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Geology 394H

Hydraulics Affecting Bedrock Erosion at a Stream Knickpoint

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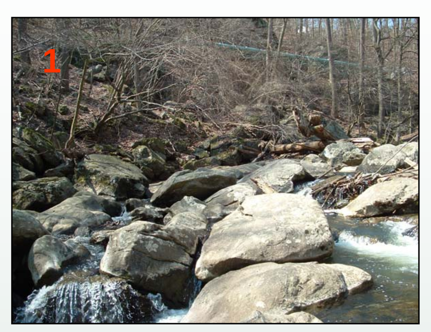
Abstract

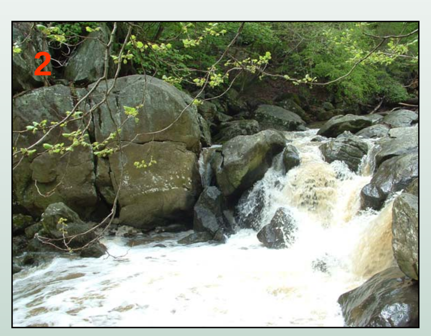
Bedrock erosion rates are generally considered to be proportional to local stream power and thus discharge times gradient. But bedrock erosion only takes place on exposed bedrock, and abrasion is by sediment load, turbulent eddies, and other factors that influence how suspended sediment particles hit the bed. A detailed study of form and hydraulic processes along a series of knickpoints was conducted to evaluate the role of large bed particles in protecting the bed influencing flow hydraulics. Bed and low flow water surface elevations were surveyed in a longitudinal profile across a complex boulder and bedrock knickpoint. Measurements also included the location of potholes, exposed bedrock, and the distribution and size of bed particles. A major flood occurred on Oct. 7-8, 2005 and water surface elevations and flood cross sections were surveyed for the flood. From the discharge, cross section, and water surface elevation data, flow depth, velocity, Froude number, local shear stress, local stream power, flow resistance, and dimensionless shear stress were calculated These hydraulic data were plotted as a function of longitudinal distance to evaluate the location of hydraulic features and bedrock morphology. The flood indicated one main knickpoint at a boulder step, which also created a transition from sub-critical to supercritical flow. Thus the boulder knickpoint appears to control the site of most active bedrock erosion.

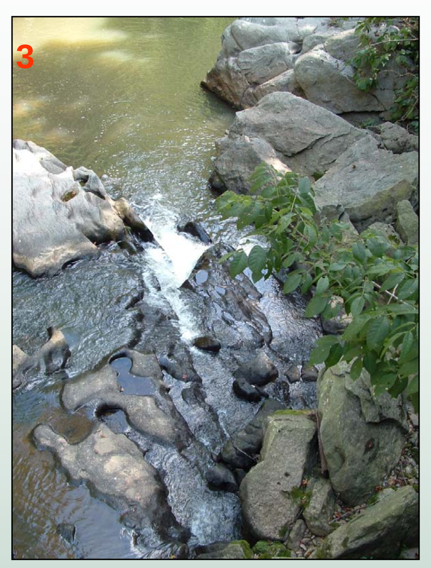
Hypotheses

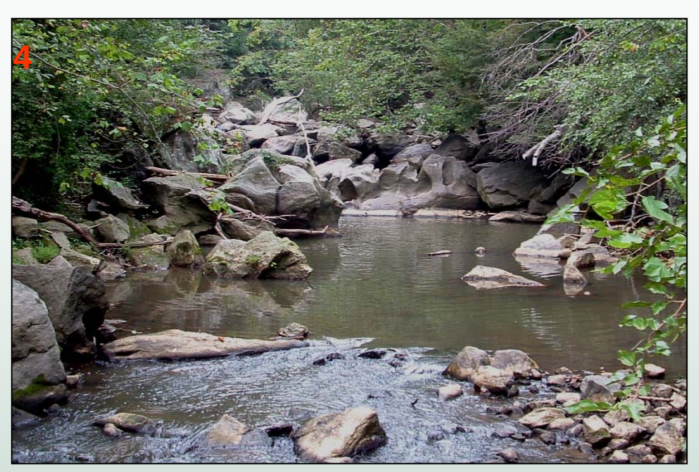
1. Knickpoints erode and migrate headward primarily through abrasion concentrated at narrow parts of the stream (with high ratios of power/width).
2. Knickpoints erode and migrate headward primarily through pothole coalescence.
3. The position of a knickpoint can be controlled by the accumulation of large particles, which can increase knickpoint height and hydraulics.

Study Site









Picture 1: Particle jam caused by width restriction.
Picture 2: Boulder knickpoint, April 21st flood.
Picture 3: Bedrock knickpoint with potholing.
Picture 4: Lower section looking upstream.

Methods

1. Observe a flood, mark high flow, and calculate flood discharge (2 methods).
2. Conduct multiple cross sectional surveys, identify floodplain steps and measure effective width, and measure particle size and orientation along cross section locations.
3. Conduct longitudinal surveys of bed, low water surface, and high water surface elevations
4. From discharge, cross section, and water surface profile data, calculate velocity, Froude number, stream power, stream power per unit width, shear stress, and dimensionless shear stress, which are used to evaluate erosion potential.

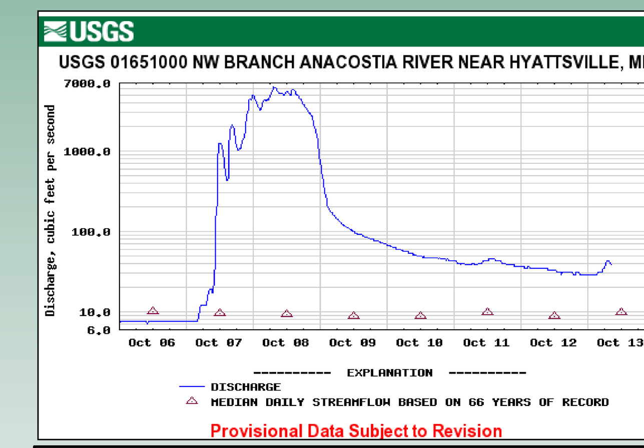
Results

1. Determination of flood discharge and velocities from October 7th-8th flood

From the hydrograph of the 7th – 8th flood (figure 1), flood frequency graph normalized to drainage basin area (figure 2), and calculated drainage basin area of the study site, a discharge of 158 ± 31 cubic meters per second was obtained.

From a surface velocity measurement of the flood and cross sectional area from three different sites, a discharge of 156 ± 76 cubic meters per second was obtained.

Discharge charge through the reach is ***constant***, error in the estimation of this value is incurred from gauging station measurements, drainage basin calculations, and cross sectional measurement error.



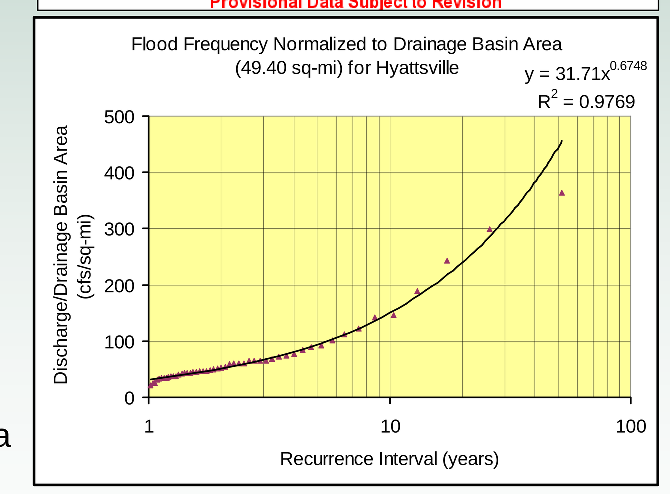


Figure 1 (above) Hydrograph of 10/7-8/05 Flood

Figure 2 (below) Flood Frequency Normalized to Drainage Basin Area

2. Flood cross sectional surveys and calculation of flood velocity and Froude Number

Calculations are made using the average of the flood measurements given above. Supercritical flow is achieved at bedrock constrictions and at the boulder knickpoint (M) (table 1).

Distance (m)	Upper/ Middle Lower	Width (m)	Depth (m)	Area (m^2)	Discharge (cubic m/s)	Velocity (m/s)	Froude Number
17.50	U	18.28	1.30	23.76	157.80	6.64	2.25
64.00	U	22.56	1.50	33.84	157.80	4.66	1.11
70.00	M	10.00	2.00	20.00	157.80	7.89	3.17
75.00	L	19.51	3.70	72.19	157.80	2.19	0.24
82.80	L	29.00	2.50	72.50	157.80	2.18	0.24
85.88	L	33.65	2.90	97.59	157.80	1.62	0.13

Table 1 Distance downstream compared to hydraulic variables

3. Bed profile and water surface profile at high and low flow

At low flow, there are two major features bed features in the reach, a boulder knickpoint and a bedrock knickpoint (figure 3). High flow water elevations indicate only one area of plunging flow (over the boulder knickpoint) and skimming flow (everywhere else). Calculations of Froude numbers suggest the flow depth increases downstream of the knickpoints due to a hydraulic jump as flow transitions from supercritical to subcritical flow.

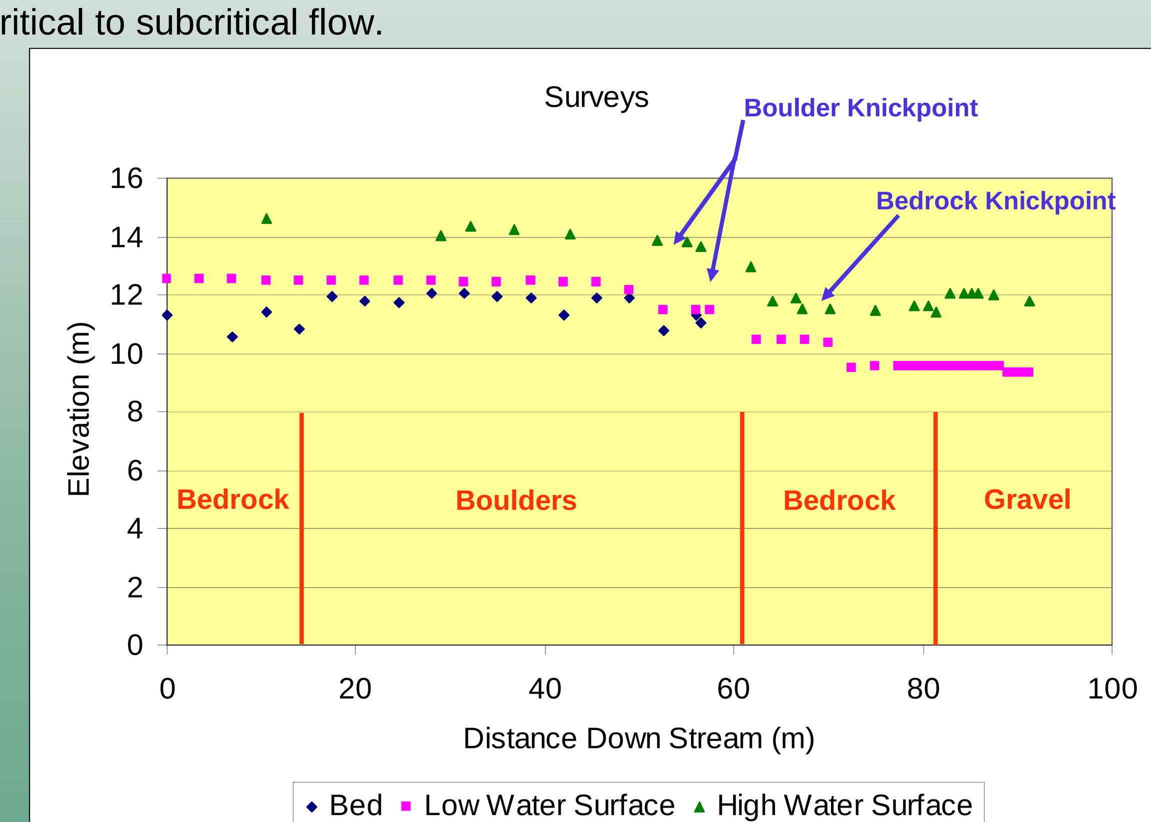


Figure 3 Distance downstream with bed and low and high water elevations

4. What produces the boulder step? Analysis of bed stability in the reaches upstream and downstream of the boulder knickpoint.

The fluid shear stress over the boulder jam is not high enough to lift the boulder-sized particles out of their place, leading to a stable feature (figure 4).

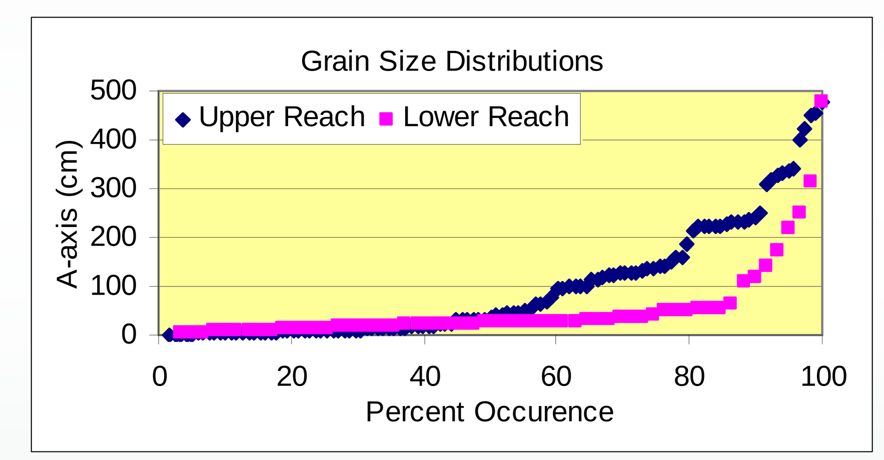
Stream power per unit width can be calculated from the gradient of the high flow and the measured widths (figure 5). Stream power per unit width decreases as you moved down stream towards the knickpoints. This allows for the conclusion that the boulder knickpoint is stable because the power does not exist to move the particles that make up it.

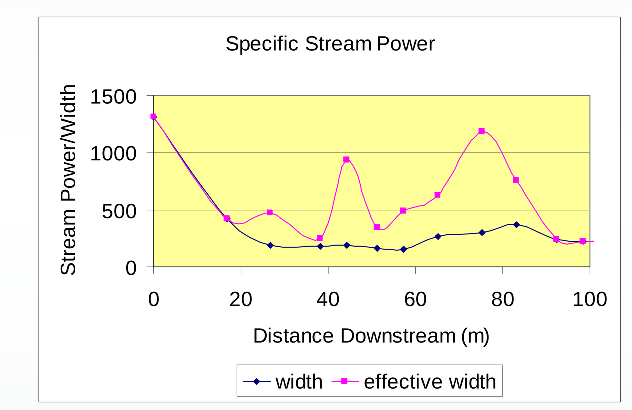
Upper Reach

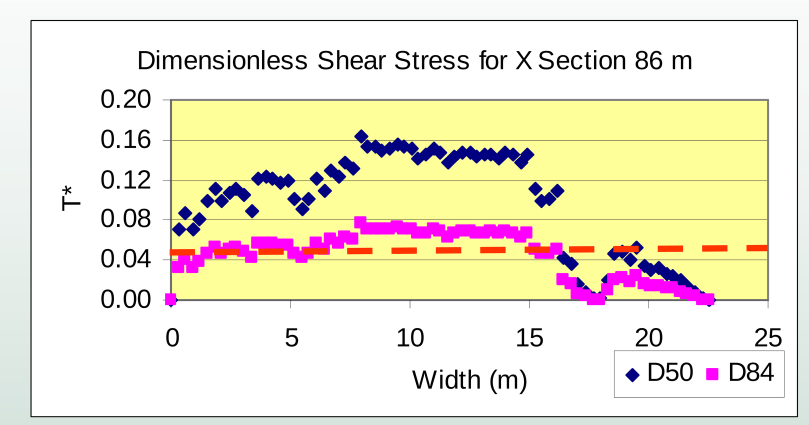
The upper reach contains particles that are all oriented with their long axis parallel to flow, which leads to the assumption that the particles have been in place long enough for flow to orient them. A plot of dimensionless shear stress (ratio of fluid shear stress to grain resisting forces) versus distance downstream indicates that large (D84) particles can not be moved at fluid shear stresses produced by the October 8 flood (figure 7). The critierion for entrainment is taken to be 0.045, a value supported by theory and empirical data for heterogeneous cobble beds (Wiberg 1991).

Lower Reach

The lower reach contains particles that are randomly oriented in relation to flow. The largest particles are form a boulder arc on the downstream rim of the plunge pool, suggesting that they were originally part of the boulder knickpoint upstream. Using the same criterion for entrainment, dimensionless shear stress values indicate that the majority of the large bed particles are at or above the threshold of motion for the Oct. 7-8 flood (figure 6).







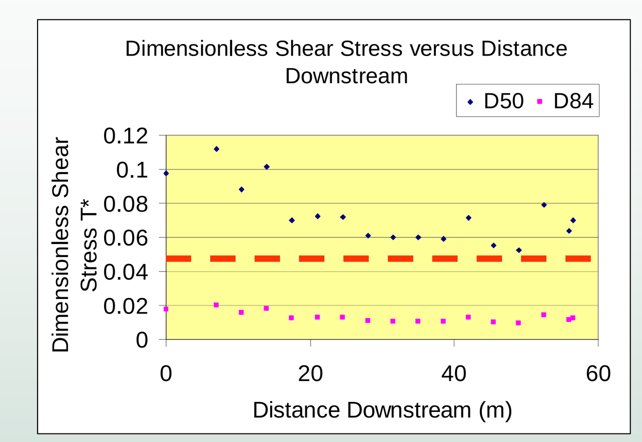


Figure 4 (top left) Grain sizes used to calculate shear stress
Figure 5 (top right) Stream power
Figure 6 (lower left) T* for lower cross section
Figure 7 (lower right) T* for upper reach

Conclusions

1. There are multiple knickpoints in the channel bed, but only one hydraulic step at high flow.
2. The hydraulic step is located at the boulder knickpoint, which focuses bedrock erosion below the step.
3. The boulder knickpoint exists due to the stability of large particles in the upper reach as evaluated using dimensionless shear stress.

Reference

Wiberg, P and Smith, J. Dungan (1991). Velocity Distribution and Bed Roughness in High-Gradient Streams. *Water Resources Research*, 27(5).

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