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. In many places, these seismometers and geophones are deployed near rivers and streams as human development has largely occurred around fluvial environments. 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 turbulence. It is difficult to record small changes in direct sampled values over great spatiotemporal ranges. Several recent studies have shown correlation between fluvial gradients/sediment transport and near-stream environmental seismic noise in the 1-20 Hz frequency band. In this paper, I further the study of this correlation by quantifying the differences in this correlation between two types of common stream channels (bedrock and alluvial).

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Introduction

As population densities continue to increase near stream environments so too does the need to understand the processes that shape stream channels. Conventional methods of data collection involve the direct sampling of morphological parameters (e.g. stream depth, velocity, sediment transport). Large gaps in data occur during high flow events where direct measurement becomes dangerous or impossible. This is unfortunate as large changes in stream morphology tend to occur during high flow events. In recent years efforts have been made to analyze seismic noise records obtained along rivers to track spatiotemporal changes in stream morphology and hydrodynamics.

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. These sources include seasonal variations in atmospheric temperature/pressure (Beauduin et al., 1996) and oceanic sources (Oliver and Ewing, 1957). 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.

Problem

Large gaps in stream morphology data remain due to the danger, difficulty, and costs of collecting data during high flow events or in reaches where direct measurement proves challenging. Recent studies have shown a relationship between several fluvial hydrodynamic properties but I have yet to see a study relating environmental seismic noise and near-bed turbulence. Relying on bedload transport events or high gradient streams for seismic noise analysis leaves a large amount of fluvial environments out of reach of this new measurement technique. The University of Maryland's proximity to both alluvial and bedrock streams allows for a unique opportunity to see if differences exist in the production and transmission of seismic noise from near-bed turbulence in various types of streams.

Hypotheses

1. The bedrock-influenced channel will have a steeper gradient and higher bed roughness than the alluvial channel.
2. A positive, linear scaling relationship exists between near-bed turbulence 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. The relationship will have a shallower slope in a bedrock stream than in an alluvial stream due to the type of bed sediment, channel geometry, and nature of the media that the seismic load is transmitted through.

Methods of Data Collection and Analysis

Site Selection

Fig. 1 View downstream of bedrock site during longitudinal survey.
Date: Nov. 5th, 2016

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. The alluvial site is located on the Little Paint Branch Creek tributary of the Anacostia River. The study site is downstream of Cherry Hill Road in College Park, MD. This site was selected due to its exemplary characteristics of an alluvial stream. The stream bed and bank is made of mobile sediment, soil, and gravel. The stream is actively forming gravel bars and meanders. Meander formation is driven primarily by the development of gravel bars and the scour of banks. The steep, bedrock-controlled site selected is a Piedmont stream that is located along the Northwest Branch of the Anacostia River near Adelphi, MD. This stream is a bedrock bounded stream with a thin veneer of coarse alluvial sediment deposited over the bed. The reach is nearly straight with a trapezoidal channel morphology. Both study sites were along straight reaches with wide channels (width/depth ratios > 30) at the time of measurement. These factors combined will make it an excellent site to study the primary objective of this research; to observe any correlation between near-bed turbulence and seismic noise. With a trapezoidal channel and a

Fig. 2 View downstream of alluvial site during initial data collection.
Date: May 1st, 2016

straight reach the turbulent processes in the stream should be driven primarily by the bed of the stream.

Stream Morphological and bed Sediment Measurements

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. Each stream was surveyed at multiple cross-sections to obtain local channel cross sectional area, surface width, and average depth (area/width) for each cross section. These data were averaged to obtain the reach-average characteristics. The gradient of each reach was also surveyed by making a measurement of the bed elevation and the water surface elevation at an interval of 2m along the thalweg of the reach for distances of 100-120m. The water and surface elevation data were plotted against distance to determine bed and water surface profiles. Grain size data were obtained by pebble count (Wolman, 1957) at each cross section location. Grain size data were plotted as cumulative percentile graphs to obtain the median and D_{84} grain sizes.

Hydraulic Measurements at the Time of the Experiments

Stream velocity varies with discharge. Therefore, velocity was measured just before the seismic measurements. In fully-turbulent flow, velocity increases logarithmically with depth above the bed (Prandle-Von Karman Law of the Wall):

$$\frac{U}{U^*} = \frac{1}{k}\ln(\frac{Z}{Z_0})$$

Due to this velocity structure, the mean velocity is 0.4 the distance above the bed and it can also be estimated by averaging the velocity values. Before the start of the seismic measurement period, the stream velocity was measured using a flow meter at 2/10 and 8/10 of total stream depth. Measurements of total depth was made at the thalweg (deepest point of stream channel) at every 5 m along the channel (corresponding to the spacing of the geophones). Four pressure transducers were also placed in the stream to monitor stream height and by extension, average stream discharge and velocity over the course of the seismological survey.

Analysis of Hydraulic Data

The stream hydraulic measurements were used to determine the following at each measurement location at the time of the seismic noise experiments: a) local depth, b) near-bed (2/10 depth) velocity, c) near-surface (8/10 depth) velocity, d) average velocity, and d) shear velocity. In addition, a set of dimensionless numbers can be calculated that define the flow conditions, relative roughness, and flow resistance. These dimensionless numbers include: a) the Reynold's number (Re), b) the Froude number (Fr), c) a resistance coefficient (U/U*), and d) relative roughness (d/D84). These dimensionless numbers can be obtained and compared to the integrated spectral power of the seismic signal as explained in the analysis section. These hydraulic measurements will be compared with data from the seismological study of the reaches to test for correlations.

The Reynolds number is the dimensionless ratio of fluid velocity to its kinematic viscosity. This ratio is used to determine whether a fluid is laminar or turbulent. The Reynolds number is defined as:

$$Re = \frac{uL}{v}$$

where u is the velocity of the fluid in (m/s), L is the characteristic linear dimension in (m) (depth being the linear dimension in open channel natural streams), and v is the kinematic viscosity of the fluid in (m^2/s). The local shear velocity is given by:

$$v_s = \frac{u}{\sqrt{gdS}}$$

where g is the acceleration due to gravity (m/s^2), d is the depth of the location (m), and S is the gradient of the stream. The local Froude number is the ratio of the flow inertia to the length of the external field. In open channel stream dynamics, the Froude number is given by:

$$Fr = \frac{u}{\sqrt{gd}}$$

Lastly, the local relative roughness is given by the ratio between local depth and the 84^{th} percentile grain size (D84).

$$Relative\ Roughness = d/D_{84}$$

Seismological Surveys

A seismologic survey was completed at each site to obtain a seismic profile of the environmental noise at each stream. The seismic study of the alluvial reach was completed in May 2016 at a moderately high flow stage (on the threshold of bedload transport). To complete this survey, two arrays of RT Clark 395 Ω vertical lead Mueller clip geophones were placed co-located on the bank of the stream running parallel to the stream. The measurements were taken in 60 second intervals at a 1000 Hz sampling speed over the course of a 25 minute measurement period. During these measurement periods, all persons engaged in the study sat down and moved minimally in an effort to contribute as little to the noise profile as possible. The seismic noise was correlated with both of these value to determine whether the environmental noise is more strongly associated with bed spawned turbulence or other sources. The seismic study of the alluvial site was conducted in May 2016. The measurements at the bedrock site were completed in November 2016 at a low flow stage. Field procedures were identical for the hydraulic-seismic experiments on the two dates.

Seismological Analysis

The analysis of these seismic signal data begins with obtaining a power spectral density estimate using the Fourier transform. The power spectral density shows how the power of the signal is distributed through various frequencies. For this project, The power spectral density was obtained using the mean-square method. The average power P of a time signal g(t) over all time T is given by:

$$P = \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} g(t)^2 dt$$

Since the goal is to analyze the frequencies, the Fourier transform must be used. The Fourier transform is used to transfer a signal in the time domain t to the frequency domain f. The truncated Fourier transform used in signal processing is defined by the equation:

$$G(f) = \frac{1}{\sqrt{T}} \int_0^T g(t) e^{-i2\pi f} \, dt$$

This allows the power spectral density to be defined as:

$$S_{xx}(f) = \lim_{T \to \infty} E\{[G(t)]^2\}$$

Once the estimated power spectral density of the signal is found, the integrated power of selectable frequency bands can be correlated with measured stream values to determine which frequencies correlate strongly with stream hydrological processes. The hydraulic measurements that are correlated are the two velocity measurements at each geophone site, the local Reynolds number, the local shear velocity, the local Froude number, and the local relative roughness.

The correlation between hydraulic and seismic parameter values will be determined by the Pearson correlation coefficient. The Pearson correlation coefficient measures the linear correlation of two variables by taking the ratio of covariance to the product of the standard deviations of the two variables. The covariance between two variables is a method of quantifying how two variables change with respect to each other. It is determined as the product of the differences between the actual variable values and the expected values. The Pearson correlation coefficient can be defined by the equation:

$$\rho_{X,Y} = \frac{cov(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X - \bar{X})(Y - \bar{Y})]}{\sigma_X \sigma_Y}$$

where cov(X,Y) is the covariance of two data X, Y and σ is the standard deviation of the respective data. Linear correlation increases as the Pearson correlation coefficient approaches one, with one being a perfect linear correlation and zero being no linear correlation.

Presentation of Data and Analysis

Reach-averaged Geomorphic Characteristics of the Two Reaches

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

Table I This table features geomorphic characteristic measurements made of the two reaches.

Dates: May 01, 2016 (Alluvial), Nov. 05, 2016 and May 20, 2016 (Bedrock influenced)

These data in Table I support the hypothesis that the geomorphology of these channels are influenced by different processes. The gradient of the Northwest Branch reach is higher than that of the Little Paint Branch reach. Additionally, the mean D50 and mean D84 grain sizes are higher in the Northwest Branch than Little Paint Branch. In a bedrock influenced stream, it is expected that the gradient would be higher (and by extension the mean grain sizes) due to the differing methods of channel formation (Anderson, 2010).

Hydraulic Data Collected during the Hydraulic-Seismic Experiments

Associated Geophone Pair	Full Depth of Thalweg (m)	Depth @ 2/10 Stream Height (m)	Depth @ 8/10 Stream Height (m)	Velocity @ 2/10 Stream Height (m/s)	Velocity @ 8/10 Stream Height (m/s)	Shear Velocity (m/s)	Avg. Velocity (m/s)
23-24	0.55	0.11	0.44	0.27	0.33	0.11	0.30
21-22	0.42	0.084	0.34	0.41	0.5	0.16	0.46
19-20	0.24	0.048	0.19	0.46	1.09	0.12	0.78
17-18	0.55	0.11	0.44	0.81	0.71	0.18	0.76
15-16	0.76	0.15	0.61	0.5	0.46	0.21	0.48
13-14	0.69	0.14	0.55	0.39	0.26	0.20	0.33
11-12	0.25	0.05	0.2	0.62	0.62	0.17	0.62
9-10	0.35	0.07	0.28	0.7	1.1	0.20	0.90
7-8	0.26	0.052	0.21	0.9	1.07	0.17	0.99
5-6	0.25	0.05	0.2	0.49	1.13	0.17	0.81
3-4	0.35	0.07	0.28	0.72	0.96	0.20	0.84
1-2	0.27	0.054	0.22	0.82	1.36	0.17	1.1

Table IIa This table features the depth measurements taken as well as the hydrologic values that can be calculated from them. The discharge per basin area during the time of measurement was 1.60 cfs/mi^2.

Site: Alluvial Stream, Paint Branch at Cherry Hill Road

Date: May 01, 2016

Geophone#	Depth (m)	Velocity @ 2/10 Depth (m/s)	Velocity @ 8/10 Depth (m/s)	Shear Velocity (m/s)	Average Velocity (m/s)
3	0.2	0.5	0.63	0.13	0.57
4	0.25	0.55	0.6	0.15	0.58
5	0.22	0.52	0.71	0.14	0.62
6	0.22	0.43	0.47	0.14	0.45
7	0.2	0.33	0.56	0.13	0.45
8	0.2	0.55	0.76	0.13	0.66
9	0.15	0.79	0.89	0.12	0.84
10	0.23	0.5	1	0.14	0.75
11	0.12	0.46	0.86	0.10	0.66
12	0.18	0.29	0.38	0.13	0.34
13	0.48	0.54	0.61	0.21	0.58
14	0.2	0.36	0.47	0.13	0.42
15	0.21	0.15	0.33	0.14	0.24
16	0.21	0.37	0.68	0.14	0.53
17	0.4	0.27	0.42	0.19	0.35
18	0.32	0.15	0.26	0.17	0.21
19	0.44	0.19	0.18	0.20	0.19
20	0.45	0.05	0.09	0.20	0.070
21	0.41	0.08	0.1	0.19	0.090
22	0.46	0.06	0.1	0.20	0.080
23	0.42	0.09	0.1	0.19	0.095
24	0.44	0.07	0.11	0.20	0.090

Table IIb This table features the depth measurements taken as well as the hydraulic values that can be calculated from them. The discharge per basin area during the time of measurement was 0.20 cfs/mi^2.

Site: Bedrock Influenced Stream, Northwest Branch South of Burnt Mills

Date: November 03, 2016

An important factor to note before the analyses of these data is the difference in flow at the two sites on the dates when the studies were completed. The discharge per basin area during the Little Paint Branch data collection was 1.6 cfs/mi^2. The Little Paint Branch data collection took place at a moderate (0.5 bankfull depth) flow stage after a rain event the previous day. The discharge per basin area during the Northwest Branch data collection was 0.20 cfs/mi^2. The Northwest Branch data collection took place under baseflow conditions near the end of a dry fall. The difference in discharge is reflected in the higher average velocities of the Little Paint Branch (Table IIa) versus the average velocities of the Northwest Branch (Table IIb).

Dimensionless Hydraulic Variables

Geophone Pair	Froude # (2/10 Depth)	Froude # (8/10 Depth)	Reynolds # (2/10 Depth)	Reynolds # (8/10 Depth)	Local Relative Roughness (2/10 depth)	Local Relative Roughness (8/10 depth)
23-24	0.26	0.16	30000	140000	1.5	6.1
21-22	0.45	0.28	34000	170000	1.2	4.7
19-20	0.67	0.79	22000	210000	0.66	2.7
17-18	0.78	0.34	89000	310000	1.5	6.1
15-16	0.41	0.19	76000	280000	2.1	8.4
13-14	0.34	0.11	54000	140000	1.9	7.5
11-12	0.89	0.44	31000	120000	0.68	2.7
9-10	0.85	0.66	49000	310000	0.95	3.8
7-8	1.3	0.75	47000	220000	0.75	3.0
5-6	0.70	0.81	24000	230000	0.72	2.9
3-4	0.87	0.58	50000	270000	1.0	4.0
1-2	1.1	0.93	44000	290000	0.77	3.1

Table IIIa This table features the dimensionless turbulence-related values which have been calculated from the hydraulic measurements shown in Table IIa. The discharge per basin area during the time of measurement was 1.6 cfs/mi^2.

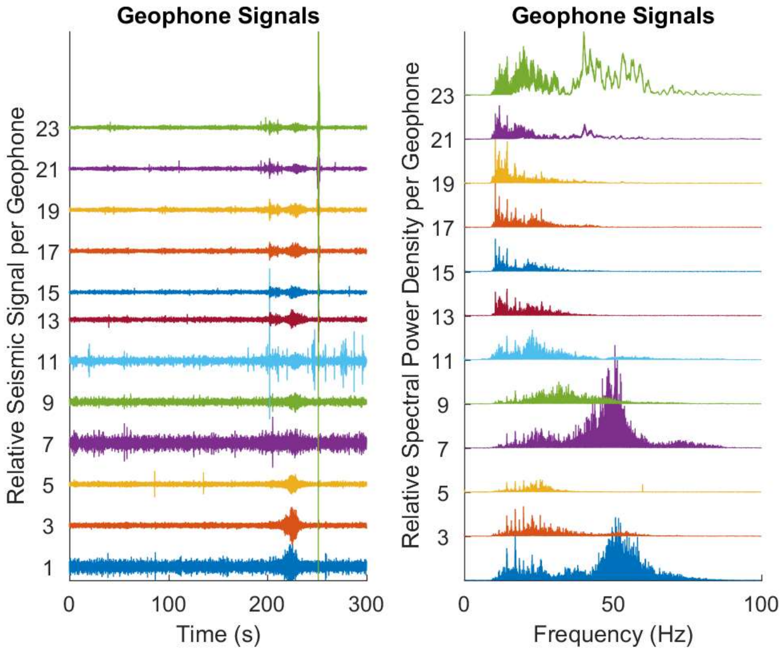
Site: Alluvial Stream, Paint Branch at Cherry Hill Road

Distance (m)	Geophone#	Froude # (2/10 Depth)	Froude # (8/10 Depth)	Reynolds # (2/10 Depth)	Reynolds # (8/10 Depth)	Local Relative Roughness (2/10 depth)	Local Relative Roughnes s (8/10 depth)
0	3	0.80	0.50	20000	100000	0.55	2.2
5	4	0.79	0.43	27000	120000	0.69	2.8
10	5	0.79	0.54	23000	120000	0.61	2.4
15	6	0.65	0.36	19000	82000	0.61	2.4
20	7	0.53	0.45	13000	89000	0.55	2.2
25	8	0.88	0.61	22000	120000	0.54	2.2
30	9	1.46	0.82	24000	110000	0.41	1.6
35	10	0.74	0.74	23000	180000	0.62	2.5
40	11	0.95	0.89	11000	82000	0.34	1.4
45	12	0.49	0.32	10000	55000	0.52	2.1
50	13	0.56	0.31	52000	230000	1.4	5.5
55	14	0.57	0.38	14000	75000	0.57	2.3
60	15	0.23	0.26	6300	55000	0.60	2.4
65	16	0.58	0.53	15000	110000	0.60	2.4
70	17	0.30	0.24	22000	130000	1.2	4.6
75	18	0.19	0.16	9600	66000	0.92	3.7
80	19	0.20	0.10	17000	63000	1.2	4.9
85	20	0.05	0.05	4500	32000	1.3	5.0
90	21	0.09	0.06	6500	33000	1.1	4.5
95	22	0.06	0.05	5500	37000	1.3	5.1
100	23	0.10	0.06	7500	33000	1.2	4.7
105	24	0.08	0.06	6100	39000	1.2	4.9

Table IIIb This table features the dimensionless turbulence-related values which have been calculated from the hydraulic measurements shown in Table IIb. The discharge per basin area during the time of measurement was 0.20 cfs/mi^2.

Site: Bedrock Influenced Stream, Northwest Branch South of Burnt Mills

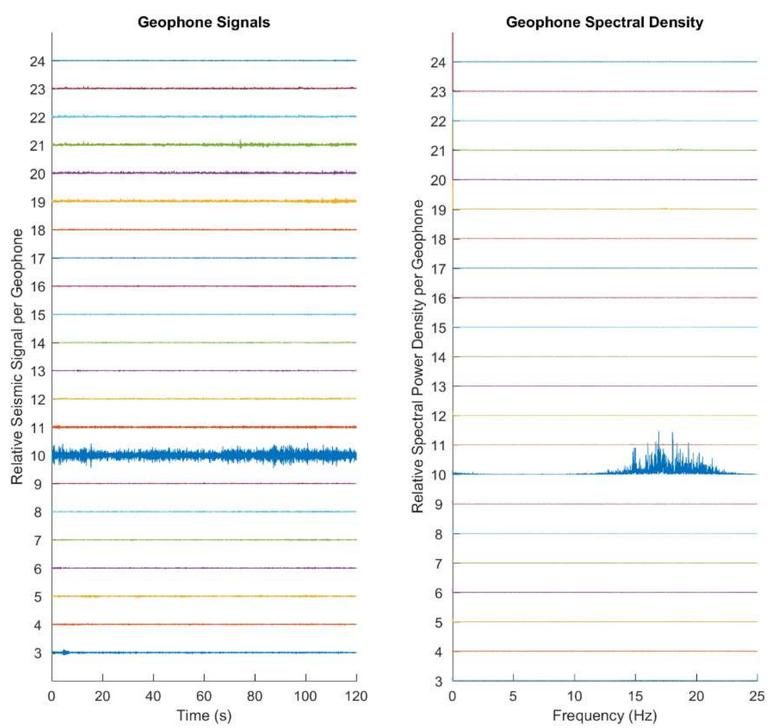
Seismic Study Data and Hydraulic Correlations



Graph Ia
This graph shows the raw seismic signal (left) and the spectral power density (right) of the alluvial stream seismic survey.

Site: Alluvial Stream, Paint Branch at Cherry Hill Road

Date: May 01, 2016



Graph Ib
This graph shows the raw seismic signal (left) and the spectral power density (right) of the bedrock-influenced stream seismic survey.

Site: Bedrock Influenced Stream, Northwest Branch South of Burnt Mills

Date: November 03, 2016

Comparing Graphs Ia and Ib shows the difference in seismic noise and spectral power between the alluvial stream and the bedrock-influenced stream. When comparing the two, both the raw seismic signal and the spectral density are lesser in Graph Ib than Graph Ia. Additionally, in Graph Ia, there are sharp increases in the spectral density at 50 Hz in geophones 1 and 7. Graph Ib shows an increase in the spectral density in the 15-20 Hz band at geophone 10. Geophone 10 in the Northwest Branch was located at a point where a tree had fallen into the stream.

Geophone #	Integrated Power	Mean Frequency (Hz)
3	9.5	16
4	4.4	15
5	5.1	16
6	3.8	15
7	3.3	15
8	4.2	15
9	2.7	13
10	330	17
11	14	17
12	5.6	13
13	2.7	14
14	2.4	13
15	4.3	15
16	2.8	15
17	2.2	12
18	5.5	11
19	35	8.4
20	27	4.8
21	32	6.8
22	17	7.3
23	15	4.9
24	3.5	15

Table IVb
This table shows the integrated spectral power and the mean frequency of each geophone from the bedrock-influenced stream survey.

Site: Bedrock Influenced Stream, Northwest Branch South of Burnt Mills

Date: November 03, 2016

Geophone Pair	Integrated Power	Mean Frequency (Hz)
23-24	2.7	17.0
21-22	1.1	17
19-20	1.5	17
17-18	2.0	17
15-16	2.0	17
13-14	2.0	16
11-12	3.1	15
9-10	2.2	15
7-8	2.4	16
5-6	3.0	15
3-4	2.5	14
1-2	3.0	14

Table IVa
This table shows the integrated spectral power and the mean frequency of each geophone from the alluvial stream survey.

Site: Alluvial Stream, Paint Branch at Cherry Hill Road

Date: May 01, 2016

	Value Correlated With					
Site	**Froude # (2/10 Depth)**	**Froude # (8/10 Depth)**	**Reynolds # (2/10 depth)**	**Reynolds # (8/10 depth)**	**Local Relative Roughness (2/10 depth)**	**Local Relative Roughness (8/10 depth)**
Little Paint Branch (Integrated Spectral Power)	0.39	0.33	0.18	0.02	0.34	0.33
Little Paint Branch (Mean Frequency)	0.80	0.70	0.18	0.37	0.56	0.56
NW Branch (Integrated Spectral Power)	0.08	0.26	0.09	0.34	0.06	0.06
NW Branch (Mean Frequency)	0.73	0.73	0.44	0.51	0.74	0.76

Table V This table shows the correlation coefficients between the integrated spectral power and the mean frequency for each dimensionless hydraulic parameter at each site.

Table V shows the calculated correlation coefficients of each parameter at each site. The correlations at Little Paint Branch between the integrated spectral power and the Froude number and local relative roughness are low and are similar between 2/10 and 8/10 depth. The correlations between the Little Paint Branch integrated spectral power and the Reynolds number are lower. The integrated spectral power for the Northwest Branch site has the highest correlation values with the Froude number and Reynolds number at 8/10 depth. At both sites, the correlation coefficients for mean frequency are higher than those of the integrated spectral power. The highest correlation coefficients are between the mean frequency and the Froude number and local relative roughness. The correlation coefficients of the Northwest Branch mean frequency are similar at 2/10 and 8/10 depth. The correlation coefficient of the Little Paint Branch mean frequency and the Froude number is higher at 2/10 depth than that of 8/10 depth.

Discussion of 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.

Suggestions for Future Work

To determine the cause of the differences in correlation coefficients between the alluvial and bedrock-influenced sites additional seismological studies must be completed at each site when the sites have similar discharge conditions. A seismological study should be completed on the Little Paint Branch site during a baseflow condition to align more closely with the discharge conditions of Northwest Branch on November 03, 2016. Additionally, a seismological study of the Northwest Branch at a discharge similar to the discharge of Little Paint Branch during the seismological study on May 01, 2016. These additional studies would aid in the determination if the differences in correlation are due to differences in discharge or the morphology of the channel.

Conclusions and Broader Implications

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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