CITY OF COLLEGE STATION

The College Station Watershed Timing Assessment (Supplemental Guidance for Detention in College Station) provides simplified engineering guidance for further determining locations within the watershed where detention is “required”, “not required”, or “evaluate”. The assessment utilized existing hydrologic and hydraulic models to refine detention requirements along watershed reaches. The assessment also provides a simplified method to determine whether or not detention is necessary for small projects located in the “evaluate” areas. Note that projects in College Station shall still comply with BCS Unified Stormwater Design Guidelines, while utilizing the Watershed Timing Assessment as a supplement. Where there is a conflict, the Assessment shall supersede. Appendices E and F in the Timing Assessment replaces Table B-2 of the Design Guidelines for development in College Station. This study is now effective and applicable as the best flood timing data.

Watershed Timing Assessment for City of College Station

January 7, 2013

Prepared by:

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1-7-2013

CITY OF COLLEGE STATION
Home of Texas A&M University®

January 7, 2013

Carol Cotter, P.E.
Public Works Department
City of College Station
P.O. Box 9960
College Station, TX 77842

Job No. 2010-CS-01

Re: Watershed Timing Assessment

Dear Carol:

The purpose of this letter report is to document the process and results of the Watershed Timing Assessment project. The purpose of this project is to provide simplified processes for determining: 1) locations in watersheds where detention is, is not, or may be required and 2) an easy-to-implement downstream impacts analysis procedure. Based on direction from the City, the following watersheds within City limits were evaluated as part of this assessment:

- Alum Creek
- Bee Creek
- Burton Creek Tributary C (Burton Creek main stem and other significant tributaries are outside City limits)
- Carters Creek
- Lick Creek
- Spring Creek
- Whites Creek (outside of Texas A&M University lands)
- Wolf Pen Creek

Because models were not available on Peach Creek or Foxfire Creek, recommendations for this watershed were based on typical watershed performance and prior recommendations in the *Unified Stormwater Design Guidelines*. For other streams or stream segments where hydrologic models were not available, recommendations were also based on typical watershed performance and prior recommendations in the *Unified Stormwater Design Guidelines*.

As requested, our technical approach relied extensively on existing, readily available data from the City of College Station. Based on direction from the City, a general timing approach was used for this evaluation rather than detailed hydrologic modeling. General process guidelines and recommendations as well as examples for performing a simplified downstream impacts analysis are included. Detailed modeling and analysis could be performed in a future phase, whereas this approach focuses on evaluation of existing models rather than modeling and development of new or updated models.

The simplified downstream impacts analysis process and detention requirements process represent significant advances from the *Unified Stormwater Guidelines* because they are based on data evaluation from existing hydrologic and hydraulic models rather than general guidelines. While this is a significant advance for the City, the level-of-accuracy is restricted by limitations of the existing hydrologic and hydraulic models. Future efforts are recommended to update this process as model updates become available.

This document also addresses stormwater mitigation options for projects that do not require on-site detention. Several recommendations are provided to guide the future direction and growth of the City's stormwater management program to solve existing challenges, create multi-functional stormwater facilities, and meet anticipated regulatory requirements.

This document includes the following segments:

- **DATA REVIEW**
- **EXISTING DATA EVALUATION**
- **STORMWATER MANAGEMENT FOR SITES NOT REQUIRING DETENTION**
- **DOWNSTREAM IMPACTS ANALYSIS PROCESS**
- **RECOMMENDATIONS**
- **FIGURES**
    - Figure 1 - Watershed Type 1 Detention Requirements
- **ATTACHMENTS**
    - Attachment 1 – Simplified Downstream Impacts Analysis Process
        - Figure 1-1 - Detention Evaluation Process
    - Attachment 2 – Alternate Modeling Approach
    - Attachment 3 – Simplified Downstream Impacts Analysis Examples
- **APPENDICES**
    - Appendix A – Summary of Models Used for Project
    - Appendix B – Summary of Hydraulic Evaluations
    - Appendix C – Key Hydrograph Locations and Data
    - Appendix D – Key Hydrograph Figures
    - Appendix E – City of College Station Watershed Graphics
    - Appendix F – Summary of Detention Requirements
    - Appendix G - Models and Spreadsheet of Key Hydrographs

DATA REVIEW

Existing Drainage Criteria

Existing drainage criteria used within the City of College Station primarily consists of the October, 2012 version of the *Unified Stormwater Design Guidelines*, which were developed and implemented jointly with the City of Bryan. Note that the 2009 version was used in this project. Based on this set of criteria, detention may be required for projects within the City watersheds for the following purposes:

- Type 1 Detention (Flood Control)
- Type 2 Detention (Conveyance Management)
- Type 3 Detention (Dual Purpose)

Type 1 (Flood Control Detention) is intended to mitigate runoff from a project that is likely to increase peak flows and flooding potential within the receiving stream. Type 2 (Conveyance Management Detention) is intended to manage runoff that must drain through adjacent properties prior to discharging into the receiving stream. Type 3 (Dual Purpose Detention) refers to detention facilities required for both flood control and conveyance management perspective.

Under the *Unified Stormwater Design Guidelines*, detention is not required for developments that meet one or more of the following conditions:

1. **Adjacent to Primary System:** Developments adjacent to the primary drainage system may not be required to provide detention, if a downstream impacts/timing analysis demonstrates it is not beneficial for peak flow mitigation.

2. **One Existing Lot:** One existing single-family lot.

3. **Small Lot:** Commercial sites ≤ one-acre and single family sites ≤ two acres.

4. **Draining to Designated Streams:** Table B-1 of Appendix B lists the watersheds within the City and detention requirements for flood control purposes (i.e., Type 1). Table B-1 indicates locations in the watershed where detention is required, is not required, and where the need for detention must be evaluated. Even where detention is not required for flood control purposes, it may be required for conveyance purposes (i.e., Type 2).

This watershed timing assessment is not intended to address or alter requirements for items two and three above related to one existing lot and small lot developments. Instead, this project is intended to develop a simplified downstream impacts analysis process to facilitate whether developments adjacent to the primary system require detention under item one above. Furthermore, this study updates the process for determining where detention is, is not, or might be required related to item four above and Table B-1 of the *Unified Stormwater Guidelines*.

In locations where detention is required, peak flow rates must be maintained at or below pre-development conditions for the following design storm events: two-year (50%), ten-year (10%), 25-year (4%), 50-year (2%), and 100-year (1%).

In addition, Chapter 13 of City code related to Flood Hazard Protection was recently updated to incorporate a No Adverse Impacts policy for flood plain management. As such, adverse impacts due to encroachment and development within the regulatory 1% flood plain or Special Flood Hazard Area must be avoided or mitigated. Chapter 13 defines adverse impacts as any of the following upstream, within, near, adjacent to, or downstream of such encroachment: increases in base flood elevations (BFEs), loss of conveyance, loss of flood plain storage, creating additional flood plain areas, and increased velocities during the Base Flood.

The simplified downstream impacts analysis methodology developed as part of this study maintains consistency with Chapter 13 requirements for No Adverse Impacts in addition to detention mitigation requirements.

GIS Data

The following geographical information systems (GIS) hydrologic and hydraulic data provided by City staff was evaluated for this assessment:

- Topography
- Aerials
- Flood Plains
- Watershed Boundaries
- Soils

Even though structural flooding occurred during recent intense rainfall in February, 2012, structural flooding has not historically been a significant issue according to City staff.

Hydrologic and Hydraulic Models

Effective hydrologic and hydraulic models for major streams and tributaries within the City were acquired from the Federal Emergency Management Agency (FEMA) by the City and provided for this project. The hydrologic models included both HEC-HMS and HEC-1 programs, while the hydraulic models included HEC-2 and HEC-RAS. Details on hydrologic and hydraulic characteristics of various watersheds within the City identified from evaluation of these models are included under the Methodology section.

The table in Appendix A lists the hydrologic and hydraulic models used for this evaluation. Copies of these models are also included on the CD attached as Appendix G. For watersheds where the hydraulic model was not provided, only the hydrologic models were evaluated.

Because of the conceptual nature of this study, overall effective or updated models were used even in locations where detailed revised models are available for a small stream segment. However, consideration of the most recent models is an important component of future detailed analysis and design projects.

EXISTING DATA EVALUATION

Hydraulic Evaluations

Output data from existing HEC-2 and HEC-RAS models was evaluated to assess typical velocities, travel times, and stream profiles. For watersheds or tributaries that were not previously modeled, no evaluation was performed. Appendix B summarizes the hydraulic evaluations including stream slopes, stream capacity, typical velocities, and average travel times.

The results of this evaluation were used in conjunction with general detention/stream routing principles to identify several stream segments in downstream reaches for hydrologic investigation.

Hydrologic Evaluation

Output data from existing HEC-1 and HEC-HMS hydrologic models was evaluated to assess typical travel times within stream routing reaches, time to peak for hydrographs, peak flows, and duration of peak flows. Hydrographs were analyzed at the key locations within City watersheds listed in Appendix C, while Appendix D includes figures of key hydrographs. Key hydrographs are also included in the spreadsheets on the attached CD. Watershed locations within the region as well as individual watersheds are illustrated in Figures E-1 to E-10. The following criteria were used to select possible key locations for analysis:

- Location of nodes/junctions in HEC-1 and HEC-HMS models
- Confluences with tributaries, especially FEMA studied tributaries
- Mouth of stream (i.e., downstream-most part of stream or point where stream discharges)
- Locations where Type 1 Flood Control Detention requirements change from Table B-1 of the *Unified Stormwater Design Guidelines*
- locations indicated in hydraulic evaluation
- Major roadway crossings
- Input by City staff

In prioritizing the key locations, the lower to middle portion of each watershed was emphasized, since on-site detention is typically more effective for peak flow mitigation in upper stream reaches. Although modeling was not performed as part of this assessment, future City or consultant studies may require hydrologic modeling.

The potential for effectiveness of detention at various locations within the watersheds was assessed by analyzing hydrographs at the identified key locations. At stream confluences, the upstream hydrograph, tributary hydrograph(s), and the combined hydrographs were evaluated. In addition, timing of contributions from drainage areas contributing directly to the streams at those points and contributing drainage area ratios were also considered.

Average travel times for residential projects up to 20 ac and commercial, high-density, or mixed use development projects up to 10 ac were conservatively estimated based on peak rainfall intensity and typical times to peak for drainage areas ranging from zero to 100 ac (focus on areas smaller than 50 ac where available in the existing models) contained within the hydrologic models evaluated for this project. Table 1 in Attachment 1 includes average Times to Peak for small drainage areas in each watershed.

Times to peak were compared to times to peak in stream at key hydrograph locations within each watershed. For stream segments with time to peak differences greater than 1.5 hours (hrs), detention is not required within that particular stream reach. For differences less than one-hour, detention is required. For stream segments with time to peak differences ranging from approximately one-hour to approximately 1.5 hrs, the need for detention must be evaluated by the Engineer. These values are approximate as hydrograph computation points and key hydrographs do not fall exactly on these limits.

Appendix F indicates those portions of the City's watersheds that Require, Do Not Require, or Possibly Require Detention for Type 1 Flood Control purposes. Figure 1 provides a conceptual illustration of these designations within a watershed. These updated requirements supersede Table B-1 of the *Unified Stormwater Design Guidelines* for projects falling within the City of College Station's jurisdiction. The designation Evaluate is used for portions of watershed that possibly require detention to maintain consistency with previous terminology. The graphics in Appendix E are for illustrative purposes only and the table in Appendix F should be consulted to determine the need for detention or evaluation. In addition, projects discharging to tributaries or streams not specifically listed in this table require evaluation.

Detention requirements are for Type 1 Flood Control Detention for projects discharging directly to noted streams. For projects discharging to tributaries or other streams, Type 2 Conveyance Detention may be required and travel time to the listed streams must be considered in the simplified detention and downstream impacts analysis.

For developments located adjacent to a stream listed in Appendix F, Type 2 Conveyance Management detention is typically not required. For developments without a designated outfall path or easement that are not located adjacent to a stream listed in Appendix F, Type 2 Conveyance Management Detention may be required in addition to any Type 1 Flood Control detention requirements.

For developments falling within a portion of a watershed that Possibly Requires Detention, a downstream impacts analysis is required and described in the Results section. Detention facilities for developments that require detention or are determined to require detention shall be analyzed in accordance with the criteria contained within the *Unified Stormwater Design Guidelines.*

Since hydrologic models were not available for Burton Creek, Bee Creek (except Tributaries B and B3), and Peach Creek, recommendations for these watersheds are based on criteria from the *Unified Stormwater Design Guidelines*. However, additional details are added to the detention requirements table as well as the accompanying graphics. Since models are not currently available for Foxfire Creek and this stream was not considered in the *Unified Stormwater Design Guidelines*, recommendations are not included for this stream.

STORMWATER MANAGEMENT FOR SITES NOT REQURING DETENTION

For those sites located in areas not needing detention, stormwater management is still a critical component of development. The City's Texas Pollutant Discharge Elimination System (TPDES) Municipal Separate Storm Sewer System (MS4) permit requirements are anticipated to continue to strengthen stormwater quality measures required within the City. The primary pollutants of concern, or targeted pollutants, within the City's watersheds are currently TSS (total suspended solids) and bacteria. Furthermore, a total maximum daily load (TMDL) requirement for bacteria (fecal coliform) is anticipated in the Carter's Creek and Burton Creek watersheds. Additional pollutants may be targeted in the future.

An additional issue related to development is the increased runoff volume and associated stream erosion during frequent rainfall events. These issues occur even with on-site detention basins as detention facilities do not mitigate the additional runoff volume associated with increased impervious cover, improved conveyance, soil compaction, and disturbed vegetation. In addition to the higher peak flows and runoff volumes, the duration of flow is typically more concentrated and "flashier" than under undeveloped conditions, which further exacerbates erosion and affects riparian species, habitat, and other environmental issues.

To address stormwater quality concerns and the additional volume of runoff associated with development, we recommend the incorporation of Low Impact Development (LID) and green infrastructure techniques for sites that do not require detention due to watershed location. LID and green infrastructure techniques are designed to provide stormwater quality treatment and to mitigate impacts of peak flows and runoff volume associated with development.

A typical goal is to match pre-development hydrologic conditions (peak flow and volume) from the site for smaller rainfall events (i.e., the two-year event in areas with significant rainfall depths. Even treating a one-inch event, which is often considered a first flush depth, is helpful from a stormwater quality perspective as many pollutants are mobilized and transported from the surface during the initial rainfall amounts.

Alternatively, post-construction Best Management Practices (BMPs), such as stormwater wetlands, wet-bottom detention basins, and other items that target TSS and bacteria should be incorporated. The use of end-of-pipe solutions, such as hydrodynamic separator devices may be problematic if on-going maintenance is not performed.

Another option the City may want to consider is assessing a stormwater impact fee to developments not requiring detention. This fee can be used to construct regional stormwater management (flood control and stormwater quality) facilities within key locations in the City's watersheds. These types of impact fees are typically based on the area being developed and/or the impervious cover of the development. The City may incorporate this program into a regional detention program that assesses a stormwater impact fee for projects within watersheds with a regional detention program as an option in lieu of on-site detention. Future efforts by the City will be needed to explore development and implementation of these options.

Green Infrastructure and Low Impact Development Examples

Green infrastructure, LID, and landscape-based stormwater management facilities are encouraged by the U.S. Environmental Protection Agency (EPA) and increasingly required as part of cities' MS4 permits. Examples of LID Integrated Management Practices (IMPs) include: bioretention and rain gardens, vegetated swales, vegetated filter strips, level spreaders, infiltration trenches, green roofs, and rainwater harvesting.

An example rain garden is illustrated in Figure 2A, which shows an overflow beehive inlet, typical rain garden vegetation, and educational signage to promote public knowledge and involvement. Rain gardens or bioretention provide shallow storage and are typically effective in mitigating peak flow and volume increases for smaller rainfall events. The stormwater quality performance of these facilities is outstanding due to the combination of biological, chemical, and physical processes as well as removal of flows from the receiving stream.

Figure 2A: Rain Garden at an Elementary School
(Glencoe Elementary, Portland, Oregon)

Figure 2B depicts bioretention along an urban roadway in Portland. The infiltration planter configuration shown here is ideal for urbanized roadway projects and retro-fits where space is at a premium. Lateral inlets convey stormwater runoff from the adjacent roadway into the stormwater planters, which are interconnected downstream. Excess runoff is returned to the City's storm sewer system. The sedge in these facilities is a typical low-maintenance bioretention plant, whereas trees are an option for the facilities depending on the design configuration.

Figure 2B: Bioretention Along an Urban Roadway
(Near Portland State University, Portland, Oregon)

Figure 2C depicts a vegetated swale during the winter in Seattle. This is a typical LID or green infrastructure feature used in public right-of-way (ROW) and is a good option for retro-fits where there is existing topography. While the vegetation is dormant during these months, evergreen plants may be used to provide year-round green vegetation. The concrete check dams and weirs are an important component to reduce velocities and prevent erosion with steeper slopes. Vegetated swales function similarly to bioretention, although their effect on peak flows, volume, and water quality tends to be reduced somewhat due to the speed of conveyance and reduced contact times.

Figure 2C: Vegetated Swale During Winter Months (Seattle Green Streets)

In portions of the City with loamy soils, infiltration and hydrologic mitigation may be accomplished through infiltration into the native soils or amended growing media. In portions of the City with clay-loam soils, this may be accomplished within amended growing media and regional design modifications including underdrain systems may be required.

Other LID hydrologic planning concepts include: cluster development with preserved open space (Figure 2D), site fingerprinting, lengthening time of concentration, reducing impervious cover, and reducing Curve Numbers through use of higher value vegetation (i.e., native grasses, trees, etc.). Future efforts by the City may be needed to develop specific criteria and design details and modifications for local hydrologic characteristics.

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Figure 2D: Cluster Development with Preserved Prairies and Open Space (Prairie Crossing, Grayslake, Illinois)

DOWNSTREAM IMPACTS ANALYSIS PROCESS

The downstream impacts process presented below is applicable for on-site and regional detention facilities. For those projects phased as part of a Master Plan development, the threshold acreages must be based on the area of the full Master Plan rather than the area of individual phases of development. To consolidate detention operations and improve efficiency and effectiveness, sub-regional and regional detention facilities should be considered. In some instances, cooperation between adjacent land owners or developers may be warranted to improve the overall stormwater management in the region.

Constructing multi-functional detention facilities is suggested and may include: stormwater quality measures (i.e., wet bottom ponds, wetland bottom ponds, native grasses/vegetation), recreational facilities (i.e., soccer fields, etc.), and trails around the detention facilities. The use of green infrastructure and LID measures is also recommended to reduce infrastructure costs, improve stormwater quality, and reduce erosion and sedimentation into the City's waterways.

Downstream Impacts Analysis Guidance

A downstream impacts analysis is required for all regional detention projects and all sites located in stream reaches that indicate a need to be evaluated in Appendix F. For small projects, the Simplified Downstream Impacts Method described in Attachment 1 is acceptable. For residential projects greater than 20 ac and commercial, high-density, or mixed use development projects greater than 10 ac, the Alternate Modeling Approach in Attachment 2 is required unless otherwise directed or approved by City staff and must be used both to determine the need for detention and to assess the effectiveness of the detention facility and outfall configuration. Note that large projects required to use the Alternate Modeling Approach may be required to extend the downstream impacts analysis past the ten-percent point described in Attachment 2. For Master Plan projects or phased projects, the total acreage must be used in determining the downstream impacts analysis methodology rather than the acreage of the individual phase under consideration. Attachment 3 includes step-by-step simplified downstream impacts analysis process examples.

Regional detention projects must always be evaluated using the Alternate Modeling Approach. The Engineer or City staff may also request the Alternate Modeling Approach for smaller, complex projects or those located in watersheds with flooding, erosion, or other specific issues. Additionally, the Engineer may elect to perform the Alternate Modeling Approach for smaller projects. Please note that this approach does not apply to those projects falling within the One Existing Lot and Small Lot categories defined in the *Unified Stormwater Design Guidelines*.

For projects located in watersheds where existing hydrologic and hydraulic models are not available (i.e., portions of Bee Creek, Burton Creek, Peach Creek and Foxfire Creek), the Engineer shall coordinate with City staff regarding availability of models and downstream impacts assessment requirements if models are not available at the time of the project.

RECOMMENDATIONS

The simplified process developed in this study provides an easy-to-implement tool for consultants with regards to determining whether detention is or is not required and for performing a Simplified Downstream Impacts Analysis. If implemented as proposed, it should assist the City in verifying that proposed detention facilities are located in appropriate portions of the watershed and function effectively to mitigate impacts to peak flows without downstream impacts during the required design storm events.

We also recommend the City implement the following items:

1. **Stormwater Mitigation:** We recommend that all projects within the City require stormwater mitigation in the form of regional detention, on-site detention, or on-site LID and water quality controls with the exception of those projects falling within the One Existing Lot and Small Lot categories defined in the *Unified Stormwater Design Guidelines*. However, the City may consider requiring lot-level controls (i.e., LID and water quality components) on these categories in the future.

2. **Stormwater Management Hierarchy:** In portions of watersheds served by regional detention facilities, we recommend implementation of an impact fee based on area of development or impervious area in lieu of on-site detention. For those projects located outside of a portion of a watershed served by regional detention, the need for on-site detention should be determined from the table included in Appendix F and the process outlined in this document. For projects not requiring on-site detention, incorporation of on-site stormwater management strategies such as LID and other water quality

components is recommended to mitigate hydrologic issues related to volume of runoff and flow duration.

3. **Regional Detention:** Implement regional detention to consolidate detention and maintenance operations and increase efficiency and effectiveness of flood control system. Regional detention facilities also offer opportunities for multi-functional facilities to provide recreational amenities and water quality features. These facilities can be used to mitigate developments requiring detention. Operation and maintenance costs may also be off-set with impact fees from developments not requiring detention that do not fully incorporate LID facilities.

4. **Low Impact Development:** For sites not requiring detention, LID facilities provide water quality treatment for mitigation of TSS and bacteria. They also reduce runoff volume, especially in frequent rainfall events that significantly impact water quality, erosion, and stream sedimentation. Future efforts by the City may be needed to develop LID criteria or guidelines for implementation. To further promote these techniques, demonstration or pilot projects on City facilities are typically beneficial and may even be required in future TPDES permits given the current trend towards this requirement.

5. **Alternate Modeling Approach:** For residential projects greater than 20 ac; commercial, high-density, or mixed used projects greater than 10 ac; or complex projects, the City may elect to require the Alternate Modeling Approach described above. In addition, developers and engineers may elect to use the Alternate Modeling Approach to demonstrate that detention is not required or that downstream impacts are not created as a result of the development. Additionally, large projects required to use the Alternate Modeling Approach may be required to extend the downstream impacts analysis past the ten-percent point described in Attachment 2.

6. **Non-Rigid Review Process:** Because the City does not have a complete, comprehensive, and current set of hydrologic and hydraulic models, a non-rigid review process may be warranted from some projects due to expected order of accuracy of the available models. For example, small projects, projects located in rural areas with minimal potential for flooding impacts, and projects in watersheds with excess capacity may benefit from this approach.

7. **Updated Watershed Studies:** To facilitate future detailed analyses, flood plain impacts studies, regional detention efforts, detention basin retro-fits and hydro-modifications, and comprehensive downstream impacts assessments, a current and complete set of hydrologic and hydraulic models is beneficial. Table 1 prioritizes updates qualitatively with high, medium, and low priority rankings. Upon completion of watershed model updates, the detention requirements included in Appendix F and the key hydrographs in Appendices C and D should be re-evaluated for that watershed.

Table 1: Watershed Modeling Updates Priority List

Watershed	Priority	Comments
Alum Creek	High	Significant development expected in watershed and only basic model available
Bee Creek	Medium	Moderate development expected in watershed, hydrologic models available for Tributary B and B3 only
Burton Creek	Medium	Redevelopment planned in Tributary C sub-watershed, hydraulic models recently updated, no hydrologic models available, only Tributary C falls within City limits
Carters Creek	Low	Models were recently updated
Foxfire Creek	Low	Watershed is not high priority for City, although no models currently available
Lick Creek	Medium	Significant development expected in watershed and overall watershed models not recently updated
Peach Creek	High	Significant development expected in watershed and no models currently available
Spring Creek	Low	Significant development expected in watershed and updated overall watershed models anticipated
Whites Creek	Low	Primarily located in TAMU limits and models available for tributary of interest to City
Wolf Pen Creek	Low	No significant development expected and models currently available

Because of the conceptual nature of this study, further detailed analysis may be warranted as updated models become available.

8. **Detention Basin Retro-Fit and Hydromodification Program:** The outfall structures on the majority of the detention basins within the City may not be effective during frequent rainfall events. In addition, dry detention basins typically perform poorly with regards to stormwater quality. In fact, many of the facilities within the City contribute sediment loads to receiving streams due to erosion within the basins. As such, we recommend the City consider a hydromodification plan to retro-fit outfall structures to mitigate smaller design storm events, such as the two-year event.

In addition, it may be beneficial to perform a detailed analysis of a few existing detention facilities to determine the operation and mitigation during a range of design storm events using stage hydrographs where appropriate rather than fixed tailwater. Of further benefit is a watershed study of the combined operation of existing detention basins within the watershed, which may be performed in HEC-HMS or HEC-RAS unsteady flow.

Watersheds, such as Wolf Pen Creek are ideal candidates as HEC-HMS models are available for the watershed and there are currently a significant number of detention basins in operation due to the level of development within these watersheds. Carters Creek may also be an option; however, the level of effort may be greater as it is a larger watershed. Although Lick Creek and Spring Creek have a great deal of undeveloped areas, if multiple detention basins are currently in operation in these watersheds, they may also be possible candidates as comprehensive HEC-HMS models are available.

While analysis of specific basins with appropriate tailwater, unit hydrograph, and rainfall conditions is needed to accurately determine the effects of outlet modification, it is likely that modifications to the outlet structures will enhance mitigation during a range of rainfall events as well as public perception of the efficacy of the facilities.

Furthermore, incorporation of native grasses and vegetation, wet bottom ponds, or wetlands vegetation may significantly improve the stormwater quality performance while reducing regular operation and maintenance of the facilities associated with on-going mowing programs. Such improvements also enhance aesthetics, recreational, and environmental benefits and convert single-purpose stormwater management facilities into multi-functional features for the community. Additional detailed recommendations on stormwater quality are provided in the Regional Detention report submitted as part of this project.

We appreciate the opportunity to assist with this important project to shape future stormwater management within the City. Please do not hesitate to contact me at 832.444.0663 with any questions.

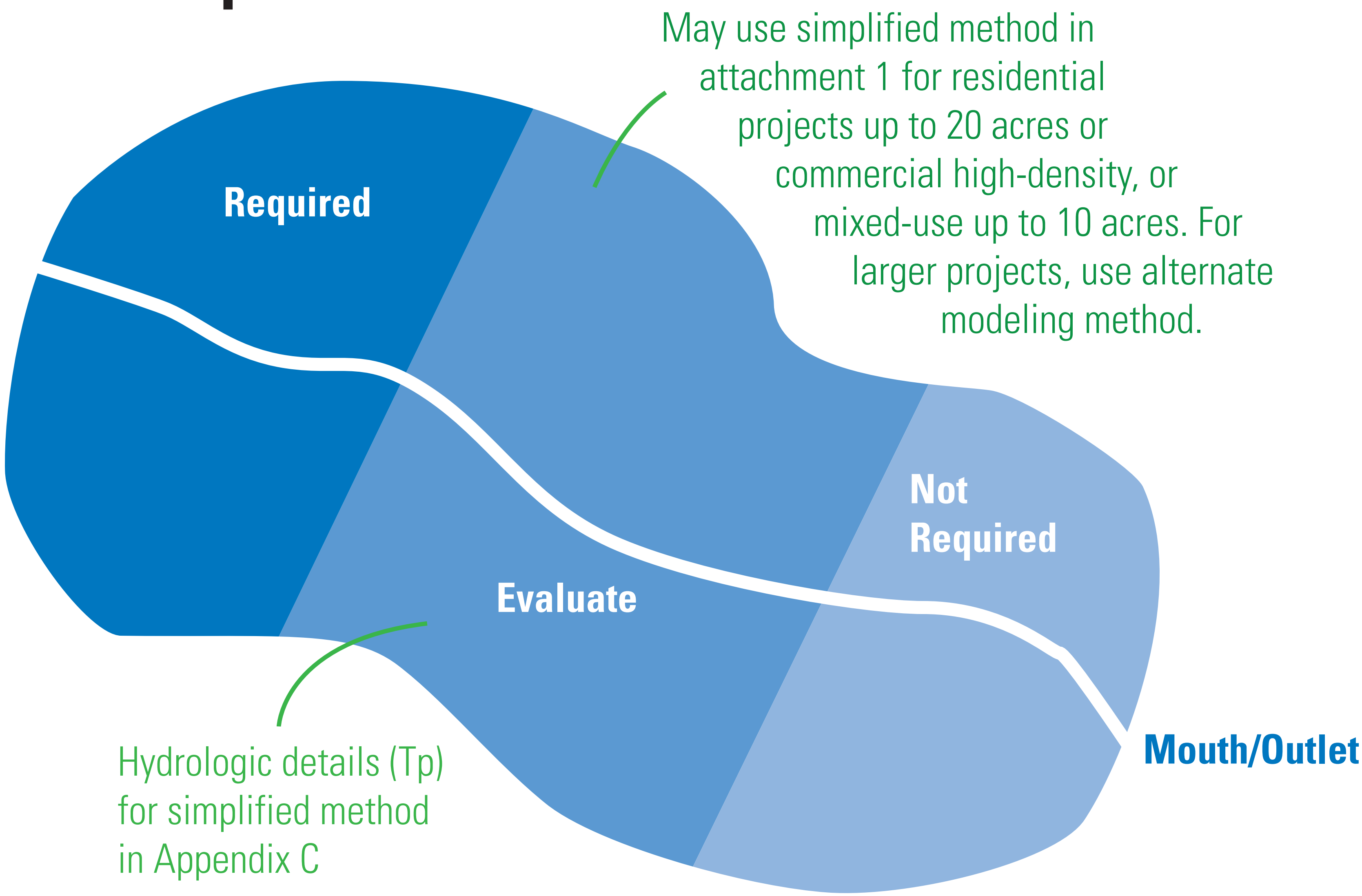
Sincerely,

Jennifer J. Walker

Jennifer J. Walker, PE, D.WRE, CFM
President
Watearth, Inc.

FIGURE 1– WATERSHED TYPE 1 DETENTION REQUIREMENTS

Figure 1 Watershed Type 1 Detention Requirements



Note: Need for Type 2 Conveyance Detention should be evaluated for projects not located adjacent to stream listed in Appendix F

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ATTACHMENT 1 – SIMPLIFIED DOWNSTREAM IMPACTS ANALYSIS PROCESS

ATTACHMENT 1 – SIMPLIFIED DOWNSTREAM IMPACTS PROCESS

For residential projects up to 20 ac or commercial, high-density, or mixed use development projects up to 10 ac requiring a downstream impacts evaluation from Appendix F, the Simplified Downstream Impacts Method is outlined below and illustrated in Figure 1-1.

1. **Check Need for Evaluation:** Check need for evaluation for Type 1 Flood Control Detention by comparing location of project within watershed to table contained in Appendix F. If project falls within stream reach designated as Required or Not Required, check need for Type 2 Conveyance Management Detention. Otherwise, if project falls within stream reach designated as Evaluate, proceed to Step 2 or the Alternate Modeling Method. Note that this Simplified Downstream Impacts Process is an approximation and is only for use in stream reaches designated as Evaluate. If the responsible engineer elects to evaluate other sections, the Alternate Modeling Method is a more accurate method and should be used.

2. **Identify Nearest Key Hydrograph Location and Time to Peak in Stream:** Determine project watershed (Figure E-1, Appendix E) and identify nearest key hydrograph location to the proposed point of outfall from table in Appendix C and associated Time to Peak in Stream (TPstream). The nearest key hydrograph will either be the closest hydrograph location upstream of the discharge point or the closest hydrograph location downstream of the discharge point. For points-of-outfall located more than 1,000 feet (ft) from the nearest key hydrograph location or equi-distant between two key hydrograph locations (i.e., upstream and downstream of the site), use the location with the shortest Time to Peak. Alternatively, the Engineer may elect to interpolate the TPstream at the point-of-outfall from Appendix C or determine a more exact TPstream from a closer node in the hydrologic model.

3. **Identify Downstream Ending Point and Time to Peak Downstream:** Identify Downstream Ending Point for analysis. Select the next key hydrograph location downstream of the Nearest Key Hydrograph location. Note Time to Peak Runoff at Downstream Ending Point (TPdownstream) from the table in Appendix C. Where the Nearest Key Hydrograph location is the mouth of the stream, use the first Key Hydrograph Location in the receiving stream as the Downstream Ending Point.

   Alternatively, the Engineer may elect to use the 10% Method to determine the 10% Point, which may be used as the Downstream Ending Point. See Alternate Modeling Approach and Downstream Impacts Example for details on the 10% Method and determining 10% Point. Please note that the nearest key hydrograph location downstream should be used even if it is located farther downstream than the 10% Point.

4. **Determine Approximate Initial Time to Peak from Site:** Determine Approximate Initial Time to Peak Runoff from Site (TPsiteinitial) from Table 1-1 based on watershed.

Table 1-1: Approximate Initial Time to Peak Runoff from Site (TPsiteinitial) by Watershed

Watershed	Peak Center of Rainfall in Hydrologic Model (hr)	TPsiteinitial (hr)
Alum Creek	14.0	14.25
Bee Creek	12.0	12.75
Carters Creek	12.0	12.50
Lick Creek	14.0	14.25
Spring Creek	12.0	12.75
Whites Creek	12.0	12.50
Wolf Pen Creek	12.0	12.50

Please note this determination is based solely on rainfall pattern and location of peak center contained within meteorological model of the hydrologic model for the City's watersheds. The TPsiteinitial is not the time of concentration (Tc) and should not be confused with the Rational Method or Triangular Hydrograph Method values. It is based on a 24-hour synthetic design storm event and is applicable for residential projects up to 20 ac or commercial, high-density, or mixed use development projects up to 10 ac only and should not be used for larger projects. Future model revisions that modify rainfall patterns and/or distribution may require revisions to this table.

The TPsiteinitial was estimated as the peak center of rainfall in each watershed plus an assumed Tc for projects within this size range. Alternatively, the Engineer may elect to add the calculated Tc for the project under developed conditions plus the peak center of rainfall listed in Table 1-1.

The Engineer may also elect to model the project area under proposed conditions without detention to determine a more precise TPsiteinitial, which may be advantageous for some projects. The meteorological data contained in the models included on the CD in Appendix G must be used to maintain consistency with the rainfall pattern. At the discretion of the Engineer or as directed by City staff, pre- and post-development hydrographs may be computed for the site for the various design storm events and compared to the hydrograph in the receiving stream.

5. **Determine Adjusted Time to Peak from Site:** Adjust TPsiteinitial to account for travel time for projects that are not located adjacent to the primary receiving stream. Estimate travel time through proposed conveyance route based on travel time methods and guidelines included in the *Unified Stormwater Guidelines*, HEC-RAS hydraulic

modeling, or other modeling methods approved in advance by City staff. Add travel time to TPsiteinitial to obtain Adjusted Time to Peak from Site (TPsiteadjusted). For projects located adjacent to the primary receiving system, the TPsiteadjusted is the same as the TPsiteinitial.

This adjustment accounts for the lagging of the runoff hydrograph (i.e., travel time) and neglects attenuation (dampening of peak flow) that may occur, since the timing is of more significance in this method than the magnitude of the peak flow. At the discretion of the Engineer or as directed by City staff, pre- and post-development hydrographs may be computed for the site for the various design storm events and compared to the hydrograph in the receiving stream.

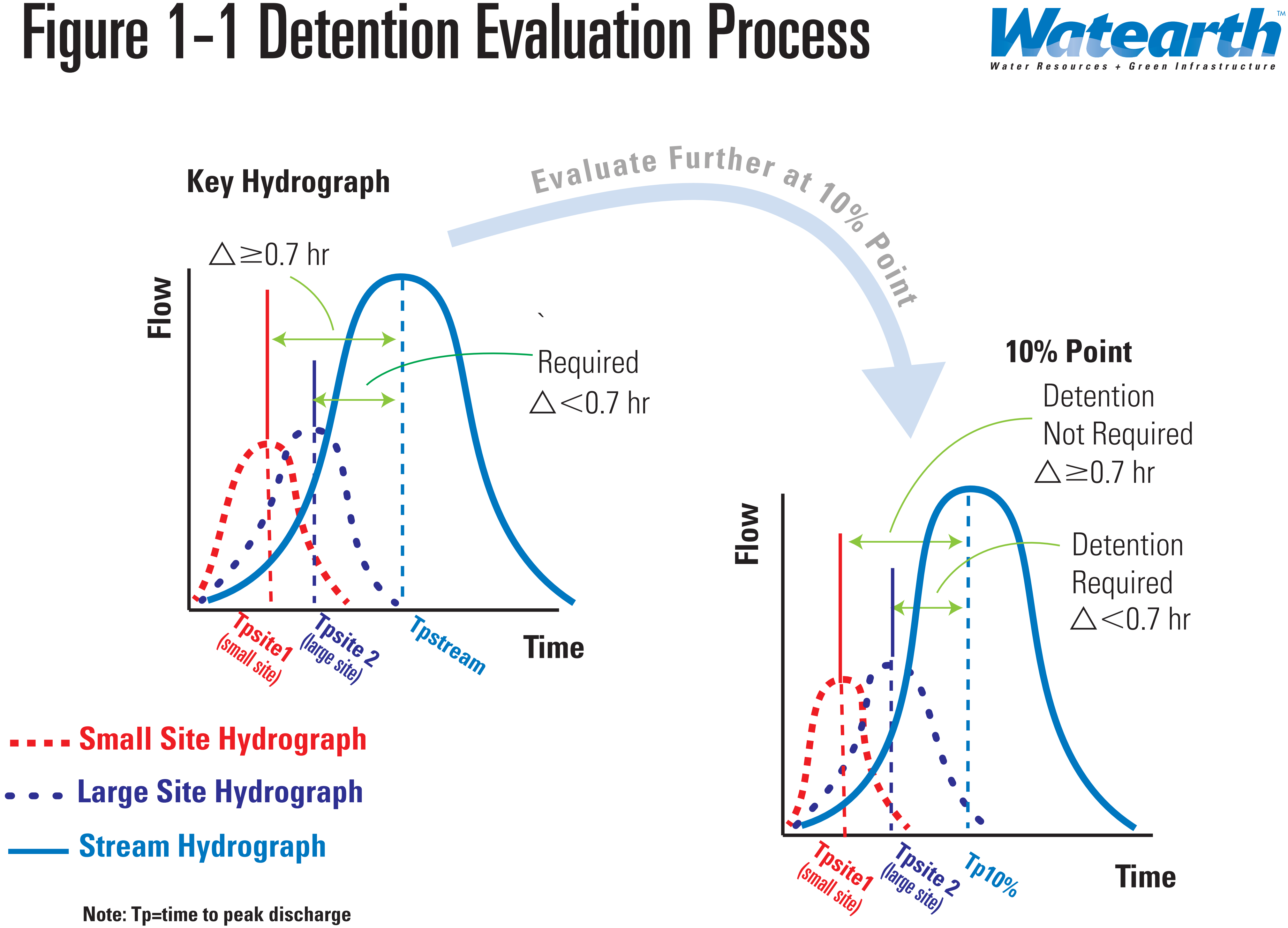
6. **Compare Times to Peak:** Compare TPsiteadjusted with TPstream at key hydrograph location nearest to point of discharge identified above. For differences less than 0.7 hours (hr), detention is required or the engineer may elect to use the more accurate Alternate Modeling Method. If the TPsiteadjusted is greater than or equal to the TPstream, detention is also required. For differences equal to or greater than 0.7 hr, detention may not be required pending the results of the time to peak comparison at the Downstream Ending Point.

7. **Estimated Time to Peak at Downstream Ending Point:** Estimate Time to Peak at Downstream Ending Point (TPsitedsend) identified above. Use average travel time from Appendix B, velocities from HEC-RAS hydraulic models for specific stream reaches, or other method approved in advance by City staff to estimate travel time from point-of-outfall downstream to the Downstream Ending Point. For distances from point-of-outfall to the Downstream Ending Point greater than 1,000 ft, Engineer must use velocities from HEC-RAS hydraulic models for specific stream reaches, or other method approved in advance by City staff. Add estimated travel time to Adjusted Time to Peak (TPsiteadjusted) to obtain Time to Peak at Downstream Ending Point (TPsitedsend).

8. **Compare Times to Peak Downstream:** Compare Time to Peak at Downstream Ending Point (TPsitedsend) with Time to Peak in Stream at Downstream Ending Point (TPstreamdsend). For differences equal to or greater than 0.7 hrs, detention is not required. For differences less than 0.7 hrs, detention is required or the engineer may elect to use the more accurate Alternate Modeling Method. If the TPsiteadjusted is greater than or equal to the TPstreamdsend, detention is also required.

The need for Type 2 Conveyance Management Detention should also be evaluated for developments that are not located adjacent to the primary receiving stream. Even though Type 1 Flood Control Detention may not be required, Type 2 Conveyance Management Detention may be needed.

Figure 1-1 Detention Evaluation Process



Note: Tp=time to peak discharge

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ATTACHMENT 2– ALTERNATE MODELING APPROACH

ATTACHMENT 2 – ALTERNATE MODELING APPROACH

Alternatively, a detailed downstream impacts/watershed impacts assessment may be warranted or required to more accurately assess the effectiveness of the detention facility and outfall configuration and potential for downstream impacts with and without detention. For regional detention projects; residential projects greater than 20 ac; and commercial, high-density, or mixed use development projects greater than 10 ac; this methodology is required for all projects unless otherwise directed or approved by City staff. In addition, this methodology may be performed at the Engineer's discretion or as requested by City staff for smaller developments.

The Alternate Modeling Approach must be performed within current HEC-1 or HEC-HMS hydrologic models for the associated watershed. The City may also accept watershed impacts analyses in other comprehensive watershed models, such as SWMM/XP-SWMM/PC-SWMM or HEC-RAS unsteady flow with prior coordination. During this analysis, the proposed development is modeled as an isolated drainage area in existing and proposed conditions to determine the downstream impacts to peak flows associated with the development. For developments not located adjacent to the receiving system, hydrographs must be routed to the receiving system and the need for Type 2 Conveyance Management detention assessed by the Engineer.

This approach utilizes the City's current design storm events and rainfall depths/patterns. Methods such as the Rational Method or other simplified hydrograph methods are not acceptable for use in this approach. Furthermore, the use of appropriate tailwater conditions is critical to the validity of this approach. Typically, a fixed tailwater condition is not adequate in cases with outlet control.

The 10% Method is used for determining the downstream stopping point for the Alternate Modeling Approach analysis. The 10% Method assumes that each development drainage area influences steam hydrology downstream to a point where the project drainage area is 10% of the total additional area beyond the discharge location contributing to that point (i.e., 10% Point). As a result, the drainage area upstream of the development is not included in this calculation. For example, a 200 ac development that discharges at a point where the total contributing drainage area is 1,000 ac has a 10% point downstream of the discharge where an additional 1,800 ac contributes for a total of 3,000 ac (i.e., 200 ac + 1,800 ac + 1,000 ac). An example including the 10% Method is illustrated in the Downstream Impacts Example.

Because of the size of the City's watersheds, the 10% Point for many developments may extend beyond the mouth of the receiving stream. In this case, the downstream impacts analysis may be stopped at the mouth of the receiving stream (i.e, confluence with Carter's Creek, etc.). However, this downstream impacts check may be carried further downstream at the discretion of the Engineer or City staff, especially for larger projects. Additionally, regional detention projects must extend the downstream impacts analysis to the mouth of the receiving stream(s) served by the facility.

The peak flows for the required design storm events must be compared at each critical point as well as the hydrographs to verify that peak flows and peak flow durations are not increased during the studied design storm events. Critical points are defined as:

- Development discharge location
- 10% Point, or downstream ending point
- Downstream confluences
- Other points with hydraulic or hydrologic issues (i.e., excessive erosion, high velocities, flooding, etc.)

ATTACHMENT 3 – SIMPLIFIED DOWNSTREAM IMPACTS ANALYSIS EXAMPLES

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ATTACHMENT 3 – SIMPLIFIED DOWNSTREAM IMPACTS EXAMPLES

Note that the Simplified Downstream Impacts Process described in Attachment 1 and illustrated in the examples below is an approximation and is only for use in stream reaches designated as Evaluate. If the responsible engineer elects to evaluate other sections, the Alternate Modeling Method is a more accurate method and should be used.

The examples below illustrates the step-by-step process for utilizing the Simplified Downstream Impacts Analysis methodology to determine the need for Type 1 Flood Control Detention for projects located in the Evaluation Required portion of a stream.

Example 1: Project < 1,000 ft from Key Hydrograph Location

Simplified Downstream Impacts Analysis to Evaluate Need for Type 1 Flood Control Detention for 10-acre Commercial and Mixed-Use Development in Spring Creek Watershed

- 10-acre commercial and mixed-use development
- Located adjacent to Spring Creek on the upstream (west) side of SH 6 with frontage to SH6 and immediately adjacent to and south of Spring Creek
- Assume Type 2 (Conveyance) Detention not required for this example
- Simplified Downstream Impacts Analysis acceptable due to project size to evaluate need for Type 1 (Flood Control) Detention

1. **Check Need for Evaluation:**

   - Located in stream reach designated as Evaluate, proceed to Step 2

2. **Identify Nearest Key Hydrograph Location:**

   - Located in Spring Creek watershed (Figure E-8, Appendix E)
   - Nearest key hydrograph location to the proposed point of outfall = Confluence Trib. 4 @ SH 6 (Node J8) from table in Appendix C
   - Located < 1,000 feet (ft) from Key Hydrograph Location, Thus Use Closest Location
   - Time to Peak Runoff (TPstream) = 13.93 hours (hr) from Appendix C
   - Drainage Area = 2.868 square miles (mi^2), or 1,836 acres (ac)

3. **Identify Downstream Ending Point and Time to Peak Downstream (TPstreamdsend):**

   - Downstream Ending Point = Point Where Project Drainage Area = 10% of Total Additional Area Beyond Discharge Location Contributing to That Point (Do Not Include Upstream Drainage Area):
     - 10 ac = 10% of 100 ac
     - 10% Point = Location with Additional 100 ac

- Total Drainage Area = 100 ac + 1,836 ac = 1,936 ac (3.025 mi^2)

Nearest key hydrograph location downstream of Downstream Ending Point = Mouth/Confluence with Lick Creek (Node ToLC) from table in Appendix C (Drainage Area = 3.782 mi^2, or 2,420 ac).

- TPstreamdsend= 14.97 hr from Appendix C

4. **Determine Approximate Initial Time to Peak from Site:** Determine Approximate Initial Time to Peak from Site (TPsiteinitial) from Table 1-1 in Attachment 1 based on watershed.

- TPsiteinitial = 12.75 hr from Table 1-1

5. **Determine Adjusted Time to Peak from Site (TPsiteadjusted):**

- Located adjacent to primary receiving system (i.e., Spring Creek)
- TPsiteadjusted= 12.75 hr (same as TPsiteinitial)

6. **Compare Times to Peak:**

- TPsiteadjusted = 12.75 hr from Step 5 above
- TPstream at key hydrograph location = 13.93 hr from Step 2 above
- Difference = 13.93 hr – 12.75 hr = 1.18 hr
- Difference > 0.7 hr, thus detention may not be required pending Steps 7 and 8

7. **Estimated Time to Peak at Downstream Ending Point (TPsitedsend):**

- Distance from point-of-discharge to Downstream Ending Point estimated at 11,149 ft from upstream face of SH 6 west frontage road bridge to mouth of Spring Creek from HEC-RAS model
- Average Travel Time from Appendix B for stream reach identified as SPRING CREEK-LOWER BELOW TRIB. 4 TO MOUTH = 3.0 miles/hour (mi/hr)
- Estimated Travel Time = (11,149 ft/5,280 ft/mi)/(3.0 mi/hr) = 0.70 hrs
- TPsitedsend = Estimated Travel Time + TPsiteadjsuted = 0.70 hr + 12.75 hr = 13.45 hr

8. **Compare Times to Peak at Downstream:**

- TPsitedsend = 13.45 hr from Step 7 above
- TPstreamdsend = 14.97 hrs from Step 3 above
- Difference = 14.97 hr – 13.45 hr = 1.52 hr
- Difference > 0.7 hr, thus **DETENTION IS NOT REQUIRED FOR PROJECT**

Example 2: Project > 1,000 ft from Key Hydrograph Location

Simplified Downstream Impacts Analysis to Evaluate Need for Type 1 Flood Control Detention for 10-acre Commercial and Mixed-Use Development in Spring Creek Watershed

- 10-acre commercial and mixed-use development
- Located adjacent to Spring Creek upstream of the upstream (west) side of SH 6
- Assume Type 2 (Conveyance) Detention not required for this example
- Simplified Downstream Impacts Analysis acceptable due to project size to evaluate need for Type 1 (Flood Control) Detention

1. **Check Need for Evaluation:**

    - Located in stream reach designated as Evaluate, proceed to Step 2

2. **Identify Nearest Key Hydrograph Location:**

    - Located in Spring Creek watershed (do not attempt to locate site on Figure E-8, Appendix E as this as an example only and does not represent an actual site)
    - Nearest key hydrograph location to the proposed point of outfall = Confluence Trib. 4 @ SH 6 (Node J8) from table in Appendix C
    - Assume for this example: located > 1,000 ft from Key Hydrograph Location, Thus Use Key Hydrograph Location with Shortest Time to Peak Runoff for TPstream
    - TPstream = 13.90 hours (hr) from Appendix C (Use Shortest Time to Peak Runoff From Upstream (J4) and Downstream (J8) Nodes Since Assumed to be > 1,000 ft from Key Hydrograph Location
    - Drainage Area = 2.868 square miles (mi^2), or 1,836 acres (ac) (based on nearest downstream node, J8)

    **Note that the Drainage Area is based on the nearest key hydrograph and not the location with the shortest time to peak when site is over 1,000 feet from the key hydrograph location, or located equidistant between two key hydrograph locations. In this case, the downstream node identified in #3 below is actually downstream from the nearest drainage basin node, not the one with shortest time to peak.*

3. **Identify Downstream Ending Point and Time to Peak Downstream (TPstreamdsend):**

    - Downstream Ending Point = Point Where Project Drainage Area = 10% of Total Additional Area Beyond Discharge Location Contributing to That Point (Do Not Include Upstream Drainage Area):
        - 10 ac = 10% of 100 ac
        - Downstream Ending Point = Location with Additional 100 ac
        - Total Drainage Area = 100 ac + 1,836 ac = 1,936 ac (3.025 mi^2)

- Nearest key hydrograph location downstream of Downstream Ending Point = Mouth/Confluence with Lick Creek (Node ToLC) from table in Appendix C (Drainage Area = 3.782 mi^2, or 2,420 ac)
- TPstreamdsend = 14.97 hr from Appendix C

4. **Determine Approximate Initial Time to Peak from Site:** Determine Approximate Initial Time to Peak from Site (TPsiteinitial) from Table 1-1 in Attachment 1 based on watershed.

- TPsiteinitial = 12.75 hr from Table 1-1

5. **Determine Adjusted Time to Peak from Site (TPsiteadjusted):**

- Located adjacent to primary receiving system (i.e., Spring Creek)
- TPsiteadjusted = 12.75 hr (same as TPsiteinitial)

6. **Compare Times to Peak:**

- TPsiteadjusted = 12.75 hr from Step 5 above
- TPstream = 13.90 hr from Step 2 above
- Difference = 13.90 hr – 12.75 hr = 1.15 hr
- Difference > 0.7 hr, thus detention may not be required pending Steps 7 and 8

7. **Estimated Time to Peak at Downstream Ending Point (TPsitedsend):**

- Distance from point-of-discharge to Downstream Ending Point estimated at (11,149 ft from upstream face of SH 6 west frontage road bridge to mouth of Spring Creek from HEC-RAS model + 2,000 ft)
- Average Travel Time from Appendix B for stream reach identified as SPRING CREEK-UPPER ABOVE TRIB. 4 TO TRIB. 5 = 4.4 miles/hour (mi/hr)
- Average Travel Time from Appendix B for stream reach identified as SPRING CREEK-LOWER BELOW TRIB. 4 TO MOUTH = 3.0 miles/hour (mi/hr)
- Estimated Travel Time = [(11,149 ft/5,280 ft/mi)/(3.0 mi/hr)] + [(2,000 ft/5,280 ft/mi)/4.4 mi/hr) = 0.79 hrs
- TPsitedsend = Estimated Travel Time + Adjusted Time to Peak = 0.79 hr + 12.75 hr = 13.54 hr

8. **Compare Times to Peak Downstream:**

- TPsitedsend = 13.54 hr from Step 7 above
- Time to Peak in Stream at Downstream Ending Point (TPstreamdsend) = 14.97 hrs from Step 3 above
- Difference = 14.97 hr – 13.54 hr = 1.43 hr
- Difference > 0.7 hr, thus **DETENTION IS NOT REQUIRED FOR PROJECT**

Example 3: Project Located On Tributary Channel

Simplified Downstream Impacts Analysis to Evaluate Need for Type 1 Flood Control Detention for 10-acre Commercial and Mixed-Use Development in Spring Creek Watershed

- 10-acre commercial and mixed-use development
- Located approximately 750 ft away from Spring Creek (i.e., drains to a tributary and not directly to main stem) between the confluence with Spring Creek Trib. 7 and Spring Creek Trib. 6
- Located closest to confluence with Trib. 6 (discharges into Trib. 6 approximately 750 ft upstream of confluence with Spring Creek); no model for Trib. 6
- Assume Type 2 (Conveyance) Detention not required for this example
- Simplified Downstream Impacts Analysis acceptable due to project size to evaluate need for Type 1 (Flood Control) Detention

1. **Check Need for Evaluation:**

   - Located in stream reach designated as Evaluate, proceed to Step 2

2. **Identify Nearest Key Hydrograph Location:**

   - Located in Spring Creek watershed (Figure E-8, Appendix E)
   - Downstream and Upstream key hydrograph locations to the proposed point of outfall = Confluence Trib. 7 (Node J2) and Confluence Trib. 6 (Node J@Endof A4) from table in Appendix C
   - Located closest to Trib. 6
   - TPstream = 14.03 hours (hr) from Appendix C (J@Endof A4)
   - Drainage Area = 2.133 square miles (mi^2), or 1,365 acres (ac) (based on nearest node, J8)

3. **Identify Downstream Ending Point and Time to Peak Downstream (TPstreamdsend):**

   - Downstream Ending Point = Point Where Project Drainage Area = 10% of Total Additional Area Beyond Discharge Location Contributing to That Point (Do Not Include Upstream Drainage Area):
     - 10 ac = 10% of 100 ac
     - Downstream Ending Point = Location with Additional 100 ac
     - Total Drainage Area = 100 ac + 1,365 ac = 1,465 ac (2.2891 mi^2)
   - Nearest key hydrograph location downstream of Downstream Ending Point = Confluence with Spring Creek Trib. 5 (Node J4) from table in Appendix C (Drainage Area = 2.426 mi^2, or 1,553 ac)
   - TPstreamdsend = 13.90 hr from Appendix C

4. **Determine Approximate Initial Time to Peak from Site:** Determine Approximate Initial Time to Peak from Site (TPsiteinitial) from Table 1-1 in Attachment 1 based on watershed.

   - TPsiteinitial = 12.75 hr from Table 1-1

5. **Determine Adjusted Time to Peak from Site (TPsiteadjusted):**

   - Located 750 ft away from primary receiving system (i.e., Spring Creek)
   - Travel Time = [(750 ft)/(2.80 ft/sec)]/[(60 sec/min)(60 min/hr)] = 0.07 hr (4.5 min)
   - TPsiteadjusted = 12.75 hr + 0.07 hr = 12.82 hr

6. **Compare Times to Peak:**

   - TPsiteadjusted = 12.82 hr from Step 5 above
   - TPstream = 14.03 hr from Step 2 above
   - Difference = 14/03 hr – 12.82 hr = 1.21 hr
   - Difference > 0.7 hr, thus detention may not be required pending Steps 7 and 8

7. **Estimated Time to Peak at Downstream Ending Point (TPsitedsend):**

   - Distance from point-of-discharge to Downstream Ending Point estimated at (1,550 ft from confluence with Trib. 6 to confluence with Trib. 5 + 400 ft) = 1,950 ft
   - Average Travel Time from Appendix B for stream reach identified as MAIN SPRING CREEK BETWEEN CONLFUENCE TRIB 7 & TRIB 6 = 3.9 miles/hour (mi/hr)
   - Average Travel Time from Appendix B for stream reach identified as MAIN BETWEEN TRIB. 6 AND TRIB. 5 = 4.1 miles/hour (mi/hr)
   - Estimated Travel Time = [(400 ft/5,280 ft/mi)/(3.9 mi/hr)] + [1,550 ft/5,280 ft/mi)/4.1 mi/hr) = 0.09 hrs
   - TPsitedsend = Estimated Travel Time + Adjusted Time to Peak = 0.09 hr + 12.82 hr = 12.91 hr

8. **Compare Times to Peak Downstream:**

   - TPsitedsend = 12.91 hr from Step 7 above
   - Time to Peak in Stream at Downstream Ending Point (TPstreamdsend) = 13.90 hrs from Step 3 above
   - Difference = 13.90 hr – 12.91 hr = 0.99 hr
   - Difference > 0.7 hr, thus **DETENTION (TYPE 1) IS NOT REQUIRED FOR PROJECT**

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APPENDIX A – SUMMARY OF MODELS USED FOR PROJECT

APPENDIX A-1: SUMMARY OF HYDROLOGIC MODELS USED FOR PROJECT

Watershed	Hydrologic Model			
	Name	Source	Type	Comments
Alum Creek	Lick_Creek	City - Lick Creek 2000 LOMR	HEC-HMS	In Lick Creek Model - Converted HEC-1 to HMS
Bee Creek	Bee_Creek_Trib_B	FEMA - Bee Creek 2006 LOMR	HEC-HMS	Includes Trib. B + Trib. B.3 as Area, Simple Model + 2 Galveston County Models
Burton Creek Trib. C	---	---	---	No Hydrology Model Available
Burton Creek Unnamed Trib. To Trib. C	---	---	---	No Hydrology Model Available
Carters Creek	Carters HMS	City 2007 Flood Hazard Study	HEC-HMS	Updated, Geo-Referenced, Entire Watershed
Carters Creek Trib. B	---	---	---	---
Carters Creek Trib. 18.6	---	---	---	---
Foxfire Creek	---	---	---	No Model Available
Lick Creek	Lick_Creek	City - Lick Creek 2000 LOMR	HEC-HMS	Converted HEC-1 to HEC-HMS
Peach Creek	---	---	---	No Model Available
Spring Creek	Spring Creek	Walter P. Moore 2010 LOMR	HEC-HMS	Updated, Geo-Referenced Includes Tribs. 5, 7, & 7.1, Used Exist. Conditions
Whites Creek	Report 2 White Creek\whites_creek_new_new.hms	Dodson Associates 2007 LOMR	HEC-HMS	Used Proposed Conditions Project Model, Includes Unnamed Tributary
Whites Creek Unnamed Trib.	---	---	---	---
Wolf Pen Creek	Meridian_LOMR_HMS	Mitchell + Morgan 2007 LOMR	HEC-HMS	Includes Trib. C + Trib. A & B Drainage Areas, Used WPC Exist 100-yr
Wolf Pen Creek Trib. A	---	---	---	---
Wolf Pen Creek Trib. C	---	---	---	---

APPENDIX A-2: SUMMARY OF HYDRAULIC MODELS USED FOR PROJECT

Watershed	Hydraulic Model			
	Name	Source	Type	Comments
Alum Creek	---	---	---	No Model Available
Bee Creek	BeeMay2010	Mitchell + Morgan 2010 LOMR	HEC-RAS	Dexter Avenue to Confluence with Carters Creek
Bee Creek Trib. A	BeeMay2010	Mitchell + Morgan 2010 LOMR	HEC-RAS	Texas Avenue to Confluence with Bee Main (D/S of SH6 East Bypass)
Bee Creek Trib. B	BeeMay2010	Mitchell + Morgan 2010 LOMR	HEC-RAS	Approximately 760 feet upstream of FM2818 and Welsh to Confluence with Bee Main (D/S of Southwood St. Bridge)
Bee Creek Unnamed Trib. To Trib. B	BeeMay2010	Mitchell + Morgan 2010 LOMR	HEC-RAS	Just upstream of Lancelot Circle to the confluence with Bee Creek Tributary B
Burton Creek Trib. C	Existing Conditions Trib C	Kling Engineering 2007 LOMR	HEC-RAS	Updated, Geo-referenced, model extents not indicated
Burton Creek Unnamed Trib. To Trib. C	Post-Project Model BCT_O7F	Kling Engineering 2007 LOMR	HEC-RAS	Updated, not Geo-referenced, model extents not indicated
Carters Creek	Carters Creek FHS	City 2007 Flood Hazard Study	HEC-RAS	2500 ft upstream of Old Reliance to 3600 ft downstream of Harvey Road (SH 30), Updated, Geo-referenced
Carters Creek Trib. B	Carters Creek Tributary B FHS	City 2007 Flood Hazard Study	HEC-RAS	Upstream of E. SH 21 to Confluence with Carters Creek, Updated, Geo-referenced (Outside City Limits)
Carters Creek Trib. 18.6	Carters Tributary 18.6 FHS	City 2007 Flood Hazard Study	HEC-RAS	1.3 Miles Upstream of Old Reliance to Confluence with Carters Creek, Updated, Geo-referenced (Outside City Limits)
Foxfire Creek	---	---	---	No Models Available
Lick Creek	LC2000	City - Lick Creek 2000 LOMR	HEC-RAS	Includes North Fork and South Fork and Main Stem of Lick Creek, Old HEC-2 Model Converted to HEC-RAS
Peach Creek	---	---	---	No Models Available
Spring Creek	SpringCreek	Walter P. Moore 2010 LOMR	HEC-RAS	Updated, Geo-referenced, Includes Trib. 7, 7.1, 6, 5, 5.1, & 4 labeled as A2-A, A2-B, A3, B2, B1, & C
Whites Creek	---	---	---	No Models Available
Whites Creek Unnamed Trib.	Report 2 HEC-RAS White Creek\unnamed stream	Dodson Associates 2007 LOMR	HEC-RAS	Includes Unnamed Tributary and Tribs. 1, 2, and 3 to Unnamed Tributary
Wolf Pen Creek	Wolf Pen Creek Main	Mitchell + Morgan 2007 LOMR	HEC-RAS	From George Bush Drive Downstream - Old HEC-2 Converted to HEC-RAS
Wolf Pen Creek Trib. A	CHillsJune08	Mitchell + Morgan 2007 LOMR	HEC-RAS	Ends at FIS XS J at Downstream End
Wolf Pen Creek Trib. C	WPCTribC1207	Mitchell + Morgan 2007 LOMR	HEC-RAS	Appears to End at Mouth of Stream

APPENDIX B – SUMMARY OF HYDRAULIC EVALUATIONS

APPENDIX B: SUMMARY OF HYDRAULIC EVALUATIONS

Watershed	Model Name	Source	Evaluated Portion	Stream Slopes	Average Velocity (fps)	Event Out of Banks	Avg. Travel Time (mi/hr)
Alum Creek							
NO HYDRAULIC MODELS AVAILABLE							
Bee Creek							
Bee Creek Main	BeeMay2010	City	Entire Reach in Model - Dexter to Confluence Carters	0.33%	3.80	10% lower, in banks upper	2.6
Bee Creek Trib. A	BeeMay2010	City	Entire Reach in Model - Texas Avenue to Confluence with Bee Main (D/S of SH6 East Bypass)	0.28%	4.57	all events (10%+)	3.1
Bee Creek Trib. B	BeeMay2010	City	Entire Reach in Model - Approximately 760 feet upstream of FM2818 and Welsh to Confluence with Bee Main (D/S of Southwood St. Bridge)	0.27%	4.73	all events (10%+)	3.2
Burton Creek Trib. C							
Burton Creek Trib. C	Trib C	City	Entire Reach	0.50%	3.44	10-yr below Texas, in-banks above Texas Ave.	2.3
Burton Creek Unnamed Tributary	Post-Project Model BCT_O7F	2007 LOMRs	Entire Reach - slope is flat in middle and 1.28% near mouth	0.38%	3.04	100-yr out throughout - no smaller events modeled%	2.1
Carters Creek							
Carters Creek	CartersRAS	2007 Study	Briar Creek (XS 24,260) to Mouth	0.12%	5.6	10%	3.8
Lick Creek							
LICK CREEK MAIN - FEMA X-SECT	LICK2000 Proposed Model LC2000	City	Entire Reach from Mouth to Confluence North & South Forks	0.16%	2.8	100-YR OUT OF BANKS (NO OTHER EVENTS INCLUDED)	1.9
N.F. LICK CREEK - N.F. Main (MAIN LICK CREEK U/S CONFLUENCE WITH TRIB. 13)	LICK2000 Proposed Model LC2001	City	Entire Reach from Mouth to U/S End	1.18%	3.6	100-YR OUT OF BANKS (NO OTHER EVENTS INCLUDED)	2.4
S.F. LICK CREEK - S.F. Main (TRIB. 13 TO CONFLUENCE WITH TRIB. 13.1)	LICK2000 Proposed Model LC2002	City	Entire Reach from Mouth to Confluence Trib. 13.1	0.35%	3.7	100-YR OUT OF BANKS (NO OTHER EVENTS INCLUDED)	2.5
S.F. WEST CREEK - WESTFIELD (TRIB. 13 U/ CONFLUENCE TRIB. 13.1)	LICK2000 Proposed Model LC2003	City	Entire Reach from Confluence Trib. 13.1 to U/S end	0.45%	3.8	100-YR OUT OF BANKS (NO OTHER EVENTS INCLUDED)	2.6
S.F. LICK BRANCH - ALEXBRANCH (TRIB. 13.1)	LICK2000 Proposed Model LC2003	City	Entire Reach from Confluence Trib. 13 to U/S end	0.70%	1.1	100-year in one side and out the other	0.8
Peach Creek							
NO HYDRAULIC MODELS AVAILABLE							
Spring Creek							
A1-A MAIN SPRING CREEK U/S TRIB. 7 CONFLUENCE	Spring Creek	City	Entire Reach in Model	0.23%	4.59	10-YR OUT IN MIDDLE, BUT ALL IN IN UPPER/LOWER	3.1
A2-LOWER TRIB. 7 TO CONFLUENCE WITH SPRING CREEK	Spring Creek	City	Entire Reach in Model	1.47%	2.27	10-yr out of banks lower, all in banks upper	1.6
A2-B TRIB. 7 U/S CONFLUENCE WITH TRIB. 7.1	Spring Creek	City	Entire Reach in Model	0.99%	3.94	10-yr out of banks	2.7
A2-A TRIB. 7.1 U/S CONFLUENCE WITH TRIB. 7	Spring Creek	City	Entire Reach in Model	0.36%	3.16	10-yr out of banks	2.2
A3-TRIB TRIB 6	Spring Creek	City	Entire Reach in Model	5.45%	2.80	ALL IN BANKS LOWER, 50-YR OUT IN UPPER	1.9
A3-MAIN SPRING CREEK BETWEEN CONFLUENCE TRIB 7 & TRIB 6	Spring Creek	City	Entire Reach in Model	1.08%	5.66	all in onside and out the other	3.9
A4-MAIN BETWEEN TRIB. 6 AND TRIB. 5	Spring Creek	City	Entire Reach in Model	0.52%	6.02	ALL OUT OF BANKS	4.1
B-B1 TRIB. 5.1	Spring Creek	City	Entire Reach in Model	0.48%	3.35	ALL IN BANKS	2.3
B-B2 TRIB 5 U/S CONFLUENCE TRIB 5.1	Spring Creek	City	Entire Reach in Model	0.88%	4.95	ALL IN BANKS	3.4
B-LOWER TRIB 5 D/S TRIB. 5.1 CONFLUENCE	Spring Creek	City	Entire Reach in Model	2.00%	3.45	ALL MOSTLY IN BANKS EXCEPTED ISOLATED AREAS	2.4
C-UPPER TRIB. 4	Spring Creek	City	Entire Reach in Model	0.88%	5.11	ALL IN BANKS EXCEPT 10-YR OUT VERY UPPER END	3.5
SPRING CREEK-LOWER BELOW TRIB. 4 TO MOUTH	Spring Creek	City	Entire Reach in Model	0.17%	4.42	all events out of banks	3.0
SPRING CREEK-UPPER ABOVE TRIB 4 TO TRIB 5	Spring Creek	City	Entire Reach in Model	0.22%	6.40	all events in except 10-yr+ out in upper end	4.4
Whites Creek							
Upper	Report 2 HEC-RAS White Creek\Unnamed_Stream	FEMA	entire portion in model	1.21%	3.17	all but 2-year out of banks in mid- to upper reach	2.2
Middle Upper	Report 2 HEC-RAS White Creek\Unnamed_Stream	FEMA	entire portion in model	0.58%	2.60	all out at lower end of reach and in banks upstream of there	1.8
Middle Lower	Report 2 HEC-RAS White Creek\Unnamed_Stream	FEMA	entire portion in model	0.70%	3.93	all events in and out along reach, almost out entirely on ROB	2.7
Lower	Report 2 HEC-RAS White Creek\Unnamed_Stream	FEMA	entire portion in model	0.71%	5.40	all events out of banks except at 2 isolated high points	2.7
Trib. 1	Report 2 HEC-RAS White Creek\Unnamed_Stream	FEMA	entire portion in model	0.87%	2.81	all mostly in banks, but all out in a couple of spots	1.9
Trib. 2	Report 2 HEC-RAS White Creek\Unnamed_Stream	FEMA	entire portion in model	2.38%	0.65	25-yr out of banks (all out of banks in upper 2/3 of stream	0.4
Trib. 3	Report 2 HEC-RAS White Creek\Unnamed_Stream	FEMA	entire portion in model	1.94%	2.69	all within banks	4.0
Trib. 15.1	Digital_Data\RevisiontoRunMod	FEMA	entire portion in model - appears to be entire Trib.	0.66%	3.32	100-yr close to in banks, but out in lower and mid-watershed	2.3
Wolf Pen Creek							
Wolf Pen Creek	Wolf Pen Creek Main Condos RAS	City	Entire Reach	0.33%	4.18	10-year (all events generally out of banks)	2.8
Wolf Pen Creek Trib. A	CHillsJune08	City	Entire Reach	0.78%	2.29	100-yr (No other events modeled)	1.6
Wolf Pen Creek Trib. C	WPCTribC1207	City	Entire Reach	0.46%	5.09	Generally in banks up to 100-year	3.5

Notes:
1. Travel time and average velocity based on 1% event.
2. Values presented are within City limits and evaluated stream portions.

APPENDIX C – KEY HYDROGRAPH LOCATIONS AND DATA

APPENDIX C: KEY HYDROGRAPH LOCATIONS AND DATA

Watershed	Location	ID No.	HEC-HMS Node	DS Key Node	Drainage Area (sq. mi.)	100-Yr Peak Flow (cfs)	Time to Peak (hr)	Dist to D/S Node (ft)
Alum Creek								
Alum Creek	Alum Creek @ SH6	A-4	AL-1	Junction-4	2.149	2,543	15.67	9,300
	Alum Creek Just U/S Confluence with AC-1	A-3	D/S End Reach A1	Junction-4	2.149	2,351	17.33	0
	Confluence Alum and AC-1	A-2	Junction-4	+ALUM	3.791	3,462	17.00	7,500
	D/S End Alum Creek	A-1	+ALUM	+@CONA (Lick Creek)	4.393	3,721	17.67	0
Alum Creek Trib. 1	Trib. AC-1 @ D/S End Before Confluence with Alum Creek	A-5	AC1-1	Junction-4	0.855	1,291	15.17	0
Bee Creek								
Bee Creek Trib. B	Trib. B U/S Confluence with Trib. B.3	B-3	Area 1	split	0.600	932	13.50	0
	Confluence Trib. B.3	B-2	split	outlet	0.920	1,482	13.25	3,500
	Mouth Trib. B @ Bee Creek	B-1	outlet	---	1.100	1,791	13.25	---
Bee Creek Trib. B3	Trib. B.3 U/S Confluence with Trib. B (Area 2)	B-4	Area 2	split	0.320	571	13.00	0
Burton Creek & Burton Creek Trib. C								
NO HYDROLOGY MODELS AVAILABLE								
Carters Creek								
Carters Creek	Confluence with Burton Creek/SH 6	C-5	J510D	J410D	22.140	18,527	14.42	687
	Confluence with Hudson Creek - Just D/S Harvey Rd	C-4	J410D	J420D	25.282	20,887	14.50	5,974
	Confluence with Wolf Pen Creek	C-3	J420D	J440	26.296	21,412	14.92	254
	Confluence with Bee Creek	C-2	J440	J470/OUT	26.800	21,621	14.92	3,593
	Mouth of Carters at Navasota River	C-1	J470/OUT	---	27.957	22,287	15.00	---
Lick Creek								
Lick Creek	South Fork @ Alexandria Ave.	L-12	+@ALEX	+@HY6S	0.854	1358	14.67	4,180
	South Fork @ SH6	L-11	+@HY6S	+S@CON	1.271	2025	15.00	2,080
	South Fork Just U/S Confluence with North ForK	L-10	+S@CON	+@CONF	1.479	2264	15.08	0
	North Fork @ Victoria Ave.	L-9	NF1	+@HWY6	0.294	676.7	14.25	5,600
	North Fork @ SH6	L-8	+@HWY6	+N@CON	1.022	1981.2	14.58	4,200
	North Fork Just U/S Confluence with South Fork	L-7	+N@CON	+@CONF	1.241	2318.7	15.00	0
	Confluence North Fork and South Fork	L-6	+@CONF	+LM2	2.720	4574	15.08	15,500
	Lick Creek U/S Confluence Spring Creek	L-5	+LM2	+T@GP	4.433	5,388	16.75	0
	Confluence Spring Creek @ Greens Prairie Rd	L-4	+T@GP	+LM4	8.293	9,268	16.67	14,000
	Lick Creek U/S Confluence Alum	L-3	+LM4	+@CONA	10.061	9,353	18.08	0
	Confluence Alum	L-2	+@CONA	+LM5	14.454	12,999	18.00	7,000
	Lick Creek @ City Limits	L-1	+LM5	---	16.008	13,085	18.75	---

Notes:
1. D/S End node should be used for sites discharging into tributaries rather than the Confluence node as the Confluence node reflects conditions in the main stem.
2. Mouth of stream is downstream-most part of stream or point where stream discharges.
3. Distance to downstream key node is approximate from HEC-HMS model routing (locations with * from HEC-RAS) and actual distance should be measured along stream centerline for project evaluations.
4. Distance of 0 to key downstream node indicates either: 1) upstream and downstream key nodes are just upstream of confluence and just downstream of confluence after hydrographs combine or
 2) drainage subarea contributes directly to downstream node.
5. Distances to downstream nodes based on distances between key hydrograph locations; however, hydrology models may contain other nodes may exist between key hydrograph locations.
6. Dashed lines indicate mouth of stream or downstream end of model.

APPENDIX C: KEY HYDROGRAPH LOCATIONS AND DATA

Watershed	Location	ID No.	HEC-HMS Node	DS Key Node	Drainage Area (sq. mi.)	100-Yr Peak Flow (cfs)	Time to Peak (hr)	Dist to D/S Node (ft)
		Peach Creek						
		NO HYDROLOGY MODELS AVAILABLE						
		Spring Creek						
Spring Creek	U/S End Spring Creek	S-7	A1-1	RS1190	0.468	843	13.23	8,425
	Just U/S Confluence Trib. 7	S-6	RS1190	J2	0.931	1,199	13.88	0
	Confluence with Trib. 7	S-5	J2	J@EndofA4	1.775	2,251	13.97	3,265
	Confluence with Trib. 6	S-4	J@EndofA4	J4	2.133	2,729	14.03	0
	Confluence Trib. 5	S-3	J4	J8	2.426	2,967	13.90	2,449
	Confluence Trib. 4 @ SH6	S-2	J8	ToLC	2.868	2,729	13.93	11,647
	Mouth/Confluence with Lick Creek	S-1	ToLC	---	3.782	3,423	14.97	---
Spring Creek Trib. 7	Confluence Trib. 7 and Trib. 7.1	S-12	J1	J@End of A2 Lower	0.504	638	13.70	6,916
	D/S End Trib. 7	S-11	J@End of A2 Lower	J2	0.844	1,063	14.10	0
Spring Creek Trib. 6	D/S End Trib. 6	S-10	A3	J@EndofA4	0.358	559	13.57	0
Spring Creek Trib. 5	D/S End Trib. 5	S-8	J@EndofB-Lower	J4	0.293	772	12.77	0
Spring Creek Trib. 5	Trib. 5 @ SH40	S-9	J3	J@EndofB-Lower	0.228	684	12.48	2,904
		Whites Creek						
Whites Creek	Whites Creek Confluence with Unnamed Tributary	W-3	J-FTC&BP9	J-EWA&HCR	4.340	5,016	13.32	12,400
	Unnamed Road off of Whites Creek Rd	W-2	J-EWA&HCR	J-BR	8.600	7,442	14.12	13,400
	Mouth/Confluence with Brazos River	W-1	J-BR	---	11.270	9,441	15.22	---
Unnamed Trib. To Whites Creek	Unnamed Trib. Confluence with Trib. 3	W-7	J-BP2&BP1_BP5	J-BP4&BP5	0.170	400	12.62	904
	Unnamed Trib. Confluence with Trib. 2	W-6	J-BP4&BP5	J-BP7&BP10	0.320	857	12.52	1,303
	Unnamed Trib. Confluence with Trib. 1	W-5	J-BP7&BP10	J-BP9	0.420	1,162	12.48	4,670
	D/S End Unnamed Trib	W-4	J-BP9	J-FTC&BP9	0.650	1,512	12.58	0
Trib. 1 to Unnamed Trib.	D/S End Trib. 1	W-8	All Trib 1 Qs	J-BP7&BP10	0.080	295	12.38	0
Trib. 2 to Unnamed Trib.	D/S End Trib. 2	W-9	J-BP4	J-BP4&BP5	0.120	375	12.52	0
Trib. 3 to Unnamed Trib.	D/S End Trib. 3	W-10	J-BP3	J-BP2&BP1_BP5	0.030	100	12.45	0
		Wolf Pen Creek						
Wolf Pen Creek	Anderson	WP-6	Anderson	40	0.294	691	12.83	1,750
	Confluence with Tributary C between Texas Ave. & Anderson	WP-5	40*	42	1.330	2,280	12.67	3,222
	Confluence with Tributary B near GBD	WP-4	42*	44	1.662	2,787	12.58	2,443
	Confluence with Tributary A	WP-3	44*	45	2.2662	4,128	12.67	4,076
	Approx. 900' Downstream of SH 6	WP-2	45*	46	2.933	4,933	13.25	4,800
	Mouth/Confluence with Carters Creek	WP-1	46	---	3.363	4,988	13.58	---
Wolf Pen Creek Trib. A	Trib. A at Mouth	WP-9	WPA1	43	0.488	1,358	12.58	0
Wolf Pen Creek Trib. B	Trib. B at Mouth	WP-8	WPB1	41	0.213	785	12.33	0
Wolf Pen Creek Trib. C	Trib. C at Millif	WP-7	Millif	40	0.903	1,403	12.58	540

Notes:

1. D/S End node should be used for sites discharging into tributaries rather than the Confluence node as the Confluence node reflects conditions in the main stem.
2. Mouth of stream is downstream-most part of stream or point where stream discharges.
3. Distance to downstream key node is approximate from HEC-HMS model routing (locations with * from HEC-RAS) and actual distance should be measured along stream centerline for project evaluations.
4. Distance of 0 to key downstream node indicates either: 1) upstream and downstream key nodes are just upstream of confluence and just downstream of confluence after hydrographs combine or 2) drainage subarea contributes directly to downstream node.
5. Distances to downstream nodes based on distances between key hydrograph locations; however, hydrology models may contain other nodes may exist between key hydrograph locations.
6. Dashed lines indicate mouth of stream or downstream end of model.

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APPENDIX D – KEY HYDROGRAPH FIGURES

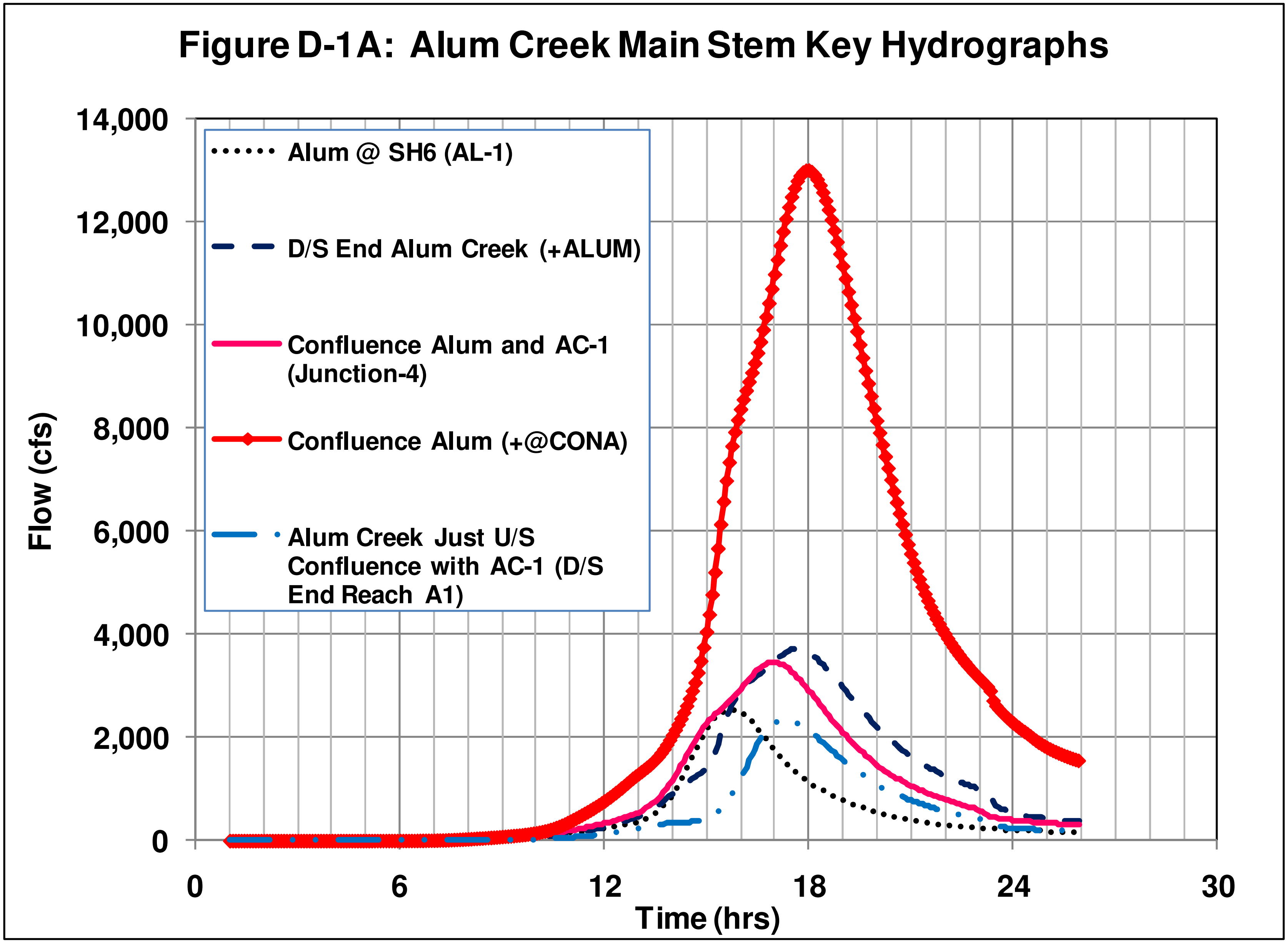
Figure D-1A: Alum Creek Main Stem Key Hydrographs
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Flow (cfs)
0
6
12
18
24
30
Time (hrs)
Alum @ SH6 (AL-1)
D/S End Alum Creek (+ALUM)
Confluence Alum and AC-1 (Junction-4)
Confluence Alum (+@CONA)
Alum Creek Just U/S Confluence with AC-1 (D/S End Reach A1)

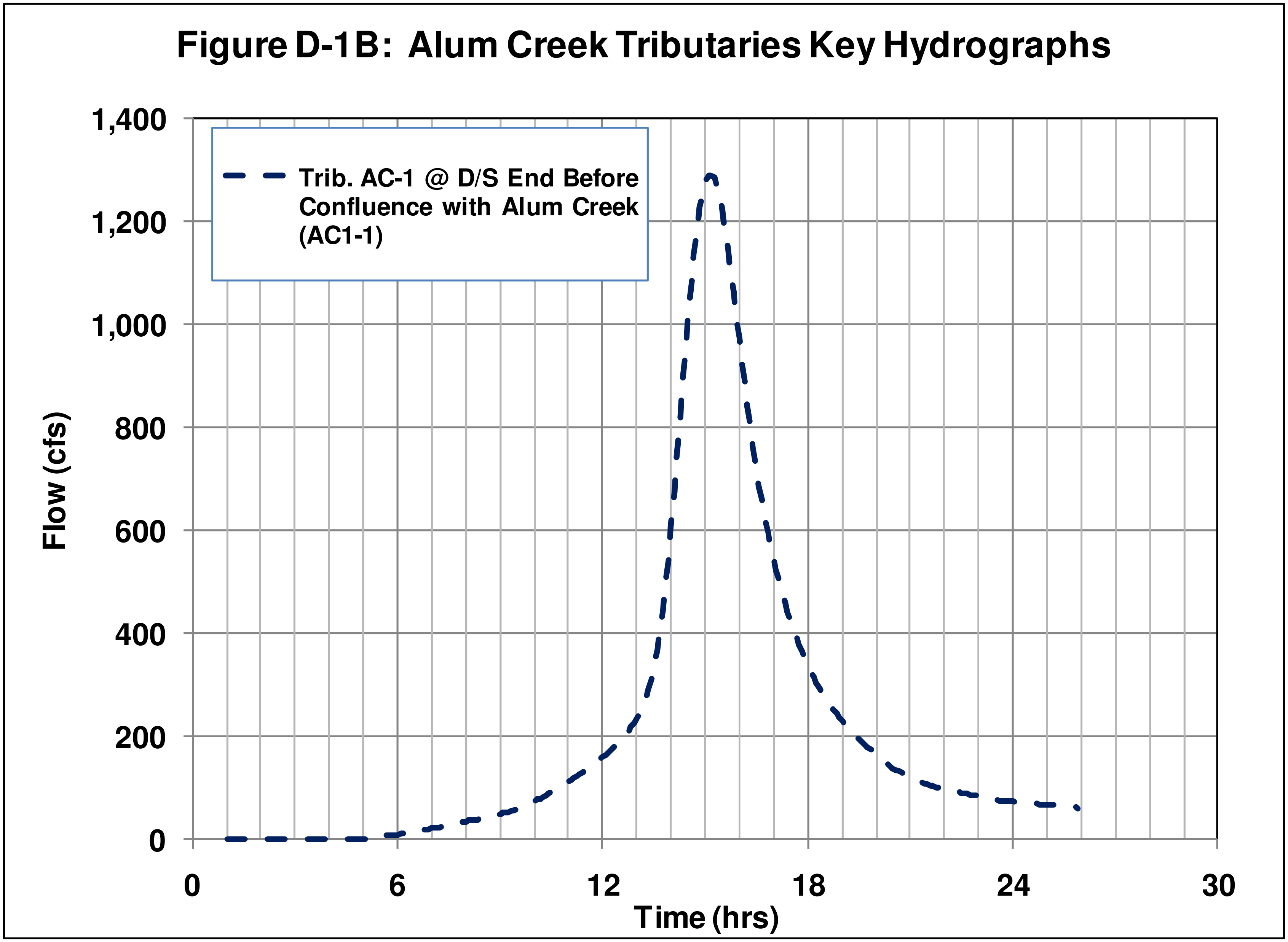
Figure D-1B: Alum Creek Tributaries Key Hydrographs
Trib. AC-1 @ D/S End Before Confluence with Alum Creek (AC1-1)
Flow (cfs)
1,400
1,200
1,000
800
600
400
200
0
0
6
12
18
24
30
Time (hrs)

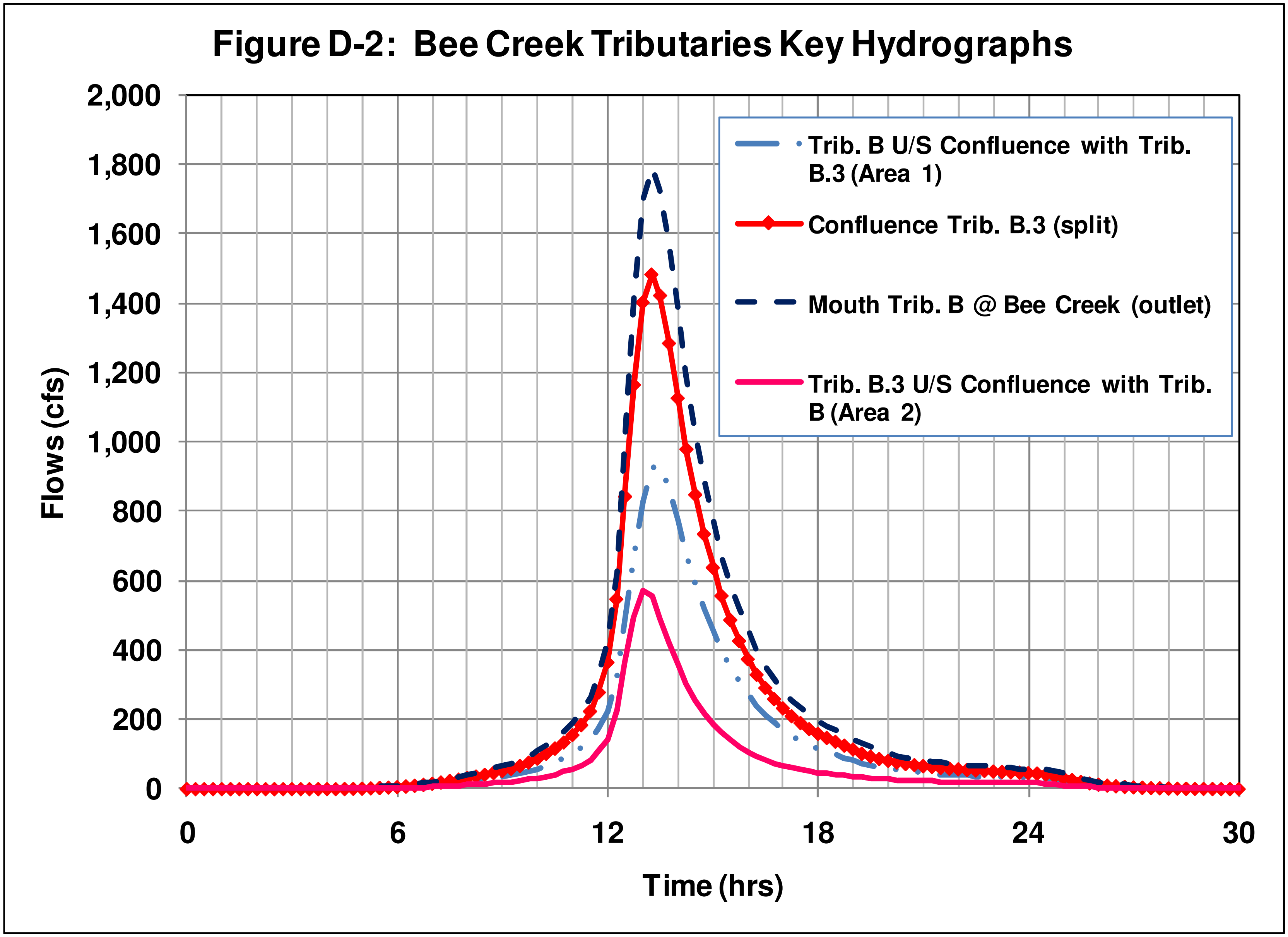
Figure D-2: Bee Creek Tributaries Key Hydrographs
Flows (cfs)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
0
6
12
18
24
30
Time (hrs)
Trib. B U/S Confluence with Trib. B.3 (Area 1)
Confluence Trib. B.3 (split)
Mouth Trib. B @ Bee Creek (outlet)
Trib. B.3 U/S Confluence with Trib. B (Area 2)

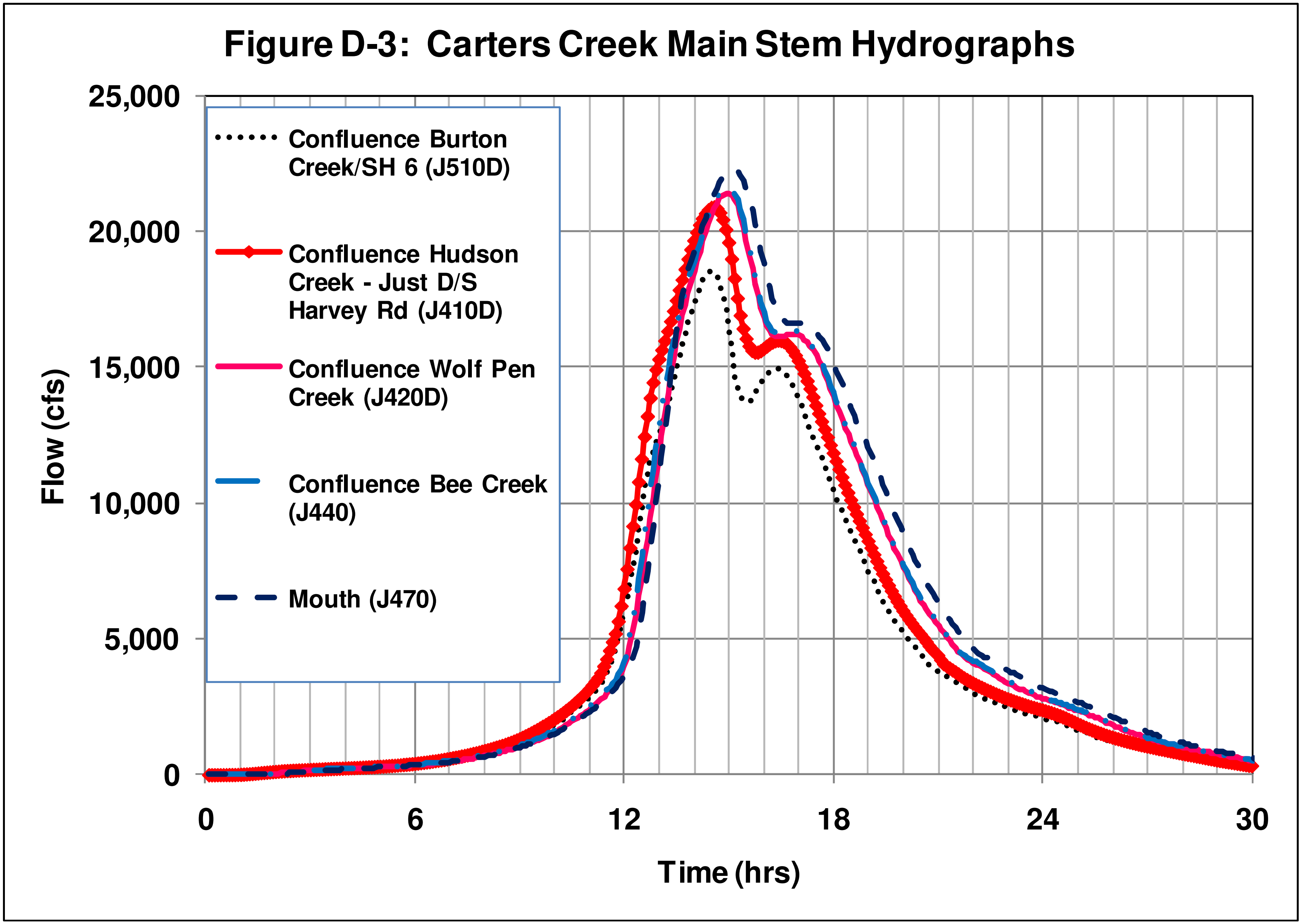
Figure D-3: Carters Creek Main Stem Hydrographs
25,000
20,000
15,000
10,000
5,000
0
Flow (cfs)
0
6
12
18
24
30
Time (hrs)
Confluence Burton Creek/SH 6 (J510D)
Confluence Hudson Creek - Just D/S Harvey Rd (J410D)
Confluence Wolf Pen Creek (J420D)
Confluence Bee Creek (J440)
Mouth (J470)

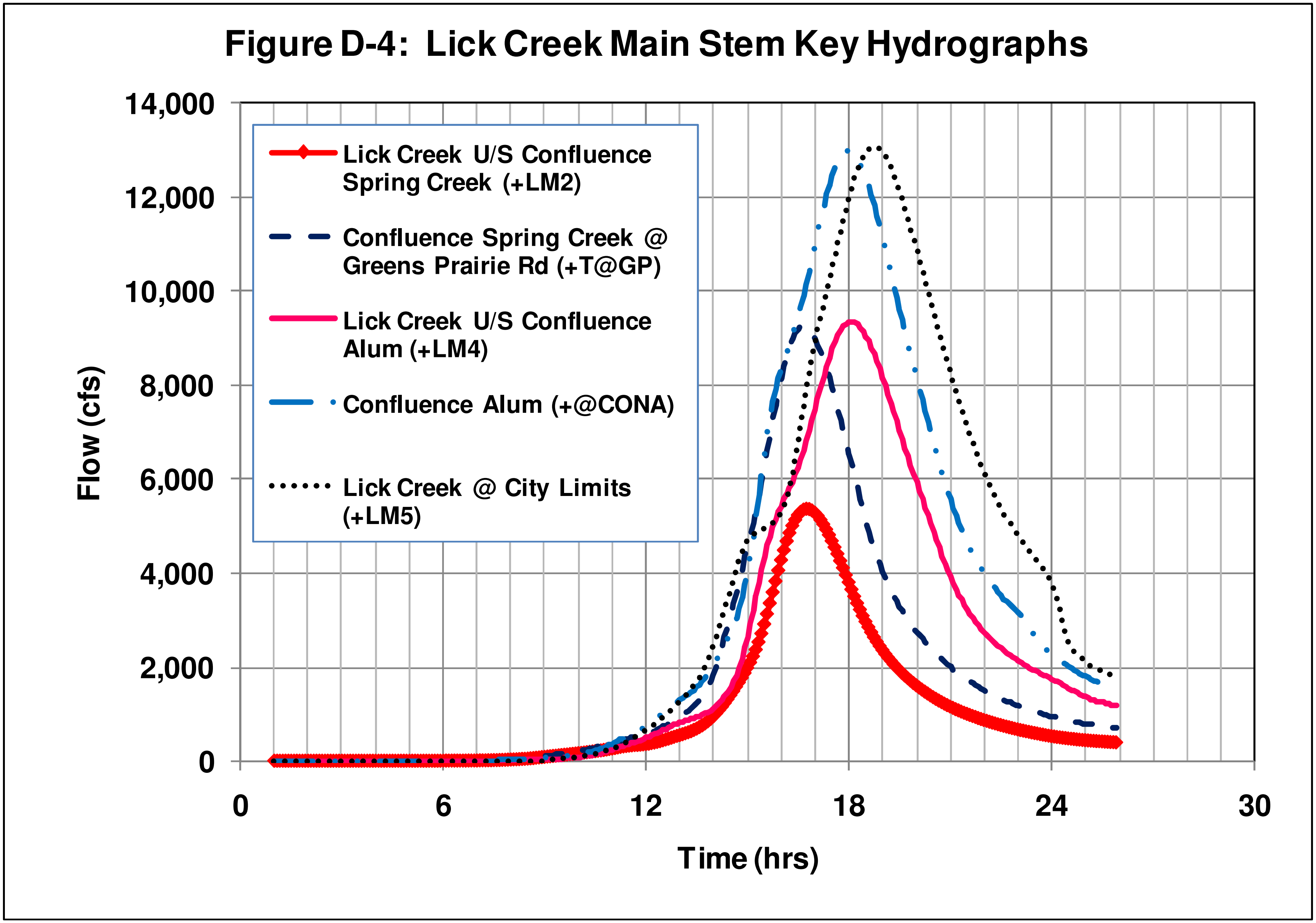
Figure D-4: Lick Creek Main Stem Key Hydrographs
Flow (cfs)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Time (hrs)
0
6
12
18
24
30
Lick Creek U/S Confluence Spring Creek (+LM2)
Confluence Spring Creek @ Greens Prairie Rd (+T@GP)
Lick Creek U/S Confluence Alum (+LM4)
Confluence Alum (+@CONA)
Lick Creek @ City Limits (+LM5)

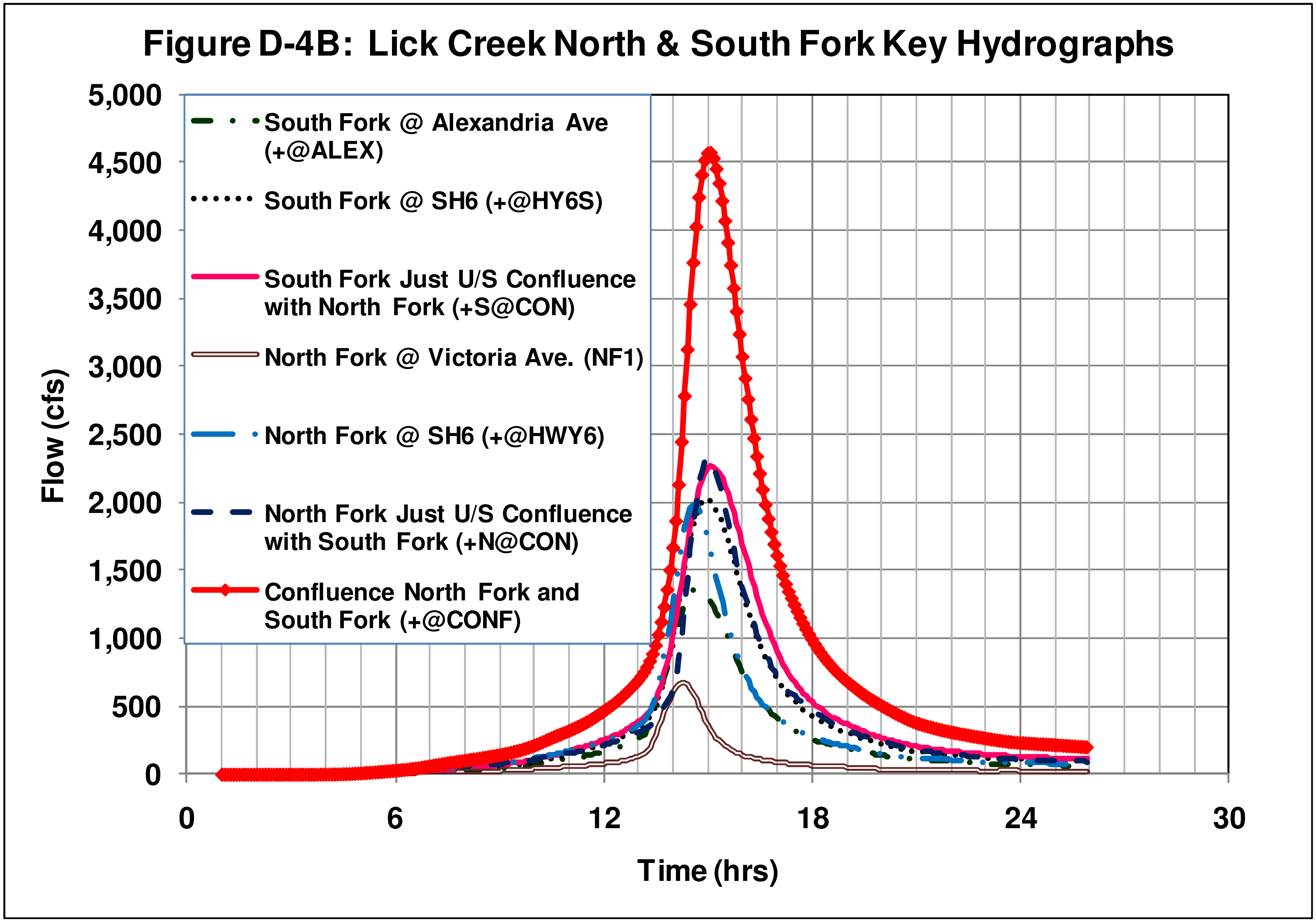
Figure D-4B: Lick Creek North & South Fork Key Hydrographs
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Flow (cfs)
South Fork @ Alexandria Ave (+@ALEX)
South Fork @ SH6 (+@HY6S)
South Fork Just U/S Confluence with North Fork (+S@CON)
North Fork @ Victoria Ave. (NF1)
North Fork @ SH6 (+@HWY6)
North Fork Just U/S Confluence with South Fork (+N@CON)
Confluence North Fork and South Fork (+@CONF)
0
6
12
18
24
30
Time (hrs)

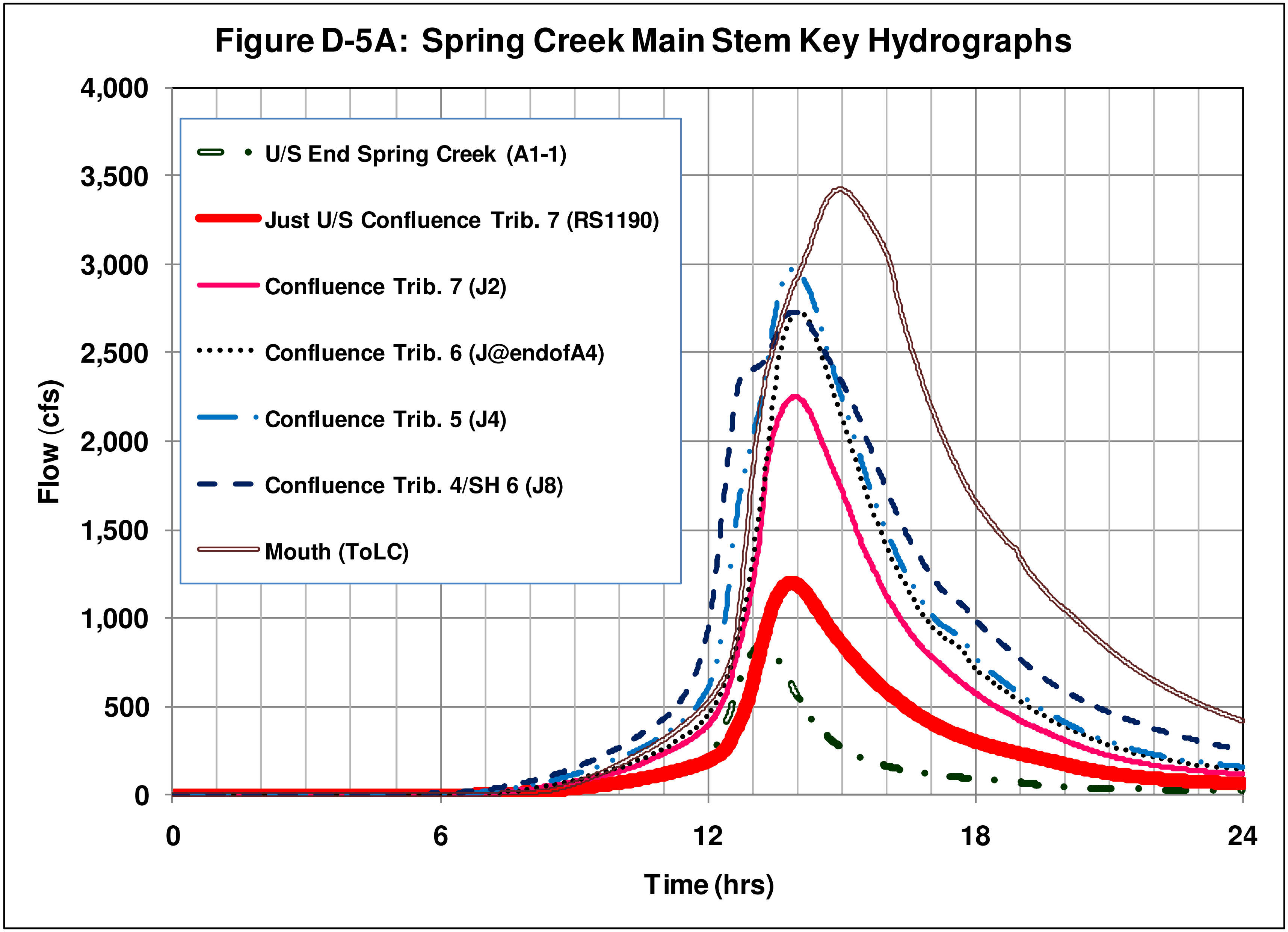
Figure D-5A: Spring Creek Main Stem Key Hydrographs
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Flow (cfs)
U/S End Spring Creek (A1-1)
Just U/S Confluence Trib. 7 (RS1190)
Confluence Trib. 7 (J2)
Confluence Trib. 6 (J@endofA4)
Confluence Trib. 5 (J4)
Confluence Trib. 4/SH 6 (J8)
Mouth (ToLC)
0
6
12
18
24
Time (hrs)

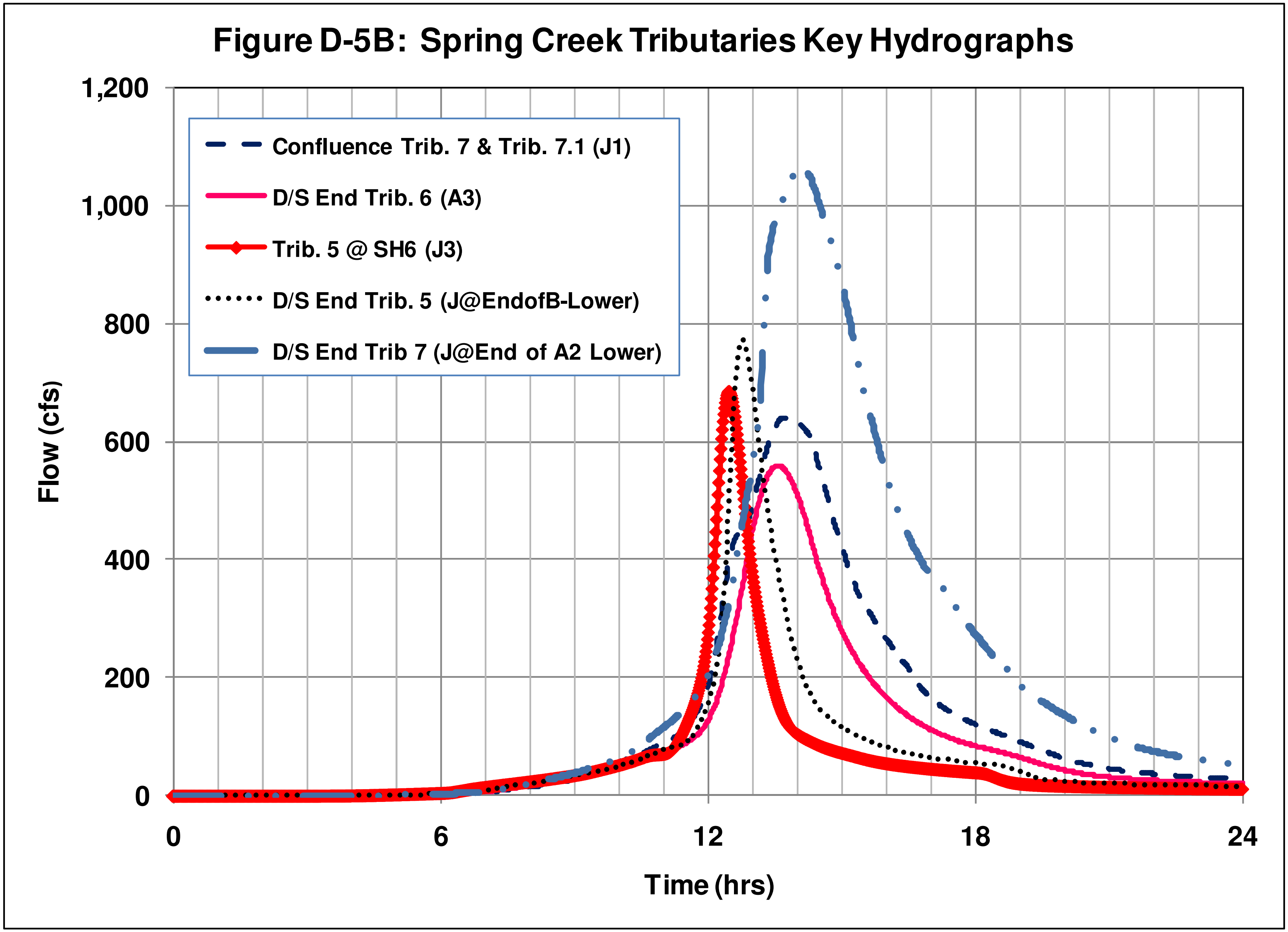
Figure D-5B: Spring Creek Tributaries Key Hydrographs
Confluence Trib. 7 & Trib. 7.1 (J1)
D/S End Trib. 6 (A3)
Trib. 5 @ SH6 (J3)
D/S End Trib. 5 (J@EndofB-Lower)
D/S End Trib 7 (J@End of A2 Lower)
Flow (cfs)
1,200
1,000
800
600
400
200
0
0
6
12
18
24
Time (hrs)

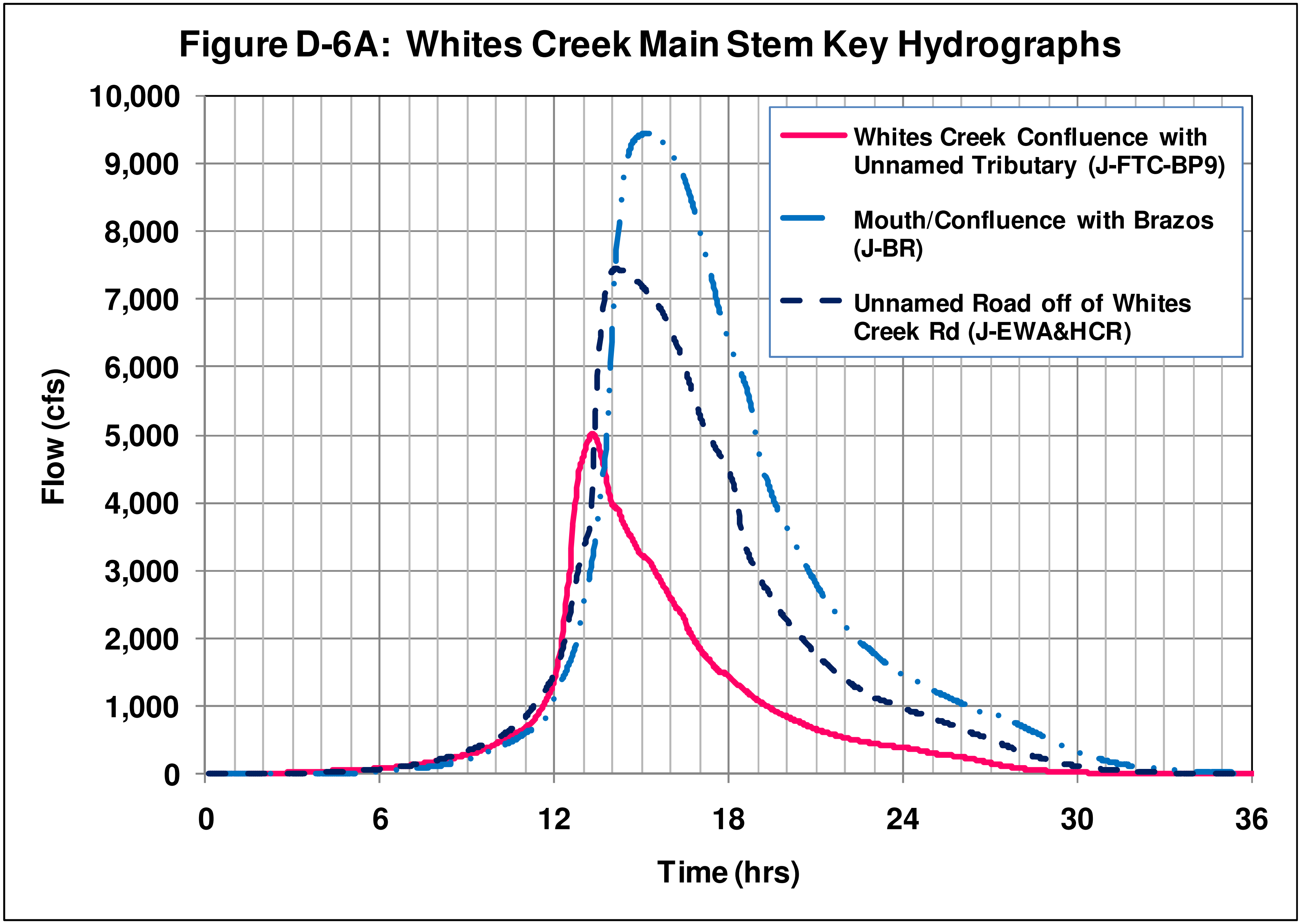
Figure D-6A: Whites Creek Main Stem Key Hydrographs
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Flow (cfs)
0
6
12
18
24
30
36
Time (hrs)
Whites Creek Confluence with Unnamed Tributary (J-FTC-BP9)
Mouth/Confluence with Brazos (J-BR)
Unnamed Road off of Whites Creek Rd (J-EWA&HCR)

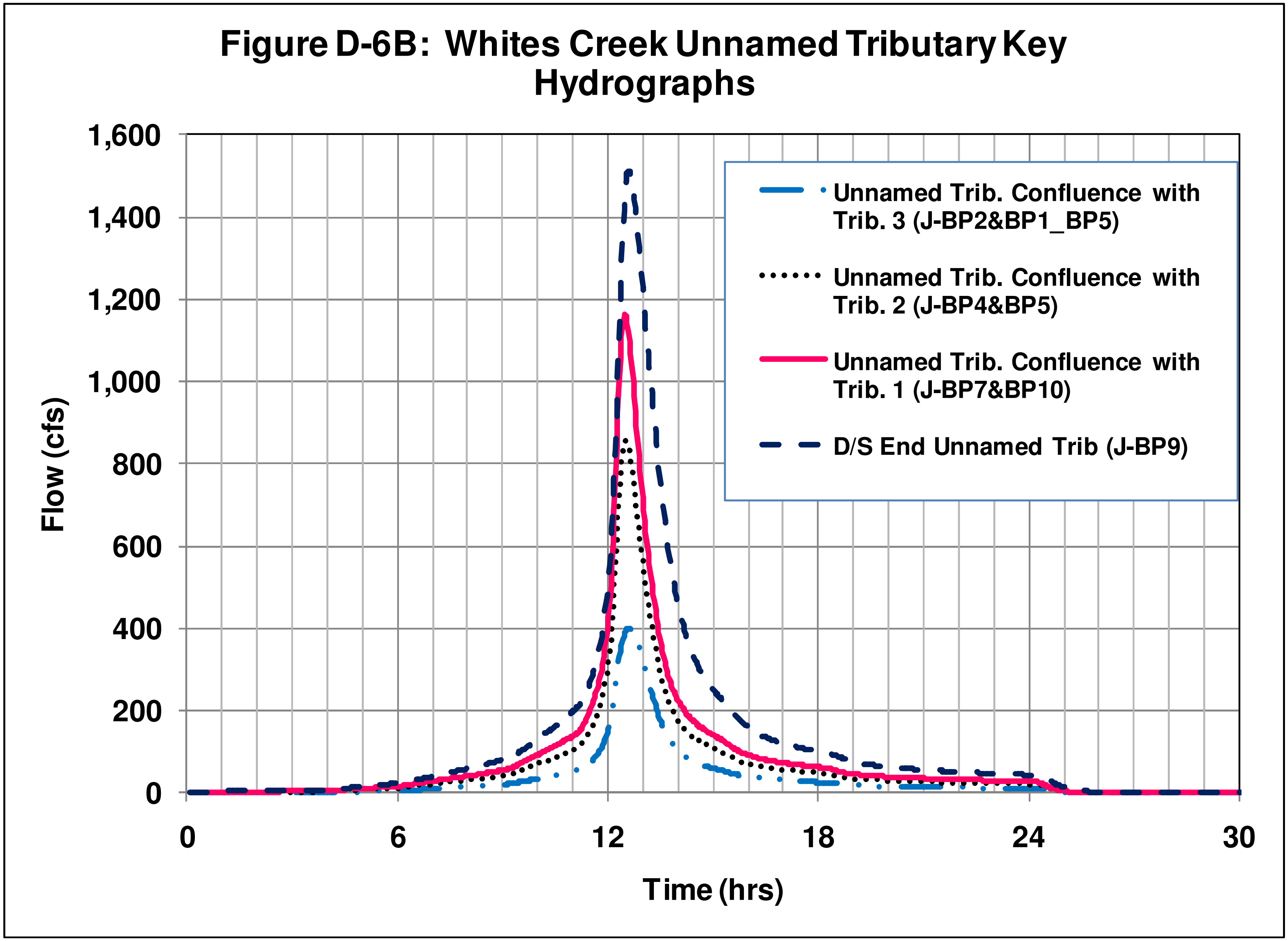
Figure D-6B: Whites Creek Unnamed Tributary Key Hydrographs
Flow (cfs)
1,600
1,400
1,200
1,000
800
600
400
200
0
0
6
12
18
24
30
Time (hrs)
Unnamed Trib. Confluence with Trib. 3 (J-BP2&BP1_BP5)
Unnamed Trib. Confluence with Trib. 2 (J-BP4&BP5)
Unnamed Trib. Confluence with Trib. 1 (J-BP7&BP10)
D/S End Unnamed Trib (J-BP9)

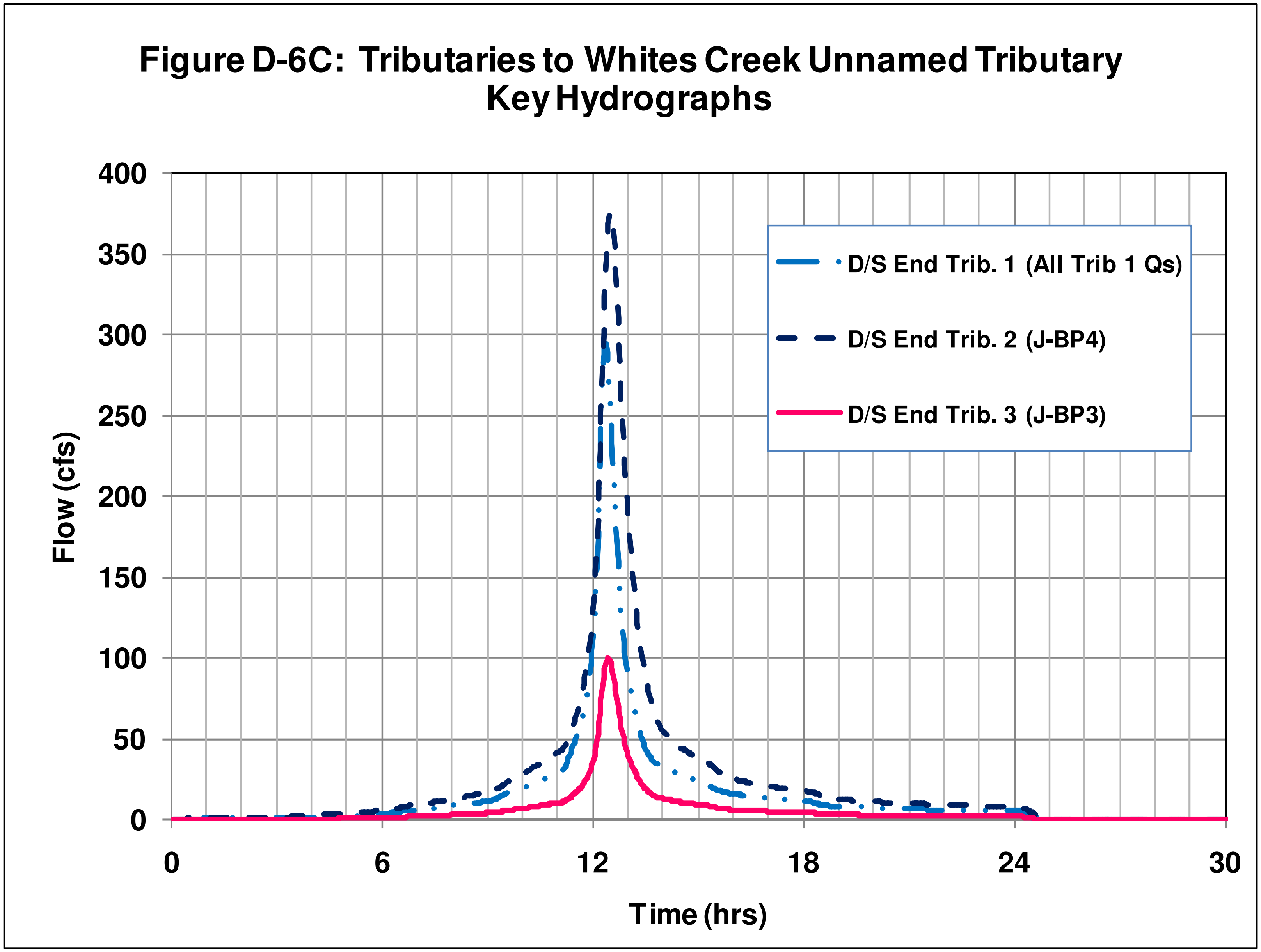
Figure D-6C: Tributaries to Whites Creek Unnamed Tributary
Key Hydrographs
Flow (cfs)
0
50
100
150
200
250
300
350
400
Time (hrs)
0
6
12
18
24
30
D/S End Trib. 1 (All Trib 1 Qs)
D/S End Trib. 2 (J-BP4)
D/S End Trib. 3 (J-BP3)

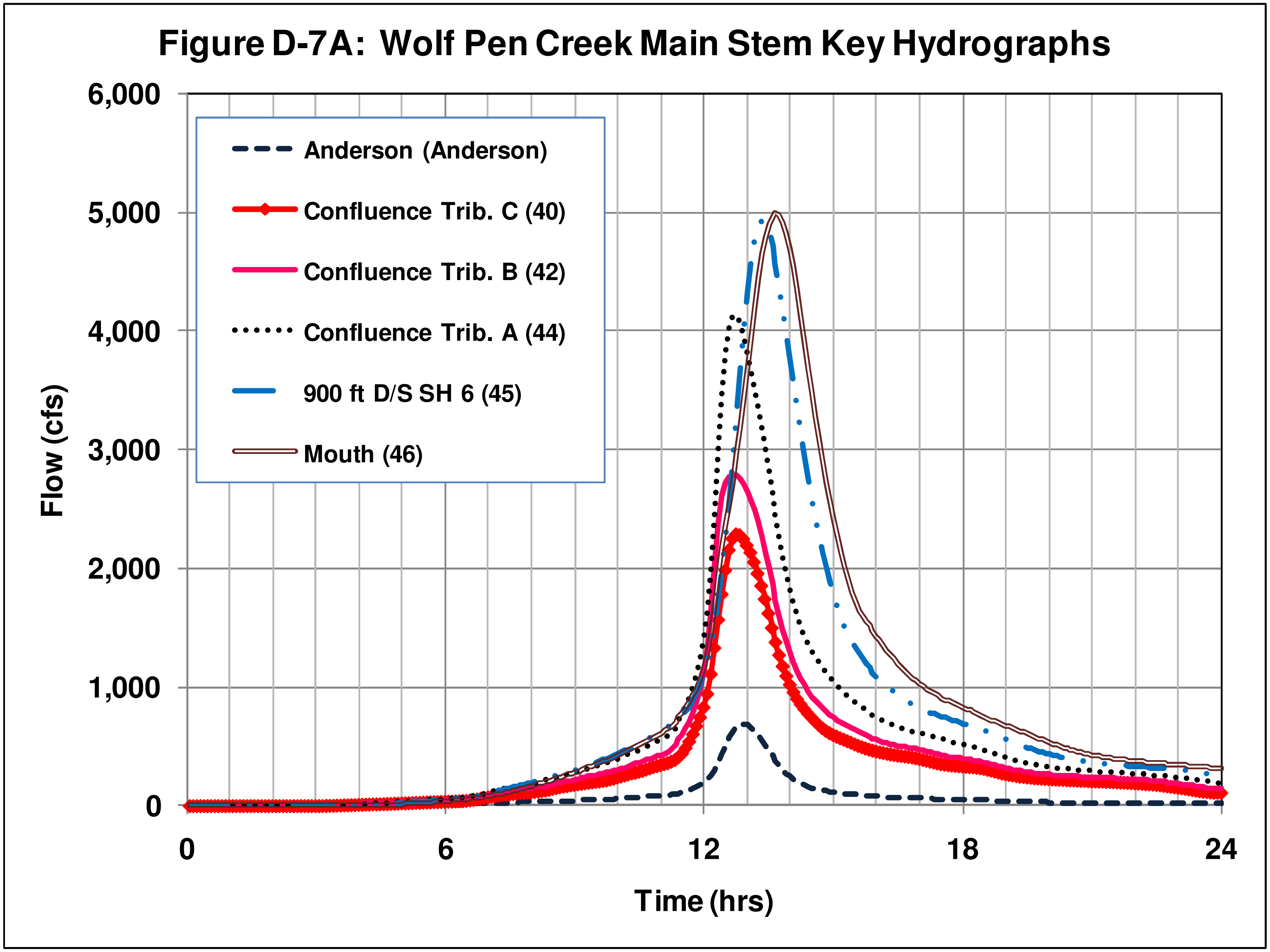
Figure D-7A: Wolf Pen Creek Main Stem Key Hydrographs
Flow (cfs)
6,000
5,000
4,000
3,000
2,000
1,000
0
0
6
12
18
24
Time (hrs)
Anderson (Anderson)
Confluence Trib. C (40)
Confluence Trib. B (42)
Confluence Trib. A (44)
900 ft D/S SH 6 (45)
Mouth (46)

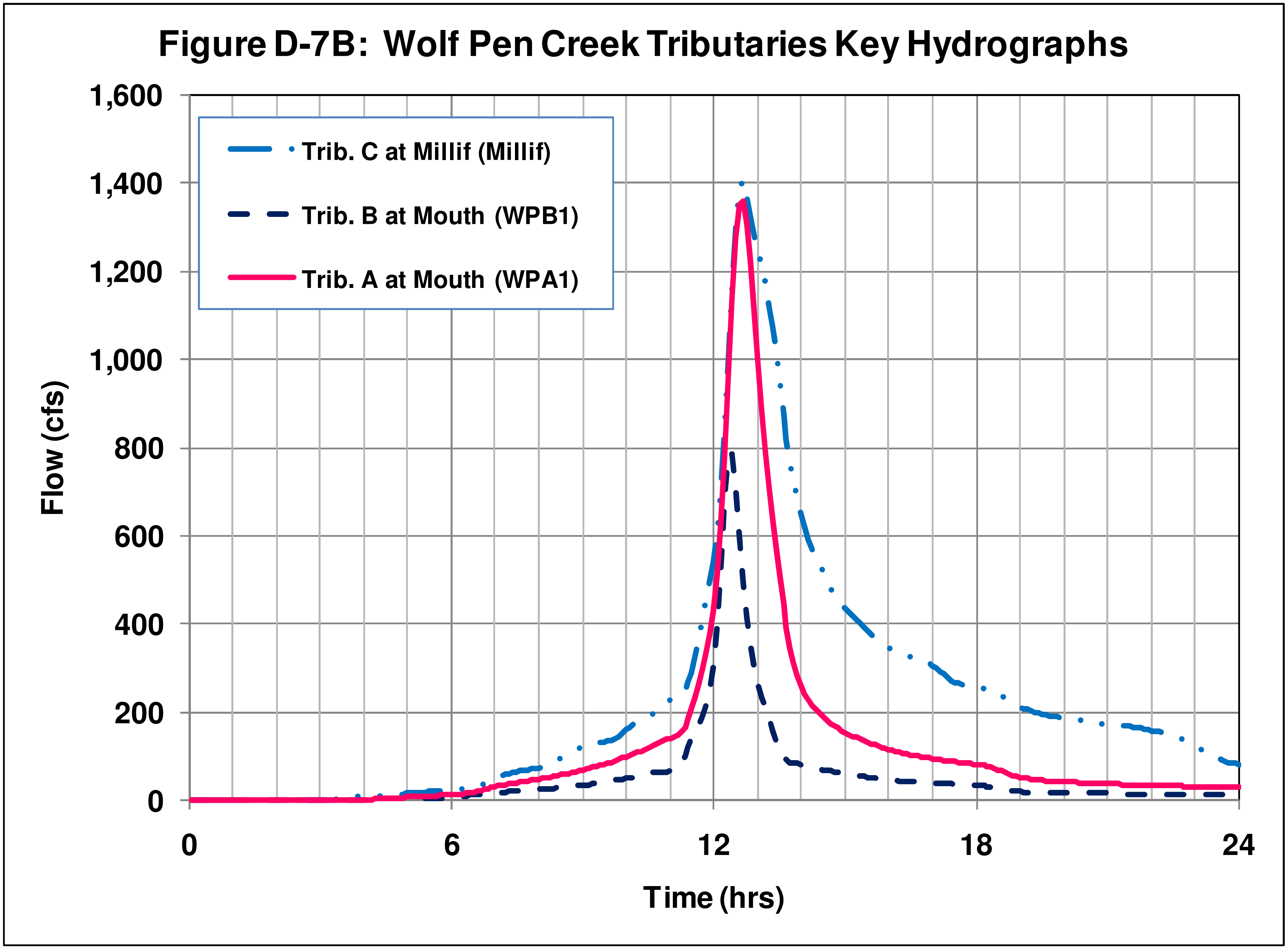
Figure D-7B: Wolf Pen Creek Tributaries Key Hydrographs
Trib. C at Millif (Millif)
Trib. B at Mouth (WPB1)
Trib. A at Mouth (WPA1)
1,600
1,400
1,200
1,000
800
600
400
200
0
Flow (cfs)
0
6
12
18
24
Time (hrs)

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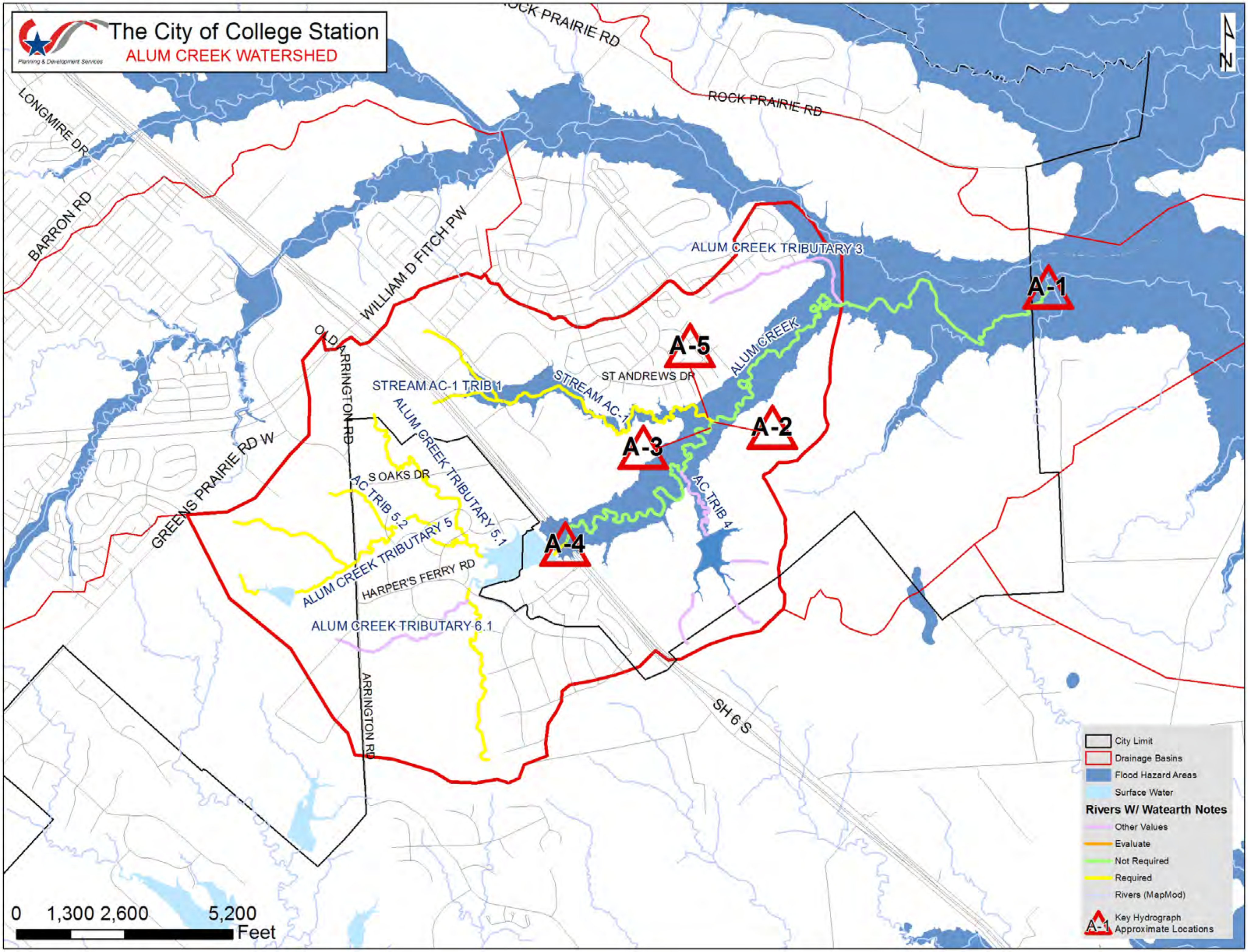
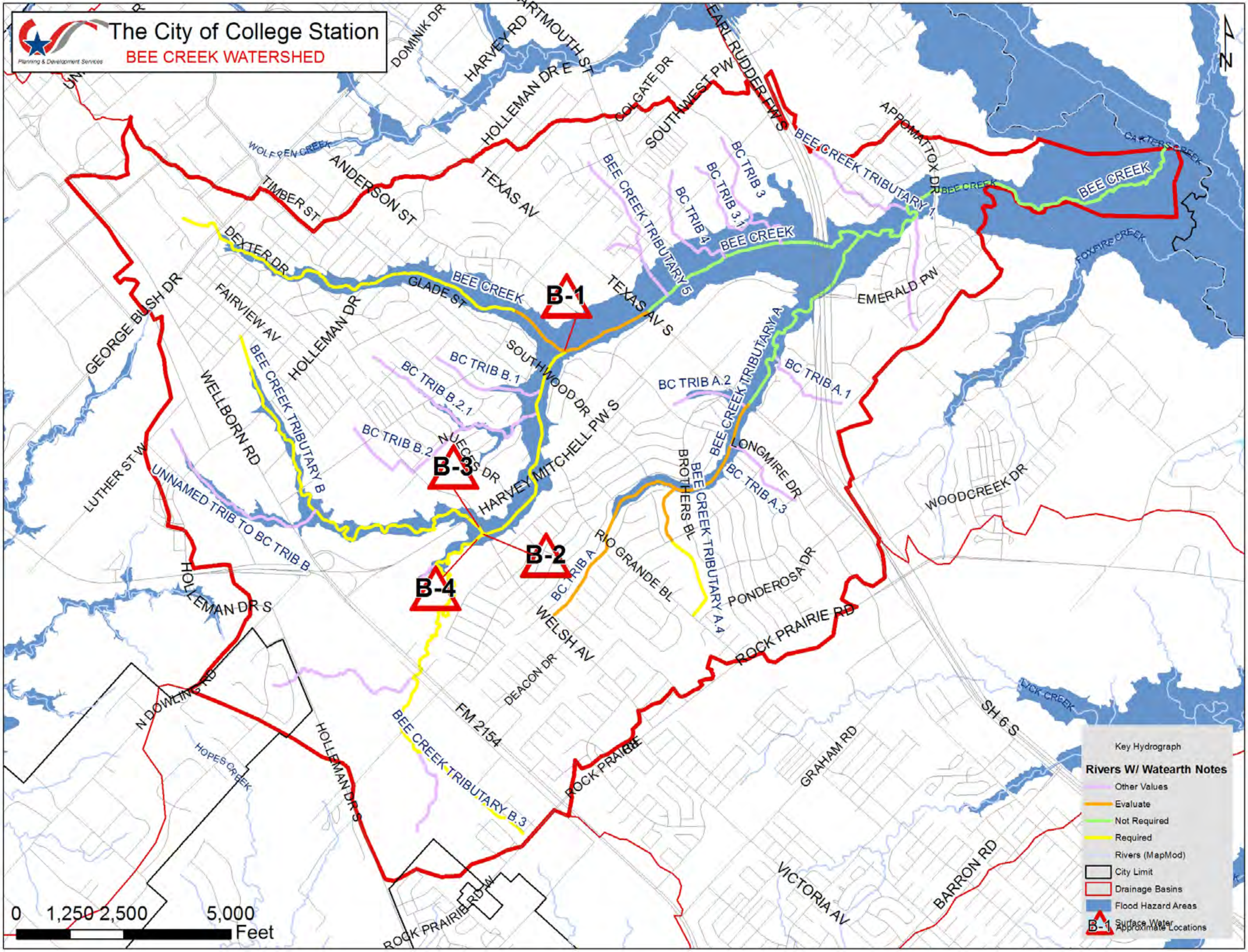
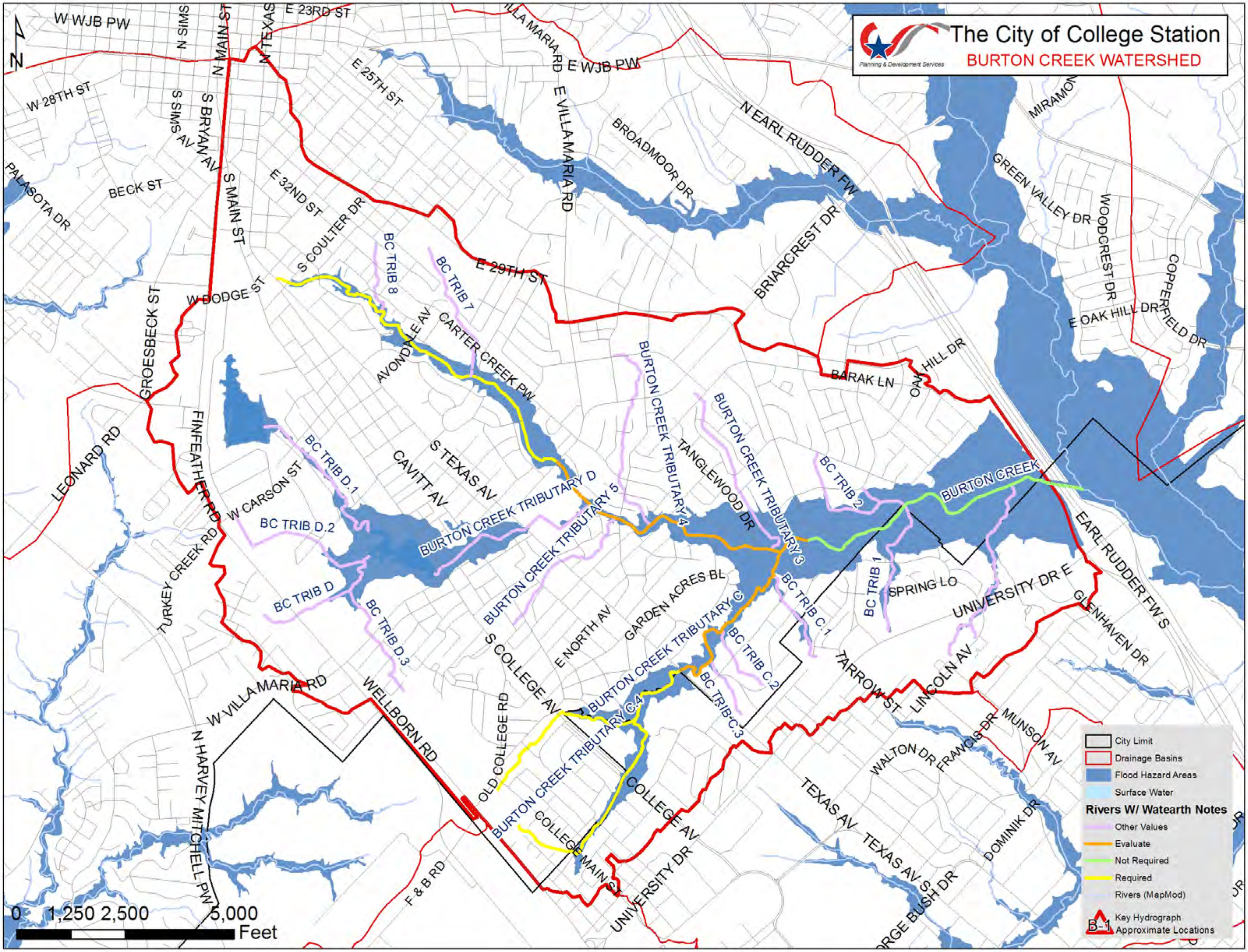
APPENDIX E – CITY OF COLLEGE STATION WATERSHED GRAPHICS (provided by City)

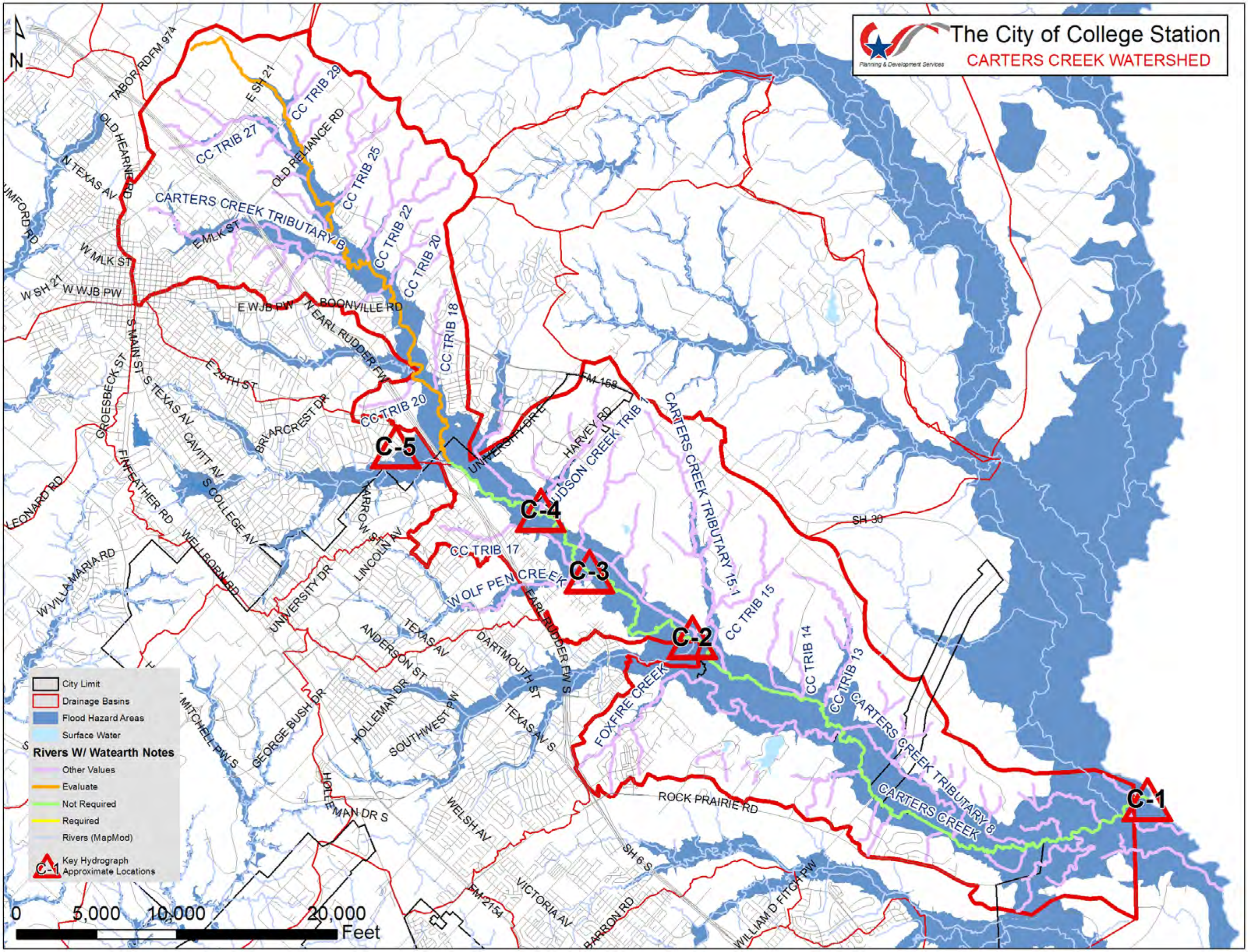


The City of College Station
Planning & Development Services
ALUM CREEK WATERSHED
ROCK PRAIRIE RD
ROCK PRAIRIE RD
LONGMIRE DR
BARRON RD
WILLIAM D FITCH PW
OLD ARRINGTON RD
GREENS PRAIRIE RD W
ALUM CREEK TRIBUTARY 3
ALUM CREEK
ST ANDREWS DR
STREAM AC-1 TRIB 1
STREAM AC-1
ALUM CREEK TRIBUTARY 5.1
S OAKS DR
AC TRIB 5.2
AC TRIB 4
ALUM CREEK TRIBUTARY 5
HARPER'S FERRY RD
ALUM CREEK TRIBUTARY 6.1
ARRINGTON RD
SH 6 S
A-1
A-2
A-3
A-4
A-5
City Limit
Drainage Basins
Flood Hazard Areas
Surface Water
Rivers W/ Watearth Notes
Other Values
Evaluate
Not Required
Required
Rivers (MapMod)
Key Hydrograph Approximate Locations
0 1,300 2,600 5,200
Feet
N

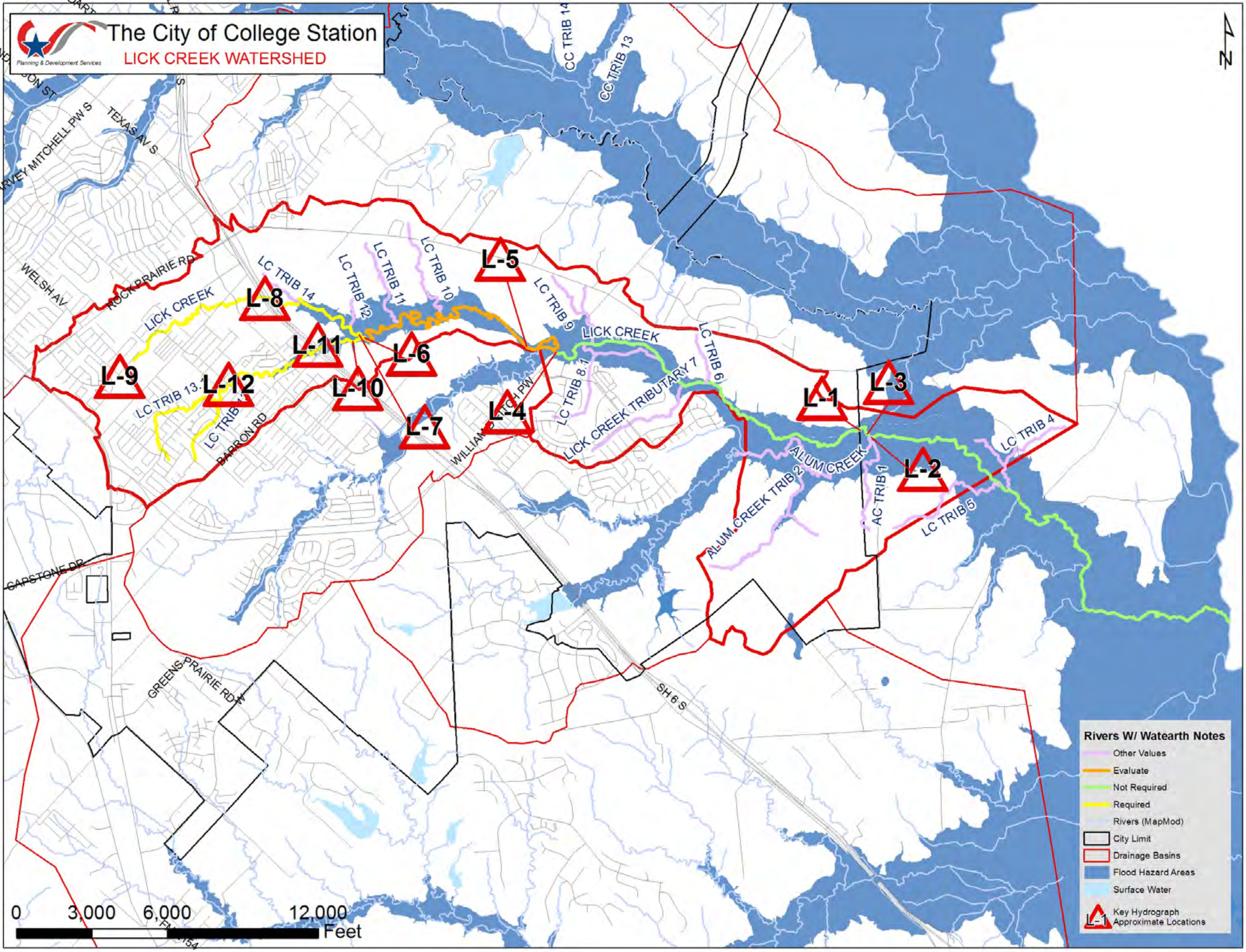


The City of College Station
Planning & Development Services
BEE CREEK WATERSHED
N
B-1
B-2
B-3
B-4
BEE CREEK
BEE CREEK TRIBUTARY 1
BEE CREEK TRIBUTARY 5
BEE CREEK TRIBUTARY A
BEE CREEK TRIBUTARY A.4
BEE CREEK TRIBUTARY B
BEE CREEK TRIBUTARY B.3
BC TRIB 3
BC TRIB 3.1
BC TRIB 4
BC TRIB A
BC TRIB A.1
BC TRIB A.2
BC TRIB A.3
BC TRIB B.1
BC TRIB B.2
BC TRIB B.2.1
UNNAMED TRIB TO BC TRIB B
WOLF PEN CREEK
CARTERS CREEK
FOXFIRE CREEK
LICK CREEK
HOPES CREEK
DOMINIK DR
HARVEY RD
DARTMOUTH ST
HOLLEMAN DR E
COLGATE DR
SOUTHWEST PW
EARL RUDDER FW S
APPOMATTOX DR
ANDERSON ST
TIMBER ST
TEXAS AV
TEXAS AV S
DEXTER DR
GLADE ST
EMERALD PW
GEORGE BUSH DR
FAIRVIEW AV
HOLLEMAN DR
SOUTHWOOD DR
WELLBORN RD
HARVEY MITCHELL PW S
LONGMIRE DR
NUECES DR
LUTHER ST W
BROTHERS BL
WOODCREEK DR
RIO GRANDE BL
PONDEROSA DR
HOLLEMAN DR S
WELSH AV
ROCK PRAIRIE RD
DEACON DR
N DOWLING RD
FM 2154
SH 6 S
GRAHAM RD
ROCK PRAIRIE RD W
VICTORIA AV
BARRON RD
0 1,250 2,500 5,000 Feet
Key Hydrograph
Rivers W/ Watearth Notes
Other Values
Evaluate
Not Required
Required
Rivers (MapMod)
City Limit
Drainage Basins
Flood Hazard Areas
Surface Water Approximate Locations

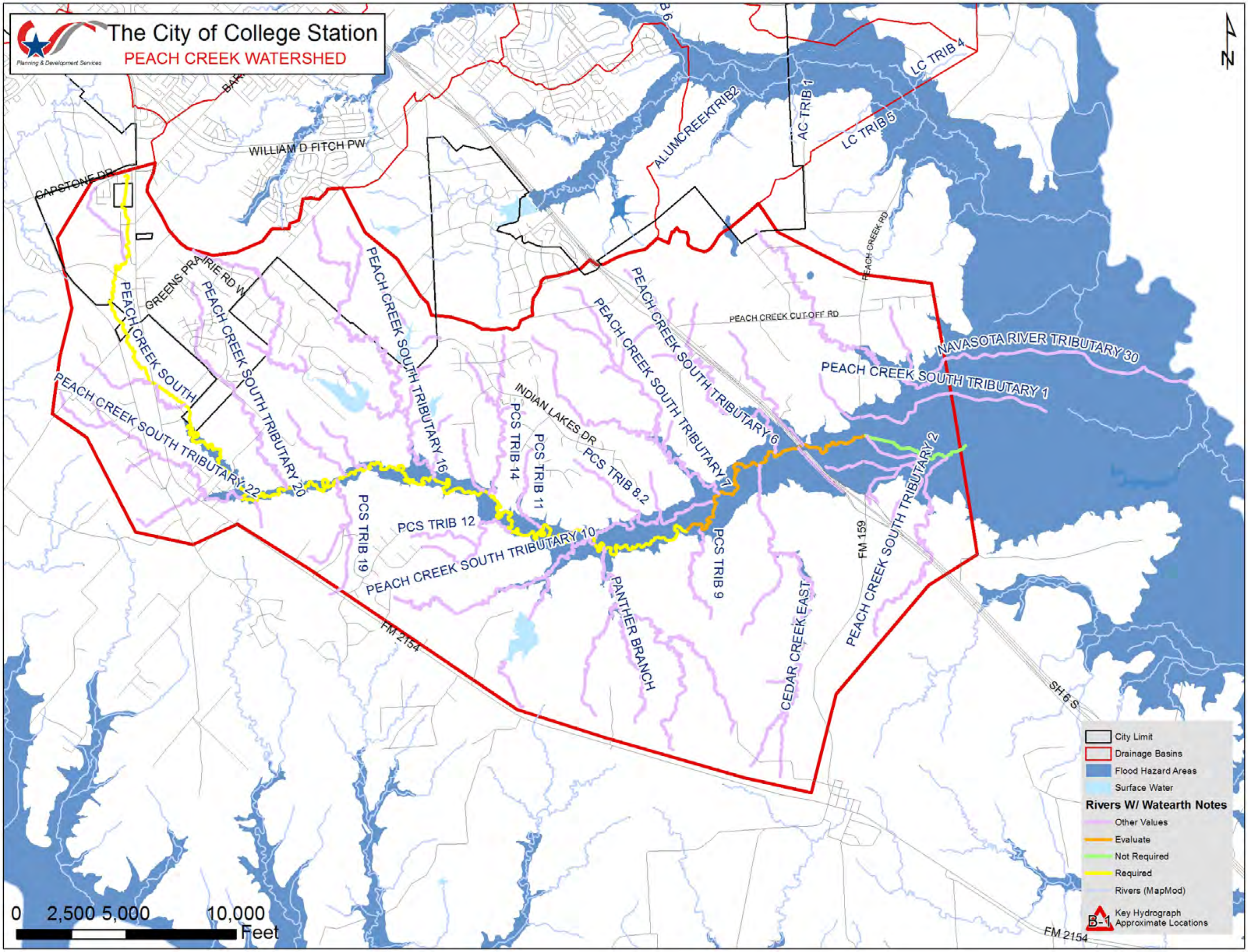

The City of College Station
Planning & Development Services
BURTON CREEK WATERSHED
N
W WJB PW
N SIMS
N MAIN ST
N TEXAS
E 23RD ST
E WJB PW
E 25TH ST
W 28TH ST
S SIMS AV
S BRYAN AV
S MAIN ST
E 32ND ST
S COULTER DR
E VILLA MARIA RD
BROADMOOR DR
N EARL RUDDER FW
MIRAMONT
GREEN VALLEY DR
WOODCREST DR
COPPERFIELD DR
E OAK HILL DR
BRIARCREST DR
PALASOTA DR
BECK ST
BC TRIB 8
BC TRIB 7
E 29TH ST
W DODGE ST
GROESBECK ST
AVONDALE AV
CARTER CREEK PW
BURTON CREEK TRIBUTARY 4
BURTON CREEK TRIBUTARY 3
TANGLEWOOD DR
BARAK LN
OAK HILL DR
LEONARD RD
FINFEATHER RD
BC TRIB D.1
CAVITT AV
S TEXAS AV
W CARSON ST
BC TRIB D.2
BURTON CREEK TRIBUTARY D
BURTON CREEK TRIBUTARY 5
BC TRIB 2
BURTON CREEK
EARL RUDDER FW S
TURKEY CREEK RD
BC TRIB D
BC TRIB D.3
GARDEN ACRES BL
BC TRIB C.1
BC TRIB 1
SPRING LO
UNIVERSITY DR E
GLENHAVEN DR
S COLLEGE AV
E NORTH AV
BURTON CREEK TRIBUTARY C
BC TRIB C.2
BC TRIB C.3
TARROW ST
LINCOLN AV
W VILLA MARIA RD
WELLBORN RD
OLD COLLEGE RD
BURTON CREEK TRIBUTARY C.4
BURTON CREEK TRIBUTARY
N HARVEY MITCHELL PW
COLLEGE AV
COLLEGE MAIN ST
MUNSON AV
FRANCIS DR
WALTON DR
TEXAS AV
TEXAS AV S
DOMINIK DR
UNIVERSITY DR
F & B RD
GEORGE BUSH DR
0 1,250 2,500 5,000
Feet
City Limit
Drainage Basins
Flood Hazard Areas
Surface Water
Rivers W/ Watearth Notes
Other Values
Evaluate
Not Required
Required
Rivers (MapMod)
B-1
Key Hydrograph Approximate Locations



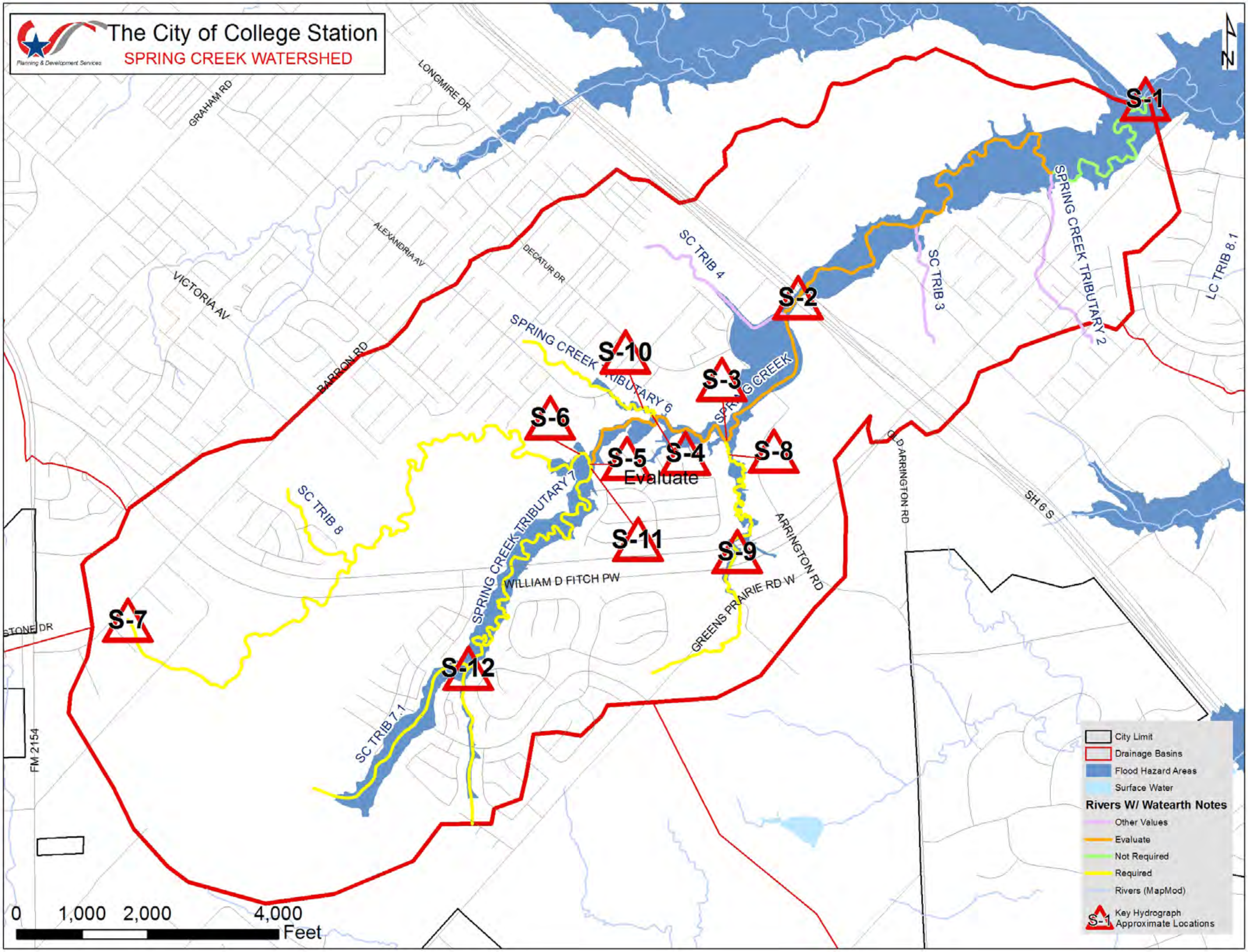
The City of College Station
Planning & Development Services
CARTERS CREEK WATERSHED
CARTERS CREEK TRIBUTARY B
CC TRIB 29
CC TRIB 27
CC TRIB 25
CC TRIB 22
CC TRIB 20
CC TRIB 18
CC TRIB 17
CC TRIB 15
CC TRIB 14
CC TRIB 13
HUDSON CREEK TRIB 1
CARTERS CREEK TRIBUTARY 15.1
CARTERS CREEK TRIBUTARY 8
CARTERS CREEK
WOLF PEN CREEK
FOXFIRE CREEK
C-1
C-2
C-3
C-4
C-5
TABOR RD
FM 974
E SH 21
OLD RELIANCE RD
OLD HEARNE RD
N TEXAS AV
E MLK ST
W MLK ST
W SH 21
W WJB PW
E WJB PW
BOONVILLE RD
N EARL RUDDER FW
E 29TH ST
S MAIN ST
S TEXAS AV
GROESBECK ST
BRIARCREST DR
CAVITT AV
S COLLEGE AV
FINFEATHER RD
WELLBORN RD
LEONARD RD
W VILLA MARIA RD
UNIVERSITY DR
UNIVERSITY DR E
HARVEY RD
FM 158
SH 30
LINCOLN AV
TEXAS AV
ANDERSON ST
DARTMOUTH ST
EARL RUDDER FW S
HOLLEMAN DR
SOUTHWEST PW
GEORGE BUSH DR
TEXAS AV S
MITCHELL PW S
HOLLEMAN DR S
WELSH AV
ROCK PRAIRIE RD
SH 6 S
FM 2154
VICTORIA AV
BARRON RD
WILLIAM D FITCH PW
City Limit
Drainage Basins
Flood Hazard Areas
Surface Water
Rivers W/ Watearth Notes
Other Values
Evaluate
Not Required
Required
Rivers (MapMod)
Key Hydrograph Approximate Locations
0
5,000
10,000
20,000
Feet
N

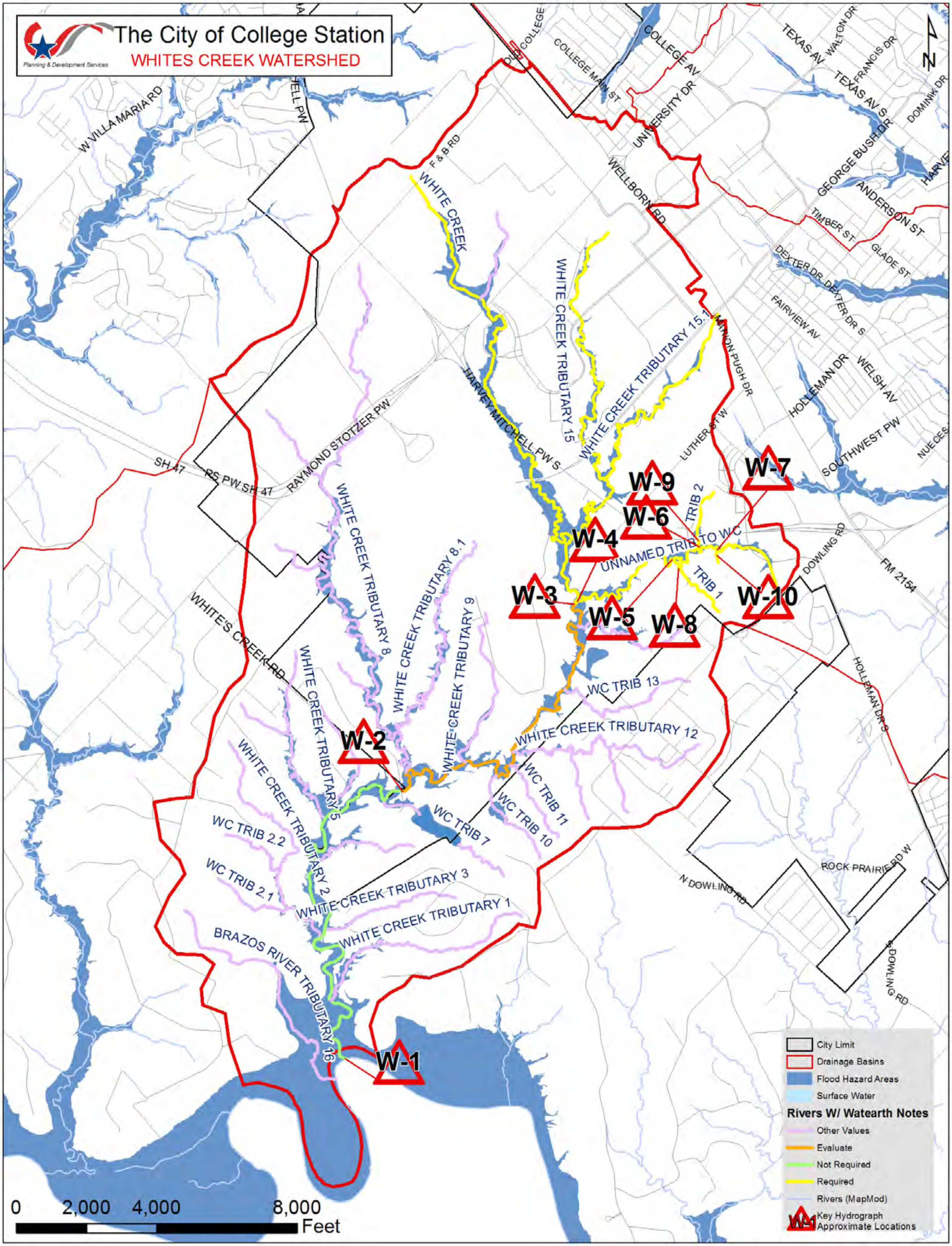


The City of College Station
Planning & Development Services
LICK CREEK WATERSHED
LICK CREEK
LC TRIB 14
LC TRIB 12
LC TRIB 11
LC TRIB 10
LC TRIB 9
LC TRIB 8.1
LC TRIB 6
LC TRIB 13.1
LICK CREEK TRIBUTARY 7
ALUM CREEK
ALUM CREEK TRIB 2
AC TRIB 1
LC TRIB 5
LC TRIB 4
CC TRIB 14
CC TRIB 13
L-1
L-2
L-3
L-4
L-5
L-6
L-7
L-8
L-9
L-10
L-11
L-12
ROCK PRAIRIE RD
WELSH AV
HARVEY MITCHELL PW S
TEXAS AV S
BARRON RD
CAPSTONE DR
GREENS PRAIRIE RD W
SH 6 S
Rivers W/ Watearth Notes
Other Values
Evaluate
Not Required
Required
Rivers (MapMod)
City Limit
Drainage Basins
Flood Hazard Areas
Surface Water
Key Hydrograph Approximate Locations
0
3,000
6,000
12,000
Feet
N

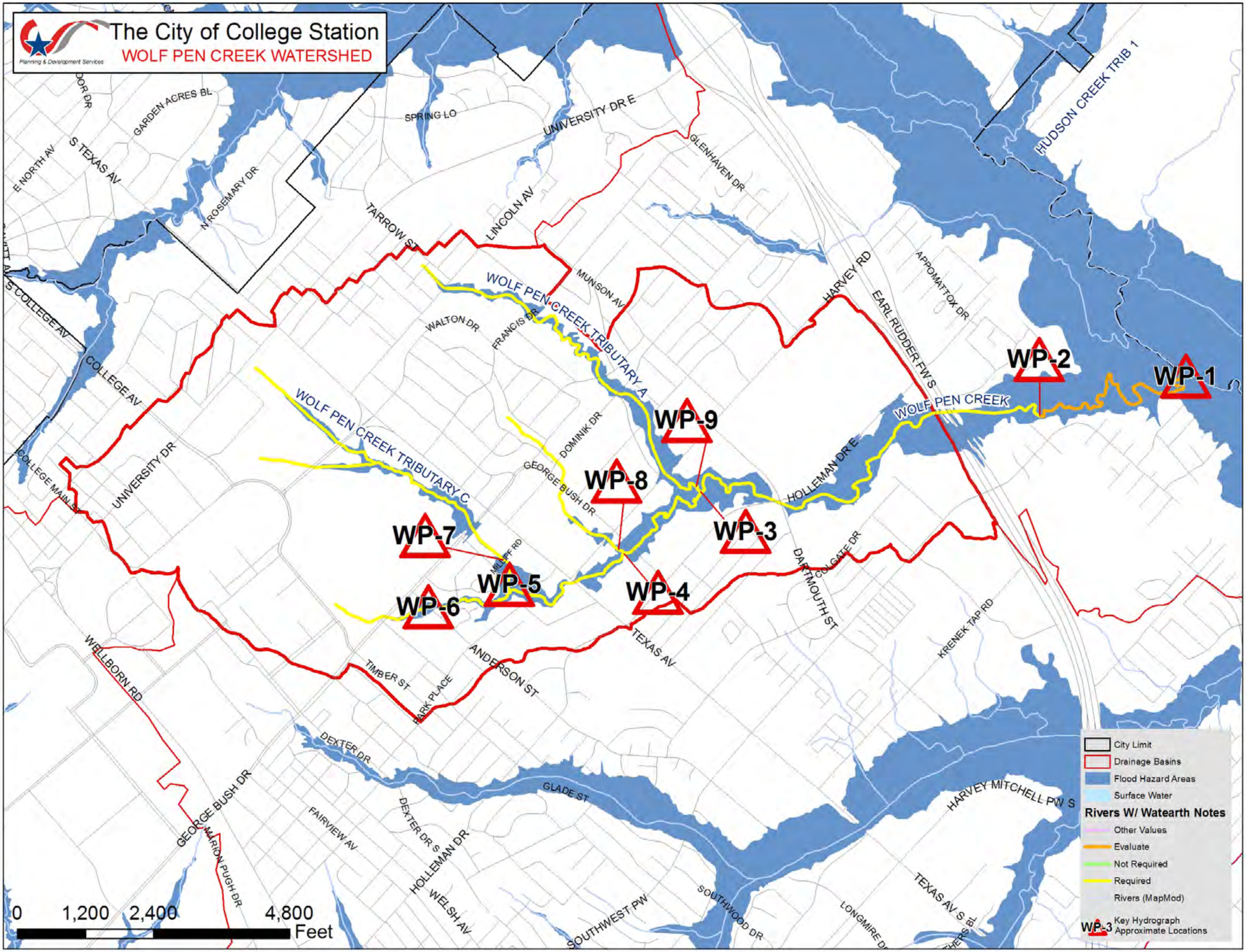


The City of College Station
Planning & Development Services
PEACH CREEK WATERSHED
WILLIAM D FITCH PW
CAPSTONE DR
GREENS PRAIRIE RD W
ALUMCREEKTRIB2
AC TRIB 1
LC TRIB 4
LC TRIB 5
PEACH CREEK RD
PEACH CREEK CUT-OFF RD
NAVASOTA RIVER TRIBUTARY 30
PEACH CREEK SOUTH TRIBUTARY 1
PEACH CREEK SOUTH
PEACH CREEK SOUTH TRIBUTARY 20
PEACH CREEK SOUTH TRIBUTARY 16
PEACH CREEK SOUTH TRIBUTARY 22
PEACH CREEK SOUTH TRIBUTARY 7
PEACH CREEK SOUTH TRIBUTARY 6
PEACH CREEK SOUTH TRIBUTARY 2
PEACH CREEK SOUTH TRIBUTARY 10
INDIAN LAKES DR
PCS TRIB 14
PCS TRIB 11
PCS TRIB 8.2
PCS TRIB 19
PCS TRIB 12
PCS TRIB 9
PANTHER BRANCH
CEDAR CREEK EAST
FM 159
FM 2154
SH 6 S
City Limit
Drainage Basins
Flood Hazard Areas
Surface Water
Rivers W/ Watearth Notes
Other Values
Evaluate
Not Required
Required
Rivers (MapMod)
Key Hydrograph Approximate Locations
B-1
0 2,500 5,000 10,000 Feet
N


The City of College Station
SPRING CREEK WATERSHED
Planning & Development Services
S-1
S-2
S-3
S-4
S-5
Evaluate
S-6
S-7
S-8
S-9
S-10
S-11
S-12
GRAHAM RD
LONGMIRE DR
ALEXANDRIA AV
DECATUR DR
VICTORIA AV
BARRON RD
SC TRIB 4
SC TRIB 3
SPRING CREEK TRIBUTARY 2
LC TRIB 8.1
SPRING CREEK TRIBUTARY 6
SPRING CREEK
SPRING CREEK TRIBUTARY 7
SC TRIB 8
OLD ARRINGTON RD
SH 6 S
ARRINGTON RD
WILLIAM D FITCH PW
GREENS PRAIRIE RD W
STONE DR
FM 2154
SC TRIB 7.1
City Limit
Drainage Basins
Flood Hazard Areas
Surface Water
Rivers W/ Watearth Notes
Other Values
Evaluate
Not Required
Required
Rivers (MapMod)
Key Hydrograph Approximate Locations
0
1,000
2,000
4,000
Feet
N



The City of College Station
WHITES CREEK WATERSHED
Planning & Development Services
W VILLA MARIA RD
F & B RD
WHITE CREEK
WHITE CREEK TRIBUTARY 15
WHITE CREEK TRIBUTARY 15.1
HARVEY MITCHELL PW S
RAYMOND STOTZER PW
SH 47
WELLBORN RD
UNIVERSITY DR
COLLEGE AV
COLLEGE MAIN ST
TEXAS AV
TEXAS AV S
GEORGE BUSH DR
ANDERSON ST
HOLLEMAN DR
WELSH AV
SOUTHWEST PW
LUTHER ST W
FM 2154
DOWLING RD
UNNAMED TRIB TO WC
TRIB 1
TRIB 2
W-1
W-2
W-3
W-4
W-5
W-6
W-7
W-8
W-9
W-10
WHITE'S CREEK RD
WHITE CREEK TRIBUTARY 8
WHITE CREEK TRIBUTARY 8.1
WHITE CREEK TRIBUTARY 9
WHITE CREEK TRIBUTARY 12
WC TRIB 13
WC TRIB 11
WC TRIB 10
WC TRIB 7
WHITE CREEK TRIBUTARY 5
WHITE CREEK TRIBUTARY 2
WC TRIB 2.2
WC TRIB 2.1
WHITE CREEK TRIBUTARY 3
WHITE CREEK TRIBUTARY 1
BRAZOS RIVER TRIBUTARY 16
N DOWLING RD
ROCK PRAIRIE RD W
HOLLEMAN DR S
S DOWLING RD
City Limit
Drainage Basins
Flood Hazard Areas
Surface Water
Rivers W/ Watearth Notes
Other Values
Evaluate
Not Required
Required
Rivers (MapMod)
Key Hydrograph Approximate Locations
0 2,000 4,000 8,000 Feet



The City of College Station
Planning & Development Services
WOLF PEN CREEK WATERSHED
WOLF PEN CREEK
WOLF PEN CREEK TRIBUTARY A
WOLF PEN CREEK TRIBUTARY C
HUDSON CREEK TRIB 1
WP-1
WP-2
WP-3
WP-4
WP-5
WP-6
WP-7
WP-8
WP-9
UNIVERSITY DR E
UNIVERSITY DR
TEXAS AV
HARVEY RD
EARL RUDDER FW S
HOLLEMAN DR E
GEORGE BUSH DR
WELLBORN RD
COLLEGE AV
HARVEY MITCHELL PW S
SOUTHWEST PW
DARTMOUTH ST
ANDERSON ST
0
1,200
2,400
4,800
Feet
City Limit
Drainage Basins
Flood Hazard Areas
Surface Water
Rivers W/ Watearth Notes
Other Values
Evaluate
Not Required
Required
Rivers (MapMod)
Key Hydrograph Approximate Locations

APPENDIX F – SUMMARY OF DETENTION REQUIREMENTS

APPENDIX F: DETENTION REQUIREMENTS BY WATERSHED

Watershed	Channel Reach			Detention for Flood Control
	Designation	Upstream	Downstream	
Alum Creek				
Alum Creek	A-3	Upstream	SH 6	Required
	A-2	SH 6	Confluence Alum Creek and AC-1	Not Required
	A-1	Confluence Alum Creek and AC-1	Mouth/Carters Creek	Not Required
Alum Creek Trib. 1	AC1-1	Upstream End	Mouth/Alum Creek	Required
Trib. 1 to Alum Creek Trib. 1	T1-AC1-2	Upstream End	Confluence AC-1 and Trib. 1 to AC-1	Required
Trib. 1 to Alum Creek Trib. 1	T1-AC1-1	Confluence AC-1 and Trib. 1 to AC-1	Mouth/Alum Creek Trib. 1	Required
Bee Creek				
NO HYDROLOGY MODELS AVAILABLE FOR BEE CREEK - BEE CREEK & BEE CREEK TRIB. A RECOMMENDATIONS FROM UNIFIED STORMWATER GUIDELINES				
Bee Creek	BEE-3	Upstream End	Southwest Parkway	Required
	BEE-2	Southwest Parkway	Texas Avenue	Evaluate
	BEE-1	Texas Avenue	Carters Creek	Not Required
Bee Creek Trib. A	BEE-TA-3	Upstream End	Welsh	Required
	BEE-TA-2	Welsh	Texas Avenue	Evaluate
	BEE-TA-1	Texas Avenue	Mouth/Confluence with Bee Creek	Not Required
Bee Creek Trib. B	BEE-TB	Upstream End	Mouth/Confluence with Bee Creek	Required
Bee Creek Trib. B3	BEE-TB3	Upstream End	Mouth/Confluence with Bee Creek Trib. B	Required
Burton Creek				
NO HYDROLOGY MODELS AVAILABLE - BURTON CREEK AND BURTON CREEK TRIB. C RECOMMENDATIONS FROM UNIFIED STORMWATER GUIDELINES				
Burton Creek	B-3	Upstream End	E. Villa Maria	Required
	B-2	E. Villa Maria	E. 29th St.	Evaluate
	B-1	E. 29th St.	Carters Creek	Not Required
Burton Creek Trib. C	BTC-2	Upstream End	Texas Avenue	Required
	BTC-1	Texas Avenue	Burton Creek	Evaluate
Carters Creek				
Carters Creek	C-2	Upstream End	Confluence Burton Creek/SH6	Evaluate
Carters Creek	C-1	Confluence Burton Creek/SH6	Navasota River	Not Required
Lick Creek				
Lick Creek	L-3	Upstream End	Confluence North Fork and South Fork (Trib. 13)	Required
	L-2	Confluence North Fork and South Fork (Trib. 13)	Greens Prairie Road	Evaluate
	L-1B	Greens Prairie Road	City Limits	Not Required
	L-1A	Greens Prairie Road	Navasota River	Not Required
Lick Creek Trib. 13 (South Fork)	L-T13	Upstream End	Confluence North Fork and South Fork (Trib. 13)	Required

APPENDIX F: DETENTION REQUIREMENTS BY WATERSHED

Watershed	Channel Reach			Detention for Flood Control
	Designation	Upstream	Downstream	
Peach Creek				
NO HYDROLOGY MODELS AVAILABLE - RECOMMENDATIONS FROM UNIFIED STORMWATER GUIDELINES				
Peach Creek	P-3	Upstream End	14,000 ft Upstream Peach Creek Rd	Required
	P-2	14,000 ft Upstream Peach Creek Rd	Peach Creek Road	Evaluate
	P-1	Peach Creek Road	Navasota River	Not Required
Spring Creek				
Spring Creek	S-3	Upstream End	Confluence Spring Creek Trib. 7	Required
	S-2	Confluence Spring Creek Trib. 7	Confluence Spring Creek Trib. 2	Evaluate
	S-1	Confluence Spring Creek Trib. 2	Mouth/Confluence Lick Creek	Not Required
Spring Creek Trib. 7-1	ST7-1	Upstream End	Mouth/Confluence Trib. 7	Required
Spring Creek Trib. 7	ST-7	Upstream End	Mouth/Confluence Spring Creek	Required
Spring Creek Trib. 6	ST-6	Upstream End	Mouth/Confluence Spring Creek	Required
Spring Creek Trib. 5	ST-5	Upstream End	Mouth/Confluence Spring Creek	Required
Whites Creek				
Whites Creek	W-3	Upstream End	Whites Creek Confluence with Unnamed Tributary	Required
	W-2	Whites Creek Confluence with Unnamed Tributary	Unnamed Road Off of Whites Creek	Evaluate
	W-1	Unnamed Road Off of Whites Creek	Brazos River	Not Required
Whites Creek Trb. 15	W-T15	Upstream End	Mouth/Confluence with Whites Creek	Required
Whites Creek Trib. 15.1	W-T15-1	Upstream End	Mouth/Confluence with Whites Creek	Required
Unnamed Trib. to Whites Creek	WUT	Upstream End	Mouth/Confluence with Whites Creek	Required
Trib. 1 to Unnamed Trib.	WUT-T1	Upstream End	Mouth/Confluence with Unnamed Trib.	Required
Trib. 2 to Unnamed Trib.	WUT-T2	Upstream End	Mouth/Confluence with Unnamed Trib.	Required
Trib. 3 to Unnamed Trib.	WUT-T3	Upstream End	Mouth/Confluence with Unnamed Trib.	Required
Wolf Pen Creek				
Wolf Pen Creek	WP-3	Upstream End	Approx. 900 ft D/S SH 6	Required
	WP-2	Approx. 900 ft D/S SH 6	Mouth/Confluence with Carters Creek	Evaluate
	WP-1	---	---	---
Wolf Pen Creek Trib.A	WPA	Upstream End	Mouth/Confluence with Wolf Pen Creek	Required
Wolf Pen Creek Trib. B	WPB	Upstream End	Mouth/Confluence with Wolf Pen Creek	Required
Wolf Pen Creek Trib. C	WPC	Upstream End	Mouth/Confluence with Wolf Pen Creek	Required

Notes:

1. Shaded items clarified from *Unified Stormwater Guidelines* as no hydrologic models were available.
2. Reaches that require detention are labeled in red, reaches that require evaluation are in fuschia, and reaches that do not require detention in black on watershed graphics.
3. Alum Creek hydrologic model is basic and simplified with minimal hydrograph locations and shaded requirements based on *Unified Stormwater Guidelines*.
4. Detention requirements are for Type 1 Flood Control Detention for projects outfalling directly to noted streams. For projects outfalling to tributaries or other streams, Type 2 Conveyance Detention may be required and travel time to the listed streams must be considered in the simplified detention and downstream impacts analysis.
5. Projects discharging to streams or tributaries not specifically listed require evaluation.

APPENDIX G – MODELS AND SPREADSHEETS OF KEY HYDROGRAPHS (PROVIDED SEPARATELY)