SAN JACINTO RIVER AUTHORITY

UPPER SAN JACINTO RIVER BASIN REGIONAL SEDIMENTATION STUDY

Technical Memorandum 4

Sediment Transport Modeling

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1 Introduction

In order to further refine the Upper San Jacinto River Basin's (USJRB's) annual sediment budgets, the USJRB Sedimentation Study (Study) obtained additional understanding of sediment transport processes within the basin through the application of sediment transport modeling. As discussed in Technical Memorandum (TM) 2, three calibration watersheds were selected to represent the clusters of watersheds contained within the USJRB. This memorandum (TM 4) details the sampling, analysis, and modeling of bedload transport within the calibration watersheds; in subsequent Study tasks, the bedload transport conclusions and results will be extrapolated to other clustered watersheds with similar characteristics to generalize bedload transport and its role in sediment budgets for the entire USJRB.

2 Sediment Transport Modeling Approach

The transport of sediment is generally categorized into the bedload, suspended load, and wash load as shown in Figure 1. The bedload describes the sediment, generally gravel and coarse sand, that is transported by rolling, bouncing, or sliding along the stream bed. Lighter, smaller particles like fine sands, silt, and clay that are kept in suspension by the turbulence of the stream's flow make up the suspended load. As stream flows change, the suspended load and bedload particles may interact; suspended particles can settle into the bedload during calmer, less turbulent flows and, conversely, bedload particles can become suspended with sufficient velocities and turbulence. A stream's wash load consists of the finest sediment particles that remain in a near-permanent suspension and do not deposit or interact with the stream bed. An understanding of a stream's sediment transport capacity is beneficial for recommending stream stability improvement projects and management practices without exacerbating sediment erosion or deposition. However, due to the multitude of variables which influence sediment transport, including sediment characteristics, flow magnitudes and patterns, and stream geometries among others, a robust understanding of a stream's sediment transport processes can be difficult to achieve. This Study makes use of sediment transport models, which simplify the complex transport processes, to predict sediment bedload transport capacities within the USJRB.

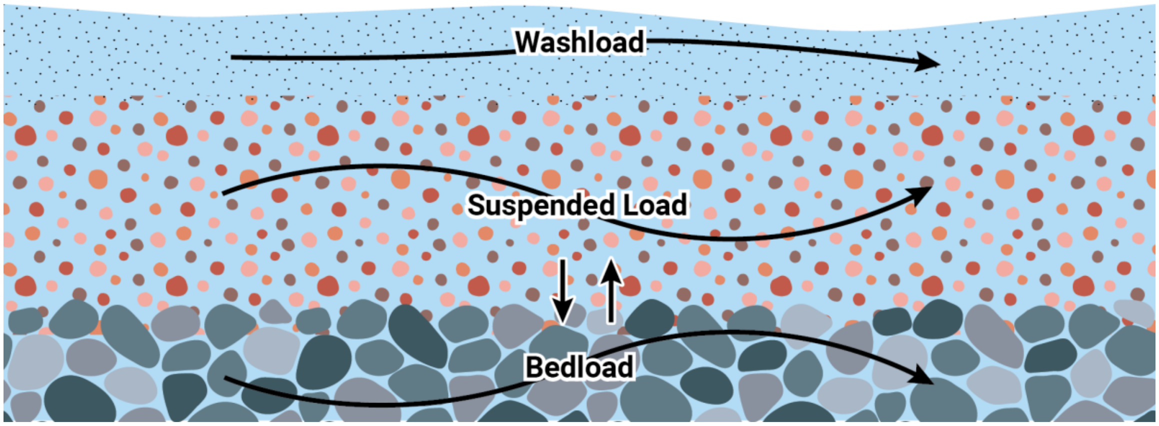

Figure 1. Sediment Transport Characterizations

The Study team utilized RIVERMorph v.5.2.0's FLOWSED/POWERSED modules to perform sediment transport modeling for two USJRB streams. The FLOWSED/POWERSED models follow an empirical methodology using dimensionless curves derived from observed data to predict sediment transport rates and annual sediment yield. In the FLOWSED model, a dimensionless sediment rating curve developed from a reference stream with similar characteristics and a dimensionless flow duration curve developed from a gauged stream site are applied to a specific stream cross-section using measured bankfull flow and sediment transport values at that cross-section. The POWERSED model uses the hydraulic geometry at the cross-section of interest to convert the discharge axis of the sediment rating curve to unit stream power; this conversion allows the impact to sediment transport rates from changing channel geometries to be modeled. For both models, with the two curves dimensionalized to the site of interest, the predicted sediment transport rates and annual sediment yield can be determined.

The FLOWSED/POWERSED predictive models for bedload transport were chosen to develop a deeper understanding of the sediment transport capacities in the USJRB. Gauged stream sites were chosen as the modeling locations for access to the historical flow data necessary for developing the flow duration curves. To develop the bedload rating curve, project scientists made several bedload measurements in the field during a stormflow event. Field sampling efforts, including bedload measurements, are discussed in Section 3. The development of the dimensionless bedload rating curve and dimensionless flow duration curves are described in Section 4. Finally, sediment transport modeling results are summarized in Section 5, and the relationships drawn from the interpretation of the results are in Section 6.

3 Field Data Collection

In order to satisfy the input requirements to run the FLOWSED/POWERSED models, the project team collected additional field data at two representative stream gauge locations. Stream cross-sections and bedload samples were collected at the Willow Creek USGS Gauge (08068325) and at the Caney Creek USGS Gauge (08070500) representing the Walnut Creek-Spring Creek and Peach Creek-Caney Creek calibration watersheds, respectively. The East Fork San Jacinto River near Coldspring USGS Gauge (08069800) did not have a sufficient data record for the development of a representative flow duration curve and was therefore omitted from the bedload transport modeling analysis; however, this site was included in other analyses, such as BANCS and dendrogeomorphic analysis, as detailed in TM 3. The locations of the calibration watersheds and USGS Gauge sites can be found in Figure 2.

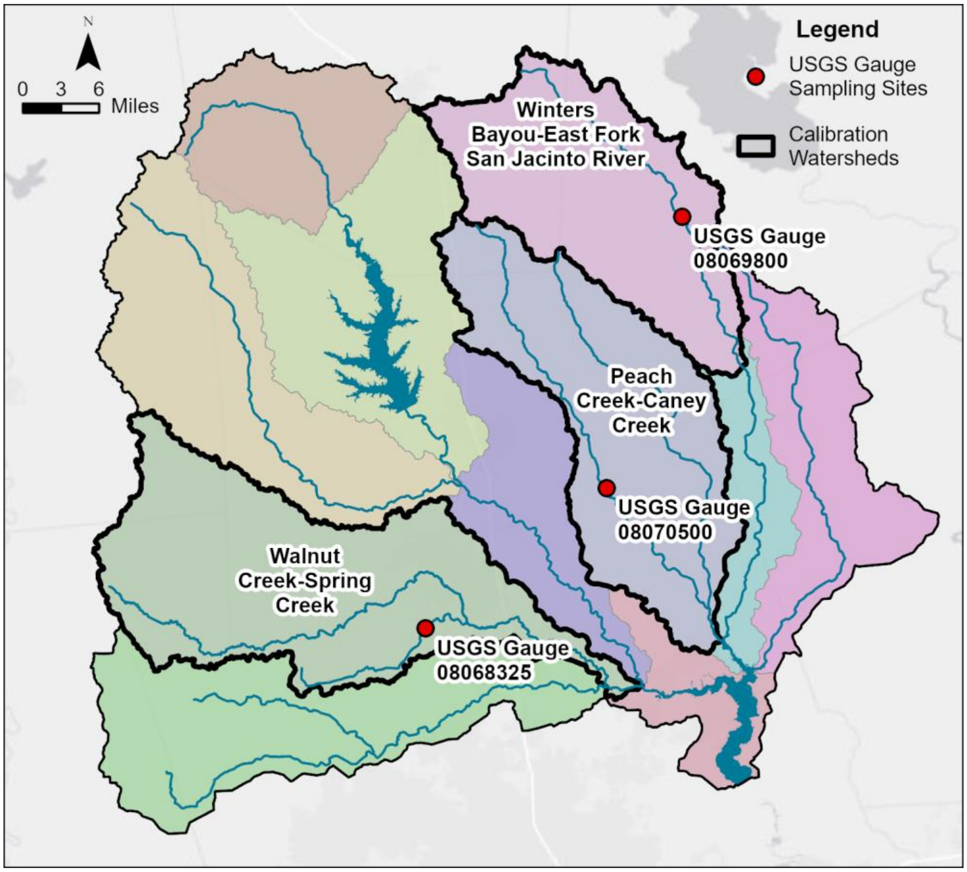

Figure 2. Calibration Watersheds and Corresponding USGS Gauge Sites

3.1 Cross-Section Delineation

The FLOWSED/POWERSED model uses channel geometry to calculate flow/stage and stream power relationships. Stream channel cross-sections were surveyed at the Willow Creek and Caney Creek gauges using laser level equipment to capture the most recent channel geometries. The surveyed gauge site cross-sections, supplemented with high resolution elevation data from TNRIS (Texas Natural Resources Information System) for points beyond the banks, are shown in Figure 3. During surveying, the project team also noted bankfull stage indicators within the stream channel. The bankfull stage of a stream is the stage right before which the water would overflow into the floodplain. The bankfull streamflow is a normalization parameter used during the development of the dimensionless curves detailed in Section 4.

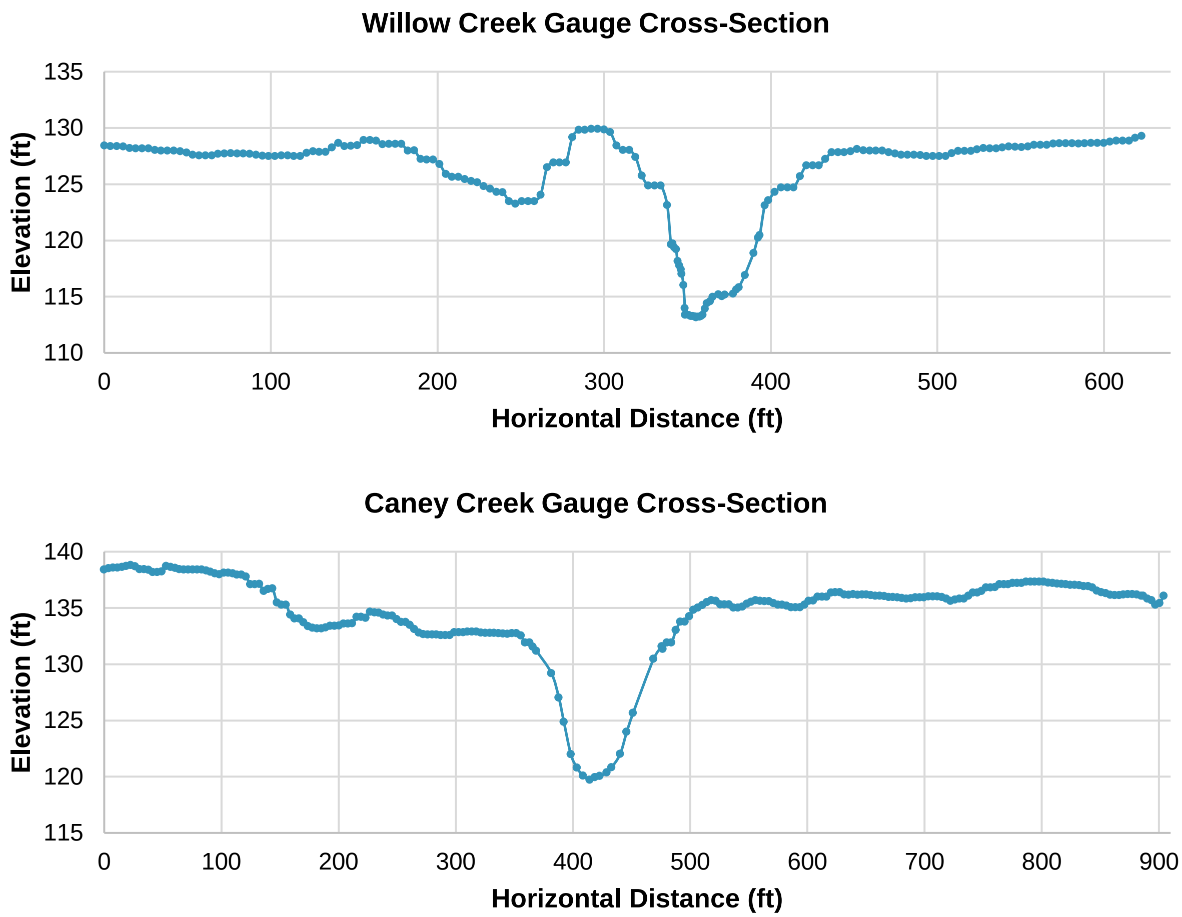

Figure 3. Stream Cross-Sections at Willow and Caney Creek Gauges

3.2 Bedload Sampling

Sediment bedload samples were also collected at the representative stream sites. A Helley-Smith bedload sampler was used to collect the bedload samples during a near-bankfull discharge event. This device is placed along the streambed's cross-section and collects sediments that are moved within the bedload through a short opening; the sediments collected within a known time period can then be weighed and a bedload transport rate can be determined. During a dry period in December of 2022, no bedload was observed at either the Willow Creek or Caney Creek sites. In addition, no bedload was found at the East Fork site during this time-period due to extremely low flows (less than 0.05 cubic feet per second [cfs]). A thunderstorm beginning January 7, 2023, which produced around 1.5 inches of rainfall, was the trigger event for bedload sampling. Peak streamflow for the rain event was approximately 300 cfs in Willow Creek and at 620 cfs in Caney Creek on the morning of January 8, 2023. Sampling occurred shortly after the peaks to ensure representative data, but also after enough time had passed such that the stream would be safely wadable for the project team's samplers. Willow Creek's streamflow following the January 7th rainfall is shown in Figure 4 along with the denotation of the bedload sample collection times which occurred following the peak flow when the stream became safe to enter; a similar graph for Caney Creek's sample collection times can be seen in Figure 5.

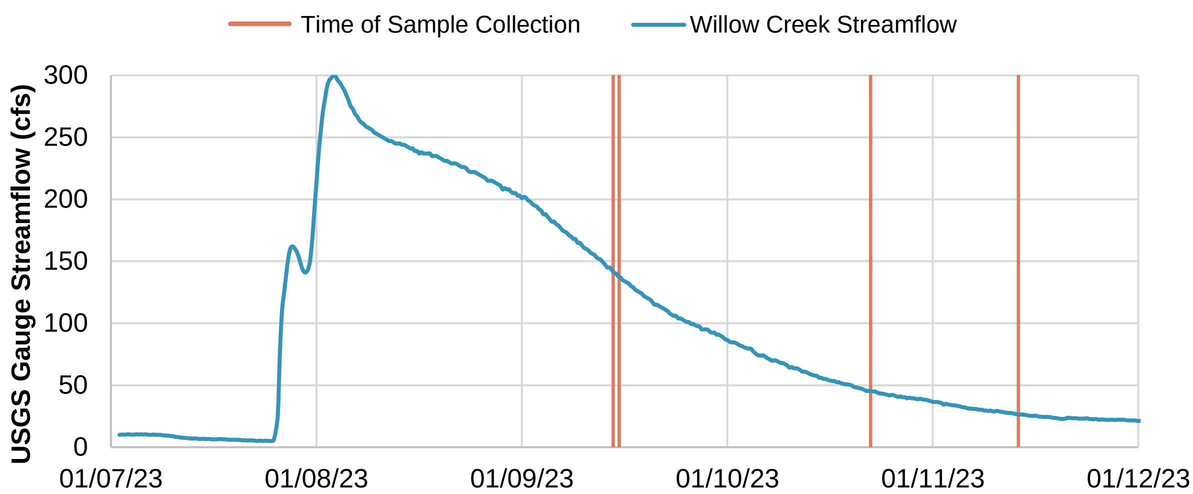

Figure 4. Willow Creek Bedload Sampling during Storm Flows

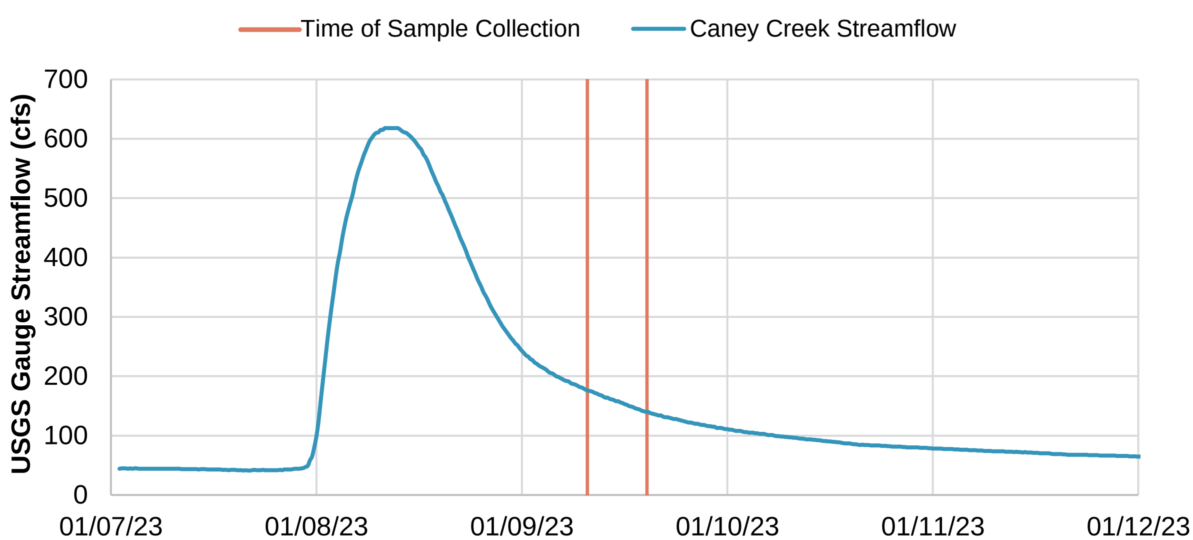

Figure 5. Caney Creek Bedload Sampling during Storm Flows

During the storm flow period, project scientists collected four bedload samples from the Willow Creek site, two samples from the Caney Creek site, and a single sample from the East Fork site. These samples were collected in addition to the zero-bedload samples collected in December at each site. Figure 6 shows the magnitude of the measured sediment bedload for Willow and Caney Creeks at the average streamflow measured during the sampling period.

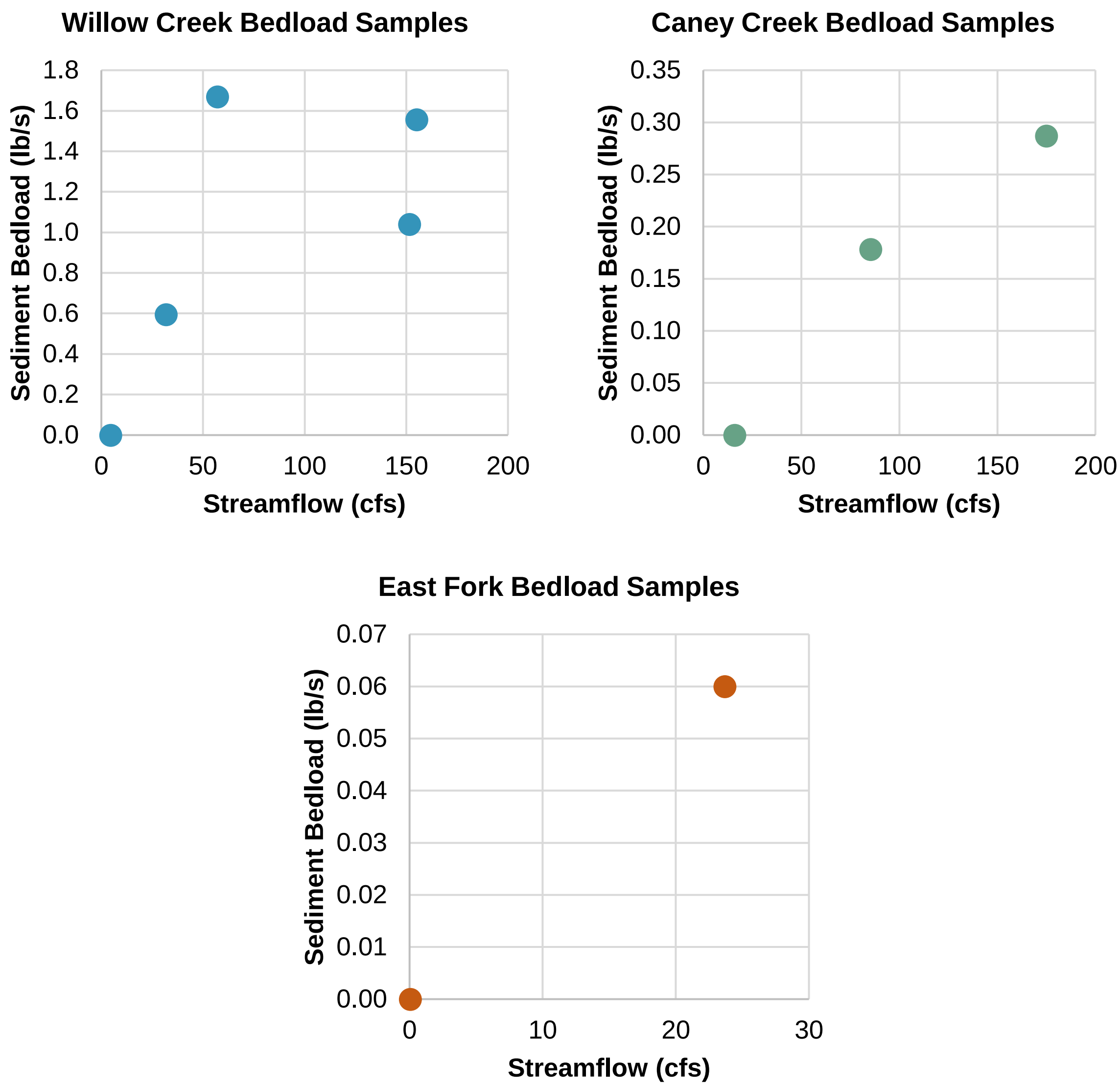

Figure 6. Sediment Bedload Samples at Average Measured Streamflow during Sampling

Willow Creek's bedload during stormflow sampling ranged from 1.67 pounds per second (lb/s) to 0.59 lb/s. The variance in these data, particularly in the two samples with similar flows above 150 cfs, demonstrate the uncertainty in sediment bedload measurement, as bedload transport is a highly dynamic process. Although the data exhibit noise, it is still possible to develop a best-fit curve in subsequent analysis. In December, when flows at the sampling site were only 4.5 cfs, no measurable bedload was found. Caney Creek's bedload was first measured at 0.29 lb/s and had decreased to 0.18 lb/s when measured on the next day. No bedload was found during the dry weather flow sampling when Caney Creek's flow was 16 cfs. The stormflow bedload sample at the East Fork site was measured at 0.06 lb/s at an average streamflow of 23.7 cfs. As discussed, no bedload transport was observed when flow was less than 0.05 cfs. Although sufficient historical data was unavailable to complete modeling for this site, this bedload sample demonstrates that bedload transport at the East Fork site is generally more similar to that at Caney Creek versus Willow Creek.

Willow Creek's bedload sample measurements were appreciably higher than the bedload sample measurements collected from Caney Creek. In TM 3, erosion rates for Willow Creek were also found to be appreciably higher than those in Caney Creek; the mechanisms that cause more erosion may also be mechanisms for the higher bedload transport and/or may provide a greater volume of bedload available for transportation. As discussed in TM 3, Willow Creek sediments are generally finer on average versus those in Caney Creek. As mentioned, the bedload sample measurement at the East Fork was generally consistent with the data trend observed for Caney Creek.

During the sample collection, project scientists noted the bedload samples were primarily composed of sand. This observation is consistent with the particle size distributions reported in TM 3 – Annual Sediment Supply and Storage. The sediment bars sampled for particle size distributions, which are likely to be reflective of what settles in the stream bed and moves in the bedload, were 94% and 98% sand, respectively, for Willow and Caney Creeks. Figure 7 shows the sediment grain size composition for point bars within the two streams. Additional details can be found in TM 3 – Annual Sediment Supply and Storage.

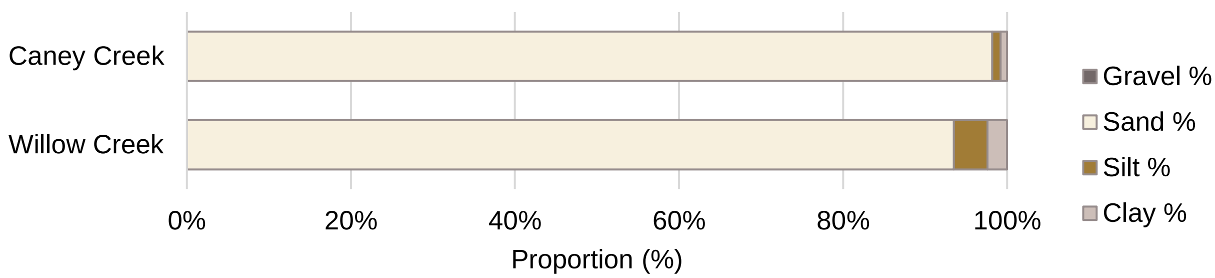

Figure 7. Sediment Compositions of Sampled Point Bars

4 Flow and Sediment Rating Curves

The FLOWSED/POWERSED model makes use of dimensionless flow duration curves and dimensionless sediment rating curves to calculate a total annual sediment yield. Using data from both public sources (USGS for flow data and Harris County Flood Control District for bankfull discharge curves) and the field collection efforts described in Section 3, flow duration curves and sediment rating curves were developed for the USJRB streams.

4.1 Flow Duration Curves

The USGS has instantaneous flow data available for gauges within its monitoring network, the National Water Information System. The Willow Creek Gauge (08068325) has instantaneous flow data beginning in October of 2006, and the Caney Creek Gauge (08070500) has instantaneous flow data beginning in

October of 1990. This flow data can be used to develop flow duration curves, which describe the percentage of time that a given flow was equaled or exceeded within a given period. The FLOWSED/POWERSED models use the entire flow duration curve to develop probabilistic estimates of sediment transport on an annual basis. The flow duration curves, based on mean daily flow data, for the Willow Creek Gauge and the Caney Creek Gauge are shown in Figure 8 and Figure 9, respectively. Over the past 17 years, the flow through the Willow Creek Gauge site was 577 cfs or less 99% of the time. Over the past 30+ years of data available for the Caney Creek Gauge, the flow was 1,100 cfs or less 99% of the time. The remaining 1% of the time is indicative of relatively extreme, low-frequency stormflows. The highest recorded mean daily flows for Willow Creek (7,400 cfs) and Caney Creek (18,800 cfs) were both more than an order of magnitude higher than their respective 99th percentile values.

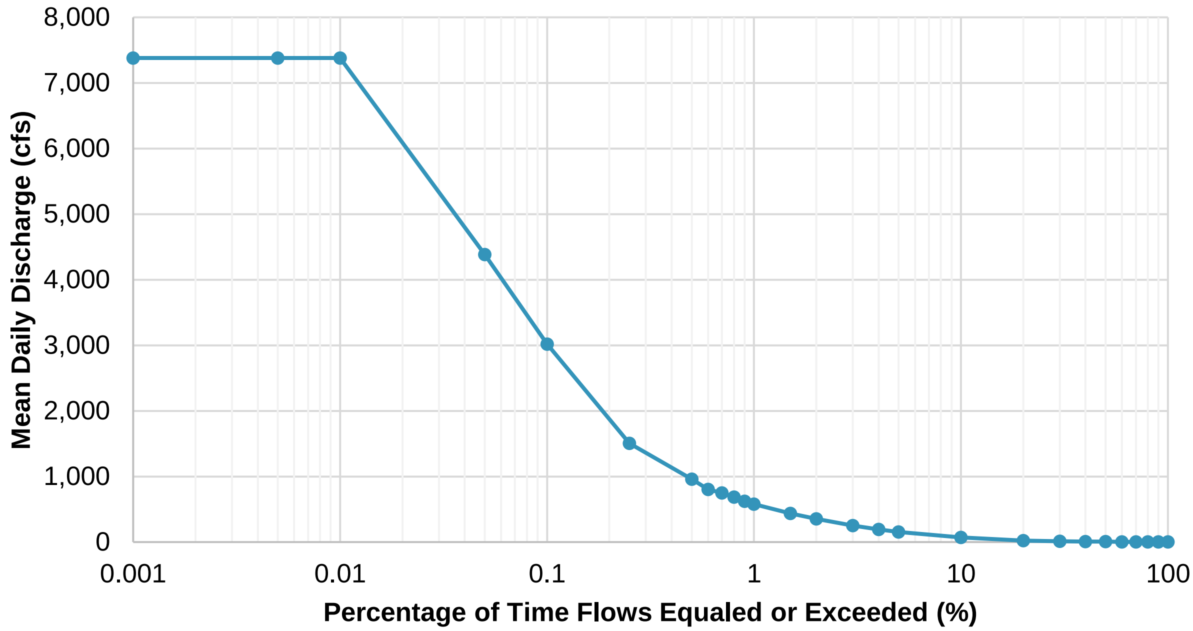

Figure 8. Flow Duration Curve for Willow Creek Gauge

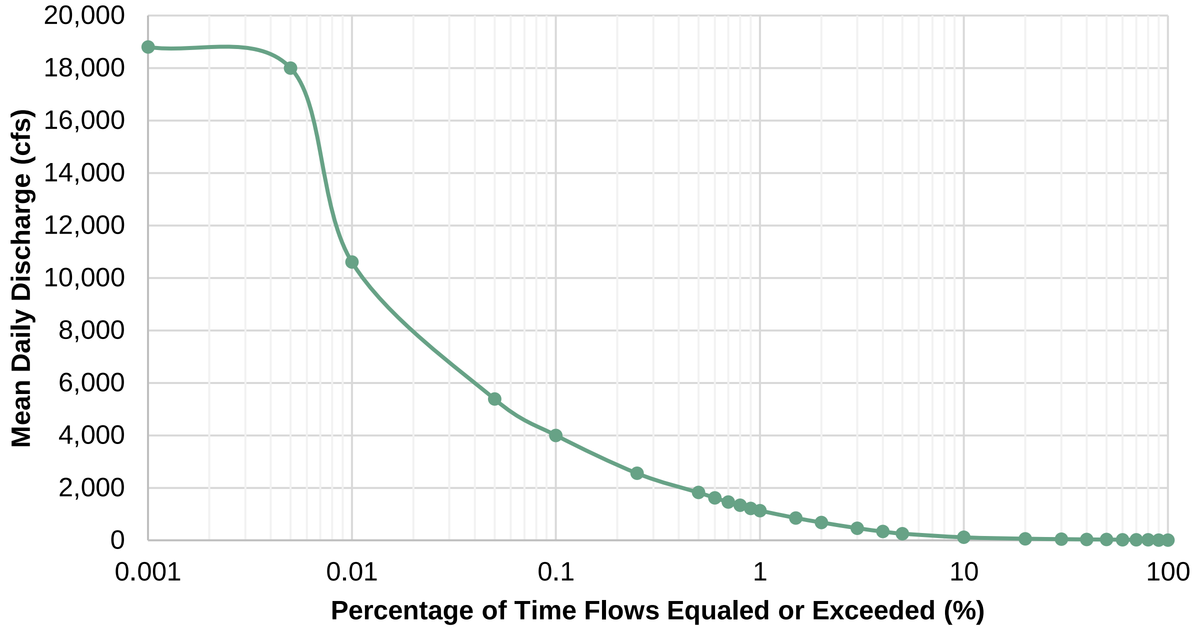

Figure 9. Flow Duration Curve for Caney Creek Gauge

4.1.1 Dimensionless Flow Duration Curve Development

To develop a generalized relationship between flow and sediment transport, flow and sediment inputs need to be made dimensionless by dividing by reference values of the same units. The FLOWSED/POWERSED model uses the mean daily equivalent bankfull discharge as the reference value. The bankfull discharge is the flow of the stream at the bankfull stage, which is the maximum flow that the stream can carry before water enters the floodplain. The bankfull discharge represents an instantaneous peak flow; the mean daily equivalent bankfull discharge is the mean daily discharge that occurs on a day whose peak is the bankfull discharge. Bankfull indicators like changes in riparian slopes or vegetation are often used to determine the bankfull stage and discharge. During the BANCS field assessments, project scientists noted bankfull heights and widths for reaches of Caney Creek and Willow Creek, including the gauged sites of interest. In addition to the physical indicators taken in the field, Harris County regional relationships between bankfull values and drainage areas from *Fluvial Geomorphological Conditions of Harris County, Texas* (AMEC 2011) were used in the determination. Table 1 contains the bankfull discharges calculated for the two modeling gauge sites.

After calculating the bankfull discharge, the mean daily equivalent was taken from the historical USGS gauge data. The mean daily equivalent bankfull discharge was taken from the gauge's daily mean flow database on the day(s) for which the gauge's peak instantaneous discharge was close to the calculated bankfull discharge. Because the majority of the instantaneous data are less than the bankfull discharge, the mean daily equivalent bankfull discharges are therefore also lower than the calculated bankfull values. The mean daily equivalent bankfull discharge for the modeled streams can also be found in Table 1.

Table 1. Bankfull Discharge Values

Gauge Site	Bankfull Discharge (cfs)	Mean Daily Equivalent Bankfull Discharge (cfs)
Willow Creek (08068325)	510	302
Caney Creek (08070500)	940	555

The dimensioned flow duration curves were divided by the mean daily equivalent bankfull discharge for each stream to develop dimensionless flow duration curves for input into the FLOWSED/POWERSED models.

4.2 Sediment Rating Curve

Another set of relational inputs into the FLOWSED/POWERSED models are sediment rating curves. The sediment rating curves define the relationship between suspended sediment load or bedload and the discharge (i.e., flow) of the stream. An empirical relationship between dimensionless discharge and dimensionless sediment load is ideal for sediment transport modeling as it can be applied and dimensioned to streams of a similar type and stability. In this section, the development of a dimensionless sediment rating curve is discussed. The FLOWSED/POWERSED models subsequently convert dimensionless sediment rating curves to dimensioned curves using the stream-specific bankfull discharge and bankfull sediment load.

4.2.1 Estimation of Bankfull Bedload

Determination of the bedload at bankfull flow was necessary to convert between dimensionless and dimensioned bedload values used in the FLOWSED/POWERSED models. However, directly measuring bedload at bankfull flows can be dangerous for field personnel due to the elevated water levels and stream velocities. As a result, the bankfull bedload was estimated using an extrapolation of the measured bedload samples, collected as described in Section 3.2, to bankfull discharge. Using the best-fit logarithmic relationship for each individual stream and the bankfull discharges in Table 1, the extrapolated bankfull bedload was calculated for each stream, as found in Table 2.

Table 2. Extrapolated Bankfull Bedload Values

Gauge Site	Bankfull Discharge (cfs)	Bankfull Bedload (lb/s)
Willow Creek (08068325)	510	1.9
Caney Creek (08070500)	940	0.5

4.2.2 Pagosa Springs Reference Curves

Pagosa Reference Curves are available in the FLOWSED/POWERSED model as defaults for use when an entity cannot collect enough data and/or has the capability to develop their own sediment rating curve. These dimensionless curves were developed by the FLOWSED/POWERSED model developer using sediment load and discharge data from several streams in the Pagosa Springs, CO area (Rosgen, 2006). The relationships found followed a power function with an exponential-like growth, as seen in Figure 10.

As discussed in the previous section, the collected bedload data most closely followed a logarithmic trend and not an exponential one. Thus, when the Pagosa Refence Curve for bedload was dimensioned to fit the sampled gauge cross-sections, it was a poor predictor of bedload at lower flows, as shown in the Willow Creek example in Figure 10. The Pagosa Reference curve predicts that bedload would not begin occurring until the stream reached 100 cfs, but all the collected samples of bedload were measured at values below that threshold. The streams around Pagosa Springs, CO are primarily gravel bed streams. As flows within these streams increase, the force along the bottom of the channel can mobilize progressively larger sizes of gravel along the bed and increase bedload as described in the Pagosa Reference Curves. However, the streams within the USJRB are predominantly homogenous sand bed streams; this distinction may be the cause of the poor fit for the Pagosa Reference Curves. Smaller, more-uniform sand grains could be more easily moved at lower flows than gravel, attributing to the initial steep increase in bedload, and with further increasing turbulence be more easily lifted into suspension and no longer moved as bedload, resulting in the leveling off the sediment rating curve. Ultimately, due to the poor fit of the Pagosa Reference Curves, a USJRB-specific dimensionless bedload rating curve was developed for use in all sediment transport modeling efforts under this Study, as described in Section 4.2.3.

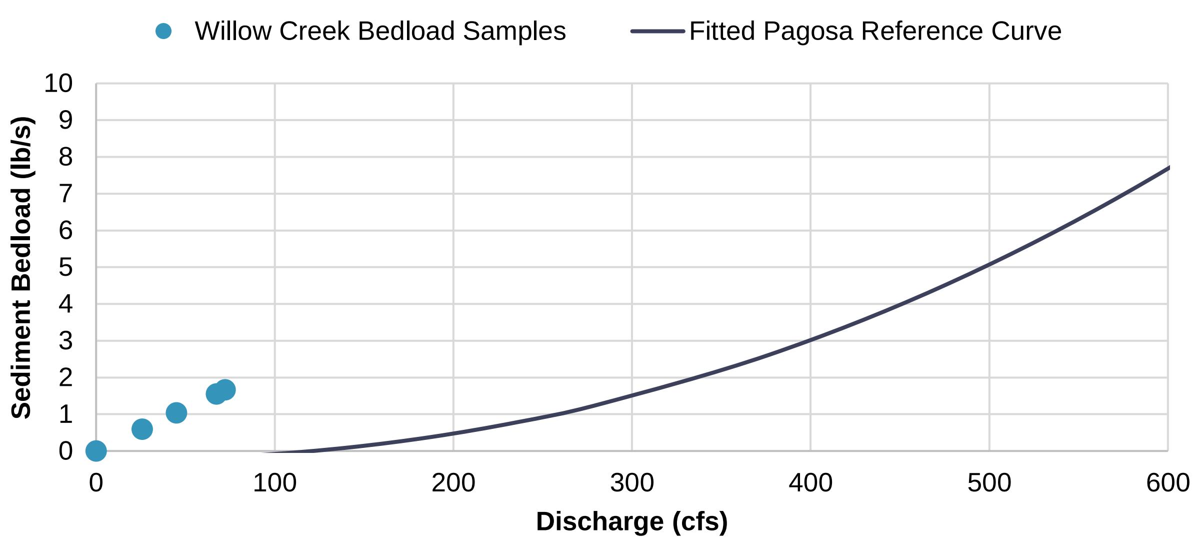

Figure 10. Pagosa Springs Reference Curves Fitted to Willow Creek Bankfull Bedload

4.2.3 Development of Upper San Jacinto Regional Bedload Curve

The USGS has found success in developing regional, dimensionless bedload rating curves that more closely predict measured bedload data for a given region than the Pagosa Springs Reference Curve. The methodology for developing regional dimensionless bedload rating curves and assessing the goodness-of-fit were outlined in the recent *Application of Dimensionless Sediment Rating Curves for Rivers in Minnesota* (Ellison 2016). Based on the example of this report, an "Upper San Jacinto Reference Bedload Curve" was developed to fit the measured bedload data more closely for Willow and Caney Creeks and improve the bedload yield estimates from the model. A dimensionless bedload database was created using the measured bedload data and the extrapolated bankfull discharge/bedload for each respective stream. The power model used by the FLOWSED/POWERSED model was fitted to the dimensionless Upper San Jacinto bedload database by minimizing the errors between the rating curve and the measured values. The resulting Reference Bedload Curve with the best-fit coefficients was found as follows:

$$Bedload_{Dimensionless} = 36.879 * Q_{Dimensionless}{}^{0.0061} - 35.882$$

where $Q_{Dimensionless}$ is the dimensionless streamflow. The extrapolated bankfull discharge and bedload for each stream (from Table 2) were then used to dimension the Upper San Jacinto bedload curve. As shown in Figure 11 (Willow Creek) and Figure 12 (Caney Creek), the resulting bedload rating curves follow an arc similar to a logarithmic curve. Although there is still uncertainty regarding the behavior of the bedload transport at high stream flows, the Upper San Jacinto Reference Bedload Curve more closely predicts the bedload measurements collected during this Study. This regional reference curve was therefore applied for subsequent analysis.

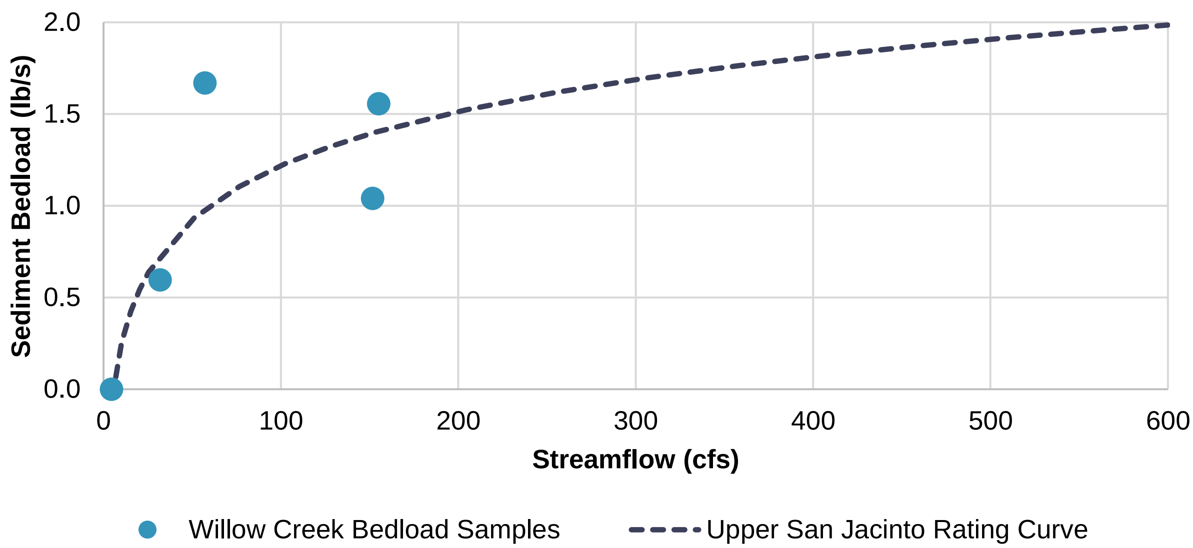

Figure 11. Upper San Jacinto Rating Curve Dimensioned to Willow Creek

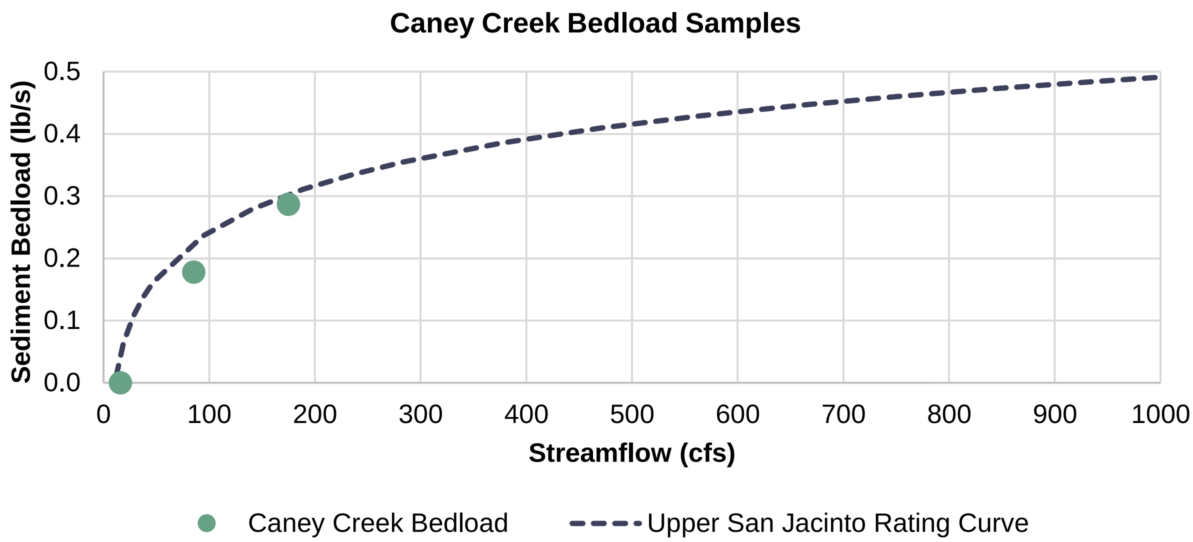

Figure 12. Upper San Jacinto Rating Curve Dimensioned to Caney Creek

5 Sediment Modeling Results

Using both the dimensionless flow duration curve and the dimensionless bedload rating curve, the FLOWSED model predicts the amount of bedload that can be expected for a percentage of time each year and the resulting total annual sediment yield. Instead of using streamflow, the POWERSED model uses unit stream power to relate the flow duration curve and dimensionless bedload rating curve. Stream power is a measure of a stream's potential energy expenditure, which has been shown to be a dominant factor in sediment transport (Yang and Stall, 1974). Unit stream power is the total stream power normalized (i.e., divided by) the width of the stream.

The model makes use of the hydraulic geometry provided in the cross-section to convert discharge into unit stream power so that changes in the channel slope, depth, and velocity are reflected in the modified bedload to unit stream power curve. This also allows the prediction of bedload rates under different cross-section conditions. After predicting the bedload under different unit stream power conditions and by percentage of time a load is expected during a year, the POWERSED model also provides an estimate of total annual sediment yield.

Under each modeling scenario, the FLOWSED/POWESED models were run twice, once in which only flows up to and including the bankfull discharge were included and one with the full extent of the flow duration curve included. Generally, only the flows up to and including the bankfull discharge are modeled because the bedload rating curve developed for bedload within the channel would not be representative of the movement of sediments in the floodplain. However, because extreme storm flows have been proven to transport significant amounts of sediment within the basin, both model runs (with and without flows above bankfull) are included in this section to avoid underestimating the amount of bedload transport that can occur during extreme events.

5.1 FLOWSED Predicted Annual Bedload Transport

The FLOWSED model was used to predict the annual bedload transport at the Willow Creek and Caney Creek Gauge sites, shown in Table 3. At the Willow Creek site, up to 6,250 – 7,230 tons of bedload are moved annually across the bottom of the channel, and at Caney Creek up to 2,650 – 2,910 tons of bedload are transported downstream annually.

Table 3. Annual Bedload Transport Estimates from FLOWSED

Cross-Section	Annual Bedload Transport w/o Flows above Bankfull (tons)	Annual Bedload Transport w/ Flows above Bankfull (tons)
Willow Creek (08068325)	6,250	7,230
Caney Creek (08070500)	2,650	2,910

Figure 13 and Figure 14 are daily mean bedload duration curves for Willow Creek and Caney Creek, respectively. Like the flow duration curves discussed in Section 4.1, these curves describe the rate of bedload sediment transport that is equaled or exceeded for a given percentage of the year. These curves are the resultant combination of the flow duration curve and sediment rating curve. For the Willow Creek cross-section location, it is expected that flows are unable to trigger any significant bedload transport for approximately 30% of the year; however, heavy, wet-weather flows that occur more infrequently can produce high bedload transport capacities. The same exponential-like increase in daily mean bedload under lower frequency (i.e., more extreme) flows occurs at the Caney Creek cross-section as well, but it is expected to have a measurable amount of bedload at nearly all times of the year, as shown in Figure 14. For both Willow and Caney Creek, the bankfull bedload is exceeded for only approximately three percent of the year.

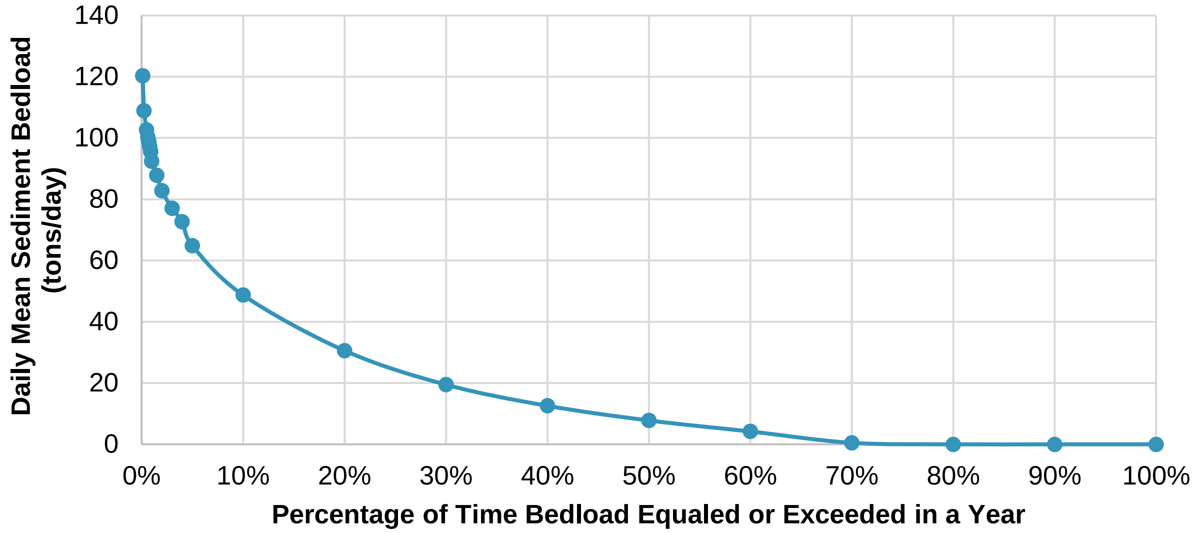

Figure 13. Daily Mean Sediment Bedload Frequency Distribution Willow Creek

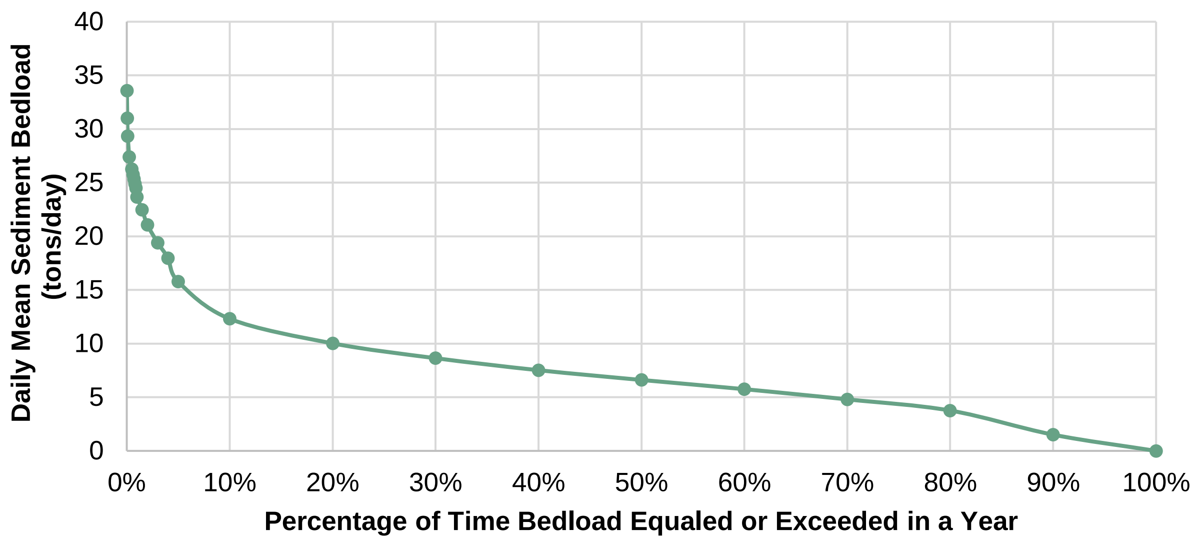

Figure 14. Daily Mean Sediment Bedload Frequency Distribution for Caney Creek

5.2 Additional Modeling Cross-Sections

The POWERSED model allows the user to run a bedload rating curve developed for one cross-section through another "evaluation" cross-section to observe the influence of channel shape on the bedload transport. For this study, six additional cross-sections from Caney Creek and five from Willow Creek were run as evaluation cross-sections to observe bedload behavior under different stream channel geometries. For each stream, an upstream and downstream location were chosen that corresponded with the streambank sampling that occurred in TM 3 (Millmac and Sycamore for Caney Creek; Tuwa and Gosling for Willow Creek). The chosen cross-sections were extracted from the USJRB HEC-RAS model, a hydraulic model of the major channels of the basin developed for the San Jacinto Regional Watershed Master Drainage Plan (2020). Figure 15 shows the location of the POWERSED-modeled cross-sections (XSs) and the bedload sampling sites where cross-sections were measured in the field by project scientists.

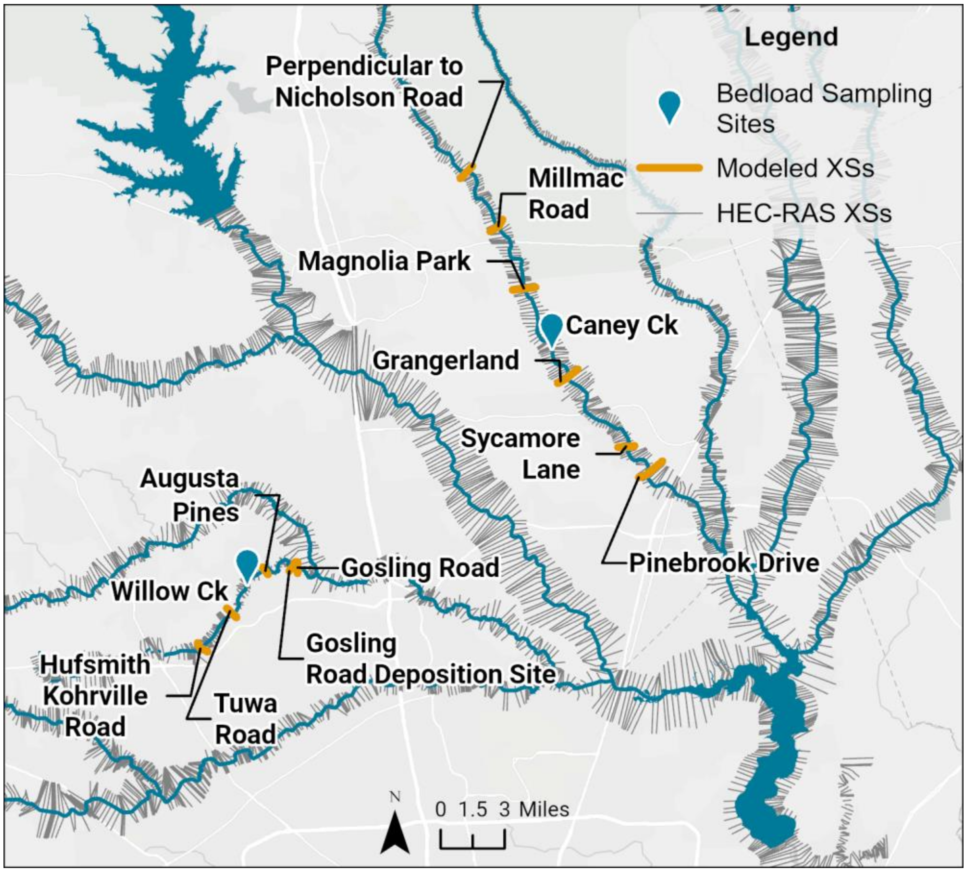

Figure 15. Locations of POWERSED-Modeled Cross-Sections in Willow and Caney Creeks

In the POWERSED model, the evaluation cross-section uses the same bedload rating curve and flow duration curve as the "comparative" cross-section, which are the bedload sampling site cross-sections. So, the further upstream/downstream the evaluation cross-section is from the comparative cross-section the less accurate the POWERSED predicted bedload will be, especially where lesser tributaries flow into the main channel between modeled cross-sections. However, the relative magnitude of the predicted bedload will be useful for determining the channel geometries that may contribute to the excessive deposition or scouring of bedload sediments.

5.3 POWERSED Predicted Annual Bedload Transport

The POWERSED model was used to estimate the annual bedload transport for the Willow Creek and Caney Creek gauge sites and at the evaluation cross-sections extracted from the USJRB HEC-RAS model. For Willow Creek, the POWERSED estimated annual bedload ranged from 120 – 14,200 tons when considering flows up to and including bankfull and 500 – 41,800 tons when including flood level flows. As shown in Figure 16, bedload at the cross sections downstream of the gauge site is more likely to be driven by flood conditions as the disparity between the model runs increased significantly. On average, the Willow Creek cross-sections were predicted to transport an average range of 8,890 – 17,450 tons of bedload annually.

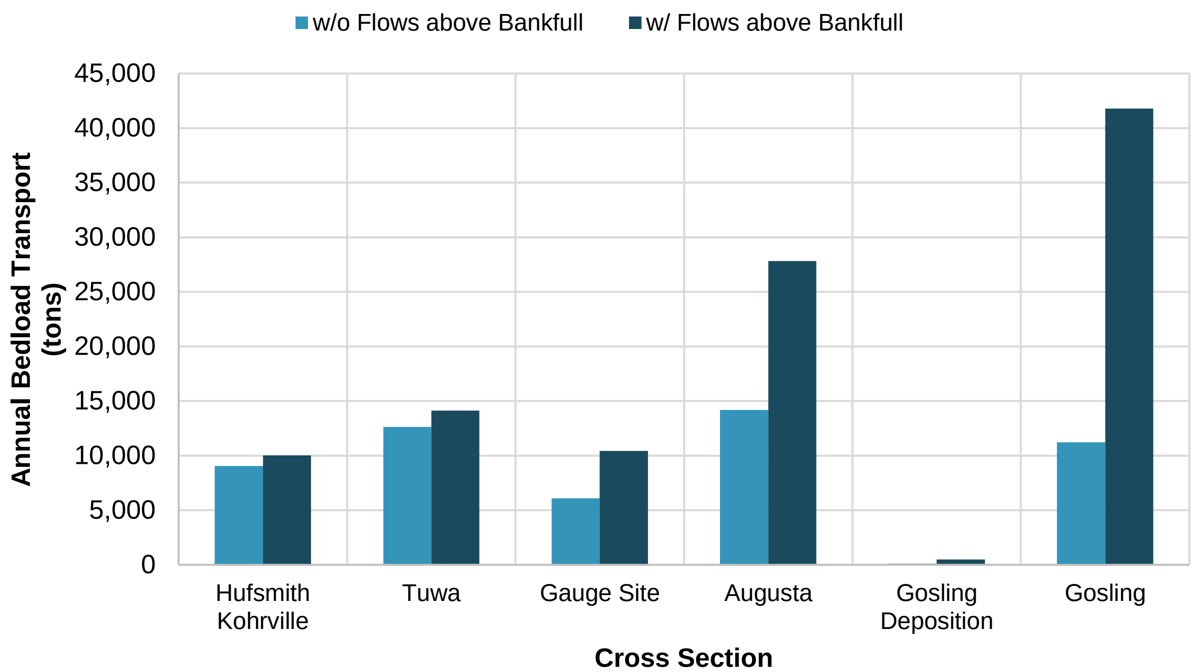

Figure 16. POWERSED Model Annual Bedload Transport Results for Willow Creek Cross-Sections

The POWERSED Model results for the Caney Creek cross-sections were less variable than those from the Willow Creek cross-sections. Summarized in Figure 17, the predicted annual bedload in Caney Creek ranged from 730 – 3,060 tons for flows up to and including the bankfull and 970 – 4,130 tons for the full range of flows. Unlike Willow Creek, there is no clear differentiation between cross sections upstream or downstream of the gauge site. The average annual bedload transport for the Caney Creek cross-sections modeled was 2,060 – 2,780 tons.

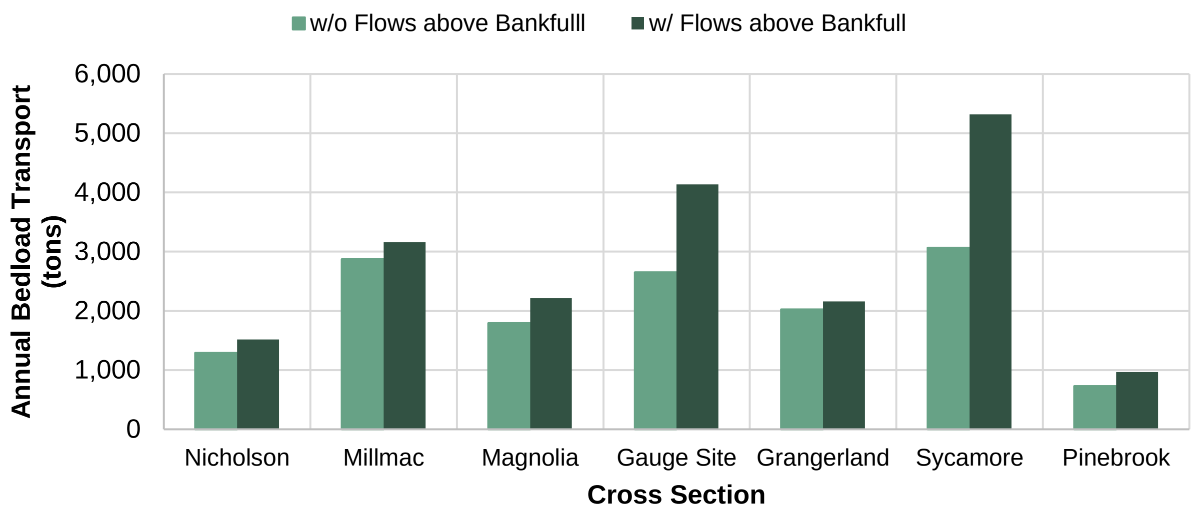

Figure 17. POWERSED Model Annual Bedload Transport Results for Caney Creek Cross-Sections

6 Findings and Conclusions

6.1 Sediment Transport Competency

The largest particle that a stream is able to transport is referred to as the stream's competency. Larger and more dense particles, like gravel and boulders, will generally require higher (i.e., stronger) flows to transport them, as compared with finer particles. However, particle cohesion (e.g., in clay sediments) or stream vegetation, among other factors, can also affect the flow needed to move particles of various sizes. Essentially no gravel was found in particle size distributions conducted on the streambank, floodplain, and point bar sediment samples gathered from the USJRB (see TM 3). The minimal amount of gravel that was found was believed to originate from anthropogenic sources (e.g., rip-rap installed at crossings and drainage outfalls). Therefore, it is likely that the largest particle naturally found in stream beds of the USJRB is coarse sand, with sediments composed primarily of fine to medium sand. As discussed in Section 4.1, the flow in the USJRB streams can vary significantly based on rainfall and, subsequently, so would the stream power and shear stress. Given the broad range of power the stream would be able to produce and the predominance of sand, it is likely that the USJRB's streams are able to move the full array of particle sizes naturally found within the basin. However, there may be periods of time or specific locations where the streams may only be competent to carry finer particles, either due to periods of low flow or stream channel geometries that result in low stream powers and shear stresses. The mouth bars at the inlets of Lake Houston are examples of locations where competency may be limited to only finer sands or silts under most circumstances.

6.2 Sediment Transport Capacities

Sediment transport capacities can be difficult to ascertain due to the complex relationships governing the movement of sediment within streams. The FLOWSED and POWERSED models in RIVERMorph were used to estimate the transport magnitudes at the two bedload-sampled streams. A summary of model results discussed in the previous section can be found in Table 4. Willow Creek was determined to have higher and more variable sediment transport capacities across its modeled cross-sections compared to Caney Creek, even though Caney Creek carries more flow. Conclusions regarding the difference between the bedload transport capacities of both streams and the variability of the transport along the streams are detailed in the subsequent sub-sections.

Table 4. Modeled Sediment Transport Capacities for Willow and Caney Creek

Cross-Section	FLOWSED Bedload Transport (tons/year)		Average POWERSED Bedload Transport (tons/year)	
	w/o Flows over Bankfull	w/ Flows over Bankfull	w/o Flows over Bankfull	w/ Flows over Bankfull
Willow Creek	6,250	7,230	8,890	17,450
Caney Creek	2,650	2,910	2,060	2,780

6.2.1 Intra-Stream Bedload Transport Relationships

As shown in Figure 16, the POWERSED model results for Willow Creek showed significant variability in bedload transport in the chosen cross-sections along the stream. To spatially demonstrate this variability, the values up to and including bankfull flows only from Figure 16 were placed into qualitative bins and mapped in Figure 18. Notably, the lowest modeled bedload transport site, "Gosling Deposition," is only 1,900 feet upstream of one the higher bedload transport sites at the Gosling Road bridge. Given that the sites receive equivalent flow but vary significantly in predicted bedload transport, it is clear that other factors apart from flow govern intra-stream bedload transport. Stream geometry, which, in addition to discharge, governs the force that the water exerts on the bed of the stream, was found to play a more significant role in the bedload transport capacities of specific cross-sections.

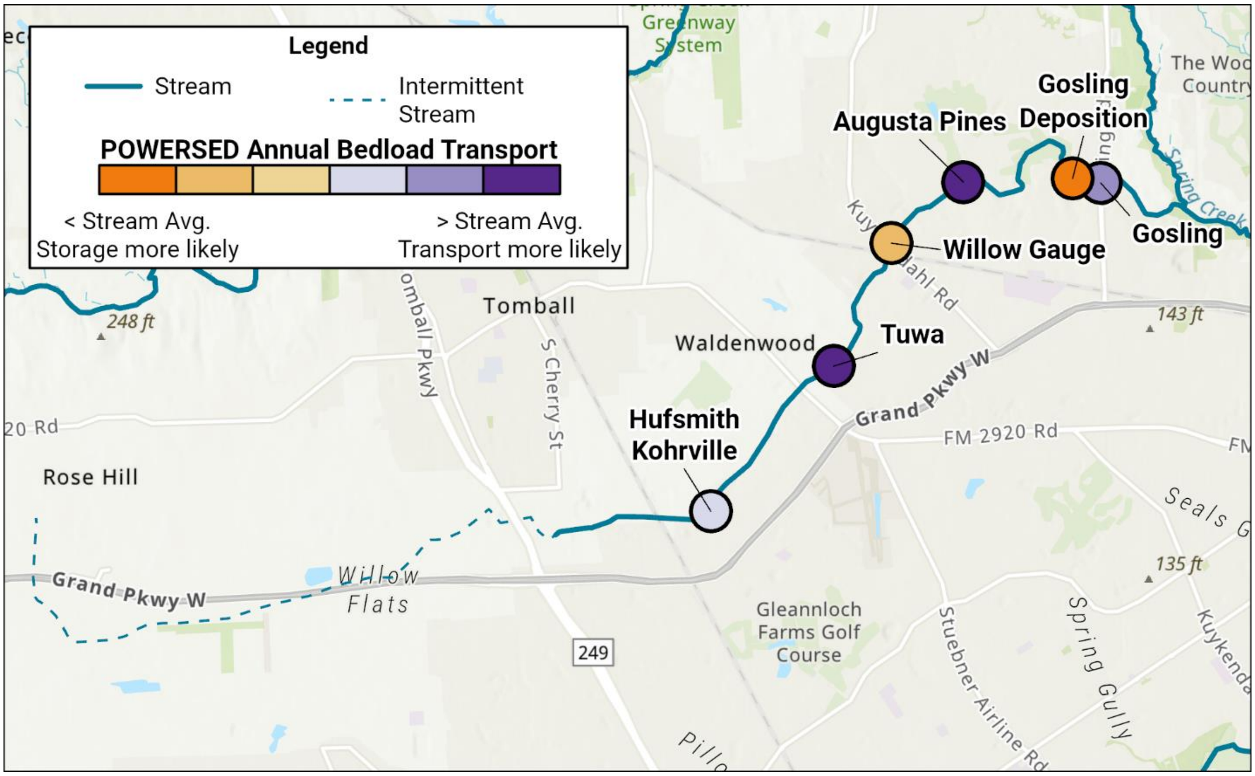

Figure 18. Qualitative Comparison of the Bedload Transport of POWERSED Modeled Cross-Sections in Willow Creek

The Gosling Deposition cross-section was specifically chosen to see if the POWERSED model results could explain the significant deposition of sediments along the banks of Willow Creek in that area shown in Figure 19. As aforementioned, the Gosling Deposition cross-section was determined to have the lowest bedload out of all the cross-sections from both streams at only an estimated yearly transport of 120 to 500 tons. In addition to bedload transport, the POWERSED model uses the channel geometry and the gauge-site flow duration curve to calculate the shear stress and unit stream power at different discharge stages for the cross-section of interest. Stream reaches with low unit stream power are less conducive to bedload transport, and bedload sediments are more likely to stall and accumulate in these reaches, particularly if the upstream inflow of sediments is higher. The unit stream powers for the Willow Creek Gauge site, Gosling Deposition cross-section, and the Gosling cross-section are shown in Figure 20. At all times during the year, the “Gosling Deposition” cross-section has a low unit stream power; without significant energy exerted on the bed of the stream, the upstream sediments transported into this reach will have an extended

Figure 19. Sediment Depositions around the Gosling Deposition XS (Source: NearMap)

residence time before being slowly transported downstream, contributing to the sediment depositions shown in the aerial imagery. In contrast, the Willow Creek Gauge site and Gosling cross-sections' unit stream powers are consistently higher throughout the year as a whole and particularly significant during the low frequency storm flows that occur for 10% or less of the year. These spikes in unit stream power during low-frequency flows are the reason for the jump in the sediment transport estimations that occur when flows above the bankfull discharge are included (Figure 16) and illustrate the sediment-moving power of storm events, as physically observed in the growth of Lake Houston mouth bar depositions during Hurricane Harvey in 2017.

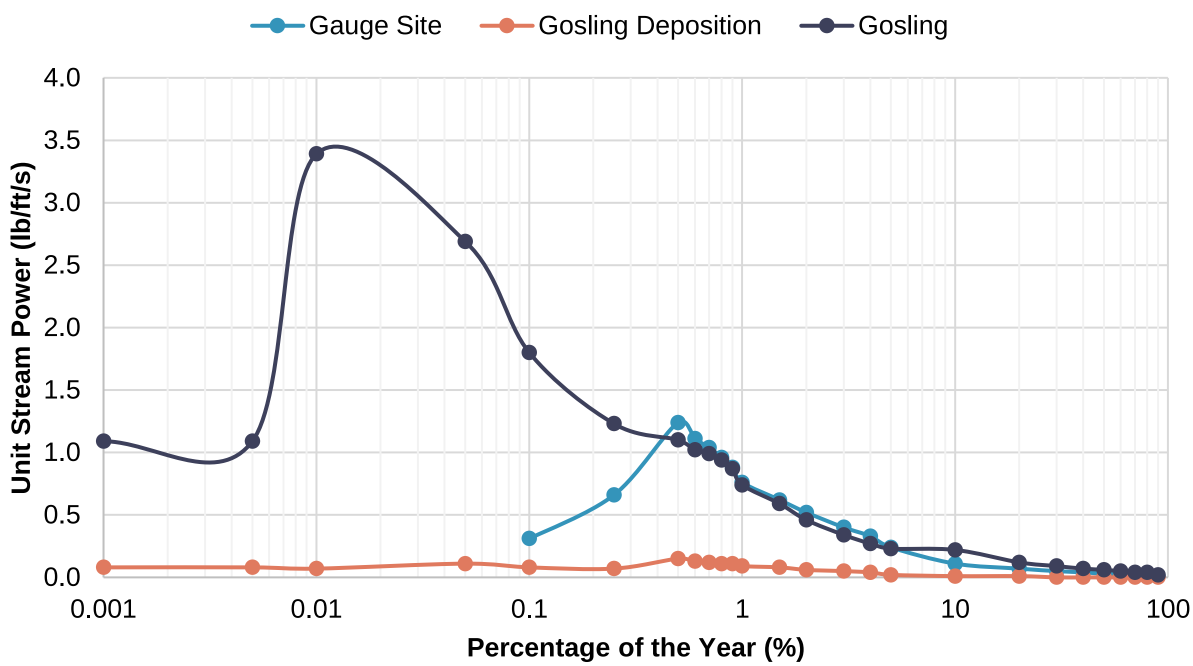

Figure 20. Unit Stream Power Frequency Distribution for Selected Willow Creek Cross-Sections

Note: Due to limitations with the width of the cross-section at the gauge site (see Figure 3), the unit stream power for values lower than 0.1% of the year were unable to be calculated as the stage height exceeded the elevations at one or both ends of the measured cross-section.

Similar conclusions can be made based on model results for the Caney Creek. Figure 21 shows a qualitative variability of the modeled bedload transports, with only flows up to and including bankfull discharge, in Caney Creek. These results also demonstrate that the stream's power and cross-sectional geometry are the strong indicators of bedload sediment transport. The Pinebrook cross-section, the lowest predicted bedload transport site for Caney Creek, has a lower stream power throughout the whole year than both the bedload-sampled gauge site and the highest bedload transport site, the Sycamore cross-section, as shown in Figure 22. With a reduced stream power compared to the upstream Sycamore, the Pinebrook area has a higher likelihood of experiencing deposition.

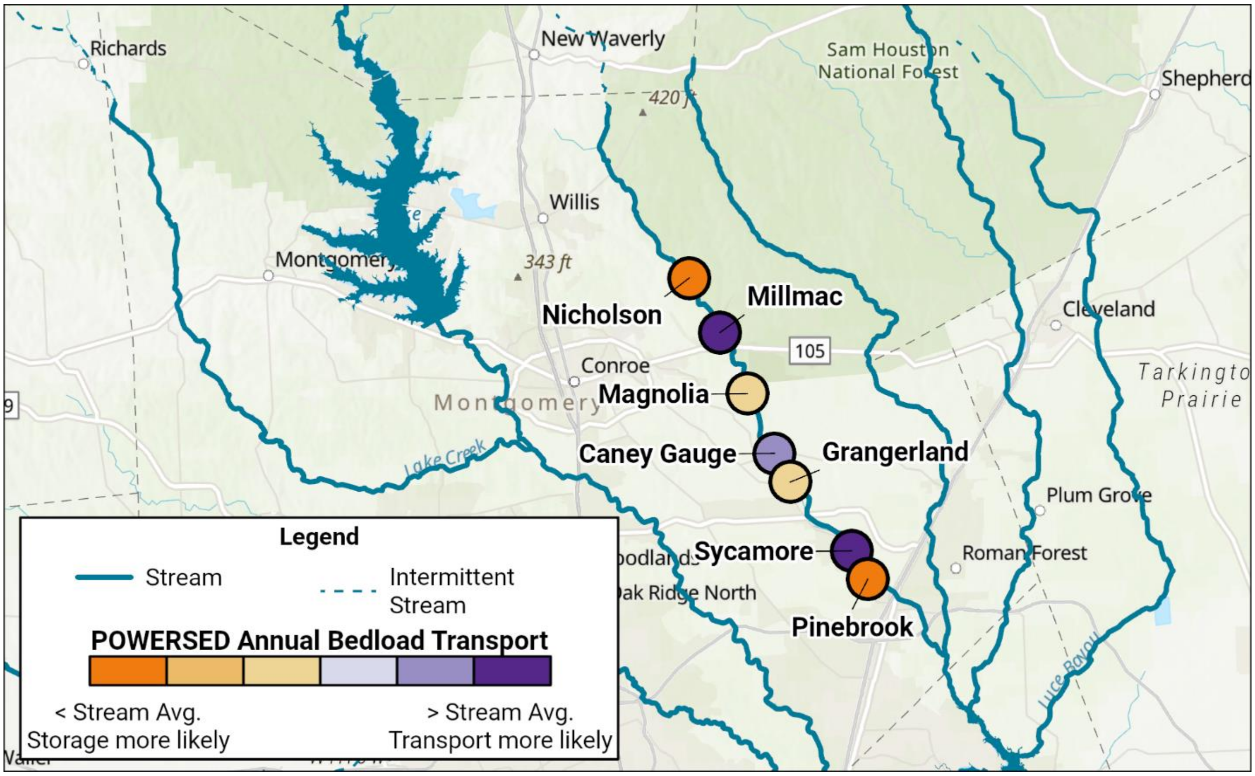

Figure 21. Qualitative Comparison of the Bedload Transport of POWERSED Modeled Cross-Sections in Caney Creek

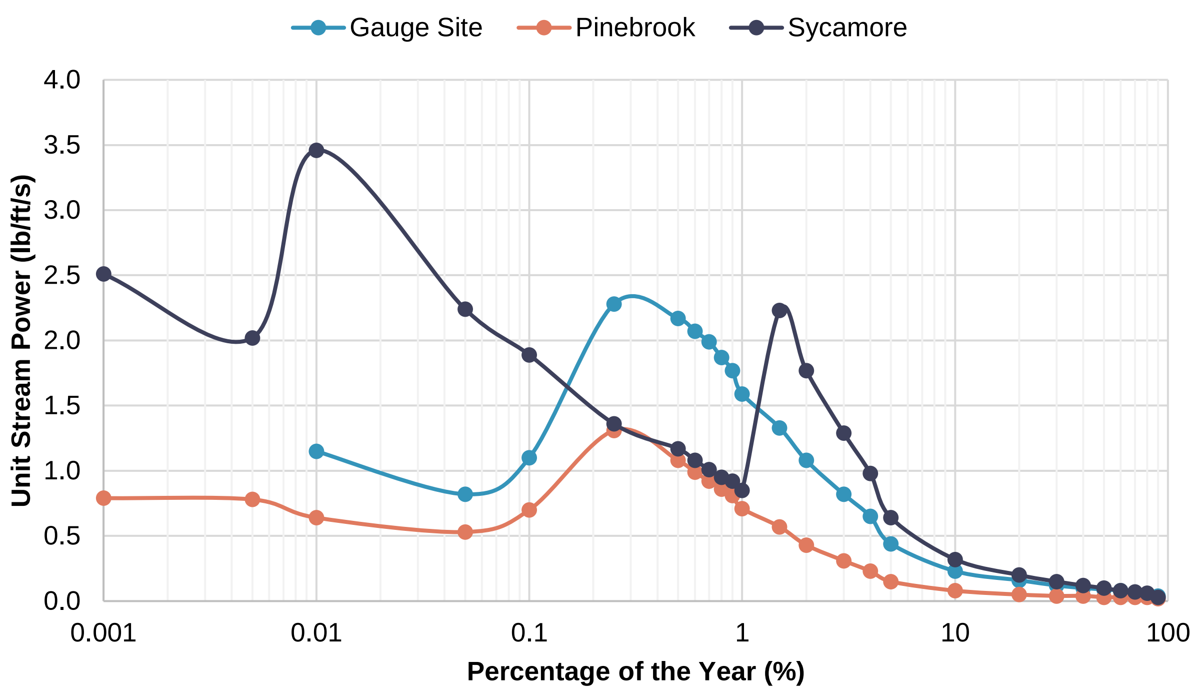

Figure 22. Unit Stream Power Frequency Distribution for Selected Caney Creek Cross Sections

Note on Figure 22: Due to limitations with the width of the cross-section at the gauge site (see Figure 3), the unit stream power for values lower than 0.01% of the year were unable to be calculated as the stage height exceeded the elevations at one or both ends of the measured cross-section.

6.2.2 Inter-Stream Bedload Transport Relationships

As previously discussed, the measured bedload sample measurements in Willow Creek were found to be appreciably higher than the values measured in Caney Creek (Section 3.2). As these measurements formed the basis of the bedload sediment loading curves used by the FLOWSED/POWERSED models, it follows that the modeled bedload transport values were significantly higher for the Willow Creek cross-sections. This trend in measured bedload occurs even though the Caney Creek Gauge site's stream power is greater than that of the Willow Creek gauge site, as found in Figure 20 and Figure 22. While changes in stream power within a stream appear to be a strong predictor of areas of low bedload transport, the aforementioned contradiction demonstrates that stream power is not the only factor governing the bedload sediment rating curve's magnitude or shape, particularly when comparing two streams with different characteristics. Additional parameters were collected by project scientists at the gauge sites to determine BANCS and dendrogeomorphic predicted erosion rates (TM 3). In these characterizations, Willow Creek had higher erosion rates than Caney Creek. It might be that the magnitude of the bedload rating curve and subsequently bedload transport are determined by the amount of available sediment for transport, to which erosion contributes. Sediment size distributions may have also played a factor in the higher Willow Creek bedload values in comparison to Caney Creek. Willow Creek's sediment bar sample was made up predominantly of fine to very fine sand (0.05 – 0.25 mm), while Caney Creek's sample was predominantly medium grain sand (0.5 – 0.25 mm). Although the size distinction is small, the finer sand within Willow Creek can be more easily mobilized and transported and may contribute to the higher bedload estimates. Vegetative growth, soil cohesion, and other factors that govern the stability of stream banks and beds may also be significant factors in determining the magnitude of sediments available for transport by the stream. Vegetative growth and stream bank stability were inputs into the BANCS assessment of erosion rates and generally followed the resultant erosion rates of their streams. Willow Creek's calibration area generally had the most unstable and unvegetated banks while Caney Creek's and the East Fork's were appreciably more vegetated and stable. As the bedload modeling results are extrapolated to the rest of the USJRB in subsequent tasks, these factors will be investigated further to see the magnitude of their impact on the generation and transport of sediments in the basin.

6.3 Conclusions

In conclusion, the results of the FLOWSED/POWERSED modeling have illuminated several relationships governing the transport of bedload sediments within the USJRB. Due to the extensive data needs that bedload transport modeling requires (bedload sampling, flow duration curves, etc.), these relationships will be used to extrapolate the likely characteristics of bedload sediments to the streams outside of the calibration watersheds.

- The prevalence of sand and near absence of gravel within the USJRB has created a unique relationship between bedload and stream flow compared to the gravel-bed streams described in literature.
- Steady sediment transport is likely to occur under a majority of flow conditions, but elevated storm flows have the potential to push considerably higher amounts of sediment downstream within the bedload if those sediments are available.
- Stream power appears to be positively correlated with bedload transport. Areas with low stream power are also likely to be areas of low bedload transport capacities and sediment deposition sites with high sediment residence times. Areas of high stream power and consequentially areas with high bedload transport capacities, may also be erosive stream reaches if the stream bed and banks are unstable.
- In addition to steam power, the magnitude of available sediment supply and the nature and characteristics of the stream bed sediments are also factors that dictate the magnitude of bedload transport.

7 References

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