint Elevation (ft-msl)
A-13	None	Unnamed Road to West	725
A-14	None	None	
A-16	TX 45 West Frontage	TX 45 West	808
A-17	Saddle at SE flood pool	Quarry to NE	775
A-17 Expanded	None	Dam 9 Aux Spillway	786
A-21	House	None	
A-27	None	AW Grimes Blvd	
A-28	CR-110	CR-110	
A-29	None	None	
A-30	None	Ridgeline Blvd/Houses	947

Table 7-3. Constraints

Alternative	Description	Drainage Area (acres)	Total Runoff Volume (acre-ft)	Approx Detention Area (acres)	Lowest Bottom Elevation	Bottom Constraint	Max. WSEL	Max. WSEL Constraint	Max. Water Depth (ft)
Constraints for Off-Channel Detention									
A-1	New Blockhouse and Trib 1 Detention	1428	763	7.3	975.0	DS stream bed elevation	986.0	S Bagdad Rd.	11
A-3	Existing LISD Detention Expansion:								
	a) Maintain existing detention volume on channel.	201	113	1.4	1010.0	Existing outlet structure	1017.0	N Lakeline Blvd	7
	b) Add new off channel storage.		113	2.6	1010.0		1021.0	Parking lot to west	11
A-12	New Broade Street Detention	1035	404	17.1	980.0	DS stream bed elevation	995.0	1 House to west	15
Constraints for Improvements to In-Line Detention									
A-11	Modify Leander HS Ponds: a) Maintain existing US pond. b) Modify existing DS pond.	345	194	11.0	994.0	Invert elevation at existing culvert	1001.9	Outlet of existing upstream detention	7.9

Table 7-4. Data Summary for In-Line Detention

New Dam	Dam			Watershed Above New Dam		Principal Spillway (PS)		Auxiliary Spillway (AS)				Flood Pool			
	Thalweg at Dam (ft-msl)	Top-of-Dam Elevation (ft-msl)	Height of Dam (ft)	Total Area (acres)	Uncontrolled Area (acre)	Crest Elevation (ft-msl)	Conduit Size	Elevation	Type	Dimensions	100 yr WSEL over AS Crest (ft)	100 yr WSEL (ft-msl)	Storage at PS (ac-ft)	Storage Volume at AS (ac-ft)	Area of Flood Pool at 100-Year WSEL (ac)
A-13	698.8	725	26.2	1130	1130	707	60	720.2	Earthen	Width: 400'	0	720.2	8	363	59
A-14	688.1	706.4	18.3	408	408	695	60	703	Earthen	Width: 200'	0	703.0	5	99	25
A-16	782.7	808	25.3	8009	2641	788	60 x (4)	803	Labyrinth	Cycles: 10, Magnification: 4.95	0	802.7	5	425	65
A-17	751.2	774	22.81	8912	903	756	60 x (4)	770.1	Labyrinth	Cycles: 13, Magnification: 4.95	0	770.1	10	338	82
A-17 Expanded	751.2	786	34.81	8912	3544	756	60 x (3)	775.2	Concrete	525'	0	775.1	10	744	101
A-21	672.2	701	28.8	1800	1800	678	60	696	Earthen	Width: 300'	0	696.0	1	642	88
A-27	730.1	750.6	20.5	442	442	740	30	747.5	Earthen	Width: 200'	0	747.5	30	214	34
A-28	637.2	660.3	23.1	786	786	642	60	655.3	Concrete	Width: 250'	1.53	656.8	1	101	22
A-29	719.7	735.7	16	185	185	728	30	733.4	Earthen	Width: 200'	0	733.2	17	79	17
A-30	920.4	946.7	26.3	69.8	69.8	926	60	938.2	Concrete	Width: 100'	2.55	940.8	0	48	12

Table 7-5. Data Summary for Off-Channel Detention

Alternative	Description	Drainage Area (acres)	Detention Area (acres)	Lowest Bottom Elevation	Bottom Constraint	Top-of-Dam Constraint Elevation	Top-of-Dam Constraint	Max. Water Depth (ft)	Max Volume Estimate (acre-ft)	Inlet Description	Inlet Dimensions	Outlet Description	Note
A-1	New Blockhouse and Trib 1 Detention	1428	7	977.0	DS stream bed elevation	986.0	S Bagdad Rd.	9.0	63	1) Weir on south stream. 2) Weir on north stream.	1) Weir width: 20', Crest elevation: 982.4' 2) Weir width: 20', Crest elevation: 982.4'	Outlet located west past confluence. Needs flap gate.	Not regulated by TCEQ
A-3	Existing LISD Detention Expansion	201											No PMF. Existing outlet could be lower, allowing for the bottom of the pond to be lowered as well. Existing inlet west of pond may need to be relocated.
	a) Maintain existing detention volume on channel (3a).		1	1009.7	Existing outlet structure	1017.5	N Lakeline Blvd	7.8	11	Existing inlet structure	Inlet invert: 1013.83'	Existing outlet structure, new weir to off channel detention (3b).	
	b) Add new off channel storage (3b).		4	1009.0	Connection to existing outlet	1020.0	Parking lot to west	11	40	Weir from on channel detention (3a)	Weir width: 20', Crest elevation: 1014.5'	New outlet to on channel detention (a). Flag gate needed.	
A-12	New Broade Street Detention	1035	17	980.0	DS stream bed elevation	996.0	1 House to west	16	274	Weir on south side	Weir width: 20', Crest elevation: 990.4'	Outlet downstream	Not regulated by TCEQ
A-22	Trib 7 Pond	64											
A-24	Off-Channel Storage near Dam 18	1847											

Table 7-6. Summary of Road Improvements

Alternative	Description	Recommended Solution	Cost
A-2 U.S. 183	U.S. 183 causes significant flooding upstream. Recommended to lower and widen the channel with addition of two 8'x10' box culverts.	Two concrete box culverts (10 ft x 8 ft)	$ 1,669.52
		Structural excavation (box)	$ 3,495.85
		Cutting and restoring pavement	$ 3,517.36
		Channel excavation	$ 9,205.95
A-2 Peach Tree Lane	Removing low-water crossing does not improve local flooding. No proposed action.	NA	NA
A-20 Red Bud Lane	Considered alternatives do little to lower the 500-yr floodplain, causing high flood scores. No proposed action.	NA	NA

Table 7-7. Data Summary for Channel Improvements

Description	Length (ft)	Bottom Width (ft)	US Invert (ft-msl)	DS Invert (ft-msl)	Slope (ft/ft)	Excavate (cy)	Fill (cy)	Net Excavation (cy)	Cost Estimate	Notes
Blockhouse Channel Improvement	1,400	150	972	965.04	0.5%	16,300	200	16,100	$1,478,000	Requires the buy-out of houses.
Cottonwood Channel Improvement	630	70	629	626	0.6%	1,600	100	1,500	$336,000	
Dam 18 Channel Modification	2,000	20	619.7	610.1	0.4%	5,600	100	5,500	$446,000	
Chandler Branch Trib 4 Diversion	1,750	20	737.2	733.67	0.2%	1,700	7	1,694	$855,000	Requires riprap basin at DS end.

Table 7-8. Summary of Combined In-Line Detention Alternatives

													Added Controls on Creek:			
	D9 Div	**A16**	**A17**	**A17 Exp**	**A14**	**A27**	**A13**	**A29**	**A28**	**A21**	**A32**	**A12**	**Lake Creek**	**McNutt Creek**	**Chandler Branch**	**Cottonwood Creek**
Existing Conditions																
Dam 9 Div, Opt 1	X												X			
Dam 9 Div, Opt 2	X												X			
A17 Expanded				X									X			
A16, Dam 9 Div, Opt 1	X	X											X			
A16, A17, Dam 9 Div, Opt 1	X	X	X										X			
A17 Expanded, Dam 9 Div, Opt 1	X			X									X			
Alternative 2	X	X	X		X						X		X		X	
Alternative 3	X	X	X		X	X							X		X	
Alternative 4	X	X	X		X	X	X						X	X	X	
Alternative 5	X	X	X		X	X	X	X					X	X	X	
Alternative 6	X	X	X		X	X	X	X	X				X	X	X	
Alternative 1	X	X	X		X	X	X			X			X	X	X	X
Alternative 7	X	X	X		X	X	X	X	X	X			X	X	X	X
Alternative 8	X	X	X		X	X	X			X		X	X	X	X	

Table 7-9. Reductions in Flood Score by Alternative

	D9 Div	A16	A17	A17 Exp	A14	A27	A13	A29	A28	A21	A32	A12	Flood Score Per TM6									
													Entire Watershed	**PA 1**	**PA 4**	**PA 6**	**PA 8**	**PA 9**	**PA 10**	**PA 11**	**PA 12**	**PA 13**
Existing Conditions													**509***	**4.5**	**18.8**	**167.3**	**10.4**	**76.5**	**40.8**	**38.3**	**3.6**	**53.3**
Dam 9 Div, Opt 1	X												426	4.5	18.8	88.4	10.4	76.5	40.9	38.3	3.6	53.3
Dam 9 Div, Opt 2	X												444	4.5	18.8	103.6	10.4	77.0	41.0	38.4	3.6	53.4
A17 Expanded			X										364	4.5	18.8	34.9	10.4	73.9	39.9	38.0	3.6	52.4
A16, Dam 9 Div, Opt 1	X	X											374	4.5	18.8	39.7	10.4	76.1	40.6	38.2	3.6	53.1
A16, A17, Dam 9 Div, Opt 1	X	X	X										349	4.5	18.8	19.8	10.4	74.1	40.0	38.1	3.6	52.6
A17 Expanded, Dam 9 Div, Opt 1	X			X									350	4.5	18.8	20.7	10.4	74.1	40.1	38.1	3.6	52.6
Alternative 2	X	X	X		X						X		339	4.5	18.8	19.8	10.4	71.8	38.0	37.2	3.6	51.2
Alternative 3	X	X	X		X	X							338	4.5	18.8	19.8	10.4	71.6	37.9	37.1	3.6	51.0
Alternative 4	X	X	X		X	X	X						331	4.5	18.8	19.8	10.4	71.6	34.8	35.8	3.6	48.9
Alternative 5	X	X	X		X	X	X	X					329	4.5	18.8	19.8	10.4	71.6	34.2	35.5	3.6	48.3
Alternative 6	X	X	X		X	X	X	X	X				328	4.5	18.8	19.8	10.4	71.6	33.8	35.3	3.6	47.7
Alternative 1	X	X	X		X	X	X			X			320	4.5	18.8	19.8	10.4	71.6	34.8	35.8	1.0	47.0
Alternative 7	X	X	X		X	X	X	X	X	X			317	4.5	18.8	19.8	10.4	71.6	33.8	35.2	1.0	45.8
Alternative 8	X	X	X		X	X	X			X		X	314	0.7	18.1	19.8	10.4	71.5	34.7	35.8	1.0	47.0

Table 7-10. Flood Depth Reductions by Alternative and Flood Return Period

		Dam 9 Div, Opt 1	Dam 9 Div, Opt 2	A17 Expanded Only	Dam A16 and Dam 9 Div Only, Opt 1	Dam A16, A17, and Dam 9 Div, Opt 1	Dam A17 Expanded and Dam 9 Div, Opt 1	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8
50-year	0.01	36	36	47	36	49	47	76	69	69	70	70	70	76	89
	0.25*	26	26	28	28*	28	28	41	28	30	38	38	38	46	43
	0.5	17	17	20	19	20	20	20	20	20	20	22	22	22	20
	0.75	8	8	12	11	12	12	12	12	12	12	12	12	12	12
	1	2	2	9	8	9	9	9	9	9	9	9	9	9	9
	1.25	1	1	4	3	4	4	4	4	4	4	4	4	4	4
	1.5	0	0	3	2	3	3	3	3	3	3	3	3	3	3
100-year	0.01	76	74	156	127	155	156	190	160	160	161	161	161	190	223
	0.25	60	56	67	67	67	67	108	78	80	91	91	102	111	113
	0.5	45	43	55	55	55	55	65	55	55	60	61	62	67	69
	0.75	39	29	49	49	50	50	52	50	50	50	50	51	53	53
	1	28	13	43	43	43	43	44	43	43	43	43	43	44	44
	1.25	13	3	41	39	41	41	42	41	41	41	41	41	42	42
	1.5	3	0	32	32	32	32	33	32	32	32	32	32	33	33
	1.75	0	0	29	29	30	30	30	30	30	30	30	30	30	30
	2	0	0	27	27	27	27	27	27	27	27	27	27	27	27
	2.25	0	0	18	17	23	23	23	23	23	23	23	23	23	23
	2.5	0	0	12	11	14	14	14	14	14	14	14	14	14	14
	2.75	0	0	8	7	10	10	10	10	10	10	10	10	10	10
	3	0	0	6	4	7	8	7	7	7	7	7	7	7	7
	3.25	0	0	2	1	6	6	6	6	6	6	6	6	6	6
	3.5	0	0	1	0	3	3	3	3	3	3	3	3	3	3
	3.75	0	0	0	0	1	1	1	1	1	1	1	1	1	1
	4	0	0	0	0	1	1	1	1	1	1	1	1	1	1

* 28 houses have 50-year flood depths reduced by over 0.25 foot.

Table 7-11. Numbers of Structures in Floodplains by Return Period

	No Projects	Dam 9 Div, Opt 1	Dam 9 Div, Opt 2	Dam A17 Only	Dam A16 and Dam 9 Div, Opt 1 Only	Dam A16, A17, and Dam 9 Div, Opt 1	Dam A17 Expanded and Dam 9 Div, Opt 1	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	A1	A3	A11
2% AEP (50-year) Flood																		
Entire Watershed	124	124	124	89	101	91	87	87	91	91	91	91	91	87	81			
PA1	6	6	6	6	6	6	6	6	6	6	6	6	6	6	1			
PA2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	45	45
PA3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
PA4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5			
PA5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
PA6	36	35	35	7	13	9	5	9	9	9	9	9	9	9	9			
PA7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
PA8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
PA9	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7			
PA10	10	10	10	8	10	8	8	8	8	8	8	8	8	8	8			
PA11	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5			
PA12	3	3	3	3	3	3	3	1	3	3	3	3	3	1	1			
PA13	13	13	13	11	13	11	11	11	11	11	11	11	11	11	11			
1% AEP (100-year) Flood																		
Entire Watershed	324	318	324	238	280	220	220	189	219	219	219	219	219	189	173			
PA1	8	8	8	8	8	8	8	8	8	8	8	8	8	8	5			
PA2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53	53	45
PA3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
PA4	13	13	13	13	13	13	13	13	13	13	13	13	13	13	5			
PA5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
PA6	69	69	69	33	34	14	14	14	14	14	14	14	14	14	14			
PA7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
PA8	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23			
PA9	39	39	39	15	38	15	15	15	15	15	15	15	15	15	15			
PA10	12	12	12	10	10	10	10	10	10	10	10	10	10	10	10			
PA11	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6			
PA12	7	7	7	7	7	7	7	3	7	7	7	7	7	3	3			
PA13	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15			
0.2% AEP (500-year) Flood																		
Entire Watershed	634	634	634	619	619	530	530	508	530	530	528	528	528	508	507			
PA1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9			
PA2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72	72	72
PA3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
PA4	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14			
PA5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
PA6	149	149	149	136	136	68	68	68	68	68	68	68	68	68	68			
PA7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
PA8	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24			
PA9	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45			
PA10	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13			
PA11	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6			
PA12	10	10	10	10	10	10	10	8	10	10	10	10	10	8	8			
PA13	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18			

Table 7-12. Summary of Other Alternatives

	A1	A3	A11	A30	Flood Scores per Section 5		
					Blockhouse Watershed	PA2	PA3
Blockhouse Creek Existing Condition					81.5	76.3	
A1	X				81.0	75.7	
A3		X			78.8	73.8	
A11			X		57.4	52.2	
South Brushy Creek Existing Condition					38.6		38.6
A30				X	38.5		38.5

Table 7-13. Flood Depth Reductions by Alternative and Flood Return Period, Block House Creek

	Depth Reduction (ft)	A1	A3	A11
50-year	0.01	19	45	45
	0.25	0	0	18
	0.5	0	0	0
100-year	0.01	49	52	53
	0.25	0	0	31
	0.5	0	0	0
500-year	0.01	20	74	73
	0.25	0	0	65
	0.5	0	0	32
	0.75	0	0	4
	1	0	0	0

Table 7-14. Summary of Structures within Floodplains for Priority Area 2

PA	50-yr	100-yr	500-yr
2	45	53	72
Outside PAs	3	3	9
Total	**48**	**56**	**81**

Table 7-15. Benefits of Alternatives Versus In-Line Damage Centers

Alternative	Bridges and Culverts That Are Prevented from Overtopping in the Listed Flood			
	50-year (2% AEP) Flood		100-year (1% AEP) Flood	
	Crossing	Model	Crossing	Model
A16	Burnet St S	Lake Creek R1		
	Oak Ridge Dr	Lake Creek R1		
A16 D9	Oak Ridge Dr	Lake Creek R1		
A17 expanded	Oak Ridge Dr	Lake Creek R2		
A16, A17, and D9 Opt 1	Burnet St S	Lake Creek R1	Oak Ridge Dr	Lake Creek R1
	Oak Ridge Dr	Lake Creek R1		
D9 Option 1 or Option 2	Oak Ridge Dr	Lake Creek R1		
A17 expanded and D9 Option 1 or Option 2	Oak Ridge Dr	Lake Creek R1	Oak Ridge Dr	Lake Creek R1
Alt 1	Burnet St S	Lake Creek R1	Oak Ridge Dr	Lake Creek R1
	Oak Ridge Dr	Lake Creek R1	HWY 79	Cottonwood
	CR 164/Limmer Loop	Cottonwood	CR 164/Limmer Loop	Cottonwood
	Red Bud Ln	Brushy Creek		
Alt 2	Red Bud Ln	Brushy Creek	Oak Ridge Dr	Lake Creek R1
	Burnet St S	Lake Creek R1		
	Oak Ridge Dr	Lake Creek R1		
Alt 3	Red Bud Ln	Brushy Creek	Oak Ridge Dr	Lake Creek R1
	Burnet St S	Lake Creek R1		
	Oak Ridge Dr	Lake Creek R1		
Alt 4	Red Bud Ln	Brushy Creek	Oak Ridge Dr	Lake Creek R1
	Burnet St S	Lake Creek R1		
	Oak Ridge Dr	Lake Creek R1		
Alt 5	Red Bud Ln	Brushy Creek	Oak Ridge Dr	Lake Creek R1
	Burnet St S	Lake Creek R1		
	Oak Ridge Dr	Lake Creek R1		
Alt 6	Red Bud Ln	Brushy Creek	Oak Ridge Dr	Lake Creek R1
	Burnet St S	Lake Creek R1		
	Oak Ridge Dr	Lake Creek R1		
Alt 7	Burnet St S	Lake Creek R1	Oak Ridge Dr	Lake Creek R1
	Oak Ridge Dr	Lake Creek R1	HWY 79	Cottonwood
	CR 164/Limmer Loop	Cottonwood	CR 164/Limmer Loop	Cottonwood
	Red Bud Ln	Brushy Creek		
Alt 8	Burnet St S	Lake Creek R1	Oak Ridge Dr	Lake Creek R1
	Oak Ridge Dr	Lake Creek R1	HWY 79	Cottonwood
	CR 164/Limmer Loop	Cottonwood	CR 164/Limmer Loop	Cottonwood
	Red Bud Ln	Brushy Creek		
	FM2243	S Brushy Creek		

Table 7-16. Summary of Total Costs per Project (Includes Contingencies)

Project	Construction Cost (Including Contingencies)	Total Estimated Cost*
A-1	$1,061,733	$1,360,000
A-2 and A-6	$25,200	$57,000
A-3	$660,754	$846,000
A-5	$339,024	$434,000
A-11	$1,575,356	$2,017,000
A-12	$4,759,661	$6,093,000
A-13	$3,277,386	$4,196,000
A-14	$1,217,304	$1,559,000
A-16	$15,388,216	$19,697,000
A-17	$15,058,585	$19,275,000
A-17 Expanded	$17,483,492	$20,194,000
A-19	$332,634	$554,000
A-21	$4,925,037	$6,305,000
A-23	$109,546	$141,000
A-25	$148,650	$191,000
A-27	$2,278,637	$2,917,000
A-28	$5,076,553	$6,498,000
A-29	$1,669,143	$2,137,000
A-30	$1,585,667	$2,030,000
A-31	$1,215,024	$1,556,000
A-32	$316,391	$405,000
Dam 9 Diversion Alternative Option 1		
B-1 Regulatory	$2,095,131	$3,071,000
C-5	$3,165,849	$4,053,000
C-2	$375,799	$482,000
Dam 9 Spillway Widening	$328,718	$421,000
Dam 9 Diversion Total	$5,965,497	$7,596,000
Dam 9 Diversion Alternative Option 2		
B-1 Regulatory	$3,443,649	$4,339,000
C-2	$375,799	$482,000
Dam 9 Spillway Widening	$269,896	$346,000
Dam 9 Diversion Total	$4,089,344	$5,167,000

*Does not include land use costs.

Table 7-17. Summary of Cost per Unit Flood Score Reduction – Detention Sites

	D9 Div	A16	A17	A17 Exp	A14	A27	A13	A29	A28	A21	A32	A12	Reduction in FS	Total Cost	Cost per FS Reduction	Base	Incremental FS Reduction Above Base	Total Incremental Cost Above Base	Incremental Cost per FS Reduction
Existing Conditions													0						
Dam 9 Div, Option 1	X												83	$7,596,000	$92,000				
Dam 9 Div, Option 2	X												65	$5,167,000	$79,000				
A17 Expanded			X										145	$20,194,000	$139,000				
A16, Dam 9 Div, Opt 1	X	X											135	$27,293,000	$202,000	Dam 9 Div Opt1	52	$19,697,000	$376,000
A16, A17, Dam 9 Div, Opt 1	X	X	X										160	$46,568,000	$291,000	Dam 9 Div Opt1	78	$38,972,000	$503,000
A17 Expanded, Dam 9 Div, Opt 1	X			X									159	$27,790,000	$174,000	Dam 9 Div Opt1	77	$20,194,000	$264,000
A17 Expanded, Dam 9 Div, Opt 2	X			X									155	$25,361,000	$164,000	Dam 9 Div Opt2	90	$20,194,000	$225,000
Alternative 2	X			X	X						X		170	$29,349,000	$173,000	A17 Expanded, Dam 9 Div	11	$1,559,000	$145,000
Alternative 3	X			X	X	X							171	$30,707,000	$180,000	A17 Expanded, Dam 9 Div	12	$2,917,000	$254,000
Alternative 4	X			X	X	X	X						178	$34,903,000	$196,000	Alt 3	8	$4,196,000	$548,000
Alternative 5	X			X	X	X	X	X					180	$37,040,000	$206,000	Alt 4	2	$2,137,000	$1,313,000
Alternative 6	X			X	X	X	X	X	X				181	$43,538,000	$240,000	Alt 5	1	$6,498,000	$4,727,000
Alternative 1	X			X	X	X	X			X			189	$41,208,000	$218,000	Alt 4	9	$4,168,000	$463,000
Alternative 7	X			X	X	X	X	X	X	X			192	$49,843,000	$260,000	Alt 1	3	$8,635,000	$2,736,000
Alternative 8	X			X	X	X	X			X		X	195	$40,996,000	$211,000	Alt 4	15	$6,093,000	$406,000

Table 7-18. Summary Prioritization of Regional Detention Projects

	Priority	Upstream Location	Reduction in FS	Notes	Program Total Cost	Project Cost	Incremental Cost per FS Reduction
Dam 9 Div, Opt 2	1	1	65	Most cost-effective solution reducing highest FS	$5,167,000		$79,000
A17 Expanded	1	1	155	Most cost-effective solution for next highest reduction in FS	$25,361,000	$20,194,000	$225,000
Add A32	3	2	163	Lowest cost portion of Alternative 2, best control option on Chandler Branch	$25,766,000	$405,000	$536,900
Add A14	4	2	170	Other project in Alternative 2, best control option on Chandler Branch	$27,325,000	$1,559,000	$536,900
Add A13	5	3	178	Best control option on McNutt Creek	$31,521,000	$4,196,000	$547,600
Add A21	6	4	189	Best control option on Cottonwood Creek	$37,826,000	$6,305,000	$616,100
Add A12	7		195	Best control option in upper Brushy Creek headwaters	$43,919,000	$6,093,000	$773,200
Add A29	8	2		Added control on McNutt Creek, least cost of two additions	$46,056,000	$2,137,000	
Add A28	9	2		Added control on McNutt Creek	$52,554,000	$6,498,000	
Alternatives to the Project Above							
A16		1		Alternative to A17 Expanded, less FS reduction, similar incremental cost		$12,000,000	$204,000
A16 and A17		1		Alternative to A17 Expanded, same FS reduction, higher incremental cost		$21,000,000	$250,000
A27		2		Alternative to A32 in Chandler Branch watershed		$2,917,000	$719,300

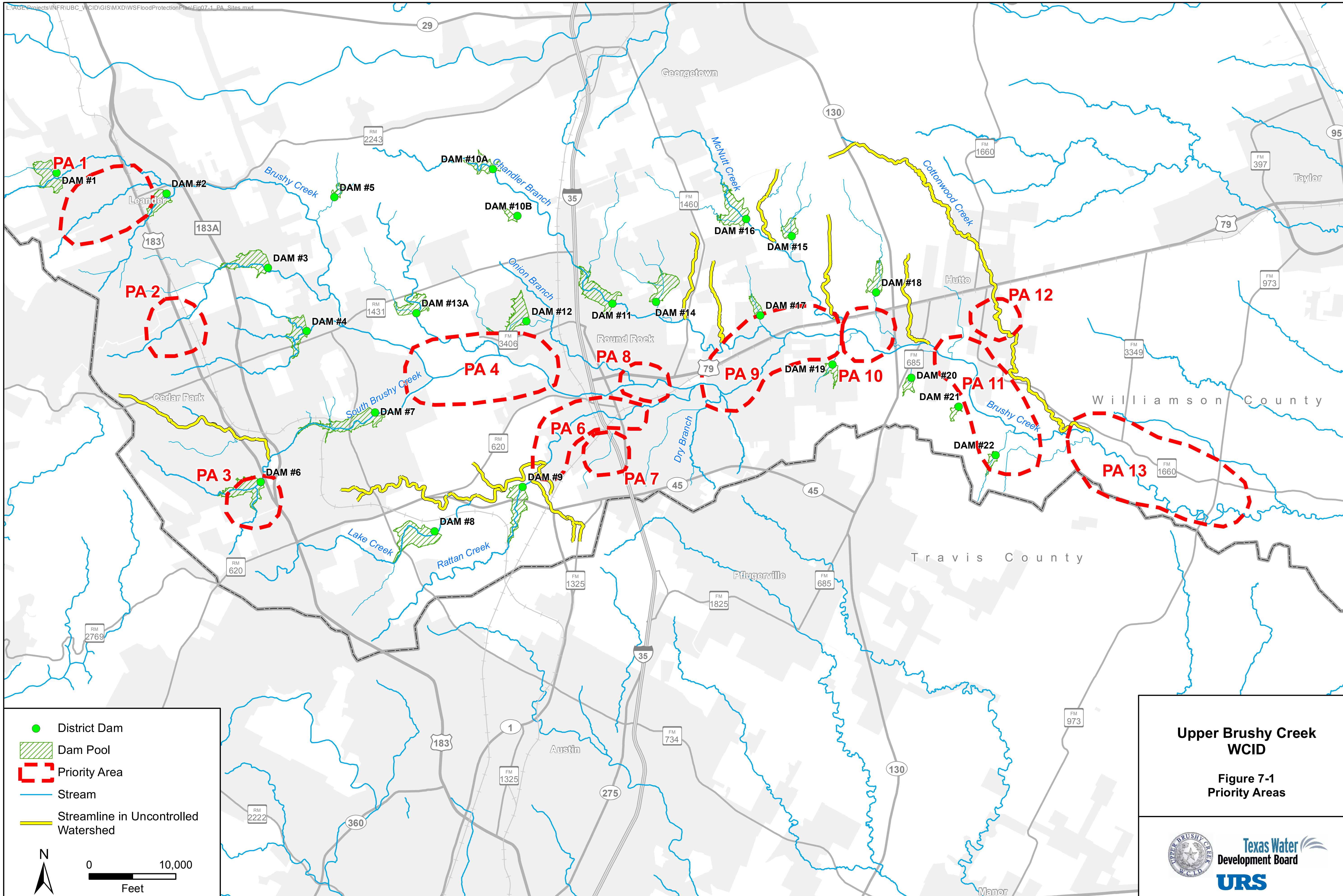
*1 = the most upstream location in the watershed of the Brushy Creek main stem.

Table 7-19. Summary of Cost per Unit Flood Score Reduction – Other Sites

	A1	A2	A3	A11	A15	A30	A5	A23	A25	A31	Reduction in FS	Total Cost	Cost per Unit of FS Reduction
Blockhouse Control											0		
A1	X										0.5	$1,360,000	$2,725,600
A2		X									32.7	$57,000	$1,700
A3			X								2.6	$846,000	$321,700
A11				X							24.0	$2,017,000	$83,900
South Brushy Control											0		
A30						X					0.03	$2,030,000	Low benefit
Lake Creek Trib 6													
A15					X						24.4	$-	TBD
Channel Modifications													
A5							X				36	$434,000	$12,100
A23								X			0	$141,000	No benefit
A25									X		0.5	$191,000	$353,700
A31										X	3.4	$1,556,000	$460,400

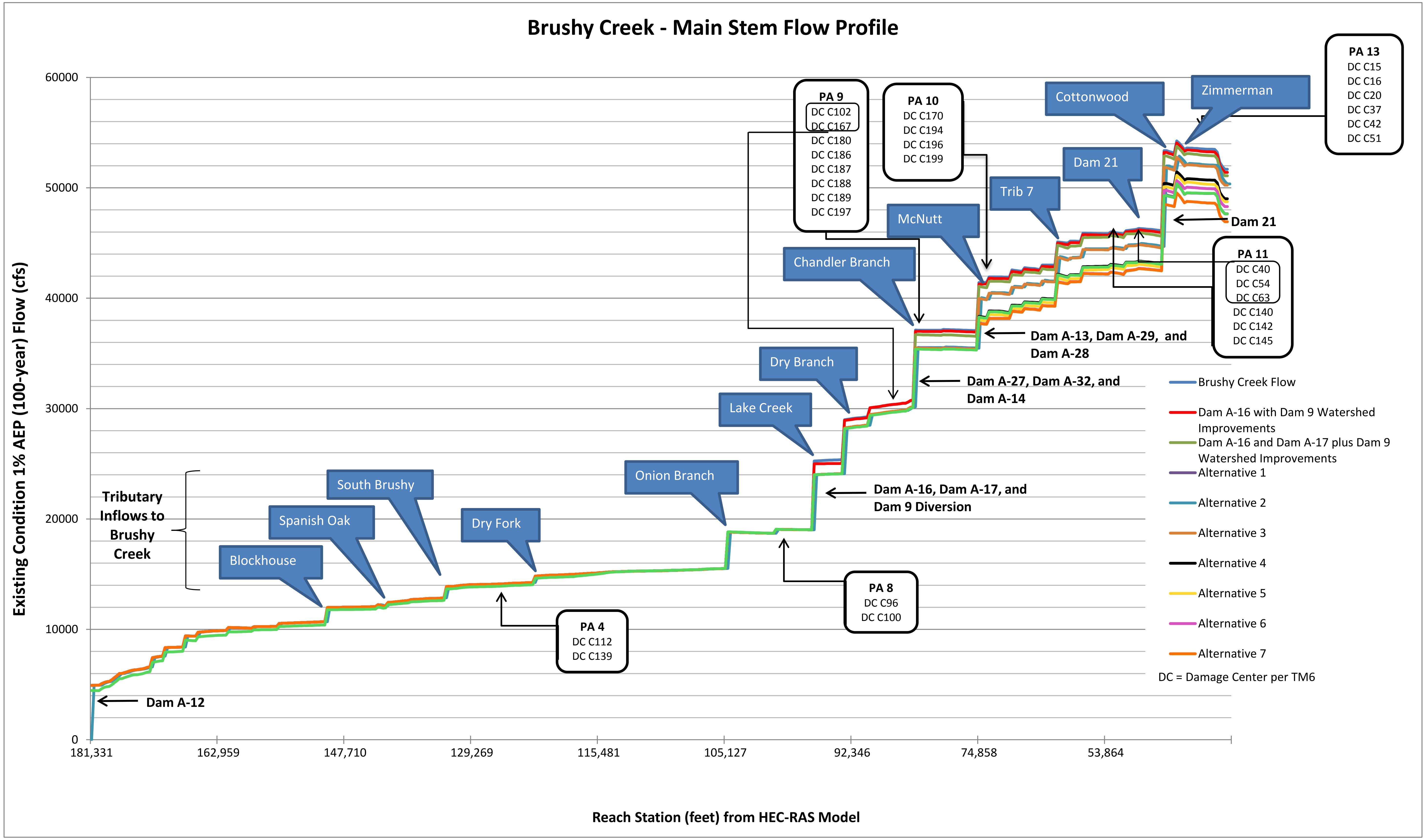
Table 7-20. Summary Prioritization of Standalone Projects

Project	Priority	Reduction in FS	Total Cost	Cost per Unit of FS Reduction	Note
Most Cost-Effective Projects in Addressing Local PAs					
A2	1	32.7	$57,000	$1,700	Most cost-effective control on Blockhouse Creek
A11	2	24.0	$2,017,000	$83,900	Potentially cost-effective addition to A2 for Blockhouse Creek
A31	3	3.4	$1,556,000	$460,400	Only project that benefits PA8 on Brushy Creek main stem
A15	??	24.4	??	??	Control on Lake Creek Tributary 6
Alternatives to Projects Above					
A1		0.5	$1,360,000	$2,725,600	Alternative to A2, A11 on Blockhouse Creek
A3		2.6	$846,000	$321,700	Alternative to A2, A11 on Blockhouse Creek
A5		36	$434,000	$12,100	Appears cost-effective control to Blockhouse Creek, but requires buyouts
Rejected Alternatives					
A30		0.03	$2,030,000	Low benefit	South Brushy Creek, no benefit
A25		0.5	$191,000	$353,700	Dam 18 Tributary Channel mod, no benefit to main stem
A23		0			Cottonwood Creek diversion channel, no benefit



Upper Brushy Creek WCID

Figure 7-1
Priority Areas



Texas Water Development Board URS

Figure 7-2. Brushy Creek Main Stem Flow Profile

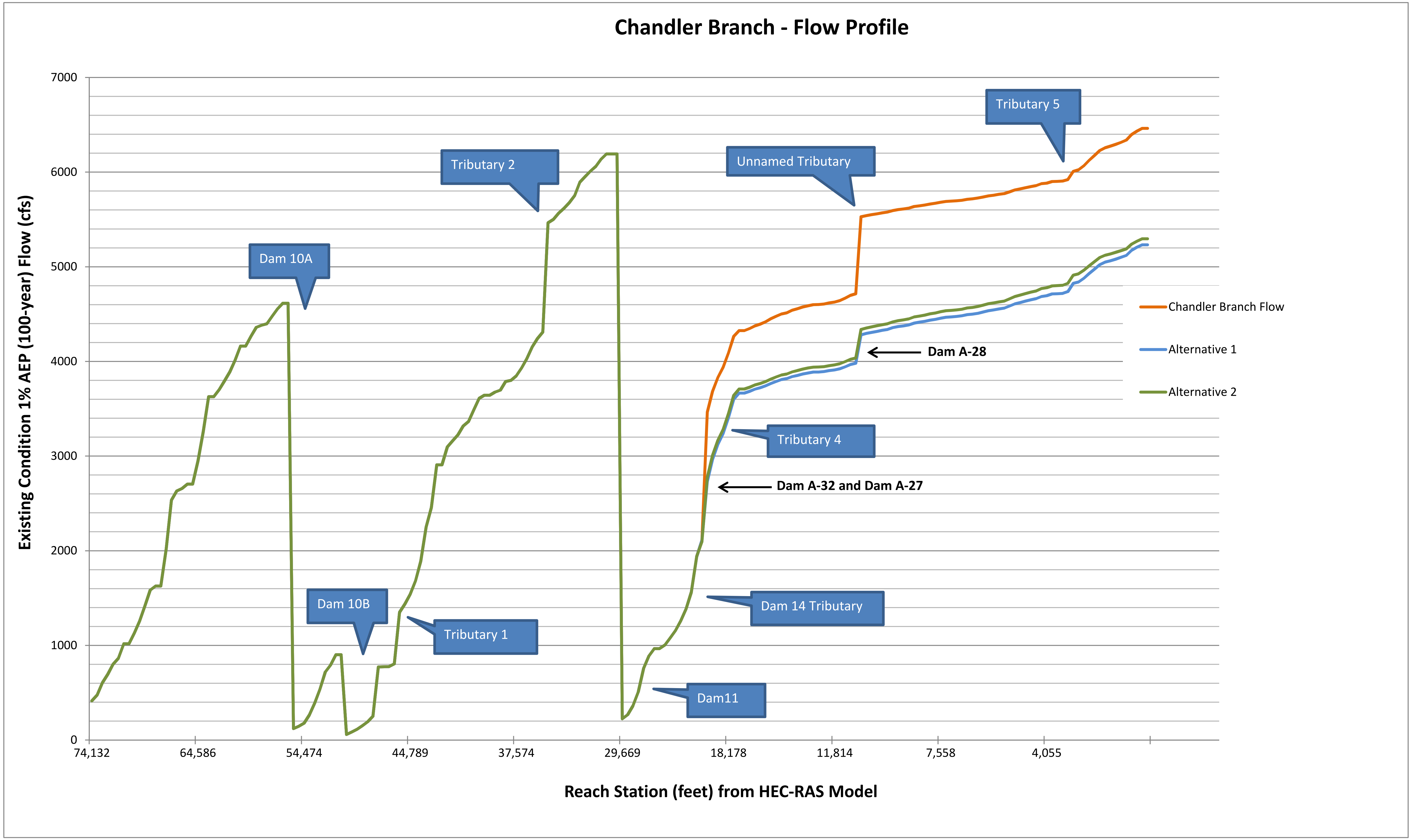


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Figure 7-3. Chandler Branch Flow Profile

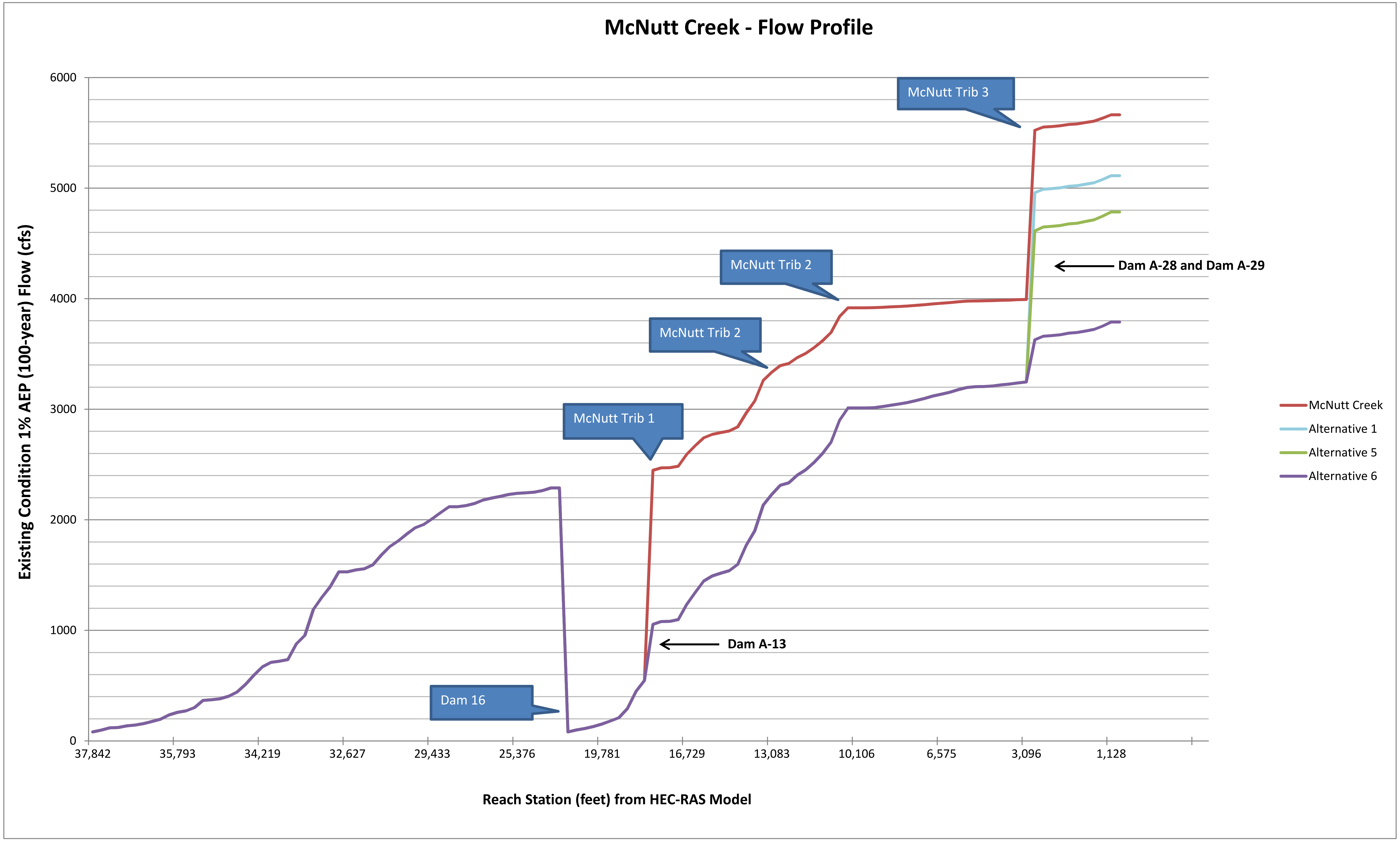

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Figure 7-4. McNutt Creek Flow Profile

Lake Creek - Flow Profile

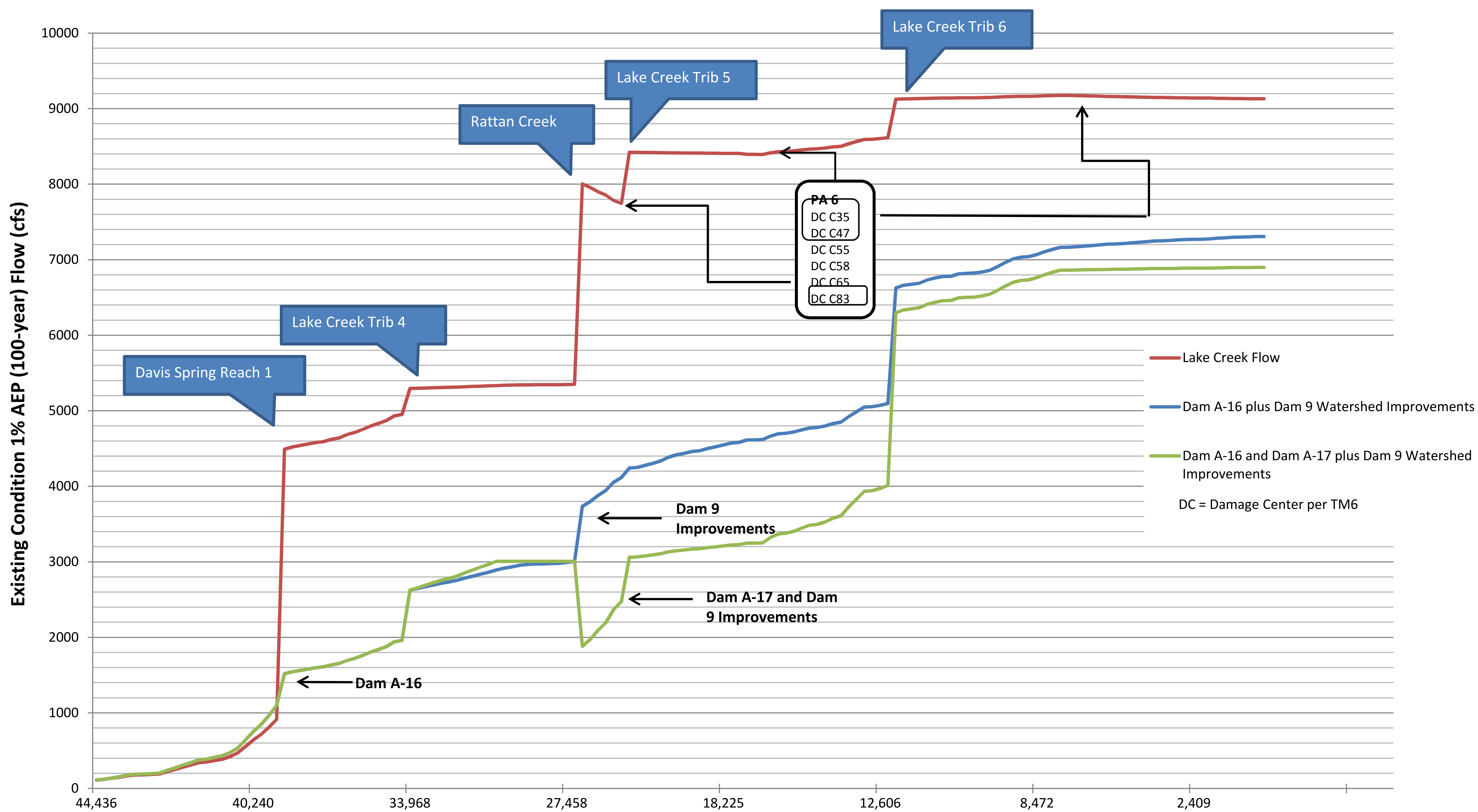
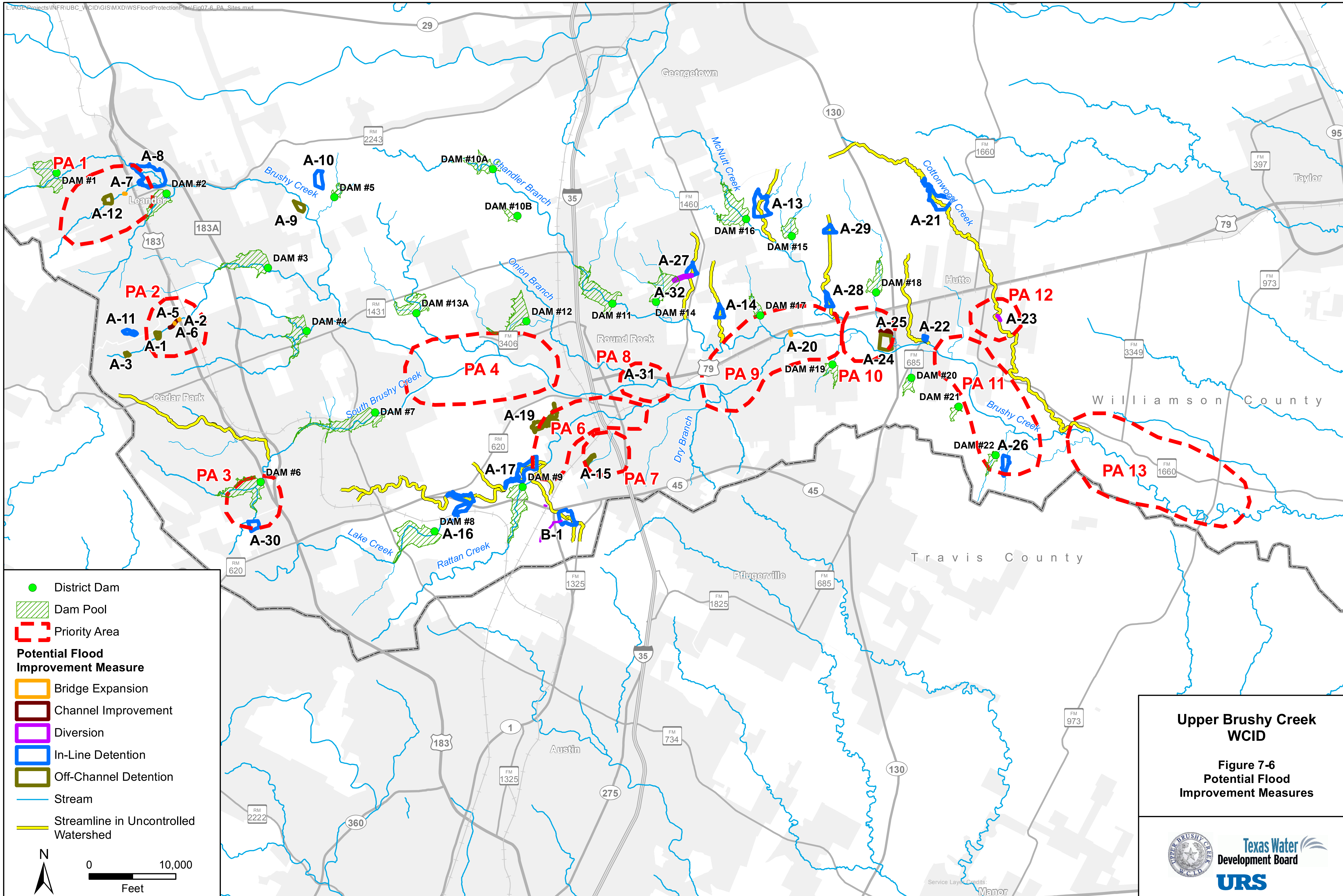


Figure 7-5. Lake Creek Flow Profile



Upper Brushy Creek WCID

Figure 7-6
Potential Flood Improvement Measures

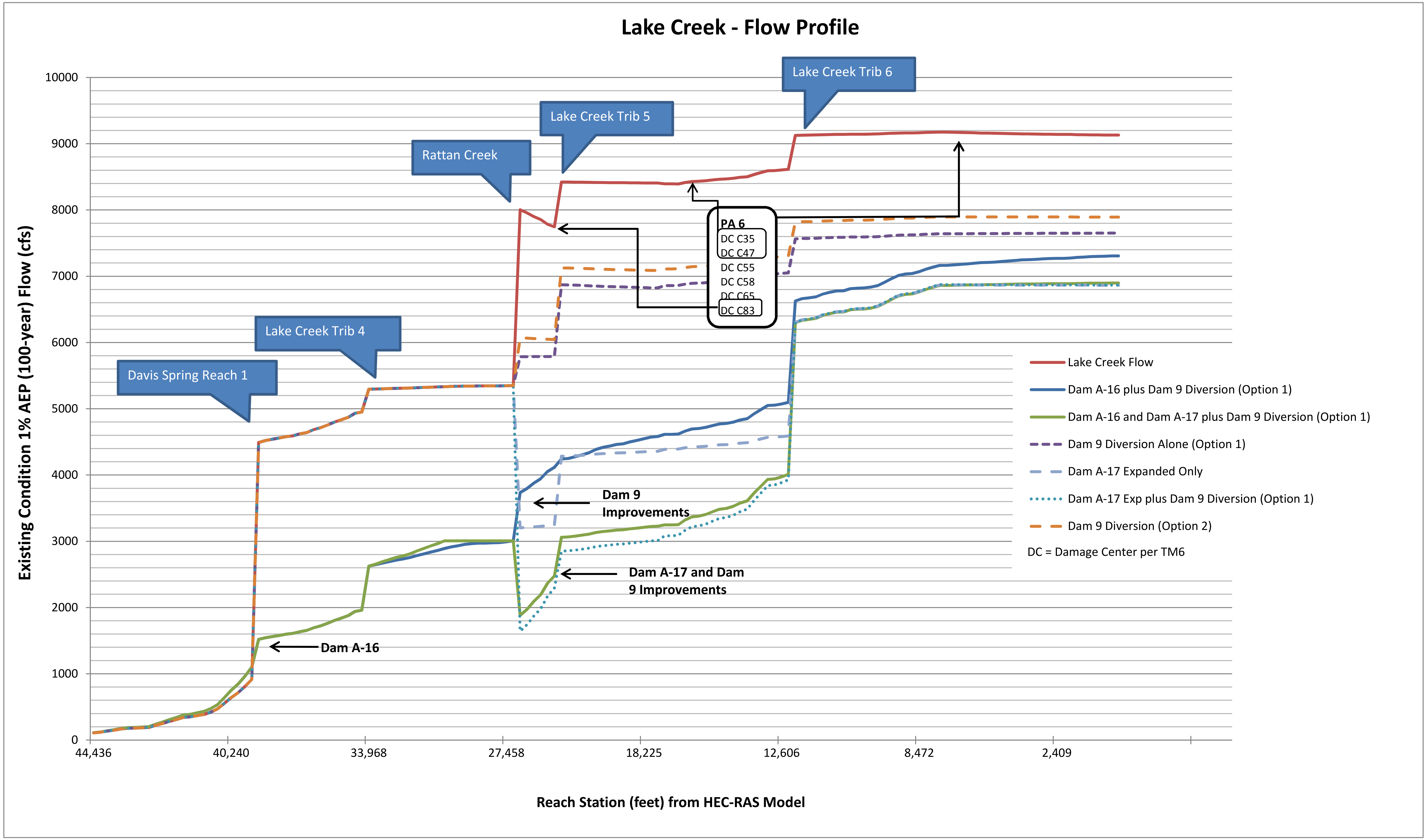


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Figure 7-7. Lake Creek Flow Profile, Effect of Improvements

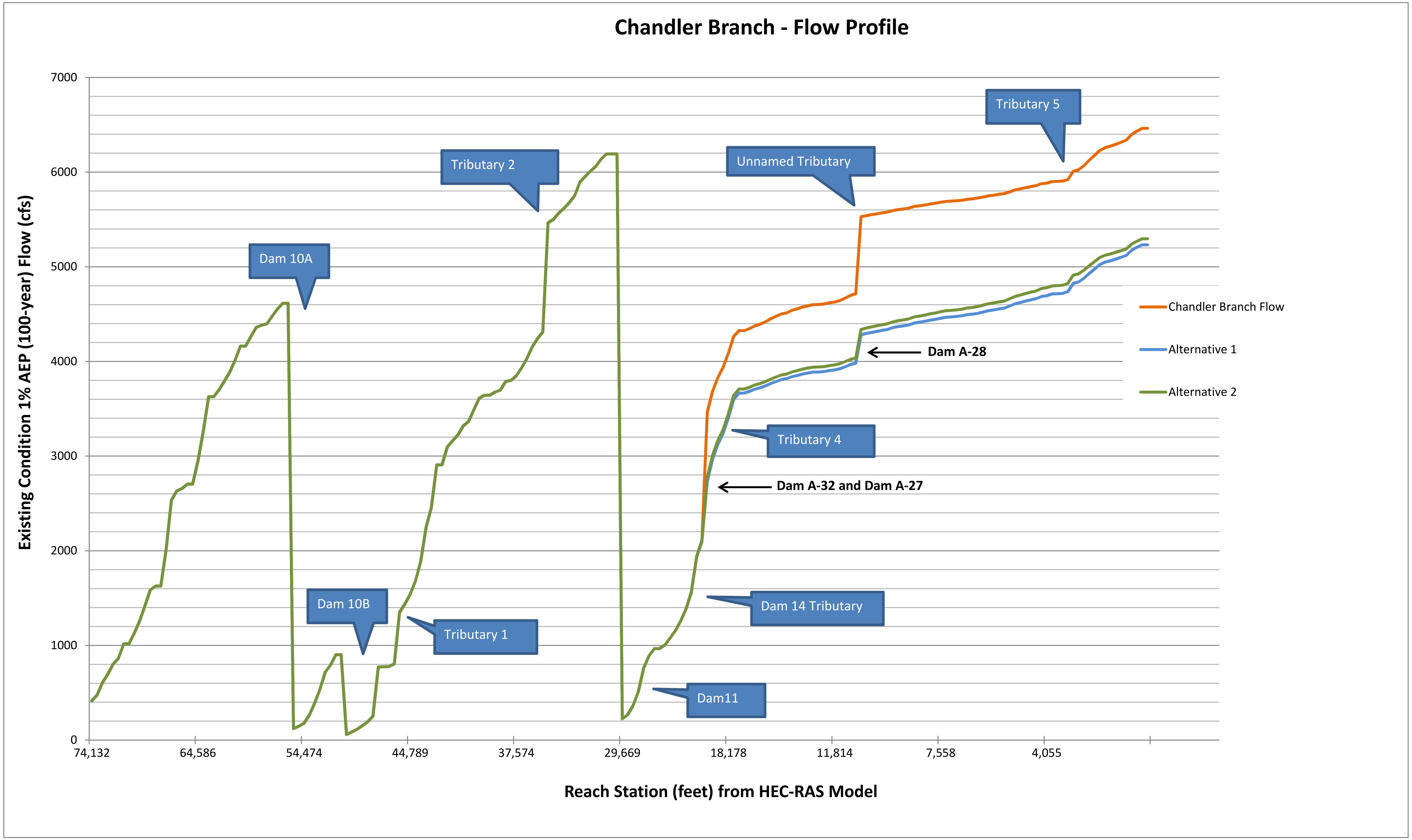

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Figure 7-8. Chandler Branch Flow Profile, Effect of Improvements

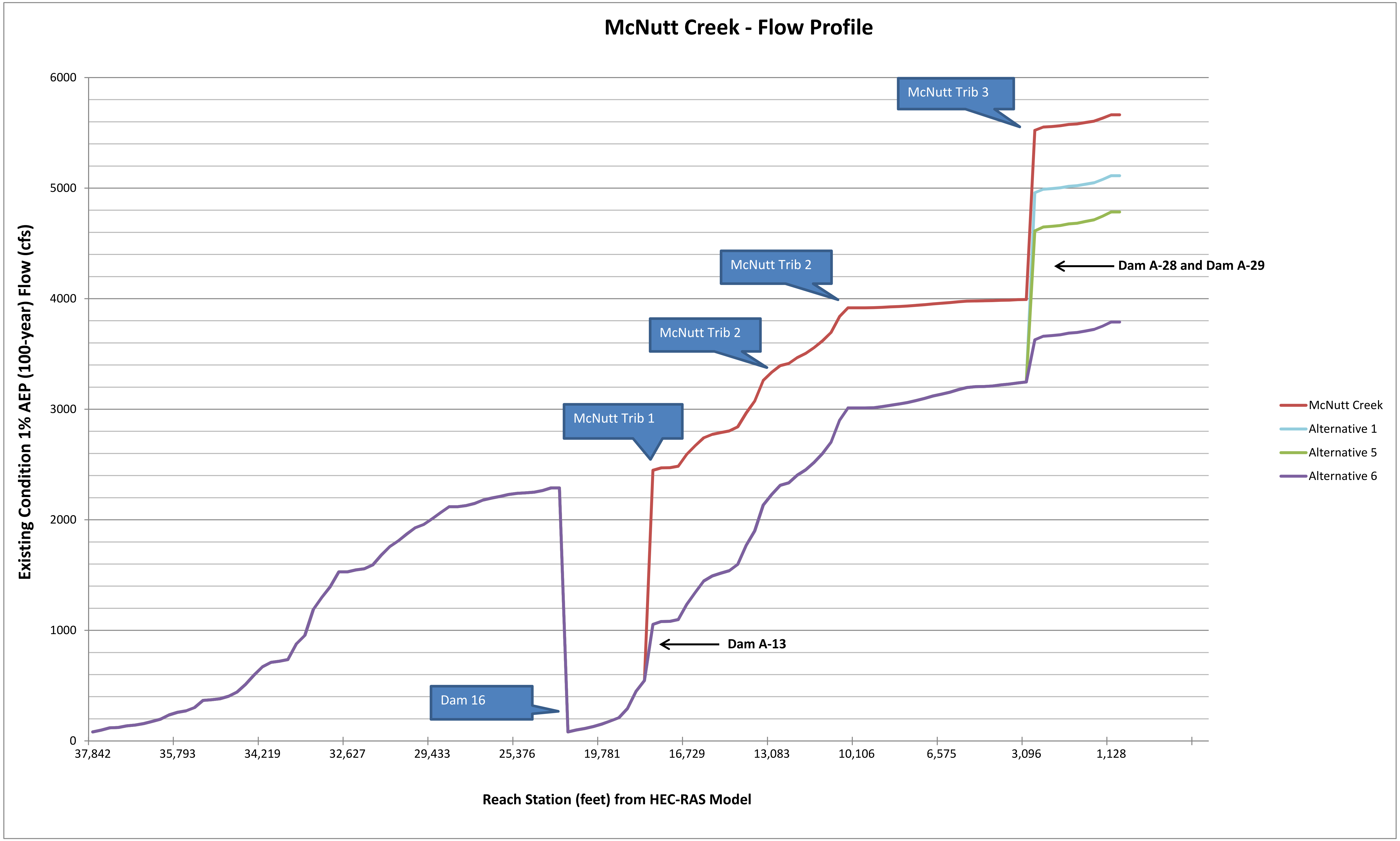

Figure 7-9. McNutt Creek Flow Profile, Effect of Improvements

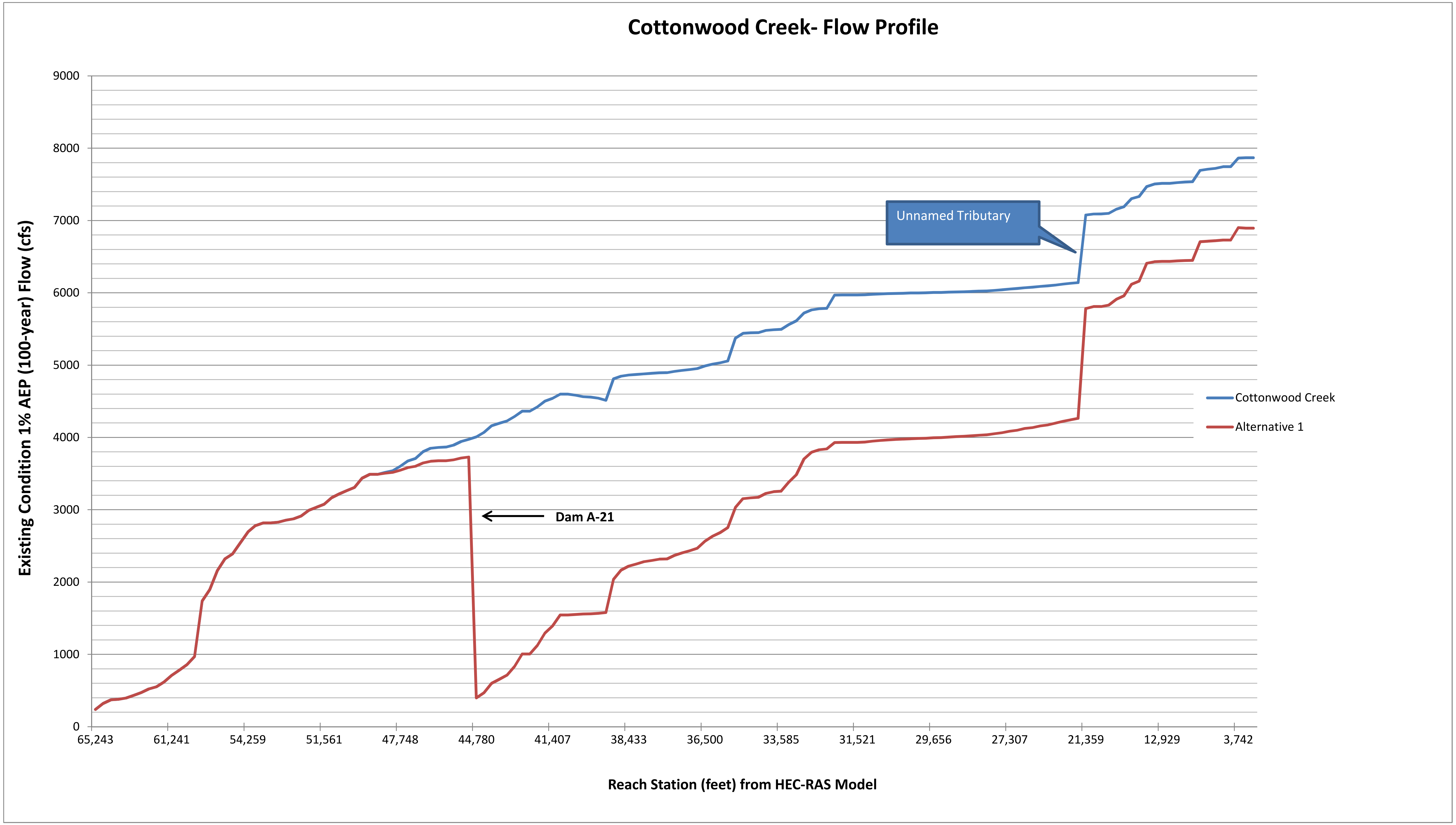

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Figure 7-10. Cottonwood Creek Flow Profile, Effect of Improvements

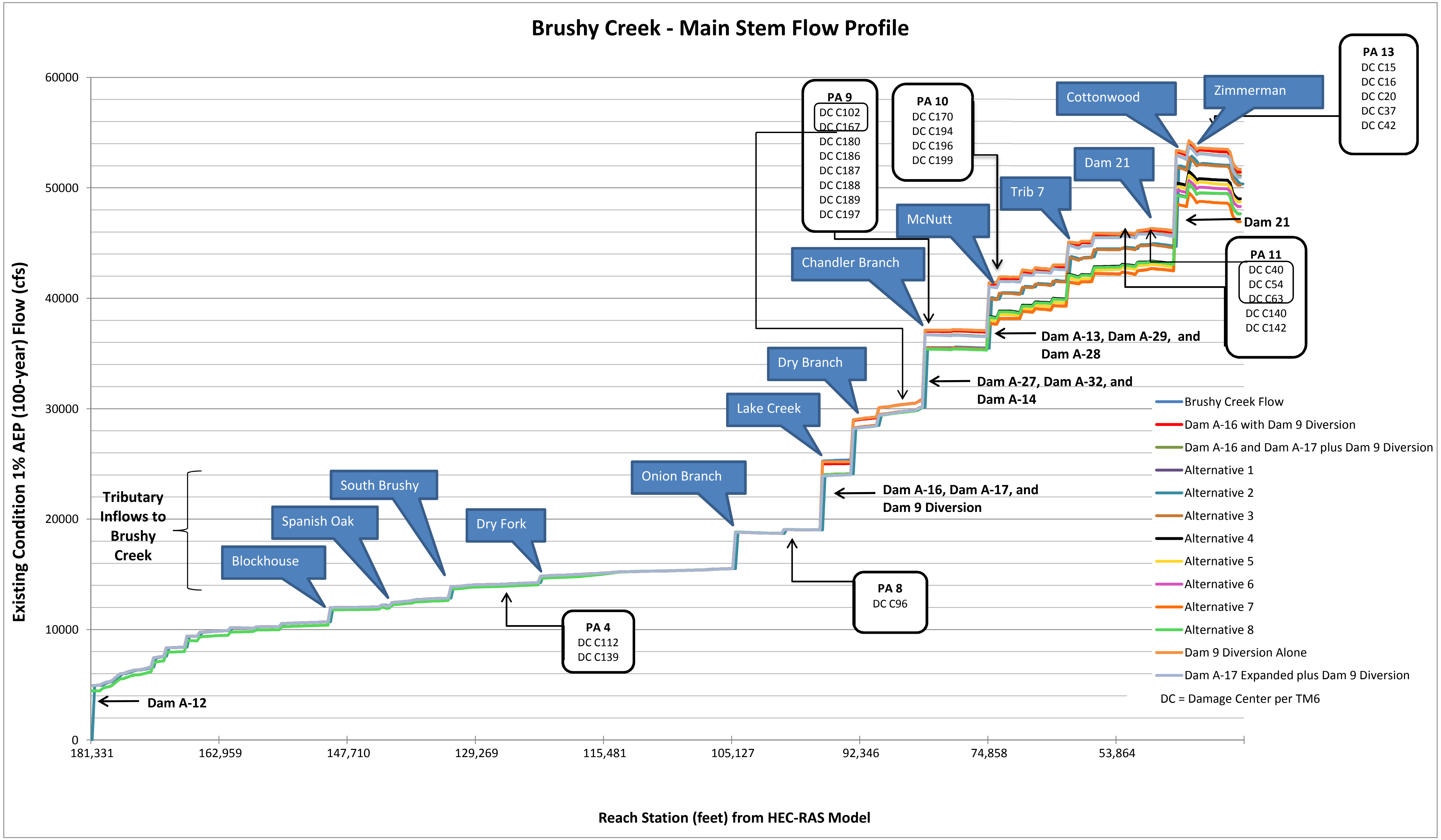

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Figure 7-11. Brushy Creek Main Stem Flow Profile,Effect of Improvements