The Effect of Sand Content on Sediment Transportation, Deposition, and Bar Morphology

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I. Problem

In summer 2012, simple alternate bars in lower Paint Branch were replaced by large diagonal bars with very sharp bar fronts. The elevations of these bars were reduced during floods associated with Hurricane Sandy. These changes occurred over short timescales (< 6 months) and coincided with an increase in upstream sand supply associated with major road construction (of the Inter-County Connector or ICC) in the watershed. This suggests that sand availability as well as flooding may have been a factor in bar morphology changes.

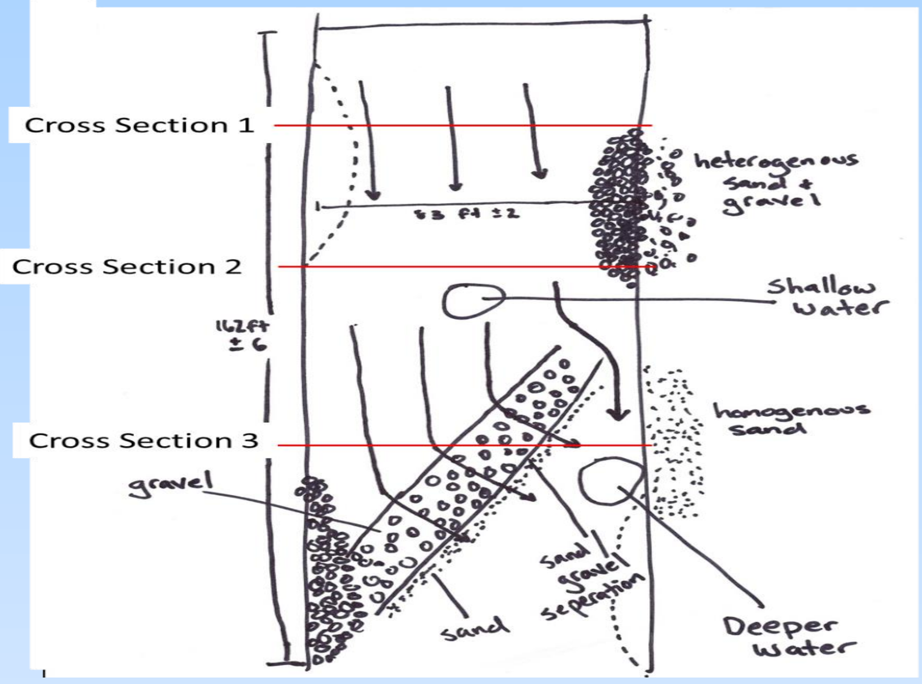

Figure 1: Sketch map of the study site at lower Little Paint Branch Creek

II. Hypotheses

1. The diagonal bar formation is evidence of gravel transport at low τ^*_{crit} associated with locally high (> ~10%) sand content.
2. The high bed sand content in lower Paint Branch is due to sand accumulated by bedload sand transport at flow events lower than bankfull stage.
3. Subsequent > bankfull floods (Sandy) entrain surface particles and suspend the subsurface sand. This increases τ^*_{crit} and re-establishes the initial alternate bar morphology.

III. Methods

Cross section morphology is surveyed and expressed as depth below a known datum established along the bank.
Average Depth, d = A/W where A: channel area and W: width
Water surface Gradient , S, was determined by surveying the elevation of flags placed along the water edge during floods.
High flow discharges, Q, were calculated using the slope-area method.
Gauge-discharge relationships and discharge correlation relationships from Blanchet (2009) were used to construct time series of **discharge, Q** and **depth, d** at the study site.
Time series of sediment transport variables (shear velocity, shear stress, Rouse number, dimensionless shear stress) were constructed using time series data of depth and discharge:

$u^* = (gdS)^{0.5}$
$\tau = \rho gdS$
$\tau^* = \dfrac{\tau}{(\rho_s - \rho)gD_{50}}$
Rouse #, $P = \dfrac{v_s}{\kappa u^*}$

Where u^* is shear velocity, g is gravity, d is depth, S is water surface gradient, τ is shear stress, τ^* is dimensionless shear stress, ρ is water density, ρ_s is sediment density, D_{50} is median grain size, v_s is particle settling velocity, and κ is von Karman's constant.

IV. Hurricane Sandy

Hurricane Sandy occurred in late October 2012. Channel cross sections were surveyed and sediment samples of bed surface and subsurface material were collected in the weeks just prior to the Hurricane-generated floods. Cross sections were surveyed and sediment samples were collected after the flood.

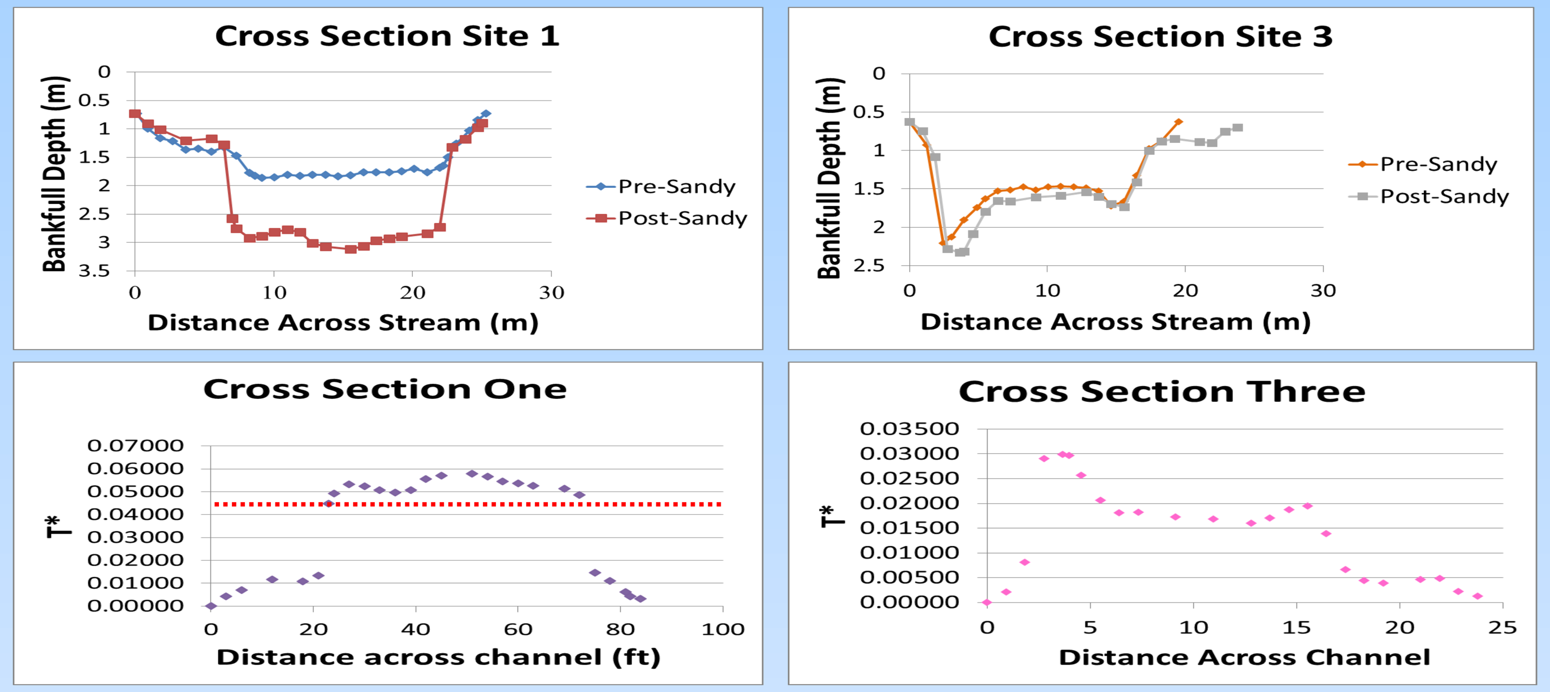

Figure 3: Upper: channel cross sections pre- and post-Hurricane Sandy and **Lower**: distribution of shear stress across the channel at peak flood depth. The red line denotes a dimensionless shear stress of 0.045, or τ^*_{crit} for gravel. Dimensionless shear stress is below that value for most of cross section one and all of cross section three, so the observed sediment transported into the reach had to be moved by a lower τ^*_{crit} caused by an increase in sand content. The deepening seen in cross section one post-Hurricane Sandy is likely a result of the winnowing of sand sized sediment from the bed, which would result in an increase in τ^*_{crit}.

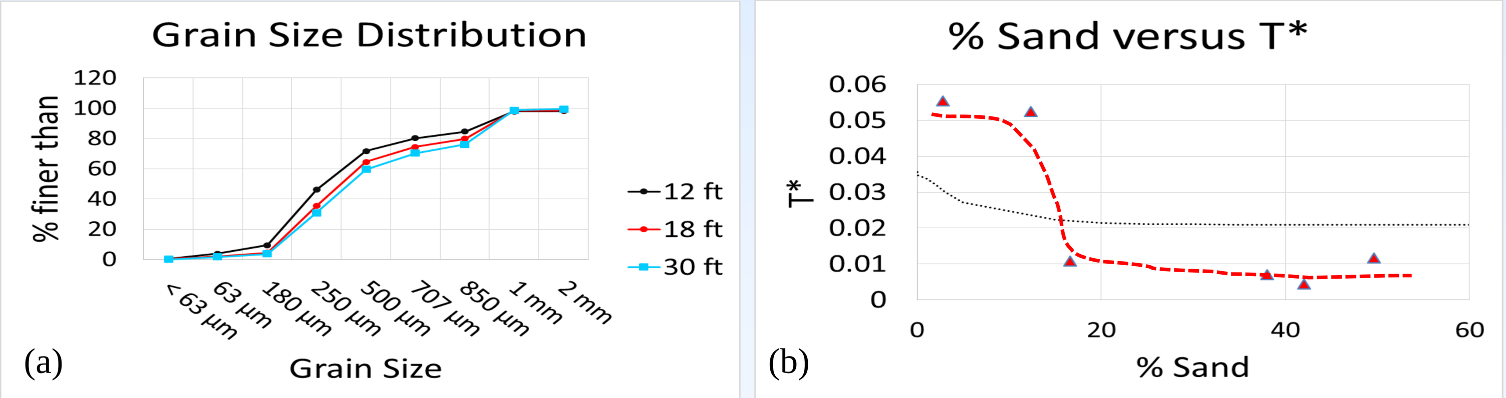

Figure 4: 4a shows the grain size distribution of sand sized particles at the study site. D_{50} falls between 250-500 µm, and most sediment is either 250 µm, 500 µm, or 1 mm. 4b shows the variance of observed and predicted τ^* with sand content. Predicted τ^*_{crit} was calculated with the empirical equation $\tau^* = 0.021 + 0.015e^{-20F_s}$, where F_s represents sand content from Wilcock and Crowe (2003). Field data from this site suggest a strong sensitivity to sand content in the range of 15-20% and lower limit of τ^*_{crit} (0.01)

Acknowledgments

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V. Hydraulic Parameters

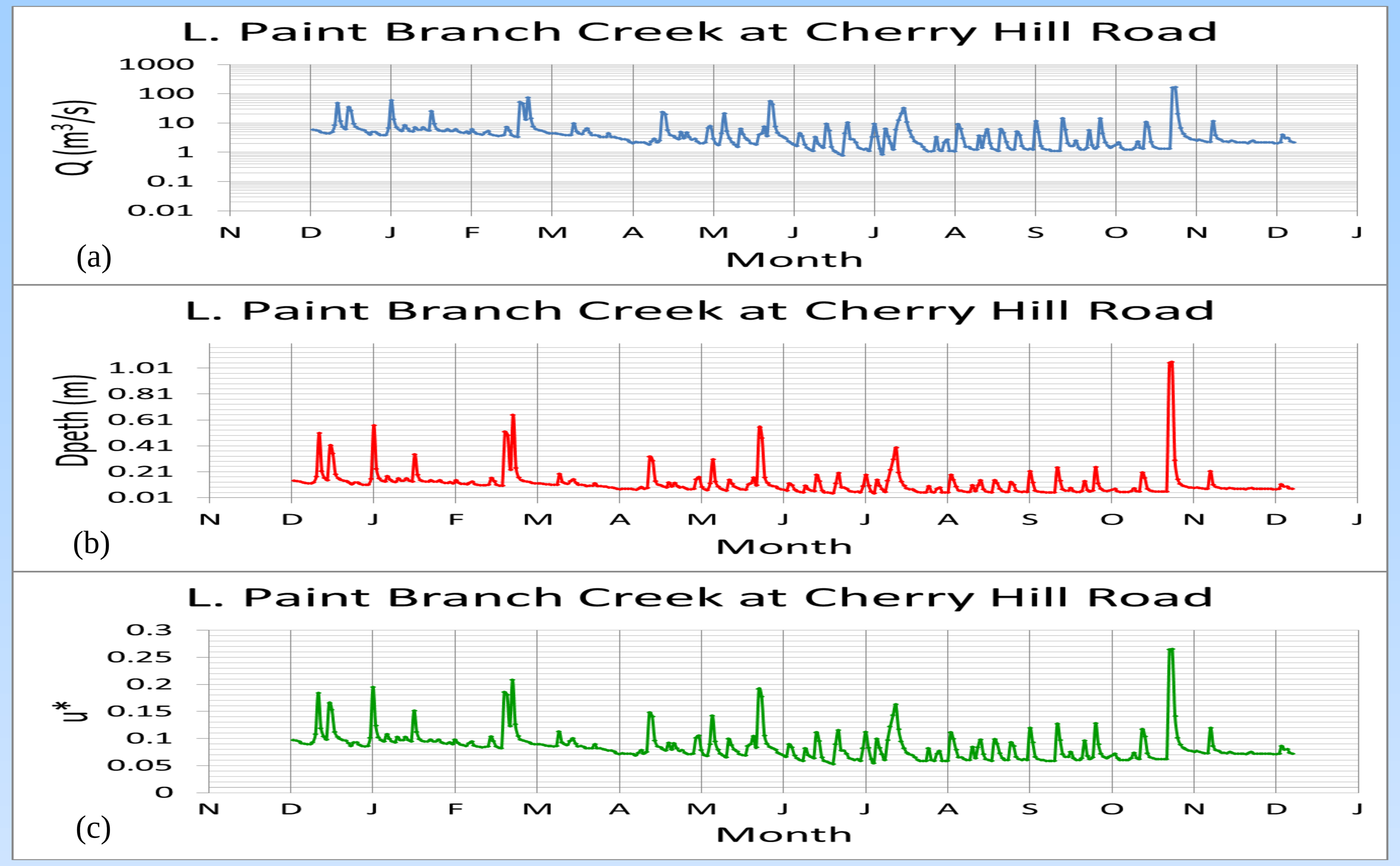

Figure 5: 5a, 5b, and 5c show time series of discharge, depth, and shear velocity for the study site. Notice the peak in late October 2012 representing Hurricane Sandy. Depth varies as a function of discharge, and shear velocity varies as a function of depth. Values of shear velocity were used to determine the size of particles that could be suspended during flow events. Large flows with high u* values will have the ability to entrain and transport larger grain sizes as suspended load, if they are entrained from stream banks or released from the subsurface by bedload transport of surface particles.

VI. Suspended Sediment Profiles

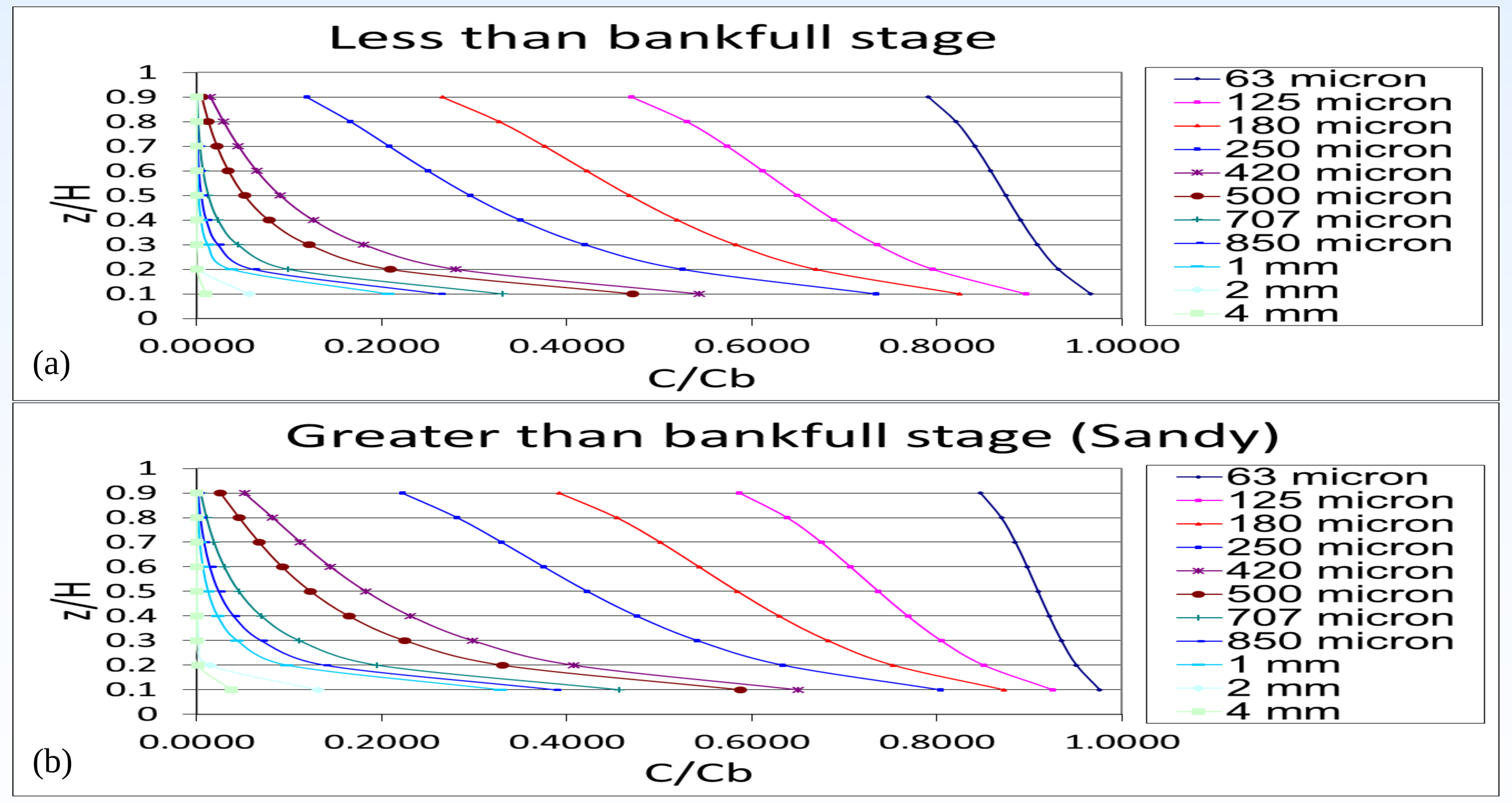

Figure 6: Rouse-Vanoni suspended sediment profiles for 0.5 m (< bankfull) (6a) and 1.0 m (Hurricane Sandy) (6b) flow depth. Average bankfull flow depth is 0.78 m. For 1.0 m, ~5% of 500 µm sand is suspended and ~28% of 250 µm sand is suspended at an overbank height and deposited over bank. D_{50} is between 250 µm and 500 µm so a Hurricane Sandy magnitude event represents the loss of a significant amount of sand from the bed and into overbank deposition. These flows move 500 µm and larger sand as bed load and increase the sand content of the bed.

VII. Rouse number

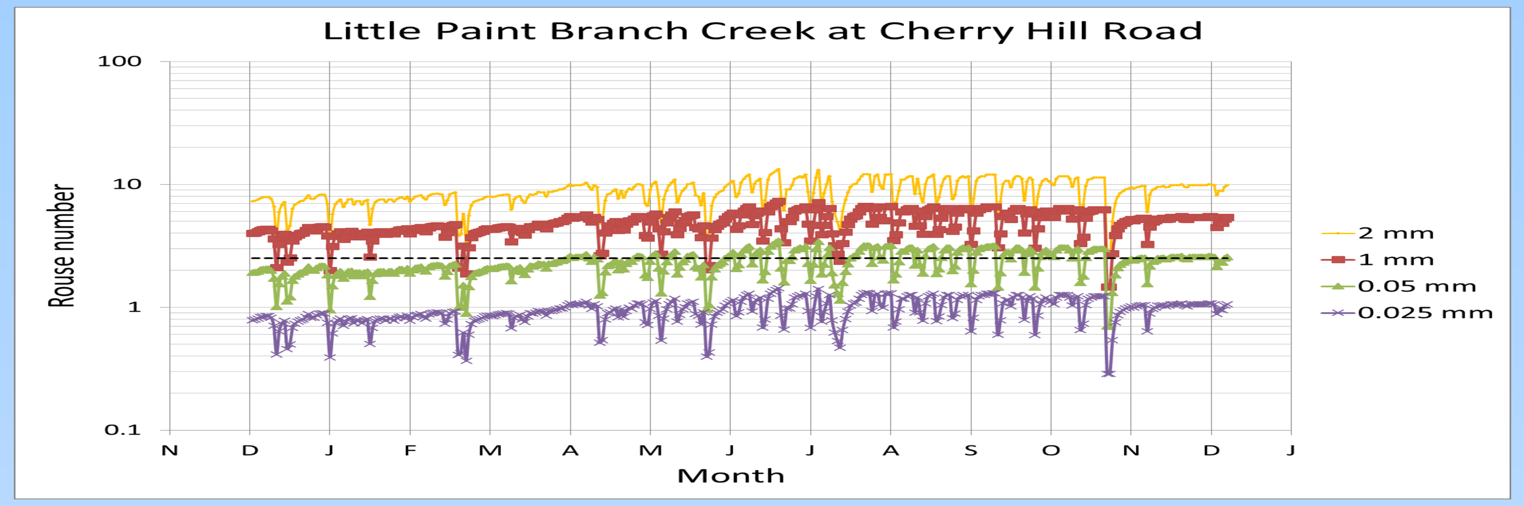

Figure 7: Times series of Rouse number determined for grain size fractions found in subsurface. The Rouse number, P, identifies the mode of sediment transport for particles of a given grain size. For P < 2.5, sediment is transported as suspended load and for P > 2.5 sediment is transported as bed load. The dotted black line represents a Rouse number of 2.5. 1-2 mm sand in the study period is only suspended during Hurricane Sandy; previous period represents bed sand accumulation.

VIII. Change in τ^*_{crit}

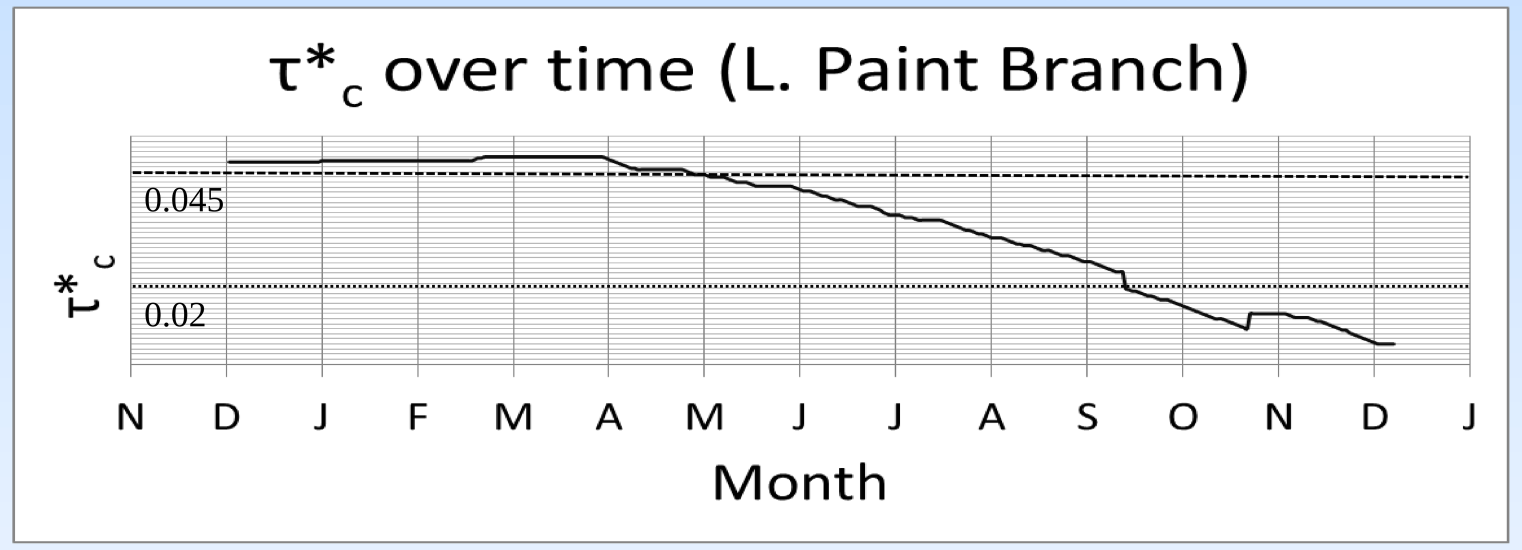

Figure 8: Conceptual evolution of critical dimensionless shear stress (τ^*) over time. Periods of bed load transport for 500 µm represent periods of sand accumulation, while periods of suspended load transport for 1 mm represent periods of sand removal (figure 7). τ^*_{crit} was constant (likely around 0.045 (upper line)) until early 2012, at which point a rapid decrease began. This decrease occurs parallel to increases in shear velocity and bed load transport events, indicating that it occurs as a result of sand accumulation at the study site.

IX. Conclusions

1. Diagonal bars aggraded the bed to an average depth of 1.5 m and cross sections coupled with. surface grain size measurements indicate that locally high sand content is responsible for sediment transport for low dimensionless shear stresses during Hurricane Sandy.
2. The developed model shows that < bankfull events transport sand sized sediment as bedload, thus depositing sand and building up sand content.
3. > bankfull events (Sandy) suspend sand sized sediment, removing it from the study site and deepening the channel, potentially leading to a re-establishment of alternate bar morphology

X. References

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Wilcock, P.R., Crowe, J.C., 2003, Surface-based Transport Model for Mixed-Sized Sediment. *Journal Of Hydraulic Engineering* ASCE 129(2): 120-128