SAN JACINTO

REGIONAL WATERSHED MASTER DRAINAGE PLAN

Prepared for:
Harris County Flood Control District
San Jacinto River Authority
Montgomery County
City of Houston

APPENDIX F

SEDIMENT MANAGEMENT STRATEGY FOR
WEST FORK SAN JACINTO RIVER AND SPRING CREEK

San Jacinto Regional Watershed
Master Drainage Plan

SEDIMENT MANAGEMENT STRATEGY
FOR WEST FORK SAN JACINTO RIVER AND SPRING CREEK

Prepared for

Harris County Flood Control District
San Jacinto River Authority
Montgomery County
City of Houston
by

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STATE OF TEXAS
GEORGE DEFOREST FOWLER II
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LICENSED
PROFESSIONAL ENGINEER

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Executive Summary

Sedimentation in Lake Houston began as soon as the lake was created with the construction of Lake Houston Dam in 1954. Ongoing deposits of sediment have resulted in reduced water supply storage in the lake. In 2019, the U.S. Army Corps of Engineers (USACE) conducted a dredging project that has removed roughly five percent of the material deposited in Lake Houston since the dam was built. The cost of this project exceeded $90 million. The projected cost to remove the annual sediment load into Lake Houston would exceed $29 million per year. If no additional removal of sediment is conducted between 2020 and 2035, the projected cost to remove all sediment deposited in Lake Houston by 2035 would exceed $2.2 billion.

To slow the rate of deposit of sediments into Lake Houston and the West Fork San Jacinto River just upstream of Lake Houston, this sediment management strategy was developed for the West Fork San Jacinto River and Spring Creek subwatersheds. The strategy was developed by identifying sediment sources and mapping locations where sediment management strategies can be implemented to reduce the flow of sediments into Lake Houston.

This study replicates methods used in previous studies with available data from the USGS to create an annual sediment rating curve to measure the amount of sediment flowing out of each of seven subwatersheds that flow into Lake Houston: West Fork San Jacinto River, East Fork San Jacinto River, Luce Bayou, Caney Creek, Peach Creek, Cypress Creek, and Spring Creek. Sediment rating curves that relate sediment load with discharge are reliable predictive tools for sediment transport. This tool, in conjunction with an assessment of historic and current topographic information, indicated that both the West Fork and Spring Creek subwatersheds contributed significant sediment to Lake Houston. The majority of this sediment, up to 80 percent, could originate from eroding streambanks. Other sources may include erosion of upland soils away from the river as well as anthropogenic activities (industrial, commercial, etc.).

Other findings of this study include the following:

- A LiDAR volumetric comparison showed that 2,693 acre-feet of material (equal to approximately 434,500 ten cubic yard dump trucks) is eroded from the San Jacinto watershed landscape per year during the studied period. This material may deposit within the landscape or enter the stream and river network as a mixture of washload, suspended sediment and bedload. The material either deposits in the stream network, deposits in Lake Houston, or is washed over Lake Houston Dam.
- An annual suspended sediment load analysis based on available stream gage data showed that an estimated 433 acre-feet per year of suspended sediment transport may be transported into Lake Houston.
- Available stream gage data located at the bridges where Cypress Creek, Spring Creek, and West Fork cross Interstate-45 predicted that their respective watersheds are the highest contributors of suspended sediment to Lake Houston, contributing an estimated 38.7 percent, 26.8 percent, and 13.0 percent of the total sediment load, respectively.
- The same gages also predicted Cypress Creek, Spring Creek, and West Fork at Interstate-45 contribute 44%, 30% and 14% respectively of the suspended sediment load to the sediment

problem area near Kingwood. The remaining 13% of sediment load originates from the region between the gages and the sediment problem area.

- Sediment is transported to Lake Houston primarily suspended in water or pushed along river bottoms as bedload. Most of the deposited sediment in the studied region (greater than 90%) of the sediment problem area around Kingwood was sand. This finding suggests sediment reduction strategies should seek to mitigate sediment sources that contribute sand to the river network.
- Forty-nine sediment management strategies were identified in the West Fork and Spring Creek subwatersheds. These strategies can be used by watershed community administrators and floodplain managers to identify opportunities to prevent sediment sources from entering the stream network.
- Public-private partnerships and/or an extension of jurisdictional authority may be needed to implement the proposed sediment management strategies. An example memorandum of understanding (MOU) to extend jurisdictional authority is provided as **Appendix F.E**.
- Manipulation of Lake Houston Dam hydraulics or construction of a sediment bypass tunnel can also decrease sedimentation in the region between the Spring Creek and West Fork San Jacinto River confluence and Lake Houston.
- Aggregate Production Operations (APOs), also known as sand mines, need to ensure the integrity of their facilities be protected to avoid releasing sediments downstream. Water quality samples are needed to assess if and how much sediment leave APOs from pond breaches and management activities. Detailed topographic surveys using drone or photogrammetry can be completed before and immediately after flooding events to assess how much material may have been washed away or deposited at APO facilities.

These methods and findings were organized by following USACE guidelines for development of a Regional Sediment Management Plan (RSM). RSMs have been used to develop solutions to complex sediment problems that result in the filling of navigable waters (USACE 2002). This report focuses on sediment from the West Fork San Jacinto River and Spring Creek as an initial phase of work to identify sediment management strategies to reduce sedimentation in Lake Houston. These areas were identified by project stakeholders as the areas of concern. A comprehensive RSM for the watershed is recommended for development as part of a future phase of work.

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1.0 Introduction

In February of 2019, the Harris County Flood Control District (HCFCD) hired Halff Associates, Inc., to prepare the San Jacinto Regional Watershed Master Drainage Plan (SJMDP). The SJMDP is being partially funded through the FEMA Hazard Mitigation Grant Program (HMGP), administered on the state level by the Texas Department of Emergency Management (TDEM). The San Jacinto River Authority (SJRA), Montgomery County, and the City of Houston are partners with HCFCD on this project and jointly provided cost shares of the funding. As a subconsultant to Halff Associates, Freese and Nichols, Inc. prepared this sediment management strategy report for the West Fork San Jacinto River and Spring Creek. This study is one part of the overall SJMDP.

The scope of services for the sediment management strategy study is summarized below:

> "Development and implementation of a maintenance plan to help control sedimentation and vegetative growth along the major streams included in this flood mitigation plan, particularly along the West Fork of the San Jacinto.
>
> 1. Coordinate with SJRA and HCFCD Facilities Maintenance Department.
> 2. Review and update the Lake Houston Watershed Flood Program report prepared by Brown & Root Services (June 2000).
> 3. Review previous sediment management reports and update as necessary.
> 4. Leverage the Lake Houston report and others to develop a sediment management strategy for during and after flood events for West Fork San Jacinto River and Spring Creek.
> 5. Determine the agency or agencies that are responsible for de-silting and vegetative debris removal efforts in the West Fork San Jacinto River. Develop a draft memorandum of understanding (MOU) for the agencies to consider.
> 6. Develop a document discussing the history of sand mining operations in the basin.
>   a. Review aerial photography and available topography to observe changes in the stream alignments for the West Fork San Jacinto River and Spring Creek.
>   b. Identify potential sources of sedimentation in Spring Creek and West Fork San Jacinto River.
>   c. Review changes in sand mining operations along the West Fork San Jacinto River, including changes in regulations that the sand mining operations are required to follow.
>   d. Submit technical report detailing the process and findings."

A sediment management strategy for both the Spring Creek and West Fork San Jacinto River subwatersheds was developed per this scope and included the following objectives:

- Replicate the methods used in previous reports to identify opportunities to prevent sediments from entering the rivers and streams within the watershed, reduce the amount of sediments depositing in the region between the confluence of the West Fork San Jacinto River and Spring Creek and the FM 1960 bridge over Lake Houston, and remove sediment that already deposited in this region.
- Identify locations where sediment management strategies can be implemented in the West Fork San Jacinto River and Spring Creek subwatersheds.

- Provide recommendations for subsequent studies for evaluating additional methodologies that were not used in previous reports. These subsequent studies are needed to understand the relationship between sedimentation and flood water surface elevations in this area, quantify a sediment budget throughout the entire San Jacinto watershed, predict the efficiency of sediment management strategies, and measure the movement of sediments through the watershed.

This sediment management strategy report was assembled using the Regional Sediment Management (RSM) plan approach, which has been implemented in other watersheds throughout the country. This approach aims to reduce sedimentation in shipping channels or flood conveyance channels by implementing cost-effective sediment management techniques that are based on sound engineering and scientific fundamentals. This approach was developed by the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (U.S. EPA); these are the federal agencies most often involved in the planning and funding of sediment management strategies. State and regional authorities also follow a similar approach to RSM planning to achieve their own watershed management goals such as water quality improvement, flood risk reduction, and hydroelectric power production.

The sections of this report were assembled following the work tasks in a typical RSM plan. Each section begins with an introduction to the task, the methods and findings used in previous reports that support the completion of the task, and recommendations on additional methods used to complete the task. The target audience for this report is watershed managers who are responsible for implementing flood conveyance and water quality improvement strategies. The expected outcome of the report for this audience is identification of what sediment management strategies can be implemented without further study and which require further study and planning.

1.1 Sediment Management Strategy Goal

Sedimentation is the process whereby soil particles are transported by flowing water and are deposited in layers of solid particles in waterbodies such as rivers and reservoirs (Ezugwu, 2013), and has been identified as an issue of concern within the upper San Jacinto watershed. The goal of this sediment management strategy as defined by the stakeholders within the watershed is to identify opportunities along the West Fork and Spring Creek mainstems to decrease sediment deposition in the West Fork San Jacinto River channel between its confluence with Spring Creek just west of West Lake Houston Parkway and Lake Houston. This sediment problem area is labeled in **Figure 1-1**, just south of the master-planned community of Kingwood.

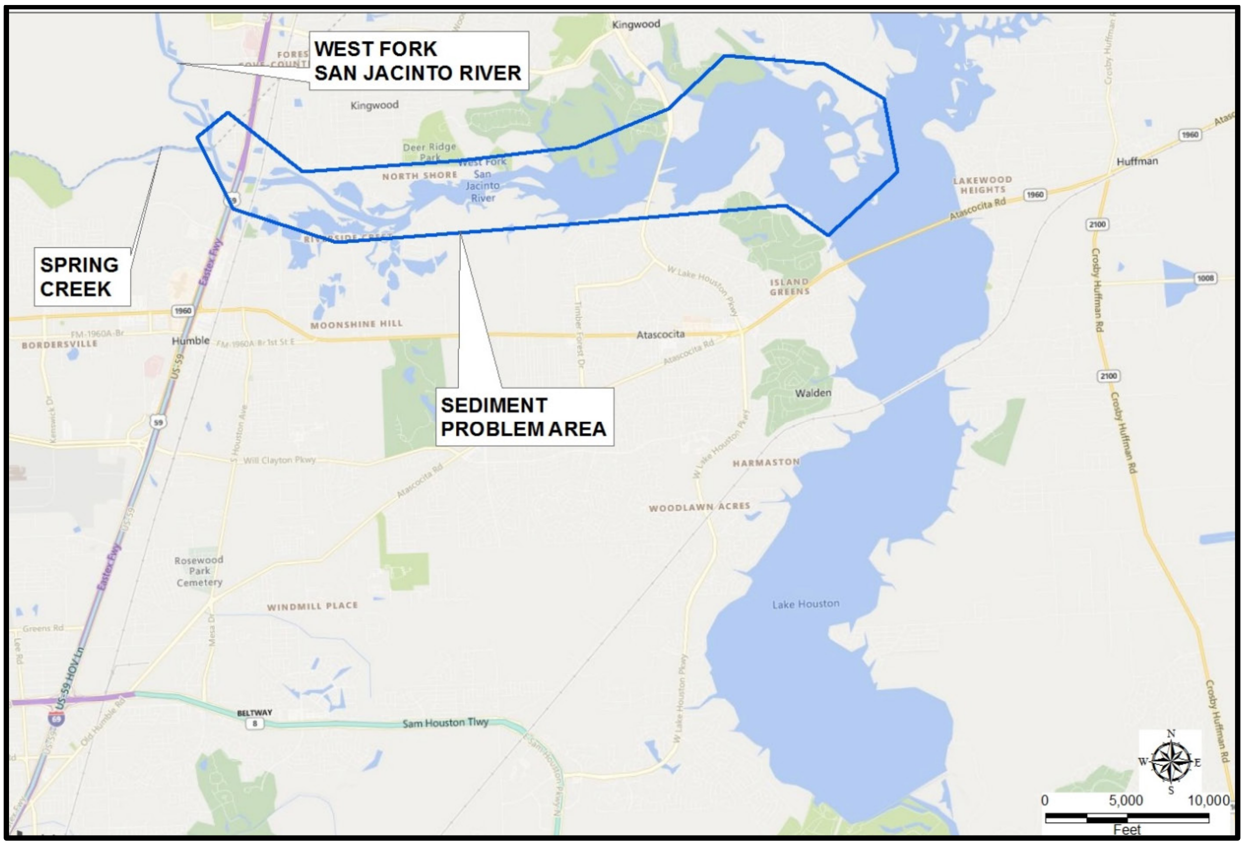

Figure 1-1: West Fork San Jacinto River between the Spring Creek Confluence and Lake Houston

Figure 1-2 shows where this reach of the West Fork San Jacinto River is located in relation to Lake Houston as a whole and indicates the location of both the Spring Creek and West Fork San Jacinto River subwatersheds. To match the approach used in previous sedimentation studies, the West Fork San Jacinto River subwatershed also includes the Lake Creek subwatershed west of Lake Conroe. In the same way, the Spring Creek subwatershed includes the Willow Creek subwatershed, the Cypress Creek subwatershed includes Little Cypress, and the Luce Bayou subwatershed includes Tarkington. As noted previously, this sediment management strategy is focused on the West Fork and Spring Creek mainstems.

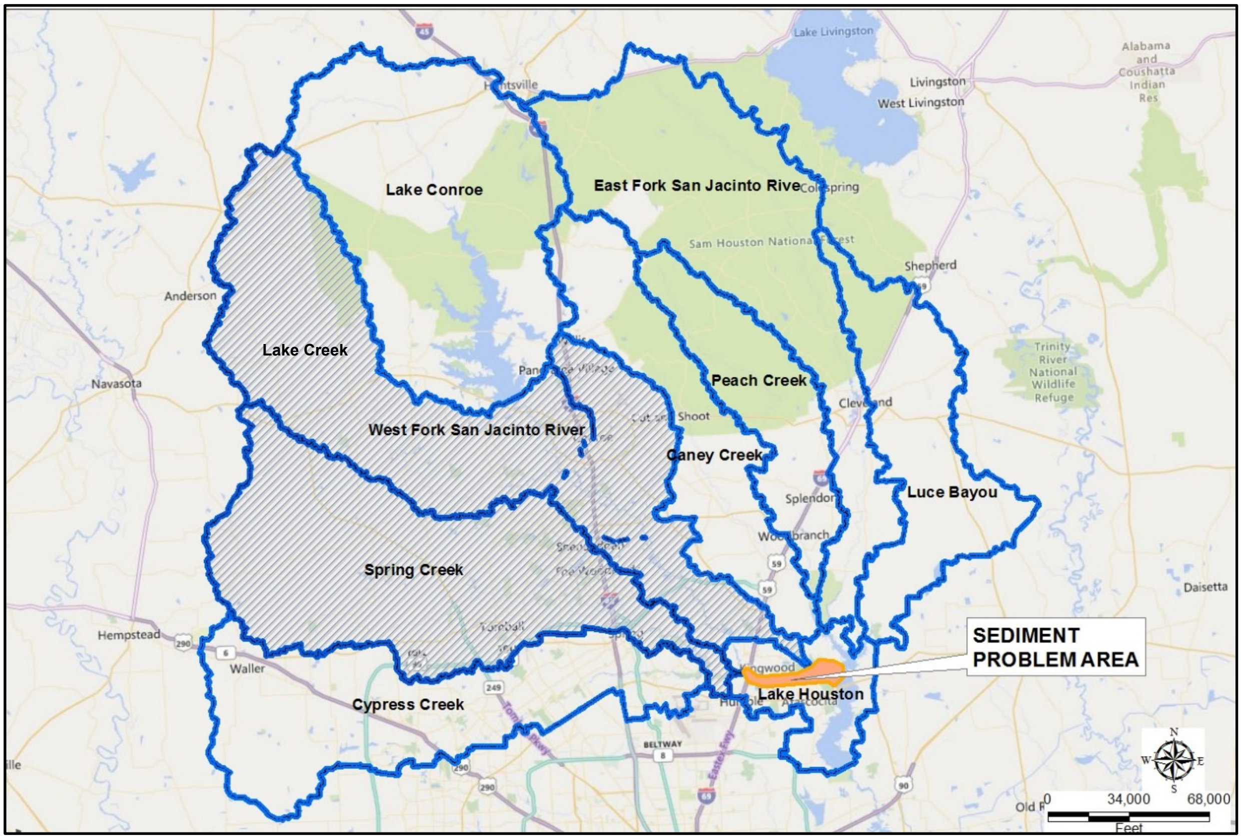

Figure 1-2: West Fork and Spring Creek Study Areas

1.2 Sediment Behavior

Nearly all stream channels are formed, maintained, and altered by the water and sediment they carry (FISRWG, 1998) and maintain a dynamic equilibrium between discharge, slope, sediment load, and sediment size (Lane 1955). Sediment deposits within a channel in a dynamic-equilibrium system create a diverse and healthy aquatic ecosystem (USBOR 2013). Lane illustrates this relationship as a balance scale between the amount of water a channel transports and the amount of sediment that is transported. When this relationship is balanced, the dynamic equilibrium is reached. When one side of the balance scale is increased, the other side will react to return to dynamic equilibrium (Lane 1955).

Land use changes in a watershed, such as the increase in impervious area from urbanization, can disturb that dynamic equilibrium. Increased impervious area results in a larger amount of flood water in receiving channels, which then results in the entrainment and transport of more sediment (SCCWRP 2013). This can result in poorer water quality and be detrimental to aquatic habitat (NRCS 1995). In the San Jacinto watershed, this balance scale has been tipped multiple times since the early 19th century, first by the clearing of forests for agriculture and more recently by urbanization. The resulting increase in transported sediment and the resulting sediment deposition downstream can result in poorer water quality, unstable water channels prone to erosion, loss of aquatic habitat, loss of land, potential changes in flooding conditions, and potential damage to public infrastructure, depending on the location and amount of sedimentation.

Stream banks within the San Jacinto watershed have likely been eroding and contributing sediment to the West Fork since the end of the last ice age approximately 10,000 years ago. Some level of background sediment would have been transported along the West Fork even if no changes to watershed land use practices had occurred. Since land use changes have occurred within the watershed, it is likely that excess sediments are now flowing into Lake Houston in addition to background sediment. This study seeks to identify sources of excess sediment and areas with excessive sediment deposition and to select measures that can reduce the current sedimentation rates toward background sedimentation rates.

1.3 Sediment and Flood Risk

This sediment management strategy focuses on problem area identification and solutions based on existing available field data. This does not include the detailed hydraulic sediment transport modeling that is necessary to quantify the relationship between transported sediment and flood risk in the study area. This relationship is complex and requires consideration of many factors, including the relationship between channel conveyance and floodplain conveyance, the dynamic interaction between sediment and water surface elevations during flood events, and the ability of the stream to move sediment particles of varying sizes at varying flow rates.

Sediment deposition in a channel can reduce its cross-sectional area over time or block outfalls from local drainage systems. During high-frequency, low-intensity storms, such as the 50% annual chance event (ACE), reduced channel conveyance may result in increased water surface elevations (Slater et al. 2015). But during low-frequency, high-intensity storms, such as the 1% ACE, flood flows are typically conveyed by the floodplain and reduced channel conveyance may have a lesser effect on water surface elevations, depending on the geometry of the channel and floodplain.

Furthermore, because the area occupied by sediment changes during each flood event, the relationship between transported sediment and water surface elevation is dynamic. During a flood, rushing water can scour deposited sediment and transport it downstream. As the flood recedes and flood waters slow down, sediments from upstream may begin to deposit and can reform the obstruction. This shifting sediment deposition complicates the calculation of water surface elevations during the peak of a flood. Typical hydraulic modeling approaches will assume static conditions. A hydraulic modeling approach that accounts for the dynamic nature of sediment transport may calculate water surface elevations that are higher or lower than those calculated assuming static conditions.

Software such as the USACE's HEC-RAS program and other proprietary software can be used to calculate the relationship between hydraulic conditions, sediment competency and particle size distribution, and the influence of downstream conditions. This relationship is governed by sediment transport equations, which relate hydraulic conditions to the stream's sediment competency, that is, its ability to move different sizes of sediment (such as sands, gravels, or cobbles). Data required for this analysis includes detailed topography, continuous water flow data, and field measurements of sediment particle size distribution transported and deposited in the stream. This analysis allows calculation of how much of the sediment deposition may remain during a flood event and how this may or may not affect water surface calculations during a flood event. The influence of downstream infrastructure such as dams, road crossings, or natural constrictions in channel width must also be considered as part of this analysis, as the influence may slow down water velocities and reduce the stream's sediment competency. This influence may be the primary factor governing floodwater elevations in the study area, regardless of channel conditions upstream.

1.4 Introduction to Regional Sediment Management Planning

This sediment management strategy has adopted and adapted a Regional Sediment Management Planning (RSM) framework for the West Fork San Jacinto River and Spring Creek. The elements selected and used from the framework were guided by the scope of work as described in Section 1.0. The RSM framework was developed by the USACE and the U.S. EPA as a proactive approach to adaptive management planning, addressing both the short-term problems caused by the deposit of sediment and the long-term goal of mitigating future sediment-related problems before they become more costly to address. Another important benefit of an RSM plan is the inclusion of easily replicable methods. Quantifiable evaluations make the RSM a "living document" and allow for future updates as more data becomes available. For example, it may be desirable to replicate an analysis after a notable flood occurs in order to understand how the watershed's sediment system has changed.

For decades, USACE and the U.S. EPA have consistently stressed a "system-based approach" to resolve sediment related problems (NDT 1998). The USACE has adopted policies to incorporate a watershed perspective in conducting civil works such as sediment management (USACE 2000). This has led to a framework which emphasizes a system-based approach and seeks to design site-specific solutions to solve sediment-related problems while considering the overall natural sediment process (USACE 2002). This framework has been implemented in multiple regions around the country to develop a holistic approach to sediment management (USACE 2014). For example, in Texas the framework has been applied to study sediment behavior resulting in the infilling of Galveston Bay near Houston, Texas (USACE 2010). The framework has also been applied in Washington and California to understand and mitigate sediment deposition in flood conveyance channels (WCPW 2012 and LACFCD 2013, respectively.)

The USACE has developed a "Regional Sediment Management Primer" which lays out a five-step RSM framework, beginning with the characterization of the sediment related problems and who they impact. It ends with a selection of a sediment management plan strategy which has been vetted with respect to implementation costs, stakeholder preferences, and regulatory constraints (USACE 2020). The five steps in the framework are:

- Specify Sediment-Related Problems and Opportunities
- Inventory and Forecast Conditions
- Formulate Alternative RSM Plans
- Evaluate and Compare Alternative RSM Plans
- Select and Implement an RSM Strategy

For this sediment management strategy, the RSM framework was used to estimate a sediment budget, identify sediment sources, and develop sediment management opportunities for the West Fork San Jacinto River and Spring Creek. The remainder of the RSM framework is recommended to be applied to the West Fork San Jacinto River and Spring Creek subwatersheds, as well as for the remaining San Jacinto subwatersheds to provide a broad, consistent understanding of sediment behavior in the entire watershed.

1.5 Previous Studies in the San Jacinto Watershed

Readily available studies and measurements for the San Jacinto watershed were obtained and reviewed to understand which of the five steps in the RSM approach were included in each document. A detailed summary of the review was included in the Sedimentation Data chapter of the San Jacinto Regional Watershed Master Drainage Plan draft report (Halff/FNI 2020). **Table 1-1** lists eight documents published between 1957 and 2018 and shows which of the five steps were included in each document.

Table 1-1: Summary of Reviewed Documents and Sediment Management Planning Steps

Document Name	Specify Sediment-Related Problems and Opportunities	Inventory and Forecast Conditions	Formulate Alternative RSM Plans	Evaluate and Compare Alternative RSM Plans	Select and Implement an RSM Strategy
Master Plan Report for the Full-Scale Development of the San Jacinto River. Prepared by the San Jacinto River Authority, 1957.	X				
Sediment Evaluation of Lake Houston for the City of Houston. Prepared by Turner Collie & Braden, October 1983.		X			
San Jacinto Upper Watershed Drainage Improvement and Flood Control Planning Study for Texas Department of Water Resources and San Jacinto River Authority. Prepared by Wayne Smith and Associates, September 1985.	X				
Regional Flood Protection Study for Lake Houston Watershed Flood Program: Technical Report for City of Houston, Harris County Flood Control District, San Jacinto River Authority, and Texas Water Development Board. Prepared by Brown and Root, Inc, 2000.	X	X	X	X	X
TIN Models for Lake Houston 1994 Survey Boundary (Re-calculated) and 2011 Survey Boundary. Prepared by Texas Water Development Board, 2011.		X			
Volumetric and Sedimentation Survey of Lake Houston: June 2018 Survey. Prepared by Texas Water Development Board, April 2019.		X			
Bathymetric Survey of the West Fork San Jacinto River: June 2018 Survey. Prepared by Texas Water Development Board, July 2018.		X			
Lake Houston Sub-bottom Profiling and Coring, Final Report. Prepared by Tetra Tech, April 5, 2019.		X			

The 2000 report completed by Brown and Root included all five RSM steps.

The "Inventory and Forecast Conditions" step was cited most often, in six of the eight reports reviewed. The reports that included this step measured bathymetry in Lake Houston and upstream into the tributaries and compared it to previously measured river topography within the same reported boundaries. The 2018 Texas Water Development Board (TWDB) report measured bathymetry from Lake Houston Dam to approximately 2 miles upstream of the Caney Creek and East Fork San Jacinto River confluence and to approximately a half-mile upstream of the Spring Creek and West Fork San Jacinto River confluence. The 2018 TWDB report also examined twelve cross sections that had previously been measured as part of the 2011 TWDB study and a 1994 TWDB survey. The 2000 Brown and Root study predicted sediment sources, calculated sediment mobility, measured sediment deposition, and presented strategies to manage sediment in Lake Houston, particularly in the area between the confluence with Spring Creek and the lake.

The TWDB began monitoring the rate of sediment deposition in Lake Houston in 1994. Measurements extended from Lake Houston Dam upstream to approximately the Interstate-69 bridge on the West Fork, and to the County Road 1485 crossings on the East Fork near New Caney. Based on a 2018 measurement, the TWDB found an estimated 29,778 acre-feet (48 million cubic yards) reduction in storage capacity in Lake Houston, at an average rate of 465 acre-feet per year (0.75 million cubic yards per year) since the lake was built in 1954 (TWDB 2018).

In 2019, the US Army Corps of Engineers (USACE) conducted a dredging project to remove approximately 2.35 million cubic yards of sediment deposited along the West Fork, beginning upstream of West Lake Houston Parkway and continuing downstream into Lake Houston upstream of FM 1960 (USACE 2019). This sediment was removed for a total contracted cost of $90.8 million, or approximately $39 per cubic yard (USACE 2019). The volume of sediment removed during this project is approximately five percent of the 48 million cubic yards of sediment deposited in Lake Houston calculated by the TWDB in 2018.

Further study, such as field measurements or hydraulic and sediment transport modeling, is needed to determine how much sediment has historically deposited along the West Fork (between West Lake Houston Parkway and FM 1960), how much has historically deposited further downstream into Lake Houston, and how much is expected to continue depositing in these areas.

If sediment continues to deposit into Lake Houston at the TWDB average rate of 0.75 million cubic yards per year, the total sediment in the lake can be expected to increase to approximately 58.4 million cubic yards by 2035. At a unit cost of $39 per cubic yard, the cost to remove all 58.4 million cubic yards would exceed $2.2 billion. The ongoing cost to remove the sediment deposition of 0.75 million cubic yards per year would be approximately $29 million per year. These estimates do not account for inflation or advances in technology that may affect the unit cost and are intended to illustrate the scale of the total and annual sediment loads.

Although the scope of services and budget for this project did not allow for applying the RSM framework to the entire watershed nor completing the complete RSM approach for Spring Creek and the West Fork San Jacinto River, the remainder of this report is organized using the RSM framework. This presents the available information in a format that can easily be revised and expanded as additional information becomes available.

1.6 Report Organization

The remaining sections of this report follow the RSM structure:

- Section 2 – Sediment-Related Problems and Opportunities
- Section 3 – Inventory and Forecast of Sediment Conditions
- Section 4 – Regional Management Strategy Alternatives
- Section 5 – Evaluation of Sediment Management Strategy Alternatives
- Section 6 – Conclusions and Recommendations
- Section 7 – References

2.0 Sediment-Related Problems and Opportunities

The first step in RSM planning is identifying sediment-related problems and opportunities.

As presented in **Section 1.1**, the sediment-related problem area for this study is located between the confluence of Spring Creek and West Fork San Jacinto River (just upstream of the Interstate-69 bridge) and Lake Houston a few miles downstream. The reported sediment deposition between the confluence of these streams and Lake Houston has been the focus of multiple sediment management studies (Brown and Root 2000, USACE 2018) and subsequent mapping efforts (Tetra Tech 2019, TWDB 2018b). A USACE dredging project has recently been completed in the West Fork to remove sediments, as shown in **Figure 2-1** below.

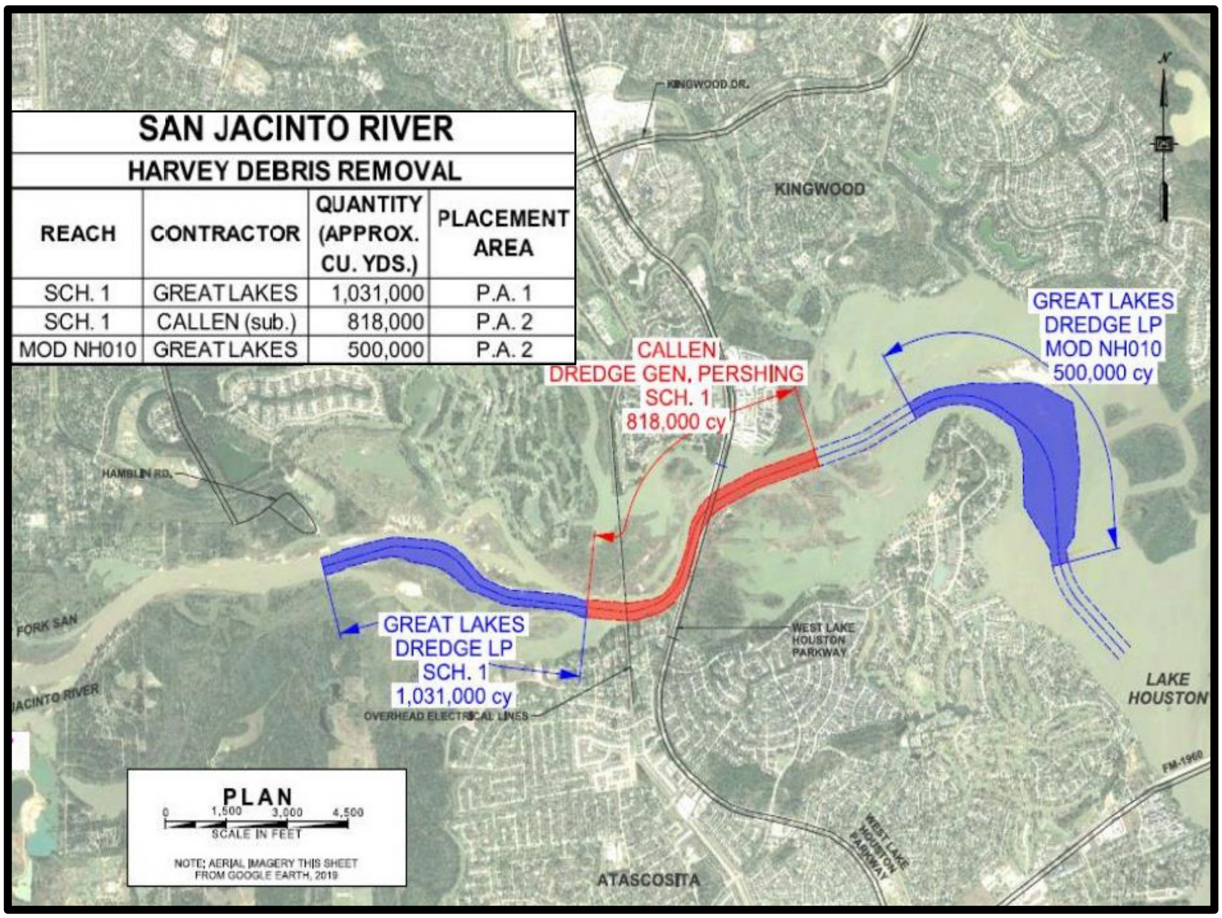

Figure 2-1: Location of Dredging Removal (USACE 2019)

This problem area was identified by project stakeholders as an area of concern and was the focus of a detailed hydraulic analysis and sediment management strategies in the 2000 Brown and Root study. This study estimated that the relationship between sediment-based obstructions and flood risk in this area causes an increase of water surface elevations ranging from 0.75 feet immediately upstream of Lake Houston Parkway to 1.1 feet downstream of Lake Houston Parkway (Brown and Root 2000) during the 1% annual chance event. The scope of work for this sediment management strategy did not include detailed hydraulic and sediment transport modeling to update this relationship. Updated modeling is recommended for future studies.

Per **Section 1.0**, the two regions of interest in the larger drainage area of the San Jacinto watershed as defined by project stakeholders are the West Fork San Jacinto River between Lake Houston Dam and Lake Conroe Dam and the mainstem of Spring Creek, which enters the West Fork close to Lake Houston. Measurements of sedimentation, which allow for a comparison of sedimentation rates over time, are available for the West Fork and Spring Creek. The West Fork subwatershed is predominantly hay pastures and mixed forests and consists of mixed land cover ranging from high-density development to open spaces (TFPL 2016). The Spring Creek subwatershed is undeveloped in its upper reaches, with large, heavily wooded areas and numerous county parks bordering the mainstem, but the downstream reach through The Woodlands includes suburban development (HCFCD 2020).

The drainage area of the West Fork and of Spring Creek upstream of this confluence are the largest of the seven major subwatersheds studied in the 2000 Brown and Root study (**Table 2-1**). Therefore, measures to control sedimentation in these two regions of interest are likely to make the most difference for this reach of the West Fork. Measures to control sedimentation in the remaining subwatersheds should be explored using the RSM framework as part of future studies in the watershed.

Table 2-1: Subwatersheds in the San Jacinto Watershed

Subwatershed Name	Drainage Area (sq mi)	Subwatershed Name	Drainage Area (sq mi)
West Fork San Jacinto River	550.0	Caney Creek	223.9
Spring Creek	438.3	Luce Bayou	208.3
East Fork San Jacinto River	397.8	Peach Creek	156.3
Cypress Creek	317.8		

As discussed in **Section 1.5**, multiple sediment assessments and sediment management strategy studies in this area have already been completed. These studies present opportunities to update assessment methodologies using recent data to understand changes in sediment behavior over time. Another sediment management opportunity is the measurement of topography in the watershed. Topography was measured remotely using LiDAR multiple times over the last two decades. Data from different areas can be compared to each other to identify trends in sediment behavior and assist with the development of sediment management strategies. Another opportunity is the San Jacinto Regional Watershed Master Drainage Plan's recent development of a detailed hydrodynamic model of the notable subwatersheds in the San Jacinto watershed. This model can be paired with sediment transport analysis to understand the local hydraulics in the sediment problem area between the confluence and Lake Houston.

This project will focus on the West Fork and Spring Creek, seeking to understand their potential sediment sources, the ability of the mainstem in each region to transport sediments downstream, and where sediments are likely to deposit before reaching Lake Houston. These characterizations are discussed in **Section 3.0**, "Inventory and Forecast of Sediment Conditions."

3.0 Inventory and Forecast of Sediment Conditions

3.1 Sediment Sources from Landscape Soil Loss

To understand and document the potential origins of sediments that may deposit in the area of concern, this study assesses the potential of sediment to run off the landscape of the San Jacinto watershed into rivers and streams. The Revised Universal Soil Loss Equation (RUSLE) is a method developed by the U.S. Department of Agriculture to measure the influence of land use practices on soil erosion (Renard 1997). This equation was originally developed to predict how different agricultural practices (contour crop farming, cover crop, etc.) will change the potential for soil erosion. The equation has been used to predict potential soil erosion from the landscape when there are large areas of land use purpose changes, for example from forest to agriculture or from pasture to residences.

The RUSLE's predecessor, the Universal Soil Loss Equation (USLE) was first used in the San Jacinto watershed in 1982 and replicated in 1993 to measure the influence of land use practices on soil erosion (Renard 1997) as presented in the 2000 Brown and Root report. This equation was originally developed to predict how different agricultural practices (contour crop farming, cover crop, etc.) will change the potential for soil erosion. The equation has been used to predict potential soil erosion from the landscape when there are large areas of land use purpose changes, for example from forest to agriculture or from pasture to residences. USLE results can be used to create maps reflecting the rate of potential soil loss and provide an inventory of potential sediment supply. These maps allow a watershed manager to identify sediment sources, i.e. areas near streams that have a high potential of soil erosion loss that may flow into the stream.

The RUSLE and the USLE do not consider impediments between the area of soil loss and the receiving streams, such as sinks or wetlands that may capture or store sediment before it reaches receiving waters. Therefore, RUSLE results are inherently conservative since a portion of the eroded sediment will not enter receiving waters. The EPA's Stormwater Management Model (SWMM) and the Soil and Water Assessment Tool (SWAT) are more recently developed landscape source models which are used to estimate land use practices on soil erosion. Both of these models are free for public download. It is recommended that RUSLE results be compared to one of these more recent landscape models to further the understanding between land use practices and soil erosion.

An updated RUSLE analysis was completed to estimate potential sedimentation for the entire San Jacinto watershed using recently collected land use data (2018) and topography (2018). Results were compiled into the seven subwatersheds shown previously in **Figure 1-2**. **Appendix F.B** gives a detailed discussion of the methodology and results of this analysis. **Table 3-1** presents the total potential annual soil loss by watershed in tons per year and the average potential annual soil loss by watershed, in tons per square mile per year. **Table 3-1** includes the average potential soil losses previously computed in 1993 (Brown and Root 2000) and a range of potential soil loss for 2020. The range was established assuming an absolute lack of conservation practices to protect against soil runoff (P-factor of 1.0) and assuming the best conservation practices to protect against soil runoff (P-factor of 0.15) (Renard 1997).

The range of potential soil loss was included in this report to demonstrate the calculation's sensitivity to the P-factor and allow for a comparison to the 1993 USLE calculations, since the P-factors used in the 1993 calculations were not published in the 2000 Brown and Root study. Use of a newly updated modeling approach such as the EPA's SWMM or SWAT is recommended to provide a more thorough understanding of land use and soil erosion.

A comparison of the total potential annual soil loss calculated in 1993 to the potential annual soil loss calculated in 2020 with the best conservation total shows a wide range of values and a general increase in soil loss in most of the seven subwatersheds. In the 1993 study, the Cypress Creek subwatershed showed the highest total potential annual soil loss – 10 percent higher than the next highest subwatershed. However, in this study, the West Fork San Jacinto subwatershed shows the highest total potential annual soil loss – 147 percent higher than the next highest subwatershed if P factors are the same for all subwatersheds. This could be attributed to land use changes in the watershed.

Table 3-1: Summary of Potential Soil Loss in San Jacinto Watershed

Subwatershed	1993 Study (USLE)			SJMDP 2020 (RUSLE)				
				No Conservation Practices to Protect against Soil Runoff (P=1.0)		Best Conservation Practices to Protect against Soil Runoff (P=0.15)		
	Average Potential Soil Loss (tons/ sqm/yr)	Est. Total Soil Loss (tons/yr)	Percent of Total	Average Potential Soil Loss (tons/ sqm/yr)	Est. Total Soil Loss (tons/yr)	Average Potential Soil Loss (tons/ sqm/yr)	Est. Total Soil Loss (tons/yr)	Percent of Total
Cypress Creek	301	95,600	30.7%	1,152	367,603	173	55,123	14.3%
Spring Creek	122	53,300	17.1%	832	368,908	128	55,286	14.4%
West Fork San Jacinto River	160	88,000	28.2%	1,664	913,536	250	137,030	35.6%
East Fork San Jacinto River	83	33,100	10.6%	832	334,048	128	50,045	13.0%
Caney Creek	77	17,200	5.5%	1,088	237,075	166	35,414	9.2%
Peach Creek	45	7,000	2.2%	506	80,188	77	11,983	3.1%
Luce Bayou	77	16,000	5.1%	269	57,039	38	8,548	2.2%
Local Lake Houston	26	1,700	0.5%	2,816	204,441	422	30,413	7.9%
Total	**-**	**311,900**	100.0%	**1,082**	**2,562,840**	**160**	**385,158**	100.0%

The average potential soil loss (reported in tons/square mile/year in **Table 3-1** above) is a good metric to compare potential soil loss between subwatersheds. Excluding the small local Lake Houston subwatershed, **Table 3-1** shows that the West Fork has the highest average potential soil loss and is much more prone to soil loss than Spring Creek. The updated 2020 RUSLE values show that the West Fork's potential for soil loss is roughly 100 percent higher than Spring Creek's. (In the 1993 analysis reported in the 2000 Brown and Root report, the West Fork's soil loss potential was only 30 percent higher than Spring Creek's.) This change could be attributed to an increase in the area of land uses with the potential to cause higher soil loss (deforestation, residential, etc.) in the West Fork subwatershed. Cypress Creek's average potential soil loss was the highest in the 1993 study (88 percent more than the second highest), but the updated 2020 RUSLE results show it to be less than the West Fork assuming equal P factors. Changes in land use (like urbanization) could cause this change.

The findings presented in **Table 3-1** suggest that land use practices over the last several decades have influenced which subwatershed has the highest total potential soil loss from the landscape. Understanding the potential soil loss due to landscape erosion can help select sediment strategies to prevent sediment from entering the river network. If a subwatershed has a relatively high amount of potential soil loss, then land use practices for that subwatershed may have a greater impact on the sediment load.

3.2 Sediment Sources from Stream Erosion

Section 3.1 discussed how landscape erosion can locate potential sediment sources in the areas of interest. Another potential source of sediment is the erosion of streambanks along channels. Streambank erosion has been found to account for up to 80 percent of sediments in streams and rivers (Simon et al. 1996, Nagle et al. 2012). Streambank erosion in the West Fork San Jacinto River and Spring Creek subwatersheds was analyzed by comparing recent LiDAR topographical data to LiDAR topographic data captured in the past. LiDAR data, a relatively new technology, was not available for the 2000 Brown and Root study.

This study examined LiDAR data measured in 2001, 2008, and 2018, all provided by HCFCD or downloaded from the Texas Natural Resources Inventory (TNRIS). The 2018 LiDAR data was available for the entire watershed, 2001 LiDAR data for Harris County and the 2008 LiDAR for Harris County and the mainstems in Montgomery County and Liberty County. The earlier data sources were measured using a different geoid than the more recent data. The differences in geoid were spot-checked around different points in the watershed and the differences were found to be between 1 and 4 inches. This difference was not considered substantial for the purposes of this study, and geoid adjustments to the LiDAR were not made. Differences due to subsidence over this time period are also considered to be negligible. The stream network and channel centerlines were defined for each LiDAR dataset. A large change in the channel centerline location over time indicates where streams may have shifted. Streams can shift when they erode the material along their boundaries; this streambank erosion process is often a large source of sediment.

To confirm the presence or absence of eroding landforms, elevation difference was measured along the stream channels using LiDAR topographic data. **Appendix F.C** gives a detailed summary of the procedure and results. Three data sources were used to evaluate this difference. The difference between the datasets was the amount of change in elevation – either a gain in elevation, a loss in elevation, or no change. A gain in elevation could be an area where material was dumped during land development activities or an area where sediment is deposited. These may be ephemeral or perennial depositions. A loss in elevation is an area where material has been removed, perhaps by mining or erosion. An erosion volume or depositional volume can be calculated within a region by multiplying the average elevation change by the region's spatial area. Overview maps of elevation gain and loss are provided in **Figures C-4** through **C-6** in **Appendix F.C**. Specific examples along Spring Creek are presented in **Figure 3-1**.

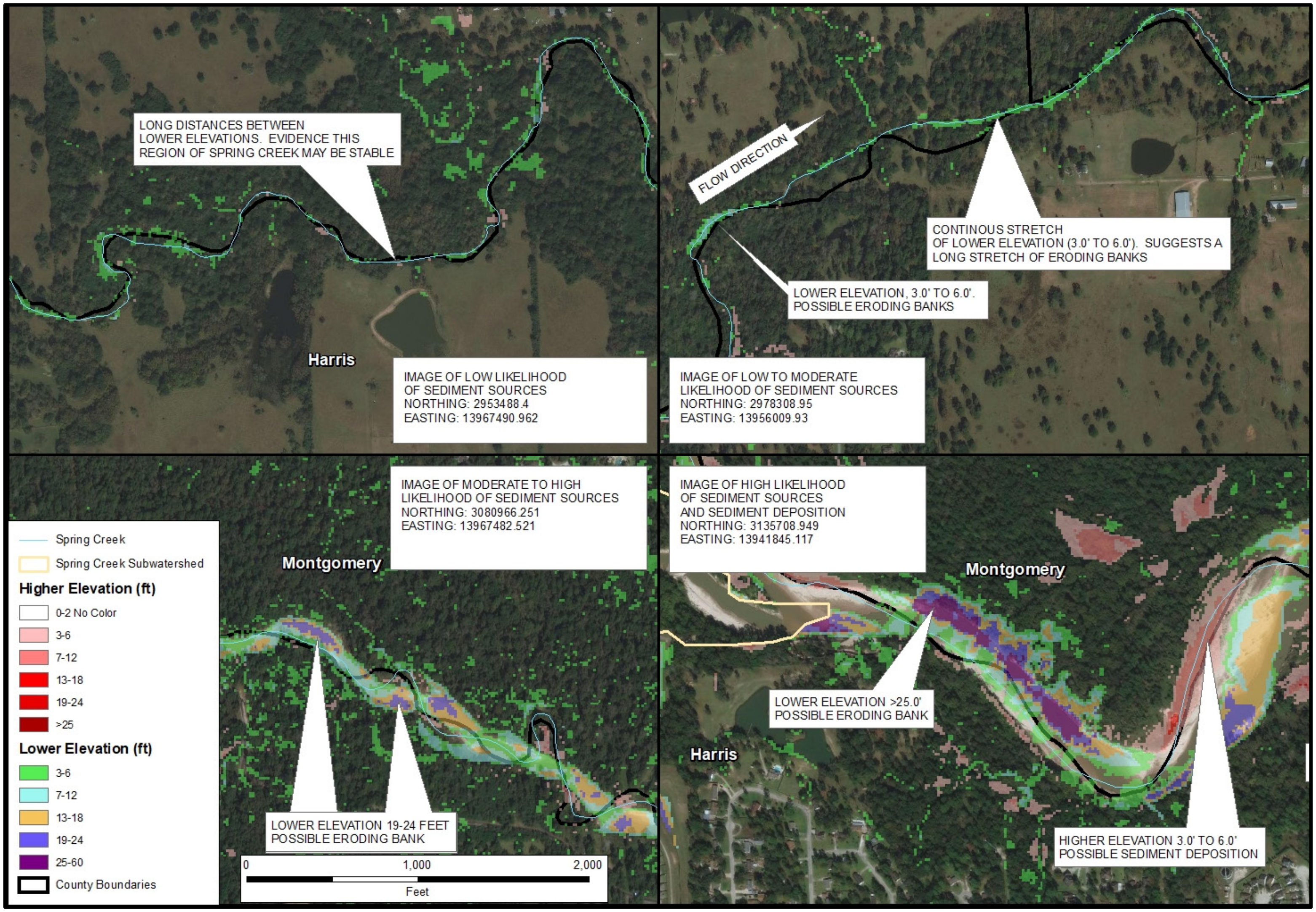

Figure 3-1: Examples of Elevation Changes Detected by LiDAR along Spring Creek

Table 3-2 summarizes the stream deviation for the West Fork and Spring Creek. Stream deviation is the distance from the recent channel alignment to historic channel alignment. Roughly 20 to 30 percent of Spring Creek and West Fork channels have severe deflections between the alignments. Roughly 40 to 50 percent of the measured deflections are minimal, and most of these occur upstream on the channels, closer to the upstream limits of the watershed.

Table 3-2: Stream Deviation in Channels of West Fork San Jacinto and Spring Creek

Deviation Severity (In Feet)	West Fork San Jacinto River	Spring Creek
Minimal (<30)	38.8%	49.6%
Moderate (30–60)	18.2%	19.6%
High (60–90)	13.2%	9.4%
Severe (>90)	29.8%	21.4%

The 2001 and 2008 LiDAR was also compared to the 2018 LiDAR for each of the seven subwatersheds as another approach to understand the watershed sediment budget. The existing-conditions 1% annual chance event floodplain boundaries, as established in the *San Jacinto Regional Watershed Master Drainage Plan* (Halff/FNI 2020), were used as the boundary of LiDAR comparison. The difference between LiDAR data may include anthropogenic impacts, such as filling of floodplains and excavation of sand mining pits, as well as fluvial processes, such as erosion and deposition. This means a portion of the differences in sediment volume may not be part of the overall sediment budget. This approach also does not include differences between in the LiDAR data sets of less than two feet nor bathymetric differences. **Table 3-3** summarizes the LiDAR comparison results, which are also summarized in **Appendix F.C**.

Between the historic LiDAR (2001 or 2008) and recent LiDAR (2018), there has been approximately 64,763 acre-feet of material lost compared to 25,217 acre-feet of material gained. The difference, 39,546 acre-feet, is equivalent to 0.3 inches of land removed across the entire watershed (2,292 square miles), excluding the drainage area upstream of Lake Conroe. The net degradation column in **Table 3-3** is positive for all streams except Peach Creek, meaning that more land has been eroded than deposited along these streams. The net degradation total also includes sediment that has deposited under the water surface of Lake Houston and is therefore not detected by LiDAR. The net degradation total may also include sediment that has washed over Lake Houston Dam, such as the wash load (very fine clay particles). Spring Creek, West Fork San Jacinto River and Cypress Creek have the largest negative change in topography in the San Jacinto watershed.

Although a detailed evaluation of sediment management strategies along Cypress Creek is not included under the scope of this study, Cypress Creek appears to be a major contributor of sediments within the watershed. It is recommended that this subwatershed be evaluated for sediment management strategies as part of a future study. Cypress Creek's erosion issue is well known to Harris County and HCFCD. Over the years, these entities have conducted spot repairs and channel bank restoration work as funding and access along the creek were available. While HCFCD has begun implementation of the Little Cypress Creek

Frontier Program, which enabled a public-private partnership in constructing regional detention ponds and in-line natural channel benched design to mitigate future erosion potential, the appointed agency is limited in its mandate to correct or adjust erosion and sediment issues. In fact, there is no single agency expressly funded and authorized to address sediment and erosion issue in this watershed.

Table 3-3: Volumetric LiDAR Comparison

Subwatershed Name	Degradation (Erosion) Volume (ac-ft)	Aggradation (Deposition) Volume (ac-ft)	Net Degradation (ac-ft)	Average Annual Degradation (ac-ft/yr)
East Fork San Jacinto (2008 vs 2018)	1,222	655	568	56.8
Peach Creek (2008 vs 2018)	22	367	-345	-34.5
Spring Creek (2001 vs 2018)	18,566	3,328	15,238	896.4
Luce Bayou (2008 vs 2018)	412	253	158	15.8
Cypress Creek (2001 vs 2018)	18,646	3,735	14,911	877.1
Caney Creek (2008 vs 2018)	1,971	948	1,023	102.3
West Fork San Jacinto, D/S of Spring Creek Confluence (2001 vs 2018)	4,908	4,412	496	29.2
West Fork San Jacinto, U/S of Spring Creek Confluence (2008 vs 2018)	19,016	11,519	7,498	749.8
Total	**64,763**	**25,217**	**39,546**	**2,692.9**

It is recommended for future studies that the boundary of the LiDAR comparison be reduced to capture differences attributable to fluvial processes only. Since the time lapse between LiDAR measurements was relatively short (17 years) and included the changes in topography due to several notable flood events, including Hurricane Harvey, the average annual degradation column is likely skewed. It is recommended that topography be remapped using LiDAR in a few years to better approximate the typical annual change in topography due to fluvial processes (erosion and deposition).

3.3 Sediment Transport

Bedload contains sediments that are too large and heavy to remain in suspension but too small to remain stationary. The force of moving water plucks and rolls these sediments down the river. These sediment sizes can range from 0.065 mm to larger than 1,000 mm. The size of the sediment that can be transported is a function of stream power, the rate of energy dissipation against the riverbed.

Understanding the method by which sediment is transported helps select a suite of sediment management strategies. Since the water's force is the physical process that transports sediment, certain sediment management strategies aim to reduce the water's force, resulting in the sediments becoming stationary so they can be removed.

3.3.1 Suspended Sediments

Since 1978, the U.S. Geological Survey (USGS) has periodically measured suspended sediment in streams in the San Jacinto watershed. Each measurement captures the concentration of suspended sediment (called total suspended solids, or TSS) and the flow at the time of the measurement. In the 2000 Brown and Root study, the measured discharge and concentration were plotted. A line of best fit was then drawn through the plotted data to form a sediment rating curve, relating sediment weight to stream flow. The curve's equation can then be used to estimate the sediment weight at different discharges. This rating curve can be used with stream flow data to estimate annual suspended sediment load, that is, the total weight of suspended sediment transported in a year (Boukhrissa et al. 2013, Horowitz 2003).

The 2000 Brown and Root study created a sediment rating curve at two stream gages, one on the West Fork and one on Cypress Creek, and calculated the annual suspended load for each location. This approach was replicated at the same two stream gages on the West Fork and Cypress Creek and added several USGS stream gages in other subwatersheds where TSS data were available. The sediment load calculated at each stream gage was then extrapolated for the subwatershed using a ratio of the drainage area to the gage to the respective subwatershed drainage ratio. Appendix F.D presents the methods and results from this analysis. A summary of the updated results is provided in Table 3-5.

The watershed draining to the sediment problem area (discussed in Chapter 2.0) contains three subwatersheds (West Fork, Spring Creek and Cypress Creek) as shown in Figure 3-2. Figure 3-2 also shows the location of the USGS gages in the subwatersheds of the East Fork used in this study's approach to calculate annual sediment loads. The USGS stream gages located upstream of the sediment problem area are located at an Interstate-45 bridge crossing of each stream (Figure 3-2). In addition to the three gages located upstream of the sediment problem area, a fourth USGS stream gage (located within the sediment problem area at the Interstate-69 bridge over the West Fork) is shown in Figure 3-2. Table 3-4 presents characteristics of the four gages in the West Fork's subwatersheds.

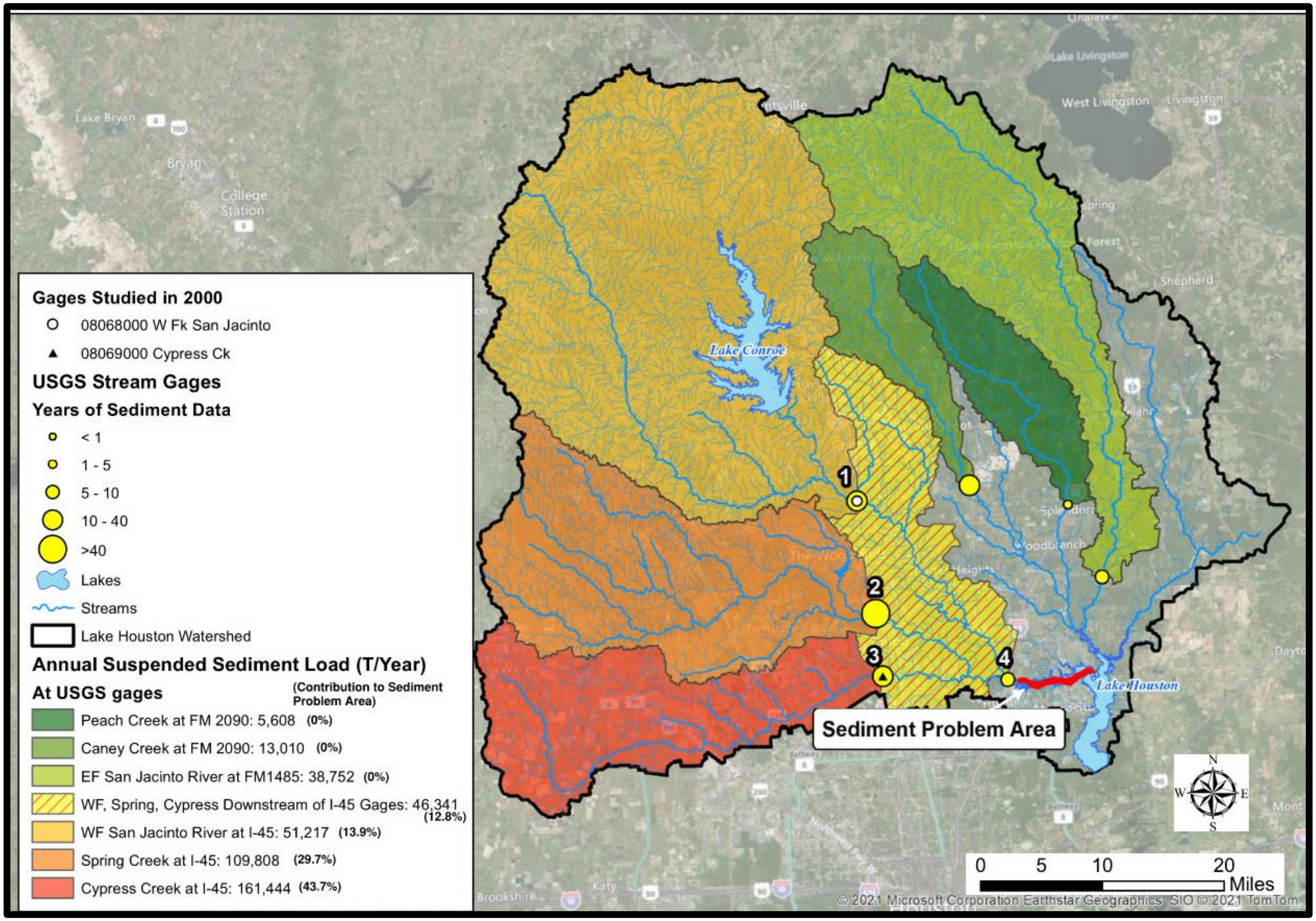

Figure 3-2: Location of USGS Gages Used to Calculate Annual Sediment Loading

Table 3-4: USGS Gages Used in Analysis

Gage #	Site Name	USGS Stream Gage ID	Drainage Area (sq mi)	Uncontrolled Drainage Area (sq mi)	Number of Discreet Sediment Samples and Date Range	Number of Years Measuring Discharge and Date Range	Annual Sediment Load (T/Yr)	% of Sediment Load to Gage #4	Annual Sediment Load per Uncontrolled Drainage Area (T/Yr/sq mi)
1	West Fork nr Conroe, TX	08068000	828	384*	187 (1924-2011)	95 (1924-2019)	51,217	13.9%	133.3
2	Spring Creek nr Spring, TX	08068500	409	409	138 (1972-2019)	80 (1939-2019)	109,808	29.7%	268.5
3	Cypress Creek nr Westfield, TX	08069000	285	285	106 (1976-2008)	75 (1944-2019)	161,444	43.7%	566.4
4	W. Fk San Jacinto Rv nr Humble, TX	08069500	1,741	1,297*	8 (2014-2019)	26 (1928-1954)	368,810	100%	284.4
*Less the drainage area upstream of Lake Conroe (444 sq mi)									

The total drainage area to the sediment problem area (gage 4) is 1,741 square miles, with Lake Conroe controlling 444 square miles, leaving 1,297 square miles of uncontrolled drainage area. The sum of the drainage areas to the three gages (gages 1 through 3) located upstream of gage 4 is 1,522 square miles with 1,078 square miles of uncontrolled drainage area. This means roughly 83 percent of the uncontrolled drainage area draining to the problem area is monitored by these three gages. The remaining uncontrolled drainage area (219 square miles,17 percent) is located between Interstate-45 and Interstate-69 which includes drainage areas in the West Fork, Cypress Creek and Spring Creek.

The annual suspended sediment load calculated at the gage in the problem area (gage 4) is 368,810 tons per year (Table 3-4). The sum of the annual suspended sediment loads from the three upstream gages is calculated to be 322,469 tons per year. Based on these estimates of annual sediment loading, the sediment loading from the area between Interstate-45 and Interstate-69, as shown in Figure 3-2, is estimated as 46,341 tons per year or approximately 12.8% of the total sediment loading at gage 4. The region between the two interstates has an annual sediment load per drainage area of 211 T/yr/sq mi. This is notably lower than the annual sediment load per drainage area upstream of the stream gages on Cypress Creek (566.4 T/yr/sq mi) and Spring Creek (268.5 T/yr/sq mi) but is greater than the respective value for the region upstream of gage #1 (133.3 T/yr/sq mi). It is worth noting that the area between Interstate-45 and gage 4 includes portions of Cypress Creek and Spring Creek, that have higher annual sediment loads. The region upstream of gage #1 has the lowest annual sediment load per drainage area which is likely due the dam at Lake Conroe intercepting roughly half the drainage area upstream of gage #1.

The estimates of annual sediment loading provided in this analysis appear to indicate that the sediment load contribution of the area between Interstate-45 and Interstate-69 is relatively small (approximately 12.8 percent) compared to the total annual sediment loading of the remaining watershed and has less tons per square mile per year than Cypress Creek and Spring Creek. However, it is noted that the amount of data (discrete sediment samples and stream discharge) available at the downstream gage (gage number 4) is limited in comparison to the other three gages. In addition, the scope of this study did not include an analysis of episodic events (i.e., individual flood events or potential releases from specific anthropogenic activities (industrial, commercial, etc.) nor was there sufficient data available at the time of the study to quantitatively address these types of events.

It is recommended to increase the number of sediment samples obtained at gage #4, obtain sediment samples at all four gages during the same discharge event, obtain sediment samples at higher discharge events and explore a relationship between turbidity and sediment concentration to develop a continuous sediment concentration measurement. areas Another recommendation is to capture sediment samples throughout the water column near the USGS gages which was also recommended in the 2000 Brown and Root study. Sampling the water column would measure suspended load and bedload samples and provide a more complete understanding of the total sediment load (washload, suspended load and bedload). It is also recommended to locate a stream gage with sediment measurements at the State Highway 99 bridge over Peach Creek and at the State Highway 99 bridge over Caney Creek. There are streamflow gages on

Luce Bayou and the East Fork and its recommended sediment sampling begin at these gages. There is not a bridge crossing downstream of the confluence of Caney Creek/Peach Creek and the East Fork so a permanent stream gage may not be reasonable to install but sediment sampling and discharge measurements downstream of the confluence would improve the understanding of the East Fork's sediment budget.

The 2000 Brown and Root study also included annual suspended sediment loads from earlier studies in 1978 and 1980, and the results from those studies are included in **Table 3-5**. The Cypress Creek subwatershed consistently had the highest annual suspended sediment load in tons per year. There is a notable increase in Spring Creek's annual sediment load in this 2020 study compared to previous reports (1980 and 1978). This could be explained by the number of samples used to develop the sediment rating curve for Spring Creek. The 1978 study used four samples in Spring Creek, the 1980 study used two samples, and this 2020 study used 138 samples. The West Fork San Jacinto River's annual sediment load in tons per year has also increased since it was first studied in 1978.

For comparative purposes, annual sediment load for each subwatershed is divided by its drainage area. According to this 2020 study, the Cypress Creek subwatershed produces the most annual suspended sediment load in tons per square mile. Spring Creek, with the second-highest suspended sediment load in tons per square mile, produces over 70 percent more sediment per square mile than Caney Creek, the third highest. The West Fork San Jacinto River's drainage area downstream of the Lake Conroe dam has a moderate amount of suspended sediment load per square mile relative to other subwatersheds. The 2000 Brown and Root suggested Cypress Creek had a higher sediment load because its sediment loads, measured at normal and higher discharges, were larger than the West Fork's sediment loads. The second reason was the West Fork having a smaller percentage of sand in its sediment load. One contributor to a lower percentage of sand and sediment load is the Lake Conroe dam which intercepts the sediment from roughly 45% of the West Fork's drainage area.

Table 3-5: Annual Suspended Sediment Load by Subwatershed in the San Jacinto Watershed

Subwatershed	Drainage Area (sq. mi)	Annual Suspended Sediment Load tons/year (tons/square mile/year)			
		USGS 1978	Bedient et al. 1980	Brown and Root 2000	SJMDP 2020
Cypress Creek	324.1		51,600 (159.2)	158,000 (487.5)	189,940 (586.1)
Spring Creek	437.6	23,400 (53.5)	14,600 (33.4)		131,061 (299.5)
West Fork San Jacinto	555.0*	36,500 (62.1)	39,700 (67.6)	45,000 (76.6)	64,138 (109.1)
East Fork San Jacinto	406.9		14,000 (34.4)		41,371 (101.7)
Caney Creek	216.7	6,390 (29.5)	27,600 (127.4)		37,981 (175.3)
Peach Creek	156.2		15,300 (97.9)		8,370 (53.6)
Luce Bayou	212.8		12,900 (76.6)		18,404 (86.5)
Total	**2,342.0**		**175,700 (75.0)**		**491,265 (209.8)**
***Drainage area of the West Fork San Jacinto downstream of Lake Conroe dam**					

Table 3-1 in **Section 3.1** showed that the Cypress Creek subwatershed does not have highest potential landscape soil erosion, but **Table 3-5** shows that it has the highest measured suspended sediment of any subwatershed. Therefore, it is reasonable to conclude that a majority of Cypress Creek's sediments are not from landscape erosion but from other sources, primarily eroding streambanks. This is consistent with other studies across the U.S. that have identified streambank erosion as contributing to 46 percent and 90 percent of total suspended sediment yield (Rosgen, 2006). It is recommended that sediment management strategies for Cypress Creek are evaluated as part of a future study.

Measured suspended sediment is also high in the Spring Creek subwatershed. In **Table 3-1**, the West Fork San Jacinto subwatershed had the highest potential soil loss by a wide margin (roughly 150 percent), but it was the third highest in measured suspended sediment (**Table 3-5**). This could mean there may be more locations within the West Fork subwatershed that either intercept soils which have eroded from the landscape (such as wetlands, basins) before the sediment reaches the river or the efficacy of Lake Conroe trapping sediment is notable. Lake Conroe Dam is estimated to intercept sediment at an annual rate of 15,000 tons/year (Brown and Root 2000). The drainage area upstream of Lake Conroe is 444 square miles, 25.5 percent of the watershed draining to the sediment problem area, or 15.8 percent of the entire San Jacinto's watershed area and 45.1 percent of the West Fork San Jacinto River subwatershed's area.

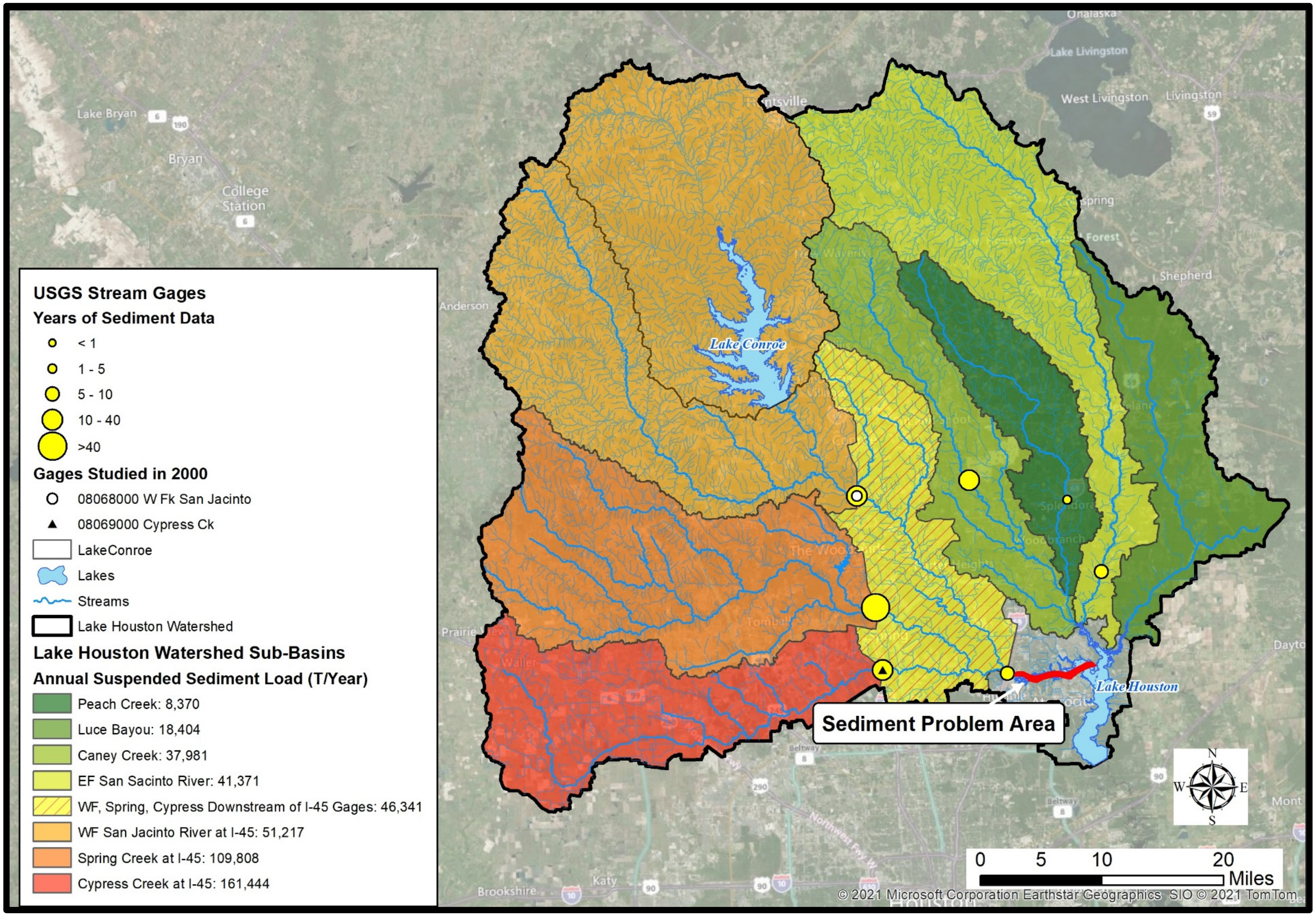

Figure 3-3: Annual Suspended Sediment Load by Subwatershed in the San Jacinto Watershed

The estimated annual suspended sediment volume flowing out of the San Jacinto watershed is approximately 491,300 tons per year as seen in **Table 3-5**. This value was calculated using suspended sediment concentration and discharge data collected at multiple stream gages throughout the watershed and could be a good predictor of the average rate of storage loss in Lake Houston since its construction. Assuming a bulk density of 52 pounds per cubic foot (the density value used in the 2000 Brown and Root study), this is an annual volume of approximately 433 acre-feet per year.

This volume is in relative agreement with the aggradation rate of sediment measured in Lake Houston by bathymetric studies between 1954 and 2018, as shown in

Table 3-6. (The data used to estimate the annual suspended sediment volume ranges from the mid-1970s to present. This volume is also in relatively good agreement with the average aggradation rates measured between 1954 and 2011, 1954 and 1994, or 1965 to 2018.) To check if the annual suspended sediment volume is in relative agreement with a future aggradation rate of sediments in Lake Houston, this analysis should be rerun using the suspended sediment concentration and discharge data that will be collected between now and the future analysis date. Assuming the annual suspended sediment volume estimated by this analysis accurately predicts aggradation rates, it could mean that:

- Most of the transported suspended sediments from the San Jacinto watershed are deposited in Lake Houston. The remainder is either washed over the dam over deposited somewhere in the watershed.
- Most of the deposited sediments in Lake Houston have been transported as suspended sediments, with a low to moderate portion of deposited sediments being transported as bedload. This is informative for guiding sediment management strategies. For example, suspended sediments are often more difficult to trap.

Table 3-6: Storage in Lake Houston and Rate of Storage Loss

Year	Storage in Lake Houston (ac-ft)	Years Lapsed Since Construction	Average Rate of Loss Since Construction (ac-ft/yr)
1954	158,553	0	
1965	146,769	11	1,070
1983	130,728	29	960
1994*	136,920	40	540
2011	126,900	57	555
2018	128,775	64	465

**It is unclear from the review of the 2018 TWDB study if the gain in storage from 1983 to 1994 was due an underestimation of storage in 1983 or an overestimation of storage in 1994.*

With an understanding that the findings from **Section 3.1** are conservative, the findings from **Section 3.2** suggest that more investigation is needed to understand the proportion of measured sediments originating from landscape erosion and from other sources, such as eroding streambanks, aggregate production operations, etc. Using the LiDAR comparison that identified areas of loss (i.e. where the recent LiDAR is lower than historic LiDAR) is one method to create a volume of sediment which has been removed from stream banks. Per the LiDAR comparison in **Table 3-3**, there was roughly 2,300 acre-feet eroded per year during the study period (2001 to 2018), which is higher than the annual suspended sediment load (433 acre-feet) and the aggradation rate in Lake Houston (465 acre-feet). One possible reason for the difference between these values is that large flood events, including Memorial Day 2016 and Hurricane Harvey, occurred during the study period; a high percentage of material eroded during these events may have been transported as bedload rather than suspended sediment and may have deposited within the watershed upstream of the lake.

The results presented in **Table 3-5** suggest the Cypress Creek subwatershed should be evaluated for sediment management strategies since it is a major contributor of suspended sediments to Lake Houston. This is beyond the scope of this study but should be considered as funds become available. A replication of the LiDAR comparison completed in **Section 3.2** would help guide the locations for these strategies. Another recommendation is to restart suspended sediment measuring at the USGS stream gage on Cypress Creek above the confluence with Little Cypress Creek (USGS gage number 08068740 near Cypress, TX) and to start suspended sediment measuring at the USGS stream gage on Little Cypress Creek (USGS gage number 08068780 near Cypress, TX). This will increase the understanding where sediment originates within the Cypress Creek watershed.

As discussed in **Section 1.2**, some level of background sediment has been transported through the watershed before the dam was in place. Therefore, it should be expected that the rate of accretion in Lake Houston will never reach zero. The rate may slow down and become constant. This could be evaluated using a more detailed land use erosion model (SWAT or SWMM) and a detailed evaluation of stream bank stability in the watershed.

3.3.2 Bedload Sediments

The 2000 Brown and Root report discussed the lack of data to adequately account for bedload movement in the total sediment load transported to Lake Houston. No bedload measurements for the San Jacinto watershed were found in the review of readily available reports. To gain insight into the percentage of bedload in the overall sediment load, this study conducted a review of geotechicnal cores of sediment in Lake Houston.

The 2000 Brown and Root study discussed “sugar sand,” a relatively small sand size flowing predominantly out of the Cypress Creek subwatershed as suspended sediment. Sediment sizes were also measured when geotechnical borings where obtained in Lake Houston, as part of several recent bathymetric investigations (TWDB 2011, TWDB 2018. TWDB 2018b).

Very fine gravel (2 to 4 mm in diameter) is typically the largest sediment that is transported in suspension. Therefore, any geotechnical boring whose sediments are predominantly larger than 4 mm is considered a “bedload only” boring, since this material could have only been transported there as bedload. In contrast, silts and clays (0.065 mm in diameter or smaller) are so small that they are transported only in suspension. Therefore any boring that contains predominantly silt and clays is considered a “suspended only” boring. It is assumed the wash load (the smallest of clay particles) are transported through the reservoir, over the dam, and out into the bay. Borings which contain predominantly sands, which range in size from 0.065 mm to 2 mm, are considered “mixed bedload and suspended load,” since these sediments can be transported in suspension or as bedload.

Table 3-7 summarizes the sediment sizes found in the geotechnical borings. There were no borings that contained predominantly large sediment sizes. In the 32 borings reviewed, there were 19 “mixed” borings and 13 “suspended only” borings. It appears that there are certain times and hydraulic conditions in Lake Houston where the stream power is very low because the smallest of transported sediments are depositing. These findings also suggest that because notable portions of the transported sediment are in suspension, it is critical to measure the size of sediments upstream of any sediment trap, in order to determine the trap’s efficacy.

Table 3-7: Sediment Sizes Found in Geotechnical Borings

Bedload Only	Mixed Bedload and Suspended	Suspended Only
0	19	13

3.4 Aggregate Production as a Sediment Source

The Bayou Land Conservancy, a nonprofit focused on Houston-area conservation efforts, evaluated the ecological footprint of sand mining operations on the West Fork San Jacinto River in 2017. The report found that the number of acres of land occupied by sand mines within the floodplain of the West Fork has more than quadrupled between 1995 and 2017, from 1,308 acres to 5,496 acres (Schafler 2019), or from 0.07 percent to 0.3 percent of the San Jacinto watershed area (1,809,920 acres). Aggregate mining occurs in areas where the desired material can be harvested with relative ease. Sand mining locations are often near existing rivers, since vast amounts of varying sand sizes can be extracted.

These large sand deposits are relics from pre-historic times when rivers flowed in different alignments. Sand and some gravels were deposited in large volumes in these pre-historic stream channels. The excavation process at a sand mine often leaves a hole in the ground filled with quiescent water, referred to as a pit. If moving water from a nearby river enters the pit, the remaining sand deposits may be transported downstream. This can occur if the river erodes the protective barrier, usually an isthmus of land between the flowing river and the pit. Sand can also be swept out of sand mines when flood waters overflow their banks and entrain stockpiled sand.

As discussed in Section 3.3.1, roughly 46,341 (13%) tons of sediment enter the Spring Creek/Cypress Creek and West Fork watershed downstream of the USGS stream gages located along Interstate-45. Most of the APOs are located within this region along the West Fork. It was beyond this study's scope to quantify sediment contributions to the West Fork or Spring Creek from individual sources. However, an attempt was made to provide recommendations of how to quantify sediment from this potential source using aerial imagery.

A review of Google Earth imagery around APOs along the West Fork during Hurricane Harvey (8/30/2017) and after the hurricane (10/28/2017) did not provide sufficient evidence or empirical data to either confirm or deny breached or damaged stockpiles, or to quantify the impact that may have resulted from such a breach. However, it is reasonable to assume that there could be hydraulic connectivity of the floodplain to APOs, and that stockpiled sand could become entrained and transported downstream during floods.

In addition, a review of additional imagery provided by Robert Rehak, a resident of Kingwood, (reduceflooding.com), was performed to characterize other potential sediment sources related to APO activities. The photo in **Figure 3-4** appears to show water leaving an APO pit (a pond that traps sediment laden water from APO activities). The scope of this study did not include the sampling or quantification of sediment loading from episodic events such as what **Figure 3-4** appears to capture. It is clear from review of **Figure 3-4** that the water being released from near the APO is turbid and discolored. However, the data required to quantify the character and nature of this turbidity (i.e., whether this turbidity is the result of organic matter, algae, or inorganic matter such as silts and clays) was not available nor within the scope of this study. Therefore, it is recommended that water quality testing be completed in the future during episodic events, such as potential releases from APOs, for the presence of organic material, inorganic material and other constituents that result in turbid water. The data from these recommended tests will provide detailed information to explain the visual data from the provided photo. If this testing indicates that sediments are present, then it is further recommended a sediment concentration test and a particle size distribution measurement be completed on the sediments. This information will inform strategies to mitigate the sediment transport as well as increase the understanding where the sediment which may originate from the APOs deposits. For example, the 2019 mapping and geotechnical measurements efforts completed by TetraTech showed that less than 10% of the sediment deposited in the sediment problem area by Kingwood were silts or clay sized particles. Most were sand size (greater than 90 percent). A particle size distribution measurement of the water leaving a breach as shown in **Figure 3-4** would measure the amount of sand, silt and clay in the water.

This study includes an inventory of Aggregate Production Operations (APO) in the fall of 2019 for the West Fork San Jacinto River and Spring Creek subwatersheds. The boundaries of pits were delineated digitally from contemporary aerial photo imagery (2019) and a historical aerial photo (1996), and the area within the boundaries was calculated using the embedded area calculation tool in ESRI's ArcGIS software program. A map of the pit areas is provided in **Figure A-2** in **Appendix F.A**, and **Table 3-8** summarizes the findings.

Since the 2000 Brown and Root study, the rapidly growing fracking industry has increased the demand for sand, which may explain the growth of mining operations.

Table 3-8: APO Inventory Results Comparison

	1996		2019	
Subwatershed Name	**No. of Pits**	**Measured Area of Pits (Acres)**	**No. of Pits**	**Measured Area of Pits (Acres)**
Spring Creek	8	392	3	201
West Fork San Jacinto	16	2,150	19	6,029

Federal, state, and local regulations and permitting requirements for APOs, also referred to as gravel and sand mines (GSMs), are outlined below.

- At the Federal level, GSMs are regulated under the Mineral Mining and Processing Effluent Guidelines and Standards under 40 CFR Part 436. The Mineral Mining regulatory requirements are incorporated into NPDES permits. As a result, permitting is handled on the state level by the Texas Commission on Environmental Quality (TCEQ).
- At the state level, commercial GSMs are required under 30 Texas Administrative Code, Chapter 342, to register with TCEQ as an Aggregate Production Operation (APO). This registration includes an annual renewal, annual fee, and inspection every three years. This act went into effect on September 1, 2012. Mining and reclamation of aggregate pits are not regulated under state law. However, if operations will affect groundwater, air, or produce hazardous waste, the facility will have to obtain permitting, which includes, but is not limited to,

Figure 3-4: Water leaving an APO pit. Credit: Robert Rehak, reduceflooding.com (Date of Photo Unknown)

- Any person who wishes to prospect from a location owned by the State of Texas is subject to permitting through the Texas General Land Office (GLO), under 31 Texas Administrative Code, Chapter 10, and the Texas Natural Resources Code, Title 2-Chapter 53. Minerals.
- APOs are regulated for safety under the Texas Department of Transportation (TXDOT). The Texas Aggregate Quarry and Pit Safety Act, effective August 26, 1991, was designed to protect the safety of the motoring public. This act requires owners and operators of active, inactive, and abandoned quarries or pits to register with the Department of Transportation.
- No local or municipal regulations pertaining to APOs were identified in the review.

The Texas Aggregate and Concrete Association (TACA) is an organization representing the interests of its aggregate, concrete, and cement industry members. TACA acts as a resource for APO members by providing information on best management practices for water quality protection, air pollution reduction, and waste management. The association provides industry information to the public, media, policy makers and regulators to facilitate the understanding of how its industry operates and complies with state regulations.

4.0 Regional Sediment Management Strategy Alternatives

For over 150 years, the landscape in the San Jacinto watershed has been manipulated by human activities. For 66 years, Lake Houston Dam has been in place, effectively trapping sediment that has run off the landscape upstream. Lake Conroe plays a similar role in the upper portion of the West Fork. Sedimentation in Lake Houston has been occurring for generations, and it may take several decades to mitigate this sediment problem. This section introduces potential strategies which can be implemented to reduce sedimentation. **Section 5.0** will evaluate which of these alternatives should be implemented along the West Fork San Jacinto River and Spring Creek mainstems.

4.1 Sediment Source Protection

4.1.1 Protect Upland Soils

Land use changes occurred in both the Spring Creek and West Fork San Jacinto River subwatersheds beginning in the mid-1800s, with clearing of forests for agriculture and industry and a transition to residential and commercial land use by the mid-1900s. In 1910, landowners in the San Jacinto watershed began to protect soil from erosion and encourage reforestation. These activities culminated in the development of the San Jacinto River Authority by an act of the state legislature in 1937.

The National Resource Conservation Service is a leading federal agency which provides technical and financial assistance for alternatives to reduce landscape erosion loss and prevent eroded soils from entering receiving waters. Several common alternatives are presented below with a hyperlink resource:

- Conservation management plans that balance agriculture activities with land conservation practices:
  - https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs141p2_018353.pdf
- Riparian buffers adjacent to receiving streams that seek to increase the width of a diverse vegetated strip of land between uphill land uses and receiving waters.
  - https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_014881.pdf
- Temporary sediment control best management practices during construction and permanent soil erosion control measures to capture sediment flowing off active construction sites and to arrest sediment flowing off continued land activities after construction has been completed.
  - https://www3.epa.gov/npdes/pubs/owm0192.pdf
- Reforesting landscapes by transforming fallow agricultural grazing fields to diverse mature forests.
  - https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/easements/?cid=nrcs142p2_044368

The RUSLE results discussed in **Section 3.1** can be used to identify regions proximal to the streams and rivers where these strategies can be implemented, for example in the floodplain. Floodplain preservation policies can serve to both manage flood risk in the watershed, as recommended by the overall SJMDP report (Halff/FNI 2020), and to limit the risk of streambank erosion. The SJMDP report also recommends ten regional detention facilities for flood control purposes (Halff/FNI 2020); these may also serve a role in limiting downstream sediment deposition (Halff/FNI 2020). Multiple upland soil protection practices include vegetative measures; once established, these measures can be self-sustaining and may provide long-term protection.

4.1.2 Protect Streambanks

Actions to protect streambanks reduce the amount of sediments entering the stream from the land immediately bordering the river. Streambanks which lack a prolific and dense root mass are most susceptible to erosion. Streambank protection increases the streambank's strength and reduces its susceptibility to erosion. Common streambank protection materials are vegetative plantings, coir (jute) fabric, large logs, large rock, metal, and concrete. The selection, size, and extent of these materials are a function of the stream's power to cause erosion. It is important to consider geomorphology in the design of streambank protection measures, as implementing measures in a way that goes against river processes or that protects too little streambank distance may cause unwanted erosion elsewhere or undesirable flooding conditions. **Figure 4-1** shows some common streambank protection approaches. Typically, the harder the engineering solution (i.e. concrete or sheet piles) the more permitting challenges that maybe faced due to the loss of ecological resource these artificial materials displace.

Bank Protection using Logs and Vegetation

Using Rock and Vegetation

Using Pre-cast Concrete

Photo Provided by John Fields, PhD, PG

Using Sheet Piling

Photo Source: concretestructures.nz

Figure 4-1: Common Streambank Protection Measures

4.1.3 Restore Stream Structure and Function

Restoration is the reestablishment of the structure and function of ecosystems (National Research Council 1992). Ecological restoration is the process of reestablishing the general structure, function and dynamic self-sustaining behavior of the ecosystem (NRCS 2007). Ecological restoration of a stream ecosystem incorporates passive and active interventions to the structure and functions of a stream and its adjacent land, referred to as the stream corridor. Unsteady pulses of energy, water, and materials moving through the stream corridor create a dynamic pattern of sediment being deposited and sediment being removed. In a stable, undisturbed watershed, this pattern is self-sustaining and reaches a dynamic equilibrium without excessive stream deposition or erosion.

Stream restoration observes, measures, and predicts this dynamic pattern and develops a Natural Channel Design, an approach to restore a self-sustaining, stable channel based on natural channel physics. This approach is different from protecting eroding streambanks, which often focuses on a singular sediment source or a close grouping of sources. In contrast, stream restoration often focuses on a greater distance of channel than streambank stabilization and is implemented with an understanding of why a given channel reach is experiencing rapid adjustment (erosion, deposition, or other processes). This can be due to watershed changes in sediment supply, flow regime, or localized disturbances in the channel reach itself. Based on this knowledge, the restoration practitioner then prescribes a series of interventions that restore the structure and function of the stream. Often this is intended to recreate the physical conditions that are necessary to restore the stream ecosystem.

The channel evolution model proposed by Simon (1989) is one of several channel evolution models which describes the adjustments that occur in natural channels when they are disturbed, either by changes in sediment and flow regimes or by localized modifications (**Figure 4-2**). These models share commonality by what occurs to a channel that undergoes a disturbance that alters its sediment transport and discharge relationship. The varying channel evolution models, after such disturbances (in **Figure 4-2** it isa stream that has been channelized (Class II) by human activities) results in a chronological chain of events resulting in excessively large amounts of sediment sources (Class III and Class IV) and sediment deposition (Class V), ultimately resulting in a return to a stable condition after deepening and widening of the channel, in which a new stable channel forms. It is important to note that, although the stream will eventually return to a stable equilibrium (Class VI), the consequences of this adjustment process are large quantities of sediment transported downstream, land loss, and potential damage to public infrastructure. Because of this, stream restoration seeks to intervene during Class III through Class V and re-establish a quasi-equilibrium (Class VI).

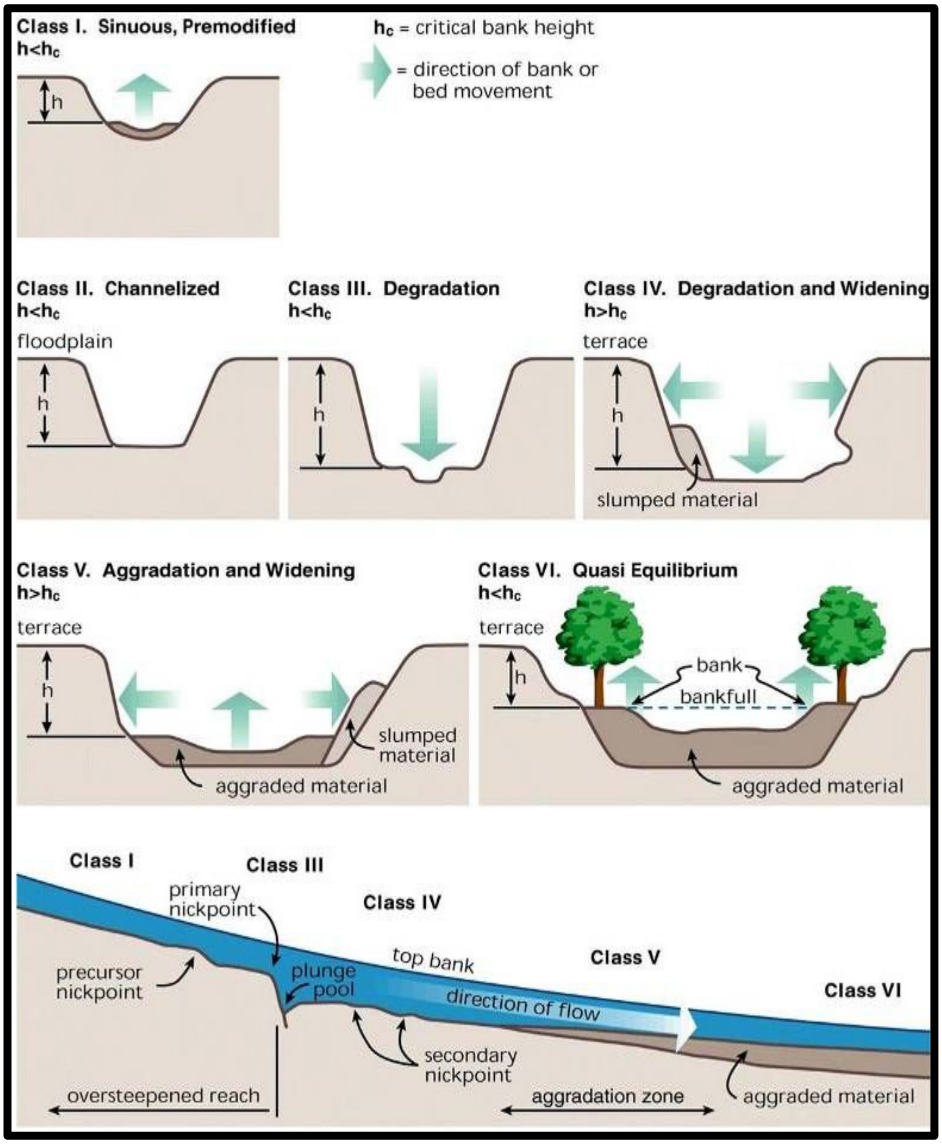

Figure 4-2: Channel Evolution Model (Simon 1989)

4.1.4 Aggregate Mine Protection

As discussed in **Section 3.4**, aggregate mines may become a source of sediment if the protective land around the pits fails in a flood condition or if floodwaters rush through stockpiles, entraining piled sand. Aerial photographs can be taken immediately after flood events to observe any loss of sediments from APO facilities. Observations to map would be alluvial fans or strewn about sediment piles downstream of an APO. If these features are observed, then measures ought to be taken to prevent neighboring rivers from eroding the protective barrier between the river and the pit. Streambank protection can be used. These measures do not need to cover the entire length of the isthmus but can be strategically located where the stream's erosive power is the highest.

Abandoned aggregate mines can also be used for sediment trapping as discussed in **Section 4.3**.

4.2 Channel Conveyance Improvement

4.2.1 Improved Channel Hydraulic Dynamics

As discussed previously, sediment deposits when the stream's ability to transport sediment is less than that needed to move the quantity of sediment. The ability of the stream to move a volume of sediment over time is also known as sediment transport capacity. Another important element of sediment transport is sediment transport competency, the ability of the stream to initiate and sustain movement of the range of particle sizes delivered from upstream. Both capacity and competency are important elements of sediment transport physics. This discussion focuses on changing the sediment transport competency as measured by unit stream power, which is a function of shear stress and velocity. A channel's stream power can be altered by manipulating the geometric shape of a river or stream or by changing the physical characteristics of the areas adjacent to a river or stream. Three common approaches to increasing stream power are:

- Increasing the steepness of the riverbed slope
- Increasing the channel's hydraulic radius by a change in a channel's ratio of width to depth
- Decreasing the roughness of the channel

Increasing the steepness of the riverbed slope can be achieved by straightening the channel and thus reducing the horizontal distance of the channel. A steeper channel will have greater power to move sediment. However, the short-term gains of this practice can be outweighed by the long-term increase in sediments being sent downstream due to the resulting instability of the modified channel. Decreasing a channel's cross-sectional area (usually by reducing its width) is one method that is popular in stream restoration because it restores a channel's geometry and ability to transport sediments during low flow conditions but allows floodwaters to spread out across a floodplain during high flow conditions. Great care must be used because reducing the cross-sectional area too much will result in conditions similar to channelizing the stream, which is why stream restoration must be based on defining a stable channel form that has the ability to move sediment without aggrading or degrading over time.

Decreasing the roughness of the stream can be accomplished by lining the stream with concrete or stacked stone. While lining a stream with hard material will result in increased velocities and therefore increase sediment transport capacity, the increased velocity can cause erosion in the unlined section immediately downstream of the lined section. This can then potentially undermine the lined channel upstream, which creates additional sediment sources and channel adjustment. Removing vegetation along the streambanks and stream beds is another way to reduce roughness and increase velocity. However, the density and depth of roots in the streambanks is one of most critical variables in keeping streambanks stable and interrupting the integrity of a streambank's root mass over even short stretches can lead to undesirable streambank failures and streambank erosion. Therefore, vegetation removal is advisable only if trees threaten infrastructure or vegetation potentially threatens to block the channel. If this action is taken, the remaining root mass should be left in place.

4.2.2 Sediment Bypass Tunnel

Sediment bypass tunnels have been used as a sediment management strategy for reservoirs in Japan, Switzerland, and Taiwan. These tunnels are used to maintain reservoir capacity and to replenish sediment in downstream reaches below that dam (Serrana et al. 2018). An underground tunnel conveys sediments around a dam using the physical properties of water rushing through the tunnel to keep the sediments moving through the tunnel. **Figure 4-3** shows an example of a sediment bypass tunnel.

A structure is built in the reservoir at the tunnel mouth to deflect and direct sediment into the tunnel. An advantage of a maintained tunnel is that no additional power is needed to move sediment through the routing system. Sediments could also be excavated in other places in the reservoir and hauled to the guiding structure to be sent downstream.

4.2.3 Hydraulic Influence of Lake Houston Dam

The 2000 Brown and Root study noted that Lake Houston Dam may influence the West Fork's ability to transport sediments downstream, leading to deposition between the Spring Creek/West Fork confluence and Lake Houston. An extensive hydraulic modeling effort is being completed to remap flooding extents in the San Jacinto watershed and to model alternatives for reducing flood risk in the watershed. A draft version of the existing conditions HEC-RAS version 5.0.7 model was used to review whether Lake Houston Dam influences the factors upstream critical to transporting sediments. Three hydraulic factors that characterize this influence were reviewed: stream power, shear stress, and the slope of the energy grade line. Hydraulic modeling output was extracted from the model and organized to look for trends upstream, through, and downstream of the region of interest.

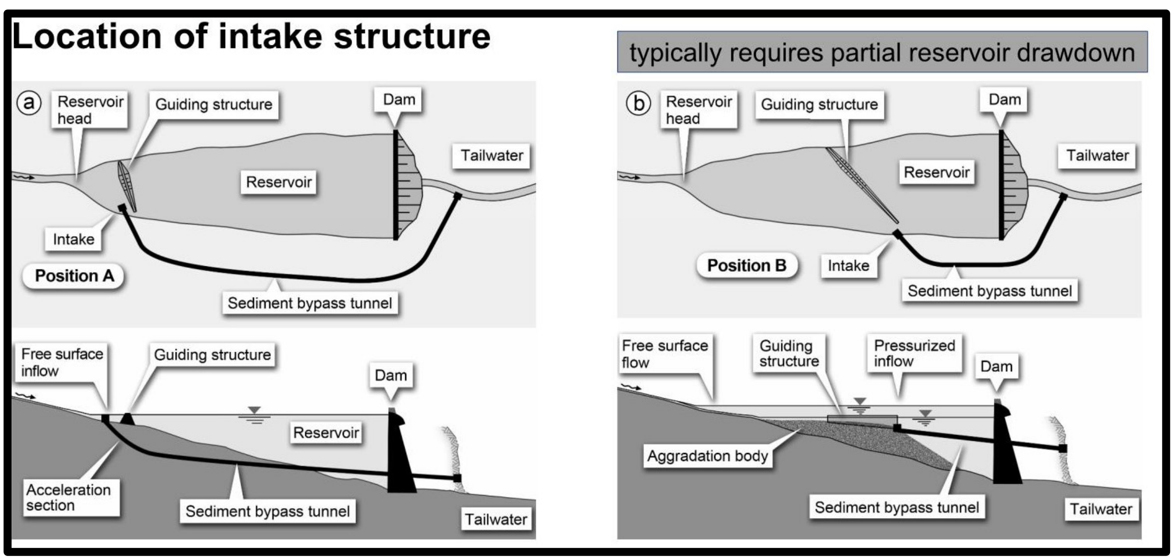

Figure 4-3: Sediment Bypass Tunnel (Auel and Boes 2011)

Figure A-3 in **Appendix F.A** depicts the energy grade line (EGL) and water surface elevation during the 50% annual chance event, the smallest studied flood in the existing conditions model. A near horizontal energy grade line slope begins at Lake Houston Dam (river station 89219) and extends for approximately 10 miles upstream to river station 141961, where the EGL slope steepens roughly 10,000 feet upstream of the FM 1960 bridge near the Kings River Estates peninsula. **Figure A-4** in **Appendix F.A** presents detailed hydraulic modeling output, with the cross sections near river station 141961 in bold and italics. A summary table is presented in **Table 4-1**. There is a notable decrease in the constituents responsible for moving sediment in the region near Kings River Estates peninsula. Because of these factors, it is not surprising that notable sediment deposition occurs in this area.

As shown in **Table 4-1** and as suggested in the 2000 Brown and Root study, Lake Houston Dam's backwater effect is suspected to be the largest influence in the reduction of the ability to move sediments out of the area of concern on the West Fork. A hydraulic analysis and sediment transport model can be completed to increase the understanding of the relationship between the reduction in the hydraulic constituents shown in **Table 4-1** and sedimentation between the FM 1960 bridge and the West Fork/Spring Creek confluence. Once this relationship is established, it is then possible to understand if any changes to the dam's configuration could improve the hydraulics to prevent sediment from depositing in this region. Any modeled change in the dam's configuration would also need to model if there is any resulting unwanted flood impacts downstream.

Table 4-1: Hydraulic Results from 50% Annual Chance Event (Existing Conditions)

Cross Section	Energy Grade Line Slope (feet/foot)	Shear Power (lb/square foot)	Stream Power (lb/foot second)
145228	0.000179	0.09	0.18
144602	0.000455	0.14	0.32
143196	0.000322	0.1	0.2
141961	0.000013	0	0.01
140359	0.000004	0	0
139211	0.000006	0	0

4.3 Sediment Trapping and Removal

4.3.1 Sediment Trapping with Removal after Flooding Events

Sediment deposition occurs naturally in rivers and streams as observed in sand bars, gravel bars and deltas. Sediment deposition also occurs due to human intervention in a river network (Waters and Rivers Commission 2002). For example, excessive sediment deposition can occur upstream of dams and bridges or within box culverts. In both the natural and anthropogenic conditions, deposition occurs when sediment enters a reach or area of the channel where sediment transport capacity has decreased below what is needed to move the sediment load through the system over time. Sediment deposits upstream of dams and bridges or in shipping channels are often undesirable and therefore removed by dredging. This sediment management strategy removes sediment, mechanically or hydraulically, and disposes of it or uses it as a beneficial material for erosion protection, habitat creation, or landscape architecture.

Sedimentation can reduce the area within a channel that is occupied by water during a flood. The resulting hydraulic conditions can lead to changes in flood hazards (Slater et al. 2015, Lane and Thorne 2007, FEMA 2016). These changes can be quantified by calculating the water surface elevations in the region around the sediment obstruction (Guan et al. 2016, Staines and Carrivick 2015). If water surface elevations with the sediment obstruction result in undesirable flood hazards, these areas can be selected for sediment management strategies.

To avoid unwanted sediment deposition, river conditions can be manipulated upstream of dams or bridges to encourage sediment deposition in a more desirable location. This sediment management strategy is referred to as sediment trapping. The amount of sediment trapped can vary, depending on the volume available to store sediment. Sediment trapping can occur as an “in-line” trap located roughly perpendicular to the flow direction or as an “off-line” trap, located roughly parallel with the flow direction.

When Mount St. Helens erupted in 1980, the resulting explosion reduced the mountain’s peak elevation by over a thousand feet and sent a tsunami of sediment down its north side. In 1989, USACE constructed an “in-line” sediment trap that, as of 2012, had captured 258 million cubic yards of sediment (Denlinger 2012). This trap was needed to prevent sediment deposition in downstream areas. For comparison, a 2018 survey found that Lake Houston captured 48 million cubic yards of sediment since it was first built 64 years before. Sediment trapping can also store much smaller sediment volumes. A few examples of “in-line” sediment trapping are shown in **Figure 4-4**. Deposited sediment may need to be removed to maintain available storage volume. Sediment traps can be designed so that sediments can be removed using conventional excavation equipment, which can lower unit costs for removal.

Using Rocks and Logs

Using Lumber

Photo Provided by: Jack Bjork

Using Engineered Log Jams

Photo Source: (Sclafani et al. 2017)

Using Concrete and Compacted Earth

Photo Source: USACE

Figure 4-4: Common Sediment Trapping Methods

"Off-line" sediment traps, also referred to as "lateral" sand traps, are an artificial feature that diverts a portion of the river into an environment that is conducive to sediment deposition. Two off-line sediment trapping methods are as follows:

- A portion of the river is deflected into an abandoned aggregate mine pit. Bedload sediment falls into the deep hole left by an aggregate pit that is no longer in use and is trapped.
- A portion of the river is deflected into a side channel, whose hydraulics have been artificially manipulated to reduce the river's power, leading to sediment deposition.

4.3.2 Sediment Trapping with Removal during a Flood Event

Sediment can be trapped and removed continuously using a mechanical screw and pumps. A bedload collector is a device inserted at the channel bed elevation with an open grate. The grate empties into a metal trench, which houses a mechanical screw that is turned using a motor. Sediment and water fall through the grate and are forced through the trench by the screw, where they deposit into a chamber. This mixture of sediment and water, referred to as a slurry, is pumped out of the chamber, through metal pipes, and onto a conveyor belt, which dumps the sediment into a pile. By itself, a bedload interceptor only captures sediment transported as bedload, but if it is combined with a sediment trap, the coarse fraction of sediments transported as suspended sediments can also be harvested. **Figure 4-5** is a photo of a bedload collector.

Photo Source: USACE

Figure 4-5: Bedload Collector

4.4 Develop Public-Private Partnerships

A public-private partnership (P3) is a collaborative effort between a government agency and a private-sector business. A P3 could be formed in the San Jacinto watershed to reduce the amount of sediment deposition in the area between the West Fork/Spring Creek confluence and Lake Houston. The goal of the P3 would be to support the sediment management strategy of sediment trapping. Sediment trapping features an area where sediment is artificially made to deposit. Over time, this area will fill with sediment, and run out of volume to capture sediment. This area will need to be abandoned, or the sediment will need to be removed.

The sediment dredged from Lake Houston in 2019 was clean of contamination and is therefore ready for beneficial use. The 2000 report noted for sediment in the San Jacinto watershed can be sold as:

- Medium sand "concrete sand"
- Fine sand "mortar sand" or "cement stabilized sand"
- Bank run sand "contains 15 percent or less of fines", passing a #200 sieve
- Common sand fill

The rapidly growing fracking industry has increased the demand for sand; private companies who excavate, store, and sell sand could benefit from a sediment trapping strategy by using the sand caught by a sediment trap.

As an example of a P3 working as part of a sediment management strategy, an agency with jurisdictional authority within the West Fork or Spring Creek mainstems would be the lead agency to design the sand trap, seek funding to construct the sand trap, obtain the environmental permits to construct and maintain the sand trap, and construct the sand trap. A private company would agree to maintain the trap by harvesting the collected sediment. Under this understanding, the sediment trap would continue trapping sediment before it reached Lake Houston, and the material being harvested would contribute to the local economy.

Another example of a P3 effort being used as a sediment management strategy is the National Resource Conservation Service's (NRCS) Environmental Quality Incentives Program (EQIP). This program leases land from willing landowners to limit farming, restore vegetative function, and preserve ecological function along streambanks.

4.4.1 Jurisdictional Authority

The following is a list of jurisdictional bodies who own or take part in regulating and/or maintaining Lake Houston and/or the West Fork San Jacinto River just upstream of the lake. The brief description of each entity is based on material in the 2000 Brown and Root study.

<u>City of Houston</u>: The City of Houston owns Lake Houston, which is in the Houston City Limits. Chapter 23 of Houston's city ordinance regulates the uses of Lake Houston, including general requirements (Article I), water supply protection (Article II), and dredging or excavating operations (Article III). The City also maintains control of its floodplains (Chapter 19) to protect against the increase in flooding dangers.

Harris County: Harris County maintains floodplain management jurisdiction over all unincorporated areas within the County, qualifying these areas for flood insurance under the National Flood Insurance Act. The county has authority to plan and construct drainage improvements in conjunction with county roadways, but it has no specific authority for flood control or sediment control projects.

Harris County Flood Control District (HCFCD): The HCFCD was created in 1937 as a special purpose district to "provide flood damage reduction projects that work, with appropriate regard for community and natural values." Although its original mandate was to serve as a local partner for USACE's major projects, the agency is limited in its legislative and regulatory powers to carry out erosion and sedimentation control projects along the open channels it is tasked to maintain. This is due to the agency's limited ownership to the channels and separate floodplain and permitting functions performed under the county's jurisdiction. It is empowered to cooperate with agencies within the State of Texas, including the City of Houston and Harris County, in the construction and maintenance of flood control projects. HCFCD lacks the jurisdiction over sedimentation or other issues not related to flooding in Harris County and has no jurisdiction outside of Harris County. It can make cooperative agreements with other agencies to partially fund studies whose scope of study extend beyond Harris County.

San Jacinto River Authority (SJRA): Through an act of state legislation, SJRA has broad general powers to engage in the storing, controlling and conserving of the storm and flood waters of the watershed of the San Jacinto River and its tributaries. SJRA's boundaries, however, explicitly exclude Harris County from its jurisdiction. This includes Lake Houston and downstream. In addition, SJRA's legislation does not provide SJRA the necessary regulatory authority to effectively address flood mitigation (e.g., no authority to regulate development activities within the floodplain or floodway), nor does it provide state allocations or taxing authority to fund flood mitigation activities.

Montgomery County: Like Harris County, Montgomery County maintains floodplain management jurisdiction over all unincorporated areas within the county, qualifying these areas for flood insurance under the National Flood Insurance Act. The county has authority to plan and construct drainage improvements in conjunction with county roadways, but it has no specific authority for flood control or sediment control projects.

Texas Water Development Board (TWDB): Created by the Texas Legislature in 1957, the TWDB provides leadership, technical services, and financial assistance to support planning, conservation, and responsible development of water for the State of Texas. Political subdivisions can apply for flood protection planning (FPP) grants and regional development planning grants. The purpose of the FPP grant program is to assist local governments in developing flood protection plans for entire major or minor watersheds. These plans include studies and analysis to determine and describe problems resulting from or relating to flooding, and to determine the views and needs of the affected public relating to flooding problems. FPP funding is currently allocated to the TWDB's Flood Infrastructure Fund (FIF), under the planning and life-and-property-protection categories. The FIF provides grant and loan funding for flood control, flood mitigation, and drainage projects, which can include erosion control, floodplain restoration, or nonstructural flood mitigation. The TWDB also offers loans through the Water Development Fund for many types of flood control projects, including channel enlargement projects and acquisition of floodplain land for use in public open space, and through the Clean Water State Revolving Fund for stormwater best management practices and protection of natural waterways.

Texas Commission on Environmental Quality (TCEQ): The TCEQ is the state agency responsible for Texas Pollutant Discharge Elimination System (TPDES) permits. Land disturbances larger than five acres require the creation of a stormwater pollution prevention plan, which establishes standards for sediment leaving active construction zones, and for permanent stormwater best management practices.

U.S. Army Corps of Engineers (USACE). The USACE is federal body responsible for enforcing Section 404 of the Clean Water Act, which governs the placement or removal of fill in or from navigable waters. The Clean Water Act also empowers the USACE to ensure that removal or placement of fill that does not impact wetlands, other waters of the US, archeological sites, or endangered species.

4.4.2 Cooperative Initiatives

There are multiple agencies that have jurisdictional authority or have been given powers to manage flood waters and the factors that lead to flooding in the San Jacinto watershed. However, there is no single agency that has complete authority over the watershed or has power to mitigate flooding and the factors that contribute towards flooding, regardless of political boundaries. This fragmentation of authority can lead to disagreement among the agencies and delays in implementation. Other challenges can include coordination of property ownership, access rights, and maintenance responsibilities for constructed projects. These challenges are common throughout the country, but there have been several examples where agencies have entered into a binding, cooperative agreement regarding watershed management.

In 1961, a concurrent compact legislation was created among the governors of Pennsylvania, New Jersey, New York, Delaware, and the USACE. This legislation formed the Delaware River Basin Commission with the goal of implementing programs for water quality protection, water supply allocation, regulatory review, watershed planning, flood loss reduction, and recreation. A simple majority vote decides most issues, except for votes to apportion the number of signature parties that are required to support the current expense budget and to declare a state of emergency due to drought or flood catastrophe. A similar agreement could be reached among the two counties, HCFCD, City of Houston, and SJRA.

Another example occurred in 1993 when the U.S. EPA issued a mandate to New York City to protect its drinking water resource, or pay for a filtration plant, which was estimated to cost $4 to $6 billion. The City's drinking water supply originates hundreds of miles away in the Catskills, a mountainous area of New York state. A memorandum of agreement (MOA) was reached between the City and the counties and municipal governments of the Catskills, which agreed that the City would invest $1.3 billion into water quality infrastructure (drinking water plants, wastewater treatment plants, utility infrastructure, eroding bank protection, private septic tank replacement, etc.) in exchange for regulatory authority for watershed management planning (Finnegan 1997). The MOA was agreed to in principle within seven months of the beginning of negotiations and ratified fourteen months later, effectively ending a century of disagreement regarding watershed management. A coalition of San Jacinto watershed jurisdictional agencies, municipalities, and counties within the watershed could take a similar approach.

In 2019, the 86th Texas Legislature passed Senate Bill 8, which established a new regional and state flood planning process. Regional flood plans will be developed from established regional flood planning groups and merged to create the State Flood Plan. The TWDB designated 15 flood planning regions based on the primary river basins in Texas. The San Jacinto River watershed will be flood planning Region 6, represented by 12 stakeholder interest groups as follows: agricultural, industrial, river authorities, counties, municipalities, water districts, flood districts, electric generating utilities, public, water utilities, environmental interests, and small business. The regional flood plan will be updated every 5 years, similar to the water plan, and will provide a forum for consistent engagement on flood related issues, across multiple interest areas, in the San Jacinto River watershed.

4.4.3 Memorandum of Understanding for San Jacinto Watershed Sediment Management Strategy

A memorandum of understanding (MOU) for sediment management is a tool created to improve the understanding and cooperation among multiple agencies who recognize the importance of managing sediment within the San Jacinto watershed. The MOU would seek to define sediment management and acceptable sediment management activities, outline the roles and responsibilities of participating agencies and establish milestones and timelines to accomplish the goal. To achieve these objectives the MOU should include the following sections:

- Purpose: Lists the agencies who are entering the agreement and describes the general commitments of participating parties.
- Background: Describes the reason for the development of the San Jacinto Watershed Sediment Management Strategy MOU. This section describes why sedimentation is a concern to the agreeing parties.
- Previous Agreements: This section explains related agreements among agencies, current or expired that demonstrate how agencies have agreed to work together on related problems.
- Party Responsibilities and Commitments: Outlines the roles and responsibilities of the parties such as a lead agency which seeks to improve communication and clarity among the participating agencies. This may include who may provide technical assistance or directly/indirectly provide funding to study and implement sediment management strategies.
- Duration and Termination: Defines how long the agreement is anticipated to last and if any amendments can be added during the duration of the agreement. This section sets forth the conditions that allow parties to end their involvement in the MOU.

A draft of a potential San Jacinto Watershed Sediment Management Strategy MOU is included in **Appendix F.E**.

5.0 Evaluation of Sediment Management Strategy Alternatives

5.1 General Sediment Management Strategies to Pursue

A long-term goal for sediment management in the San Jacinto watershed is to reduce sedimentation in the region of concern (between the Spring Creek and West Fork confluence and the FM 1960 bridge in Lake Houston). This report evaluated opportunities to reduce sediment that originates within the Spring Creek mainstem and the West Fork mainstem. This section presents strategies that can begin immediately and can be implemented over time to achieve sediment reduction goals.

5.1.1 Completion of Regional Sediment Plan

Regional sediment management plans have been used across the country to develop sediment management strategies specific to watershed needs. This is accomplished through a collaborative effort among concerned stakeholders which is supported by scientific and engineering investigations to develop a sediment budget for the watershed.

The sediment management strategies presented in this report were developed reviewing, updating and expanding on previous studies. This study focused on the West Fork San Jacinto River and Spring Creek. The tributaries which flow into these streams and the other subwatersheds in the San Jacinto watershed also contribute to the sediments flowing into Lake Houston. For example, Cypress Creek subwatershed had the highest suspended sediment annual load out of all the major subwatersheds in the San Jacinto watershed.

An expanded analysis, following the guidelines of regional sediment management and building on this and previous reports, would greatly improve knowledge of where sediment strategies should be located and their effectiveness. This would include the following:

1. Verify LiDAR comparison results by mapping and measuring size of depositional areas and erosional areas in the field. Measure sediment sizes throughout the watershed to characterize the size of sediment being transported in the subbasins.
2. Expand LiDAR comparison into all subbasins within the San Jacinto watershed. Create a watershed sediment budget.
3. Establish a working group with watershed managers and stakeholders who make decisions or are impacted by sediment within the San Jacinto watershed. Solicit information on additional problem areas, possible sediment sources and solutions.
4. Complete a sediment transport model for the entire watershed to identify areas prone to sediment deposition and erosion.
5. Develop cost effective sediment management strategies using sediment removal efficacy as a guide to prioritization.

5.1.2 Protection of Upland Soils

Areas near the West Fork San Jacinto River and Spring Creek were evaluated to identify locations of relatively high landscape erodibility. These locations were mapped using a GIS shapefile for future reference. Results for Spring Creek and the West Fork are presented in **Figure A-5a** and **Figure A-5b** in **Appendix F.A**, respectively. A representative region is shown in **Figure 5-1** along with RUSLE results that have been clipped to the 1% annual chance floodplain. There are multiple locations which border the mainstems that have a high potential for soil loss. In these areas, the following alternatives are recommended to reduce the amount of eroded upland soils reaching receiving waters:

- Require conservation management plans, which are provided free of charge by NRCS, on agriculture fields.
- Increase riparian buffer widths on all land adjacent to the West Fork and Spring Creek mainstems to a minimum of 35 feet, with 100 feet preferred.
- Require land development construction activities covering more than 0.25 acres to install temporary sediment control best management practices during construction and permanent soil erosion control measures.
- Convert barren or low producing grazing lands to forested landscapes.

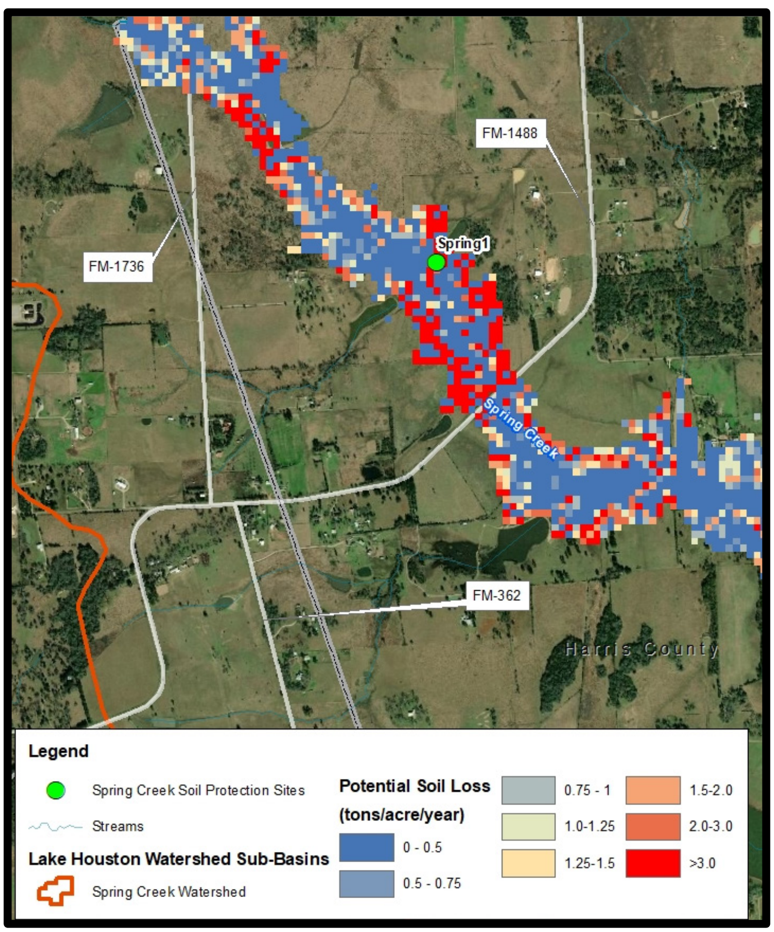

Figure 5-1: Example Location of Upland Protection Sites with RUSLE Results

5.1.3 Channel Erosion Protection and Sediment Trapping

The review of LiDAR data described in **Section 3.2** was used to select locations for source protection and sediment trapping strategies. Sediment source protection strategies were located at areas with “high” and “severe” stream deviations and where recent LiDAR elevations are significantly lower than historic LiDAR elevations (evidence of an eroding bank). Sediment trapping strategies were located at areas where the recent LiDAR elevations are significantly higher than historic LiDAR elevations (an indicator of sediment deposition). These areas are desirable since sediments are naturally depositing and a sediment trap would utilize the natural conditions causing this deposition. Storing and removing sediment in these areas could be more cost effective than removing the sediments in the sediment problem area between the West Fork/Spring Creek confluence and the FM 1960 bridge. LiDAR comparison results coupled with the recommended sediment transport modeling (as part of the completion of the regional sediment management plan) will also serve as a guide to identify other regions where additional sediment storage and removal strategies may exist.

These strategies were organized into a proposed implementation strategy. The sediment management strategies were assigned an identification number starting from upstream to downstream. Strategies were grouped into a proposed implementation plan and organized by the likelihood they will reduce sediments depositing downstream. It may take several decades to complete the sediment strategies presented here, so the sedimentation strategies with the most immediate impacts on sediment reduction are prioritized first.

Spring Creek

Spring Creek can generally be summarized as a meandering stream that receives runoff from agricultural land that drains to the southeast. Once it passes under Kickapoo Road, approximately four miles southeast of Fields Store, the creek enters a deeper inset floodplain which is bordered by relatively steeper valley walls. The higher terrace on top of these valley walls is drained by steep channels and gullies. This valley type continues eastward for several miles until the creek passes under Murrell Road where it enters a wider valley where larger tributaries join the creek. This pattern of valley expansion and contraction repeats multiple times while Spring Creek flows eastward toward the West Fork.

Spring Creek was divided into 33 reaches based on geomorphic characteristics. Eleven sediment sources were mapped. The frequency and magnitude of potential sediment sources and sediment deposition increased notably beginning around reach 29 near the Interstate-45 bridge (**Figure A-14** in **Appendix F.A**). There was also ample evidence that Spring Creek has eroded large portions of valley walls and streambanks. A high concentration of eroded valley walls is located downstream of the State Route 99 crossing and Pundt Park (**Figure A-15**). Often when a tall streambank or valley wall is eroded, there is observable sediment deposition immediately downstream.

Twenty-eight strategies to reduce sedimentation were identified along the Spring Creek channel. **Table 5-1** groups these strategies and organizes the groups by potential to reduce sediment. The strategies were identified using visual observation of a map that contained the LiDAR comparison and the stream deviation. Sediment management strategies were grouped into three categories: sediment source protection, sediment trapping, and stream restoration. Sediment source protection were located where there was notable lowering in the topography (i.e. in a stream bank or valley wall) and/or where a relatively long stream of moderate to severe stream deviation occurs. Sediment trapping strategies are located in regions that demonstrate a relative increase in LiDAR change suggesting sediment deposition is occurring within the region. Stream restoration strategies are located in regions where there is notable stream deviation and if there are relatively notable changes in LiDAR differences. The identified strategies in this report only used LiDAR comparison and stream deviation to locate strategies. Additional methods are recommended for identifying sediment management strategies, including field mapping completed by professionals with geomorphology and engineering experience, unmanned aerial vehicle photos, and a detailed TSS analysis at different locations in the subwatershed. These strategies should be used as a guidance for watershed managers to identify opportunities to manage sediment in the watershed.

Preference was assigned to sites located close to the confluence with the West Fork, since they are more likely to affect the area of interest on the West Fork just upstream from Lake Houston. Sediment trap #27 (**Figure A-16**) is a high priority for implementation since it is located near the downstream end of Spring Creek and would therefore be located downstream of most of the creek's sediment sources. This location is roughly 900 feet east of Carter Park and in a sparsely populated area. The proximity to public land will reduce the number of temporary and permanent easements needed and improve access for maintenance. The exact location of the trap could be adjusted to accommodate the recreational users for Carter Park Canoe Launch. Depending on the volume of sediment this location can store, sediment trap #25 (**Figure A-15**) would be the second highest priority site to work in tandem with trap #27. Head cut protection #20 (**Figure A-12**) is also a high priority because it is located close to the downstream end of Spring Creek. If erosion were to progress upstream at this location, it would increase the number of sediment sources and the amount of sediment originating from each source. Stream restoration #26 (**Figure A-15**) is located near the confluence of the West Fork in a region which features large eroding streambanks and valley walls. Streambank/valley wall protection strategy #23 (**Figure A-13**) and stream restoration #19 (**Figure A-12**) are also assigned a high priority due to their proximity to Lake Houston and their length and height.

There are probably many more sediment sources in Spring Creek that were not identified in this study. The methodology used for this project identified the largest of the sediment sources that were measurable using LiDAR topographic data. A detailed field assessment and sediment transport hydraulic analysis is recommended to identify other sediment sources within the channel itself.

West Fork San Jacinto River

Since Lake Conroe Dam effectively prevents sediment from the upper half of the West Fork's subwatershed from being transported downstream, this study focused on the part of the West Fork San Jacinto River from Lake Conroe to the FM 1960 bridge in Lake Houston roughly 46.5 miles downstream. The impact of Lake Conroe Dam causes the West Fork between Lake Conroe and Lake Houston to be divided into three broad sediment systems: transfer, transitional, and depositional. This understanding influences the approach to sediment management strategy for the West Fork.

Because Lake Conroe Dam captures most of the sediment from upstream, the channel downstream of the dam is carrying relatively little sediment. Since the West Fork can still carry sediment, it removes material from its streambed and streambanks to replace the sediment captured by the dam. The dam causes a downstream reaction similar to channelization, discussed in **Section 4.2.3** (Brandt, 2000, USGS 1984). Degradation of the river boundaries begins at Lake Conroe Dam and extends approximately 7.5 miles downstream to about reach 10 (**Figure A-19**). The West Fork in this region features steeper streambanks, numerous sediment sources, shorter reaches, variable valley characteristics, and a notable lack of sediment deposition. The lack of sediment deposition is the reason that this region of the West Fork is referred to as a sediment transfer system. Sediment source protection (protecting eroding streambanks, valley walls or completing stream restoration activities) is recommended rather than sediment trapping in this area.

The next part of the channel downstream of reach 10 is a transitional system (**Figure A-19**), which begins just upstream of the West Fork's first notable tributary, Lake Creek. Notable sediment deposition is observed within several hundred feet of this confluence. The transitional system ends around the downstream end of reach 22 (**Figure A-24**) near the confluence with Spring Creek. Its governing characteristic is a relationship between relatively large sediment deposits, a shift in river alignment and an eroding streambank or valley wall on the opposing side of the river. This pattern is present throughout the transitional zone (approximately 31.5 miles) and is readily evident near aggregate production operations (APOs). The relationship is strongest in **Figure A-23**. Local hydraulics resulting from natural topography (riverbed slope, wider stream cross sectional area, etc.) and land use practices (increased valley flood conveyance volume) may contribute to this pattern.

The last region in the West Fork is the sediment depositional system, which begins near the Spring Creek confluence and extends approximately 7.5 miles to the end of the West Fork near the FM 1960 bridge in Lake Houston. This region is dominated by sediment deposition and relatively less frequent occurrences of sediment sources in comparison with the two regions upstream. As discussed in **Section 4.2.3**, Lake Houston Dam's hydraulic influence extends into this region and is suspected to be a primary reason that sediment deposition is the dominant feature in this region.

Twenty-one sediment management strategies were identified in the West Fork. The sediment management strategy for the West Fork differs from Spring Creek because of the presence of these three distinct sediment systems and the presence of existing infrastructure and resources near the West Fork. Sediment trapping upstream of the Spring Creek confluence offers an opportunity to trap a notable percentage of the sediments flowing down the West Fork. Sediment trapping should take advantage of the APOs bordering the West Fork. River water and the sediment it carries can be deflected/directed into the deep APO pits where a portion of the sediments can be trapped. Trapped sediments can then be harvested and sold. Since unwanted sedimentation is occurring in the sediment problem area near Kingwood, a reduction of sediments would be beneficial. Therefore strategy #9, #11 (**Figure A-21**), #12 (**Figure A-22**) and #16 (**Figure A-23**) are high priority.

Sediment trapping strategies can be implemented first, assuming willing landowners and an agreement for maintenance. However, the efficacy of these strategies and their maintenance frequency are unknown at this time and therefore other sediment management strategies are needed.

In conjunction with the sediment trapping strategy, a stream restoration project (strategy #21 in **Figure A-26**) near Lake Houston could push sediments further into Lake Houston and out of the area of concern near Kingwood. This region is presented in **Figure 5-2**, showing a proposed concept to beneficially use the material excavated during dredging activities. If future dredging is planned in Lake Houston, this concept could reduce the cost of hauling and disposing of dredge spoils. This material is strategically placed in areas to improve the hydraulics and push sediments further out into the lake. An advantage of using dredging spoils is their proximity to this site, reducing transportation costs.

This project is likely to have a low to negligible impact on flood water surface elevations. The areas proposed to be filled in to create new floodplains are generally in areas referred to as ineffective flow. Ineffective flow is a hydraulic engineering term to describe areas in a floodplain that do not actively convey floodwaters and thus can be altered without meaningfully affecting flood water elevations. This concept alone would not reduce the long-term sedimentation into Lake Houston but could serve to push sediment out of the area of concern.

If sediment source mitigation is needed, an optimal approach would mitigate sediments in regions located downstream of the most downstream APO sediment trap and the sediment problem area. Siting a sediment source mitigation in this region would reduce the amount of sediments that have a high probability of flowing into the sediment problem area. Therefore, sediment strategy #18 on **Figure A-24** is a high priority. Another source of sediment is streambanks and valley walls, which can be mitigated using streambank/valley wall protection, as with strategy #19 on **Figure A-24**. The lowest priority region would begin in the most upstream reach where the degradation caused by Lake Conroe begins and progress downstream, focusing on regions with excessive sediment sources.

Table 5-1: Sediment Management Strategies for Spring Creek and West Fork

Potential to Reduce Sediments Flowing to Lake Houston	Strategy	Strategy Number (Spring Creek)	Strategy Number (West Fork)
High	Streambank/valley wall protection	23, 28	19
	Head cut protection	20	
	Sediment trap	22, 27, 25	9, 11, 12, 16
	Stream restoration	19, 26	18, 20, 21
Moderate	Streambank/valley wall protection	10, 18, 24A	5, 13
	Head cut protection	6, 11	
	Sediment trap	13, 16	6, 8
	Stream restoration	15, 21, 24	4, 7, 10, 14, 15
Lower	Streambank/valley wall protection	2, 3, 4, 9, 17	2A, 3
	Sediment trap	5, 7, 8	
	Stream restoration	14	1, 2
	Upland soil protection	1	

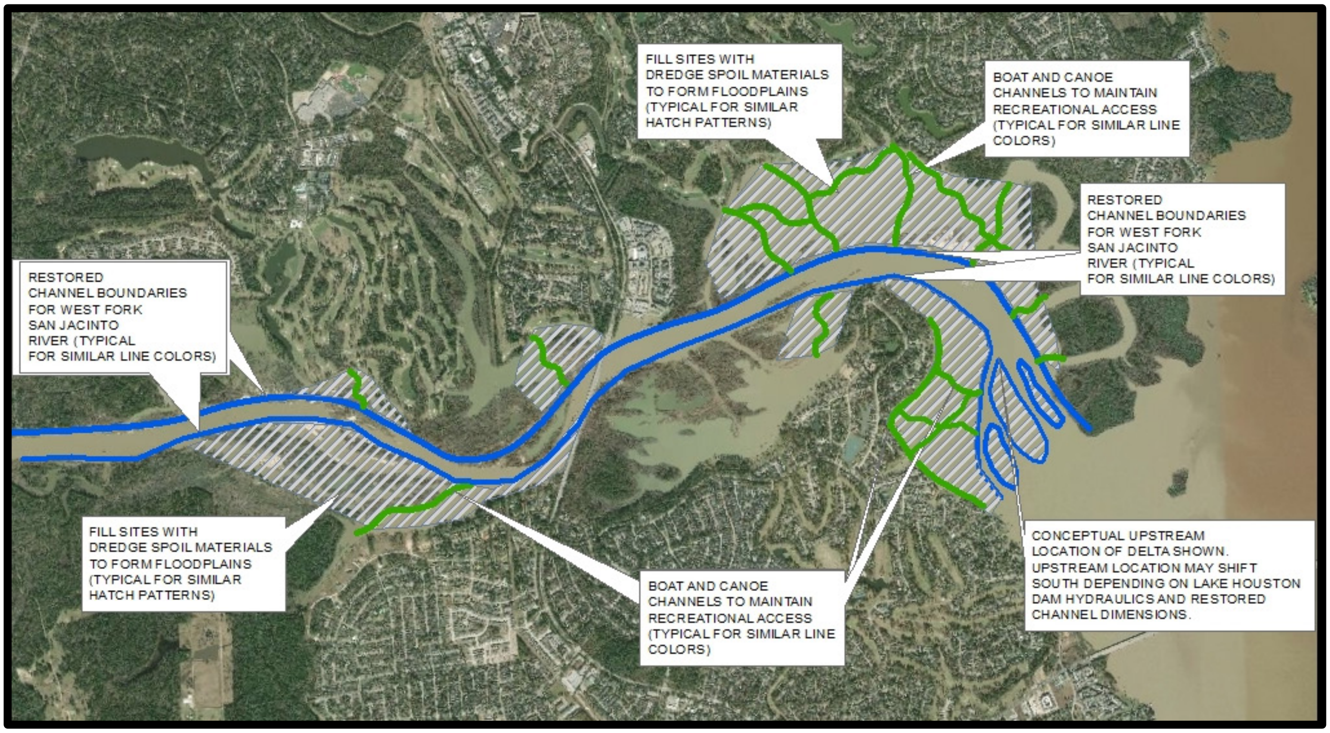

Figure 5-2: Stream Restoration Concept For West Fork San Jacinto River

5.1.4 Overall Implementation of Protection and Trapping Strategies

Sediment management strategies were mapped using readily available GIS data and organized based on their likelihood to reduce sediment deposition in the region of concern between the West Fork and Spring Creek confluence and Lake Houston. Using GIS data to develop sedimentation strategies is the first step in a multi-step process before these strategies are constructed and implemented. The following steps are recommended to complete design and implementation for these strategies.

1. Complete field mapping visits to proposed strategy sites to improve the understanding of the likelihood these sites can reduce sediment deposits in the region of concern. This can be accomplished using handheld GPS units to map the characteristics of sediment sources and opportunities to trap sediments. Reorganize strategies by their likelihood to reduce sediment deposition.
2. Refine the regional sediment management plan to develop the San Jacinto watershed's sediment budget. Identify by subwatershed the areas that contribute the most sediments to the region of concern. This can be completed using a refined GIS analysis that measures streambank height, streambank slope and streambank length. Reorganize strategies using the expected reduction of sediment they will achieve in proportion to the overall San Jacinto watershed sediment budget.
3. Complete a hydraulic analysis to understand if there are reasonable ways to reduce the hydraulic effects of Lake Houston Dam that result in sediment deposition in the region of concern near the Kingwood.

4. Identify regions prone to sediment deposition which contain a flood hazard. A flood hazard is defined as a region whose flood water elevations result in undesirable consequences such as damaged buildings, flooded roadways or erosion. Measure the extent of sediment deposition and calculate water surface elevations, velocity, shear stress, etc. under existing conditions and with the sediment deposition removed.
5. Complete a preliminary engineering report to document implementation opportunities and constraints, environmental permitting requirements, right of way acquisitions, and implementation costs.
6. Proceed to detailed design and implementation of sedimentation strategies.

5.2 Sediment Tunnel Conceptual Alternative

A proposed tunnel alignment to bypass sediments around Lake Houston Dam was drafted and presented in **Figure A-27** in **Appendix F.A**. The intake to the proposed sediment tunnel is located in an area where the hydraulics will move sediment downstream into the tunnel. The proposed tunnel length is approximately 10 miles and would enter the San Jacinto River just downstream of Lake Houston Dam. The cost per foot of the tunnel can range widely depending on the material that the tunnel will cut through, as shown in **Table 5-2** (Auel and Boes, 2011). Based on the 2011 Auel and Boes average costs, the cost of a 10-mile tunnel could range from $83 million to $690 million (2011 dollars). For comparison, by the year 2035, the estimated cost to restore Lake Houston to its design conditions by dredging would be $2.2 billion and the recent one-time dredging activity completed for just a small portion of Lake Houston cost $25 million. Since the proposed tunnel length of 10 miles is notably longer than the 2011 Auel and Boes tunnels listed in **Table 5-2**, the cost per foot of the proposed Lake Houston sediment tunnel may be lower for a given diameter.

In 2019, Freese and Nichols completed planning-level, AACE Class 5 cost estimates for deep flood control tunnels in Harris County for the HCFCD. The estimated construction cost range for a 150-foot deep 25-foot-diameter tunnel ranged from $13,809 to $29,602 per foot, with an estimated cost of $19,735 per foot. The estimated construction cost range for a 150-foot deep 40-foot-diameter tunnel ranged from $20,284 to $43,466 per foot, with an estimated cost of $28,977 per foot. These ranges reflect the uncertainty of project complexity, project definition, contingency, and other factors (Brierley/FNI, 2019). The total cost of a deep, large-diameter 10-mile tunnel could range from $1.0 to $1.5 billion.

The elevations at the mouth and end of the tunnel were also evaluated. The tunnel's invert would need to be a minimum of 30 to 35 feet below existing ground to connect the upstream and downstream elevations. Full development of this strategy will require considerable additional study, including hydraulic analysis to determine the required diameter, alternatives analysis, examination of the potential flood control benefits in addition to the benefits of transporting sediment around Lake Houston, and development of more detailed design and cost estimates. There are also multiple environmental permitting regulations that would have to be considered and resolved. Property acquisition may be required near the tunnel inlet and outlet location, and the tunnel will need to be constructed sufficiently deep to avoid disturbing existing structures.

Table 5-2: Range of Tunneling Costs for Sediment Bypass Tunnel for Alignment A

Study	Location	Diameter/ Height of Tunnel (ft)	Construction Cost per Foot (2011 US Dollars)	Total Construction Cost for 10-Mile Tunnel
Auel and Boes, 2011	Pfaffensprung	17.2	$10,809	$572,900,000
	Egschi	9.2	$4,089	$216,700,000
	Palagnedra	20.3	$7,861	$416,600,000
	Rempen	11.2	$5,230	$277,200,000
	Solis	12.5	$13,028	$690,500,000
	Asashi	17.2	$12,457	$660,200,000
Brierley/FNI, 2019	Harris County (Proposed)	25.0	$19,735*	$1,042,000,000*
		40.0	$28,977*	$1,530,000,000*

** 2019 US Dollars*

5.3 Strategies During and After Future Flooding Events

As discussed in **Section 4.2.3**, Lake Houston Dam influences the West Fork's ability to transport sediment through the area of concern. Lowering the water surface elevation upstream of the dam or improving the dam's hydraulic conveyance might move the location where sediments deposit further out into the lake. Any manipulation to the dam's conveyance with water needs to be coupled with an evaluation of how the manipulation impacts downstream flood water elevations. Staging equipment near sites that are prone to sediment deposition or woody debris accumulation will decrease response time in clearing river channels.

The following strategies are recommended immediately following flooding events:

1. Survey channel dimensions in regions where reported sedimentation occurs in areas that are at risk of flooding.
2. Compare these channel dimensions to the channel dimensions used in the preliminary hydraulic modeling. Run the hydraulic models again with new channel dimensions. Determine the impact to flood risk, if any.
3. Determine if the additional flood risk is unacceptable. Remove sediments from channel and place the sediments into beneficial use areas if the impact is unacceptable.
4. Survey stormwater outfalls that are prone to being obstructed by sediment deposits. If the degree of obstruction is unacceptable, remove sediment.

6.0 Conclusions and Recommendations

6.1 Conclusions

Sedimentation in Lake Houston began when Lake Houston Dam began impounding water and will continue in the future. Implementation of sediment management strategies can affect the rate and location of sedimentation. The total cost of returning Lake Houston to its pre-sedimentation storage capacity by dredging is expected to exceed $2.2 billion by the year 2035.

The analyses conducted for this study showed that a significant portion of the sediments depositing in Lake Houston originate from eroding streambanks and valley walls along the West Fork San Jacinto River and Spring Creek mainstems. Sediment also originates from soil erosion. Analysis with the RUSLE shows that land use changes over time have increased potential soil erosion in the watershed. Sediment size analysis of geotechnical cores obtained from Lake Houston found that the sediment ranged in size from fine gravel to clay with the dominant sediment size being a medium sand. This suggests that the load in the lake was transported mostly in suspension with some of the sediments transported as bedload. This is confirmed by the finding that stream gages measuring suspended sediment in the watershed are a good predictor of the sediments deposited in Lake Houston. Aggregate production operations may be a contributor to sediment loads to the lake, but this contribution is likely to occur only in large floods or when protective barriers around mining operations fail.

Twenty-one sediment management strategies were identified along the West Fork and twenty-eight along Spring Creek. These strategies were prioritized based on their potential to reduce sediment deposition in the problem area between the Spring Creek and West Fork confluence and Lake Houston. Potential sediment sources in the two mainstems were mapped. The largest predicted contributors are eroding valley walls.

Opportunities to trap sediments along the mainstems were also identified. These were organized by predicted reduction of sediments that would otherwise flow into the lake. Existing infrastructure near the West Fork and/or East Fork mainstems may create opportunities to remove suspended or bedload sediment from the river(s) via public-private partnerships providing for removal of captured material and/or use of existing pits.

Several other sediment management strategies were also explored. Manipulating Lake Houston's water management could create conditions conducive to moving sediment deposition further downstream, away from sediment problem area. A sediment tunnel is another alternative to route sediments around the dam. This strategy, although expensive, would provide a passive mechanism to reduce sediment deposition in the region of concern and the lake in general. Another sediment management strategy is a stream restoration project upstream of the FM 1960 bridge, which would use dredging spoils to reduce construction costs. This project would push sediments further out into Lake Houston, away from Kingwood.

A regional sediment management strategy was also introduced in this report. A regional sediment management strategy is a holistic plan for mitigating sediment problems since it analyzes the entire watershed for sediment sources and develops a sediment budget. This study focused on the West Fork San Jacinto River and Spring Creek subwatersheds. A comprehensive regional sediment management strategy might show other effective sediment strategies in other subwatersheds.

6.2 Recommendations

The following recommendations were developed from the updated analyses and findings of ways to reduce sedimentation in the region between the West Fork and Spring Creek confluence and the FM 1960 bridge in Lake Houston.

1. Complete a regional sediment management (RSM) plan and develop an annual sediment budget for the San Jacinto watershed, including individual subwatersheds and notable drainage areas within each subwatershed. The RSM will include a working group consisting of watershed managers and stakeholders who make sediment management decisions or are impacted by sediment related problems. The RSM must include sediment transport analysis and a volumetric analysis of sediment sources and sediment depositional areas using LiDAR comparisons. This approach will help guide recommendations for sediment management strategies by clarifying their efficacy in removing sediment loads and allowing for cost comparisons.
2. Divide the West Fork and Spring Creek subwatersheds into smaller regions and use existing stream gage data to develop a sediment budget for each of these smaller regions. Increase the number of sediment samples obtained at the West Fork gage at Interstate-69 in the sediment problem area. Obtain sediment samples at the four gages used in this study on Cypress Creek, Spring Creek and the West Fork during the same discharge event. Obtain sediment samples at higher discharge events and explore a relationship between turbidity and sediment concentration to develop a continuous sediment concentration measurement.).
3. It is recommended to locate a stream gage with sediment measurements at the State Highway bridge over Peach Creek and at the State Highway 99 bridge over Caney Creek. There are streamflow gages on Luce Bayou and the East Fork and its recommended sediment sampling begin at these gages. Identify a location downstream of the confluence of Caney Creek/Peach Creek and the East Fork to measure sediment concentration and discharge.
4. Obtain water quality sampling downstream of breaches at APOs and measure the particle size distribution if sediments are found in the water quality samples. Measure pre-flood topography and post-flood topography at APOs to estimate the amount of sediment that was entrained from staged sand piles.
5. Identify areas where new stream gages can be installed to measure suspended sediment in the Cypress Creek subwatershed and other subwatersheds to improve the understanding of where sediments in the subwatershed originate as noted for the West Fork and Spring Creek above.
6. Complete a GIS exercise similar to the one provided in **Appendix F.C** in order to quantify potential sediment sources from eroding streambanks and valley walls and determine the percentage of sediments originating from eroding banks versus landscape erosion or anthropogenic activities. Measure topography using LiDAR in a few years to map changes in the landscape and river corridors. The recent LiDAR used in the study was obtained post-Hurricane Harvey and topographic changes are not reflective of an average annual change.
7. Evaluate reasonable manipulations to Lake Houston Dam hydraulics to improve sediment transport in the region of concern and reduce sediment deposition in the water channel. Ensure these improvements do not increase flood risk downstream or affect the lake's water supply.

8. Identify regions where sediment deposition occurs and the resulting obstruction is suspected to result in flooding. Measure the extent of sediment deposition and complete a hydraulic modeling exercise to calculate water surface elevations with and without the sediment obstruction in place. If water surface elevations with sediment in place are unacceptable, complete an annual sediment transport calculation and stable sediment size calculations to understand channel dimension manipulation options to reduce sediment deposition.
9. Complete a feasibility study to implement pilot projects such as:
    a. Sediment trapping to remove sediment from Lake Houston's tributaries
    b. Channel manipulation to improve sediment transport competency in regions sensitive to channel infilling
    c. Sediment source protection in sections of Lake Houston tributaries where large potential sediment sources have been measured. Sediment source protection includes activities such as natural channel design and stream bank stabilization.
10. Identify stormwater outfalls that are prone to being blocked by sediment deposition and are suspected to contribute to localized flooding due to the system not being able to convey stormwater. Survey these locations to measure the degree the outfall has been blocked and develop recommendations when the outfall should be cleared.
11. Conduct additional analysis of a sediment tunnel connecting the West Fork San Jacinto River to downstream of Lake Houston Dam. This could allow sediment to bypass the lake by gravity by potentially intercepting and directing the sediments around the area of concern.
12. Conduct reach level assessments of calibration reaches to evaluate in-channel sediments loading rates. In this phase, the streambanks that are contributing the greatest sediment load can be prioritized for any stabilization efforts that become a part of the RSM.

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END OF REPORT

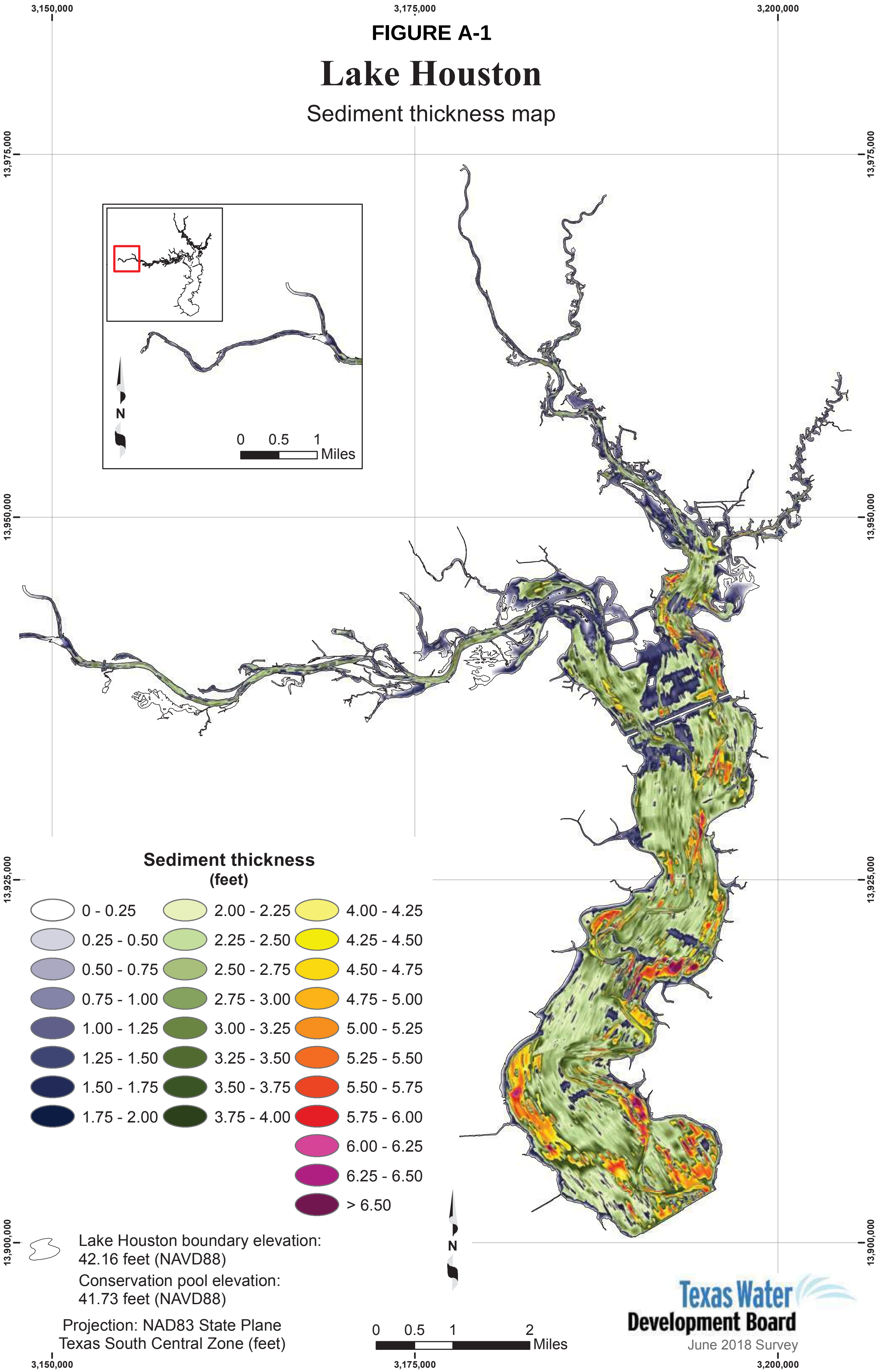
APPENDIX F.A

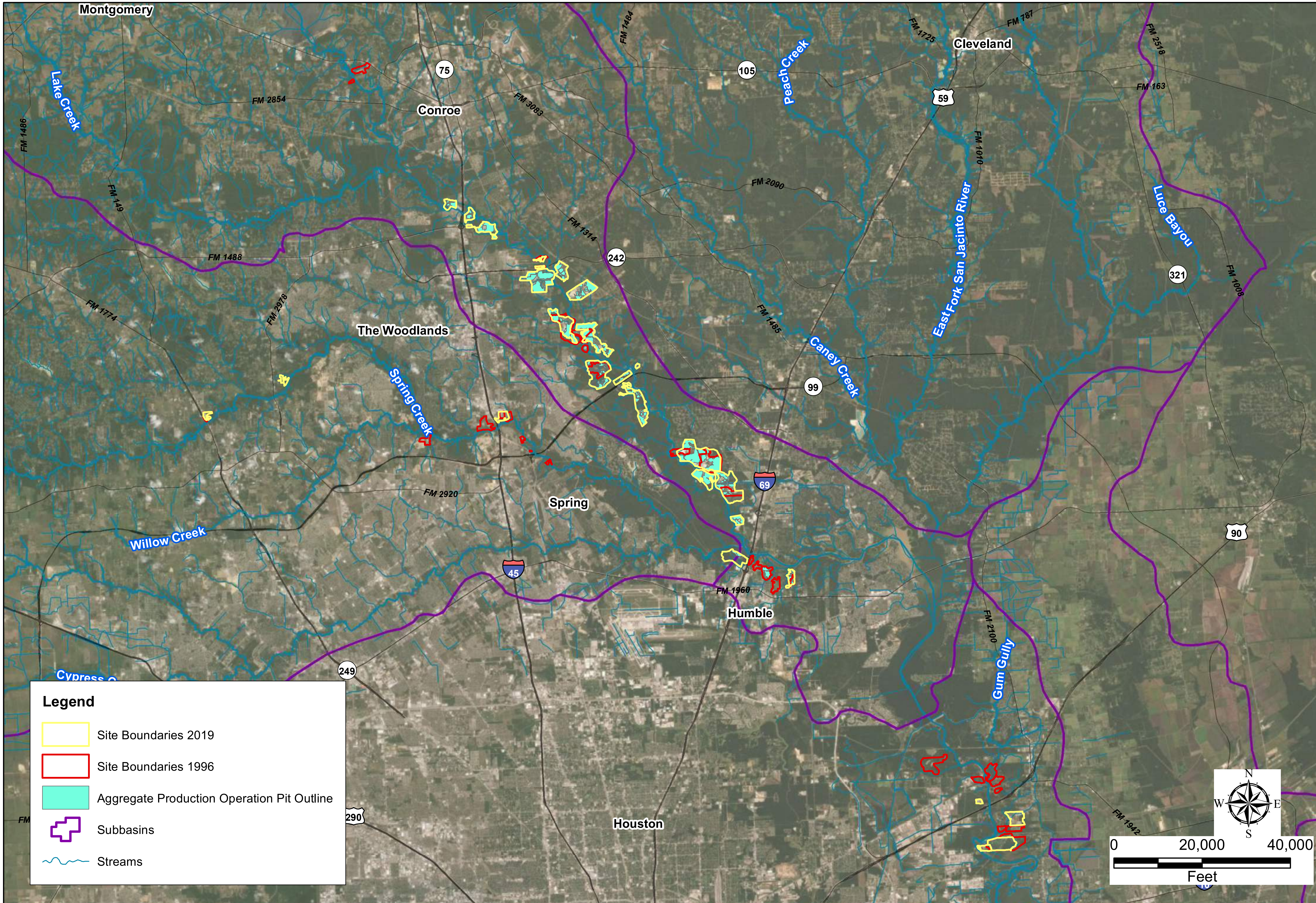
FIGURES

FIGURE A-1

Lake Houston

Sediment thickness map





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DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central

FILE NAME Figure_A2_APO Sites-Westward Env

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San Jacinto Regional Watershed Master Drainage Plan

Sand and Gravel Mine Location Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-2

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FIGURE A-3

Water Surface Elevation in Lake Houston and Sediment Problem Area During a 50% ACE Flood

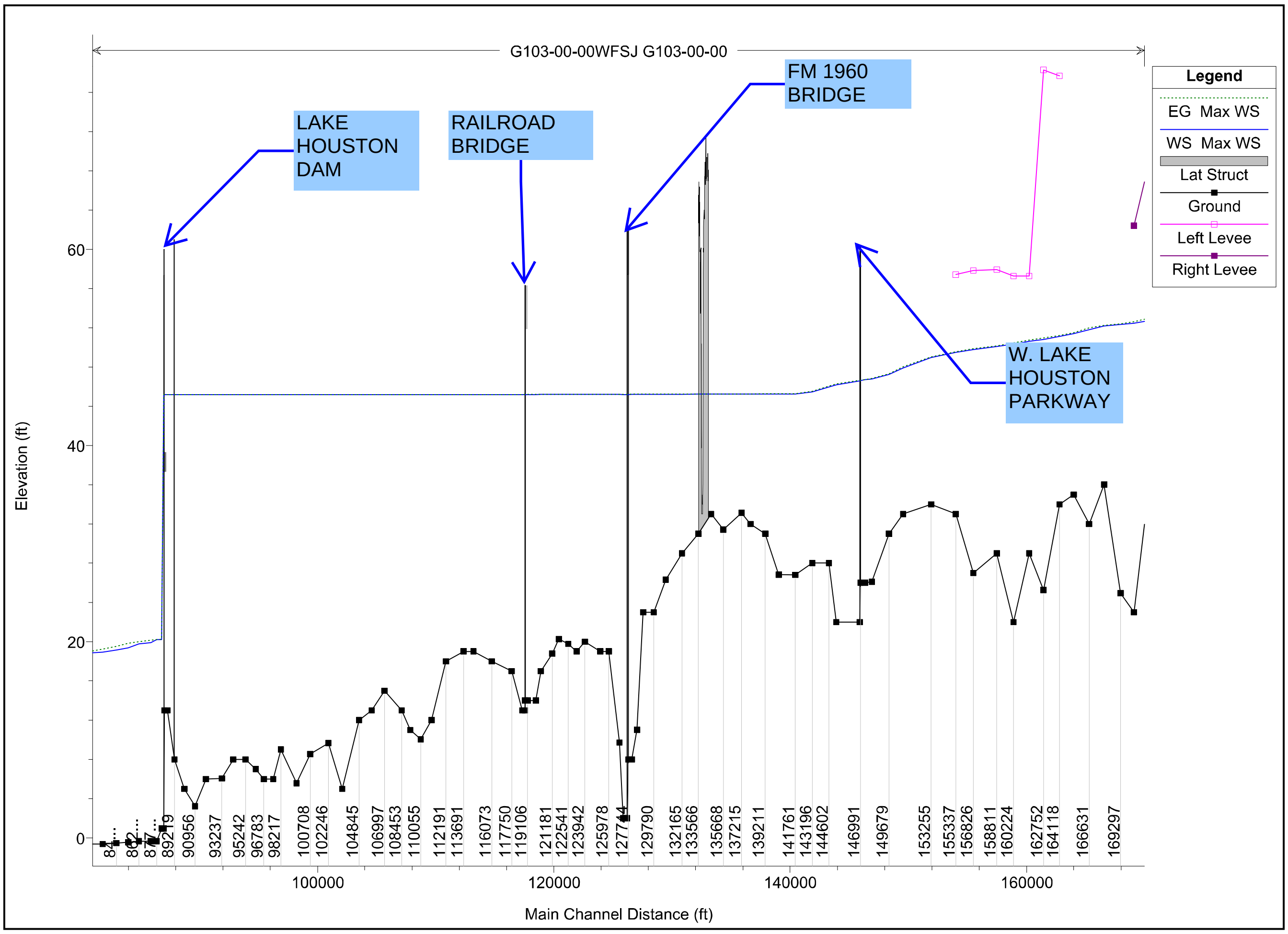
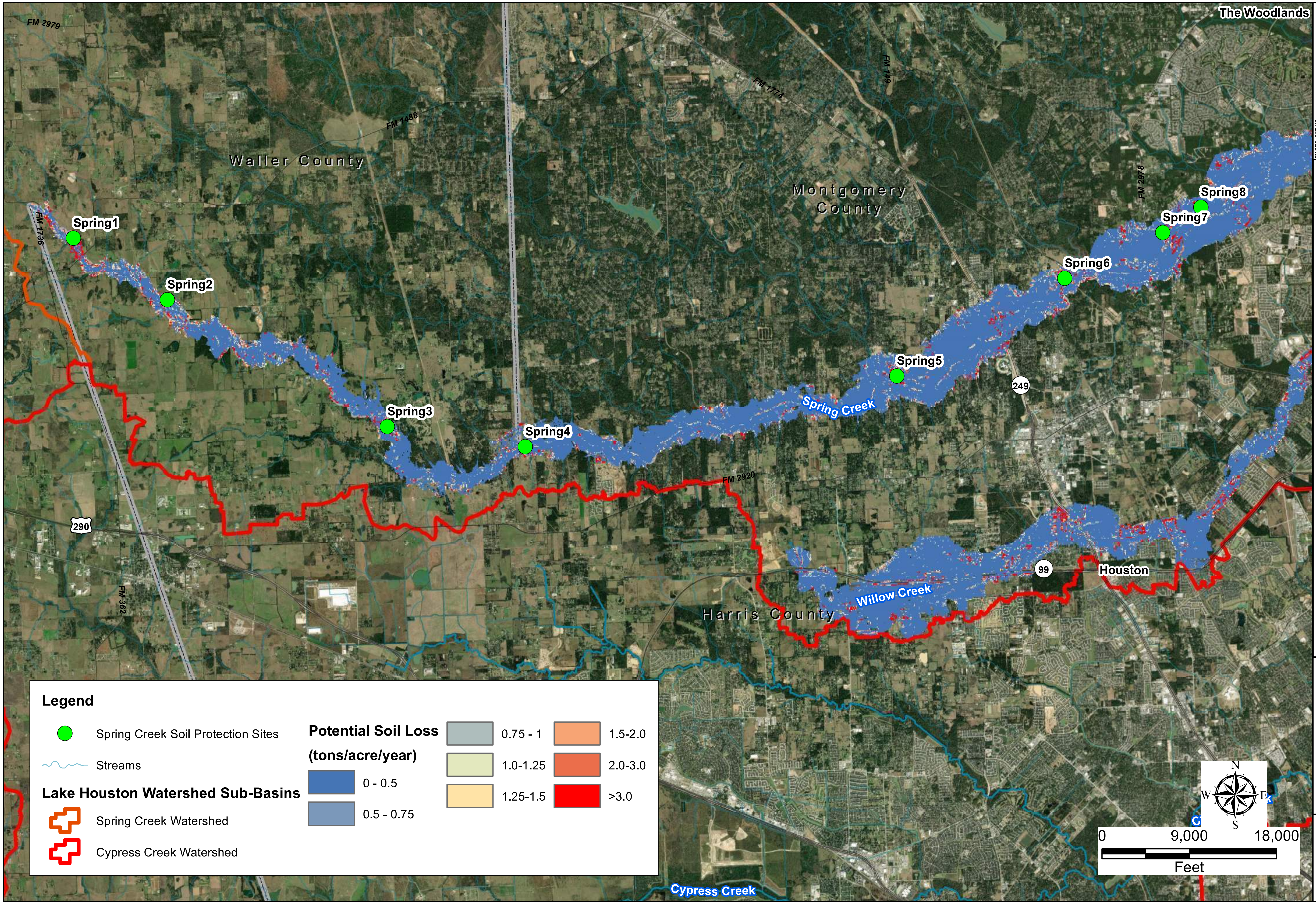


FIGURE A-4

Detailed HEC-RAS Output in Lake Houston and Sediment Problem Area During a 50% ACE Flood

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Ch	Shear Chan	Power Chan
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(lb/sq ft)	(lb/ft s)
G103-00-00	170418	Max WS	38976.4	23	52.449		52.61	0.000203	3.64	24853.51	4300.61	0.15	0.23	0.83
G103-00-00	169297	Max WS	38959.58	24.95	52.332		52.39	0.0001	2.67	42939.48	6038.58	0.11	0.12	0.32
G103-00-00	167895	Max WS	38940.9	36	52.192		52.23	0.00012	2.33	52755.54	7068.56	0.11	0.1	0.24
G103-00-00	166631	Max WS	38899.18	32	51.813		51.99	0.000403	4.18	28271.06	5950.33	0.2	0.33	1.4
G103-00-00	165332	Max WS	38855.57	35	51.413		51.5	0.000228	3.16	36028.95	5670.41	0.15	0.19	0.6
G103-00-00	164118	Max WS	38826.26	34	51.124		51.22	0.000257	3.34	31958.03	6314.07	0.16	0.21	0.71
G103-00-00	162752	Max WS	38792.28	25.25	50.797		50.96	0.000196	3.59	25062.35	4609.63	0.15	0.22	0.79
G103-00-00	161544	Max WS	38776.51	29.01	50.618		50.73	0.000155	3.02	29735.98	5740.15	0.13	0.16	0.49
G103-00-00	160224	Max WS	38754.8	22	50.333		50.46	0.000229	3.37	31767.09	6260	0.15	0.21	0.71
G103-00-00	158811	Max WS	38732.94	29	50.083		50.16	0.000139	2.6	37725.59	6976.39	0.12	0.13	0.33
G103-00-00	156826	Max WS	38710.92	27	49.756		49.87	0.000175	3.16	27485.31	4514.02	0.14	0.18	0.56
G103-00-00	155337	Max WS	38696.47	33	49.484		49.55	0.000225	2.84	41387.9	7435.82	0.15	0.16	0.46
G103-00-00	153255	Max WS	38670.75	34	48.969		49.02	0.000281	2.33	33739.41	6753.55	0.15	0.13	0.29
G103-00-00	150888	Max WS	38589.66	33	47.887		48.04	0.000747	4.38	20054.9	3798.61	0.26	0.42	1.83
G103-00-00	149679	Max WS	38503.2	31	47.23		47.31	0.000339	2.4	24497.84	6419.98	0.16	0.14	0.33
G103-00-00	148240	Max WS	38416.84	26.11	46.782		46.83	0.000218	1.81	21951.12	3800.69	0.13	0.08	0.15
G103-00-00	147664	Max WS	38397.06	26	46.703	33.19	46.74	0.000117	1.45	26535.32	4228.59	0.1	0.05	0.07
G103-00-00	146991		Bridge	**West Lake Houston Parkway Bridge**										
G103-00-00	***145228***	***Max WS***	***38169.23***	***22***	***46.191***		***46.25***	***0.000179***	***2.02***	***18901.91***	***3106.03***	***0.12***	***0.09***	***0.18***
G103-00-00	***144602***	***Max WS***	***37919.26***	***28***	***45.981***		***46.06***	***0.000455***	***2.3***	***17862.12***	***3653.2***	***0.18***	***0.14***	***0.32***
G103-00-00	***143196***	***Max WS***	***35730.87***	***28***	***45.469***		***45.53***	***0.000322***	***1.95***	***20705.42***	***5146.85***	***0.15***	***0.1***	***0.2***
G103-00-00	***141761***	***Max WS***	***35592.19***	***26.8***	***45.252***		***45.29***	***0.000013***	***1.49***	***25969.51***	***5762.35***	***0.12***	***0***	***0.01***
G103-00-00	***140359***	***Max WS***	***35647.36***	***26.84***	***45.254***		***45.27***	***0.000004***	***1.08***	***33094.97***	***5207.14***	***0.08***	***0***	***0***
G103-00-00	***139211***	***Max WS***	***35644.19***	***31.01***	***45.235***		***45.27***	***0.000006***	***1.44***	***25720.05***	***3464.72***	***0.09***	***0***	***0***
G103-00-00	***137964***	***Max WS***	***35641.44***	***32***	***45.23***		***45.26***	***0.000008***	***1.37***	***32692.68***	***5611.85***	***0.1***	***0***	***0***
G103-00-00	137215	Max WS	35645.85	33.14	45.245		45.25	0.000001	0.64	56276.52	6970.52	0.04	0	0
G103-00-00	135668	Max WS	35648.61	31.42	45.241		45.25	0.000002	0.7	51481.09	7075.13	0.05	0	0
G103-00-00	134631	Max WS	35649.86	33	45.243		45.25	0.000001	0.56	63402.36	7590.92	0.03	0	0
G103-00-00	134630		Lat Struct											
G103-00-00	133566	Max WS	65509.59	31	45.22		45.23	0.000003	0.99	66680.83	8207.04	0.06	0	0
G103-00-00	132165	Max WS	65497.8	29	45.204		45.23	0.000006	1.27	51536.86	8224.48	0.09	0	0
G103-00-00	130798	Max WS	65496.39	26.33	45.2		45.22	0.000004	1.19	55177.17	7226.35	0.08	0	0
G103-00-00	129790	Max WS	65500.08	23	45.21		45.22	0.000001	0.7	93424.27	8796.89	0.04	0	0
G103-00-00	128881	Max WS	65506.57	23	45.21		45.22	0.000001	0.67	98351.3	8412.65	0.03	0	0
G103-00-00	128370	Max WS	65505.09	11.02	45.212		45.22	0	0.56	116120.2	8084.65	0.03	0	0
G103-00-00	127923	Max WS	65498.98	8	45.199	22.57	45.22	0.000001	1.11	59117.89	7843.94	0.05	0	0
G103-00-00	127744		Bridge	**Farm to Market 1960 Bridge**										
G103-00-00	127207	Max WS	65497.94	2	45.186		45.2	0.000001	1.07	61471.77	7903.1	0.04	0	0
G103-00-00	126888	Max WS	65878.72	9.71	45.197		45.2	0	0.54	120947.4	7898.37	0.02	0	0
G103-00-00	125978	Max WS	66765.32	19	45.196		45.2	0	0.55	121347.4	8362.08	0.03	0	0
G103-00-00	125254	Max WS	67596.63	19	45.196		45.2	0	0.57	120081.1	8272.09	0.03	0	0
G103-00-00	123942	Max WS	68655.03	20	45.196		45.2	0	0.52	132617	8491.85	0.02	0	0
G103-00-00	123244	Max WS	69371.53	19	45.196		45.2	0	0.5	137592.6	8201.44	0.02	0	0
G103-00-00	122541	Max WS	69911.45	19.79	45.195		45.2	0	0.55	126152.1	8580.98	0.03	0	0
G103-00-00	121737	Max WS	70807.96	20.26	45.194		45.2	0	0.6	119046.9	8836.35	0.03	0	0
G103-00-00	121181	Max WS	71225.48	18.79	45.194		45.2	0	0.54	131094.6	8984.74	0.03	0	0
G103-00-00	120226	Max WS	71546.04	17	45.193		45.2	0	0.57	126328.1	8915.94	0.03	0	0
G103-00-00	119798	Max WS	72919.31	14	45.191		45.2	0.000001	0.65	111756.3	8354.45	0.03	0	0
G103-00-00	119106	Max WS	73702.62	14	45.182	25.84	45.2	0.000001	1	73344.57	4120.56	0.04	0	0
G103-00-00	118974		Bridge	**Railroad Bridge**										
G103-00-00	118665	Max WS	73702.3	13	45.175		45.19	0.000001	1	73924.52	4128.31	0.04	0	0
G103-00-00	117750	Max WS	73698.3	17	45.176		45.19	0.000001	0.94	78783.68	5420.35	0.04	0	0
G103-00-00	116073	Max WS	73701.05	18	45.178		45.19	0.000001	0.78	96755.09	7113.66	0.04	0	0
G103-00-00	114534	Max WS	73699.16	19	45.181		45.19	0	0.62	118567.1	6828.97	0.03	0	0
G103-00-00	113691	Max WS	73703.8	19	45.181		45.19	0	0.59	125264.4	8053.52	0.03	0	0
G103-00-00	112191	Max WS	73702.43	18	45.182		45.19	0	0.5	147661.9	9474.3	0.02	0	0
G103-00-00	110987	Max WS	73702.71	12	45.183		45.19	0	0.42	173609.1	9563.31	0.02	0	0
G103-00-00	110055	Max WS	73702.68	10.04	45.182		45.19	0	0.5	146920.9	8460.03	0.02	0	0
G103-00-00	109165	Max WS	73704.1	11	45.183		45.19	0	0.44	167349.5	8196.14	0.02	0	0
G103-00-00	108453	Max WS	73702.53	13	45.18		45.19	0	0.58	128225.9	7338.9	0.02	0	0
G103-00-00	106997	Max WS	73701.54	15	45.178		45.18	0	0.68	108970.9	5515.69	0.03	0	0
G103-00-00	105896	Max WS	73700.8	13	45.18		45.18	0	0.57	130216.2	6941.12	0.02	0	0
G103-00-00	104845	Max WS	73700.94	12	45.179		45.18	0	0.57	128687.8	7610.17	0.02	0	0
G103-00-00	103420	Max WS	73701.3	5	45.179		45.18	0	0.55	134529.7	8619.73	0.02	0	0
G103-00-00	102246	Max WS	73699.38	9.66	45.18		45.18	0	0.48	152180.1	7327.71	0.02	0	0
G103-00-00	100708	Max WS	73701.94	8.54	45.179		45.18	0	0.5	147636.5	7482.16	0.02	0	0
G103-00-00	99544	Max WS	73702.16	5.58	45.18		45.18	0	0.45	164422.5	8040.66	0.02	0	0
G103-00-00	98217	Max WS	73700.93	9	45.181		45.18	0	0.37	196993.7	9359.42	0.01	0	0
G103-00-00	97578	Max WS	73700.4	6	45.181		45.18	0	0.37	201379	9756.94	0.01	0	0
G103-00-00	96783	Max WS	73701.27	6	45.18		45.18	0	0.38	195041.6	8787	0.01	0	0
G103-00-00	96091	Max WS	73700.66	7	45.18		45.18	0	0.38	195013.7	8558.16	0.01	0	0
G103-00-00	95242	Max WS	73700.01	8	45.18		45.18	0	0.4	182058.7	8307.15	0.02	0	0
G103-00-00	94198	Max WS	73700.7	8	45.179		45.18	0	0.44	167628.8	7730.78	0.02	0	0
G103-00-00	93237	Max WS	73700.38	6.07	45.179		45.18	0	0.42	177314.1	8036.03	0.02	0	0
G103-00-00	91893	Max WS	73699.98	6	45.179		45.18	0	0.41	181315.3	9388.24	0.02	0	0
G103-00-00	90956	Max WS	73699.66	3.25	45.18		45.18	0	0.37	198499.4	9701.44	0.01	0	0
G103-00-00	90058	Max WS	73699.78	5	45.18		45.18	0	0.33	220798	9990.9	0.01	0	0
G103-00-00	89219	Max WS	73699.69	8	45.179		45.18	0	0.44	169109.3	7947.21	0.02	0	0
G103-00-00	89000		Lat Struct	**Lake Houston Dam**										
G103-00-00	88621	Max WS	14339.46	13	45.185	20.31	45.18	0	0.1	144028.2	7001.73	0	0	0
G103-00-00	88492		Inl Struct											
G103-00-00	88129	Max WS	14336.19	0.95	20.206		20.23	0.000022	1.55	18888.01	3612.47	0.06	0.02	0.04
G103-00-00	87711	Max WS	14337.52	0	20.209		20.22	0.000011	0.99	26824.62	3275.02	0.05	0.01	0.01
G103-00-00	87211	Max WS	73599.28	0	19.909		20.14	0.000229	4.89	35257.61	3497.83	0.21	0.24	1.17
G103-00-00	86213	Max WS	73591.56	0	19.771		19.99	0.000205	4.83	32874.43	4839.78	0.2	0.23	1.1
G103-00-00	85301	Max WS	73562.54	0	19.377		19.83	0.000322	5.68	22146.8	2634.16	0.25	0.32	1.84
G103-00-00	84303	Max WS	73544.4	0	19.159		19.53	0.000238	5.13	22700.24	2105.3	0.22	0.26	1.33
G103-00-00	83144	Max WS	73527.19	0	18.94		19.26	0.000229	4.79	26376.15	3660.33	0.21	0.23	1.11
G103-00-00	82085	Max WS	73524.59	0	18.839		19.01	0.000116	3.64	38983.6	5856.47	0.15	0.13	0.47
G103-00-00	80830	Max WS	73511.77	0	18.636		18.83	0.000193	4.28	45358.46	8643.22	0.19	0.19	0.8



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PREPARED BY	DML

San Jacinto Regional Watershed Master Drainage Plan

Spring Creek Locations To Prioritize Upland Soil Protection

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-5a

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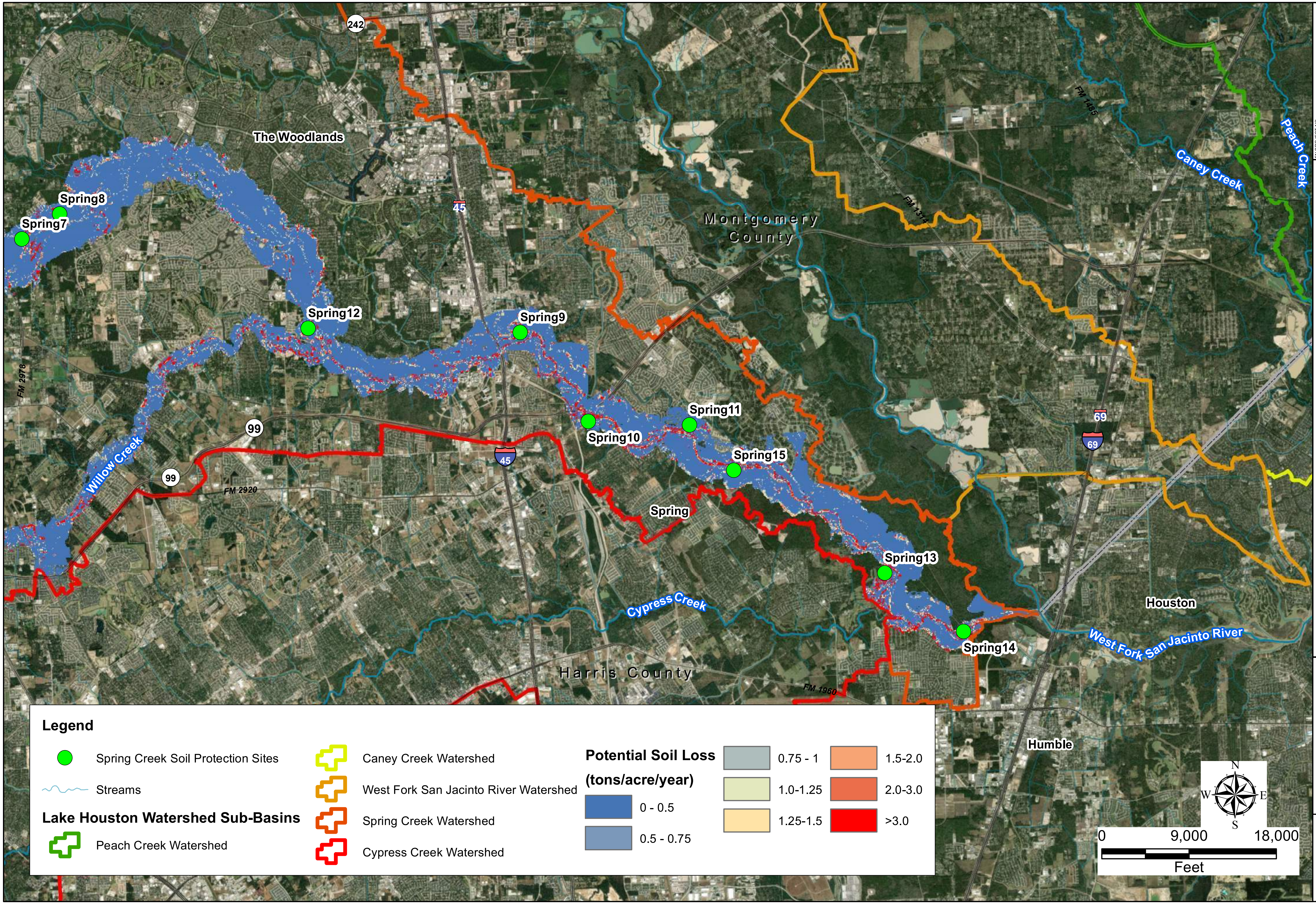

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DATE CREATED 6/26/2020
DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central
FILE NAME Figure_A5b_SC_UplandSoilProtection
PREPARED BY DML

San Jacinto Regional Watershed Master Drainage Plan

Spring Creek Locations To Prioritize Upland Soil Protection

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE A-5b

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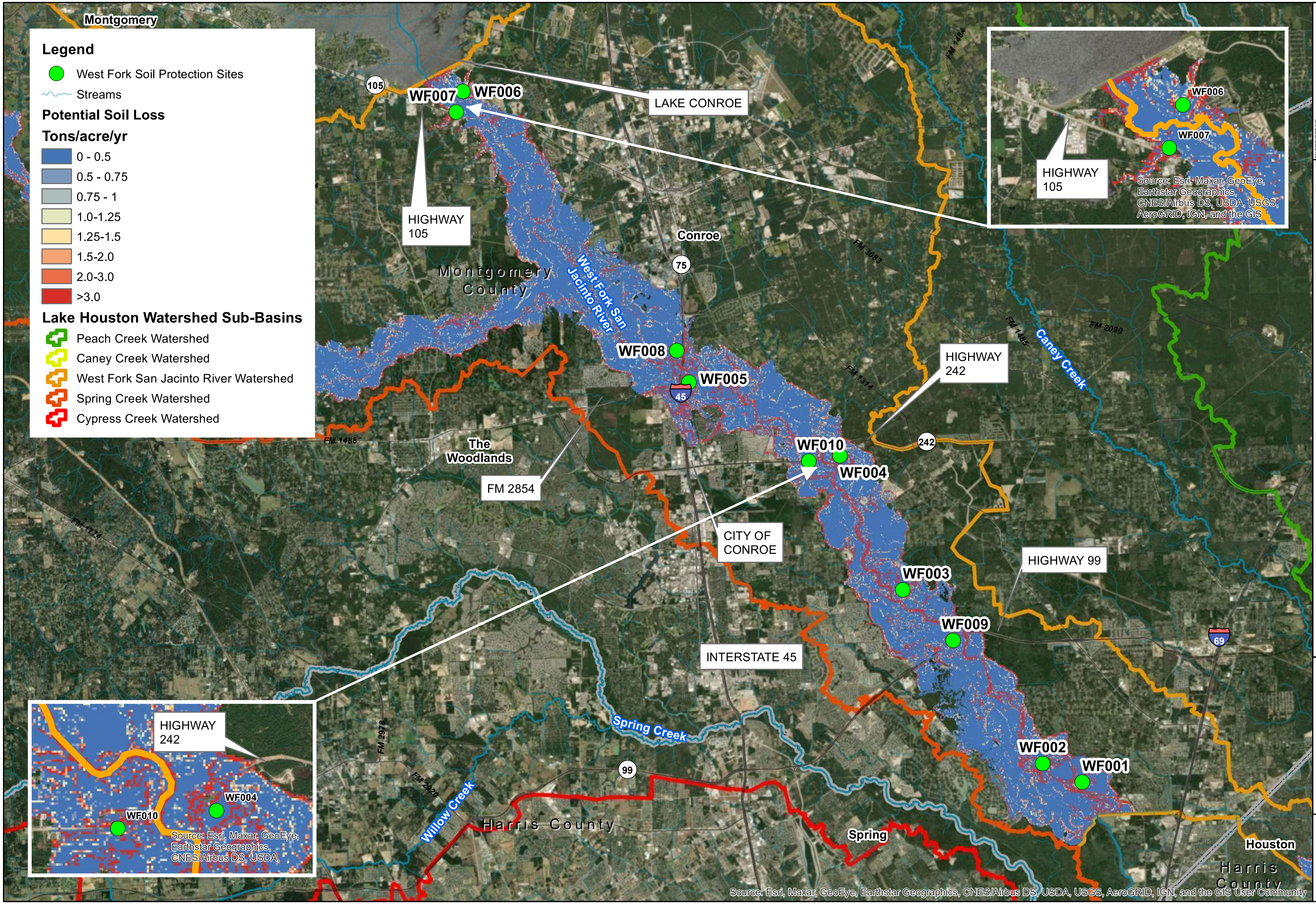

San Jacinto Regional Watershed Master Drainage Plan

West Fork Locations To Prioritize Upland Soil Protection

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-6

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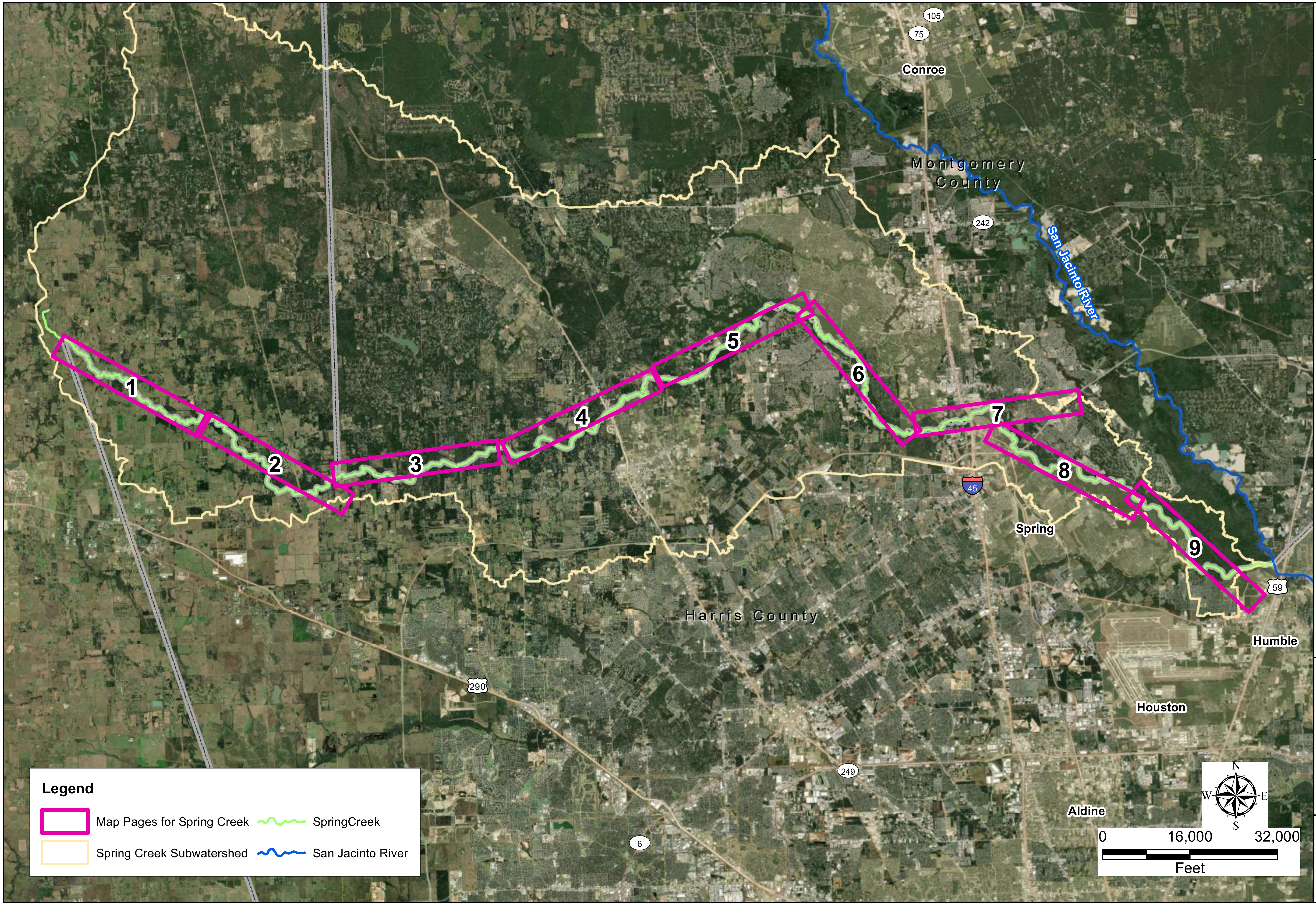

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FILE NAME	Figure_A7_SC_SedimentationStrategy_Index
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San Jacinto Regional Watershed Master Drainage Plan

Spring Creek Sedimentation Strategy: Index Sheet

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-7

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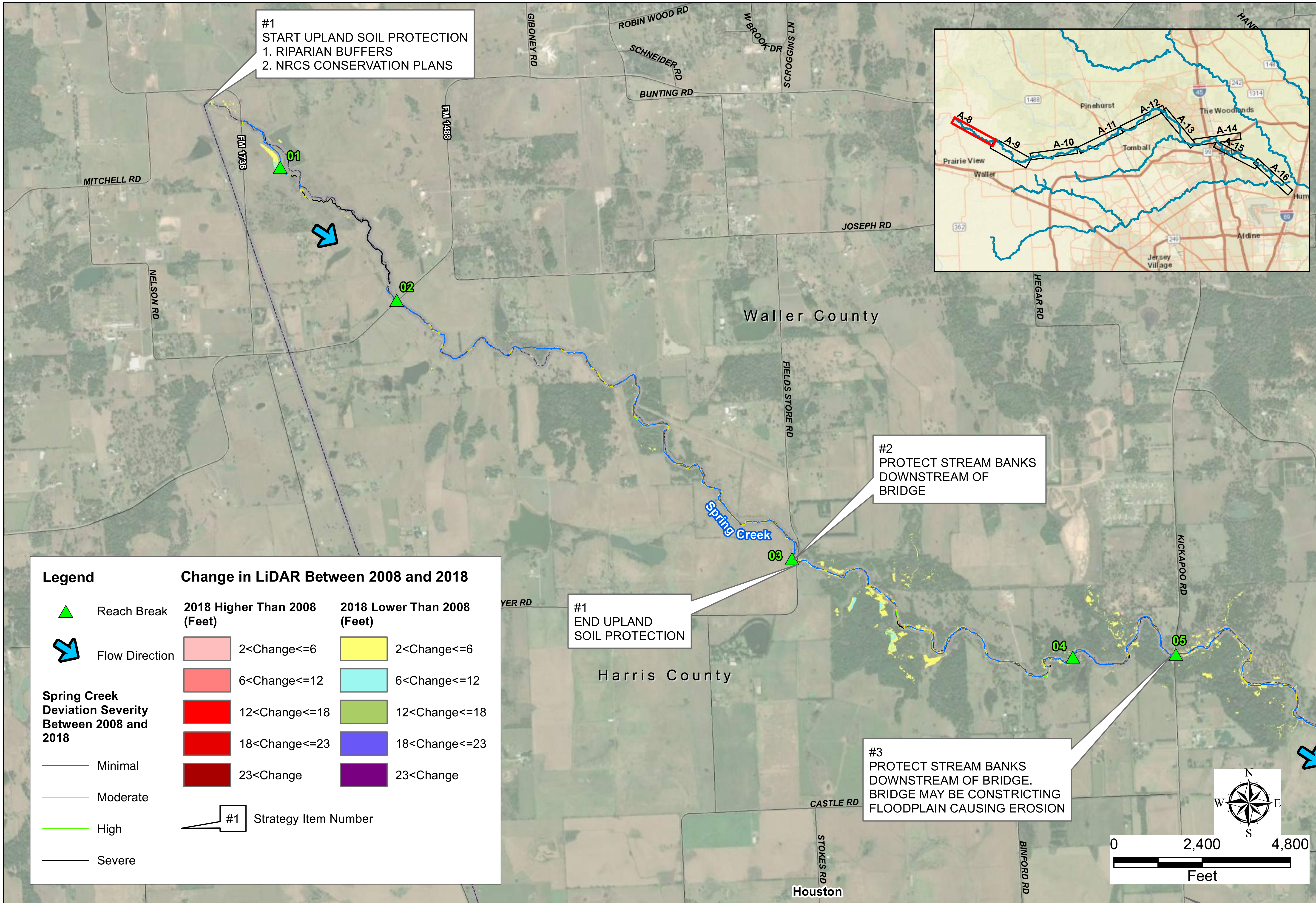


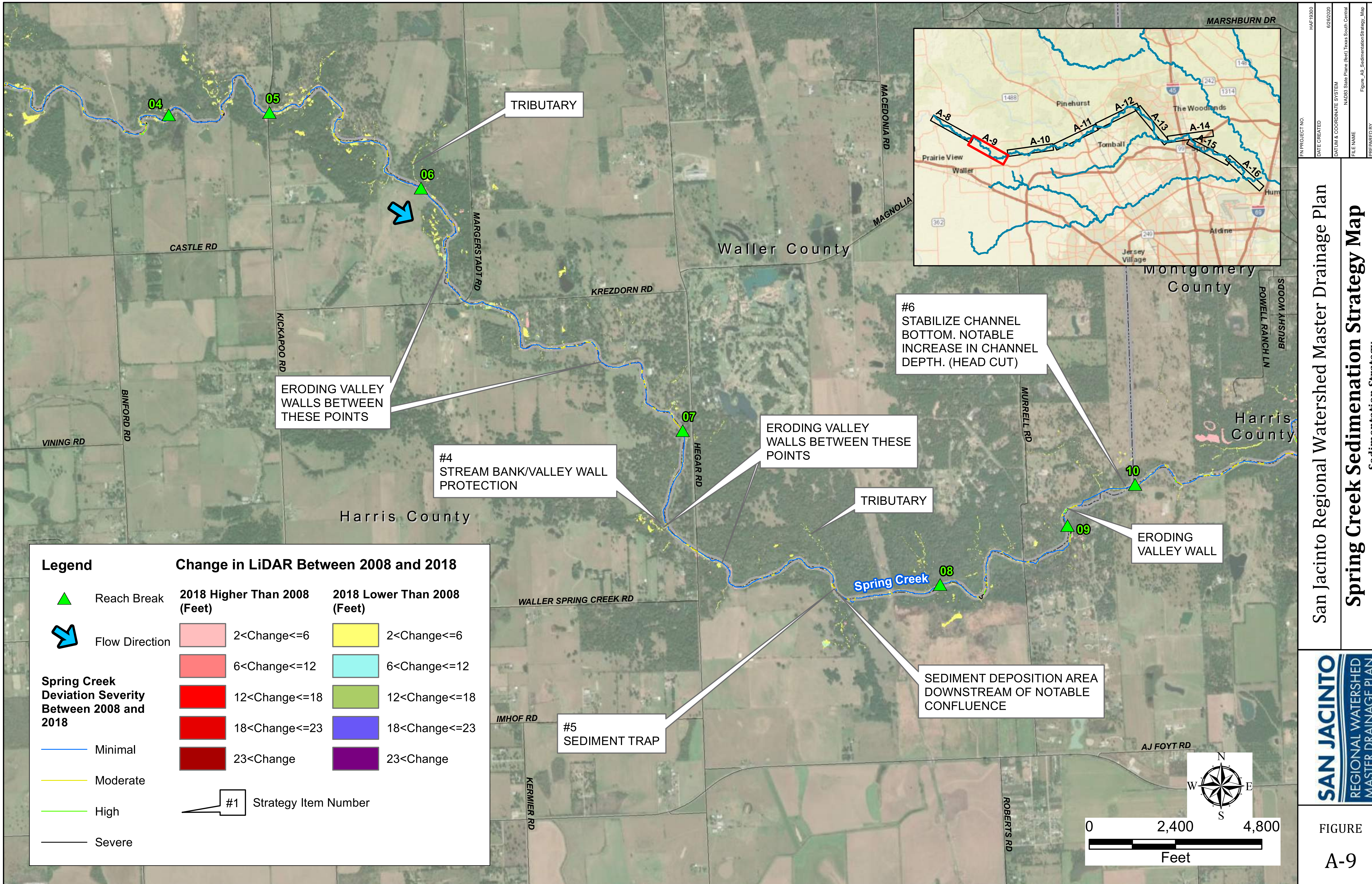
San Jacinto Regional Watershed Master Drainage Plan

Spring Creek Sedimentation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE A-8



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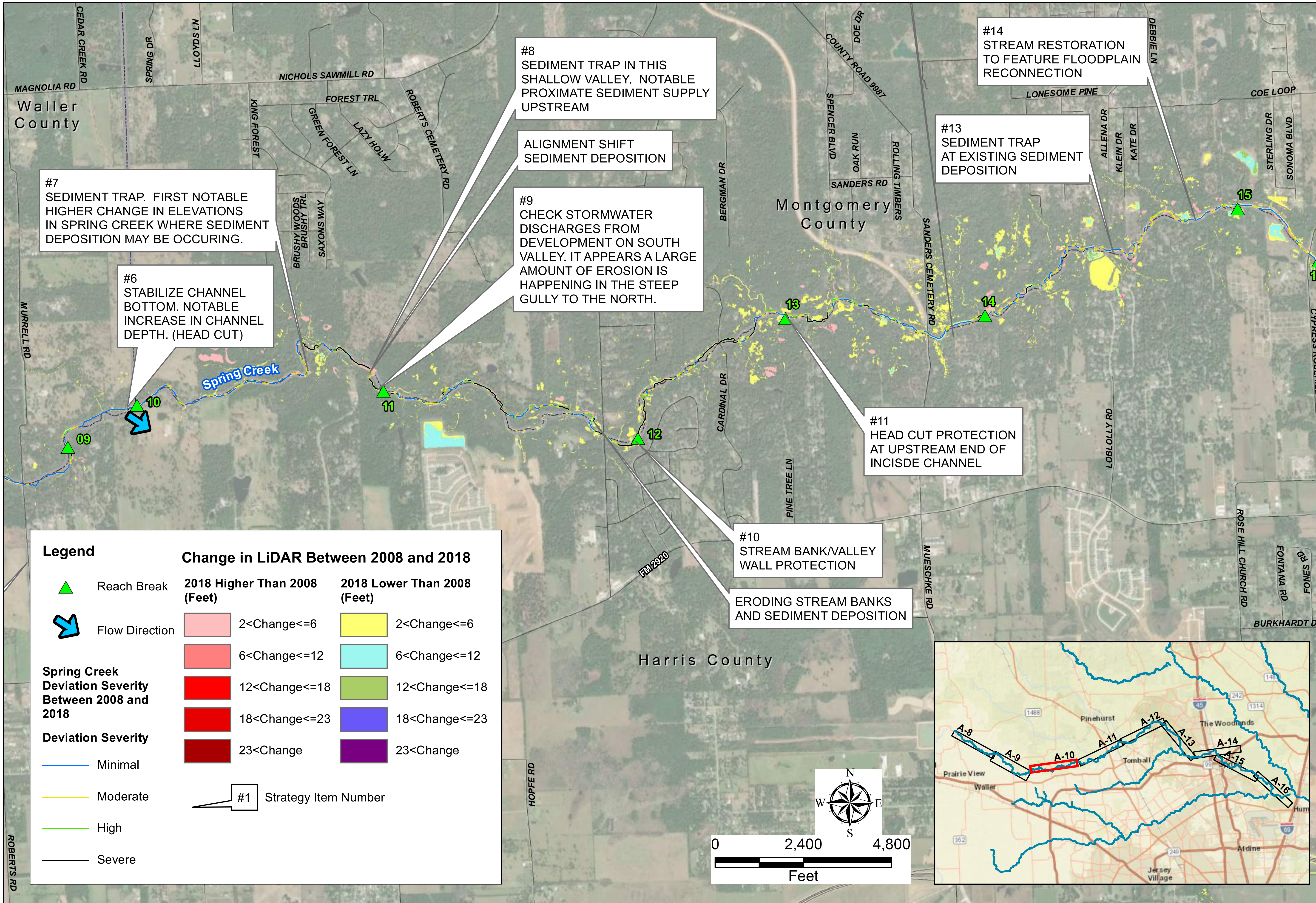


San Jacinto Regional Watershed Master Drainage Plan

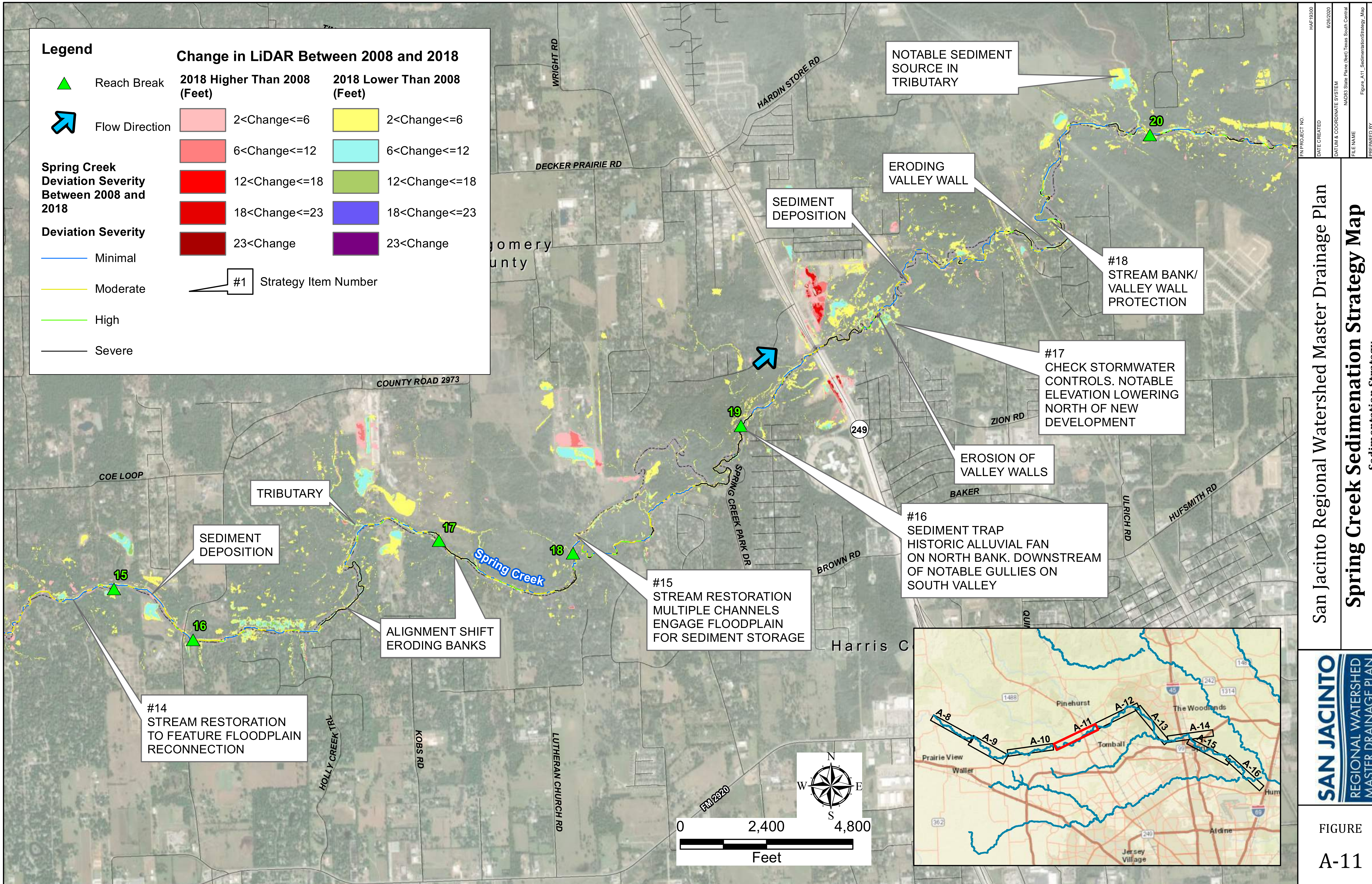
Spring Creek Sedimentation Strategy Map

Sedimentation Strategy

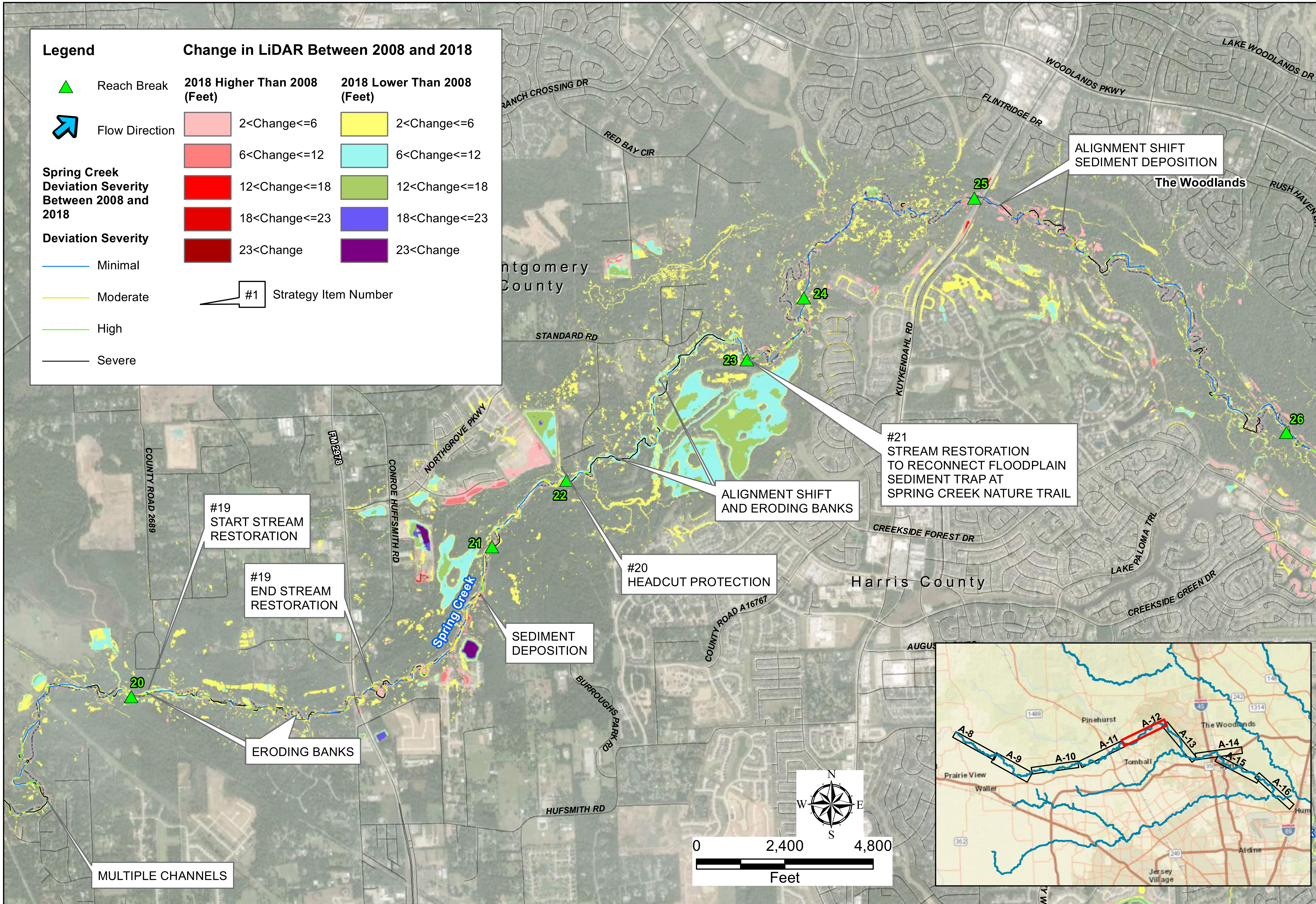
SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-10



Legend
Reach Break
Flow Direction
Spring Creek Deviation Severity Between 2008 and 2018
Deviation Severity
Minimal
Moderate
High
Severe
Change in LiDAR Between 2008 and 2018
2018 Higher Than 2008 (Feet)
2<Change<=6
6<Change<=12
12<Change<=18
18<Change<=23
23<Change
2018 Lower Than 2008 (Feet)
2<Change<=6
6<Change<=12
12<Change<=18
18<Change<=23
23<Change
#1 Strategy Item Number
NOTABLE SEDIMENT SOURCE IN TRIBUTARY
ERODING VALLEY WALL
SEDIMENT DEPOSITION
#18 STREAM BANK/ VALLEY WALL PROTECTION
#17 CHECK STORMWATER CONTROLS. NOTABLE ELEVATION LOWERING NORTH OF NEW DEVELOPMENT
EROSION OF VALLEY WALLS
#16 SEDIMENT TRAP HISTORIC ALLUVIAL FAN ON NORTH BANK. DOWNSTREAM OF NOTABLE GULLIES ON SOUTH VALLEY
#15 STREAM RESTORATION MULTIPLE CHANNELS ENGAGE FLOODPLAIN FOR SEDIMENT STORAGE
TRIBUTARY
SEDIMENT DEPOSITION
ALIGNMENT SHIFT ERODING BANKS
#14 STREAM RESTORATION TO FEATURE FLOODPLAIN RECONNECTION
Spring Creek
15
16
17
18
19
20
WRIGHT RD
HARDIN STORE RD
DECKER PRAIRIE RD
COUNTY ROAD 2973
COE LOOP
ZION RD
BAKER
HUFSMITH RD
ULRICH RD
BROWN RD
SPRING CREEK PARK DR
HOLLY CREEK TRL
KOBS RD
LUTHERAN CHURCH RD
FM 2920
249
Harris C
N
S
E
W
0
2,400
4,800
Feet
A-8
A-9
A-10
A-11
A-12
A-13
A-14
A-15
A-16
Pinehurst
Tomball
Prairie View
Waller
The Woodlands
Aldine
Jersey Village
San Jacinto Regional Watershed Master Drainage Plan
Spring Creek Sedimenation Strategy Map
Sedimentation Strategy
SAN JACINTO
REGIONAL WATERSHED MASTER DRAINAGE PLAN
FIGURE
A-11



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FILE NAME Figure_A12_SedimentationStrategy_Map
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San Jacinto Regional Watershed Master Drainage Plan

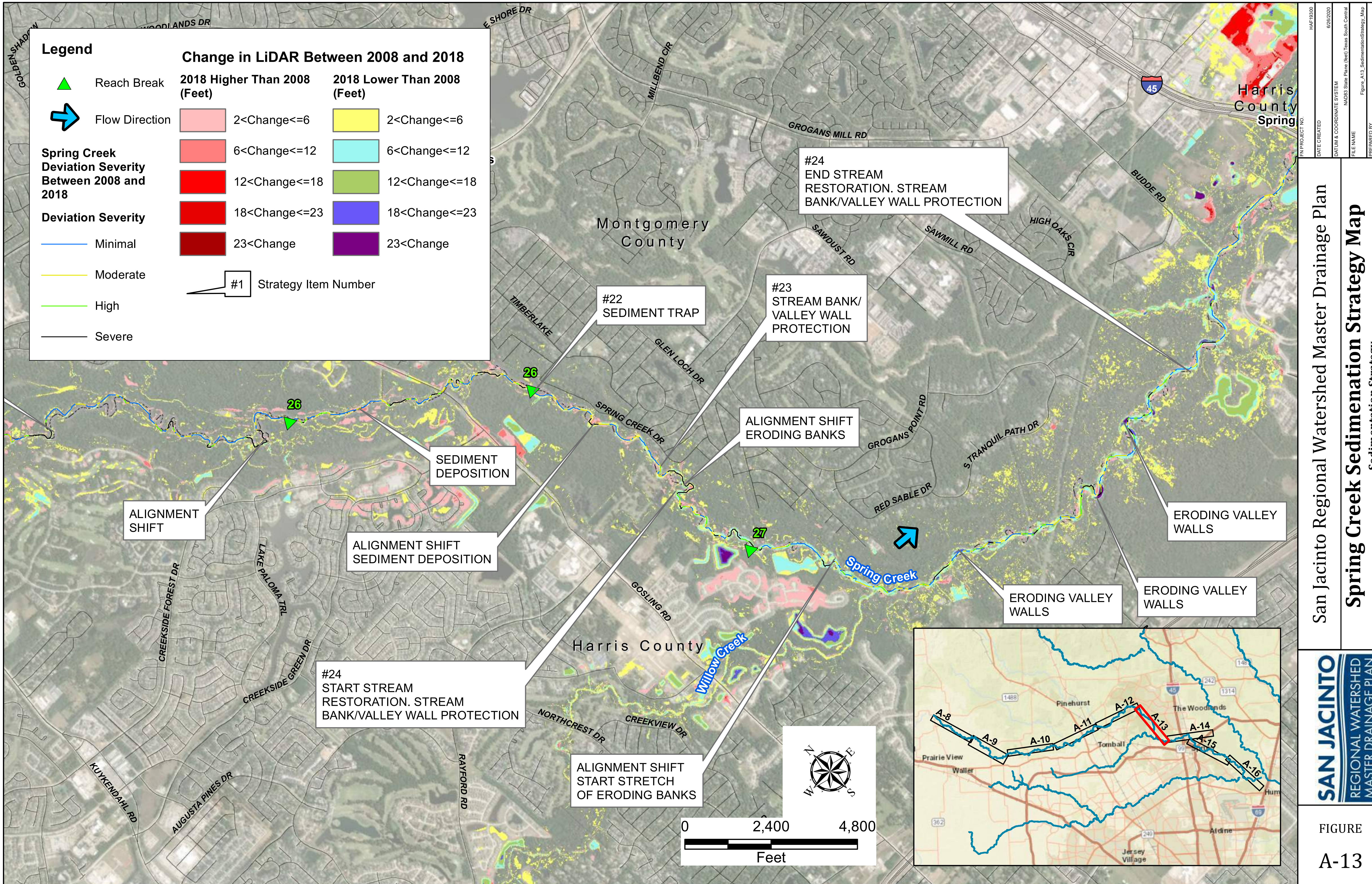
Spring Creek Sedimenation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-12



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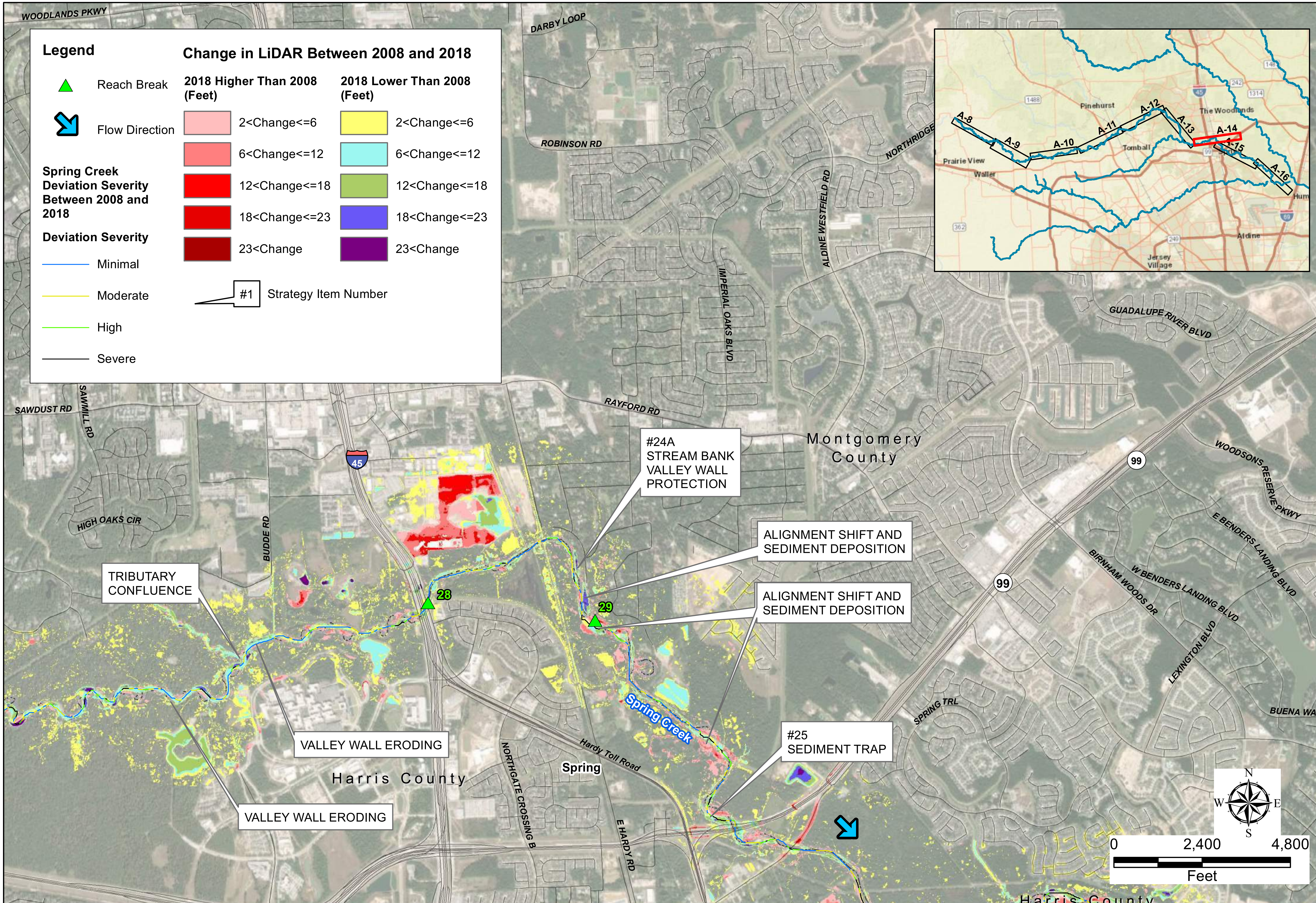


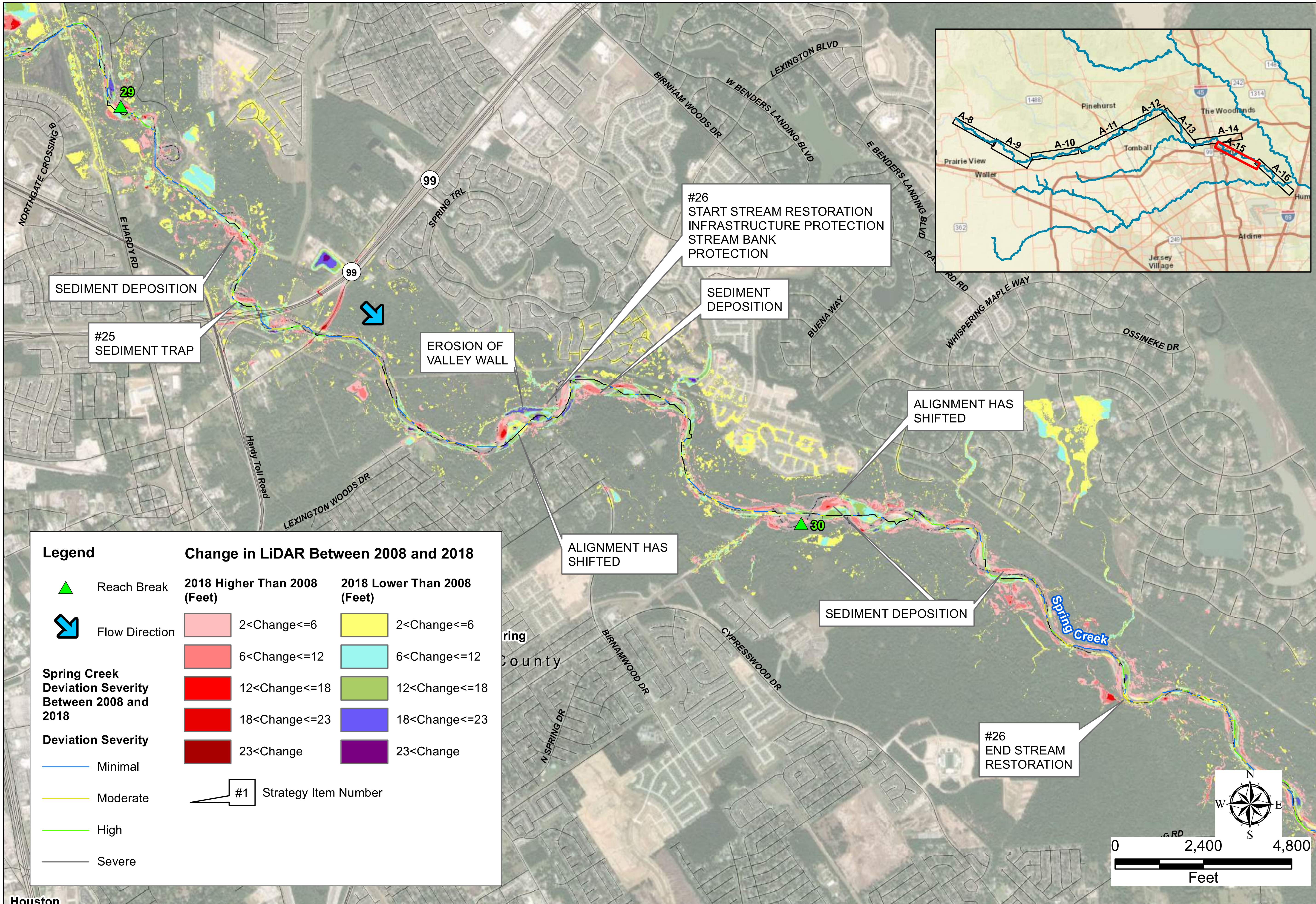
San Jacinto Regional Watershed Master Drainage Plan

Spring Creek Sedimenation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE A-14



San Jacinto Regional Watershed Master Drainage Plan

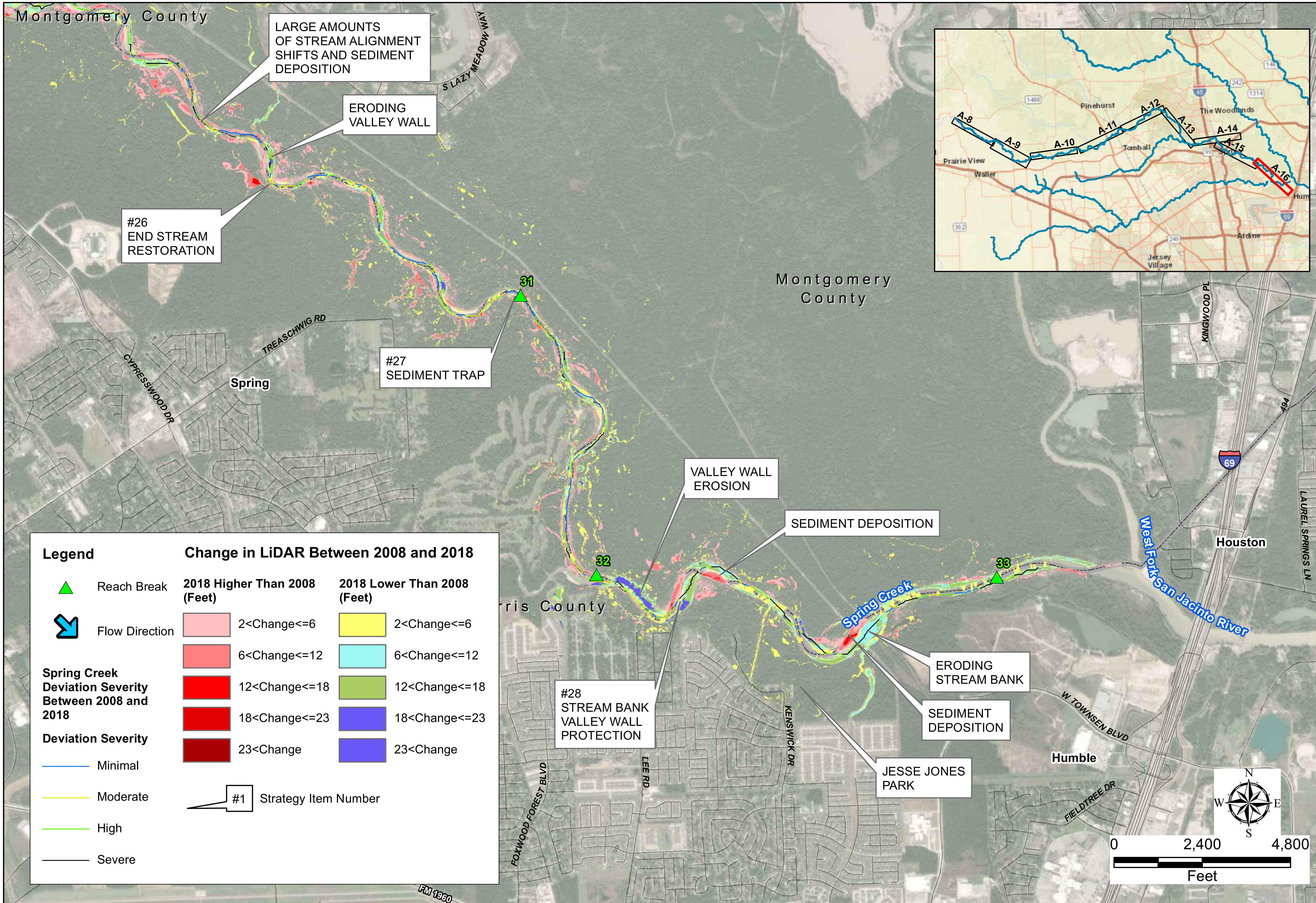
Spring Creek Sedimentation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-15



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PREPARED BY DML

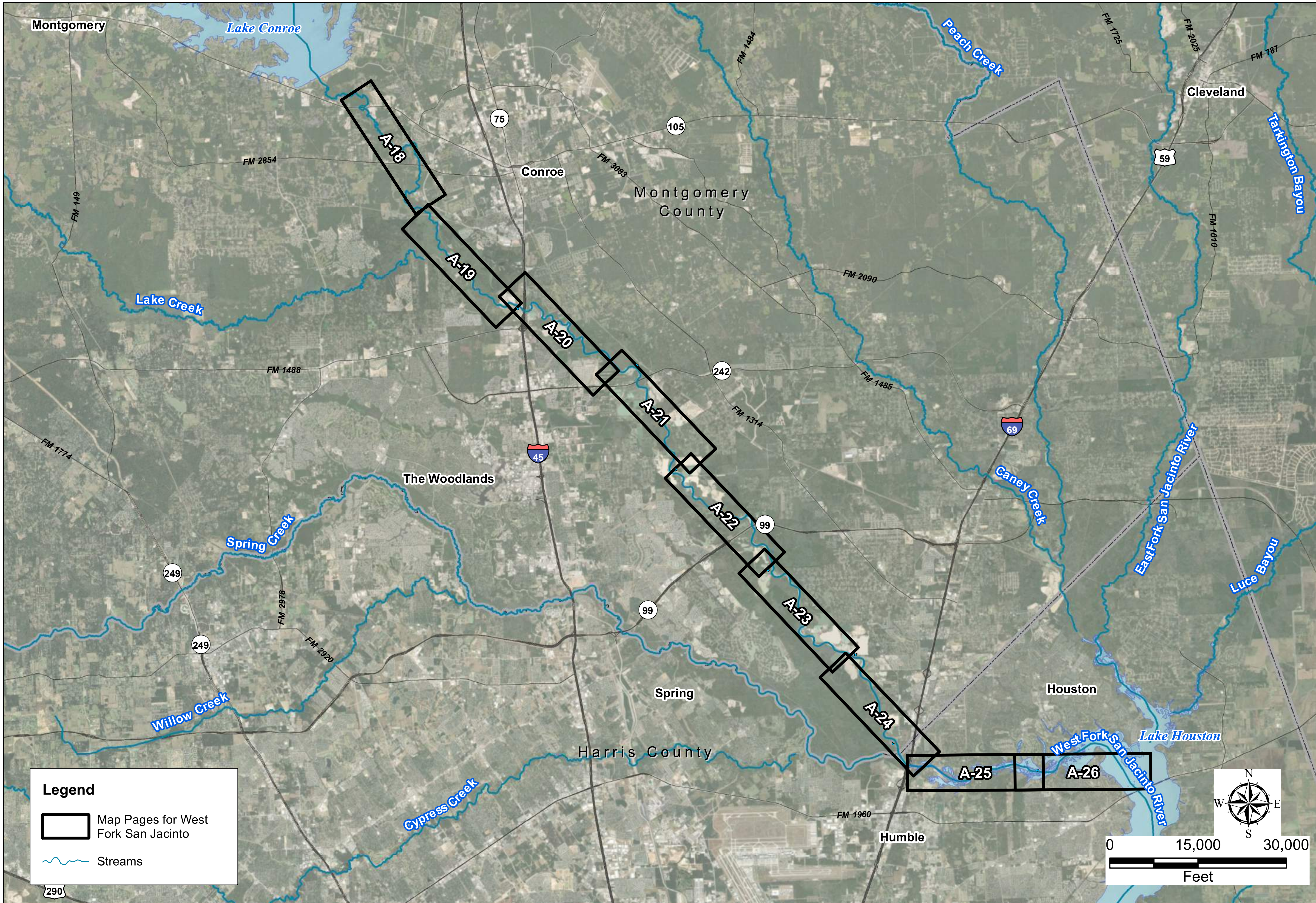
San Jacinto Regional Watershed Master Drainage Plan

Spring Creek Sedimenation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE A-16



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DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central

FILE NAME Figure_A17_WFSJSedimentationStrategy_Index

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San Jacinto Regional Watershed Master Drainage Plan

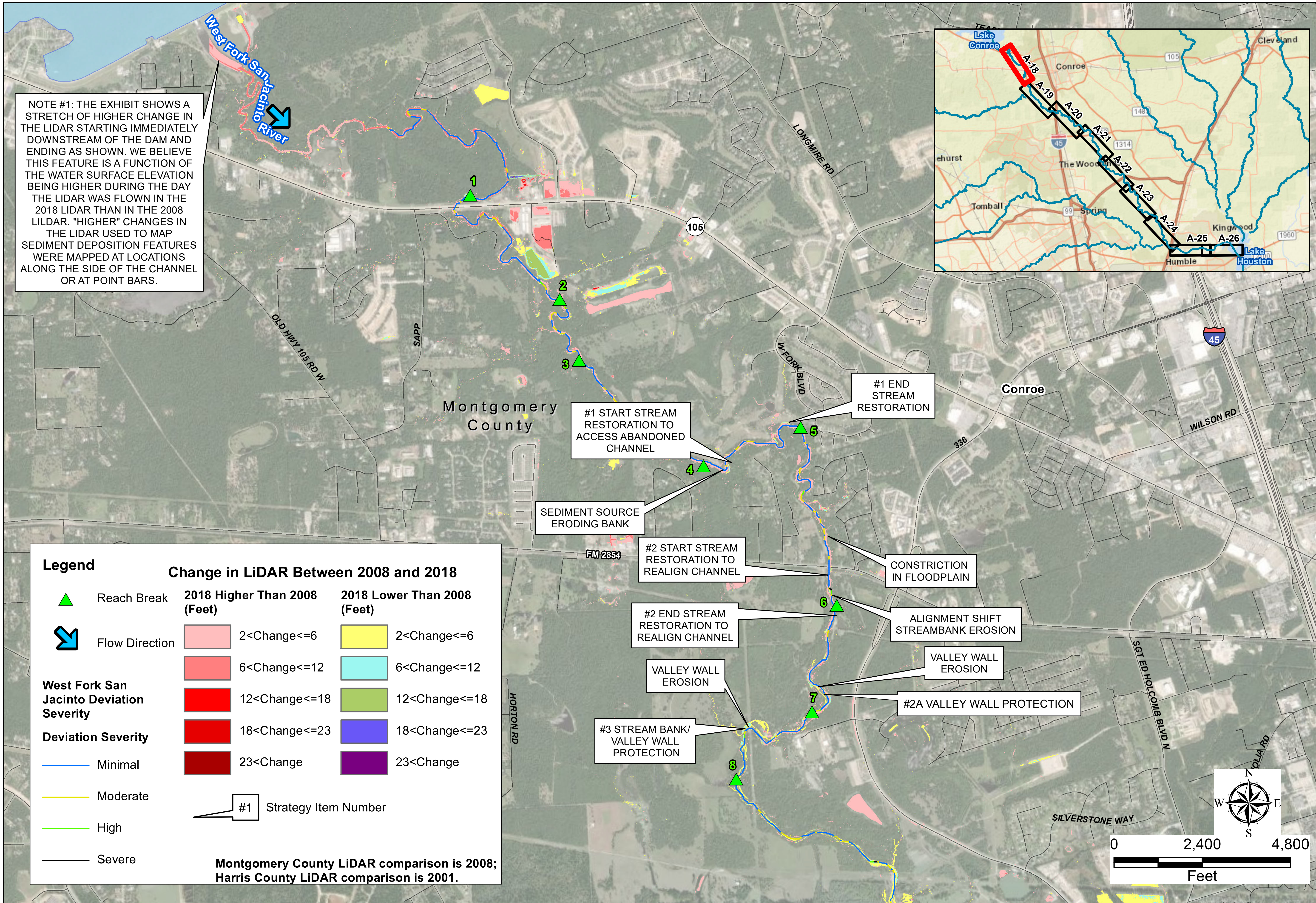
West Fork San Jacinto Sedimentation Index Sheet

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-17



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FILE NAME Figure_A18-24_WFSJSedimentationStrategy_MB

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San Jacinto Regional Watershed Master Drainage Plan

West Fork San Jacinto Sedimenation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-18

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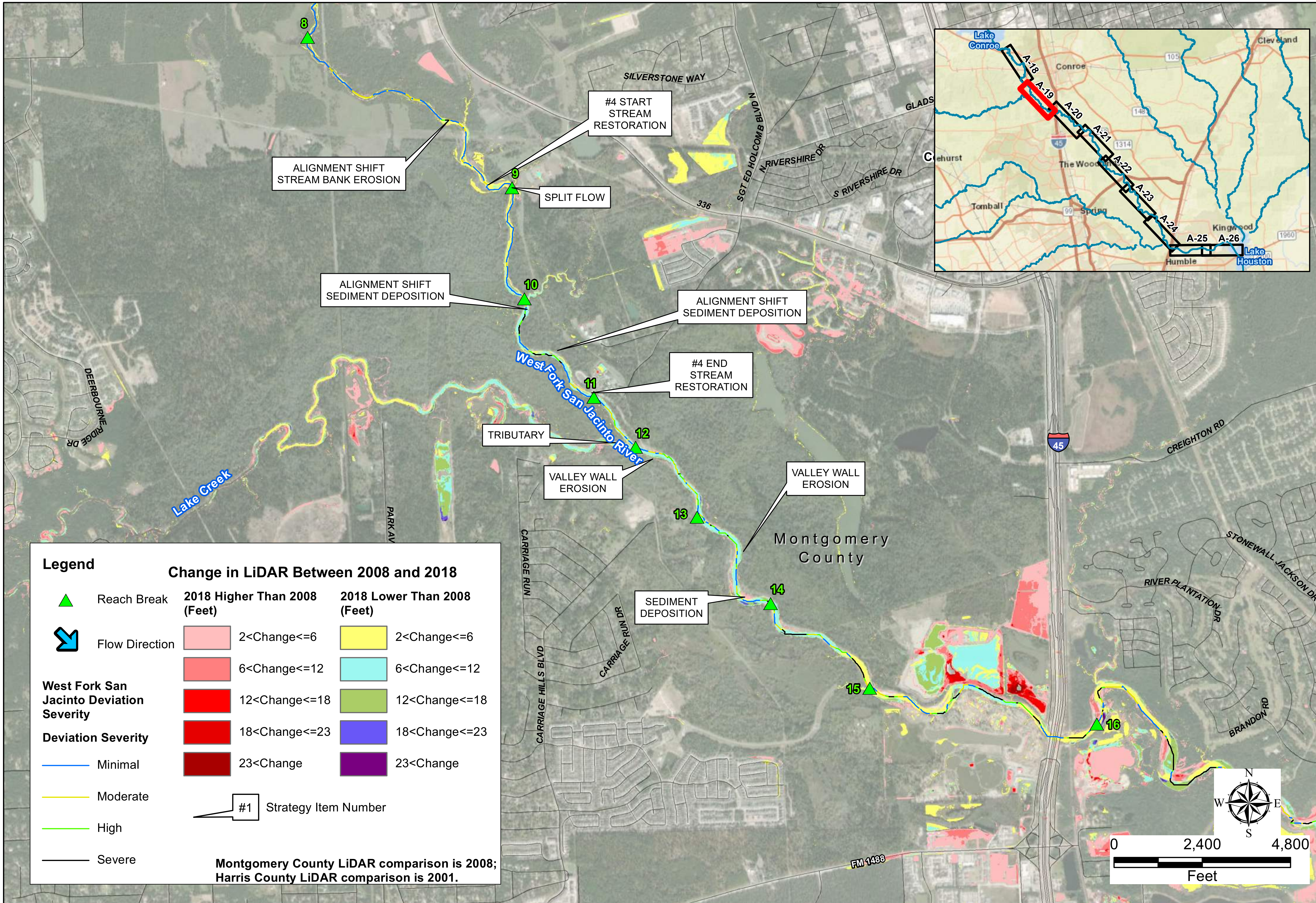

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FILE NAME Figure_A18-24_WFSJSedimentationStrategy_MB
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San Jacinto Regional Watershed Master Drainage Plan

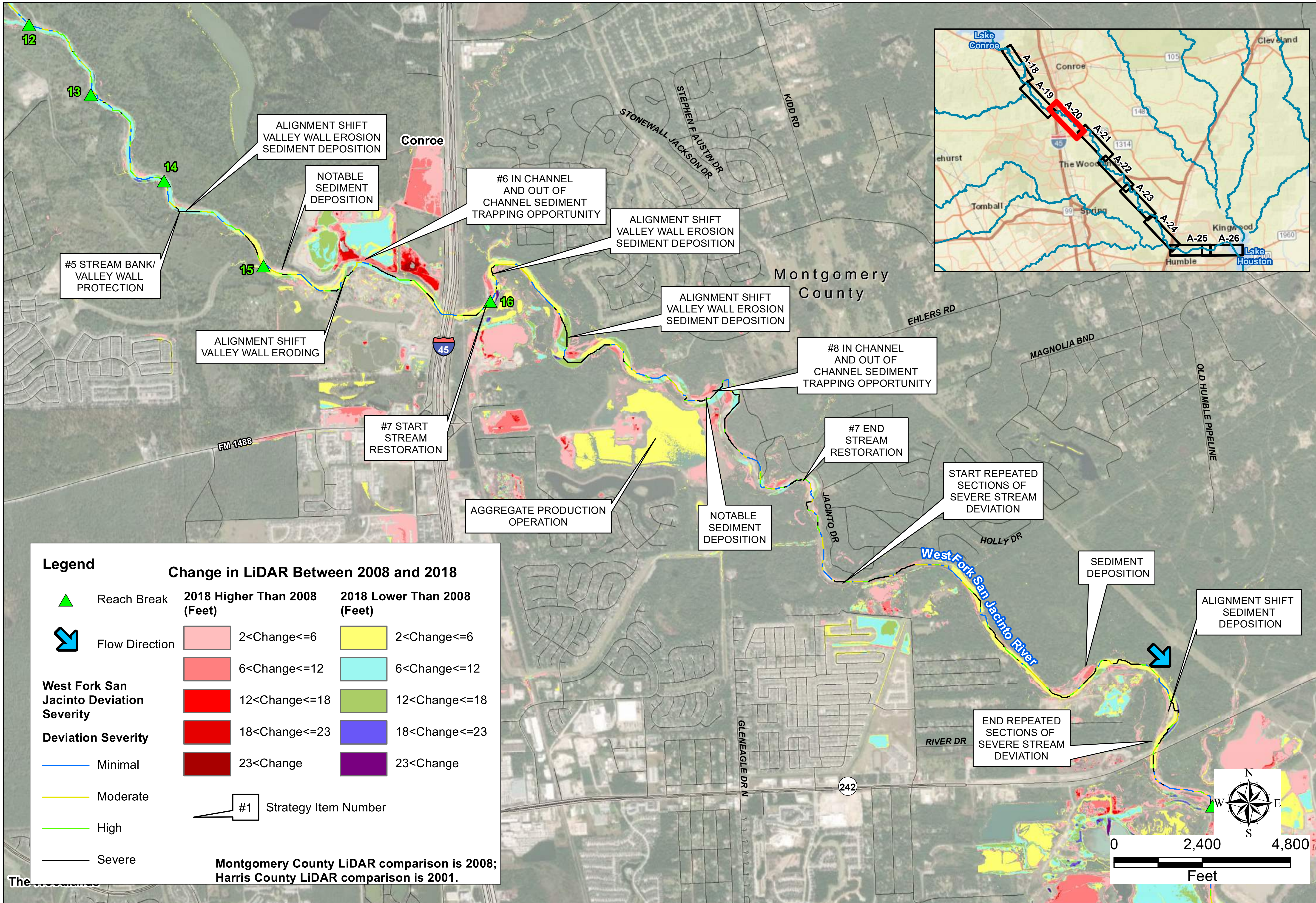
West Fork San Jacinto Sedimentation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-19



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PREPARED BY DML

San Jacinto Regional Watershed Master Drainage Plan

West Fork San Jacinto Sedimenation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE A-20

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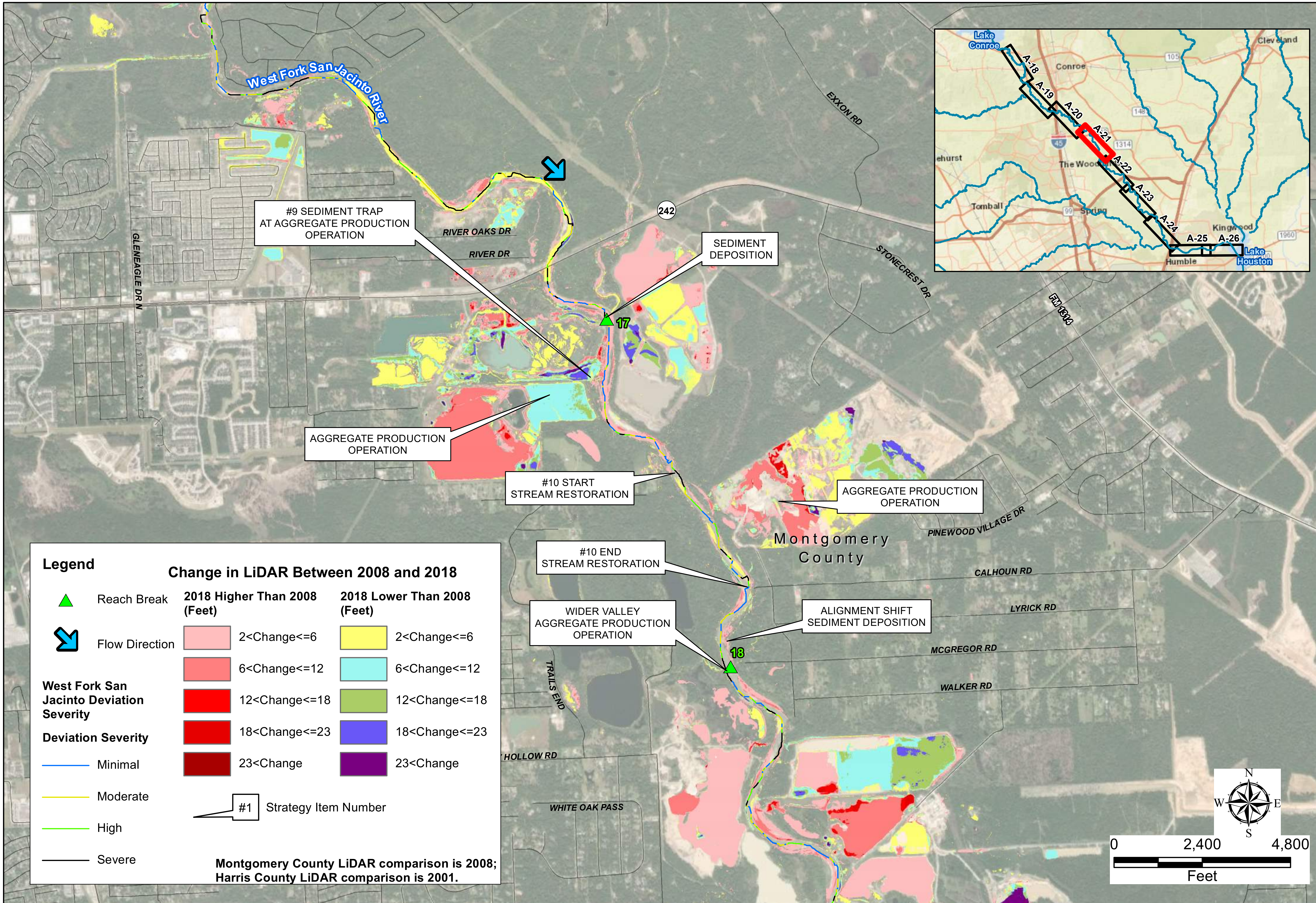

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FILE NAME Figure_A18-24_WFSJSedimentationStrategy_MB

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San Jacinto Regional Watershed Master Drainage Plan

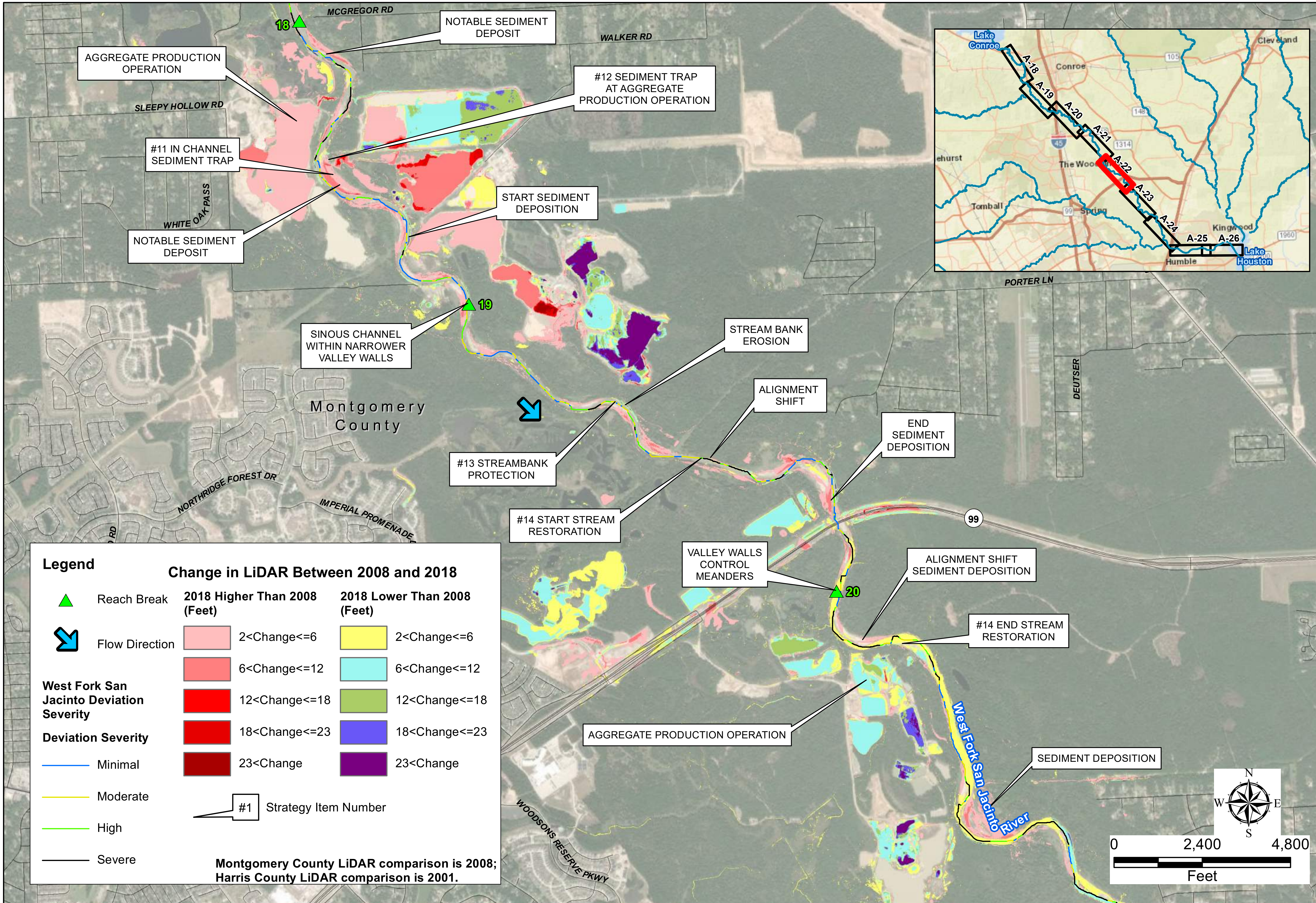
West Fork San Jacinto Sedimenation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-21



San Jacinto Regional Watershed Master Drainage Plan

West Fork San Jacinto Sedimentation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-22

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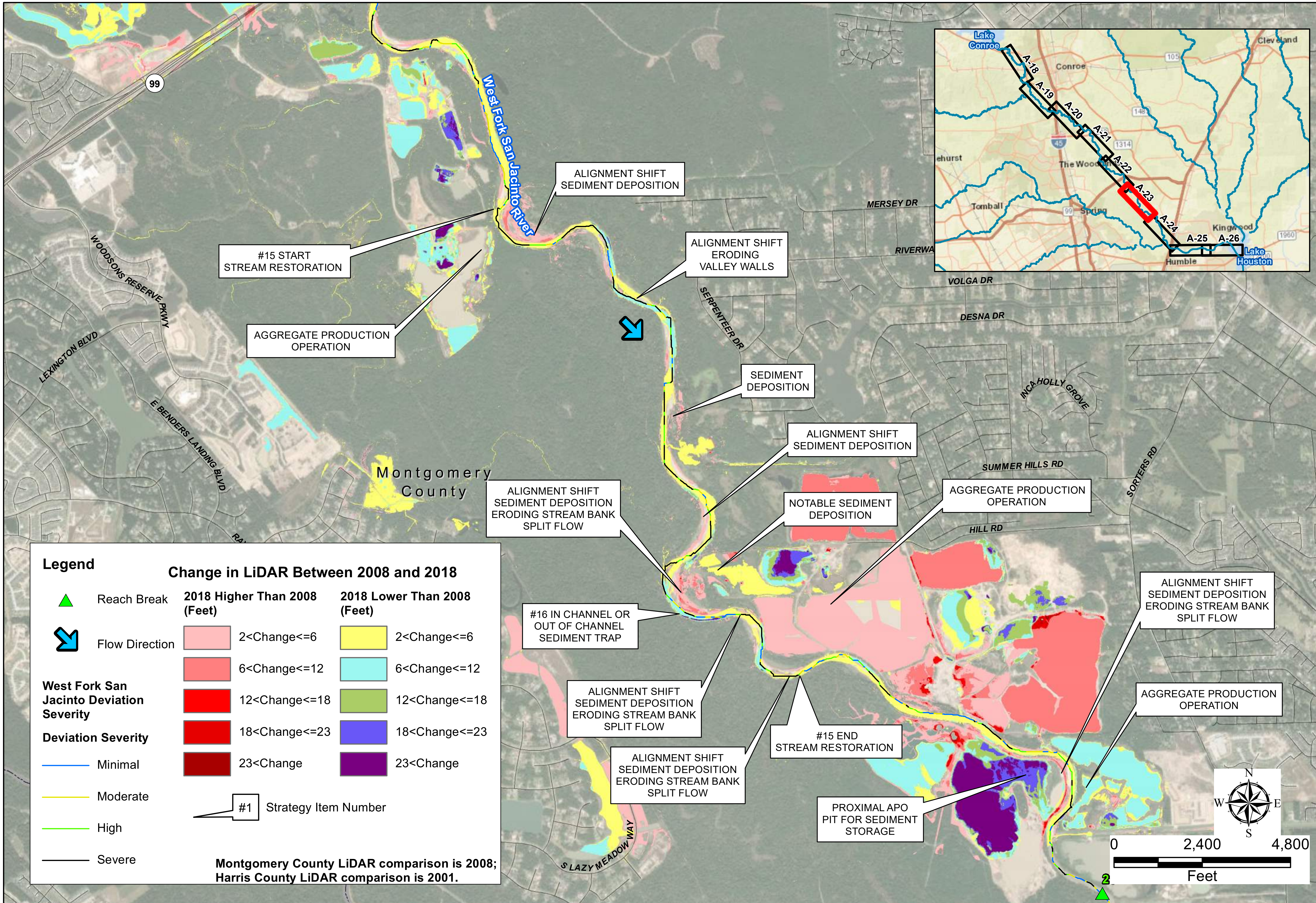

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San Jacinto Regional Watershed Master Drainage Plan

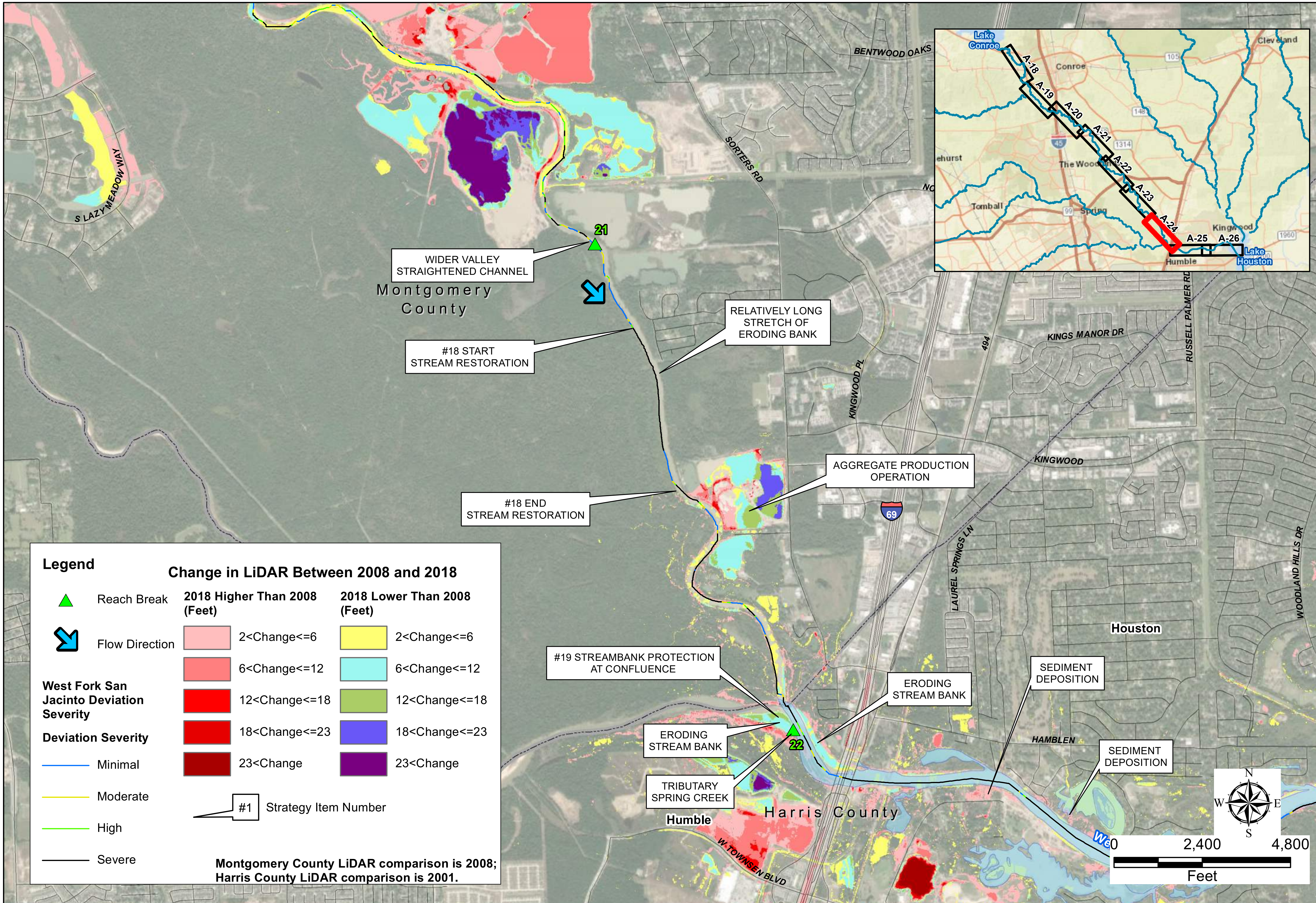
West Fork San Jacinto Sedimentation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-23



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San Jacinto Regional Watershed Master Drainage Plan

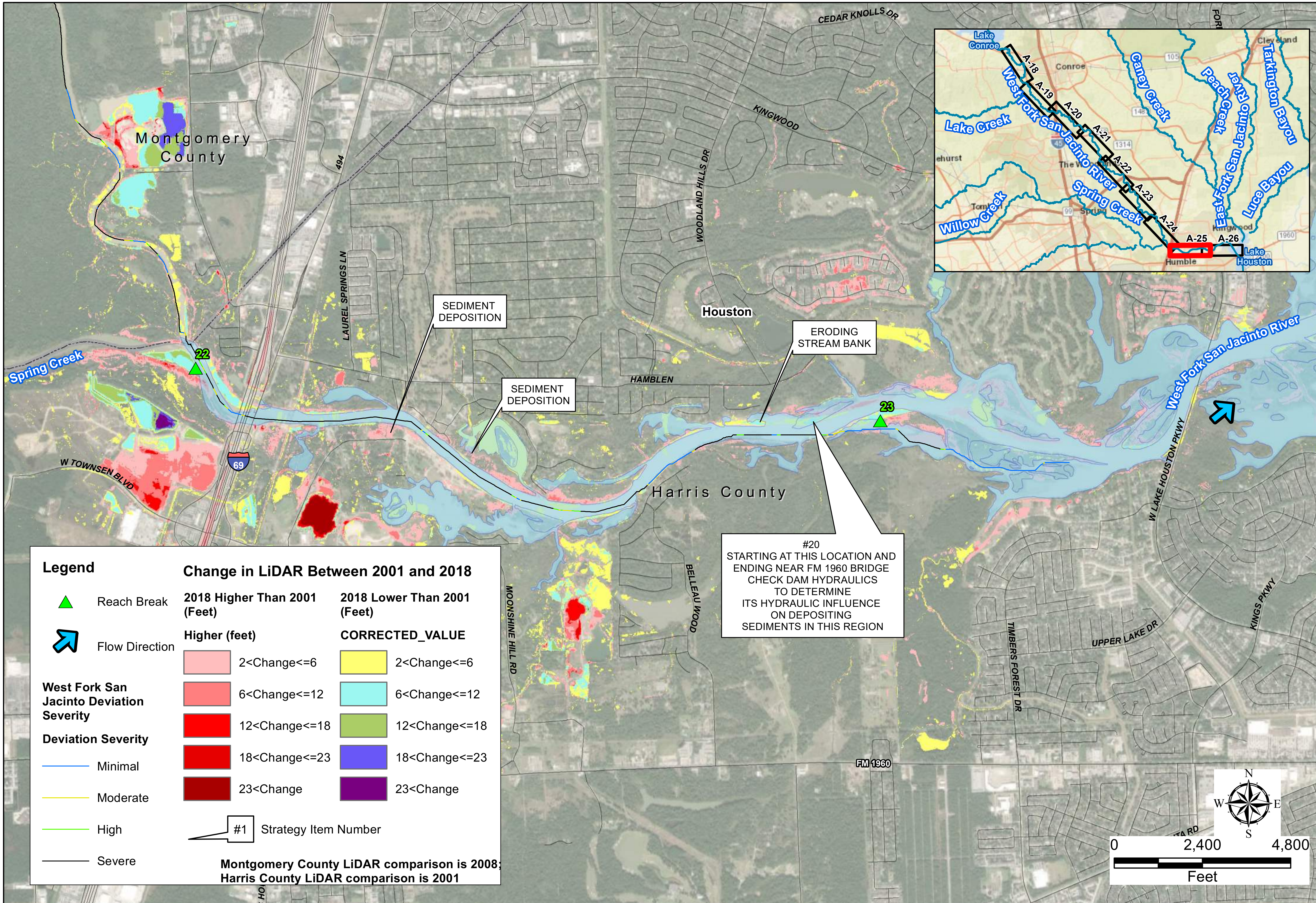
West Fork San Jacinto Sedimentation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-24



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DATE CREATED 6/28/2020

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FILE NAME Figure_A25-26_WFSJSedimentationStrategy_MB

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San Jacinto Regional Watershed Master Drainage Plan

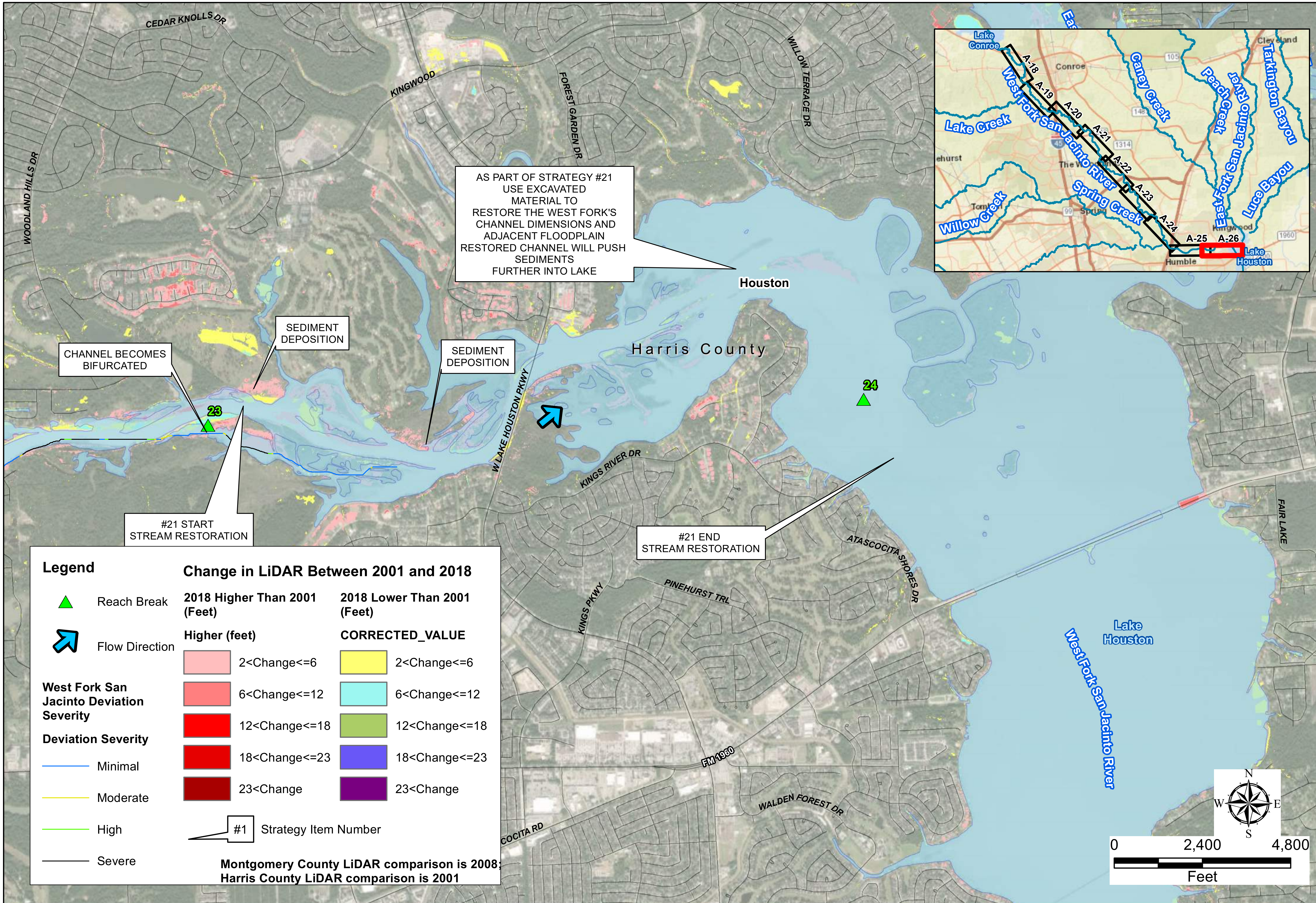
West Fork San Jacinto Sedimentation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-25



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San Jacinto Regional Watershed Master Drainage Plan

West Fork San Jacinto Sedimentation Strategy Map

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-26

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PREPARED BY	DML

San Jacinto Regional Watershed Master Drainage Plan

Spring Creek Sedimenation Strategy MaP

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

A-27

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APPENDIX F.B

RUSLE ANALYSIS

APPENDIX F.B

Revised Universal Soil Loss Equation Analysis

INTRODUCTION

As part of the San Jacinto Regional Watershed Master Drainage Plan (SJRWMDP), Freese and Nichols (FNI) evaluated and recommended sediment management strategies for the Spring Creek and West Fork subwatersheds. Evaluation of landscape erosion in the entire watershed was included as part of this investigation. The sediment loss caused by landscape erosion is a result of rainfall and concentrated rainfall runoff sweeping sediment off the landscape. Landscape erosion does not account for alluvial erosion processes such as stream bank erosion.

Landscape erosion was estimated using the Revised Universal Soil Loss Equation (RUSLE). The RUSLE is a widely accepted method of estimating sediment soil loss from the landscape. This method was originally published in 1965 by the USDA for use in agricultural management and was known as the Universal Soil Loss Equation (USLE) [1]. Since then, it has been updated and adapted beyond its intended use for quantifying erosion over forest lands, reclaimed mines, and urban landscapes.

This study seeks to estimate the total amount of sediment eroding from the landscape in the San Jacinto Watershed and locate regions where sediment management strategies could be focused to prevent sediment from being swept into receiving rivers and streams. Landscape soil loss was estimated for each subwatershed of the San Jacinto Watershed to parallel previous USLE analyses conducted in the watershed. These subwatersheds are:

- Cypress Creek
- Spring Creek
- West Fork San Jacinto
- Caney Creek
- Peach Creek
- East Fork San Jacinto
- Luce Bayou
- Local Lake Houston

It should be noted that the drainage area above Lake Conroe in the West Fork San Jacinto watershed was excluded from this study. It is assumed that any sediment loss from landscapes upstream of Lake Conroe is sequestered in the lake and does not contribute to downstream sediment yields.

Sediment storage and delivery after landscape erosion is not considered in this analysis. This means that the estimated soil loss has not been related to watershed sediment yields (the sediment that enters into receiving water and then is transported into streams, rivers, or Lake Houston). It is not known how much sediment is redeposited on the landscape after the initial erosion and therefore does not actually contribute to total sediment yields in streams, rivers, or Lake Houston. A separate sediment storage and delivery analysis is needed to acquire this information.

Previous soil loss studies in the region include nationwide studies investigating soil erosion on cropland and conservation land using the USLE [2] and a Lake Houston Watershed Management Study from 1993 that also used the USLE [3].

METHODOLOGY

FNI used ArcGIS software as a tool to evaluate the eight sub-watersheds spatially within the greater San Jacinto Watershed. The RUSLE methodology estimates average annual soil loss for each watershed in tons per year and calculates the soil loss per acre in tons/acre/year. The RUSLE equation [4] is:

$$A = R * K * LS * C * P$$

where:

A = estimated average soil loss in tons per acre per year
R = rainfall-runoff erosivity factor
K = soil erodibility factor
LS = slope length and steepness factor
C = cover-management factor
P = support practice factor

The subwatersheds considered in this study match those used in the soil loss study conducted in the 1993 Lake Houston Watershed Management Study [3] (referred to as the 1993 study). The results from the 1993 study were presented in the 2000 Brown and Root Regional Flood Protection Study for Lake Houston Watershed Flood Program [5] (referred to as the 2000 study). In the 2000 study, the values for the individual RUSLE factors used in the 1993 study were not presented. Therefore, new data was needed to rerun the analysis.

In this method, each variable (R, K, LS, C, and P) is defined by a 30-meter resolution raster of the sub-watersheds. Using the data for each variable for each raster, soil loss can be computed for the raster and a map of soil loss can be developed (**Figure B-1**). The variables and data are described below.

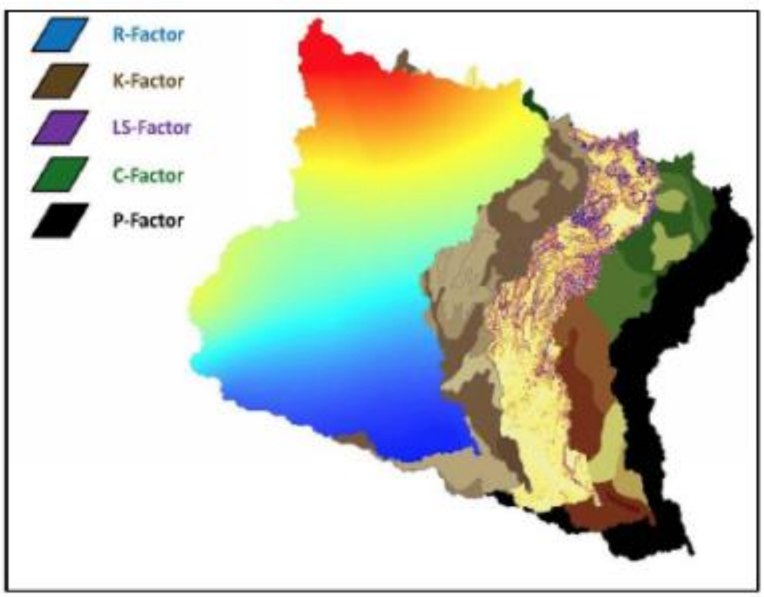

***Figure B-1**. Example of a raster for each RUSLE variable being overlain on a watershed, adapted from Kim, 2014 [8]*

R-factor – The R-factor is the rainfall erosivity parameter of RUSLE. This is affected by storm intensity, duration, and frequency for an area. A higher rainfall erosivity factor means that the area's storms are more erosive on the landscape. Data was generated for this parameter from isoerodent maps (map of R-factors) provided in the USDA's RUSLE Handbook [4]. The isoerodent maps (**Figure B-2)** were georeferenced into ArcMap and converted into a raster for each watershed.

The R-factors generally increase from the northwest of the project area to the southeast approaching the Gulf of Mexico. The R-factors within the study area are high compared to the rest of the country.

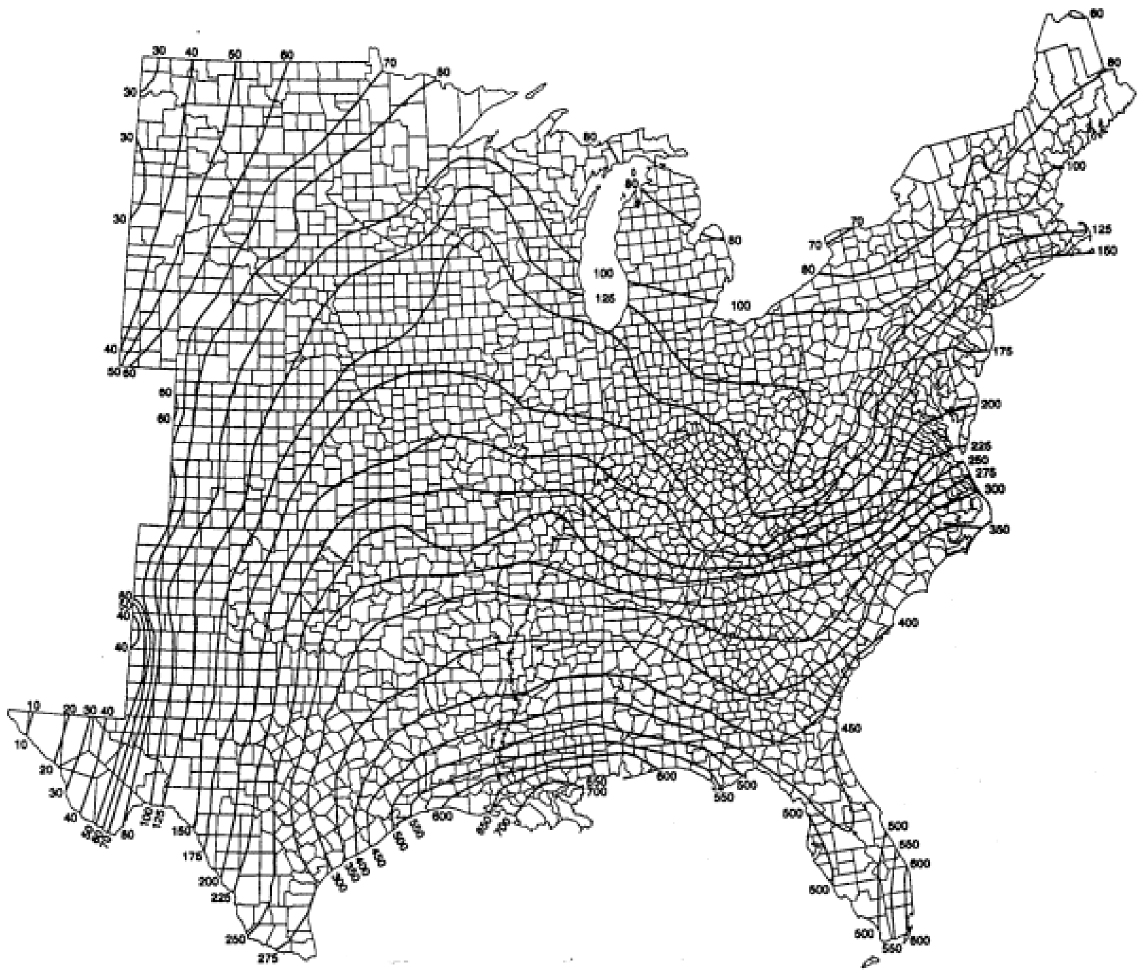

***Figure B-2**. Isoerodent map of R-values for the eastern United States, adapted from USDA Handbook 703 [4].*

K-factor – The K-factor is the soil erodibility parameter based on the soil texture, structure, organic matter, and permeability. Soils more susceptible to erosion (easily transported and detached from soil surface), such as silt, have higher K-factors, whereas soils resistant to detachment, such as clay, have lower K-factors. K-factors for the soils in each watershed were gathered from the Soil Survey Geographic Database (SSURGO) from the Natural Resources Conservation Service (NRCS) [6]. This database provides geographic data for the soils in the United States. This data was brought into ArcMap directly from the NRCS's web-soil survey and converted to a raster (**Figure B-3**). However, there are data gaps for the K-factor. In these cases, the average K-factor value for the watershed was used to fill the data gap.

In general, K-factors are lower in headwaters of Spring, West Fork San Jacinto, Caney, Peach, and East Fork San Jacinto. The Cypress Creek subwatershed also has a higher K-factor than the other subwatersheds. Soil erodibility also increases closer to Lake Houston. This appears to be a geographic phenomenon likely due to the underlying geology/parent material of the soil.

LS-factor – The LS factor represents the slope steepness of the landscape and the effects of the length of slope before overland flow becomes channelized into a rill, gully, or stream. This factor is calculated using a digital elevation model (DEM) of a watershed of interest and a set of equations known as the Unit Stream Power Erosion and Deposition (USPED) model. This model has been validated by research from the U.S. Forest Service [7] and is also used in the Soil Erosion Toolbox for ArcGIS. The USPED model uses the following equations to derive the LS factor:

$$L = (1.4)(\frac{A}{22.1})^{1.4}$$

$$S = \left(\frac{\sin(0.01745 * \theta_{deg})}{0.09}\right)^{1.4}$$

$$LS = L * S$$

Where L is the L component of LS, A is the area of upland flow as calculated by the watershed DEM with the hydrology toolbox in ArcMap, S is the S component of LS, and θ_{deg} is the slope angle of the landscape in degrees. The L and S components of each equation are multiplied together to generate a LS-factor. For in-depth description of this model, refer to references [7], [8], and [9].

In general, LS-factors are higher in the headwaters of each watershed (**Figure B-4**). They are also higher on the boundaries of historic stream terraces where slopes are higher and around man-made earthen embankments, such as locations where roads and infrastructure are present.

C-factor – The C-factor is the land-cover management factor. The C-factor is used to reflect the effect of plants, ground cover, soil biomass, and management practices on erosion rates. Land-use data from the Houston-Galveston Area Council (HGAC) Land Cover Data Sets was used to define the land-use within each watershed. Each land-use type was then given a C-factor value. **Table B-1** below shows the C-factors used for each land cover type. The higher the C-Factor, the more prone the landscape is to erosion.

For example, barren lands have no vegetative cover or biomass, exposing the soil to direct impacts from rain and weakening its strength to withstand erosion. Compare the barren lands C-factor of 1 to the forest/shrub C-factor of 0.001, several of orders of magnitude lower. The forest/shrub land cover type has a diverse tree canopy to intercept rain and a healthy, erosion-resistant soil. The developed – high intensity land use (for example, a large industrial complex) has less exposed soils than the developed – low intensity land use (for example, single residences on small lots), which is reflected in its lower C-factor value.

Because RUSLE was originally designed to be used on agricultural lands, there is much debate over C-factor values in non-agriculture land uses. There have been multiple studies to investigate C-factor values in non-agricultural settings. Unfortunately, C-factor values vary widely depending on the source in non-agricultural setting. Some studies show that site-specific C-factors are necessary due to the lack of community consensus [13]. In this study, C-factor values were chosen based on professional judgement after review of the available literature.

Table B-1. *Chosen C-factor values for land cover types from the HGAC Land Cover Data Set*

Land Cover Type	C-Factor Value	Reference
Open Water	0	[10], [11]
Developed – High Intensity	0.001	[12]
Developed – Medium Intensity	0.002	[12]
Developed – Low Intensity	0.004	[12]
Developed – Open Space	0.008	[11]
Barren Lands	1	[2]; [10]
Forest/Shrubs	0.001	[10]
Pasture/Grassland	0.01	[10]
Cultivated Crops	0.1	[2]
Wetlands	0.001	[10]

<u>P-factor</u> – The P-factor represents the impact of erosion management practices used on the landscape. Example practices include contour farming and use of erosion control matting. P-factor values for agricultural land uses are provided in the RUSLE Handbook. However, there is little consensus on the value for P-factors in non-agricultural land uses. Since the stormwater management and sediment control practices within the watersheds are unknown, P-factor values were set to 1.0, the most conservative value. This may over-estimate the amount of landscape erosion occurring in the watershed.

Table B-2 shows the results of the RUSLE analysis for each subwatershed as a whole. Maps showing the spatial distribution of erosion intensity are presented in **Figures B-6** through **Figures B-7**. Erosion is highest where the land cover type is designated as barren lands, which has the highest C-factor (1.0). These locations show extreme erosion compared to the average soil loss within a watershed. Other locations where erosion is higher are in areas with higher LS-values. This means that areas with steeper slopes are eroding more rapidly than areas with flatter slopes. This generally occurred at the headwaters of watersheds, on river terrace boundaries, and near existing roads and infrastructure.

Table B-2. *Results of RUSLE Analysis*

Watershed	Drainage Area (sq mi)	Average Soil Loss (tons/acre/year)	Estimated Total Soil Loss (tons/year)
Cypress Creek	319	1.80	367,603
Spring Creek	443	1.30	368,908
West Fork San Jacinto	549	2.60	913,536
East Fork San Jacinto	401	1.30	334,048
Caney Creek	217	1.70	237,075
Peach Creek	158	0.79	80,188
Luce Bayou	212	0.42	57,039
Local Lake Houston	72	4.40	204,441
Total	**2,374**	**1.69**	**2,562,840**

RESULTS AND DISCUSSION

This RUSLE analysis predicts similar values of soil loss compared to the USDA's National Resource Inventory (NRI) [2], which has estimated the tons/acre/year of sediment lost on cropland, Conservation Reserve Program (CRP) land, and pasture land using USLE, RUSLE and the Modified Soil Loss Equation (MUSLE) at various points in time. Within the study area, the 1997 NRI estimated an average soil loss of between 1 and 3 tons/acre/year. Additionally, the 1982 NRI estimated between 1 and 5 tons/acre/year of erosion [15].

However, the 1993 Lake Houston Watershed Management Study [3] predicted significantly less erosion than the RUSLE analysis performed here. The results of the 1993 study are presented in **Table B-3**. It should be noted that this report was not reviewed as part of this study and details of its methodology are unknown. Discrepancies between this RUSLE analysis and the 1993 study could be due to values attributed to land cover type (C-factor values) or the land management practice values (P-factor values). C-factor and P-factor values can be both the most influential and least reliable factors in a RUSLE analysis [16]. At present there is a lack of consensus for C-factor and P-factor values in non-agricultural landscapes.

Table B-3. *USLE results from the 1993 Lake Houston Watershed Management Study [3]*

Watershed	Average Soil Loss in 1993 (tons/acre/year)	Estimated Total Soil Loss in 1993 (tons)
Cypress Creek	0.47	95,600
Spring Creek	0.19	53,300
West Fork San Jacinto	0.25	88,000
East Fork San Jacinto	0.13	33,100
Caney Creek	0.12	17,200
Peach Creek	0.07	7,000
Luce Bayou	0.12	16,000
Local Lake Houston	0.04	1,700
Total	**-**	**311,900**

Additionally, the accuracy of soil loss estimates using RUSLE and USLE has been evaluated by studies in 1994 and 1993 [17] [18]. These studies claim that accuracy of estimated soil loss can be as great as ±50%.

The bulk results from this study appear reliable due to the quality of the input data. However, two inconsistencies of the results warrant additional discussion. First, there are localized areas with extremely high soil loss estimates that are multiple standard deviations above the mean soil loss within the subwatershed (sometimes greater than 5,000 tons/acre/year). These extremely high soil loss estimates are most likely a reflection of the RUSLE model, not the input data, as this model was not initially designed for non-agricultural land uses. These localized areas with extreme soil loss estimates may be erroneous and bring up the average soil loss within the watershed. Secondly, there are locations which showed landscape erosion within a river/stream or on paved impervious surfaces. While these areas should not be included in the model, their contributions to the average sediment loss in each watershed is likely minimal.

SUMMARY

The average soil loss computed using the RUSLE in the San Jacinto watershed was 1.69 tons/acre/year. The range of soil loss in each of the eight subwatersheds (Cypress Creek, Spring Creek, West Fork San Jacinto, Caney Creek, Peach Creek, East Fork San Jacinto, Luce Bayou, and the Local Lake Houston) is between 0.42 and 4.4 tons/acre per year. An estimated 2,562,840 tons of sediment are eroded from the landscape each year.

Higher erosion was estimated at locations with a land cover type of “barren land” and areas with steeper slopes. Typical areas with steeper slopes include near existing roads and infrastructure, stream headwaters, and the boundary between historic flood plain terraces.

While the results of this analysis are consistent with national USLE studies from the USDA, they are significantly higher than the 1993 USLE analysis. This could be due to the differences in the C-factor values and P-factor values used or the use of RUSLE on non-agricultural land (with more of the landscape in 2020 being non-agricultural). Resolving this discrepancy with the 1993 study would require obtaining historic land cover data and recalculating the RUSLE using the same P-factor but varying the C-factor.

Lastly, this analysis only estimates soil loss from landscape erosion. This does not include river, gully, or floodplain erosion. It also does not estimate sediment yields or sediment delivery ratios into streams of the San Jacinto Watershed. Further analysis of landscape erosion, including identification of local topography sinks and wetlands, would be needed to determine whether the soil loss estimated with RUSLE ultimately ends up in streams, rivers, or Lake Houston.

Finally, to help identify sediment management strategies in the overall SJRWMDP Sediment Management Strategy report, the final RUSLE results were clipped to the 100-year floodplain boundary developed from the preliminary existing conditions flood models (Halff/FNI 2019). Note that the RUSLE tables presented here and in the main report reflect landscape erosion for the overall watershed. The RUSLE results within the 100-year floodplain were used to guide selection of sediment management strategies that would be effective where landscape erosion enters the stream and river network. The identified sediment management strategies are presented in the Sediment Management Strategy report.

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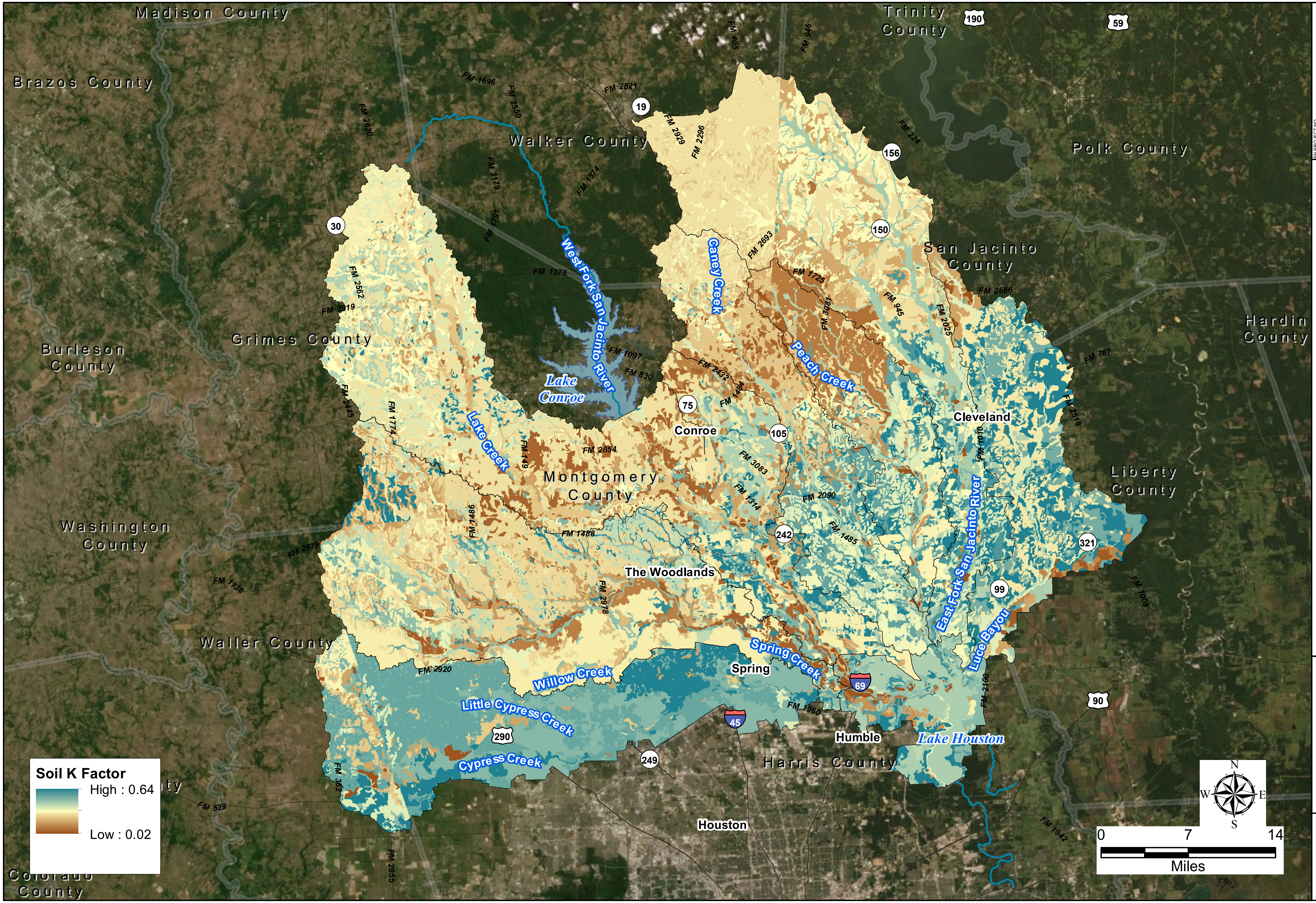


San Jacinto Regional Watershed Master Drainage Plan

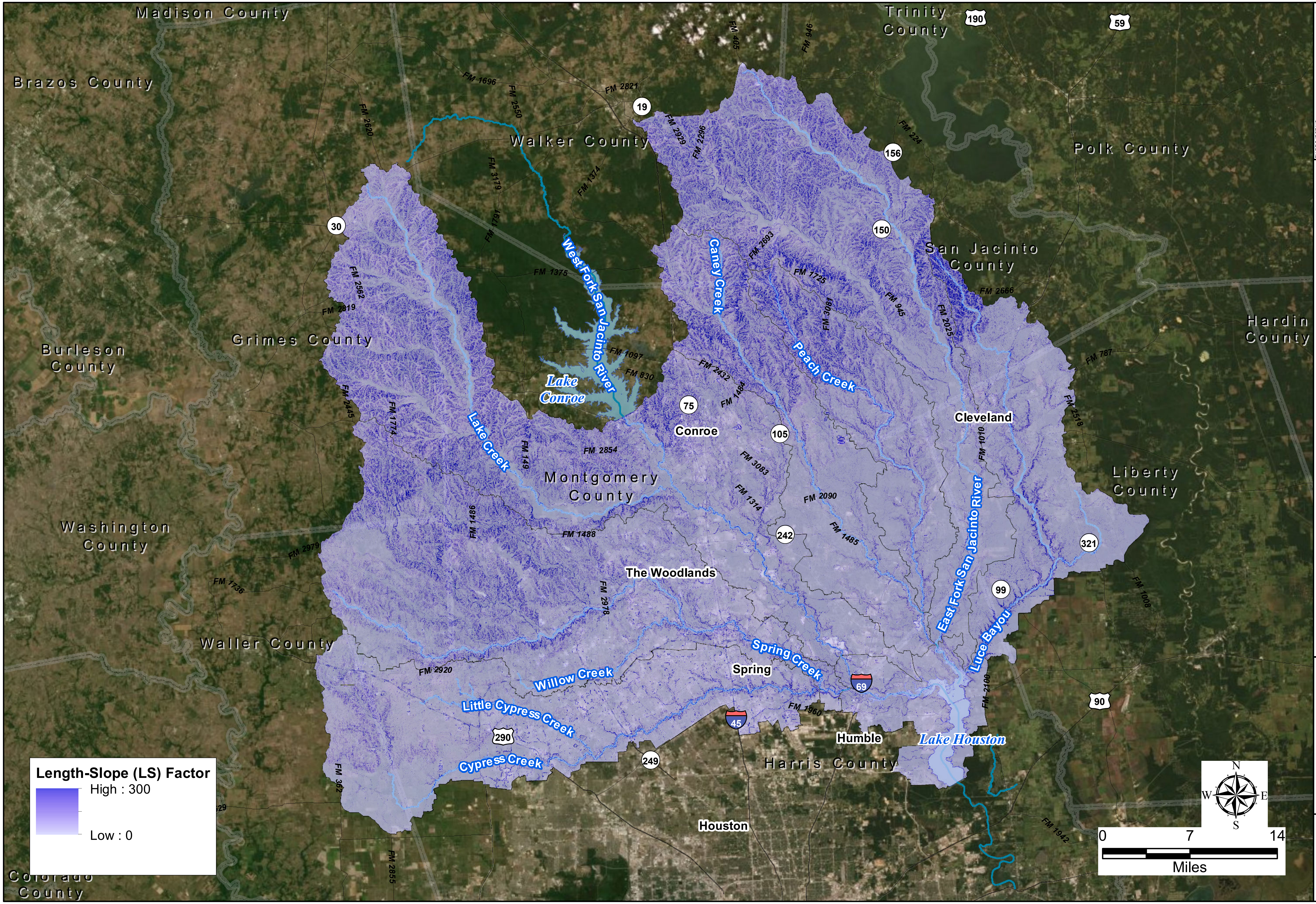
Annual Suspended Sediment Loads of Soil K-Factors

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

B-3



San Jacinto Regional Watershed Master Drainage Plan

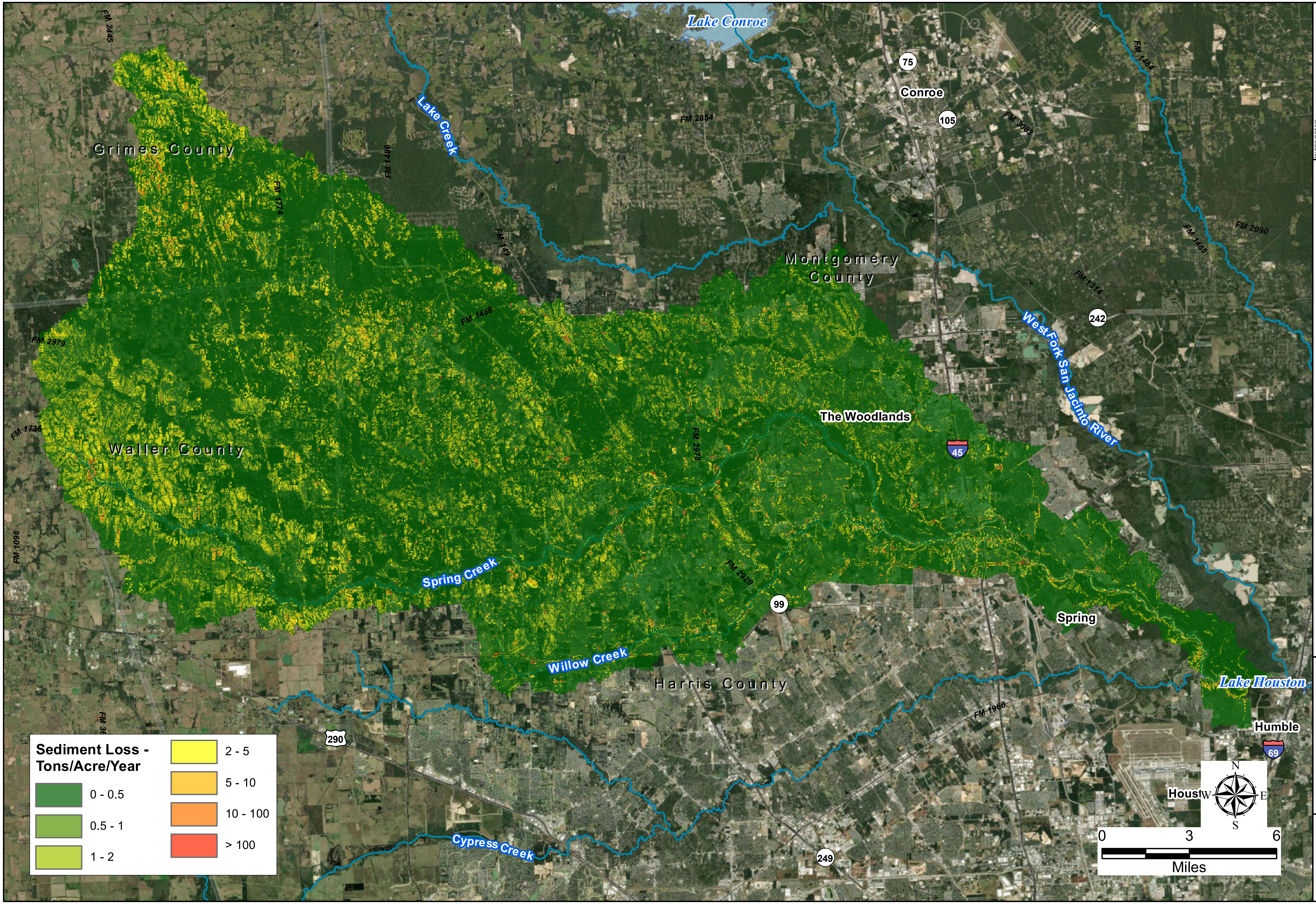
Annual Suspended Sediment Loads of Soil Length-Slope (LS) Factors

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

B-4



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PREPARED BY	DML

San Jacinto Regional Watershed Master Drainage Plan

RUSLE Analysis Results Spring Creek Sub-Basin

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

B-5

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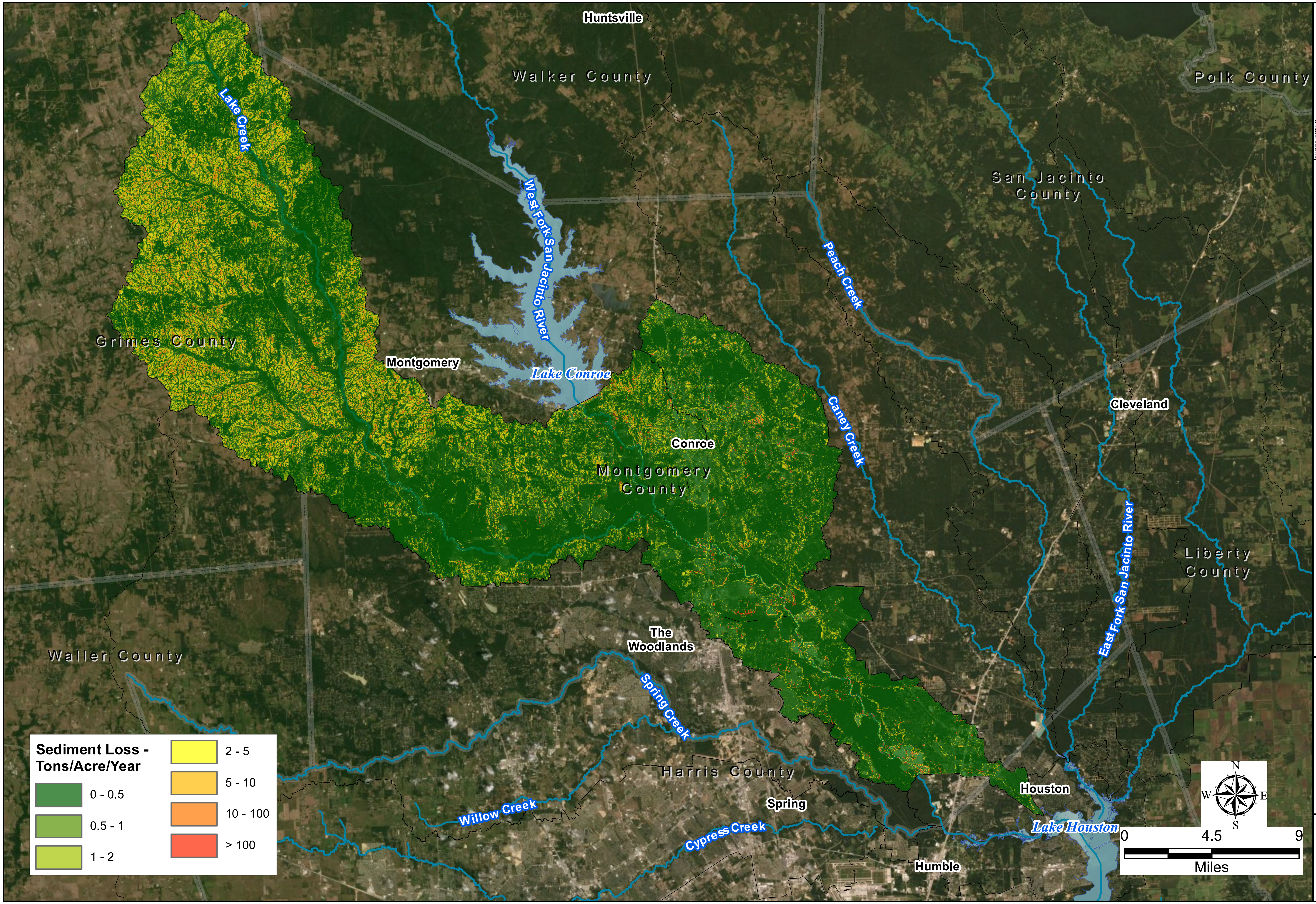

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San Jacinto Regional Watershed Master Drainage Plan

RUSLE Analysis Results West Fork San Jacinto Sub-Basin

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

B-6

APPENDIX F.C

STREAM DEVIATION AND ELEVATION DIFFERENCE ANALYSIS

APPENDIX C

Stream Deviation and Elevation Difference Analysis

INTRODUCTION

As part of the San Jacinto Regional Watershed Master Drainage Plan (SJRWMDP), Freese and Nichols (FNI) evaluated and recommended sediment management strategies for the Spring Creek and West Fork subwatersheds. As part of this effort, a semi-quantitative analysis was conducted using ArcGIS to identify locations where stream channels have moved from their historic alignments. Potential sediment sources may be located where a stream has migrated, and identification of sediment sources is valuable to long range regional flood risk mitigation and reduction. This analysis was conducted on the main stem of Spring Creek and West Fork San Jacinto River below Lake Conroe.

In addition, topographic data collected by Light Detection and Ranging (LIDAR) surveys were compared to measure elevational differences over time. LiDAR data sets collected at different times were compared to measure changes in topography. Areas that have become lower over time may be sediment sources, and areas that have become higher may be sediment deposits.

METHODOLOGY

FNI used digital elevation models (DEMs) to generate the stream networks for the West Fork San Jacinto River and Spring Creek in the greater San Jacinto Watershed. River networks were generated using DEMs of the landscape based on 2018 and 2008 data for the West Fork San Jacinto River and 2018 and 2001 data for Spring Creek. This was done by calculating the flow direction and flow accumulation from the DEMs, then converting the areas with high flow accumulation to lines that represent the stream centerline. The stream centerlines were then clipped to the West Fork San Jacinto River and Spring Creek.

After the stream centerlines were delineated at two different points in time, the change in channel location over time was quantified (from 2008 to 2018 for the West Fork San Jacinto River in Montgomery County and from 2001 to 2018 for Spring Creek and the portion of the West Fork San Jacinto River in Harris County). The 2018 centerline for each channel was marked by points at 50 foot intervals, and the distance from the previous (2001 or 2008) channel was established for every point. The change in channel location over time was divided into the four categories shown in **Table C-1** using a statistical method called quartile binning. The results were arranged from lowest to highest and the value at the quartile statistic of 25%, 50%, 75% was selected. These values were approximately 30 feet, 60 feet and 90 feet.

Table C-1: Categories of Stream Centerline Deviation Based on Distance from Previous Centerline

Deviation Severity Designation	Distance Between Stream Centerlines
Minimal	< 30 feet
Moderate	30 – 60 feet
High	60 – 90 feet
Severe	> 90 feet

The analysis of change in elevation focused on the area along the channels in order to show where the rivers may have shifted into its adjacent stream banks, resulting in a loss of stream bank material (i.e. sediment sources) or in other regions proximal to the channels that may be influenced by alluvial processes. LiDAR elevation data for 2001 and 2018 were used to compare elevations in the Spring Creek sub-watershed. LiDAR data for 2001 and 2018 were also used for the Harris County part of the West Fork San Jacinto channel and adjacent floodplain. LiDAR data from 2001 were not available for the upstream portion of the West Fork San Jacinto River in Montgomery County, and 2008 LiDAR data were used instead.

If the elevation measured by the 2018 LiDAR survey was notably lower than the elevation measured in the earlier LiDAR surveys, material has been removed from the channel. The removal could have been caused by human activity (such as a quarry) or by natural erosion (such as stream bank erosion).

If the elevation in the 2018 LiDAR survey was notably higher than the elevation in the earlier LiDAR data, material has been added to an area over time. This may result from human activity (land development construction) or from sediment deposits in the river corridor.

Differences between the two elevation data sets were categorized by elevation change between the two datasets to differentiate between smaller changes in topography and larger changes in topography.

The 2001, 2008, and 2018 LiDAR data for this study was all provided by HCFCD. The 2001 and 2018 LiDAR data was available for the entire watershed and the 2008 LiDAR for the mainstems in Montgomery County, San Jacinto County, and Liberty County. The earlier data sources were measured using a different geoid then the more recent data. The differences in geoid were spot-checked around different points in the watershed and the differences were found to be between 1” and 4”. This difference was not considered substantial for the purposes of this study, and geoid adjustments to the LiDAR were not made. Differences due to subsidence over this time period are also considered to be negligible.

RESULTS

Table C-2 shows the channel deviation by category for each stream. **Figures C-2** and **C-3** show the locations where stream centerline deviation has occurred for Spring Creek and the West Fork San Jacinto River.

In Spring Creek (**Figure C-2**) there does not appear to be a pattern associated with the location of severe deviation, except that there is little deviation in the headwaters of the stream. It also appears that many locations that show the most significant deviation may be errors associated with historic floodplain oxbows instead of the actual flow path of the river. This means that more deviation is shown by this analysis than is actually occurring.

In the West Fork San Jacinto River, the amount of deviation of the stream centerline increases downstream (**Figure C-3**). One explanation is that the effect of erosion is compounded downstream due to the increased contributions of transported sediment from tributaries. Tributaries convey their load to the mainstem leading to excessive deposition which forms obstructions. These obstructions force the river to shift its alignment into its stream banks.

The two watersheds showed a similar pattern of elevational change, with greater elevational change downstream. Overview maps for Spring Creek mainstem (2018 vs. 2001) and West Fork San Jacinto mainstem in Montgomery County (2018 vs. 2008) and West Fork San Jacinto mainstem in Harris County (2018 vs. 2001) can be seen in **Figures C-4**, **C-5**, and **C-6** respectively. Notable loss of elevation was observed in multiple locations on both mainstems. **Figure C-7** is a representative exhibit of elevation change, both loss and gain, in various locations along the West Fork San Jacinto River.

A common observation in the elevational change maps is that where the 2018 LiDAR is notably lower than historic elevations (13 feet or greater), notably higher elevations were observed nearby and downstream as seen in **Figure C-1** (a representative area of this phenomenon shown below). These large losses of native material are the result of erosion along tall stream banks or the valley walls that border the floodplain. The erosion releases a lot of sediment, some of which deposits immediately downstream and is measured as a higher elevation in the 2018 LiDAR data. The streambank across from the depositional area is often another location of significant erosion. This cycle is repeated creating a perpetual sediment source. These should be high priority areas for streambank protection.

Table C-2: Summary of Deviation Results

Deviation Severity	West Fork San Jacinto River	Spring Creek
Minimal (<30 feet)	38.8%	49.6%
Moderate (30-60 feet)	18.2%	19.6%
High (60-90 feet)	13.2%	9.4%
Severe (> 90 feet)	29.8%	21.4%

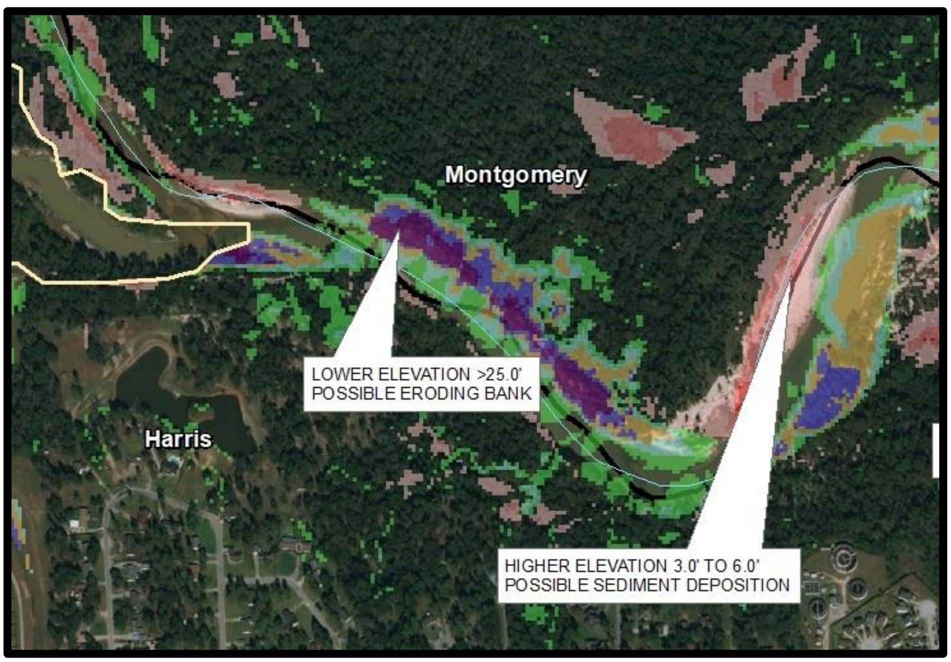
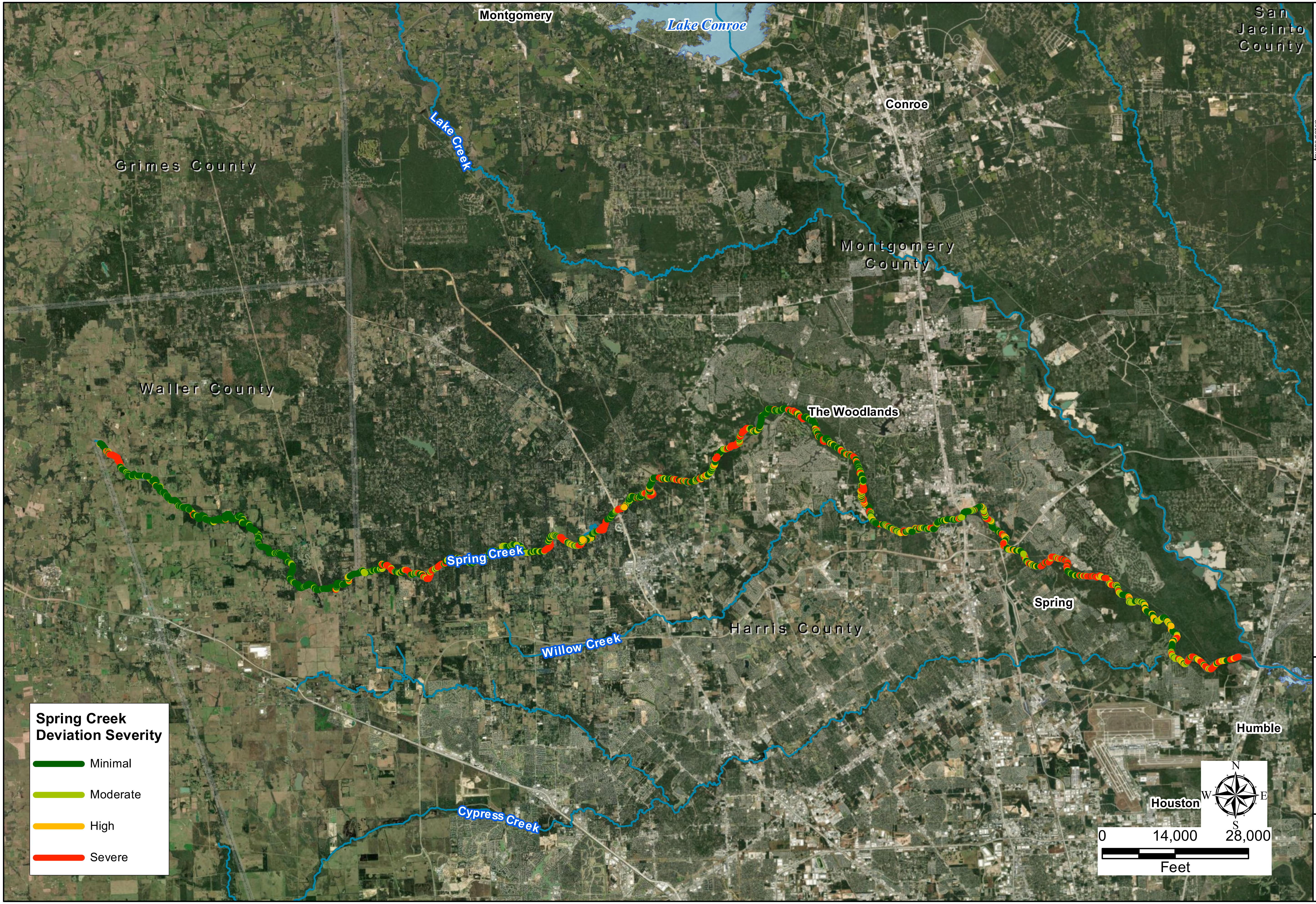


Figure C-1: Locations of Notable Lower Elevations and Notable Higher Elevations

SUMMARY

The stream deviation analysis used current and historic DEMs to estimate the current and past stream centerlines of the West Fork San Jacinto River and Spring Creek. The deviation between the past and present centerlines was then measured. This analysis identified discrete locations where these alignments have shifted resulting in potential stream bank erosion. Stream bank erosion is a sediment source.

Results of this analysis show that generally more stream deviation occurs in the downstream regions of both the West Fork San Jacinto watershed and Spring Creek watershed. Notable portions of both mainstems showed minimal deflection. Deflection mapping and the elevational change mapping have identified potential sediments sources and how these sediment sources can contribute to the creation of additional sediment sources downstream.



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PREPARED BY	DML

San Jacinto Regional Watershed Master Drainage Plan

Stream Deviation Analysis Spring Creek

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

C-2

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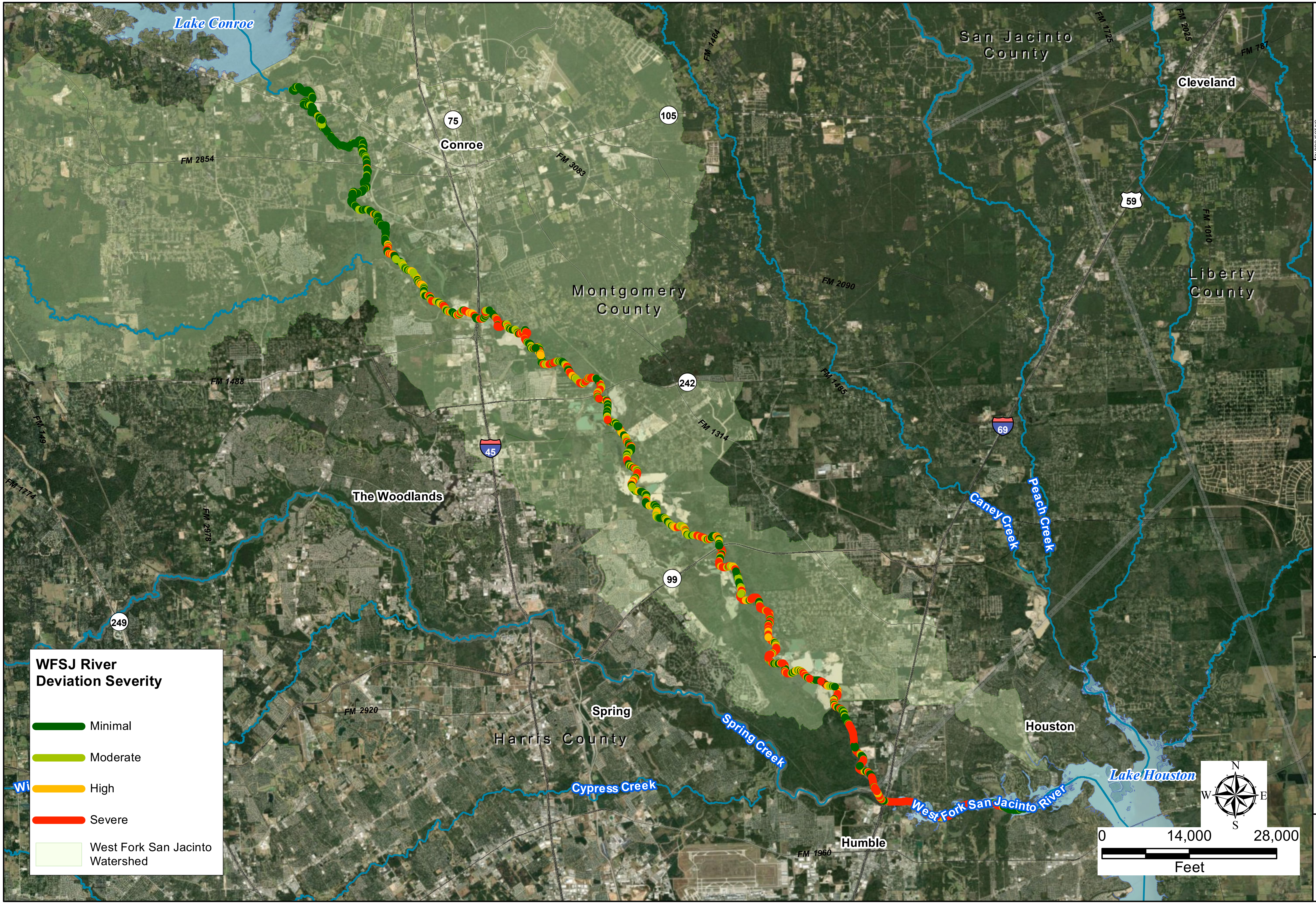

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San Jacinto Regional Watershed Master Drainage Plan

Stream Deviation Analysis West Fork San Jacinto

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

C-3

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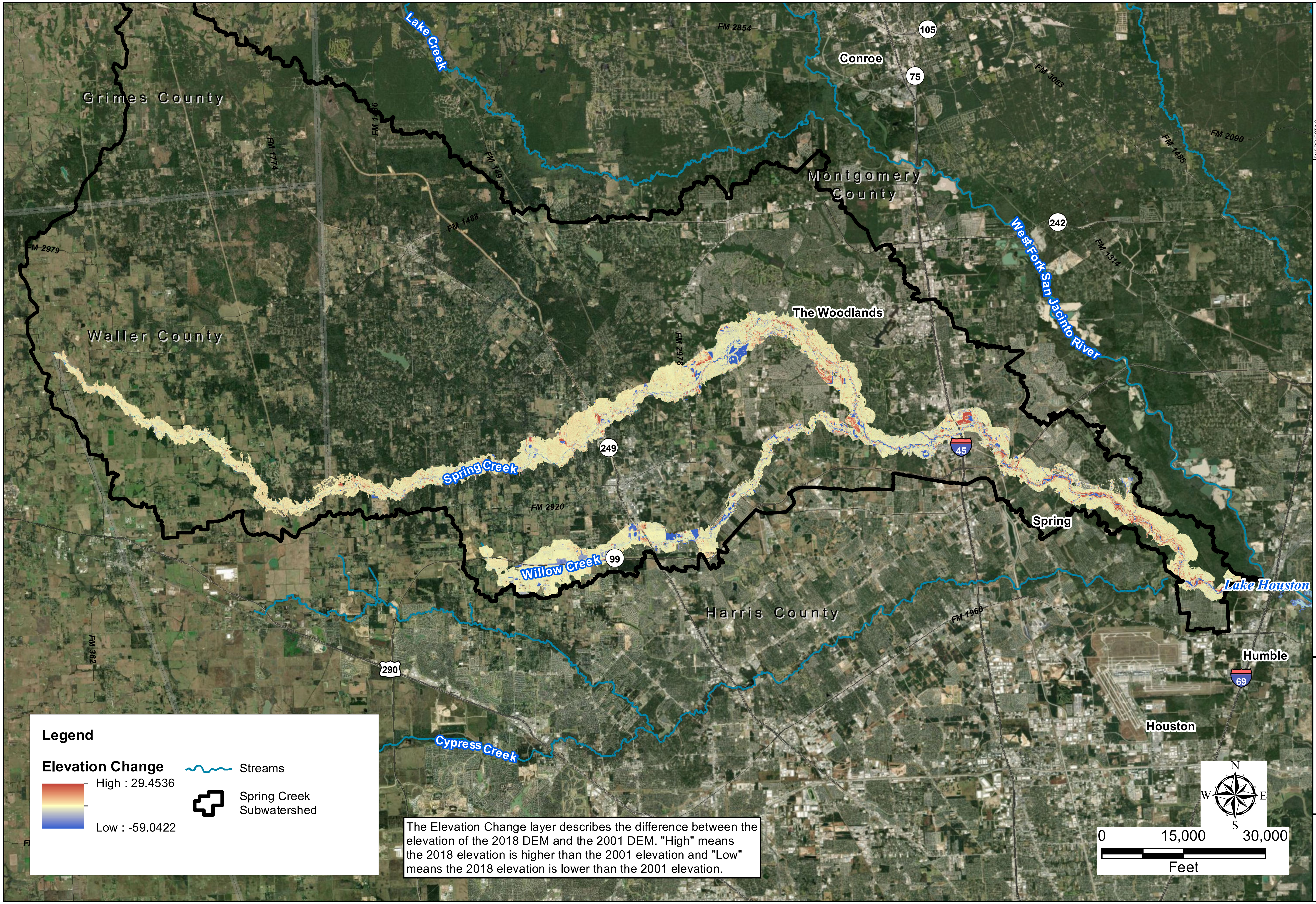

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PREPARED BY	DML

San Jacinto Regional Watershed Master Drainage Plan

LiDAR Comparison 2001 vs. 2018 - Spring Creek

Sedimentation Strategy

SAN JACINTO
REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE
C-4

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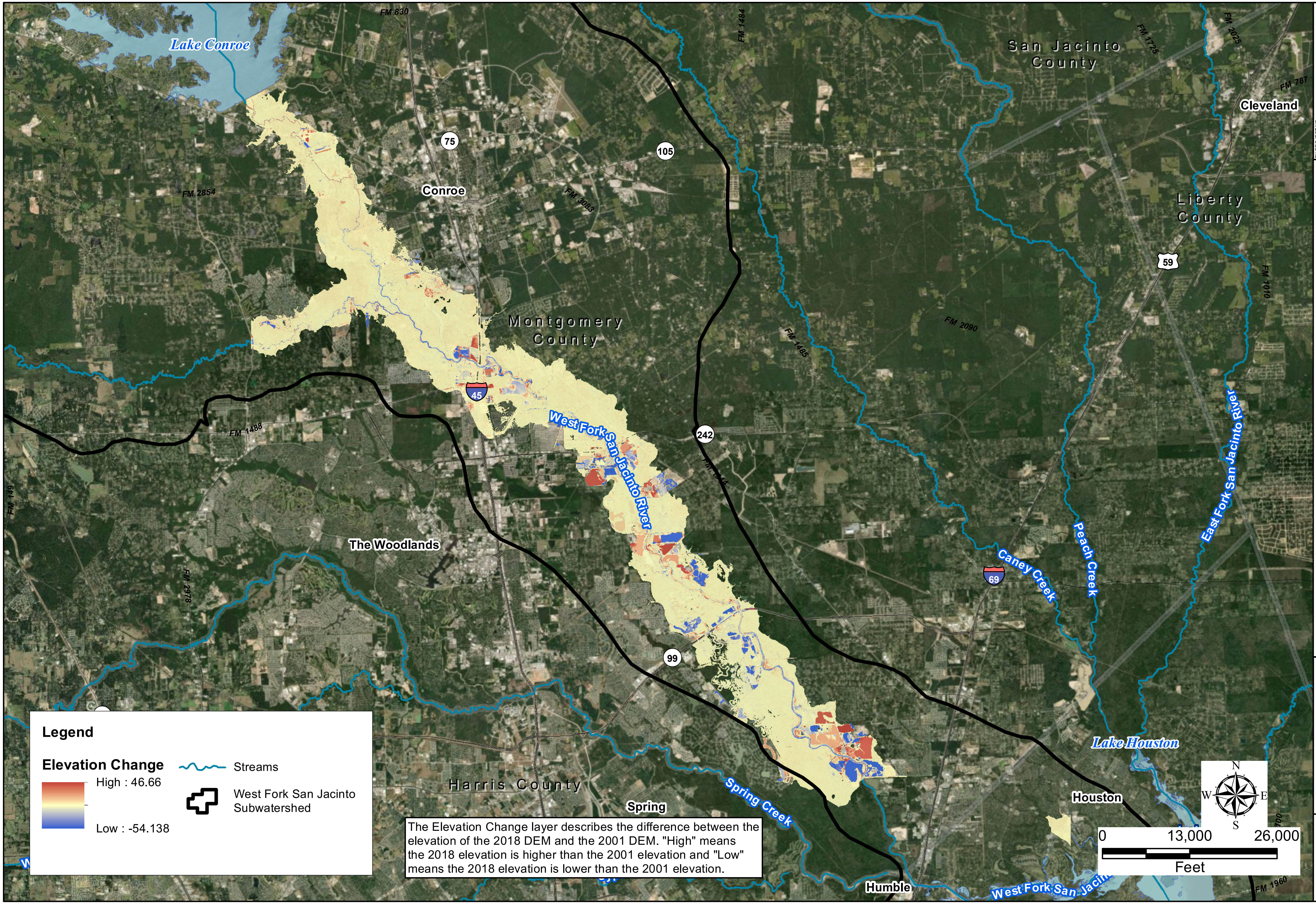

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San Jacinto Regional Watershed Master Drainage Plan

LiDAR Comparison 2008 vs. 2018 - West Fork San Jacinto

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE C-5

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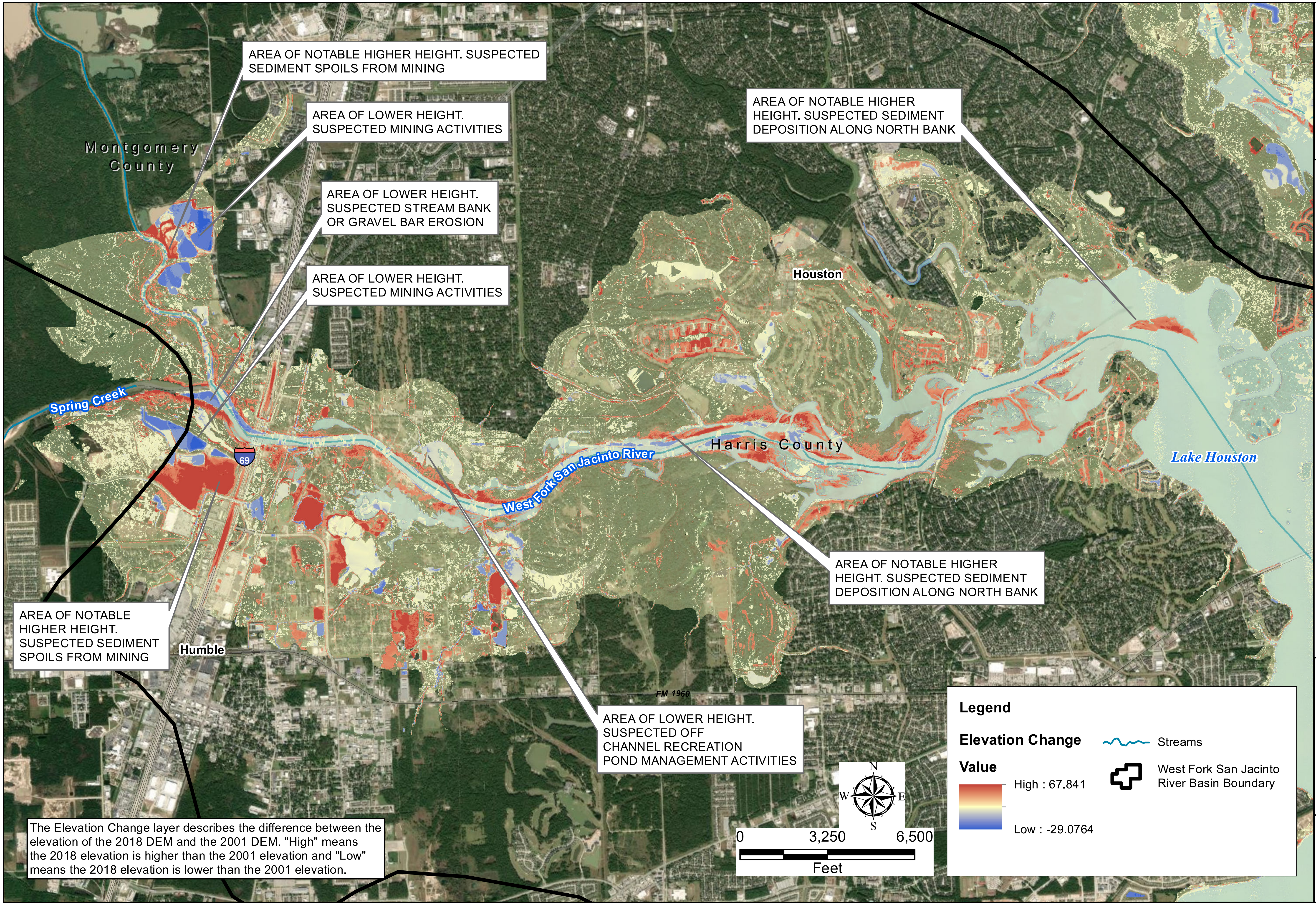

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PREPARED BY	DML

San Jacinto Regional Watershed Master Drainage Plan

LiDAR Comparison 2001 vs. 2018 - West Fork San Jacinto Subwatershed

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

C-6

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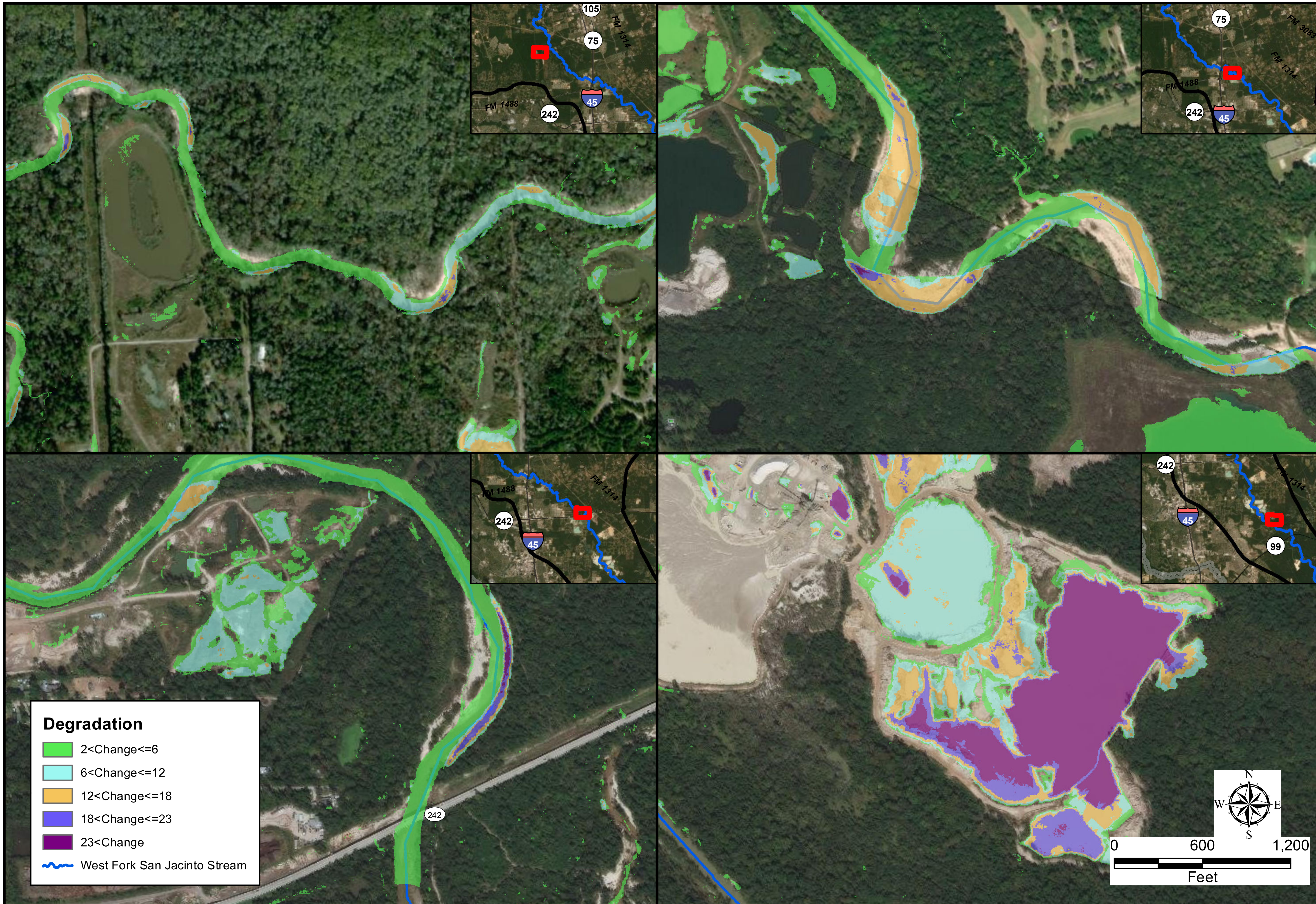

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DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central

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PREPARED BY DML

San Jacinto Regional Watershed Master Drainage Plan

LiDAR Comparison 2008 vs. 2018 - West Fork San Jacinto Subwatershed

Sedimentation Strategy

SAN JACINTO REGIONAL WATERSHED MASTER DRAINAGE PLAN

FIGURE

C-7

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APPENDIX F.D

TOTAL SUSPENDED SEDIMENT ANALYSIS

APPENDIX F.D

Total Suspended Solids Analysis

INTRODUCTION

Freese and Nichols, Inc. (FNI) was contracted to provide Halff Associates, Inc. with sediment mitigation strategies for the San Jacinto River watershed draining to Lake Houston. Phase 1 of this project involved data collection, modeling, and evaluation of previous studies in the watershed. A previous study of interest is the “Regional Flood Protection Study for the Lake Houston Watershed Flood Program” (Brown and Root 2000) prepared for the City of Houston, Harris County Flood Control District, Montgomery County, San Jacinto Water Authority, and Texas Water Development Board by Brown & Root Services (2000). One component of the Brown and Root 2000 report was a review of methods used to measure transported sediment in previous reports. In addition to this review, the Brown and Root 2000 report included a total suspended solids (TSS) analysis in which available suspended sediment data collected at United States Geological Survey (USGS) stream gages were used to estimate annual suspended sediment loads (in tons per year). As part of this study, FNI updated this TSS analysis with data collected since the Brown and Root 2000 report was completed. The purpose of this memorandum is to detail the methodology and findings of FNI’s updated TSS analysis to understand the amount of suspended sediments flowing out of the subwatersheds in the San Jacinto River watershed.

METHODOLOGY

FNI replicated the methodology used in the Brown and Root 2000 report. The following sections summarize these procedures and document deviations from the Brown and Root 2000 report.

USGS Stream Gage Data

Data for the following parameters were downloaded from USGS stream gages in the San Jacinto River watershed draining to Lake Houston:

- Suspended sediment discharge (tons per day, T/Day)
- Instantaneous discharge (cubic feet per second, CFS)
- Daily mean discharge (CFS)

A summary of downloaded data is presented in **Table D-1**.

The USGS obtains discharge-weighted mean suspended sediment concentrations in the vertical and in cross section (Porterfield, 1972). Samples are sent to a lab where concentrations are computed in parts per million. (They are later converted to milligrams per liter (mg/L).) Concentrations in the vertical are typically obtained by collecting depth-integrated samples with standard velocity-weighting samplers or by collecting point samples that represent equal units of depth (Porterfield, 1972). Concentrations in cross section are then calculated from the average of several verticals or from an average of composite samples of equal volume.

Table D-1: Summary of Available USGS Gage Data and Annual Suspended Sediment Load Estimates

Entries in **bold** were evaluated in the Brown & Root 2000 Report.

			Periods of Record							
			Sediment Data*		Daily Mean Discharge Data**					
Site Name	USGS Stream Gage ID	Drainage Area (sq mi)	Date Range	Number of Years	Date Range	Number of Years	Number of Discreet Sediment Samples*	HUC-8	Basin Name	Annual Sediment Load (T/Year)
W Fk San Jacinto Rv Bl Lk Conroe nr Conroe, TX	08067650	451	2008-2011	3	1973-2019	46	29	12040101	West Fork San Jacinto	36,318
White Oak Ck at Memorial Dr, Conroe, TX	08067652	-	2009-2009	0	-	-	7	12040101	West Fork San Jacinto	-
W Fk San Jacinto Rv at FM 2854, Conroe, TX	08067653	-	2008-2009	1	-	-	5	12040101	West Fork San Jacinto	-
Alligator Ck on Sgt Ed Holcomb Rd, Conroe, TX	08067657	-	2009-2009	0	-	-	4	12040101	West Fork San Jacinto	-
Lake Ck nr Richards, TX	08067660	40.2	2002-2004	2	-	-	7	12040101	West Fork San Jacinto	-
Lake Ck nr Dobbin, TX	08067690	157	2002-2004	2	-	-	7	12040101	West Fork San Jacinto	-
Caney Ck nr Dobbin, TX	08067700	40.4	2002-2004	2	1963-1965	2	7	12040101	West Fork San Jacinto	1,588
Lake Ck nr Karen, TX	08067800	256	2002-2009	7	-	-	16	12040101	West Fork San Jacinto	-
Lake Ck nr Conroe, TX	08067900	291	2002-2009	7	2002-2005	3	16	12040101	West Fork San Jacinto	25,389
W Fk San Jacinto Rv nr Conroe, TX	**08068000**	**828**	**1972-2011**	**39**	**1924-2019**	**95**	**187**	**12040101**	**West Fork San Jacinto**	51,217
W Fk San Jacinto Rv Abv Lk Houston nr Porter, TX	08068090	962	2011-2011	0	1984-2019	35	1	12040101	West Fork San Jacinto	-
Bear Br at Research Blvd, The Woodlands, TX	08068390	15.4	1999-1999	0	1999-2019	20	4	12040102	Spring Creek	1,865
Panther Br at Gosling Rd, The Woodlands, TX	08068400	25.9	1999-1999	0	1974-2019	45	7	12040102	Spring Creek	19,774,636
Panther Br nr Spring, TX	08068450	34.5	1973-1999	26	1972-2019	47	8	12040102	Spring Creek	11,534
Spring Ck nr Spring, TX	08068500	409	1972-2019	47	1939-2019	80	138	12040102	Spring Creek	109,808
Cypress Ck nr Westfield, TX	**08069000**	**285**	**1976-2008**	**32**	**1944-2019**	**75**	**106**	**12040102**	**Spring Creek**	161,444
W Fk San Jacinto Rv nr Humble, TX	08069500	1741	2014-2019	5	1928-1954	26	8	12040101	West Fork San Jacinto	368,810
E Fk San Jacinto Rv nr New Caney, TX	08070200	388	2004-2019	5	1984-2019	35	110	12040103	East Fork San Jacinto	38,752
Caney Ck nr Cut and Shoot, TX	08070495	94.9	2002-2004	2	-	-	9	12040103	East Fork San Jacinto	-
Caney Ck nr Splendora, TX	08070500	105	1972-2004	32	1944-2019	75	31	12040103	East Fork San Jacinto	13,010
Caney Ck nr New Caney, TX	08070600	178	2002-2004	2	-	-	9	12040103	East Fork San Jacinto	-
Peach Ck nr Cleveland, TX	08070900	70.1	2002-2004	2	-	-	8	12040103	East Fork San Jacinto	-
Peach Ck at Splendora, TX	08071000	117	2002-2004	2	1943-2019	76	9	12040103	East Fork San Jacinto	5,608
Peach Ck nr New Caney, TX	08071100	155	2002-2004	2	-	-	9	12040103	East Fork San Jacinto	-

*Limited to data points with both suspended sediment discharge (T/Day) and instantaneous discharge (CFS)

** Only includes non-zero measurements of daily mean discharge

According to USGS technical papers (Porterfield, 1972; Gray and Simões, 2008), the USGS converts suspended sediment concentrations (mg/L) to suspended sediment discharges (T/Day) using the following equation:

$$Q_s = Q_w C_s k$$

Where Q_s is suspended sediment discharge (T/Day), Q_w is water discharge (CFS), C_s is suspended sediment concentration (mg/L), and k is a coefficient that assumes a specific weight of 2.65 for sediment. The coefficient k includes the conversion from mg/L to T/Day and is equal to 0.0027 in inch-pound units or 0.0864 in metric units (Porterfield, 1972; Gray and Simões, 2008). The coefficient is derived as follows:

$$k = \frac{(60 * 60 * 24)\ seconds\ per\ day * 62.4\ pounds\ per\ cubic\ foot}{2000\ pounds\ per\ ton * 1000000} = 0.0027$$

Only two stream gages were evaluated in the 2000 Brown and Root report – West Fork San Jacinto River near Lake Conroe (USGS site 08068000) and Cypress Creek near Westfield (USGS site 08069000). In contrast, this study evaluates a total of 24 stream gages with suspended sediment data within the San Jacinto River watershed draining to Lake Houston (including the two evaluated in 2000). However, only 13 of the 24 gages had corresponding records of instantaneous and daily mean discharge over their respective periods of record.

Sediment Rating Curves and Flow Duration Curves

As in the Brown and Root 2000 report, sediment rating curves and flow duration curves were created for each of the 13 stream gages selected for evaluation (**Figure D-1**). Sediment rating curves were generated by plotting instantaneous discharge versus suspended sediment discharge on a logarithmic scale and fitting the data with a power function. Flow duration curves were generated by plotting exceedance probability versus daily mean discharge. Exceedance probability – the percentage of days in which a given flow is equaled or exceeded – was calculated for each value of daily mean discharge using the following equation:

$$P = 100 * \left(\frac{M}{n+1}\right)$$

Where P is the exceedance probability, M is the rank of a given discharge (from highest to lowest), and n is the total number of records in the dataset.

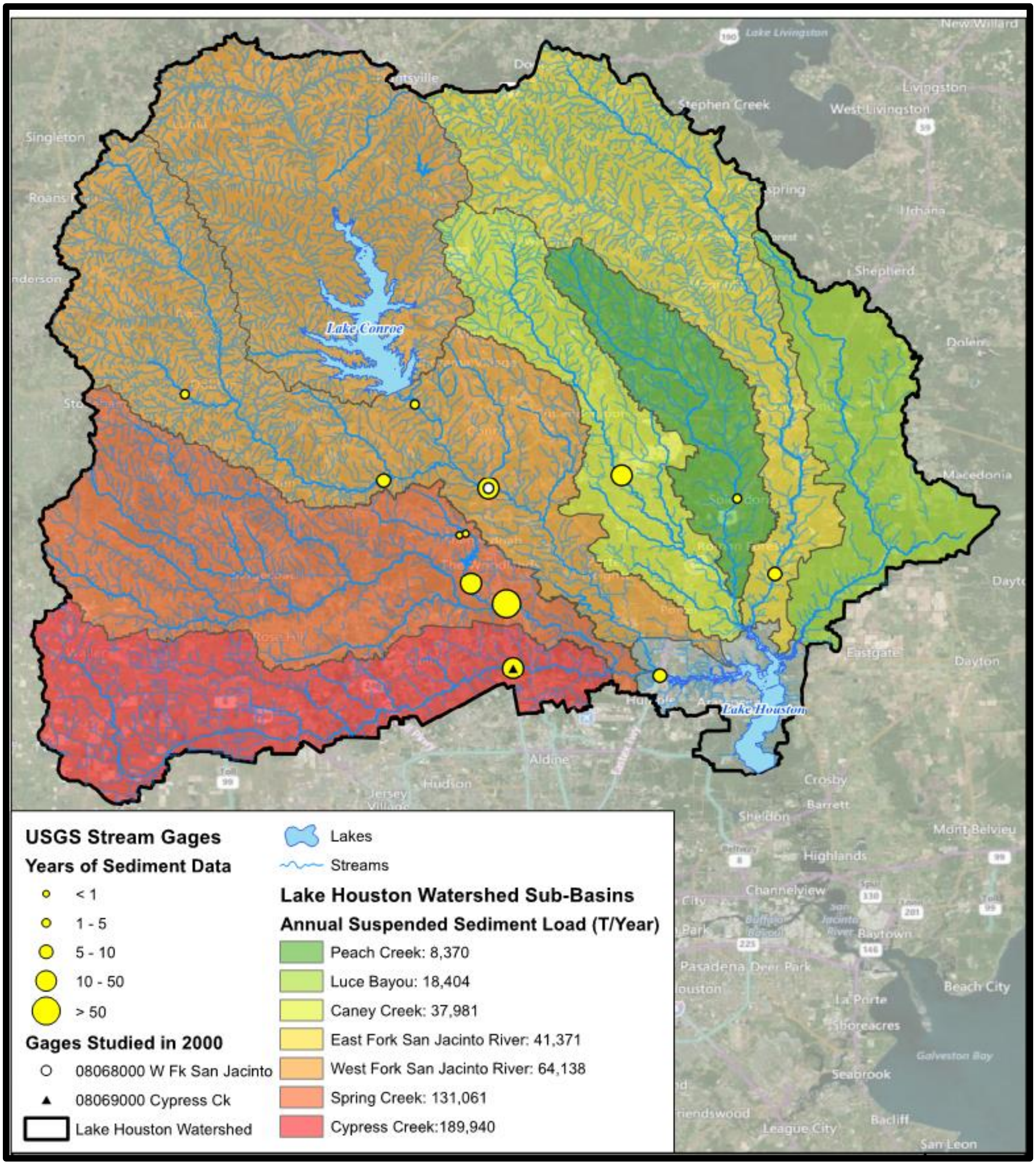

Figure D-1: Locations of USGS Stream Gages and Annual Suspended Sediment Load

Estimation of Annual Suspended Sediment Load by Individual Gage

The sediment rating curves and flow duration curves were used to estimate annual suspended sediment loads in tons per year for each gage. The attached **Figure D-3** presents all the sediment rating curves and flow duration curves used in this study.

Flow events were organized into the same 17 bins (occurrence ranges) used in the Brown and Root 2000 report. The daily mean discharge occurring at each average occurrence was obtained from the flow duration curve. The sediment load for each average occurrence flow was calculated using the equation of the power function from the sediment rating curve. Finally, an increment of load per occurrence was calculated by multiplying the load per occurrence flow by the occurrence increment and normalizing the result (Brown & Root, 2000; Welborn and Bezant, 1978). These values were then summed (total daily sediment load) and multiplied by 365 days to estimate a total annual suspended sediment load in tons per year, as presented in the attached **Figure D-4**.

Estimation of Annual Suspended Sediment Load by Subwatershed

An estimate of the total annual suspended sediment load for each of the seven subwatersheds was obtained by applying the drainage-area ratio method using a representative gage in each subwatershed. The attached **Figure D-5** presents all the total annual suspended loads for the seven subwatersheds. The drainage-area ratio method is a technique used to estimate streamflow at an ungaged location using streamflow from a nearby gage (Emerson et al., 2005). The relevant equation is as follows:

$$\widehat{Q_1} = Q_2 K \left(\frac{A_1}{A_2}\right)^{\phi}$$

Where $\widehat{Q_1}$ is the streamflow (CFS) at the ungaged location (the discharge points of the seven subwatersheds in the case of this study), Q_2 is the streamflow (CFS) at the representative gage, K is a bias correction factor, A_1 and A_2 are the drainage areas at the locations of $\widehat{Q_1}$ and Q_2, and ϕ is a dimensionless exponent.

Generally, the exponent ϕ is assigned a value of 1; however, analysis by Asquith et al. (2006) suggests that the exponent more accurately scales by a fractional power of drainage area (ϕ varies and is less than 1). The same study also concluded that the bias correction factor K is generally between 1 and 1.01 for most percentile ranges. For the purposes of this study, the bias correction factor was kept at 1 while the exponent ϕ was assigned a value based on Table 5 provided by Asquith et al. (2006). After using this method to calculate streamflow at the ungaged subwatershed discharge points, the methods described above for estimating annual sediment load were repeated at those locations.

Geotechnical Core Analysis

In the absence of collected and measured bedload data, geotechnical data from two previous studies were examined to characterize percent suspended sediment versus percent bedload sediment deposited in Lake Houston. FNI examined 32 boring logs from two studies of Lake Houston. Six borings are documented in "Volumetric and Sedimentation Survey of Lake Houston: December 2011 Survey" by the Texas Water Development Board (TWDB) (2011) and 26 additional borings are documented in "Lake Houston Sub-Bottom Profiling and Coring" by Tetra Tech (2019). The boring logs and figures showing boring locations can be found in those reports. Percentages of sand, silt, and clay in the surficial layer of each boring were recorded.

RESULTS AND DISCUSSION

Table D-1 above provides a summary of available gage data and corresponding estimates of annual suspended sediment load. **Figure D-1** above shows the locations of the 13 gages evaluated in the seven subwatersheds. The attached **Figure D-3** presents sediment rating curves and flow duration curves for each of the 13 gages. The attached **Figure D-4** presents a table of annual suspended sediment load calculations for each of the 13 gages. The attached **Figure D-5** shows the total suspended sediment load calculations using the drainage-area ratio method for each of the seven subwatersheds of the San Jacinto River watershed draining to Lake Houston.

Estimation of Annual Suspended Sediment Load by Individual Gage

As shown in **Table D-1**, estimated annual sediment loads for the individual 13 gages range from 1,500 to 19,800,000 tons per year. **Figure D-2** below confirms that higher annual sediment loads are associated with larger drainage areas. The stream gage on Panther Branch near Gosling Road at The Woodlands has an estimated sediment load value of 19,800,000 tons per year, two orders of magnitude higher than the highest value among the other 12 sites. This estimation of annual sediment load appears to be an outlier, and when it is removed from the data set, the remaining data fit the regression line much closer (**Figure D-2**). This individual gage was not used to estimate suspended sediment loads at the watershed level.

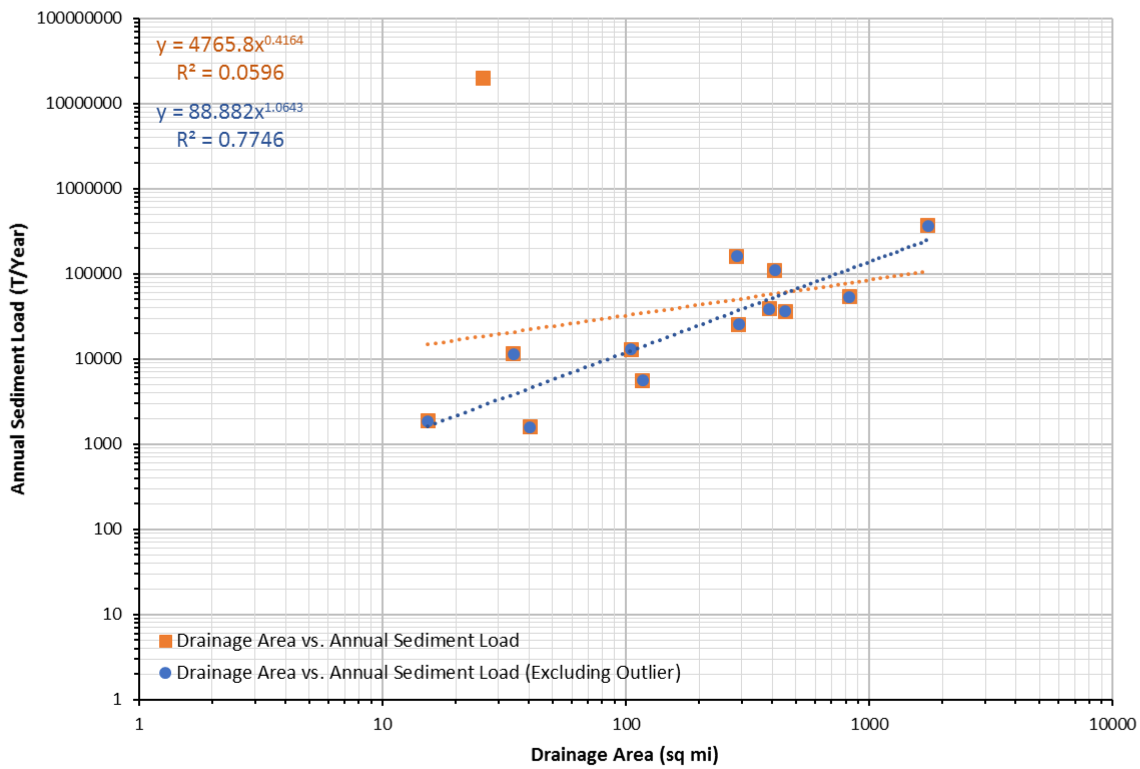

Figure D-2. Drainage Area vs. Annual Suspended Sediment Load in the Lake Houston Watershed

Estimation of Annual Suspended Sediment Load by Subwatershed

Table D-2 below compares updated estimates of total annual sediment load for the two subwatersheds evaluated in the Brown and Root 2000 report. The updated estimates are similar to the original estimates, with differences of 20 percent and 2 percent for the West Fork San Jacinto River and Cypress Creek subwatersheds, respectively. The increase in estimated annual sediment load in the West Fork San Jacinto subwatershed may be attributed to increasing development. The data continue to show that sediment loads are much higher in Cypress Creek than in the West Fork San Jacinto River.

Table D-2. Summary of Annual Suspended Sediment Loads by Subwatershed

Basin	Previous Studies (Before 2000)		Lake Houston Report (2000)	FNI Study (2019)			Percent Change
	Range	Mean		At Gage*	Adjusted**	Gage ID	(2000-2019)
Cypress Creek	42,000 - 87,000	68,000	158,000	161,444	189,940	08069000	2%
Spring Creek	15,000 - 51,000	27,000	-	109,808	131,061	08068500	-
West Fork San Jacinto	24,000 - 59,000	35,000	45,000	54,060	64,138	08068000	20%
East Fork San Jacinto	8,000 - 19,000	16,000	-	38,752	41,371	08070200	-
Caney Creek	5,000 - 14,000	10,000	-	13,010	37,981	08070500	-
Peach Creek	3,000 - 27,000	11,000	-	5,608	8,370	08071000	-
Luce Bayou†	5,000 - 22,000	9,000	-	-	18,404	08070200	-
Total	102,000 - 279,000	176,000			491,265		

* Annual sediment load (tons per year) estimated from the gage closest to the pour point
** Annual sediment load adjusted using the drainage-area ratio method to account for the entire watershed
† No gages with sediment data as of 2019; estimation of annual sediment load was derived using data from the East Fork San Jacinto gage

The updated estimates for annual suspended sediment load by subwatershed (**Table D-2**) also show the same trends reported in previous studies, including the Lake Houston report, with Cypress Creek and Spring Creek having the largest values for annual sediment load. The previous studies used a mixture of theoretical and empirical methods to estimate annual suspended sediment loads. The replication of the empirical methods used in the 2000 Brown and Root report produced comparable results to previous efforts. Estimated sediment loads across the seven subwatersheds in this analysis range from 8,000 to 190,000 tons per year. The sum of the adjusted values of sediment load for this study (491,265 tons/year) is over 2.5 times the sum estimated by studies predating 2000.

Note that the sediment load estimate for Caney Creek is derived from a gage that is located in the middle of the subwatershed, which is why the adjusted value for the subwatershed is nearly double the estimated value at the gage. Also note that the estimate for Luce Bayou was obtained using data from the East Fork San Jacinto gage, since there were no gages with sediment data found along Luce Bayou. This probably results in an overestimate of sediment load, whereas previous studies showed Luce Bayou to be the subwatershed with the lowest annual sediment load.

Geotechnical Core Analysis

Percentages of sand, silt, and clay in the surficial layer of each boring were recorded in **Table D-3** below. Note that the TWDB report (2011) did not provide percentages; therefore, a soil classification ternary diagram was used to estimate an average size distribution based on the qualitative descriptions of the material. Groten et al. (2016) found that sediment finer than 0.25 mm (fine sand) is likely to be transported in the water column as suspended sediment, whereas sediment larger than 2 mm (very fine gravel) likely rolls along the channel bottom as bedload sediment. Sediment ranging in size between 0.25 mm and 2 mm is likely a mixture of suspended load and bedload. Following these principles, borings with surficial layers dominated by predominantly clay, silt, and fine sand were designated as deposits of suspended load. None of the borings recorded gravel-sized particles or larger, meaning that none of the surficial deposits sampled by the borings were dominated by bedload sediment.

Table D-3: Summary of Surficial Sediment Characteristics from 32 Borings Across Lake Houston

Report	Log	% Sand	% Silt	% Clay	USCS	USDA	Sediment Load Type*
Tetra Tech, 2019	LH-1	10%	85%	5%	ML	Silt	Suspended
Tetra Tech, 2019	LH-2	20%	80%	0%	ML	Silt Loam	Suspended
Tetra Tech, 2019	LH-3	95%	5%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-4A	95%	5%	0%	SP	Fine Sand	Suspended
Tetra Tech, 2019	LH-5	1%	9%	90%	CH	Clay	Suspended
Tetra Tech, 2019	LH-6	100%	0%	0%	SP	Coarse Sand	Mixed
Tetra Tech, 2019	LH-7	100%	0%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-8	95%	5%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-9	100%	0%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-10	95%	5%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-11	95%	5%	0%	SP	Coarse Sand	Mixed
Tetra Tech, 2019	LH-12	95%	5%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-13A	90%	10%	0%	SP	Fine Sand	Suspended
Tetra Tech, 2019	LH-14	95%	5%	0%	SP	Coarse Sand	Mixed
Tetra Tech, 2019	LH-15	95%	5%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-16	95%	5%	0%	SP	Coarse Sand	Mixed
Tetra Tech, 2019	LH-17	95%	5%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-18	100%	0%	0%	SP	Coarse Sand	Mixed
Tetra Tech, 2019	LH-19	100%	0%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-20	100%	0%	0%	SP	Coarse Sand	Mixed
Tetra Tech, 2019	LH-21	90%	10%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-22	95%	5%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-23	5%	90%	5%	ML	Silt	Suspended
Tetra Tech, 2019	LH-24	95%	5%	0%	SP	Sand	Mixed
Tetra Tech, 2019	LH-25A	55%	40%	5%	SM	Fine Sandy Loam	Suspended
Tetra Tech, 2019	LH-26	90%	10%	0%	SP	Sand	Mixed
TWDB, 2011	H-1	23%	14%	63%	ML	Silt Loam	Suspended
TWDB, 2011	H-2	7%	46%	47%	CH	Silty Clay	Suspended
TWDB, 2011	H-3	7%	46%	47%	CH	Silty Clay	Suspended
TWDB, 2011	H-4	7%	46%	47%	CH	Silty Clay	Suspended
TWDB, 2011	H-5	7%	46%	47%	CH	Silty Clay	Suspended
TWDB, 2011	H-6	7%	46%	47%	CH	Silty Clay	Suspended

*"Mixed" denotes grain size distributions that likely represent a mixture of bedload and suspended load

Further investigation to estimate the percentage of bedload sediment and suspended sediment in the remaining borings (designated as "Mixed") would require particle size distributions and percentages of different size classes of sand (very coarse, coarse, medium, and fine). Since several of the boring logs differentiate between coarse sand and fine sand, it is possible that entries described as "sand" are referring to medium sand. While more detailed analysis cannot be undertaken due to lack of data, it is important to note that the annual sediment load estimates reported above and in past analyses likely underestimate total sediment load because bedload is not accounted for. It is recommended that future studies collect sediment samples to create a particle size distribution of the total sediment load. These samples should be collected in various locations around the watershed to compare if the sediment size of the sediment load changes.

CONCLUSIONS

This study updates the 2000 Brown and Root Services total suspended sediment analysis performed in the San Jacinto River watershed draining to Lake Houston. Thirteen stream gages were used to create sediment rating curves and flow duration curves, which were used to estimate annual suspended sediment load at each gage. The drainage-area ratio method was used to estimate annual suspended sediment loads for each of the seven subwatersheds in the Lake Houston watershed. Thirty-two geotechnical boring logs were examined to understand the distribution of suspended sediment load versus bedload in Lake Houston. Significant findings of the study include:

- The data show that instantaneous discharge has a significant impact on suspended sediment load.
- Updated estimates of total annual sediment load for the two gages evaluated in the Lake Houston report are similar to the original estimates, with changes of 20 percent and 2 percent for the West Fork San Jacinto and Cypress Creek subwatersheds, respectively.
- The data continue to show similar trends among the seven subwatersheds, with much higher sediment loads in Cypress Creek than West Fork San Jacinto River.
- Estimated sediment loads at the 13 gages range from 1,500 to 370,000 tons per year. The estimate at USGS 08068400 Panther Brook at Gosling Road, 19,800,000 tons per year, appears to be an outlier. This gage's suspended sediment discharge curve (**Figure D-1**) shows a very large outlier which is three orders of magnitude greater than the other measurements. This causes the slope of the line of best fit to be steep, resulting in a very high annual sediment load. If a more detailed analysis for this particular gage is desired, this outlier can be removed and the analysis rerun. Results can be compared to other gages with similar drainage areas and watershed characteristics. The second largest estimate is 370,000 tons per year at USGS gage 08069500 West Fork San Jacinto River near Humble, Texas. Per **Table D-1**, the sediment data was measured in the early to mid-20th century but the discharge data used in the analysis included only five years of data from 2014 to 2019. The temporal difference in measurements may be the reason why this gage's annual suspended data is significantly higher than the third-largest sediment load of 161,444 tons per year at USGS gage 08069000 Cypress Ck near Westfield, TX.
- Estimated suspended sediment loads across the seven subwatersheds range from 8,000 to 190,000 tons per year. The highest value, 190,000 tons per year for the Cypress Creek subwatershed, is lower than the two highest estimated suspended sediment loads at individual USGS stream gages. Per the reasoning above, more data collection is needed to increase the level of confidence in the recorded data at these two gages.
- The sum of the adjusted values of sediment load for this study (491,265 tons/year) is over 2.5 times the sum estimated by studies predating 2000. This may be due to an actual increase in sediment load over time due to changes in land use, or due to better availability of data.

- There is insufficient data in the geotechnical reports examined to reach distinct conclusions regarding percent bedload; however, it is important to note that the sediment load estimates reported above and in past analyses likely underestimate total sediment load because bedload is not accounted for. It is recommended that future studies collect sediment samples to create particle size distributions.

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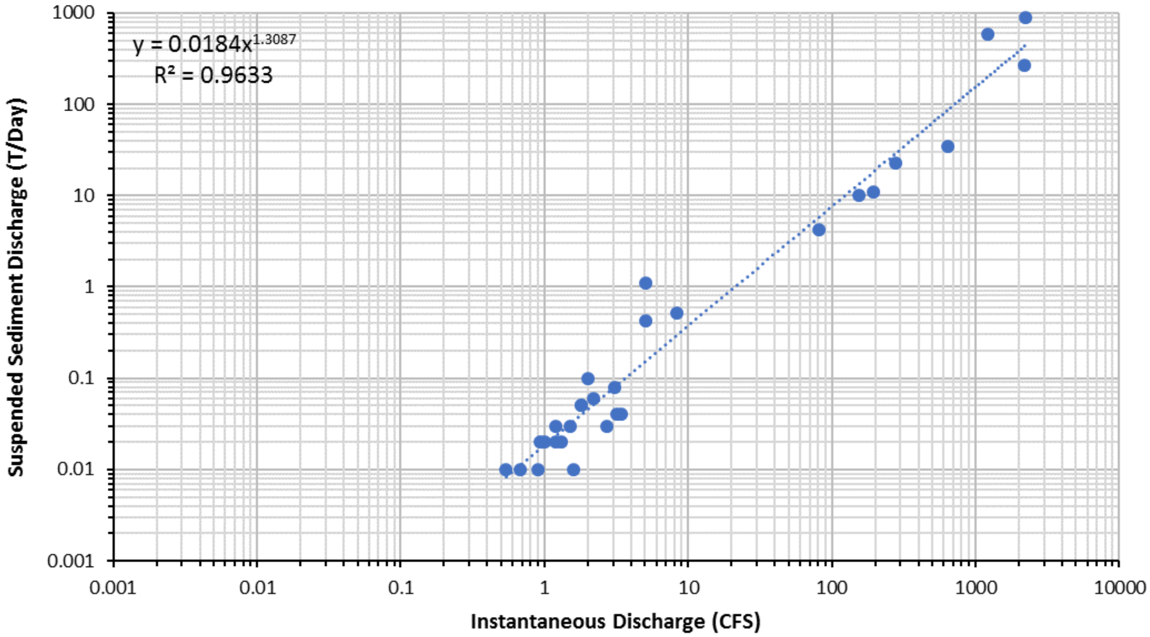
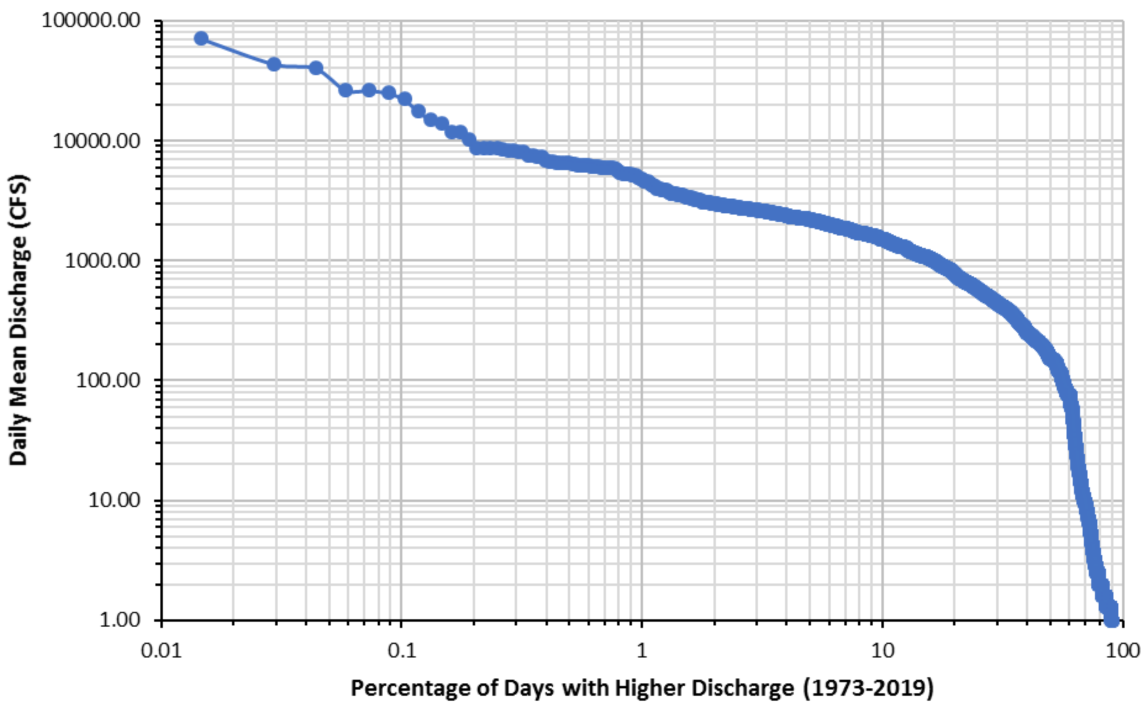
APPENDIX F.D

FIGURE D-3

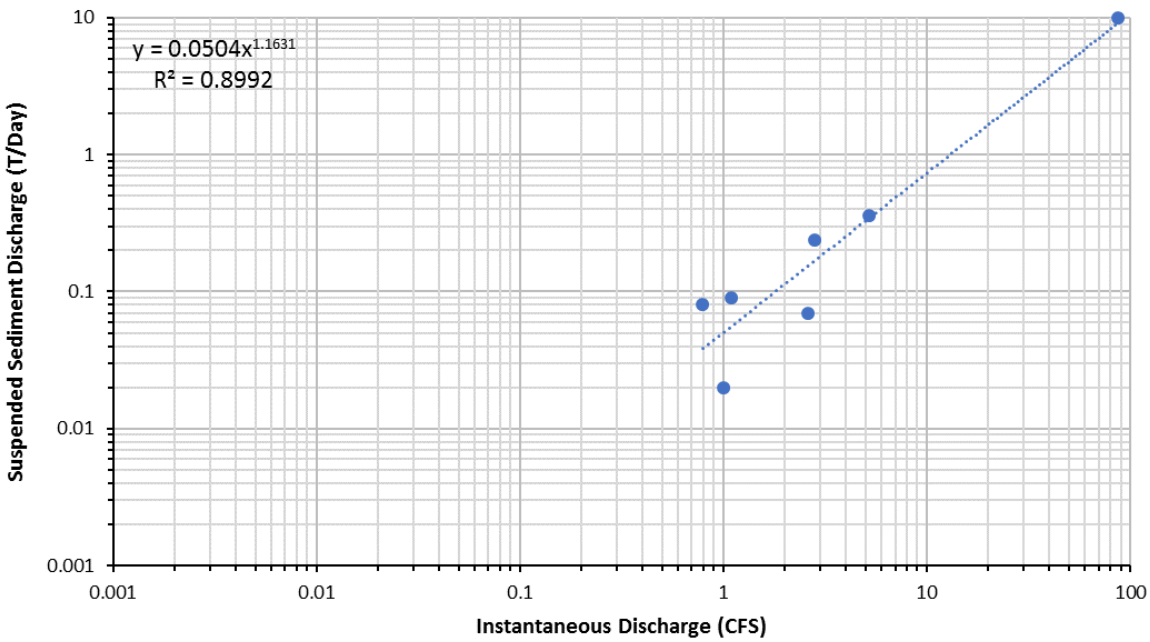
SEDIMENT RATING CURVES AND FLOW DURATION CURVES

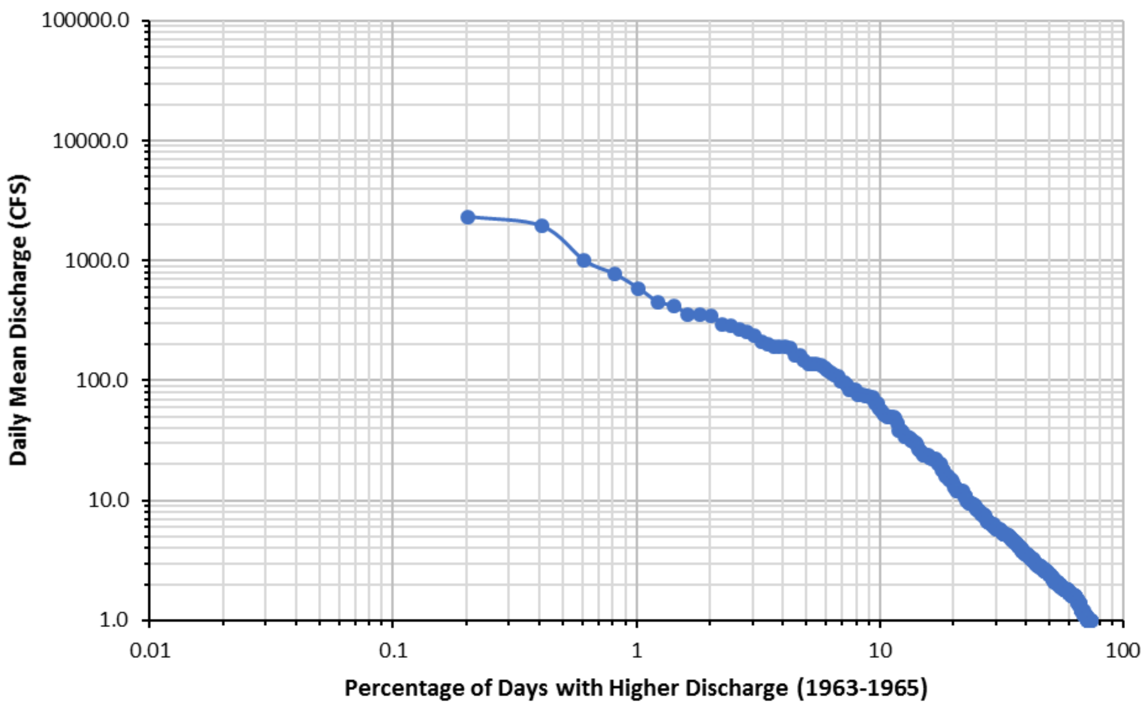
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves
USGS 08067650 W Fk San Jacinto Rv Bl Lk Conroe nr Conroe, TX



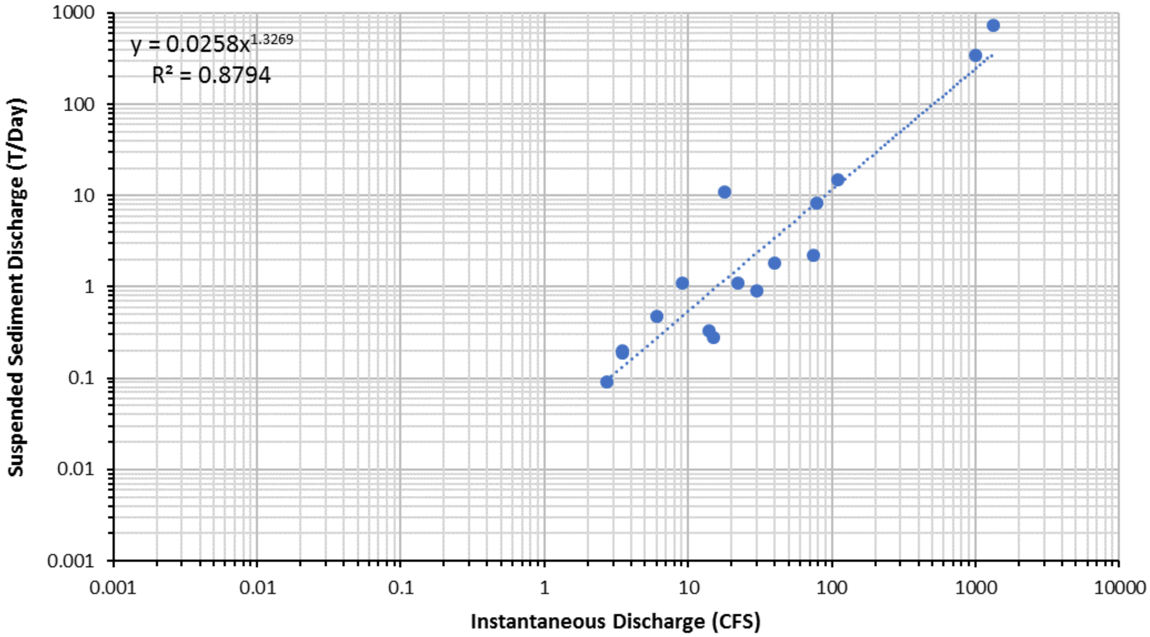


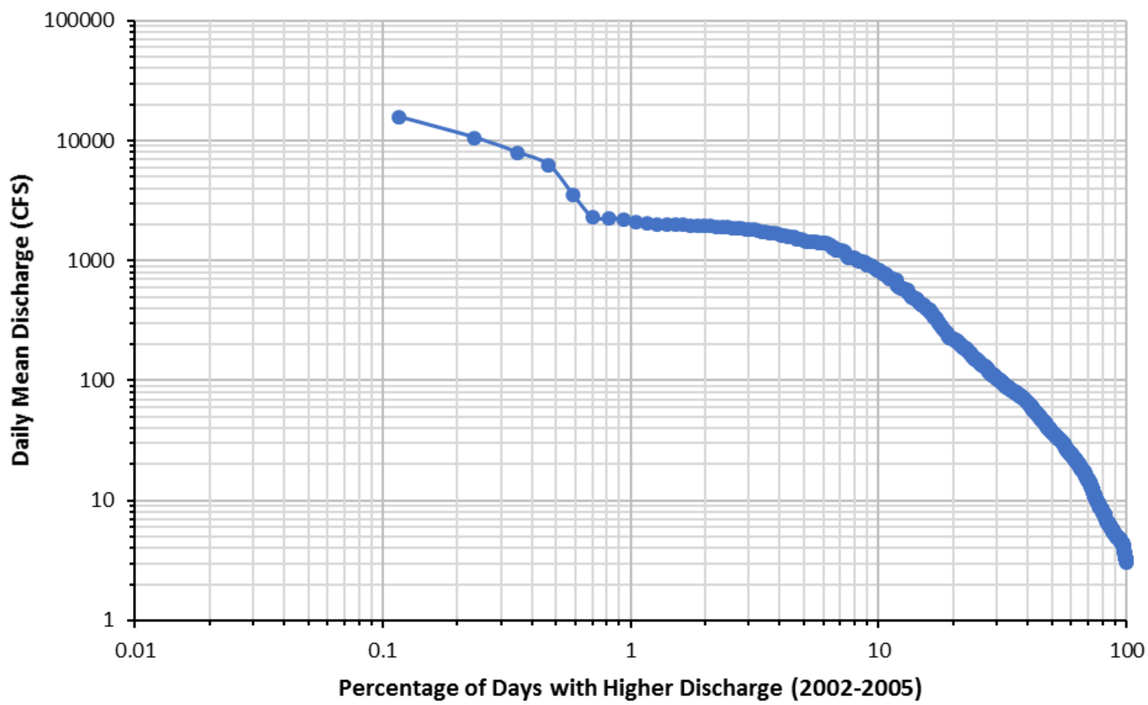
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves
USGS 08067700 Caney Ck nr Dobbin, TX





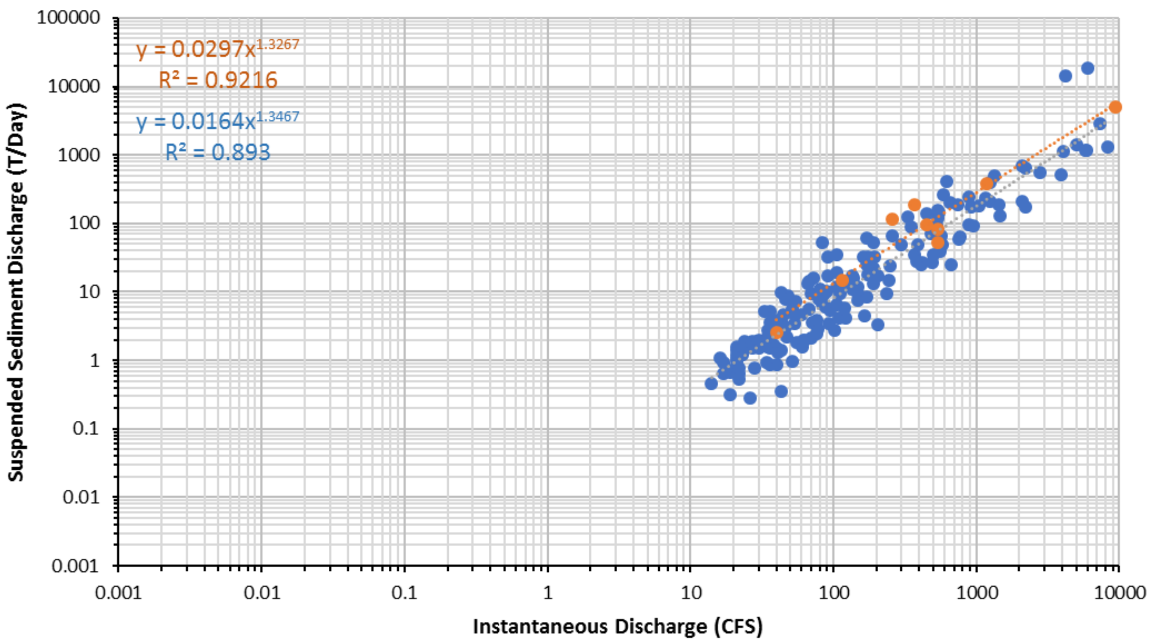
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves
USGS 08067900 Lake Ck nr Conroe, TX





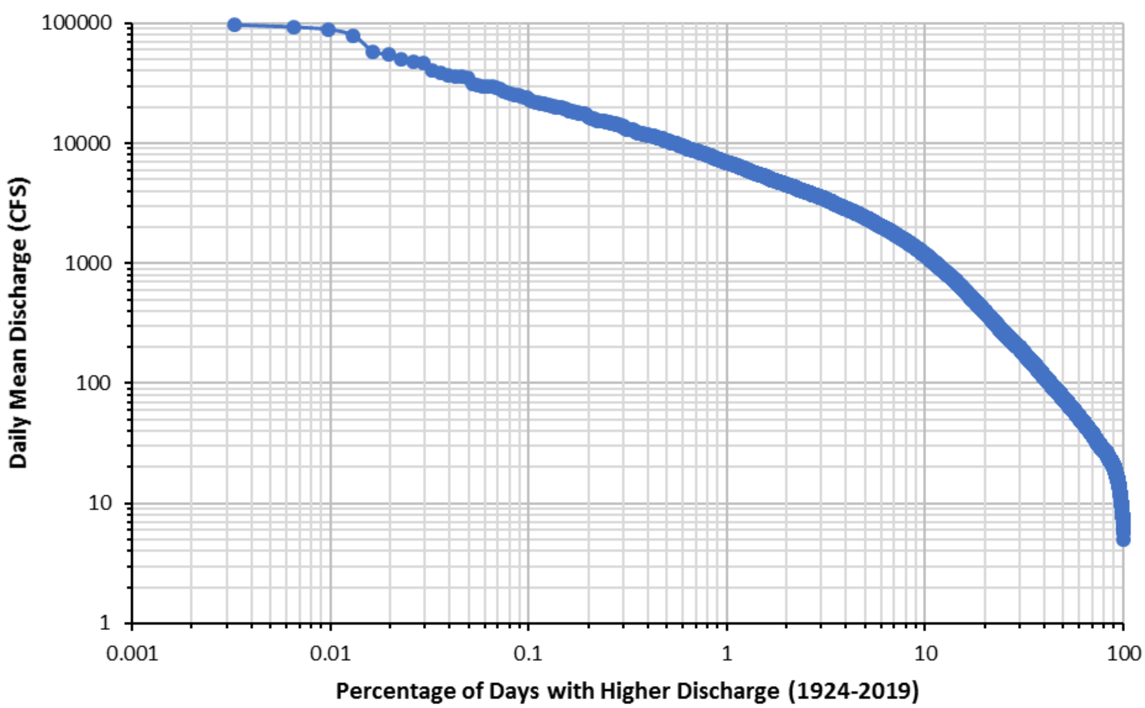
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves

USGS 08068000 W Fk San Jacinto Rv nr Conroe, TX



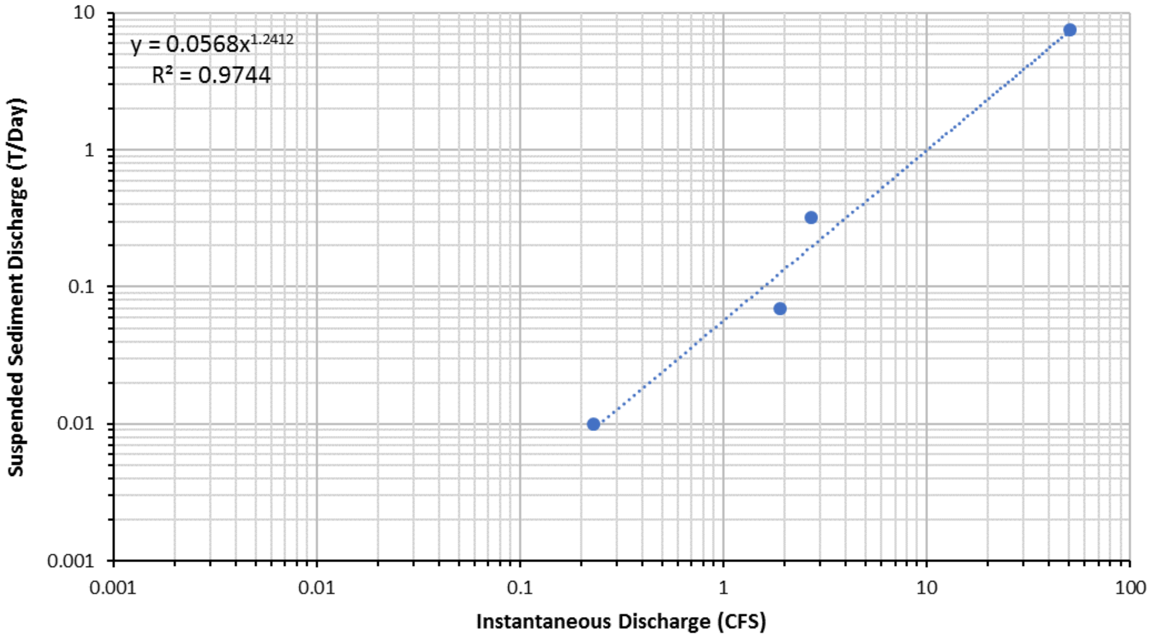
Equation for pre-1974 (pre-Lake Conroe) sediment data

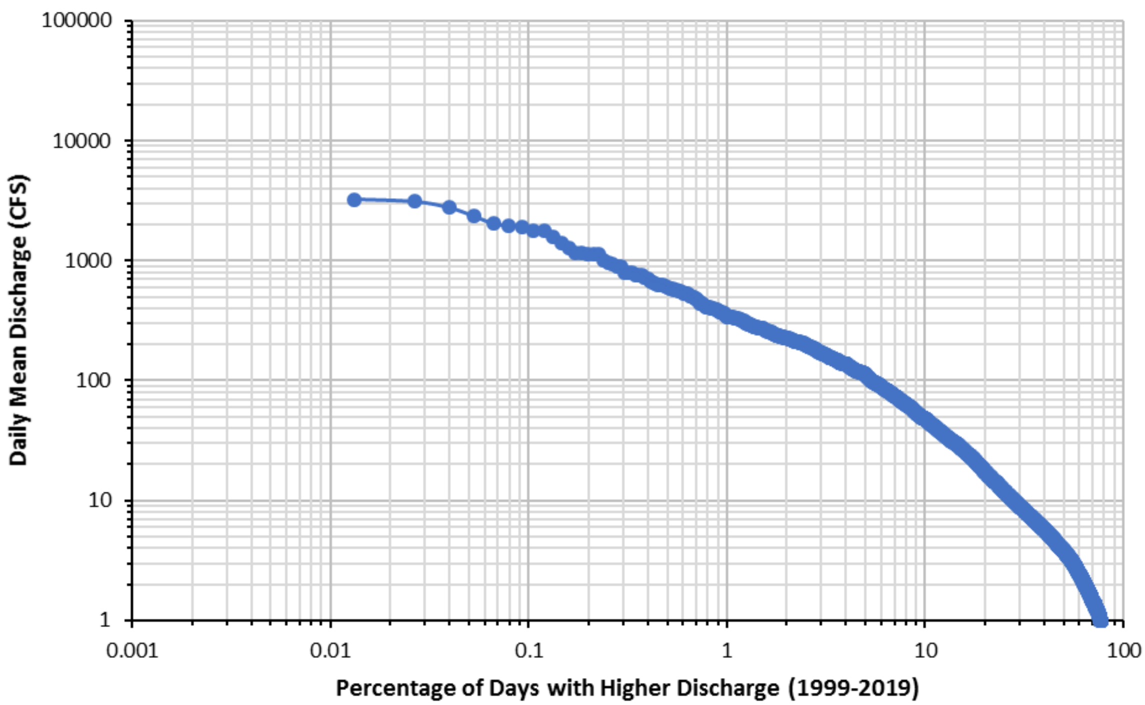
Equation for post-1974 (post-Lake Conroe) data



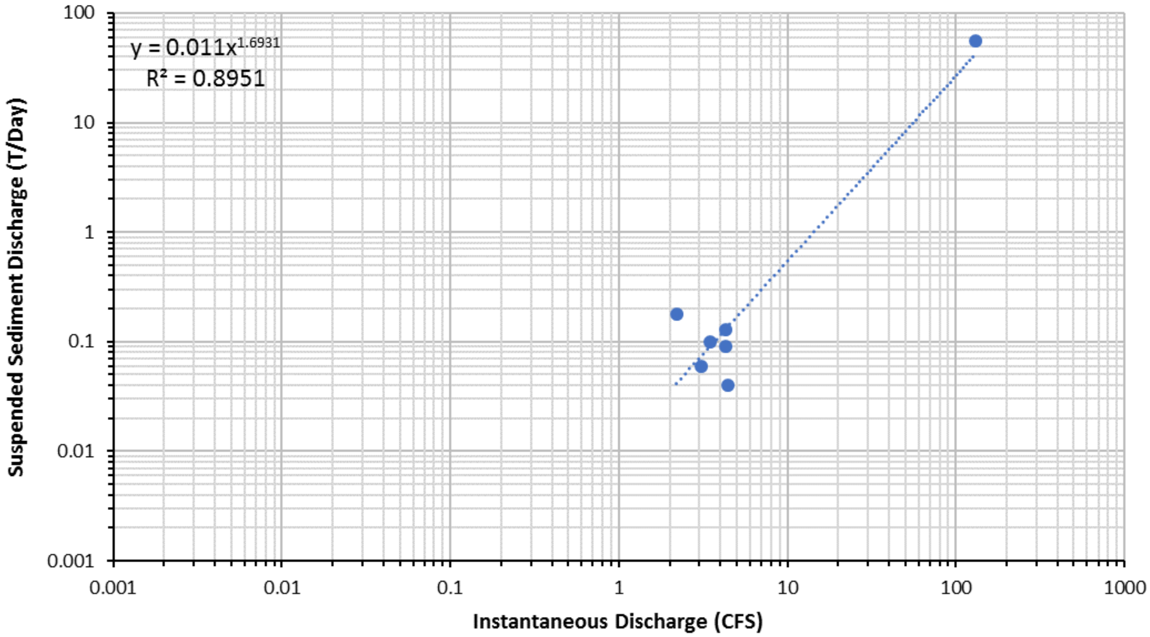
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves

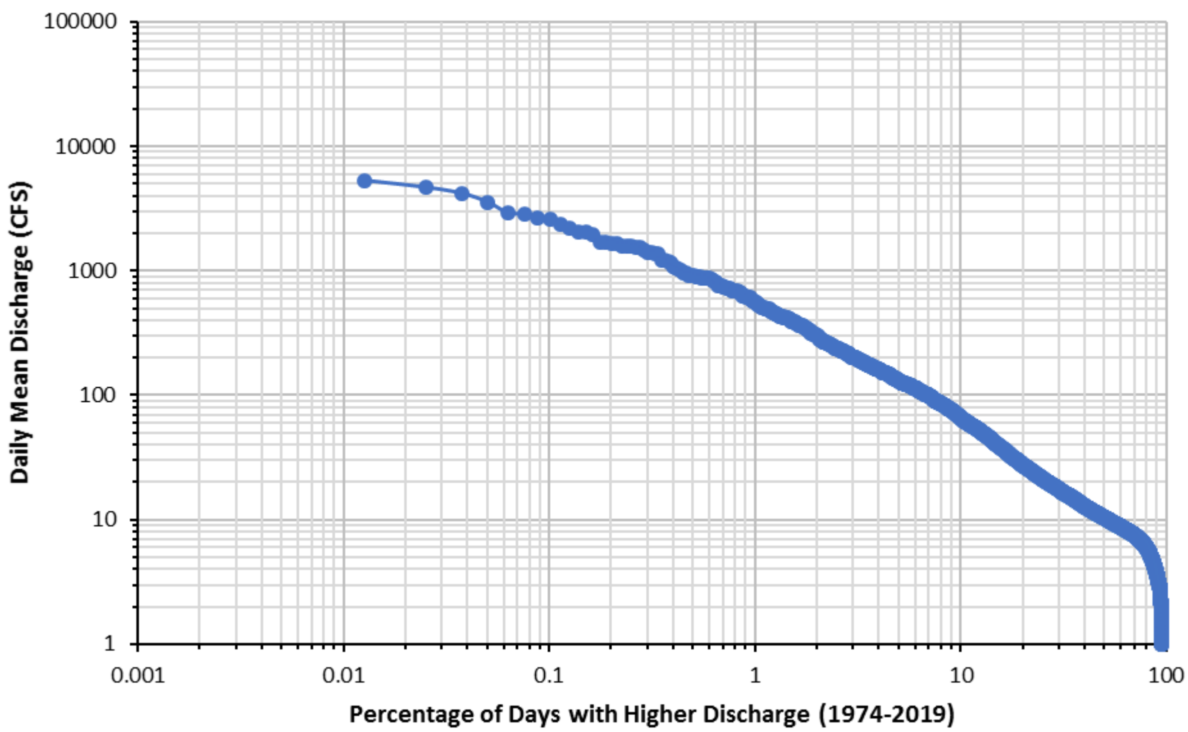
USGS 08068390 Bear Br at Research Blvd, The Woodlands, TX



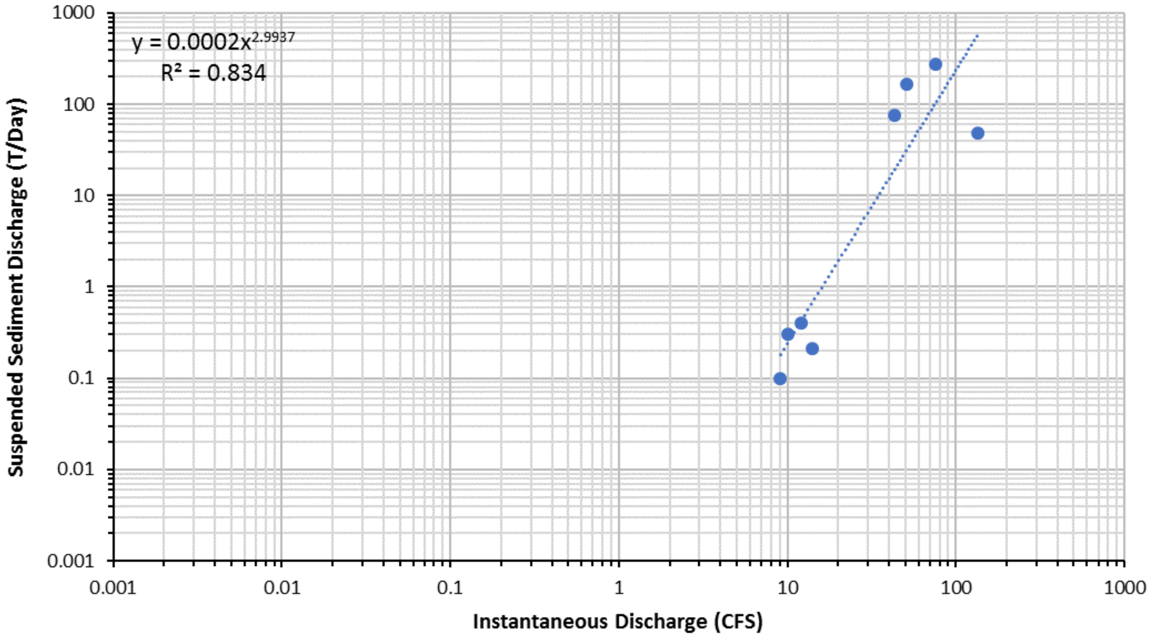


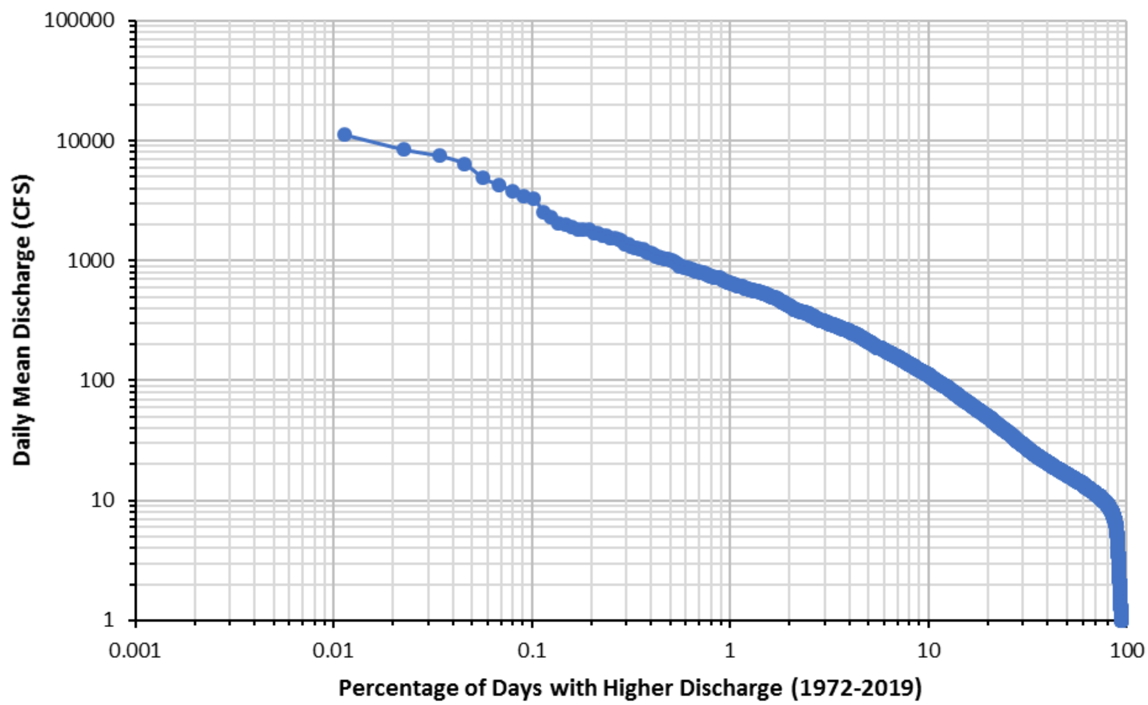
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves
USGS 08068400 Panther Br at Gosling Rd, The Woodlands, TX





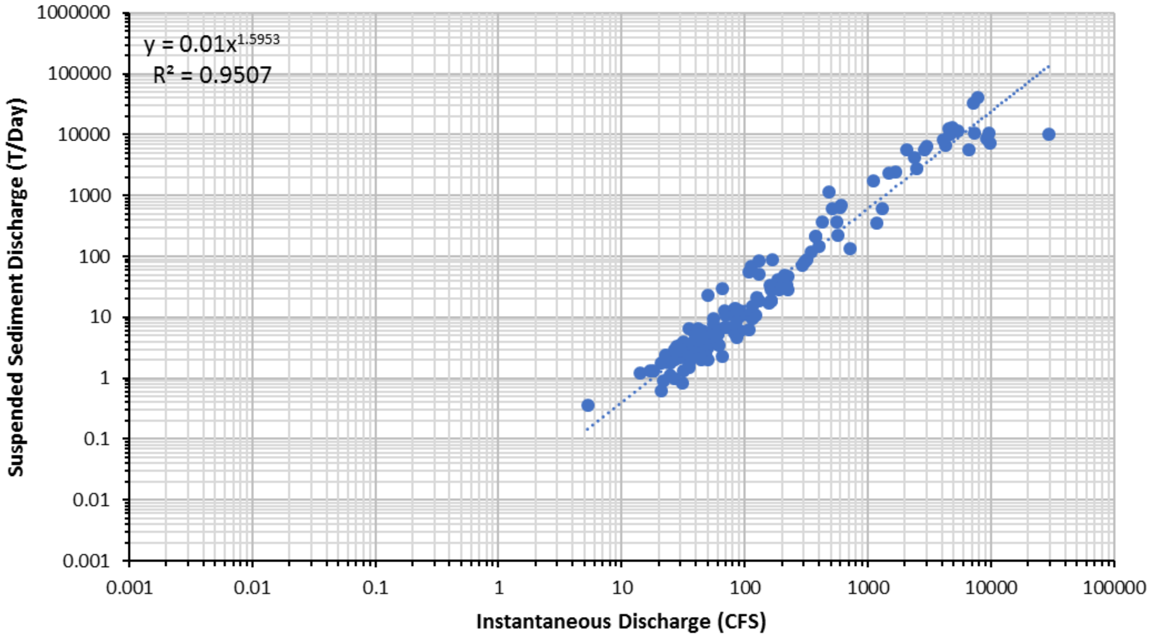
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves
USGS 08068450 Panther Br nr Spring, TX

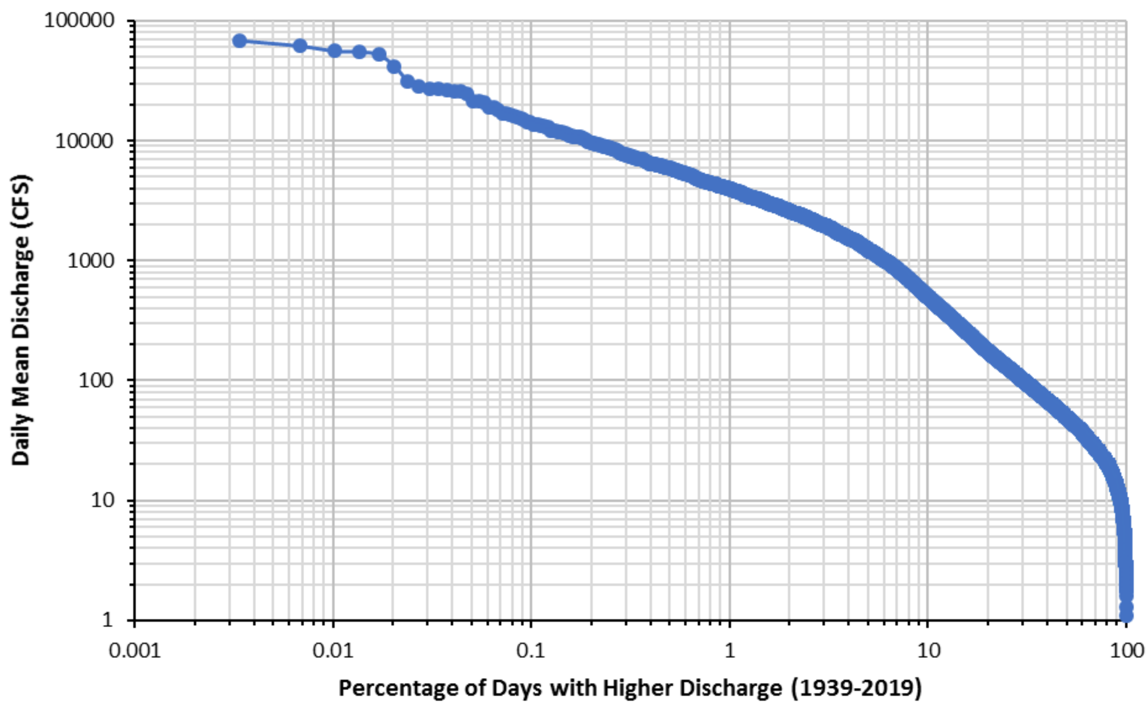




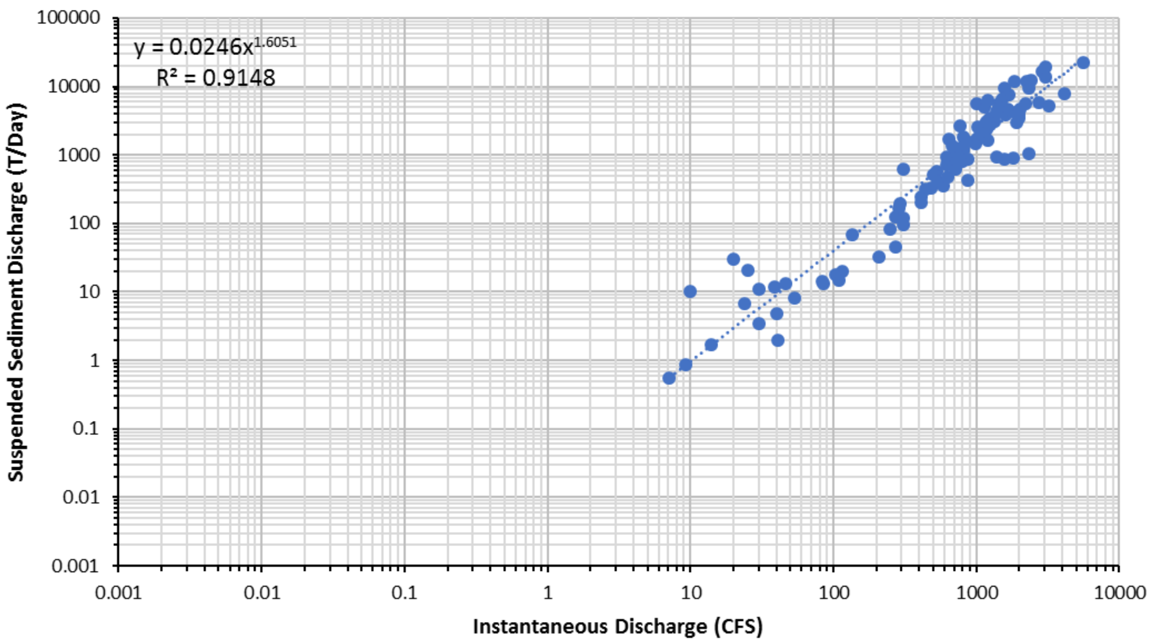
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves

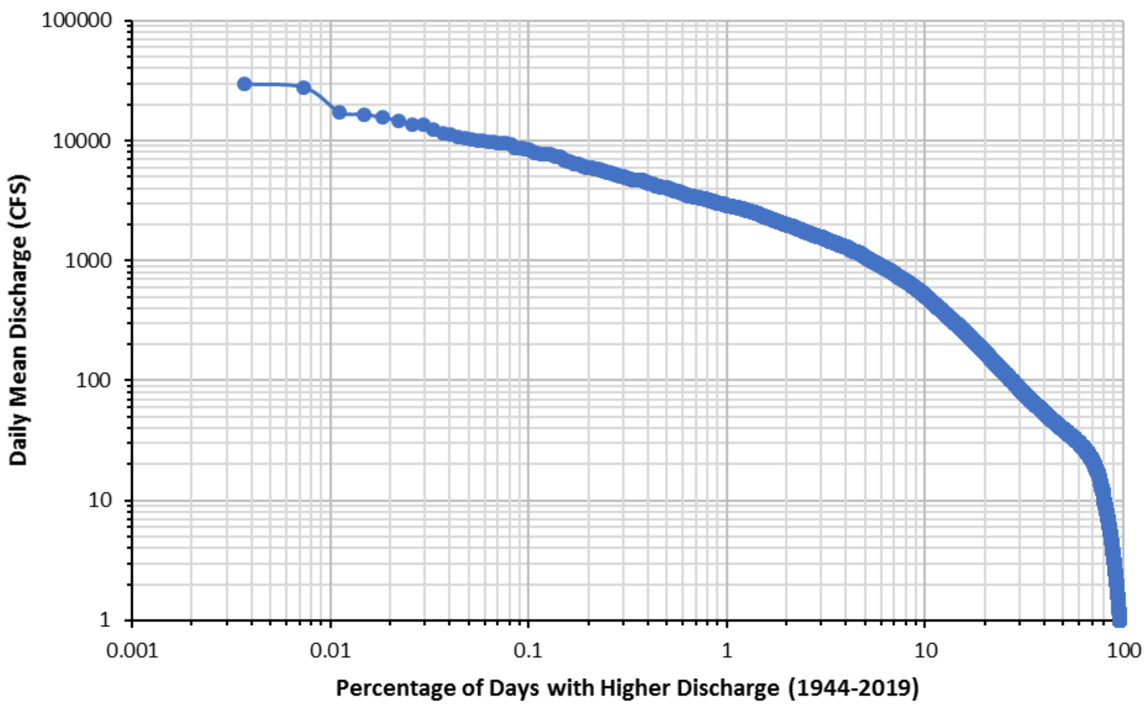
USGS 08068500 Spring Ck nr Spring, TX



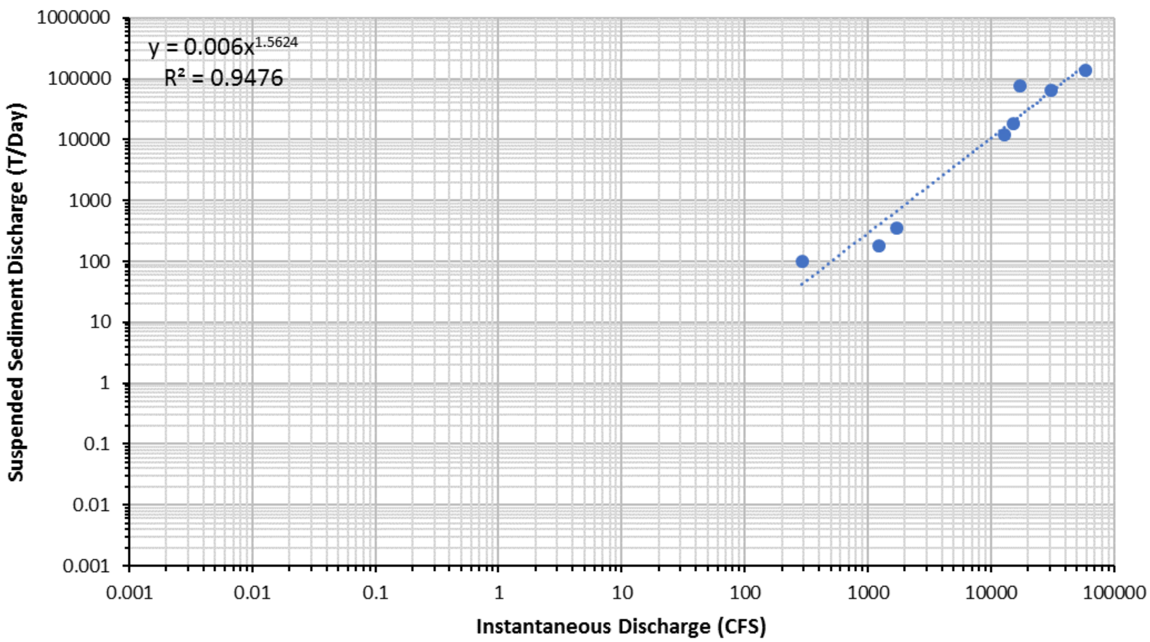


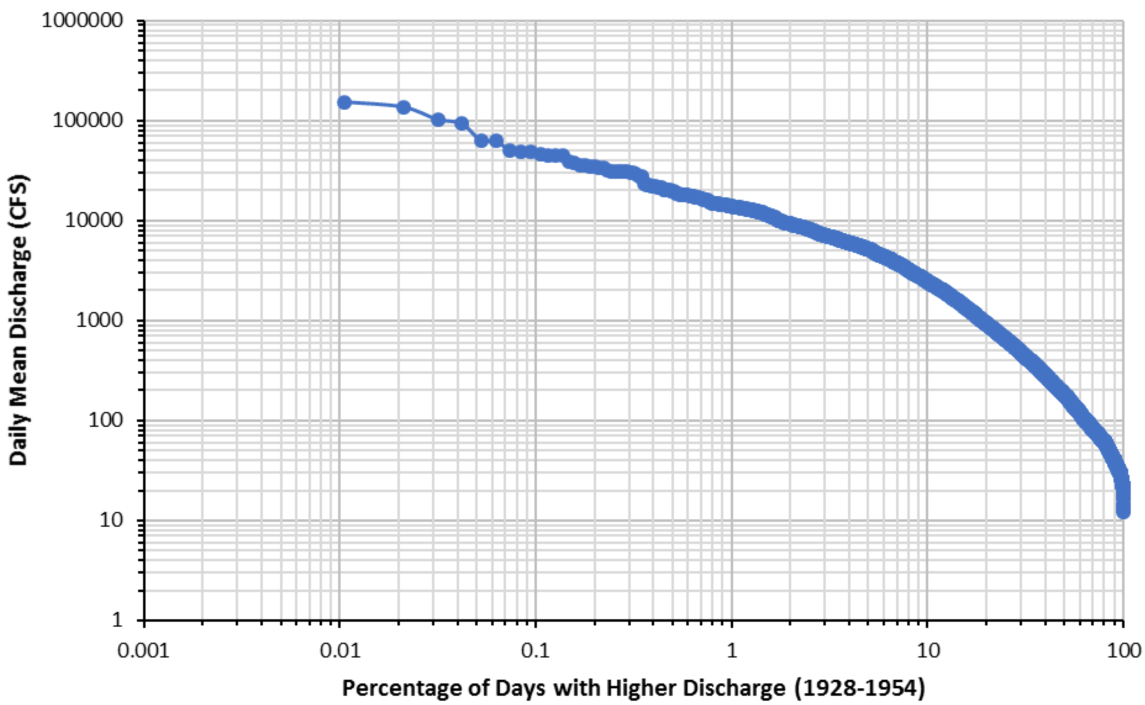
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves
USGS 08069000 Cypress Ck nr Westfield, TX



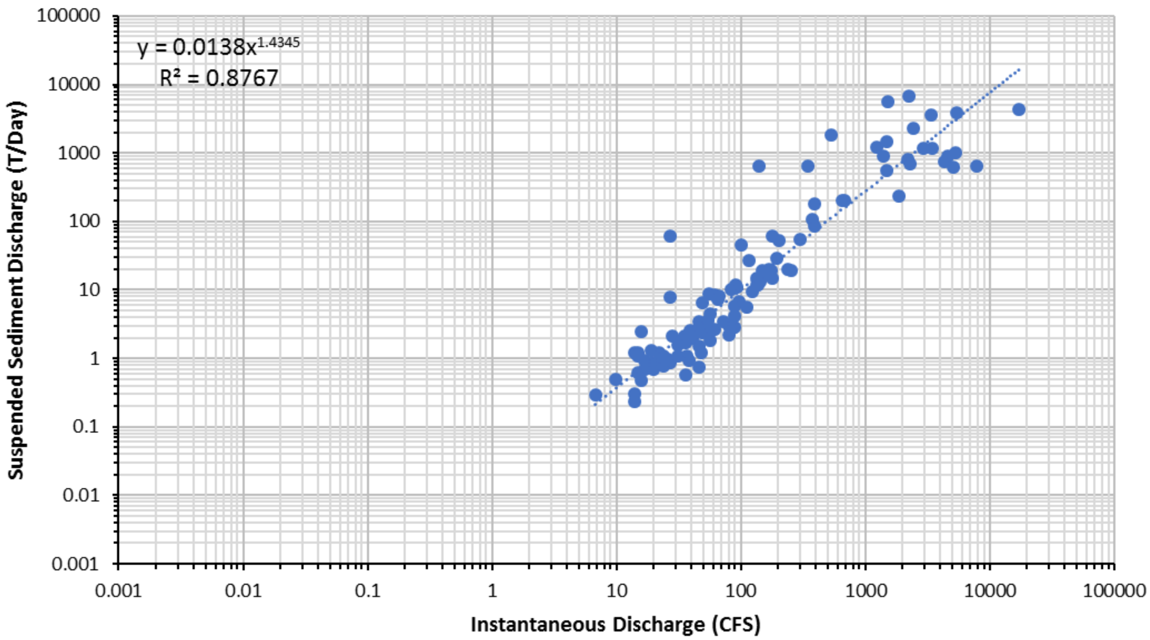


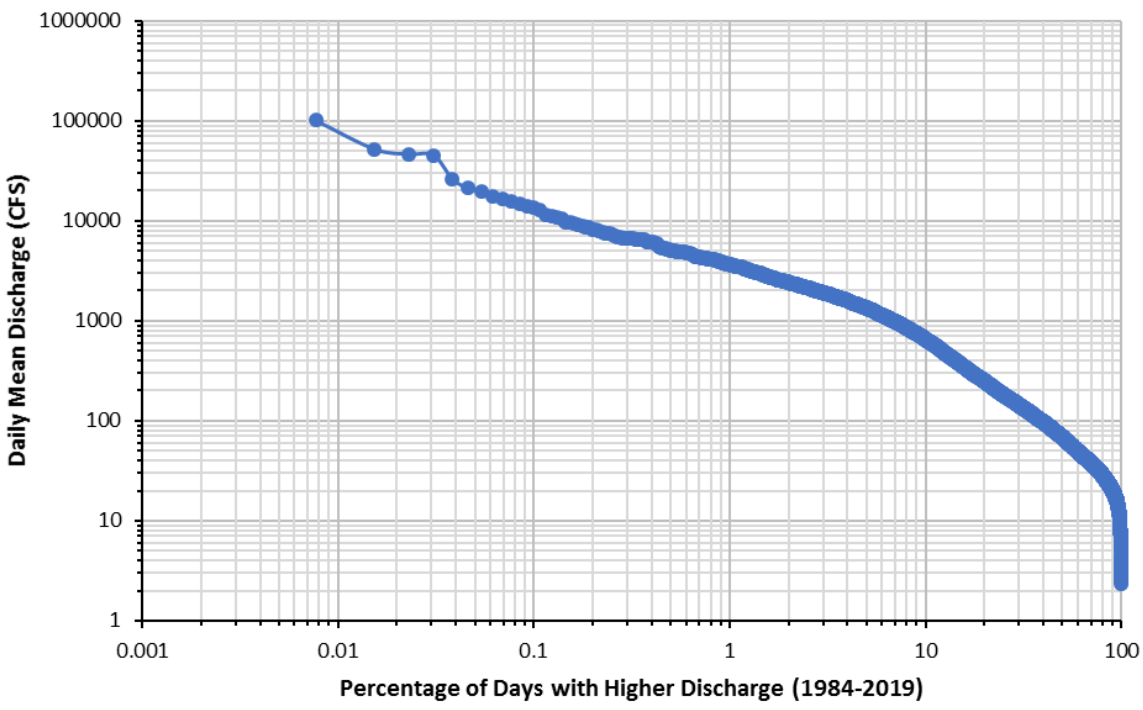
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves
USGS 08069500 W Fk San Jacinto Rv nr Humble, TX





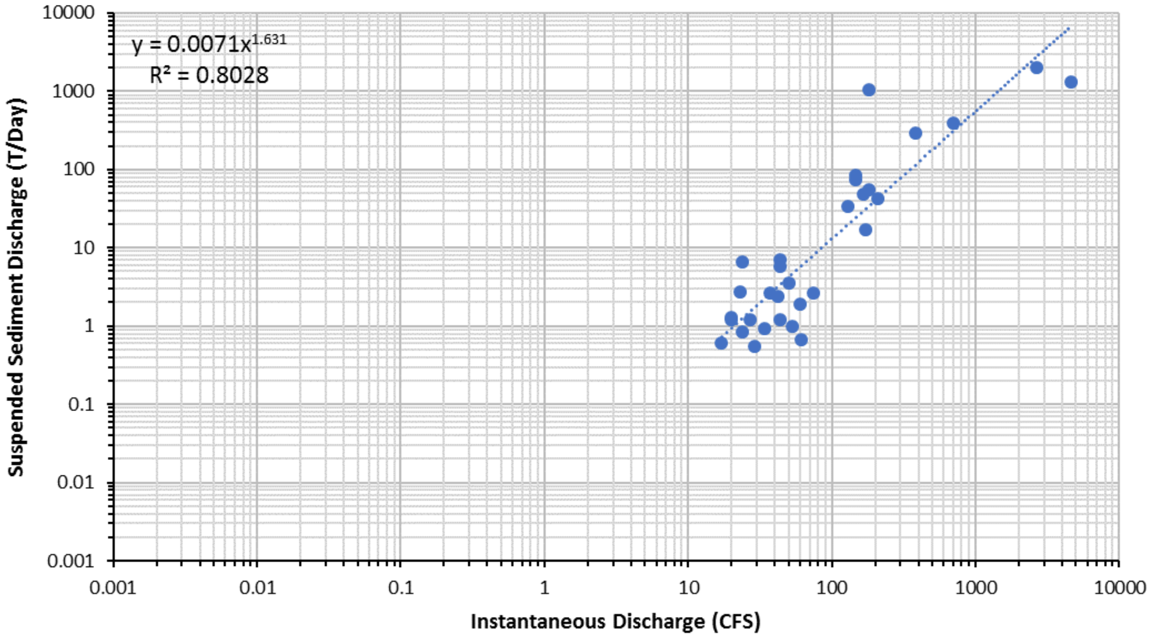
Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves
USGS 08070200 E Fk San Jacinto Rv nr New Caney, TX

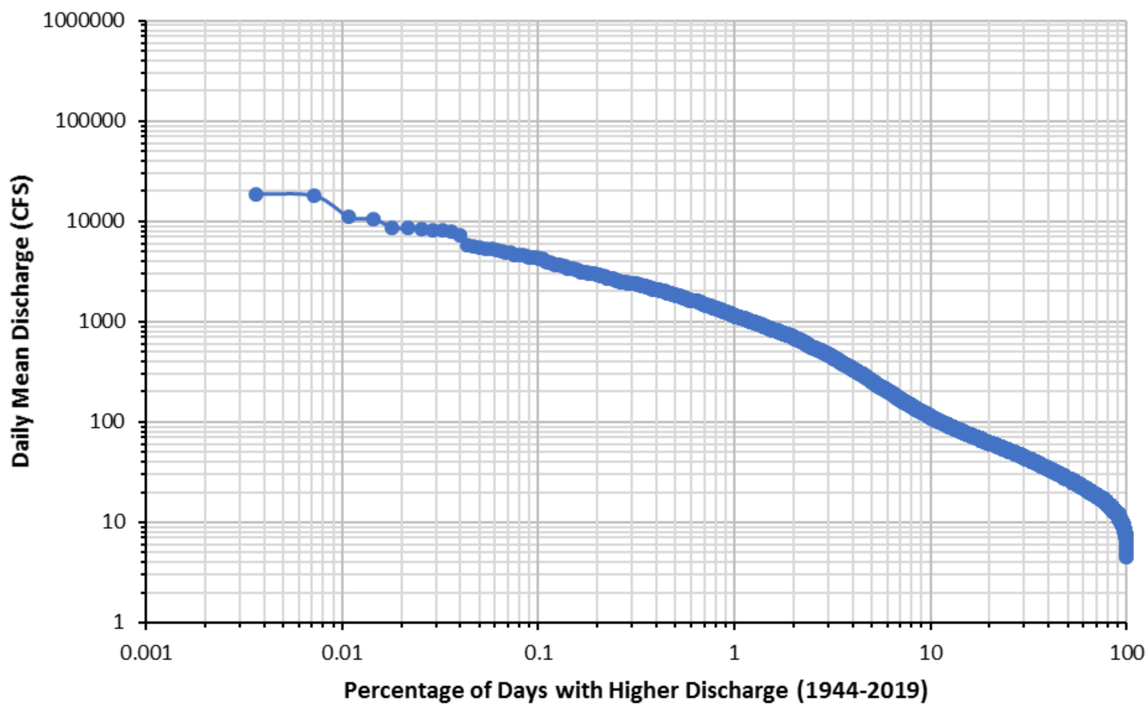




Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves

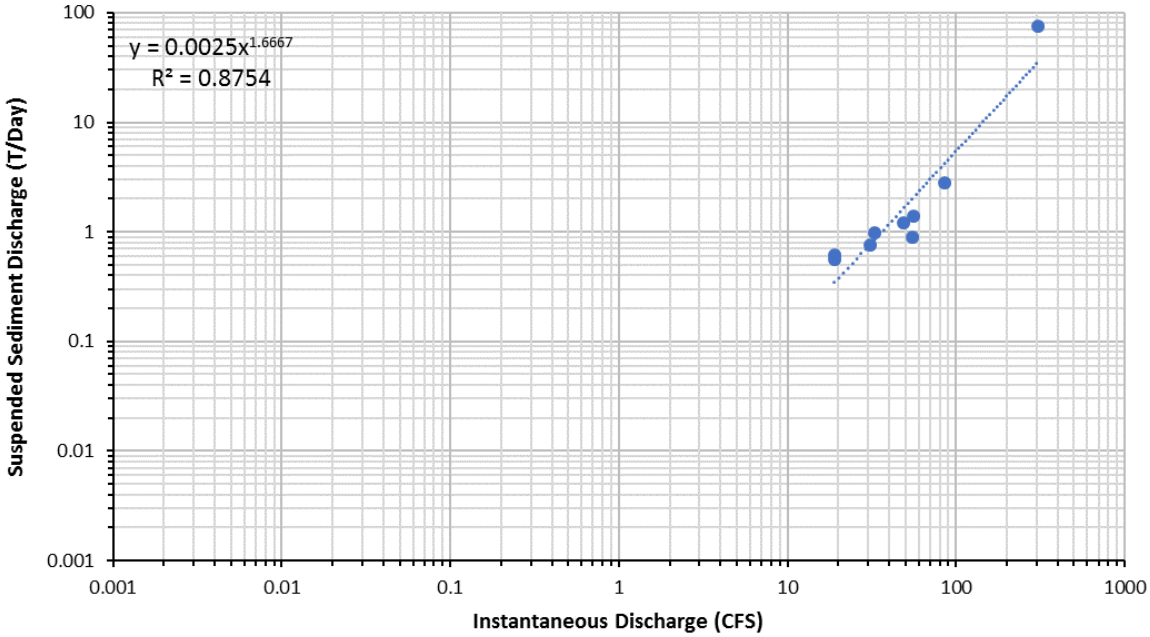
USGS 08070500 Caney Ck nr Splendora, TX

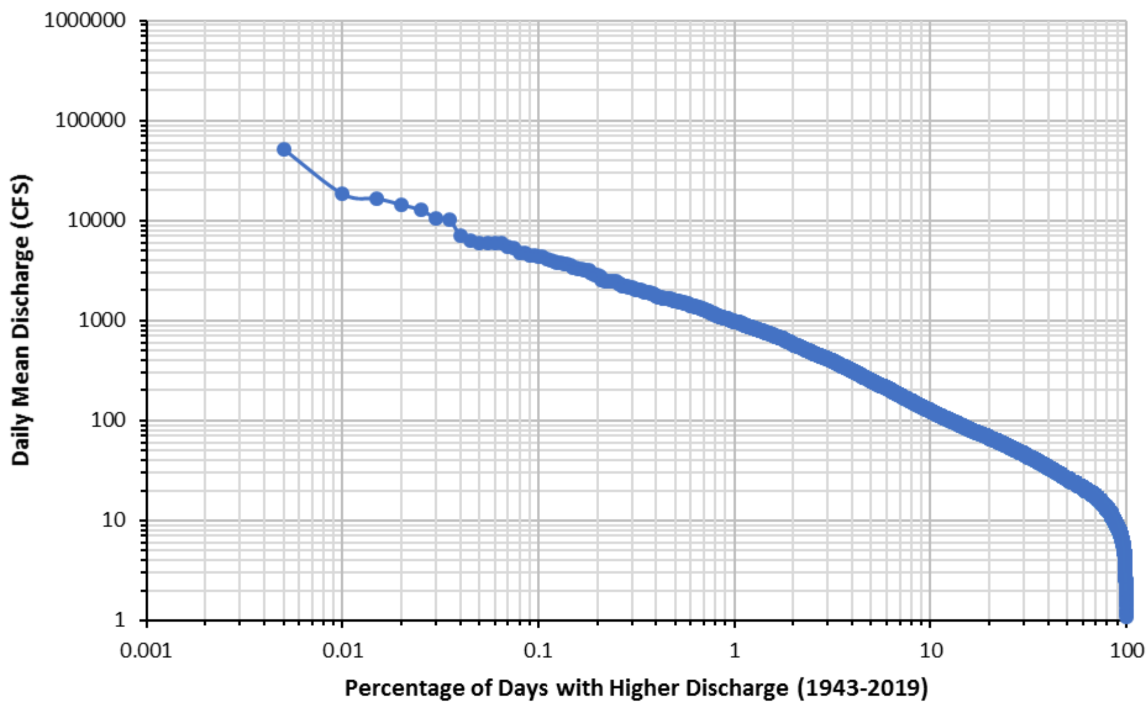




Appendix F.D – Figure D-3
Sediment Rating Curves and Flow Duration Curves

USGS 08071000 Peach Ck at Splendora, TX





APPENDIX F.D

FIGURE D-4

ESTIMATION OF ANNUAL SUSPENDED SEDIMENT LOAD AT EACH GAGE

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08067650 W Fk San Jacinto Rv Bl Lk Conroe nr Conroe, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	26,500	11,311	11.3
0.1-0.3	0.2	0.2	8,760	2,657	5.3
0.3-0.5	0.2	0.4	6,870	1,933	3.9
0.5-1.0	0.5	0.75	5,890	1,580	7.9
1-2	1	1.5	3,470	791	7.9
2-4	2	3	2,640	553	11.06
4-8	4	6	2,000	384	15.4
8-15	7	11.5	1,340	228	15.9
15-25	10	20	770	110	11.02
25-35	10	30	450	55	5.5
35-45	10	40	250	25	2.5
45-55	10	50	150	13	1.3
55-65	10	60	70	5	0.5
65-75	10	70	10	0.4	0.04
75-85	10	80	2	0.05	0.005
85-95	10	90	1	0.02	0.002
95-100	5	97.5	0.3	0.004	0.0002
			Total Sediment Load (T/Day):	19,646	99.5
				Total Sediment Load (T/Year):	36,318

* Sediment [T/Day] = 0.0184*(Flow [CFS])^1.3087

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08067700 Caney Ck nr Dobbin, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	-	-	-
0.1-0.3	0.2	0.2	2,320	414	0.8
0.3-0.5	0.2	0.4	1,940	336	0.7
0.5-1.0	0.5	0.75	770	115	0.6
1-2	1	1.5	420	57	0.6
2-4	2	3	240	30	0.6
4-8	4	6	130	14	0.6
8-15	7	11.5	50	5	0.3
15-25	10	20	14	1	0.1
25-35	10	30	6	0.4	0.04
35-45	10	40	3.6	0.2	0.02
45-55	10	50	2.4	0.1	0.01
55-65	10	60	1.7	0.1	0.01
65-75	10	70	1.1	0.1	0.01
75-85	10	80	0.6	0.03	0.003
85-95	10	90	0.3	0.01	0.001
95-100	5	97.5	0.1	0.003	0.0002
			Total Sediment Load (T/Day):	972	4.4
				Total Sediment Load (T/Year):	1,588

* Sediment [T/Day] = 0.0504*(Flow [CFS])^1.1631

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08067900 Lake Ck nr Conroe, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	-	-	-
0.1-0.3	0.2	0.2	10,600	5,660	11.3
0.3-0.5	0.2	0.4	6,250	2,808	5.6
0.5-1.0	0.5	0.75	2,300	745	3.7
1-2	1	1.5	2,000	619	6.2
2-4	2	3	1,830	550	11.0
4-8	4	6	1,390	382	15.3
8-15	7	11.5	690	151	10.6
15-25	10	20	220	33	3.3
25-35	10	30	104	12	1.2
35-45	10	40	66	7	0.7
45-55	10	50	38	3	0.3
55-65	10	60	24	2	0.2
65-75	10	70	15	1	0.1
75-85	10	80	8	0.4	0.04
85-95	10	90	5	0.2	0.02
95-100	5	97.5	4	0.2	0.01
			Total Sediment Load (T/Day):	10,974	69.6
				Total Sediment Load (T/Year):	25,389

* Sediment [T/Day] = 0.0258*(Flow [CFS])^1.3269

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08068000 W Fk San Jacinto Rv nr Conroe, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)			
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Load per Occurrence Flow**	Increment of Load per Occurrence*	Increment of Load per Occurrence**
0.0-0.1	0.1	0.05	34,800	31,483	21,428	31.5	21.4
0.1-0.3	0.2	0.2	16,800	11,980	8,037	24.0	16.1
0.3-0.5	0.2	0.4	11,700	7,413	4,937	14.8	9.9
0.5-1.0	0.5	0.75	8,240	4,656	3,079	23.3	15.4
1-2	1	1.5	5,410	2,664	1,747	26.6	17.5
2-4	2	3	3,540	1,518	987	30.4	19.7
4-8	4	6	2,040	731	470	29.2	18.8
8-15	7	11.5	975	274	174	19.2	12.2
15-25	10	20	396	83	52	8.3	5.2
25-35	10	30	198	33	20	3.3	2.0
35-45	10	40	114	16	10	1.6	1.0
45-55	10	50	75	9	5	0.9	0.5
55-65	10	60	52	6	3	0.6	0.3
65-75	10	70	38	4	2	0.4	0.2
75-85	10	80	28	2	1	0.2	0.1
85-95	10	90	20	1.6	0.9	0.16	0.1
95-100	5	97.5	11	0.7	0.4	0.04	0.0
			Total Sediment Load (T/Day):	60,875	40,954	214.5	140.5
					Total Sediment Load (T/Year):	78,278	51,271

* Pre-1974 Sediment [T/Day] = 0.0297*(Flow [CFS])^1.3267
** Post-1974 Sediment [T/Day] = 0.0164*(Flow [CFS])^1.3467

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08068390 Bear Br at Research Blvd, The Woodlands, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	2,340	863	0.9
0.1-0.3	0.2	0.2	1,140	354	0.7
0.3-0.5	0.2	0.4	671	183	0.4
0.5-1.0	0.5	0.75	434	107	0.5
1-2	1	1.5	271	59	0.6
2-4	2	3	170	33	0.7
4-8	4	6	89	15	0.6
8-15	7	11.5	40	5	0.4
15-25	10	20	18	2	0.2
25-35	10	30	9	1	0.09
35-45	10	40	6	0.5	0.05
45-55	10	50	4	0.3	0.03
55-65	10	60	2	0.2	0.02
65-75	10	70	1	0.1	0.009
75-85	10	80	0.8	0.04	0.004
85-95	10	90	0.4	0.02	0.0017
95-100	5	97.5	0.08	0.002	0.00012
			Total Sediment Load (T/Day):	1,624	5.1
				Total Sediment Load (T/Year):	1,865

* Sediment [T/Day] = 0.0568*(Flow [CFS])^1.2412

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08068400 Panther Br at Gosling Rd, The Woodlands, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	3,560	11,333	11.3
0.1-0.3	0.2	0.2	1,650	3,083	6.2
0.3-0.5	0.2	0.4	1,090	1,528	3.1
0.5-1.0	0.5	0.75	724	764	3.8
1-2	1	1.5	393	272	2.7
2-4	2	3	201	87	1.7
4-8	4	6	115	34	1.4
8-15	7	11.5	56	10	0.7
15-25	10	20	28	3	0.3
25-35	10	30	18	1	0.1
35-45	10	40	13	0.8	0.08
45-55	10	50	10	0.6	0.06
55-65	10	60	9	0.4	0.04
65-75	10	70	8	0.3	0.03
75-85	10	80	6	0.2	0.02
85-95	10	90	4	0.1	0.01
95-100	5	97.5	0.2	0.001	0.00003
			Total Sediment Load (T/Day):	17,118	31.6
				Total Sediment Load (T/Year):	11,534

* Sediment [T/Day] = 0.011*(Flow [CFS])^1.6931

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08068450 Panther Br nr Spring, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	6,450	50,781,896	50781.9
0.1-0.3	0.2	0.2	1,700	937,616	1875.2
0.3-0.5	0.2	0.4	1,160	298,606	597.2
0.5-1.0	0.5	0.75	782	91,711	458.6
1-2	1	1.5	532	28,946	289.5
2-4	2	3	311	5,802	116.0
4-8	4	6	178	1,092	43.7
8-15	7	11.5	95	168	11.7
15-25	10	20	50	24	2.4
25-35	10	30	29	5	0.5
35-45	10	40	21	2	0.2
45-55	10	50	17	1	0.09
55-65	10	60	14	1	0.05
65-75	10	70	11	0.3	0.03
75-85	10	80	9	0.2	0.02
85-95	10	90	5	0.02	0.002
95-100	5	97.5	0.2	0.000002	0.0000001
			Total Sediment Load (T/Day):	52,145,870	54177.1
				Total Sediment Load (T/Year):	19,774,636

* Sediment [T/Day] = 0.0002*(Flow [CFS])^2.9937

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08068500 Spring Ck nr Spring, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	21,600	82,178	82.2
0.1-0.3	0.2	0.2	9,580	22,463	44.9
0.3-0.5	0.2	0.4	6,440	11,921	23.8
0.5-1.0	0.5	0.75	4,550	6,849	34.2
1-2	1	1.5	3,100	3,713	37.1
2-4	2	3	1,970	1,802	36.0
4-8	4	6	1,010	621	24.8
8-15	7	11.5	406	145	10.2
15-25	10	20	177	39	3.9
25-35	10	30	101	16	1.6
35-45	10	40	69	9	0.9
45-55	10	50	50	5	0.5
55-65	10	60	37	3	0.3
65-75	10	70	28	2	0.2
75-85	10	80	21	1	0.1
85-95	10	90	13	0.6	0.06
95-100	5	97.5	6	0.2	0.009
			Total Sediment Load (T/Day):	129,767	300.8
				Total Sediment Load (T/Year):	109,808

* Sediment [T/Day] = 0.01*(Flow [CFS])^1.5953

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08069000 Cypress Ck nr Westfield, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	10,300	67,911	67.9
0.1-0.3	0.2	0.2	5,940	28,070	56.1
0.3-0.5	0.2	0.4	4,450	17,657	35.3
0.5-1.0	0.5	0.75	3,310	10,980	54.9
1-2	1	1.5	2,370	6,423	64.2
2-4	2	3	1,560	3,283	65.7
4-8	4	6	903	1,365	54.6
8-15	7	11.5	415	392	27.4
15-25	10	20	173	96	9.6
25-35	10	30	85	31	3.1
35-45	10	40	54	15	1.5
45-55	10	50	39	9	0.9
55-65	10	60	30	6	0.6
65-75	10	70	22	4	0.4
75-85	10	80	11	1	0.1
85-95	10	90	3	0.2	0.02
95-100	5	97.5	0.5	0.01	0.0004
			Total Sediment Load (T/Day):	136,242	442.3
				Total Sediment Load (T/Year):	161,444

* Sediment [T/Day] = 0.0246*(Flow [CFS])^1.6051

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08069500 W Fk San Jacinto Rv nr Humble, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	63,400	190,957	191.0
0.1-0.3	0.2	0.2	34,600	74,132	148.3
0.3-0.5	0.2	0.4	22,000	36,539	73.1
0.5-1.0	0.5	0.75	16,000	22,216	111.1
1-2	1	1.5	11,600	13,442	134.4
2-4	2	3	7,110	6,256	125.1
4-8	4	6	4,400	2,956	118.2
8-15	7	11.5	2,100	931	65.1
15-25	10	20	939	265	26.5
25-35	10	30	480	93	9.3
35-45	10	40	284	41	4.1
45-55	10	50	182	20	2.0
55-65	10	60	120	11	1.1
65-75	10	70	82	6	0.6
75-85	10	80	62	4	0.4
85-95	10	90	40	2	0.2
95-100	5	97.5	28	1	0.05
			Total Sediment Load (T/Day):	347,870	1010.4
				Total Sediment Load (T/Year):	368,810

* Sediment [T/Day] = 0.006*(Flow [CFS])^1.5624

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08070200 E Fk San Jacinto Rv nr New Caney, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	19,800	20,112	20.1
0.1-0.3	0.2	0.2	8,100	5,580	11.2
0.3-0.5	0.2	0.4	6,140	3,750	7.5
0.5-1.0	0.5	0.75	4,240	2,205	11.0
1-2	1	1.5	2,880	1,266	12.7
2-4	2	3	1,920	708	14.2
4-8	4	6	1,140	335	13.4
8-15	7	11.5	545	116	8.1
15-25	10	20	250	38	3.8
25-35	10	30	145	17	1.7
35-45	10	40	97	10	1.0
45-55	10	50	68	6	0.6
55-65	10	60	49	4	0.4
65-75	10	70	38	3	0.3
75-85	10	80	29	2	0.2
85-95	10	90	20	1	0.1
95-100	5	97.5	12	0.5	0.02
			Total Sediment Load (T/Day):	34,151	106.2
				Total Sediment Load (T/Year):	38,752

* Sediment [T/Day] = 0.0138*(Flow [CFS])^1.4345

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08070500 Caney Ck nr Splendora, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	5,500	8,949	8.9
0.1-0.3	0.2	0.2	2,900	3,151	6.3
0.3-0.5	0.2	0.4	2,090	1,847	3.7
0.5-1.0	0.5	0.75	1,430	995	5.0
1-2	1	1.5	855	430	4.3
2-4	2	3	470	162	3.2
4-8	4	6	205	42	1.7
8-15	7	11.5	99	13	0.9
15-25	10	20	62	6	0.6
25-35	10	30	45	4	0.4
35-45	10	40	34	2	0.2
45-55	10	50	27	2	0.2
55-65	10	60	22	1	0.1
65-75	10	70	19	0.8	0.1
75-85	10	80	15	0.6	0.1
85-95	10	90	12	0.4	0.04
95-100	5	97.5	9	0.2	0.01
			Total Sediment Load (T/Day):	15,604	35.6
				Total Sediment Load (T/Year):	13,010

* Sediment [T/Day] = 0.007*(Flow [CFS])^1.631

Appendix F.D – Figure D-4
Estimation of Annual Suspended Sediment Load at Each Gage

USGS 08071000 Peach Ck at Splendora, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	6,040	5,009	5.0
0.1-0.3	0.2	0.2	2,830	1,416	2.8
0.3-0.5	0.2	0.4	1,750	635	1.3
0.5-1.0	0.5	0.75	1,210	344	1.7
1-2	1	1.5	741	152	1.5
2-4	2	3	413	57	1.1
4-8	4	6	212	19	0.8
8-15	7	11.5	110	6	0.4
15-25	10	20	68	3	0.3
25-35	10	30	46	1	0.1
35-45	10	40	34	0.9	0.09
45-55	10	50	26	0.6	0.06
55-65	10	60	21	0.4	0.04
65-75	10	70	17	0.3	0.03
75-85	10	80	13	0.2	0.02
85-95	10	90	9	0.1	0.01
95-100	5	97.5	5	0.04	0.002
			Total Sediment Load (T/Day):	7,645	15.4
				Total Sediment Load (T/Year):	5,608

* Sediment [T/Day] = 0.0025*(Flow [CFS])^1.6667

APPENDIX F.D

FIGURE D-5

ESTIMATION OF ANNUAL SUSPENDED SEDIMENT LOAD FOR EACH SUBWATERSHED

Appendix F.D – Figure D-5
Estimation of Annual Suspended Sediment Load for Each Subwatershed

WEST FORK SAN JACINTO SUB-BASIN (INCLUDES LAKE CONROE)

USGS 08068000 W Fk San Jacinto Rv nr Conroe, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)			
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Load per Occurrence Flow**	Increment of Load per Occurrence*	Increment of Load per Occurrence**
0.0-0.1	0.1	0.05	41,090	39,247	26,802	39.2	26.8
0.1-0.3	0.2	0.2	19,837	14,935	10,052	29.9	20.1
0.3-0.5	0.2	0.4	13,815	9,242	6,175	18.5	12.4
0.5-1.0	0.5	0.75	9,729	5,804	3,851	29.0	19.3
1-2	1	1.5	6,388	3,321	2,185	33.2	21.9
2-4	2	3	4,180	1,892	1,234	37.8	24.7
4-8	4	6	2,409	911	588	36.4	23.5
8-15	7	11.5	1,151	342	217	23.9	15.2
15-25	10	20	468	104	65	10.4	6.5
25-35	10	30	234	41	25	4.1	2.5
35-45	10	40	135	20	12	2.0	1.2
45-55	10	50	89	11	7	1.1	0.7
55-65	10	60	62	7	4	0.7	0.4
65-75	10	70	45	5	3	0.5	0.3
75-85	10	80	33	3	2	0.3	0.2
85-95	10	90	24	2.0	1.2	0.20	0.1
95-100	5	97.5	13	0.9	0.5	0.04	0.0
			Total Sediment Load (T/Day):	75,888	51,224	267.4	175.7
					Total Sediment Load (T/Year):	97,599	64,138

* Pre-1974 Sediment [T/Day] = 0.0297*(Flow [CFS])^1.3267
** Post-1974 Sediment [T/Day] = 0.0164*(Flow [CFS])^1.3467

Appendix F.D – Figure D-5
Estimation of Annual Suspended Sediment Load for Each Subwatershed

SPRING CREEK SUB-BASIN

USGS 08068500 Spring Ck nr Spring, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	26,294	112,460	112.5
0.1-0.3	0.2	0.2	10,507	26,029	52.1
0.3-0.5	0.2	0.4	6,922	13,377	26.8
0.5-1.0	0.5	0.75	4,883	7,666	38.3
1-2	1	1.5	3,327	4,157	41.6
2-4	2	3	2,114	2,017	40.3
4-8	4	6	1,084	695	27.8
8-15	7	11.5	436	162	11.4
15-25	10	20	190	43	4.3
25-35	10	30	108	18	1.8
35-45	10	40	74	10	1.0
45-55	10	50	54	6	0.6
55-65	10	60	40	4	0.4
65-75	10	70	30	2	0.2
75-85	10	80	22	1	0.1
85-95	10	90	14	0.7	0.07
95-100	5	97.5	7	0.2	0.010
			Total Sediment Load (T/Day):	166,647	359.1
				Total Sediment Load (T/Year):	131,061

* Sediment [T/Day] = 0.01*(Flow [CFS])^1.5953

Appendix F.D – Figure D-5
Estimation of Annual Suspended Sediment Load for Each Subwatershed

CYPRESS CREEK SUB-BASIN

USGS 08069000 Cypress Ck nr Westfield, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	11,491	80,948	80.9
0.1-0.3	0.2	0.2	6,563	32,943	65.9
0.3-0.5	0.2	0.4	4,917	20,723	41.4
0.5-1.0	0.5	0.75	3,657	12,887	64.4
1-2	1	1.5	2,619	7,538	75.4
2-4	2	3	1,724	3,853	77.1
4-8	4	6	998	1,602	64.1
8-15	7	11.5	459	460	32.2
15-25	10	20	191	113	11.3
25-35	10	30	94	36	3.6
35-45	10	40	60	17	1.7
45-55	10	50	43	10	1.0
55-65	10	60	33	7	0.7
65-75	10	70	24	4	0.4
75-85	10	80	12	1	0.1
85-95	10	90	4	0.2	0.02
95-100	5	97.5	1	0.01	0.0005
			Total Sediment Load (T/Day):	161,143	520.4
				Total Sediment Load (T/Year):	189,940

* Sediment [T/Day] = 0.0246*(Flow [CFS])^1.6051

Appendix F.D – Figure D-5
Estimation of Annual Suspended Sediment Load for Each Subwatershed

EAST FORK SAN JACINTO SUB-BASIN

USGS 08070200 E Fk San Jacinto Rv nr New Caney, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	22,033	23,444	23.4
0.1-0.3	0.2	0.2	8,340	5,818	11.6
0.3-0.5	0.2	0.4	6,322	3,910	7.8
0.5-1.0	0.5	0.75	4,396	2,322	11.6
1-2	1	1.5	2,965	1,320	13.2
2-4	2	3	1,977	738	14.8
4-8	4	6	1,174	349	14.0
8-15	7	11.5	562	121	8.5
15-25	10	20	257	40	4.0
25-35	10	30	149	18	1.8
35-45	10	40	100	10	1.0
45-55	10	50	70	6	0.6
55-65	10	60	51	4	0.4
65-75	10	70	39	3	0.3
75-85	10	80	30	2	0.2
85-95	10	90	21	1	0.1
95-100	5	97.5	19	0.9	0.05
			Total Sediment Load (T/Day):	38,107	113.3
				Total Sediment Load (T/Year):	41,371

* Sediment [T/Day] = 0.0138*(Flow [CFS])^1.4345

Appendix F.D – Figure D-5
Estimation of Annual Suspended Sediment Load for Each Subwatershed

CANEY CREEK SUB-BASIN

Note: The gage used is located in the center of the sub-basin, resulting in a large difference in load estimates between the two locations

USGS 08070500 Caney Ck nr Splendora, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	10,804	26,919	26.9
0.1-0.3	0.2	0.2	5,612	9,249	18.5
0.3-0.5	0.2	0.4	3,990	5,301	10.6
0.5-1.0	0.5	0.75	2,730	2,855	14.3
1-2	1	1.5	1,634	1,236	12.4
2-4	2	3	897	465	9.3
4-8	4	6	391	120	4.8
8-15	7	11.5	189	37	2.6
15-25	10	20	118	17	1.7
25-35	10	30	86	10	1.0
35-45	10	40	65	6	0.6
45-55	10	50	52	5	0.5
55-65	10	60	43	3	0.3
65-75	10	70	37	2.5	0.3
75-85	10	80	30	1.8	0.2
85-95	10	90	23	1.2	0.12
95-100	5	97.5	15	0.6	0.03
			Total Sediment Load (T/Day):	46,229	104.1
				Total Sediment Load (T/Year):	37,981

* Sediment [T/Day] = 0.007*(Flow [CFS])^1.631

Appendix F.D – Figure D-5
Estimation of Annual Suspended Sediment Load for Each Subwatershed

PEACH CREEK SUB-BASIN

USGS 08071000 Peach Ck at Splendora, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	8,370	8,628	8.6
0.1-0.3	0.2	0.2	3,791	2,305	4.6
0.3-0.5	0.2	0.4	2,309	1,009	2.0
0.5-1.0	0.5	0.75	1,600	548	2.7
1-2	1	1.5	973	239	2.4
2-4	2	3	542	90	1.8
4-8	4	6	278	30	1.2
8-15	7	11.5	144	10	0.7
15-25	10	20	89	4	0.4
25-35	10	30	61	2	0.2
35-45	10	40	45	1.4	0.14
45-55	10	50	34	0.9	0.09
55-65	10	60	28	0.6	0.06
65-75	10	70	23	0.5	0.05
75-85	10	80	17	0.3	0.03
85-95	10	90	12	0.2	0.02
95-100	5	97.5	7	0.06	0.003
			Total Sediment Load (T/Day):	12,869	25.1
				Total Sediment Load (T/Year):	9,173

* Sediment [T/Day] = 0.0025*(Flow [CFS])^1.6667

Appendix F.D – Figure D-5
Estimation of Annual Suspended Sediment Load for Each Subwatershed

LUCE BAYOU SUB-BASIN

Note: Used data from the Eask Fork San Jacinto River; no gages in this sub-basin with sediment data as of this 2019 study

USGS 08070200 E Fk San Jacinto Rv nr New Caney, TX

Normalized Occurrence (%)			Daily Discharge per Occurrence (CFS)	Suspended Sediment Load (T/Day)	
Occurrence Range	Occurrence Increment	Average Occurrence		Load per Occurrence Flow*	Increment of Load per Occurrence
0.0-0.1	0.1	0.05	12,534	10,438	10.4
0.1-0.3	0.2	0.2	4,744	2,590	5.2
0.3-0.5	0.2	0.4	3,596	1,741	3.5
0.5-1.0	0.5	0.75	2,501	1,034	5.2
1-2	1	1.5	1,687	588	5.9
2-4	2	3	1,125	328	6.6
4-8	4	6	668	156	6.2
8-15	7	11.5	320	54	3.8
15-25	10	20	146	18	1.8
25-35	10	30	85	8	0.8
35-45	10	40	57	5	0.5
45-55	10	50	40	3	0.3
55-65	10	60	28	2	0.2
65-75	10	70	22	1	0.1
75-85	10	80	16	1	0.1
85-95	10	90	12	0	0.0
95-100	5	97.5	7	0.2	0.01
			Total Sediment Load (T/Day):	16,966	50.4
				Total Sediment Load (T/Year):	18,404

* Sediment [T/Day] = 0.0138*(Flow [CFS])^1.4345

APPENDIX F.E

MEMORANDUM OF UNDERSTANDING TO COORDINATE SEDIMENT MANAGEMENT STRATEGIES

DRAFT MEMORANDUM OF UNDERSTANDING AMONG HARRIS COUNTY FLOOD CONTROL DISTRICT, SAN JACINTO RIVER AUTHORITY, CITY OF HOUSTON, MONTGOMERY COUNTY, AND HARRIS COUNTY TO COORDINATE SEDIMENT MANAGEMENT STRATEGIES

I. **Introduction:** Harris County Flood Control District (HCFCD), San Jacinto River Authority (SJRA), City of Houston (City), Montgomery County (Montgomery) and Harris County (Harris) are the "Parties" to the Memorandum of Understanding (MOU) when one or more of the Parties seeks to mitigate sediment or removal of vegetative obstructions to maintain conveyance for floodwater channels, floodwater crossings and floodwater conduits.

II. **Purpose:** This purpose of this MOU is to link the efforts of the Parties to mitigate sedimentation between the headwaters of the San Jacinto watershed and Lake Houston Dam. These efforts may include financing and coordinating the following efforts:

1) The study of the feasibility and efficacy of sediment mitigation strategies
2) Final design and construction document development
3) Acquisition of necessary permitting to implement strategies
4) Construction service contract procurement and management
5) Operation and maintenance of implement strategies

III. **Background:** 1) With Texas House Bill 1824, passed in September 2019 (Legiscan 2020), HCFCD and SJRA were given authority to remove sediment from the San Jacinto River and its tributaries, to improve stormwater flows. The Bill amends Section 86.017 and Section 86.0192 of the Texas Parks and Wildlife Code and is reproduced below:

H.B. No. 1824

AN ACT

relating to the sale and taking of sand, gravel, marl, shell, and mudshell, including the use of funds collected from the sale of those materials and the taking of those materials from the San Jacinto River and its tributaries.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF TEXAS:

SECTION 1. Section 86.017, Parks and Wildlife Code, is amended to read as follows:

Sec. 86.017. USE OF FUNDS. (a) Except as provided by Subsection (b), funds collected by the commission from the sale of marl, sand, gravel, shell, and mudshell may be used for:

(1) the enforcement of the provisions of this chapter;
(2) the payment of refunds;

(3) the construction and maintenance of fish hatcheries; and

(4) the enhancement, preservation, and restoration of fish habitats in rivers and streams.

(b) No less than three-fourths of the proceeds from the sale of marl, sand, gravel, shell, and mudshell, after the payment of refunds, shall be used for:

(1) the construction and maintenance of fish hatcheries; and

(2) the enhancement, preservation, and restoration of fish habitats in rivers and streams.

SECTION 2. Chapter 86, Parks and Wildlife Code, is amended by adding Section 86.0192 to read as follows:

Sec. 86.0192. EXEMPTION FOR CERTAIN POLITICAL SUBDIVISIONS. (a) This section applies only to the following political subdivisions:

(1) San Jacinto River Authority; and

(2) Harris County Flood Control District.

(b) A political subdivision may take sand, gravel, marl, shell, and mudshell from the San Jacinto River and its tributaries to restore, maintain, or expand the capacity of the river and its tributaries to convey storm flows.

(c) A political subdivision acting under this section is not required to:

(1) obtain a permit or pay a fee to take sand, gravel, marl, shell, or mudshell under Subsection (b); or

(2) purchase sand, gravel, marl, shell, or mudshell taken under Subsection (b).

(d) A political subdivision acting under this section may deposit sand, gravel, marl, shell, or mudshell taken under Subsection (b) on private land.

SECTION 3. This Act takes effect September 1, 2019.

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2) HCFCD considers its sediment management duties in the watershed to implement natural channel repairs on its own property and conduct maintenance where channel conditions pose an increased risk of flooding, or where channel erosion may pose a threat to public infrastructure or public safety. Channel conditions that pose an increased risk of flooding can include channel impediments that reduce conveyance capacity. Maintenance activities include desilting, selective clearing and removing blockages after storm events to maintain the capacity of a channel to convey stormwater flow. Maintenance activity incorporates principles of natural stable channel design to minimize impacts to streambanks. If a project is deemed necessary for public benefit to reduce flooding, HCFCD would first have to obtain property rights (either temporary or permanent) prior to commencing a project.

3) SJRA considers its sediment management duties in the watershed to conserve all soils against destructive erosion thereby preventing the increased flood menace incident thereto.

IV. **<u>Governing Agencies:</u>** The following is a list of jurisdictional bodies who own or take part in regulating and/or maintaining Lake Houston and the San Jacinto River Watershed.

<u>City of Houston</u>: The City of Houston owns Lake Houston. Chapter 23 of Houston's city ordinance regulates the uses of Lake Houston, including general requirements (Article I), water supply protection (Article IV), and dredging or excavating operations (Article V). The City also maintains control of its floodplains (Chapter 19) to protect against the increase in flooding dangers.

<u>Harris County</u>: Harris County maintains floodplain management jurisdiction over all unincorporated areas within the county, qualifying these areas for flood insurance under the National Flood Insurance Act. The county has authority to plan and construct drainage improvements in conjunction with county roadways, but it has no specific authority for flood control or sediment control projects. The County must authorize development by issuing a floodplain development permit for any excavation or placement of fill within FEMA-delineated floodplains and floodways.

<u>Harris County Flood Control District</u>: Created in 1937, the HCFCD has been empowered to cooperate with agencies within the State of Texas, including the City of Houston and Harris County, in the construction and maintenance of flood control projects. Given no authority over land use or development along the banks of the county's waterways, the district has focused these efforts in dedicated easements and rights-of way, where they exist. It can also alter or "improve" the channel-way with limited impact on neighboring property holders. It lacks the jurisdiction over sedimentation or other issues not related to flooding in Harris County and lacks jurisdiction for flood management and other river management issues outside of Harris County. It can make cooperative agreements with other agencies outside of Harris County such as the SJRA to partially fund studies whose scope of study extend beyond county lines.

<u>San Jacinto River Authority</u>: Through an act of state legislation, SJRA, a political subdivision of the State of Texas (Article SVI, Section 59 of the Constitution of Texas) has broad general powers to engage in the storing, controlling and conserving of the storm and flood waters of the watershed of the San Jacinto River and its tributaries. SJRA's boundaries, however, explicitly exclude Harris County from its jurisdiction. This includes Lake Houston and downstream. In addition, SJRA's legislation does not provide SJRA the necessary regulatory authority to effectively address flood mitigation (i.e., no authority to regulate development activities within the floodplain or floodway), nor does it provide state allocations or taxing authority to fund flood mitigation activities.

<u>Montgomery County</u>: Similar to Harris County, Montgomery County maintains floodplain management jurisdiction over all unincorporated areas within the county, qualifying these areas for flood insurance under the National Flood Insurance Act. The county has authority to plan and construct drainage improvements in conjunction with county roadways, but it has no specific authority for flood control or sediment control projects. The county must authorize by issuing a floodplain development permit for any excavating or placing fill within FEMA delineated floodplains and floodways.

V. Scope and Applicability

The Parties agree upon the following:

1) Sedimentation Meetings: The Parties will meet at least once every six months to discuss sedimentation concerns expressed by the public and other stakeholders, review of ongoing sedimentation mitigation projects, future sedimentation mitigation projects, new technology to measure the movement of sediment, updates to the regional sediment management plan, and legislative initiatives.

2) The Parties will provide appropriate personnel and/or expertise to these meetings and according to the agreed-upon conditions in this MOU.

3) Floodwater conveyance to be maintained occurs in one or more of the following locations:

    a. Floodwater Channel – A natural, modified, or natural and modified channel conveying floodwaters within the San Jacinto River watershed.

    b. Floodwater Crossing – A publicly maintained bridge or culvert which intersects a floodwater channel.

    c. Floodwater Conduit – The outfall of a subsurface stormwater conveyance system which daylights into a floodwater channel and which is publicly maintained.

4) Maintaining floodway conveyance will be furthered by understating the feasibility of, developing the final design for, and developing construction procurement documents to build and permit one or more of the following sedimentation mitigation activities:

    a. Floodwater channel boundary protection – Stabilize channel banks when a surrounding land form slumps, fails, and slides (referred to as mass wasting) into a floodwater channel, notably reducing the cross sectional area from adjacent to and upstream of the suspected mass wasting.

    b. Desilting – A practice which includes the removal of sediment from a floodwater channel and floodwater crossing to restore its floodwater conveyance. Also known as shoaling.

    c. Natural channel design – A design concept applied to floodwater channels and floodwater crossings which seeks to transport sediment downstream and maintain floodwater conveyance by matching channel dimensions and plan and profile alignments. Natural channel design material can include stone, woods, and vegetative plantings.

    d. Sediment trapping – A facility whose purpose is to capture sediment and provide frequent access to remove and maintain the facility. These facilities are located in or adjacent to floodwater channels.

    e. Vegetative obstructions – Removal of vegetation that forms an obstruction to floodway conveyance or public safety only when the loss of any aquatic habitat benefits can be mitigated near the removal site.

5) When a sediment mitigation strategy is sought, the seeking party (referred to as the Sponsoring Party) will reach out to the Lead Agency regarding its sediment mitigation strategy (referred to as the Sponsored Project).

6) The Lead Agency will be HCFCD for Sponsored Projects in Harris County and the SJRA for Sponsored Projects outside Harris County.

7) The Lead Agency will coordinate among the other Parties to solicit participation in the coordination and/or financing of the Sponsoring Party's Sponsored Project. Furthermore, the Parties agree to:

    a. Work together to align each Party's mission and objective to support the Sponsoring Party's Sponsored Project

    b. Submit reviews of the Sponsored Project within the timeline established by the Lead Agency with concurrence of the Sponsoring Party

    c. Identify opportunities to assist the Sponsoring Party with technical information to aid the Sponsoring Party to coordinate or finance the Sponsored Project

    d. Seek opportunities to streamline coordination and consultation processes including the application for environmental permits and procurement of professional services

    e. Share data including environmental, hydraulic, geomorphic and planning data

8) The Sponsoring Party will be responsible to provide the Lead Agency with sufficient time and information to coordinate with all parties in order to allow them the opportunity to participate in the funding process of the project.

9) The Sponsoring Party will be responsible to provide the Lead Agency with any information necessary to complete reviews of the Sponsored Project in accordance with the timeline as established by the Sponsoring Party and Lead Agency. This information should include

    a. The location of Sponsored Project,

    b. How the Sponsored Project will maintain floodway conveyance,

    c. Coordination and financial resources needed to implement the Sponsored Project, and

    d. The timeline for implementation.

VI. **<u>Duration:</u>** This MOU shall remain in effect for a three (3) year term. Prior to this time, Parties may consider the MOU's terms and extend the MOU for another term. All agreements to reconsidered terms and the extension of the MUO must be completed the meeting prior to the completion of the three-year term. Continuation of the MOU and all reconsidered terms will be captured in writing.

VII. **<u>Termination</u>**: Any Party may determine that during the term of the MOU, the conditions of the MOU will not or cannot be carried out. That Party shall immediately consult the other Parties to development an amendment to the MOU. If within three months an amendment cannot be reached, any Party may terminate the MOU after providing written notification to the other Parties.

VIII. Signatures:

Signature	Date	Printed Name
______________________________	__________	______________________________
Signature of Harris County Flood Control District Representative	Date	Printed Name of Harris County Flood Control District Representative
______________________________	__________	______________________________
Signature of San Jacinto River Authority Representative	Date	Printed Name of San Jacinto River Authority Representative
______________________________	__________	______________________________
Signature of Harris County Representative	Date	Printed Name of Harris County Representative
______________________________	__________	______________________________
Signature of Montgomery County Representative	Date	Printed Name of Montgomery County Representative
______________________________	__________	______________________________
Signature of the City of Houston Representative	Date	Printed Name of the City of Houston Representative

References

Legiscan. 2020. Referenced on 6/26/20. https://legiscan.com/TX/text/HB1824/2019