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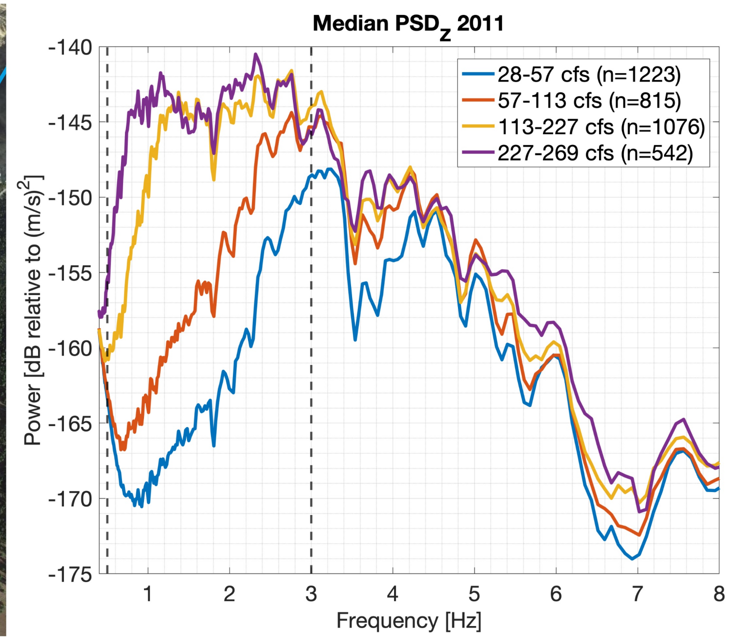
TITLE

Seismic estimation of the waterfall impact force over decadal scale at the Upper and Lower Falls of the Grand Canyon of the Yellowstone River

ABSTRACT

Waterfalls are manifestations of landscape disequilibrium and experience highly focused mechanical work. The Yellowstone River flows over the two closely spaced Upper Falls (33 m) and Lower Falls (93 m) that separate the low-gradient channel supplied by Yellowstone Lake from the steep, rapidly eroding Grand Canyon of the Yellowstone. Annual minimum discharge is typically ~10-15 m^3/s and snowmelt-supplied peak summer discharge can exceed 260 m^3/s. Knowing the erosive force of the water where it impacts the ground at the base of a waterfall would inform evolution of the waterfall itself and the surrounding landscape. Measuring such forces directly is difficult, however, especially for waterfalls that experience large seasonal changes in discharge. Seismic methods provide an opportunity to measure these forces remotely. The 0.4-8 Hz signals recorded since mid-2008 at a continuous borehole seismometer ~1.1 km from both the Upper and Lower Falls are dominated by signals from the waterfalls such that cultural sources, even during peak tourism, have no effect on the signal. Seismic power at this seismometer is most sensitive to discharge in the 0.5-3 Hz band. Polarization analysis suggests that the two waterfalls - which have azimuths within 30 degrees of each other relative to the seismometer - are the dominant sources of seismic energy arrivals. Comparison of seismic data with discharge records shows that ground velocity amplitudes increase approximately linearly with discharge from ~42-212 m^3/s. We estimate the absolute force at the base of the larger Lower Falls by using a Green's function calibrated with data from a vertical source vibroseis survey. In 2019, the force of the Lower Falls ranged from 22 kN at a discharge of 12 m^3/s to 318 kN at 133 m^3/s. This work demonstrates a novel seismological method to remotely quantify forces associated with waterfall systems.


B206
Lower Falls
Upper Falls
0
250
500 m


Median PSD$_Z$ 2011
28-57 cfs (n=1223)
57-113 cfs (n=815)
113-227 cfs (n=1076)
227-269 cfs (n=542)
Power [dB relative to (m/s)^2]
Frequency [Hz]
-140
-145
-150
-155
-160
-165
-170
-175
1
2
3
4
5
6
7
8