Hurricanes in Puerto Rico control boulder transport

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Take Home Message

- Hurricanes play a significant role in boulder transport in Puerto Rico
- Climate change has potential to rapidly change landscape of mountainous rivers.

Motivation

Large sediment play a crucial role in shaping long term river landscape.

Boulders influence the river flow by creating pools, rapids, and waterfalls; create large erosion and abrasion in the channel during entrainment; provide channel stability by lowering flow rate.

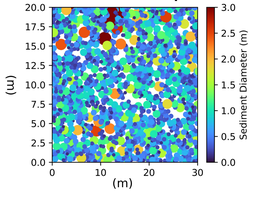
- How frequently do boulders in Puerto Rico move?
- What controls the entrainment rate?

Sediment diameter calculation

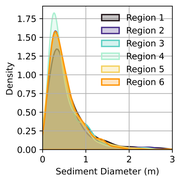
6 regions in Rio Cerrillos, a mountainous river in Puerto Rico

1. Digital Elevation
2. Rectangle Fitting
3. Sediment Diameter

4. Sediment Diameter Map



5. Sediment Diameter Distribution



Sediment Transport Calculation

When basal shear stress of flow exceeds critical shields stress of particle, the particle is considered "in motion"

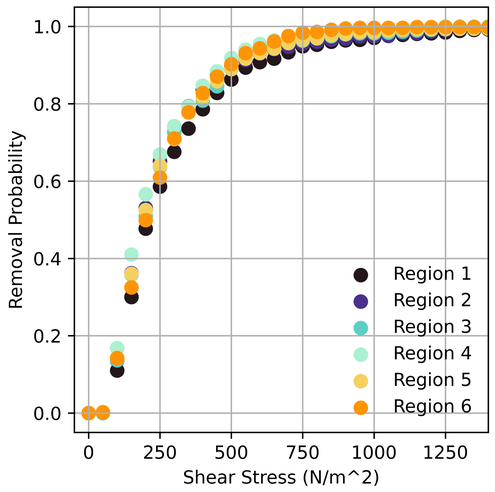
Basal shear stress $(\tau) = \gamma HS$

where γ is specific weight of water, H is flow depth, and S is channel slope

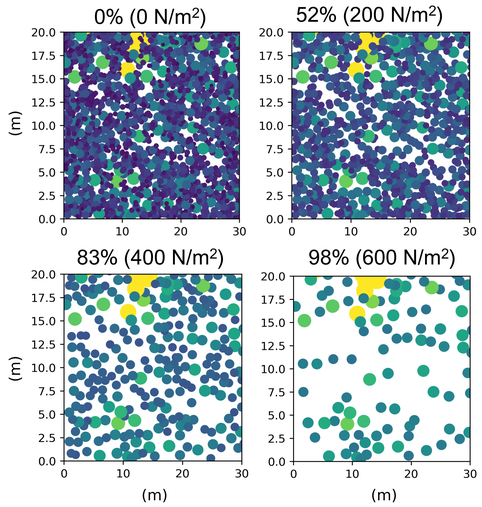
Critical shear stress equation $(\theta_C) = \frac{\tau}{(\rho_s - \rho)gD}$

where θ_C is Shields number (0.06), $\rho_s - \rho$ is the sediment and fluid density difference, g is gravity, and D is diameter.

Sediment transport capability



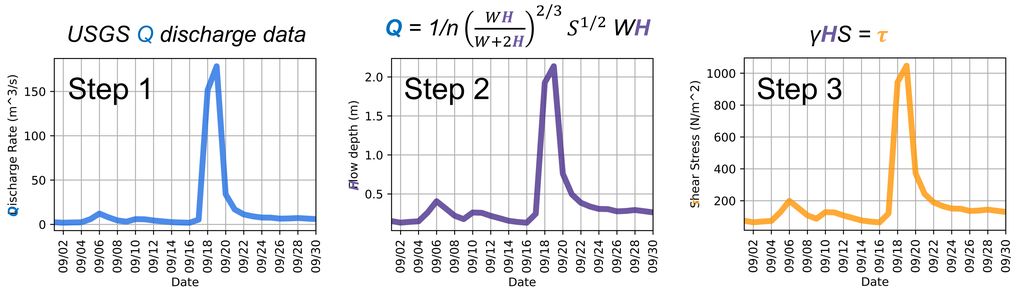
Removal percentage example



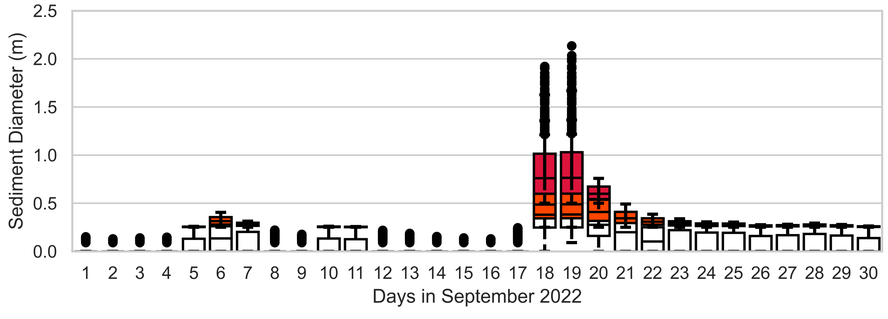
Hurricane Fiona

Fiona landed on September 18th in Puerto Rico. Sediment entrainment is calculated with the daily discharge rate expressed as riverbed shear stress using the Manning's equation and shear stress equation.

USGS Q discharge data | $Q = 1/n \left(\frac{WH}{W+2H}\right)^{2/3} S^{1/2} WH$ | $\gamma HS = \tau$



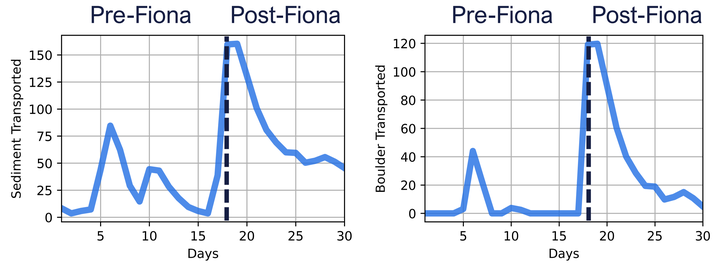
The violin plot shows the distribution of sediment diameter capable of entrainment in September 2022. During non-hurricane periods, boulder entrainment is improbable.



$\tau = \theta_C(\rho_s - \rho)gD$ (Minimum shear stress required for sediment transport)
$\gamma HS < \theta_C(\rho_s - \rho)gD$, sediment transport does not occur.
$\gamma HS \geq \theta_C(\rho_s - \rho)gD$, sediment transport occur.

Daily sediments transported

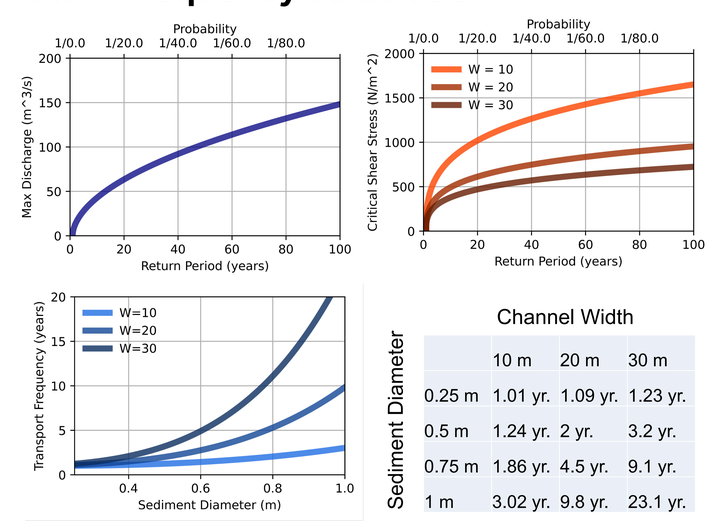
Daily number of sediment transported is measured. Boulders are sediments greater than 0.25 m.



pre-Fiona sediment transported: 297, 54 boulders
post-Fiona sediment transported: 872, 419 boulders

- Sediment transport increased by **1~2 times**.
- Boulder transport increased by **6~7 times**.

Return frequency calculation



Channel Width

Sediment Diameter	10 m	20 m	30 m
0.25 m	1.01 yr.	1.09 yr.	1.23 yr.
0.5 m	1.24 yr.	2 yr.	3.2 yr.
0.75 m	1.86 yr.	4.5 yr.	9.1 yr.
1 m	3.02 yr.	9.8 yr.	23.1 yr.

Results

- Boulder entrainment rate is around 1 magnitude greater during Fiona.
- Boulder entrainment in Puerto Rico is controlled by discharge cause by hurricanes.
- Transport frequency is 1~20 years depending on the sediment diameter and channel width.
- As hurricane frequency increases, we expect large particles to become increasingly mobile.

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