<u>**Sediment Transport into an Urban Tributary Junction**</u>

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Geology 394

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Abstract

Tributary junctions are an important component of stream morphology and sediment transport within drainage basins. Urbanization affects the hydrology of these river junctions by changing the timing and magnitude of peak flow depth while also changing stream gradients coming into the tributary junction. The hydrology at an urbanized tributary junction was measured at a site that has two tributaries that forming into a single stream at confluence. The results show that the smaller tributary responds faster to a storm event and experiences a higher peak water surface elevation than the larger tributary, resulting in a backwater effect that decreases the stream gradient of the larger tributary. The larger tributary decreases in shear stress while coarse sediment gets deposited upstream while fine sediment gets deposited in the tributary junction during storms.

Introduction

A tributary junction is the point where two tributaries meet to form a single channel. Tributary junctions join in to form channel confluences, which often exhibit considerable scour at high discharges. Changes in flow dynamics, sediment transport and bed morphology have been shown to respond to confluence characteristics such as junction angle, depth ratios, and momentum ratios (Ribeiro et al, 2012). Reach-averaged channel morphology can also change significantly at or downstream of tributary junctions due to changes in valley widths, stream gradients, and sediment characteristics (Montgomery and Buffington, 1997; U.S.

Forest Service 2016; fig. 1). Tributary junctions thus exert a significant influence on stream morphology and sediment transport within drainage basins.

Many gravel-bed streams are threshold streams. The coarse bed sediments are mobilized only if critical shear stresses are reached during flood events. Many gravel bed streams reach these critical bed shear stresses during bankfull or higher flood events (Parker, 1979).

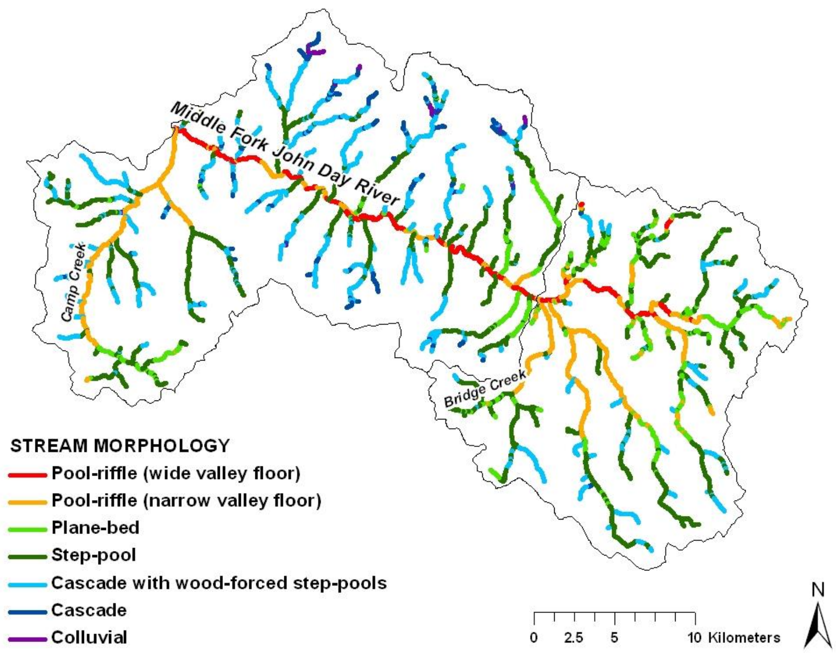


Fig. 1: U.S. Forest Service Stream Network map of the John Day River, Oregon using the Montgomery and Buffington (1997) stream classification. Note the changes in channel morphology at many of the tributary junctions.

During high flow events, shear stresses are high enough to entrain and transport coarse bed sediment, releasing fine sediment that may be stored in the subsurface of gravel bars. During periods of low discharge, the stream is unable to move the coarser sediment and form gravel bars. During high flow events, shear stresses are high enough to entrain and transport coarse bed sediment, releasing fine sediment that may be stored in the subsurface of gravel bars. During periods of low discharge, the stream is unable to move the coarser sediment and form bars.

Previous works on stream confluences indicate that flow separation and turbulence influence the location of bar deposition and the depth of turbulent scour in the confluence zone (fig. 2, after Best, 1987). Flume and field studies both suggest that the depth of confluence scour is influenced by the tributary junction angle, θ, and local hydraulics (depth, discharge, and momentum ratios). Research by Horton (1945) suggests that the tributary stream gradients (S) influence the stream junction angles: $\cos\theta = S_{main}/S_{tributary}$.

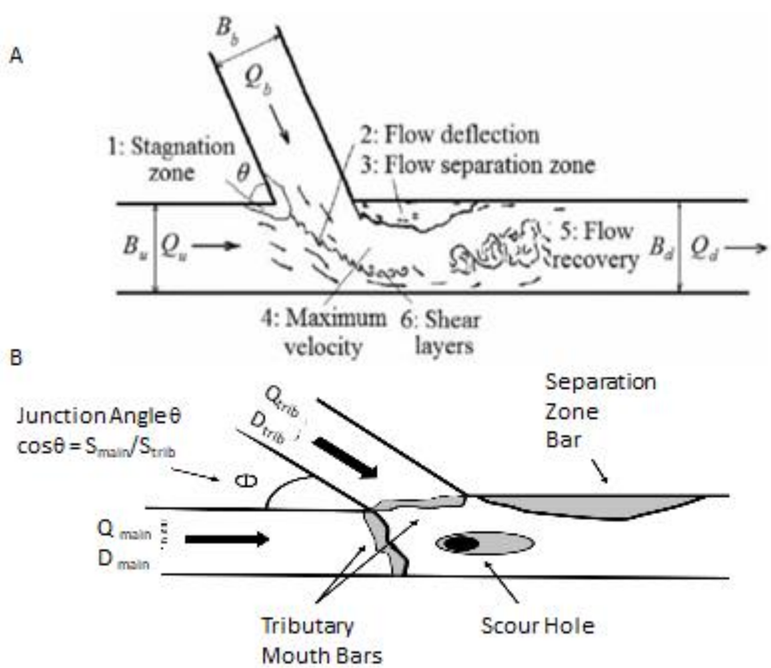
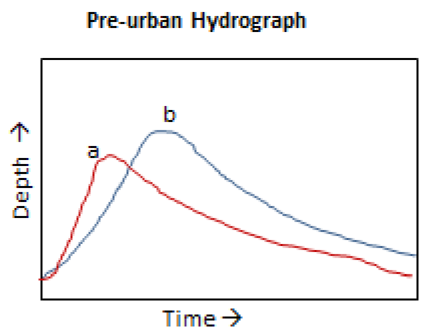


Fig. 2: a) Tributary junction and location of separation zones and turbulent scour, after Best, 1987 . B) Morphology of tributary confluence showing location of bars and scour holes

1. Statement of Problem

Previous studies of tributary scour have been conducted in laboratory flumes or on natural river tributary junctions. Human impacts such as stream channelization can directly modify stream tributary junctions angles, channel widths, and channel depths. Channel widening and straightening decreases flow resistance, decreasing water depths for a given discharge. Urbanization can have a noticeable impact on stream hydrology, affecting the timing and magnitude of peak discharges. Manmade structures such as sewer networks and impervious surfaces lower lag times and increase peak discharge during flood events (e.g. Leopold, 1968). In a non-urban watershed, both peak discharge and lag time increase with drainage basin area. Urbanization and channelization change the timing of peak flow depth on tributaries, affecting stream gradients coming into the tributary junction (fig. 3).



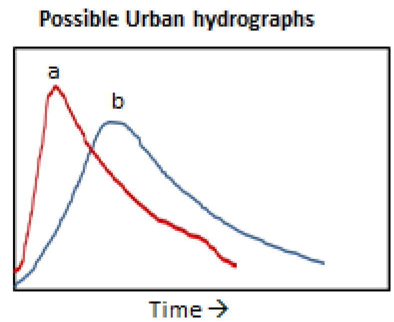


Fig. 3a: Smaller stream (a) has a shorter lag time And a smaller peak water depth than the Stream in the larger watershed (b)

Fig. 3b: Smaller stream (a) is in a more Impermeable watershed, which decreases Lag time and increases peak discharge. Channelization of the larger stream (b) Could also reduce its peak depth.

2. Hypotheses

1. During a storm event, the smaller tributary responds faster than the larger one (shorter lag time). The response of the small stream results in a backwater effect on the larger stream that decreases the stream gradient of the larger tributary.
2. When peak flow occurs in the smaller tributary, the gradient of the larger stream decreases, resulting in a decrease in shear stress.
3. Due to the low stream gradient and shear stress at the tributary junction, coarse sediment is deposited upstream of the tributary junction in the larger

stream while fine sediment is deposited in the tributary junction during storms.

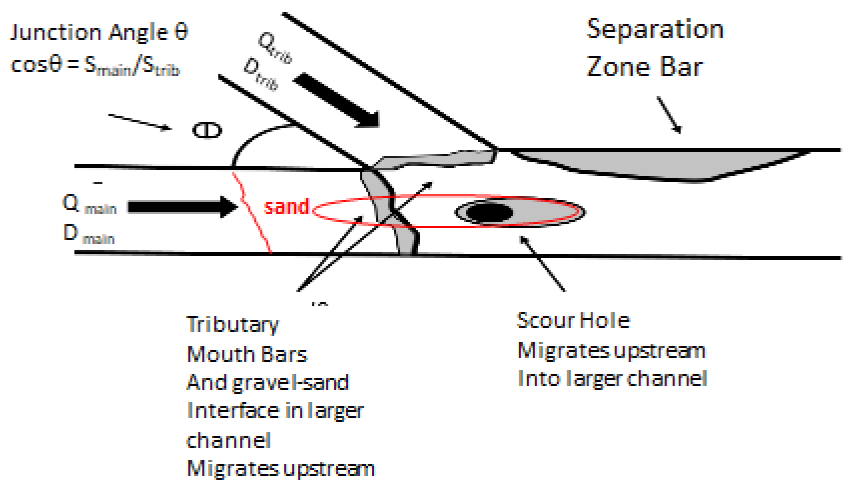


Fig. 4: Changes in location of tributary mouth bars and the gravel-sand transition in the larger channel.

3. Previous work

Previous works on tributary junctions have evaluated many topics including controls on tributary junction angles (Horton, 1945; Howard, Abrahams). Junction angles can be used to distinguish between drainage patterns while impacting the availability of space between streams. Many studies in both geomorphology and engineering journals have examined scour depths downstream of tributary junctions.

Many gravel-bed streams are threshold channels where coarse bed sediment is only entrained at bankfull or higher events. Critical shear stress is τ_c is the minimum fluid shear stress (t = rgdS) needed to start bedload transport of grains on a streambed.(e.g. Wong, 2008). Critical fluid shear stress for a particle is obtained by using Shields (1938) critical dimensionless shear stress equation:

$$\tau^*_{crit} = \tau_c / [(\rho_s - \rho_w) g D_{84}]$$

τ^*_{crit} is the critical dimensionless shear stress at the initiation of motion, obtained by comparing D_{84}, the reference grain size of the bed material and D_{50} the grain size at fifty percent cumulative percent. ρs is the density of the sediment (2,650 g/m3), while ρw is the density of water (1,000 g/m3), and g is gravitational acceleration. Therefore, the critical shear stress to move sediment, τ_C, is determined primarily by the ratio of D_{84}/D_{50}.

Previous work on stream confluences have not observed surface gradient continuously during storm events (Rhoads et al, 2008 ; Borghei and Shebari, 2010). This study is designed to observe dynamic changes in water surface gradient, local shear stress, and sediment transport in an urban stream confluence.

Study Site and Methods

<u>1. Study Site:</u> The study site is located close to the Paint Branch Golf Course, which is a short drive from the University of Maryland's campus. The site has two tributaries that form into a single stream. The larger channel has been straightened and the

banks are stabilized with rip-rap, which is used to support the bridge that is built on it. These features can be seen in Picture 2. The confluence is covered with sand at low flow, which is likely deposited from suspension during the falling stages of hydrographs. Picture 1 compares the grains that are deposited from the smaller tributary and the confluence. The smaller tributary has gravel-sized beds, while the confluence zone's sand grains.

Picture 1: Photograph of Little Paint Branch at the confluence zone. Taken Nov 12, 2017


Picture 2: Photograph of Paint Branch. Taken Oct 5, 2017

<u>2. Installation and Monitoring of Stream Gauges:</u> One of the primary sources of data for this study comes from the installation and surveyings of pressure gauges and channel cross sections. Six sensors were installed to gauge stream stage (depth). . Two were installed in the Paint Branch (PB1 and PB2), two in Little Paint Branch (LPB1 and LPB 2), and two in the main channel where both meet (DS1 and DS2). Figure 5 is a Color-Infrared image of the site where the six gauges and channel cross sections are labeled. The Paint Branch tributary is the stream on the right; Little Paint Branch is the stream on the right, and the stream where both tributaries meet is at the bottom.

The gauges were set to record temperature and water pressure at 5-minute intervals. Another gauge was installed nearby to record air temperature and pressure. The data were processed to calculate water depth from water pressure depth = $\rho g/P$ after correcting for atmospheric pressure changes. The gauges are able to read pressure, temperature, and depth of the sensors. Figure 6 shows the stream depth during a storm hydrograph on over time.

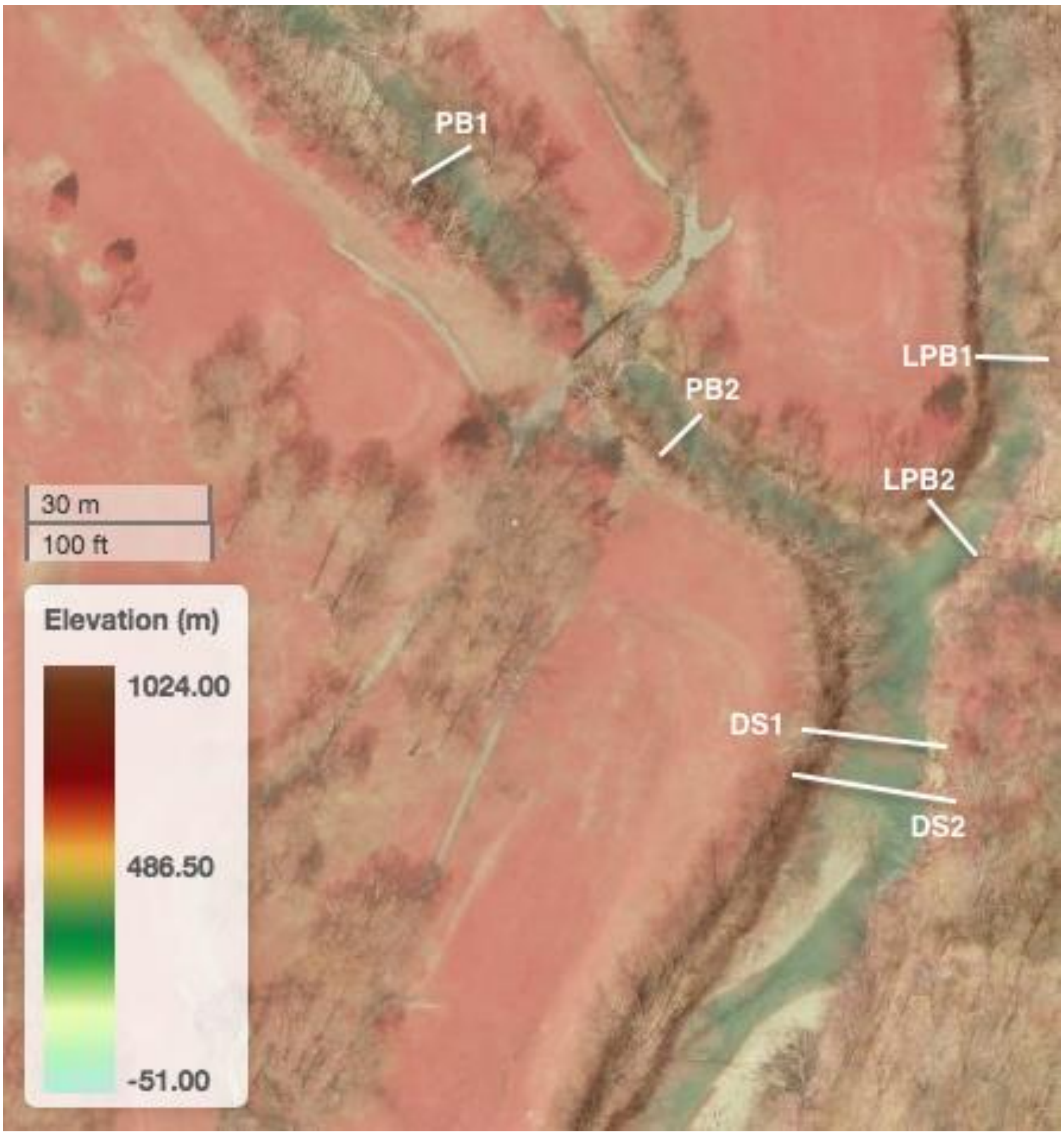


Figure 5: Colored-Infrared image of site, obtained from Maryland iMap Topography Viewer. The Paint Branch tributary (PB) is to the left, and Little Paint Branch (LPB) to the right. The lines represent where each gauge was installed and the cross section across them

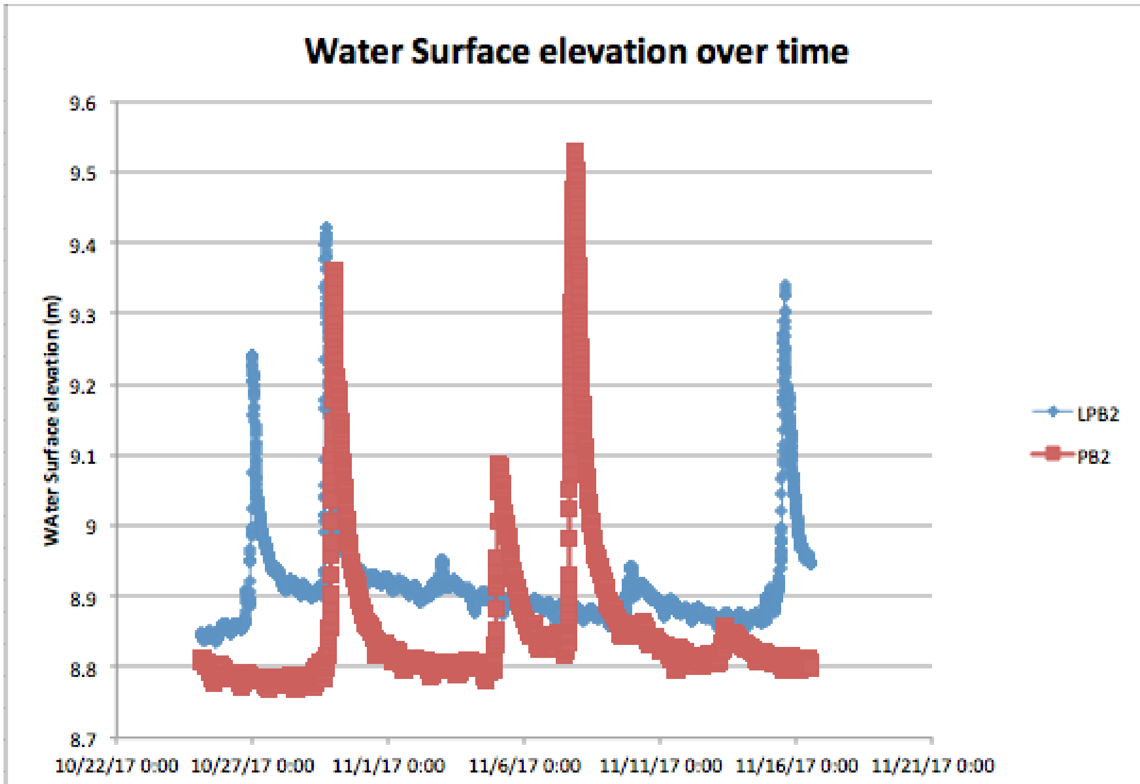


Figure 6: Graph of sensor depth over time between October 25 and November 16, 2017 for LPB2 and PB2

<u>3. Channel cross section and stream gauge surveys</u>: Once they were installed, the elevation of each stream gauge was surveyed within a local reference system. The distance between the stream gauges was measured in the field to use in the calculation of stream gradient. Cross section elevations were surveyed with the same elevation reference system as the gauges. An example of a channel cross-section survey is shown in fig. 7. From the channel cross-section surveys and the

gauge data, I can obtain channel width and depth during base flow and storm events.

<u>4. Stream Grain Size Measurements:</u> Grain Size measurements were conducted using two types of measurements using the pebble count method of Wolman (1954). This method involves walking a grid pattern across the stream and picking up and measuring the intermediate axis of 100 or more particles. Bed sediment sizes were sampled before and after storm events to determine if changes occurred as a result of changes during the storm hydrograph. Figure 7 shows the cumulative grain size distribution of gravel bars and channels in Paint Branch Creek located upstream of the channel confluence. Figure 8 shows the cumulative grain size distribution of a gravel bars in Little Paint Branch. The grain size analysis for the bar was done on November 2, 2017.

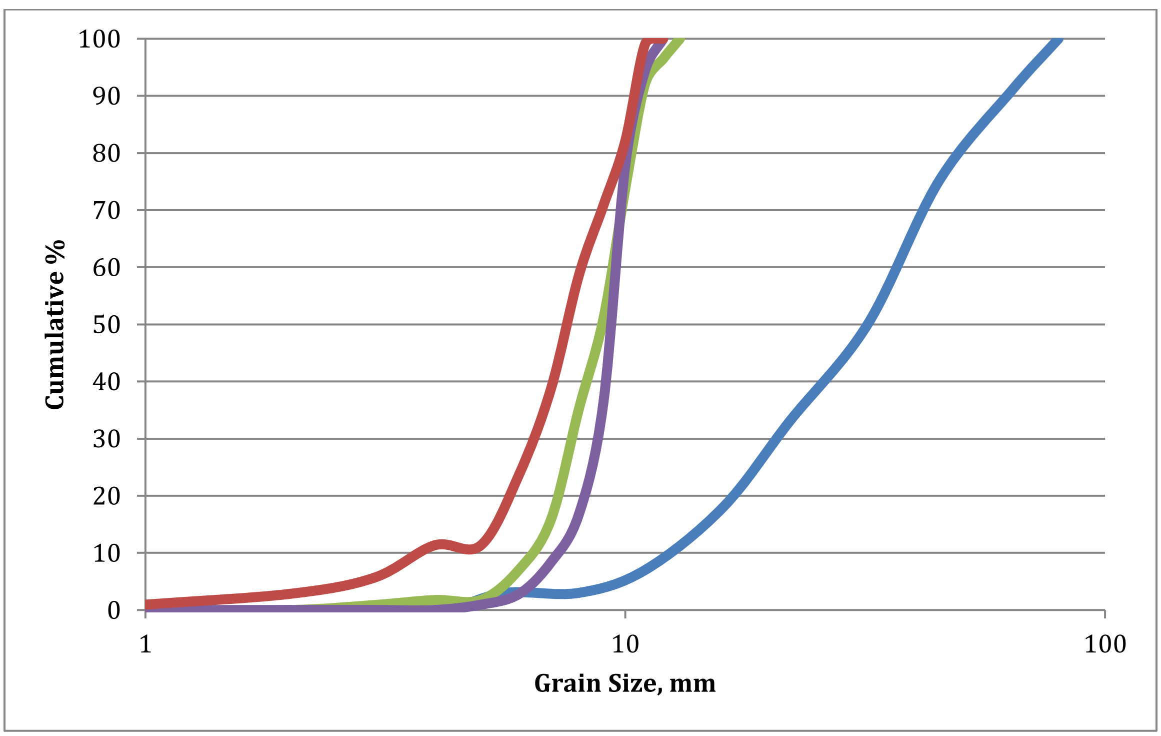


Figure 7: Cumulative grain size distribution curves for Paint Branch, taken on November 2, 2017
Bar 1: blue, Bar 2: green, Channel 1: red, Channel 2: purple

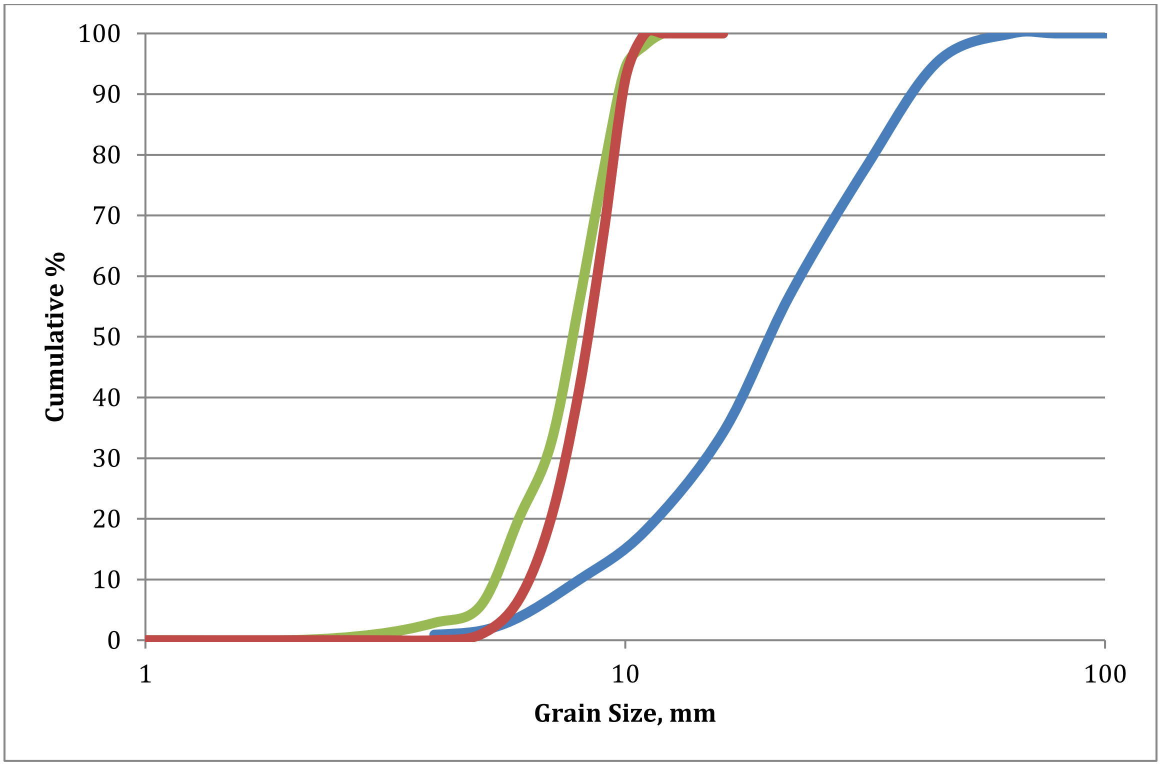


Figure 8: Cumulative grain size distribution curves for Little Paint Branch, taken on November 17, 2017
Bar 1: blue, Bar 2: red, Bar 3: green

Data Analysis:

The main procedures of the data analysis is to determine the water surface gradient and depth at each site during the storm hydrographs and to use these data to calculate fluid shear stress for storm hydrographs. These fluid shear stress values can then be compared with critical fluid shear stress values to determine whether bed sediment can be entrained during storm events.

Determination of Water Surface Gradient during storm hydrographs:

The elevation of each gauge base is determined from the surveys. The depth of the water determines the change in elevation during storm events over the sensor. Therefore the water surface gradient is calculated as:

$$\frac{\text{Upstream Gauge Elevation} - \text{Downstream Gauge Elevation}}{\text{Distance between gauges.}}$$

An example of water surface gradients in the two tributaries, the confluence, and the downstream channel is shown in fig. 9.

Evaluation of Critical Shear Stress required to move bed sediment:

Critical shear stress is τ_c is the minimum shear stress needed to start bedload transport of a grain (Wong, 2008) and is obtained by rearranging the Shields (1938) equation:

$$\tau_c = \tau^*_{crit}(\rho s - \rho w) g D_{84}$$

τ^*_{crit} is the critical dimensionless shear stress with the value of 0.045, D_{84} is the reference grain size of the bed material, ρ_s is the density of the sediment (2,650 g/m^3), ρ_w is the density of water (1,000 g/m^3), and g is gravitational acceleration.

Using these values for Paint Branch Creek Bar 1:

D_{84}: 50mm

The critical shear stress is 36.6 Pa

Using these values for Little Paint Branch Bar 1:

D_{84}: 32mm

The critical shear stress is 23.28 Pa

Preliminary Observations and Results

<u>Depth changes during storm events:</u>

Figure 6 shows that Little Paint Branch responds quicker to the storm event and experience greater flooding compared to Paint Branch. The site that experiences the least change in depth over time is Paint Branch, which is the cause for its lower gradient.

<u>Gradient changes during storm events.</u>

Figure 9 shows a graph of the upstream gradient of Little Paint Branch and Paint Branch over time. The gradient for LPB1 to LPB2 fluctuates with a higher gradient over time while PB1 to PB2 displays a low gradient that does not fluctuate. These trends are shown on figure 9. The dip in gradient is caused by a backwater effect that lowers the gradient due to the fact that the Little Paint Branch's shear stress peaks before Paint Branch's shear stress. A chart displaying the shear stress of the upstream stations over time is shown on figure 10.

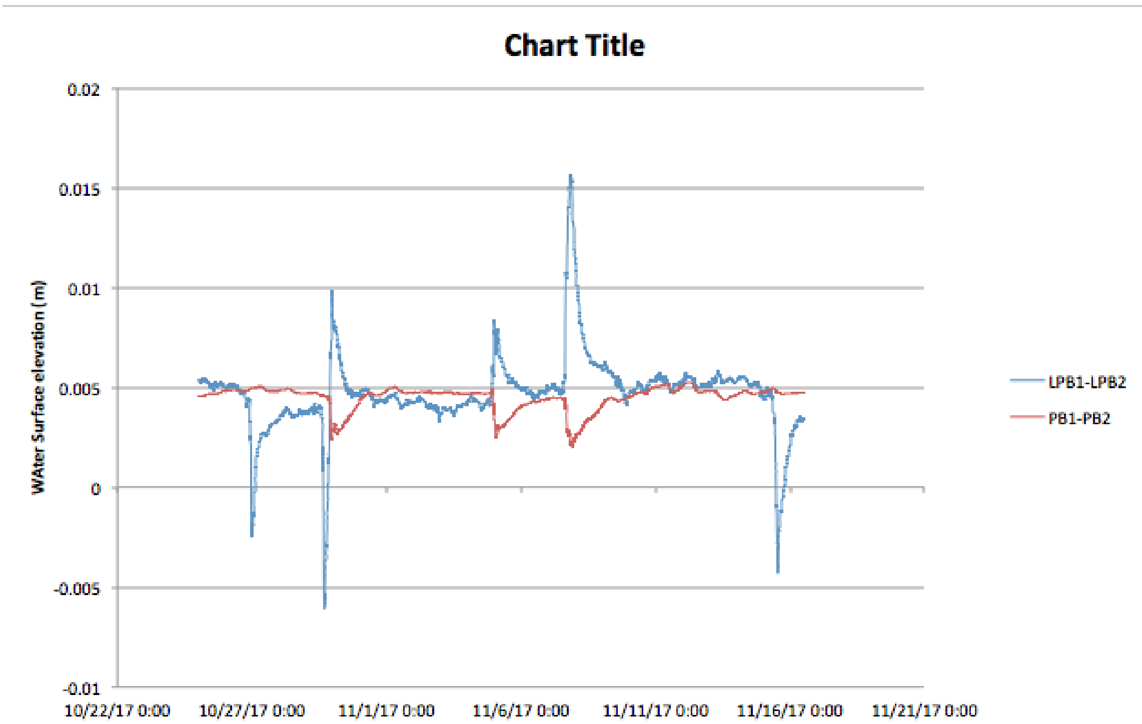


Figure 9: Graph of water surface slope over time for the upstream sites between October 25 and November 16, 2017

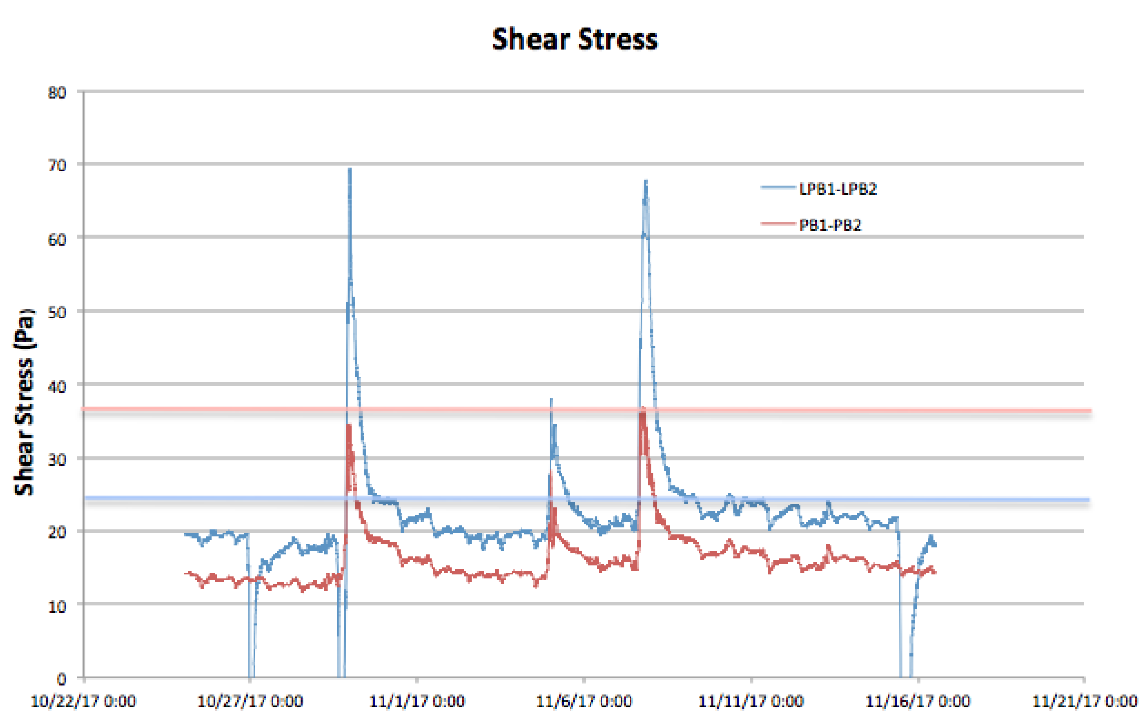


Figure 10: Graph of water shear stress over time for the upstream sites, the lines (LPB: 23.28 Pa, PB: 36.6 Pa) represent the critical shear stress that's required for sediment transport in this system between October 25 and November 16, 2017

The critical shear stress for Paint Branch is considerably higher than Little Paint Branch's. The horizontal lines on figure 10 represent the critical shear stress. The backwater effect is responsible for the dip in gradient that results in a lower shear stress at the larger tributary. The times that the shear stress is enough to move grains in Little Paint Branch occurred during October 25 and November 16. While the only time that Paint Branch exceeded the critical shear stress was during November 7 between 15:45 and 16:45. This explains why the bar in Paint Branch has larger bed grains as most storms do not have enough shear stress to transport them.

Sediment

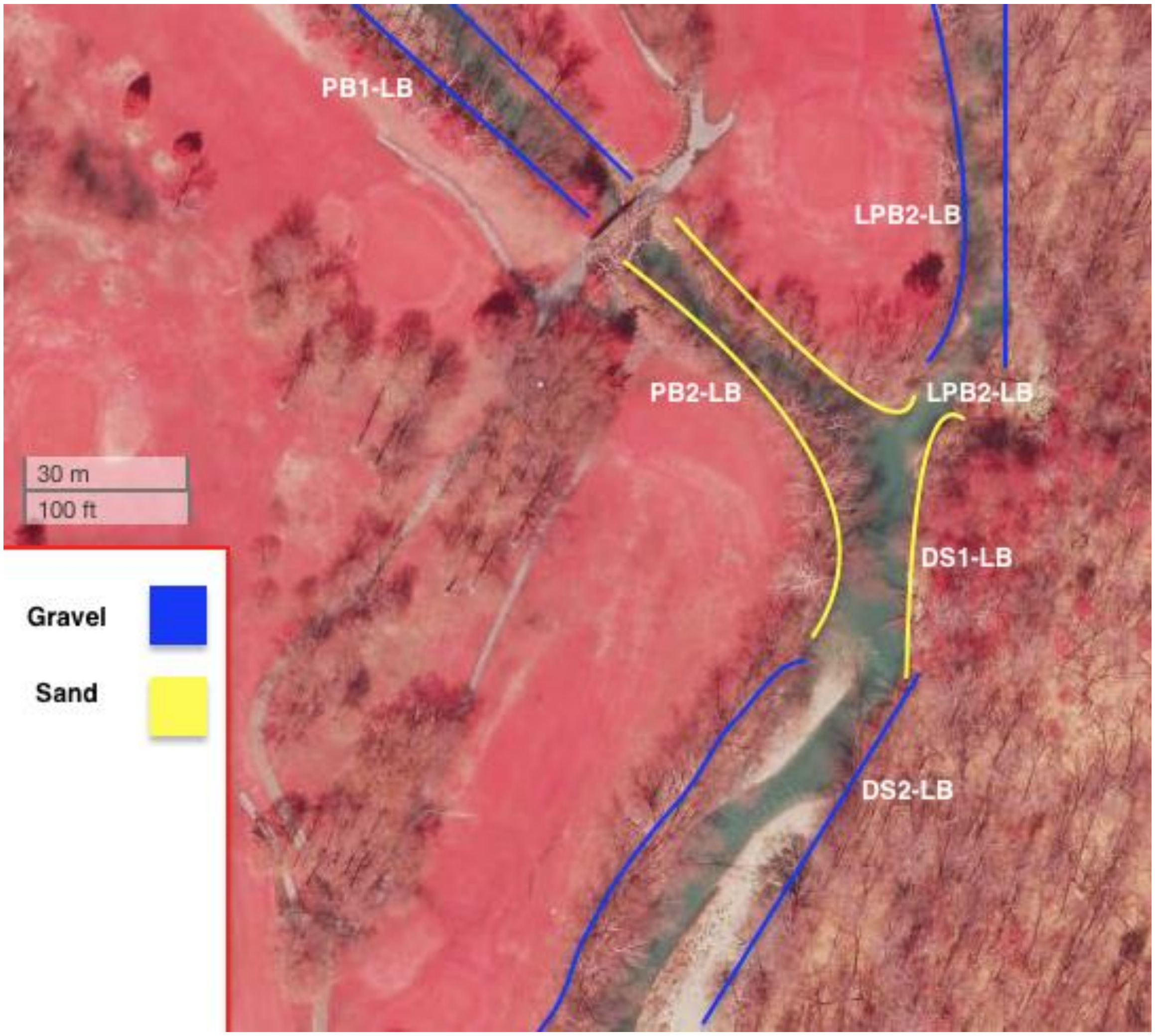


Figure 11: Colored-Infrared image of site, with a chart showing the grain size of sediment deposits, where sand is outlined with yellow and gravel is outlined with blue

Figure 11 shows the distribution of different grain sizes across the study site. Coarse sediment gets deposited upstream in both tributaries and downstream past the confluence. Fine sediment gets deposited in the confluence and in the lower section of Paint Branch, which are places with low gradient. These areas do not have enough shear stress to move coarser sediment. While areas with higher gradients such as the upper portion of Paint Branch, Little Paint Branch, and downstream the confluence have coarse sediment deposits.

Conclusion

1. The smaller tributary, Little Paint Branch, responds faster than Paint Branch with higher peak flows during the storm events from October 25 and November 16. Little Paint Branch has a higher stream gradient than Paint Branch. The lower stream gradient of Paint Branch is a result of Little Paint Branch's shorter lag time and peak flow, creating a backwater effect that lowers the stream gradient of Paint Branch
2. When peak flow occurs in Little Paint Branch, the gradient of Paint Branch decreases. This decrease in gradient results in lower shear stresses for Paint Branch. The maximum shear stress for Little Paint Branch is approximately 70 Pa while the max for Paint Branch is approximately 36 Pa during the storm events from October 25 and November 16. Paint Branch has lower gradients and shear stresses during storm events than Little Paint Branch.
3. Due to the low stream gradient at the tributary junction, coarse sediment gets deposited upstream of the tributary junction in Paint Branch while fine sediment gets deposited in the tributary junction during storms. Paint Branch has coarse sediment bars further upstream because the shear stresses during most storm events do not exceed the critical shear stress required for sediment transport of bars. Fine sediment requires a lower critical shear stress for sediment transport, which is why fine sediment gets transported to the tributary junction during storm events.

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