Quantifying Differences in Turbulence Between Alluvial and Bedrock Streams Using Analyses of Seismic Noise

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ABSTRACT

- Recent studies have examined the relationship between the power of select frequency bands of environmental seismic noise and fluvial processes. Seismometers and geophones have been deployed to study a wide range of Earth processes.
- The study of the relationships between environmental seismic noise (frequencies greater than 1 Hz) and fluvial processes allow researchers the possibility to analyze instantaneous hydraulic data and reduce the reliance on averaged values. Additionally, the current methods for obtaining stream hydrodymanic measurements are hindered by the necessity to directly sample values such as bedload transport and velocity, which are difficult to sample over great spatiotemporal ranges.
- Several recent studies have shown correlation between sediment transport and near-stream environmental seismic noise in the 1-20 Hz frequency band. The noise generated by turbulence in rivers with varying amounts of bedrock and alluvial beds has not been examined. .

BACKGROUND

- The study of Earth processes via seismic signals has a long and detailed history. Part of this study has resulted in relationships being drawn between distinct environmental features and certain frequency bands and power thresholds. Low-frequency signals below 10^{-1} Hz have been largely attributed to natural sources. High frequency noise (>1 Hz) is typical of human activity (McNamara and Buland, 2004) however Burtin et al. (2008) showed through the Hi-CLIMB experiment the potential for hydrodynamic features to be monitored through the frequency analysis of high frequency (>1 Hz) seismic noise. The Hi-CLIMB experiment consisted of 115 broadband seismometers deployed along the Trisuli River in Nepal. The Trisuli River has great seasonal variation in discharge and receives most of its rainfall during the June to late-September monsoon season. Burtin et al. sought to couple certain frequency bands of high frequency seismic noise to the turbulence and sediment transport of the river. For this purpose, averaged power of the seismic noise was correlated with the moving average of the water height and the precipitation. In their paper, they focus on data from an area of the river that is narrow and has a high gradient. These data were chosen as this area of the river was expected to have a high capacity for transporting sediment. The correlation coefficient was found to be 0.86 between water height and 0.61 with precipitation. The continued refinement of this technique can result in the monitoring of lower gradient streams in which the noise is driven by bed turbulence rather than sediment transport.

HYPOTHESES

- A positive, linear scaling relationship exists between near-bed turbulence (and thus velocity) and the integrated power of high frequency (1-100 Hz) seismic noise as measured along the bank of the streams in question. Additionally, this relationship exists without the presence of bedload transport.
- In the comparison of alluvial and bedrock channels, the bedrock-influenced channel will have a steeper gradient, higher bed roughness, and thus greater seismic noise (at similar unit discharges) than the alluvial channel.

STUDY SITES & METHODS

- For the purposes of this experiment, two sites were selected for study. One site was a steep Piedmont reach, with bedrock protrusions and large particles over a bedrock bed. The other site was alluvial with well-sorted gravel bed material.
- At each of the two sites, morphological measurements were made to characterize each stream reach. The morphological measurements included channel cross sectional area, stream longitudinal gradient, and bed grain size.
- A seismologic survey was completed at each site to obtain a seismic profile of the environmental noise at each stream. Both the integrated spectral power of the environmental noise and the mean frequency were correlated with turbulence-related hydraulic parameters.

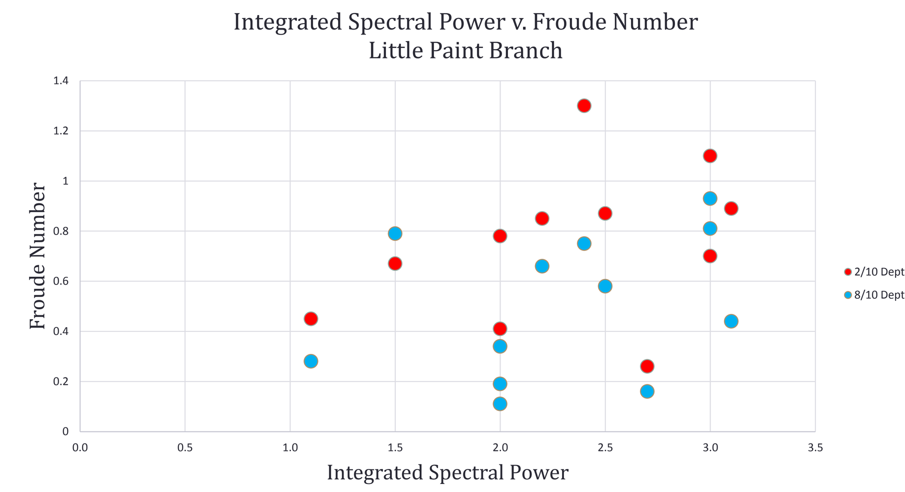
	Froude Number (2/10,8/10 Depth)	Reynolds Number (2/10,8/10 Depth)	Local Relative Roughness
Little Paint Branch (ISP)	0.39, 0.33	0.18, 0.02	0.34
Little Paint Branch ($\bar{f}$)	0.80, 0.70	0.18, 0.37	0.56
NW Branch (ISP)	0.08, 0.26	0.09, 0.34	0.06
Little Paint Branch ($\bar{f}$)	0.73, 0.73	0.44, 0.51	0.74

- *(Left) Alluvial Stream, Little Paint Branch, 39° 0'57.25"N 76°56'8.43"W*
- *(Right) Bedrock Stream, Northwest Branch, 39° 0'30.19"N 76°59'22.28"W*

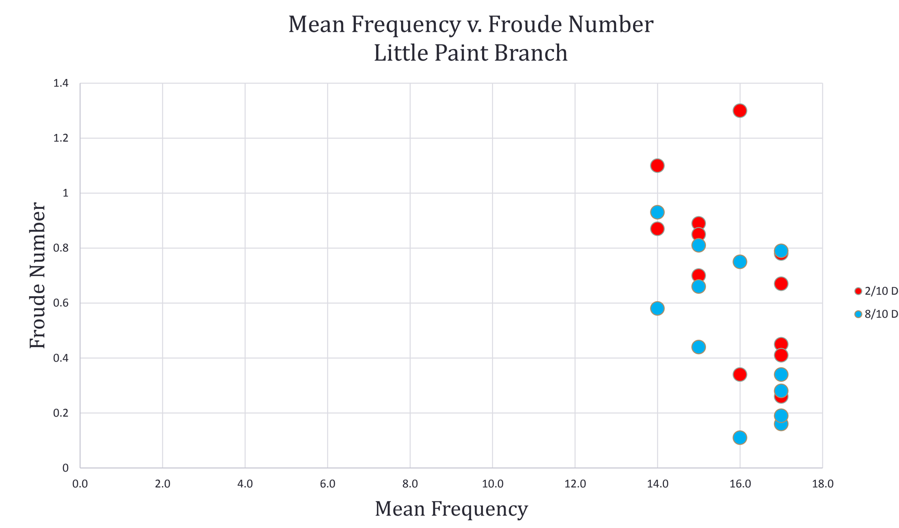
RESULTS

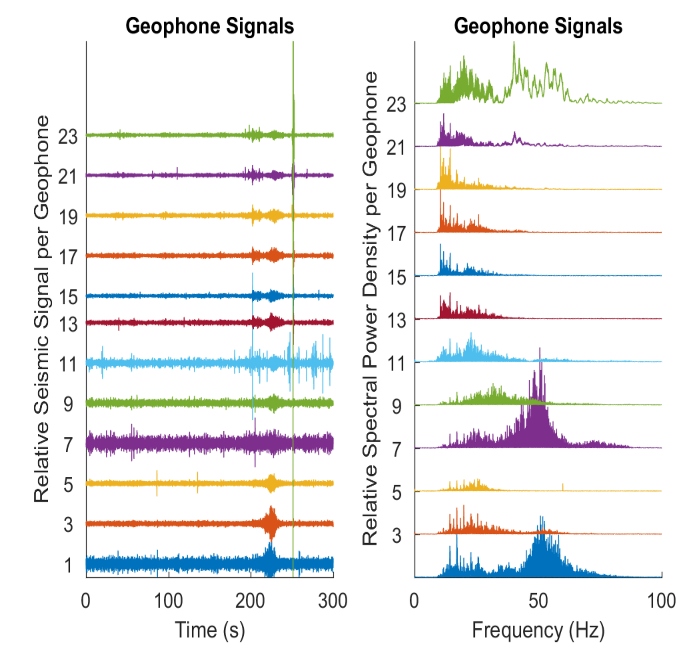
- In all of the correlations, the alluvial stream showed higher correlation with the hydraulic parameters than those of the bedrock-influenced stream. A possible cause for this is the difference in flow regimes. The alluvial seismological study was completed while the discharge (normalized by basin area) was 1.4 cfs/mi^2 higher than the discharge of the bedrock-influenced stream during the seismological study performed there. Past research on this topic (Huang, 2007) (Burtin, 2008) has focused primarily on studying correlations during discharge events high enough to induce bedload transport. Neither of the sites studied experienced consistent bedload transport during the seismological studies. These low correlation coefficients may be indicative of a flow threshold below which the correlation is lessened.
- The correlation between mean frequency and hydrologic parameters was not studied in any papers I have read. This correlation is higher in both the Little Paint Branch and Northwest Branch studies across all hydrologic parameters. The mean frequency correlation may prove to be consistently higher than integrated spectral power during flow conditions without bedload transport.

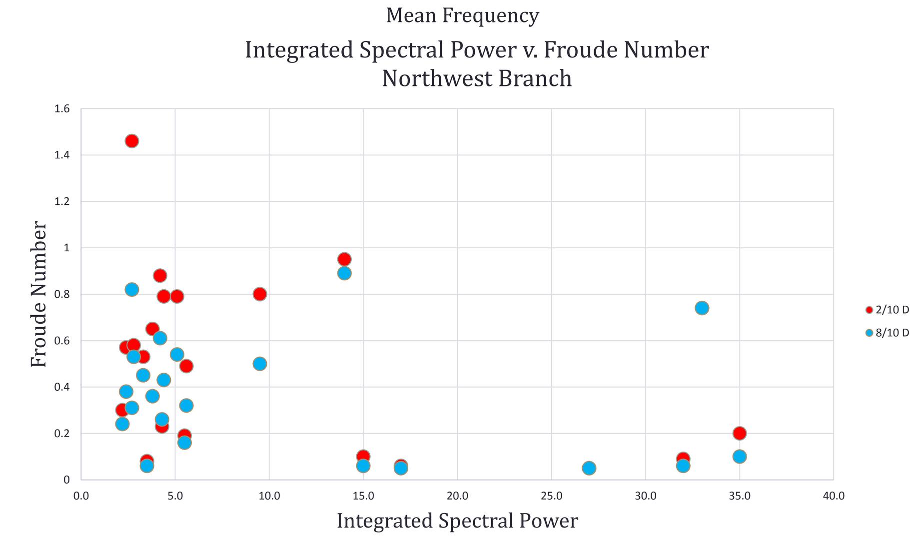
RESULTS

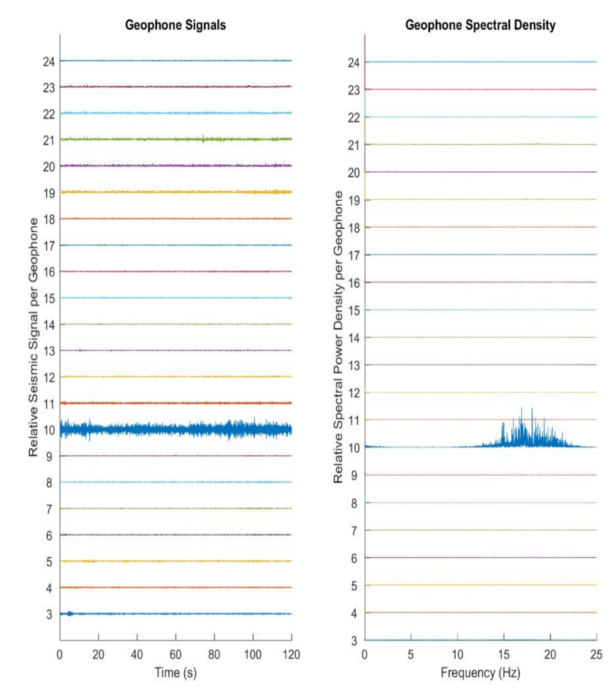


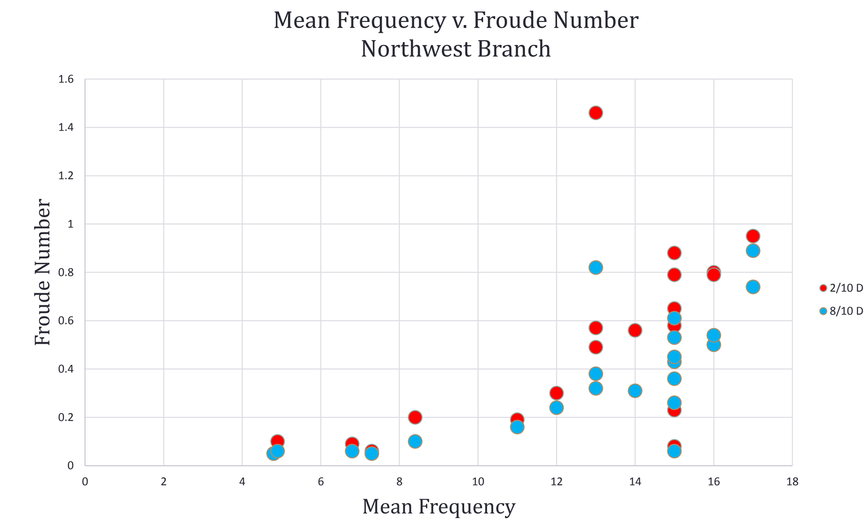
Site	Bankful Width (m)	Gradient	Mean D_50 (mm)	Mean D_84 (mm)
Little Paint Branch; Alluvial	15	0.0025	12	50
Northwest Branch; Bedrock influenced	25	0.0091	51	73











CONCLUSIONS

- The geomorphological measurements made during the study support the hypothesis that the bedrock-influenced channel will have a steeper gradient and higher bed roughness than the alluvial channel (shown in Table I).
- The correlations (Table V) in the study did not support the hypothesis that a positive linear scaling relationship exists between the integrated spectral power and the hydraulic parameters which define turbulence without the presence of bedload transport. Additional studies of the alluvial and bedrock-influenced sites are needed to determine the reason for the differences in correlation coefficients and whether a low-discharge boundary exists for the integrated spectral power correlations. If the correlations are shown to have a low-discharge boundary, correlations between the mean frequency and the hydraulic turbulent parameters may prove to be an alternative. The new field of fluvial seismology will allow for the study of rivers over large spatio-temporal scales while also removing geomorphologists and seismologists from potentially life-threatening situations. Further development of the techniques and correlations in this new field are needed for the field to become solidified as a method of measurement.

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