EGU General Assembly 2021

Development of Model for Acoustic Noise Generated from Bedload in Rivers

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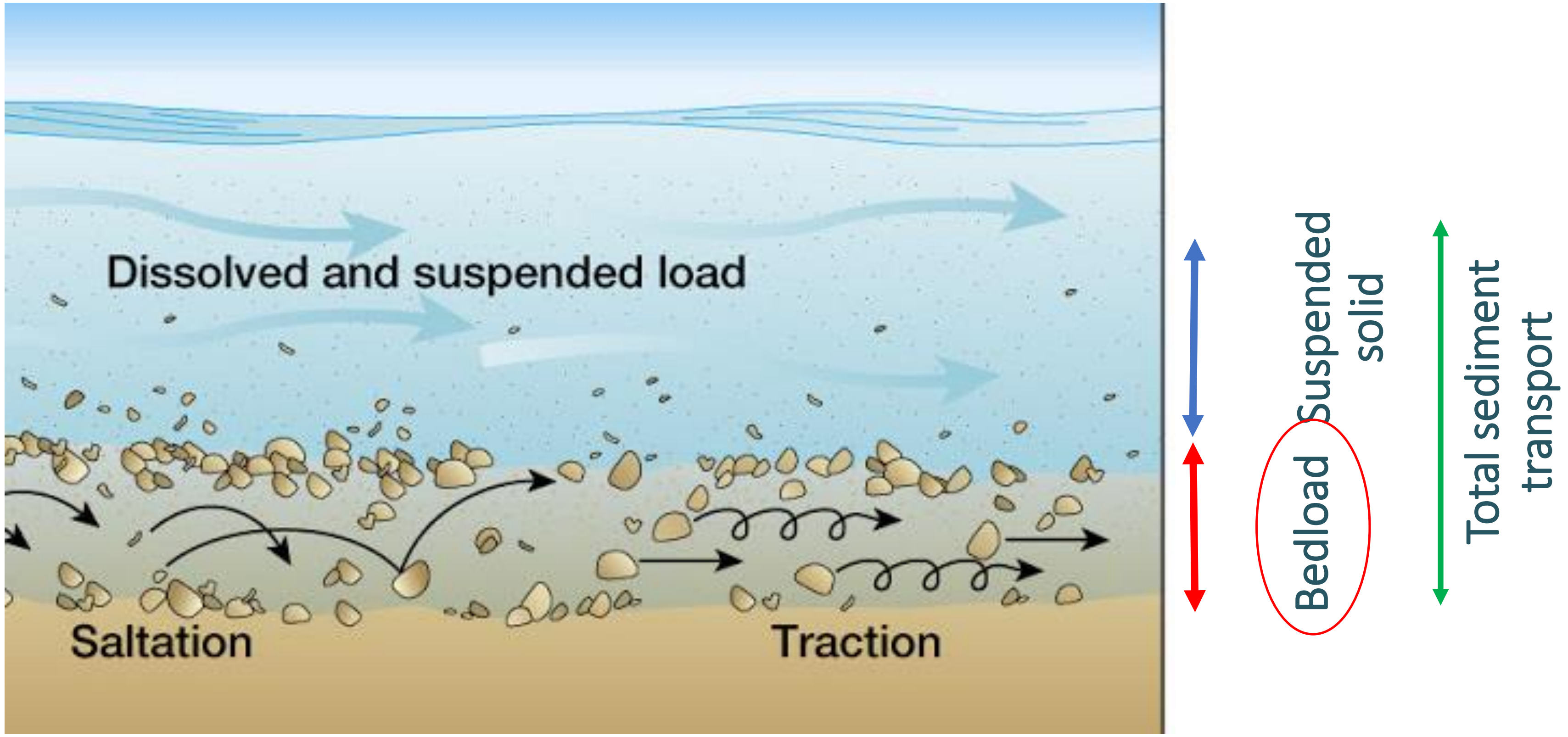
Outline

I. Introduction

Sediment transport in rivers

- In rivers, sediments are transported by flow with different modes (saltation, rolling, suspension…)

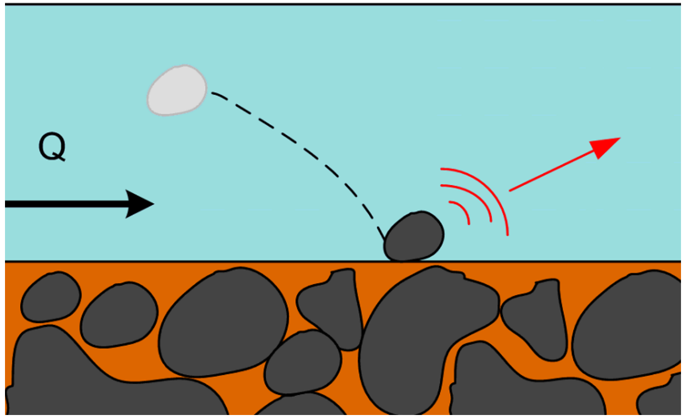


http://www.geologyin.com/2016/01/how-do-streams-transport-and-deposit.html

Bedload self generated noise (SGN)

- Sediments moving along the bottom of the watercourse generate sounds referred to self generated noise (SGN). (1)

Bedload impacts generate noise (1)

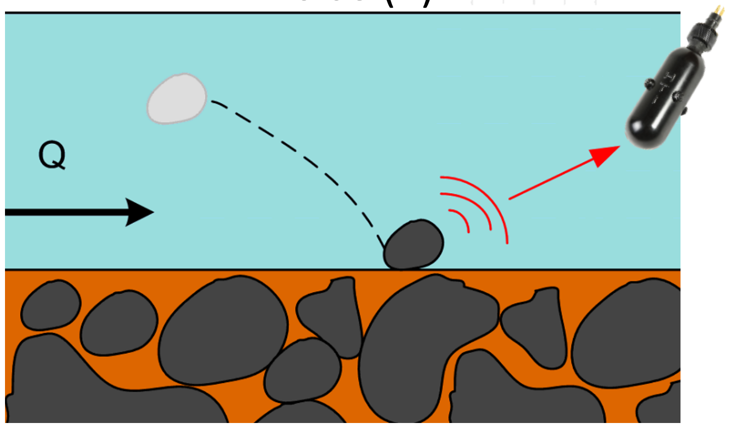


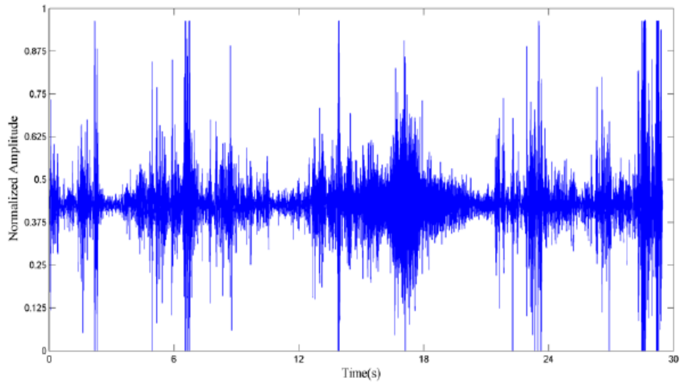
Bedload self generated noise (SGN)

- Sediments moving along the bottom of the watercourse generate sounds referred to self generated noise (SGN). (1)
- Hydrophone sensor can detect the SGN in water. (2)

Bedload impacts generate noise (1)

Recording Acoustics (2)





Bedload self generated noise (SGN)

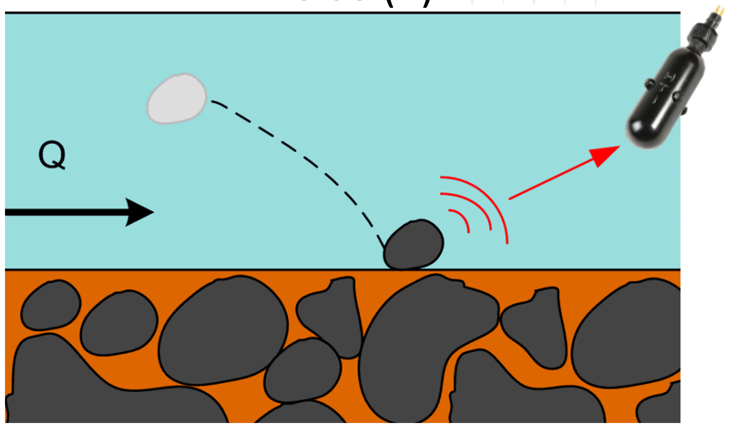
- Sediments moving along the bottom of the watercourse generate sounds referred to self generated noise (SGN). (1)
- Hydrophone sensor can detect the SGN in water. (2)
- Acoustic signal can be analyzed to estimate bedload flux and grain sized distribution. (3)

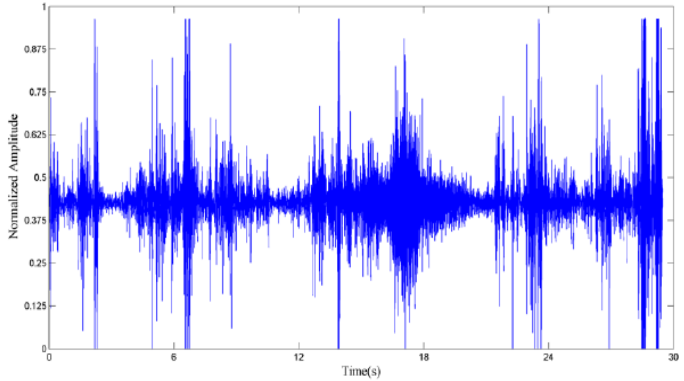
Fourier Transform (FT)

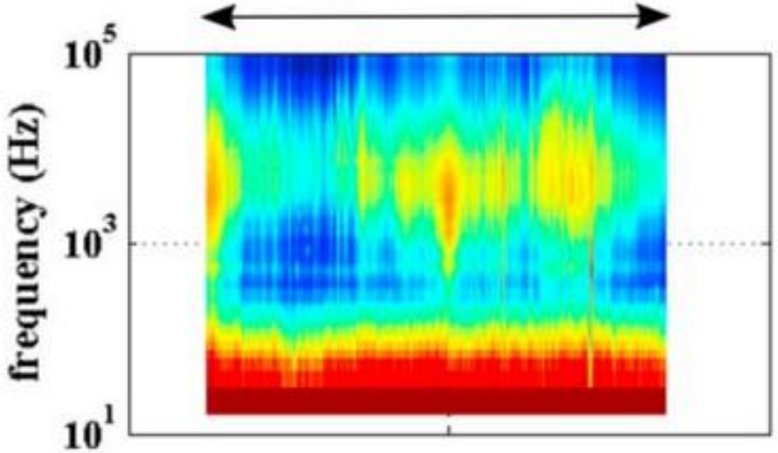
Bedload impacts generate noise (1)

Recording Acoustics (2)

Signal Analysis (3)







Measurement by hydrophone

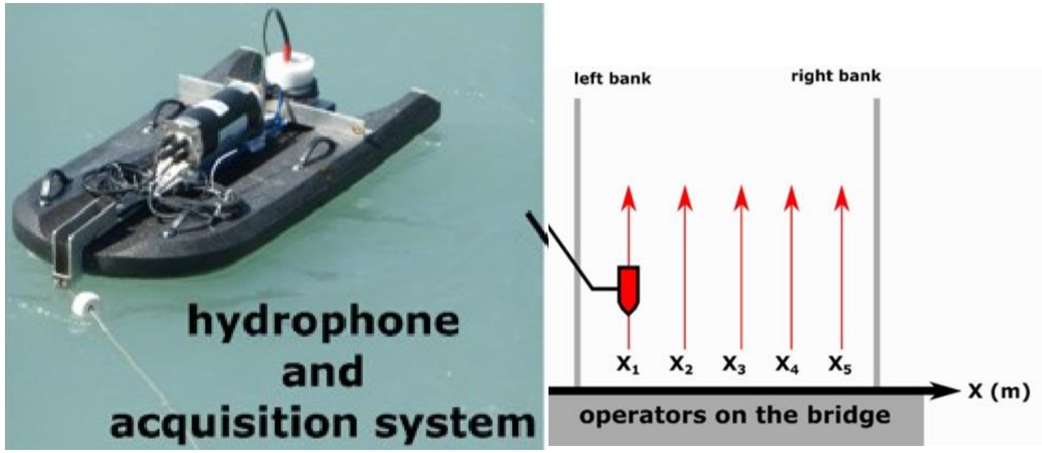
- **Fixed hydrophone** **measurement**
  a) **Continues hydrophone measurement for time monitoring of PSD and acoustic power evolution**

a

Severaisse River

- **Drifted hydrophone** **measurements**
  b) **The measurements processing gives the cartography of acoustic power in the river.**

b

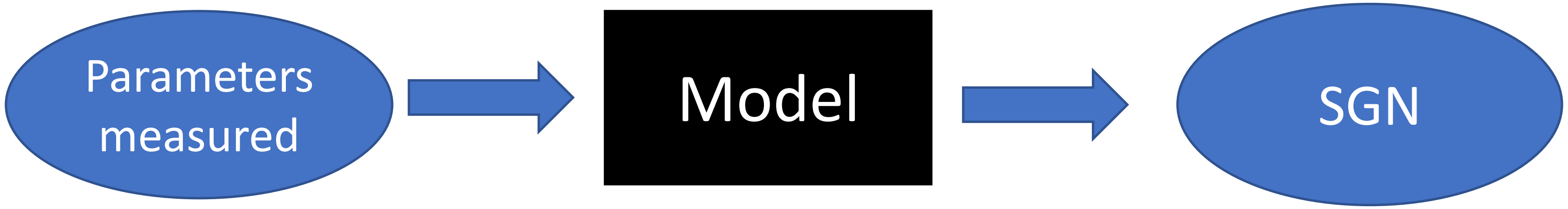


Geay et al., 2020

II. Model Framework

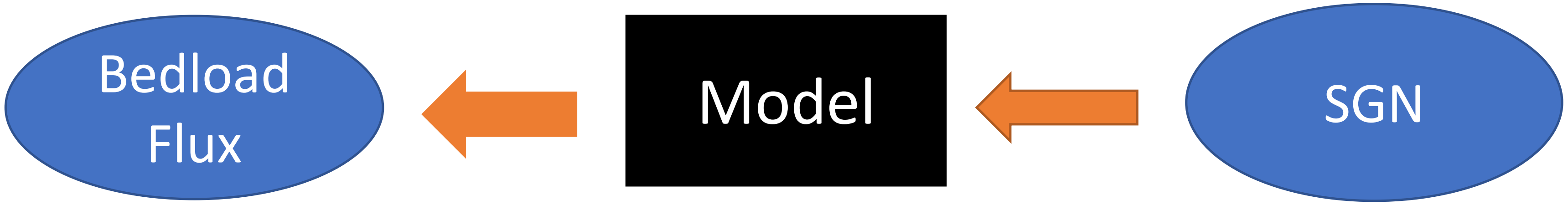
Model objectives

1. **To predict SGN from measured parameters.**

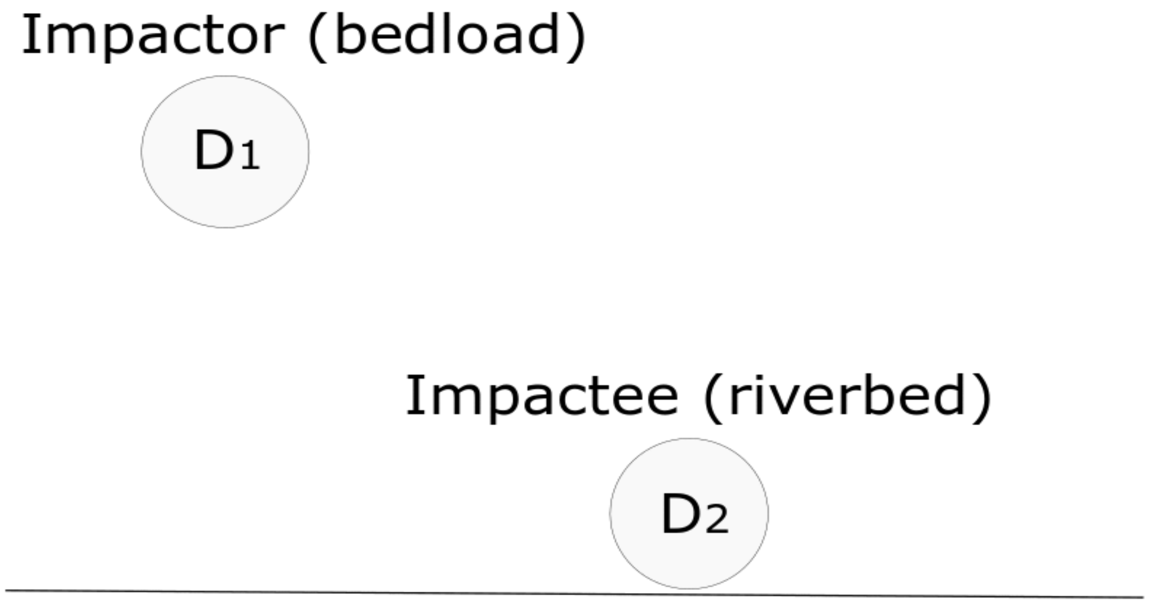


2. **Understand which parameters influence SGN measurements.**

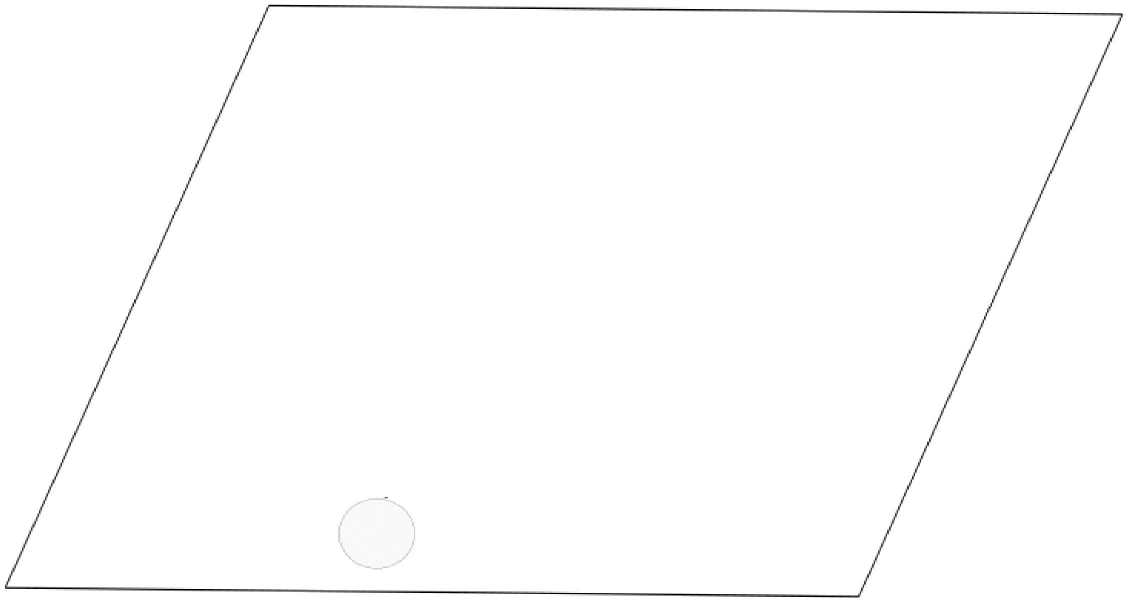
3. **Inversion of bedload flux from measured SGN.**



Model framework - Single impact

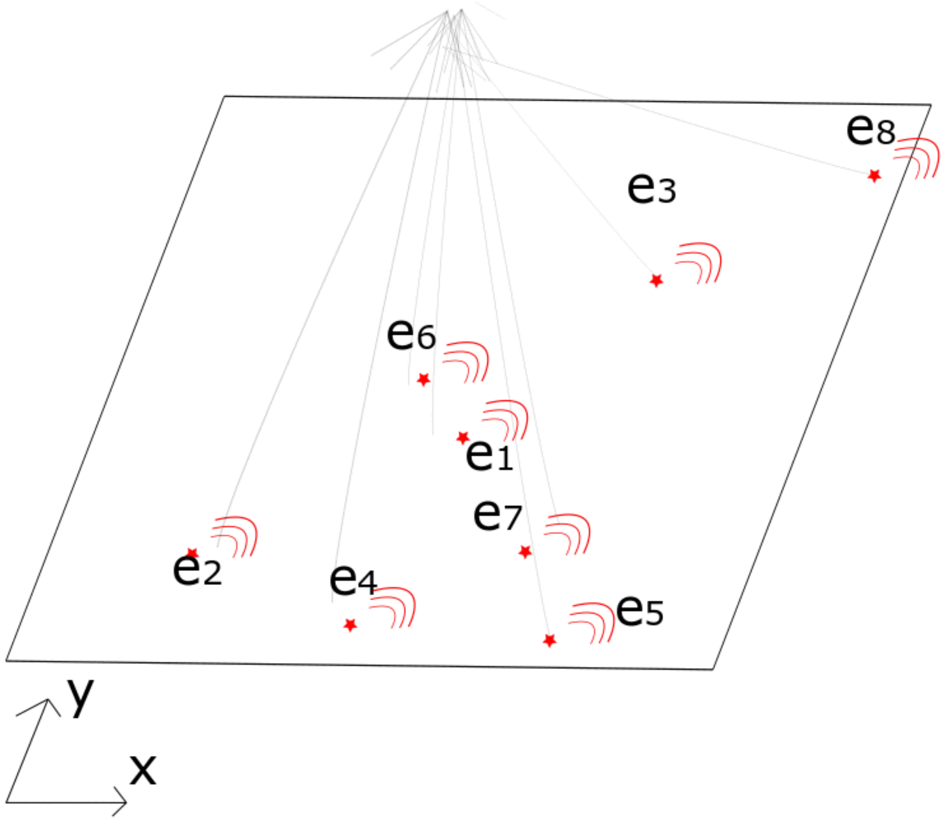


Model framework - Multiple impact



Model framework - Total noise

$$P^{xy}_{@1m} = \sum_{i}^{n} e_i \quad (Pa^2/Hz)$$



Model elements

- Single impact acoustic signal model (*Thorne model (1988))*

- Bedload particles kinematics:

    1. impact velocity (multiple formulas exist)
    2. Impact rate (multiple formulas exist)

High variability

- Propagation model (*Geay et al., (2019)*)

For more details check Appendix

III. Model Application on Field Measurements

Application on field data

- 8 different rivers, 12 experiment (Geay et al. (2020) ,Geay et al. (2020))

- Measured parameters :
  1. Beldoad flux over cross section $\bar{q}_{s,x}$
  2. Bedload GSD
  3. Water level h
  4. Slope S
  5. Attenuation coefficient α_{λ}.
  6. Cross sectional acoustic power $\mathrm{P_x}$
- Variability in river characteristics

Parameter	Min value	Max value
Slope (%)	0,05	2,5
h (m)	0,49	2,8
D_{50} (mm)	0,9	41
W (m)	8	60
$\bar{q}_{s,x}$ (g/s/m)	14	328
α_{λ} (nepers)	10^{-3}	2.10^{-1}

Application on field data

- Modeled parameters:

1. PSD for each hydrophone position p_x.
2. Power for each hydrophone position P_x.

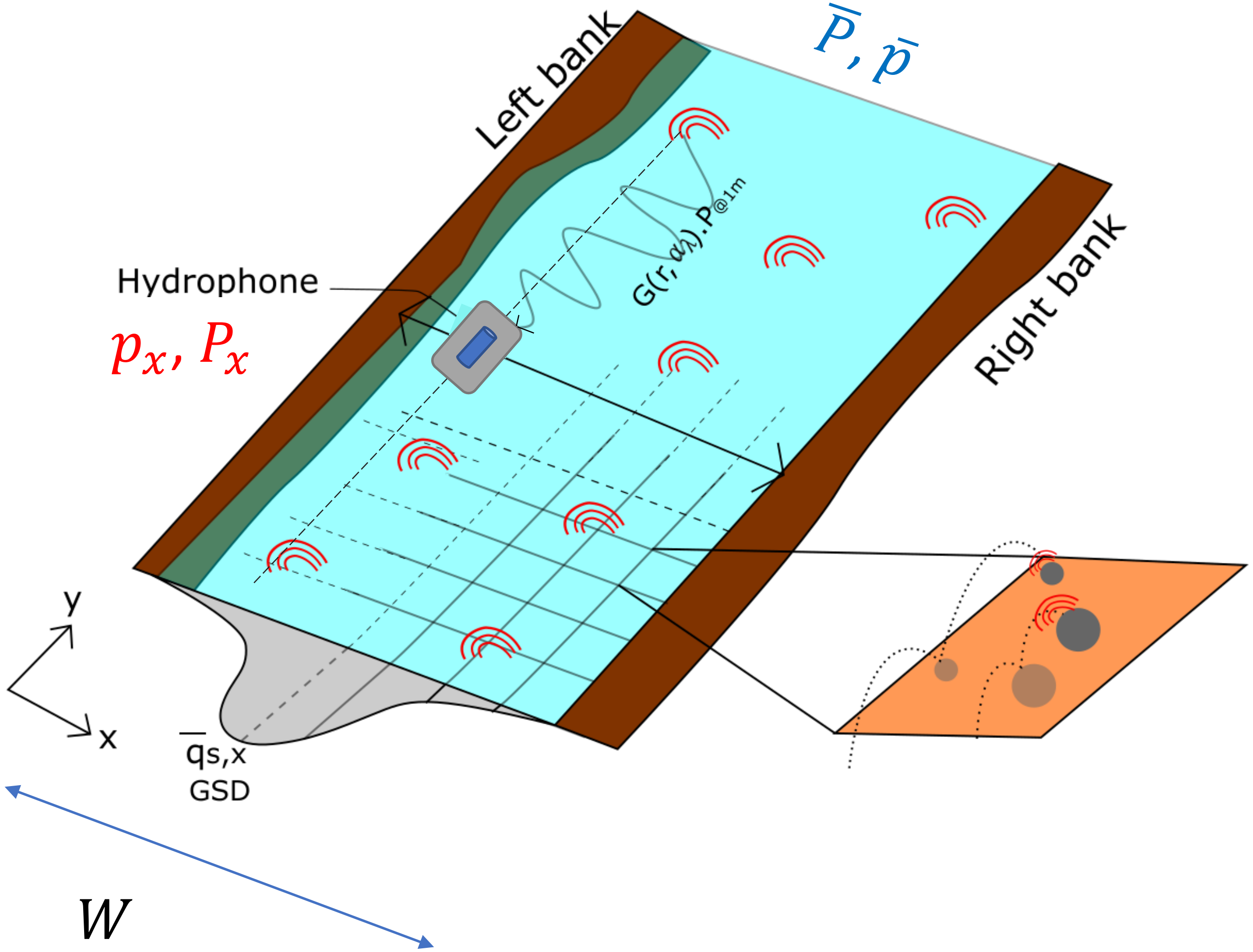
$$P_x = \int_{f_{min}}^{f_{max}} p_x(f)df,$$

3. Average cross sectional power.

$$\overline{P} = \frac{1}{W}\int P_x dx,$$

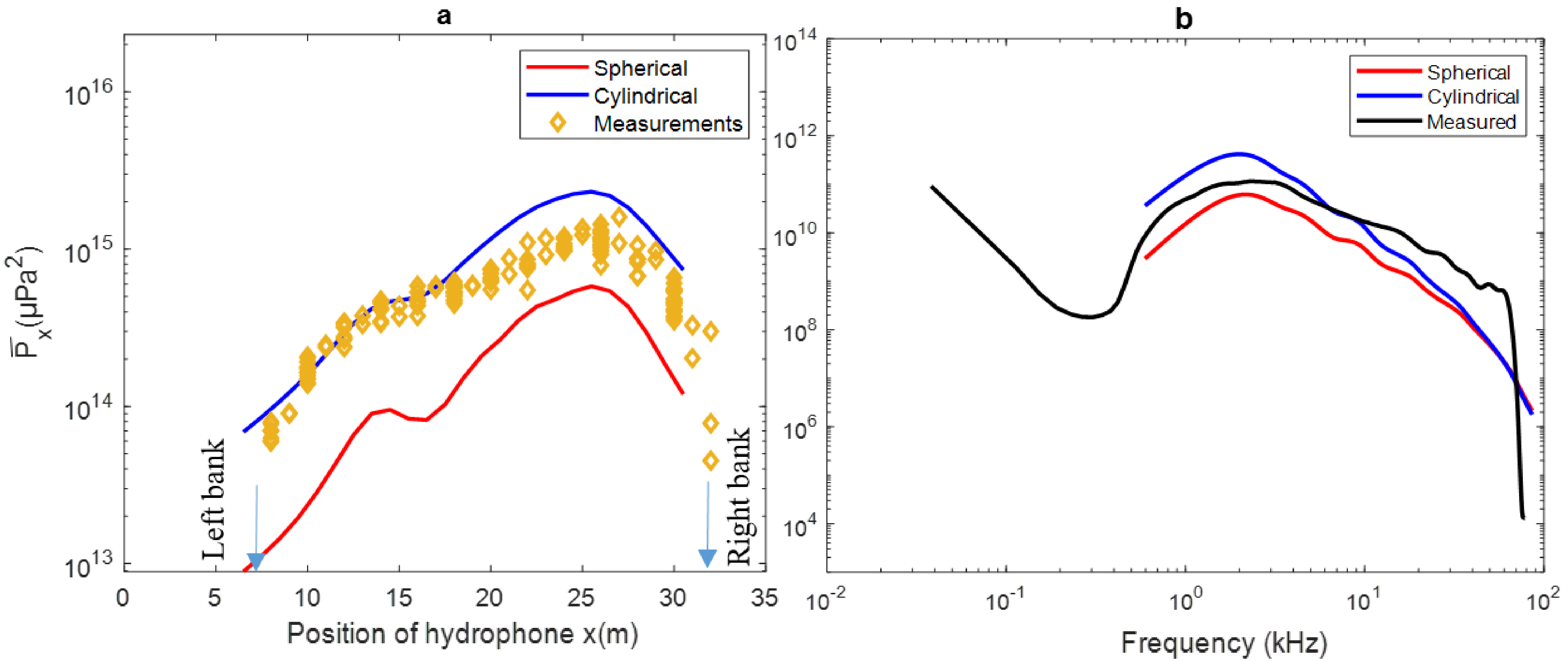
4. Average cross sectional PSD.

$$\bar{p} = \frac{1}{W}\int p_x dx,$$



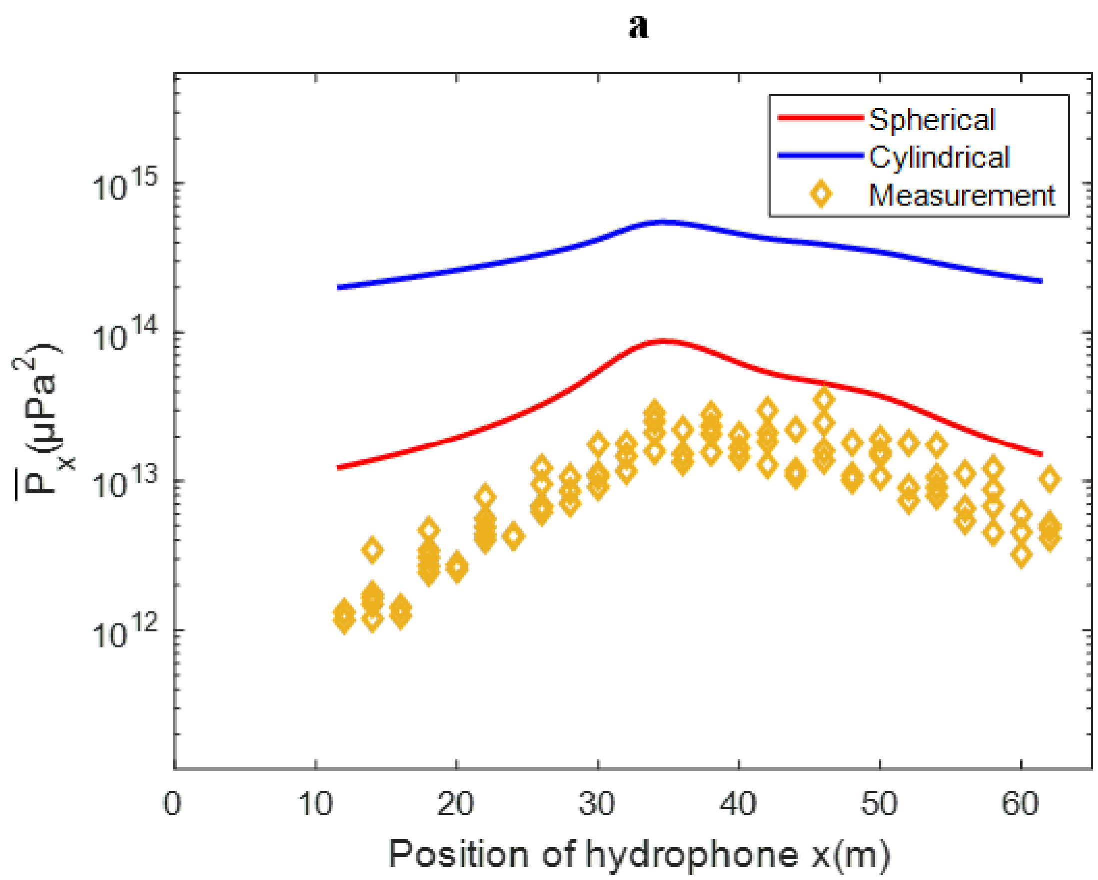
Results

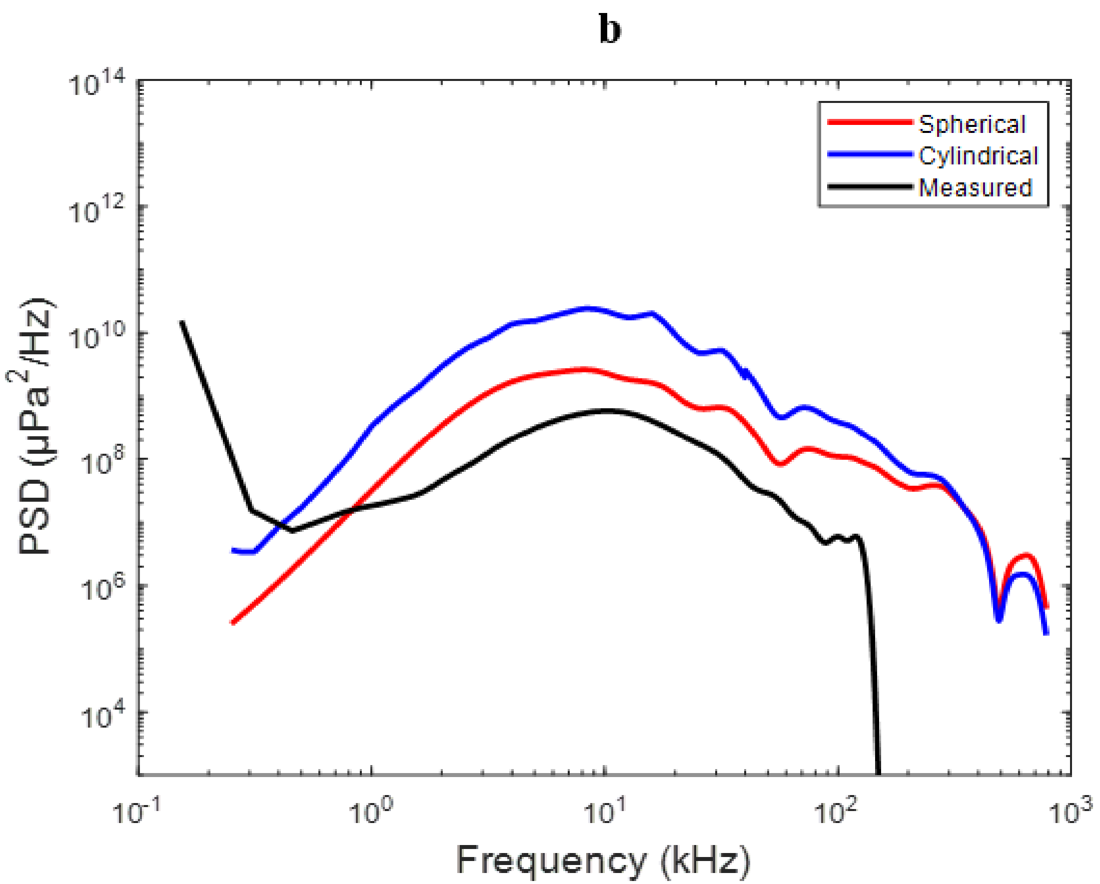
Giffre River



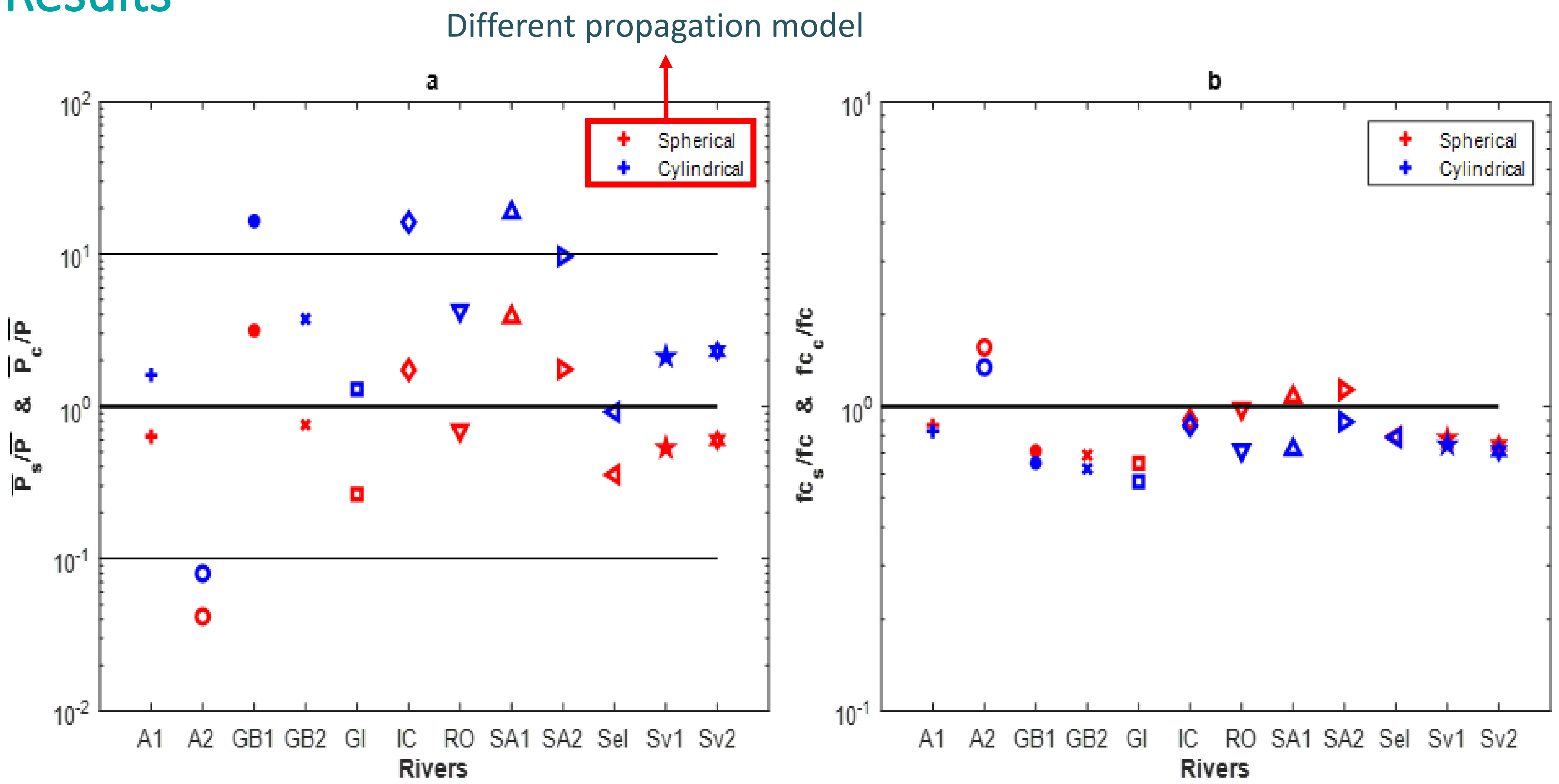
Results

Isere River





Results

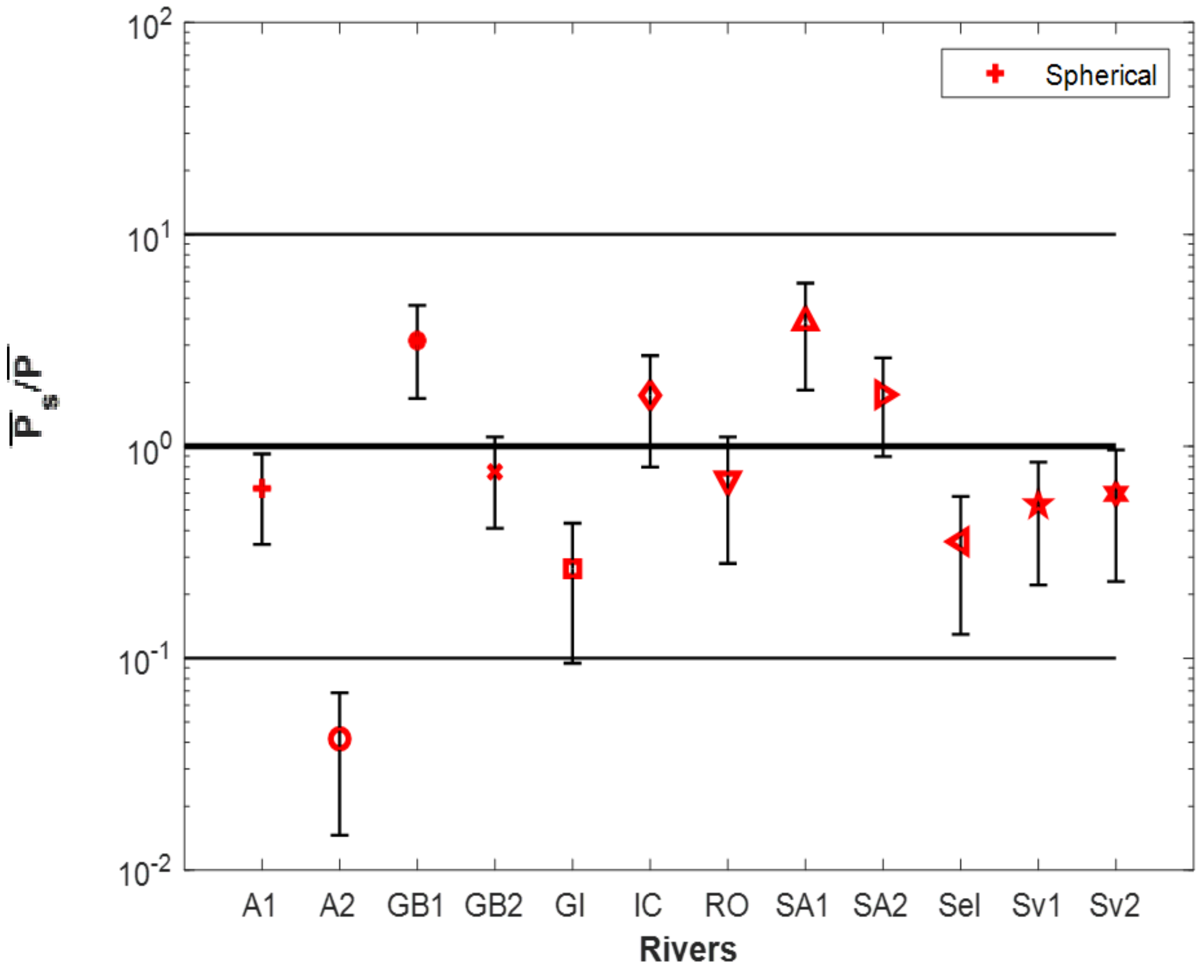

Different propagation model
a
Spherical
Cylindrical
10^2
10^1
10^0
10^{-1}
10^{-2}
$\overline{P}_s/\overline{P}$ & $\overline{P}_c/\overline{P}$
A1 A2 GB1 GB2 GI IC RO SA1 SA2 Sel Sv1 Sv2
Rivers
b
Spherical
Cylindrical
10^1
10^0
10^{-1}
fc_s/fc & fc_c/fc
A1 A2 GB1 GB2 GI IC RO SA1 SA2 Sel Sv1 Sv2
Rivers

Results

- Different prediction accuracy for different rivers.
- Variation from measurements more that one order of magnitude.
- Significantly variable results due to different propagation model.
- Globally, spherical model better estimate SGN.

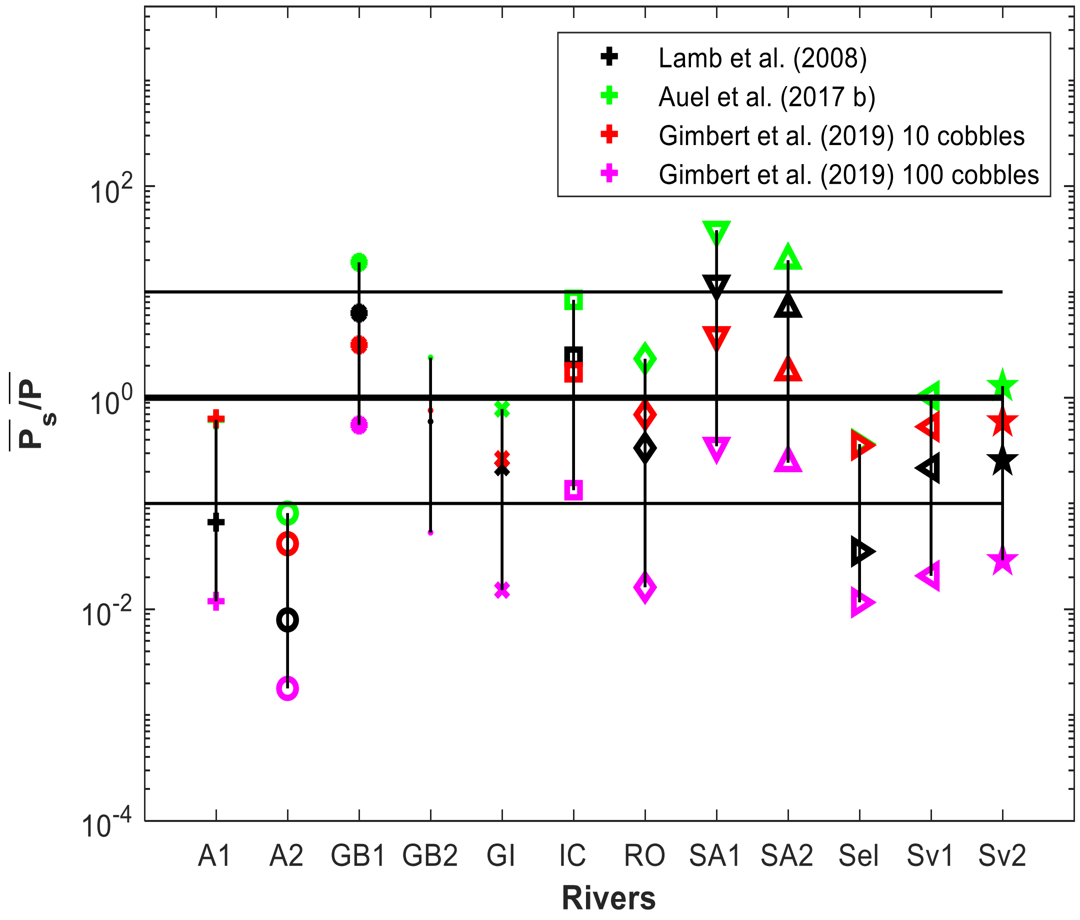
Effect of measurements uncertainty

- Effect of bedload flux and acoustic measurements.



Other uncertainty exists (e.g., propagation parameter, geometry, GSD…)

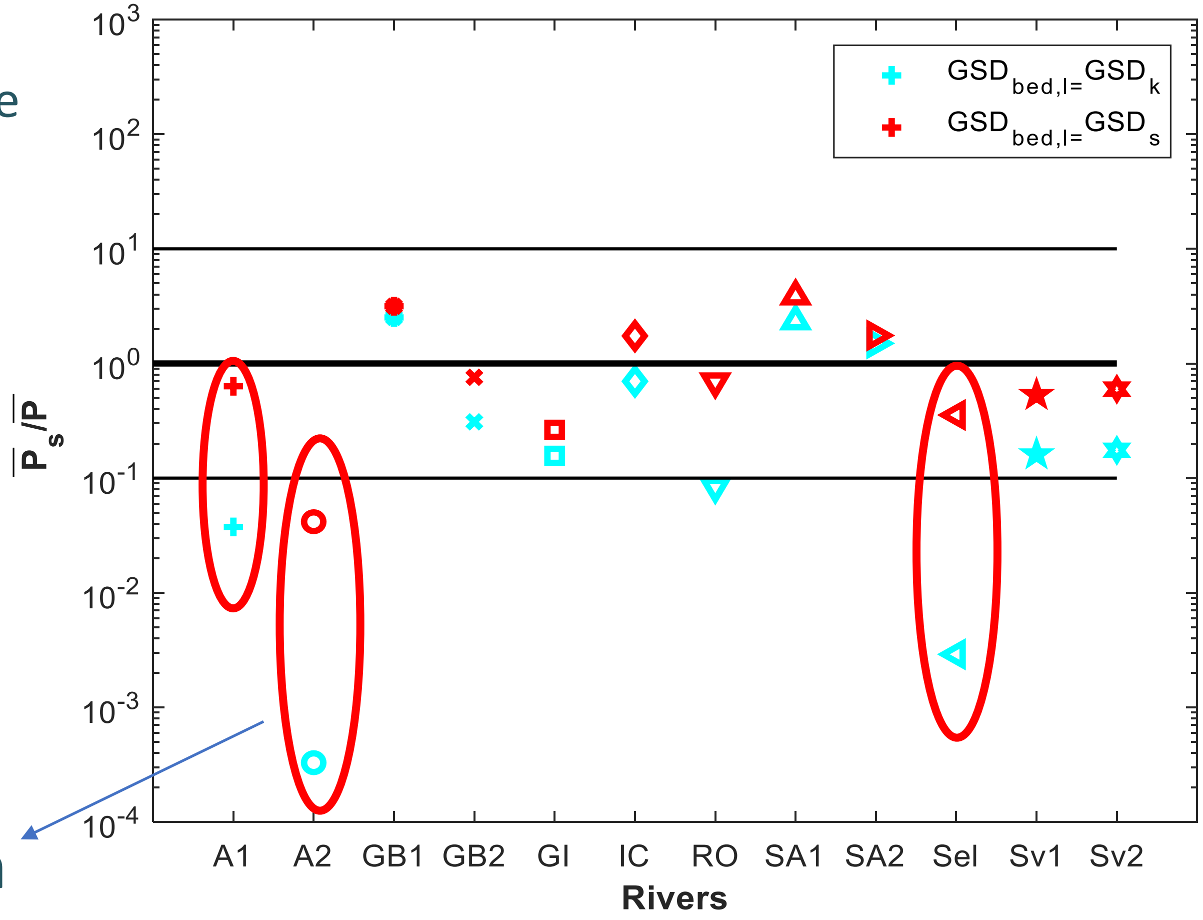
Effect of impact velocity (Uc) and impact rate (n) model



Nature of impacted particles

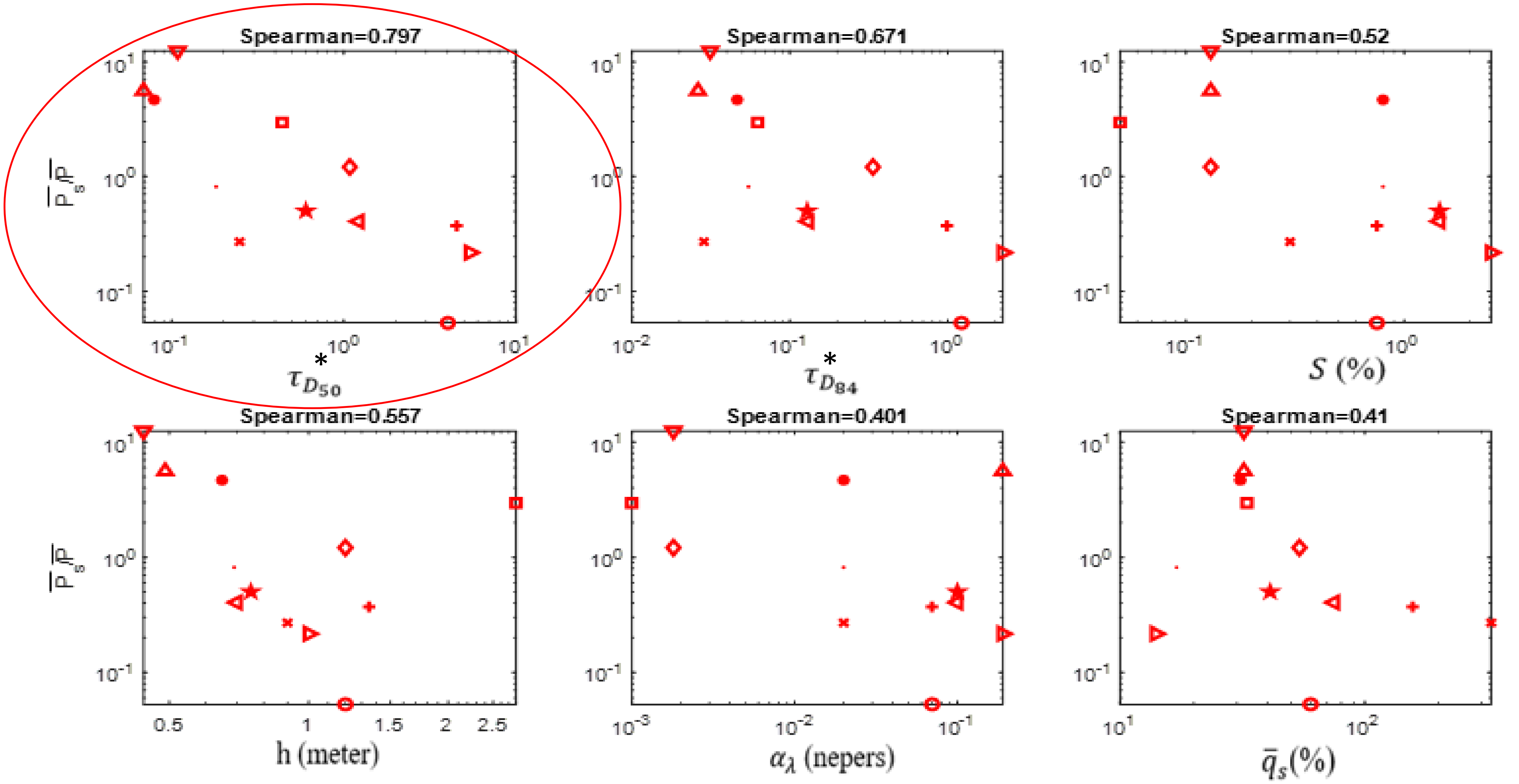
GSDimpactee=GSDbedload & Free to move

GSDimpactee=GSDriverbed & Fixed to bed



- River with improtant sand fraction

Model error analysis.



Conclusion

- We proposed a model for SGN for transported bedload.
- The model accounts for multiple impacts in river and propagation effects.
- The model prediction accuracy varies between river.
- The model is highly sensitive to multiple hypothesis used specially impact velocity
- The model performance is limited by the knowledge on particle dynamics in river.

Thank You

Appendix

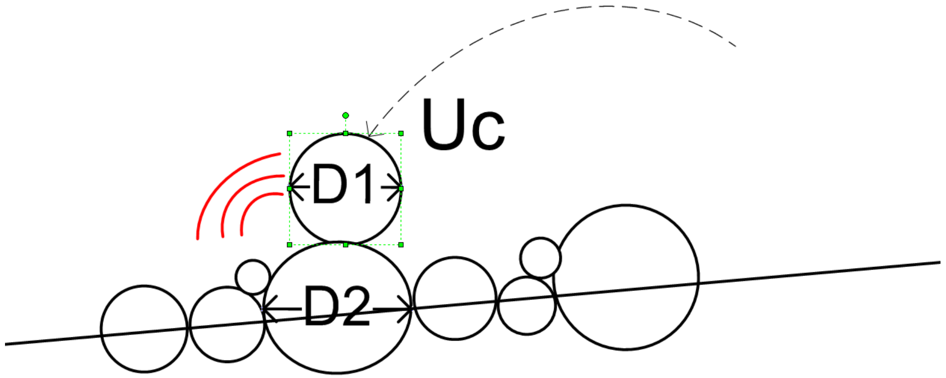
I. Thorne Model
II. Propagation Model
III. Impact Velocity Formulas
IV. Impact Rate

I. Single Impact Model

Thorne (1988)

Single impact model

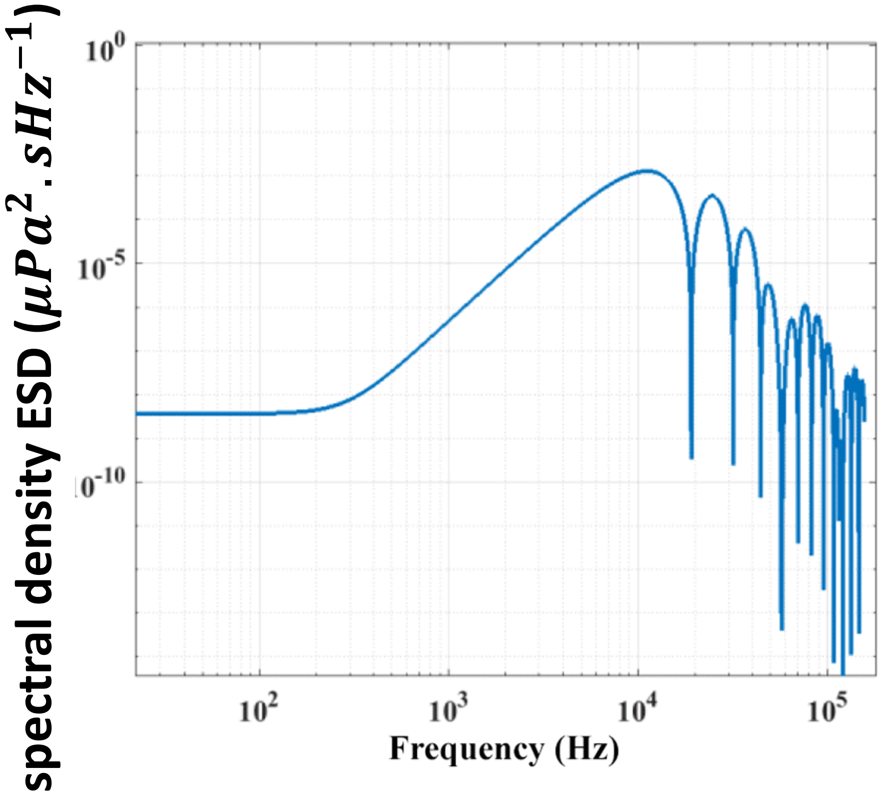
- A moving particle (impactor) impact another (impactee)
- Collision velocity (Uc)
- The collision generate acoustic signal.

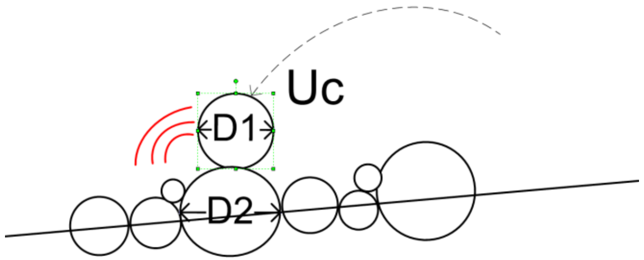


- D1 diameter of impactor
- D2 diameter of impactee

Single impact model

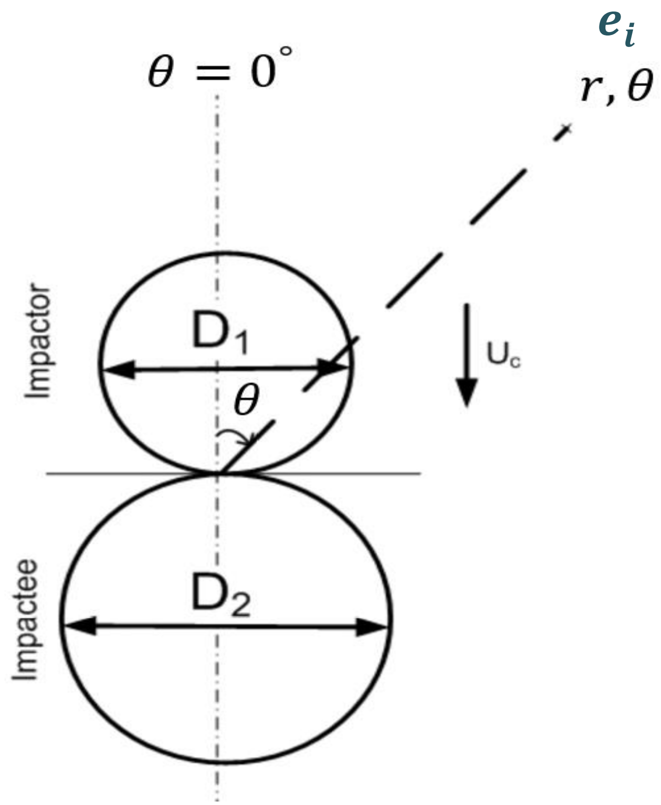
- The signal can defined by the energy and its <u>spectral density ESD $(\mu Pa^2.sHz^{-1})$</u>





Thorne (1988) model

- Assumptions:
    1. Sphere-Sphere Impact
    2. Normal Impact
    3. Elastic collision
    4. r>>$D_1 \& D_2$



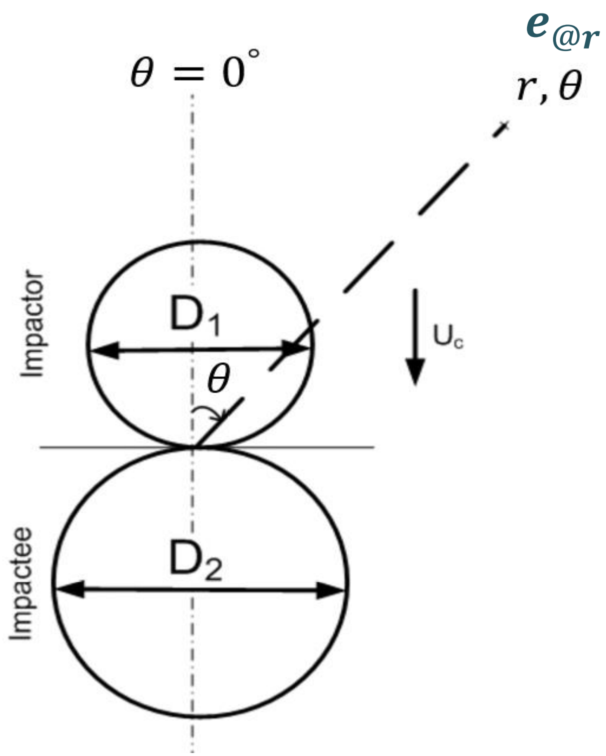
$\boldsymbol{e_i}$=The energy spectrum measured at distance r

Thorne (1988) model

- Signal is calculated using model of Thorne (1988).
- ESD is the energy spectrum density for finite time.

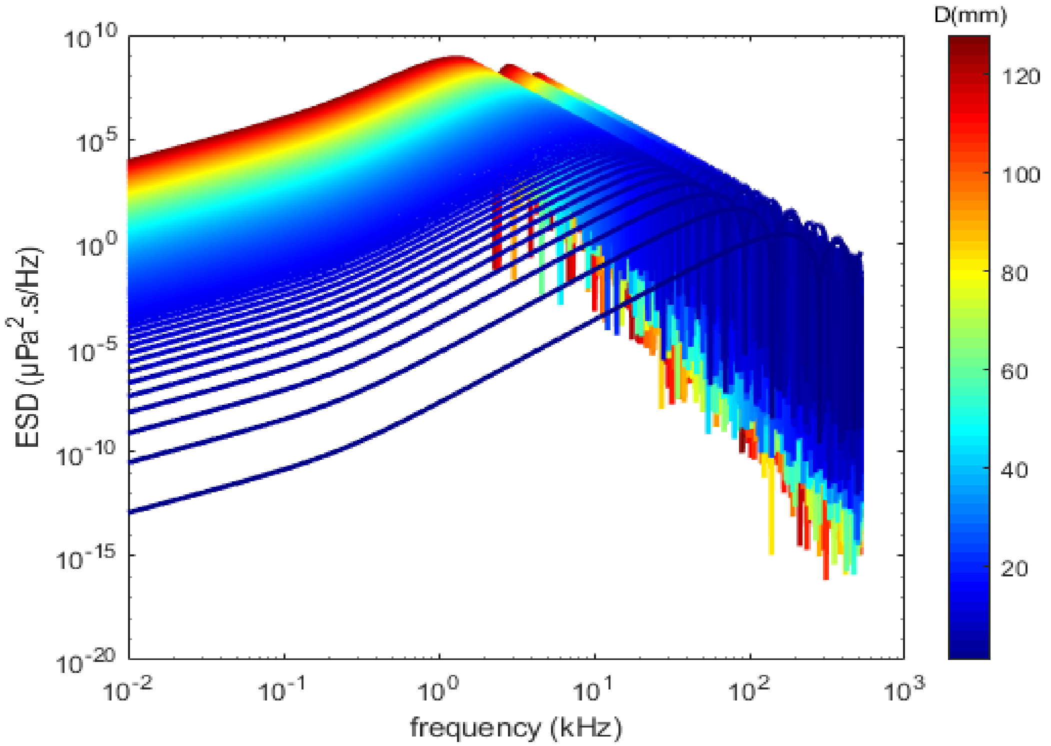
$$e_{@r}\,(D_1, D_2, Uc, r, \rho_s, \rho, E, \vartheta, \theta, cw, f\,)$$

- The generated signal is dependent on:
  1. Particles size (D1,D2)
  2. Impact Velocities (Uc)
  3. Distance r
  4. Particle density (ρ_s) and fluid density (ρ)
  5. Particle modulus of elasticity (E) and poisons ratio (ϑ)
  6. Angle of observation θ
  7. Celerity of sound in water cw



Thorne (1988) model

- Spectrum amplitude increases with diameter.
- Spectrum frequency band decreases with diameter.

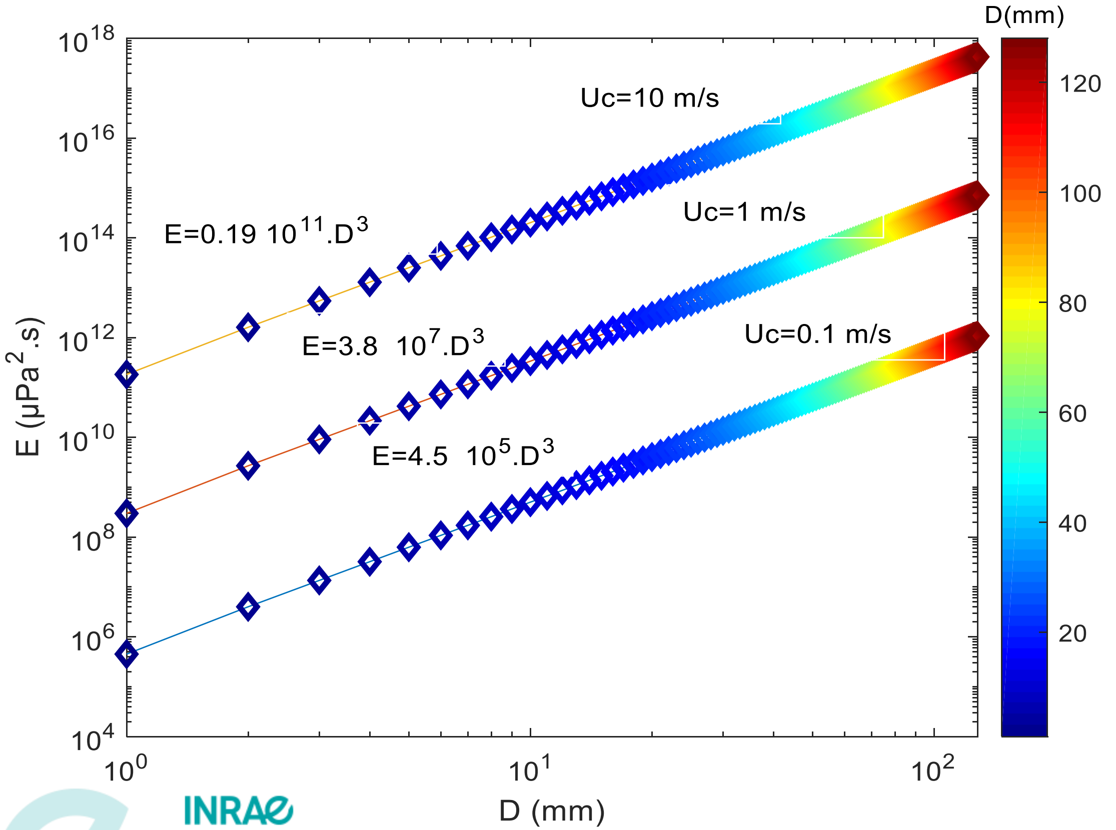


$$U_c = 0.1\ m/s$$

$$D = D_1 = D_2$$

Thorne (1988) model

- Generated energy E$\propto D^3$.
- Generated energy E$\propto Uc^{2.8}$.



$$E = \int_0^\infty e_{@r}\,(f)dDf,$$

$$D = D_1 = D_2$$

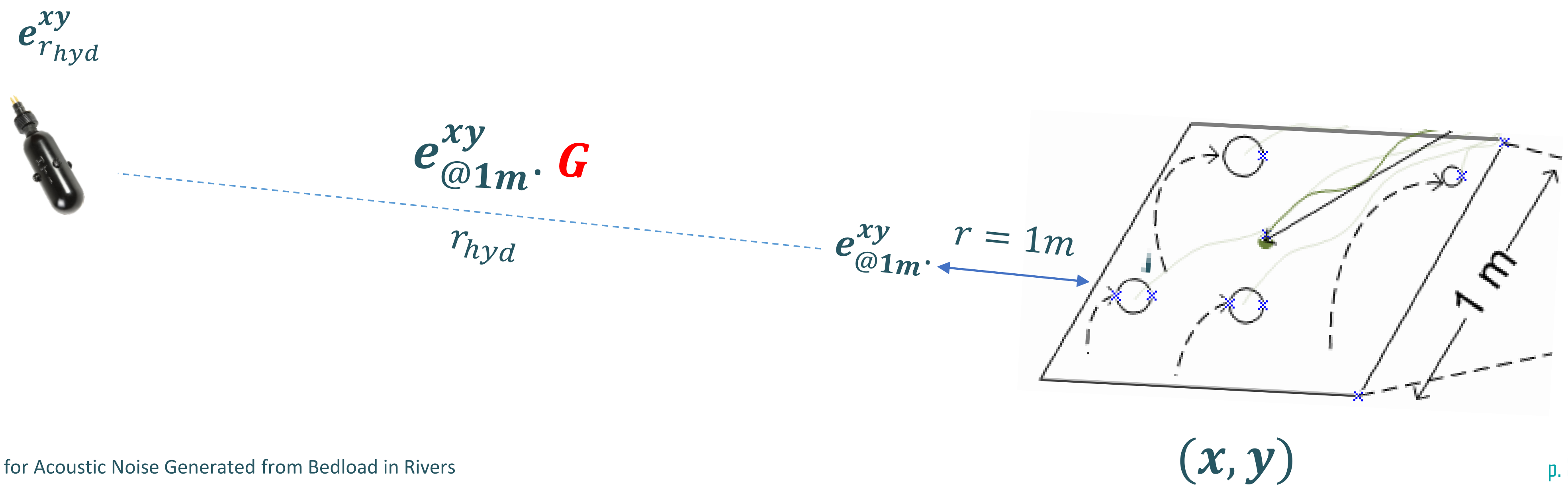
II. Propagation Model

Geay et al., 2019

Propagation Function

- The signal modeled at reference distance @1m is attenuated to the position of hydrophone at distance r_{hyd} using propagation function G

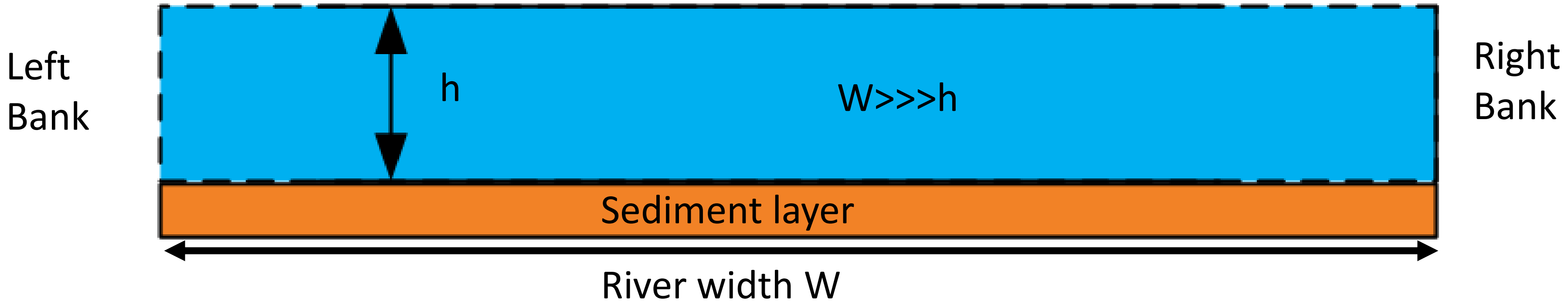
$$e_{r_{hyd}}^{xy} = e_{@1m}^{xy} \cdot G$$



Propagation Function

- Empirical function proposed by Geay et al. (2019) based on field studies .

- Assumptions:
  1. River section rectangular with uniform water depth h
  2. Banks effect are ignored.



Propagation function

- The propagation has two components:

$$G(f,r) = G_1(r).G_2(f,r)$$

Geometrical spreading function G_1

Geometrical function due to absorption an scattering G_2

Spherical

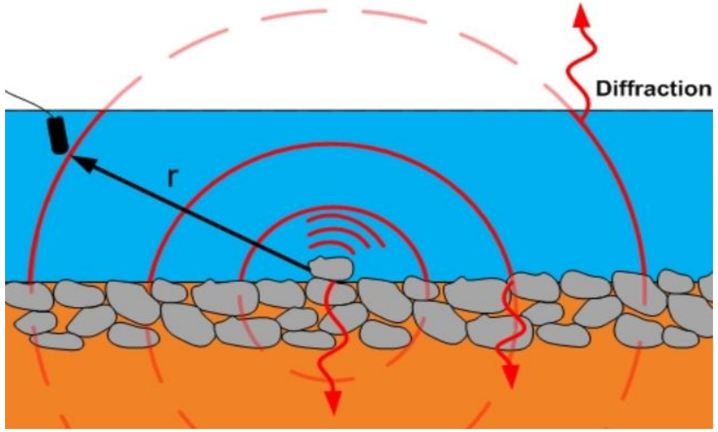
Cylindrical

Propagation function

a. Geometrical spreading function G_1

- Interface are absorber:

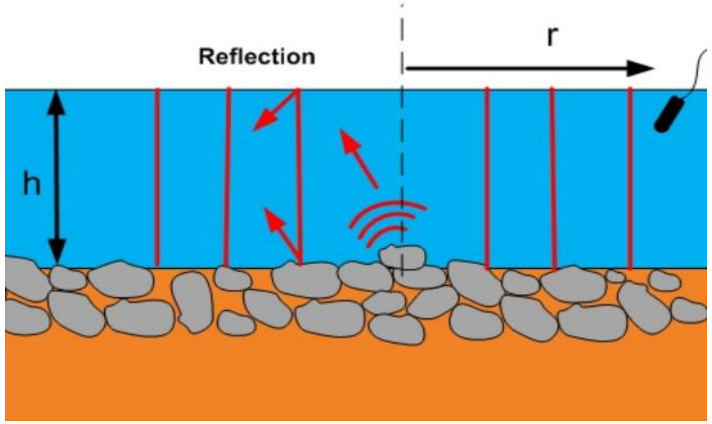
$$G_1(r) = \frac{1}{r^2}$$



Spherical

- Interface are reflector:

$$G_1(r) = \frac{1}{hr}$$



Cylindrical

Propagation function

b. Propagation function due to absorption an scattering G_2

- G_2 is frequency dependent function
- $G_2(f,r) = e^{-2\propto r}$; α = Attenuation coefficient (nepers/m)

$$\alpha = \alpha_\lambda . \frac{f}{c_w}$$

Frequency (Hz)

Celerity of Sound (m/s)

Propagation function

b. Propagation function due to absorption an scattering G_2

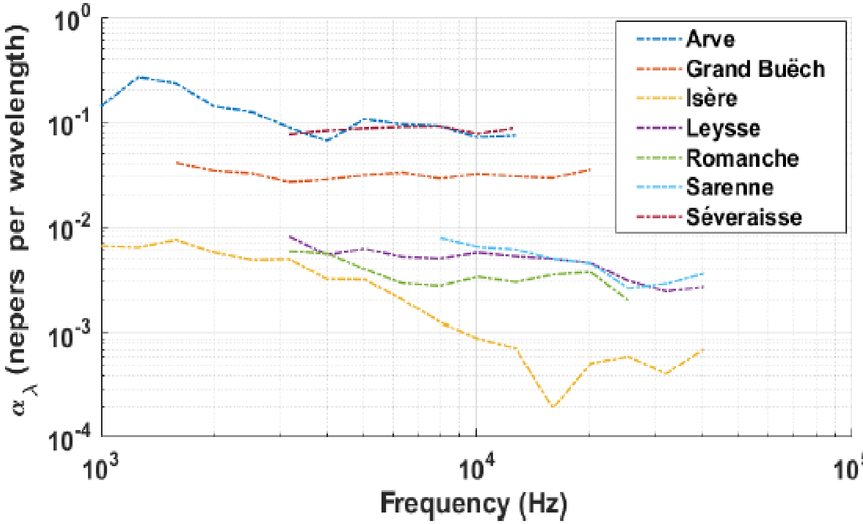
- G_2 is frequency dependent function
- $G_2(f,r) = e^{-2\alpha r}$; α = Attenuation coefficient (nepers/m)

$$\alpha = \alpha_\lambda . \frac{f}{c_w}$$

Frequency (Hz)

Celerity of Sound (m/s)

- α_λ (nepers)
- is determined experimentally (Geay et al. 2019)
- α_λ is constant with frequency for rivers



(Geay et al. 2019)

III. Impact Velocity

Impact Velocity

- Multiple formulas exit based on physical or experimental studies.

- Uc is dependent mainly hydraulic condition and particles diameter.

- Uc is related to transport stage τ_{stage} parameter

- Transport stage τ_{stage} is calculated as function of water level, riverbed slope and particle size.

Impact Velocity

- Multiple formulas exit based on physical or experimental studies.
- Uc is dependent mainly hydraulic condition and particles diameter.
- Uc is related to excess transport stage τ^*_{stage} parameter.
- The excess transport stage τ^*_{stage} is calculated as function of water level, riverbed slope and particle size.

Impact Velocity Formulas

- Multiple formulas exit based on physical or experimental studies.

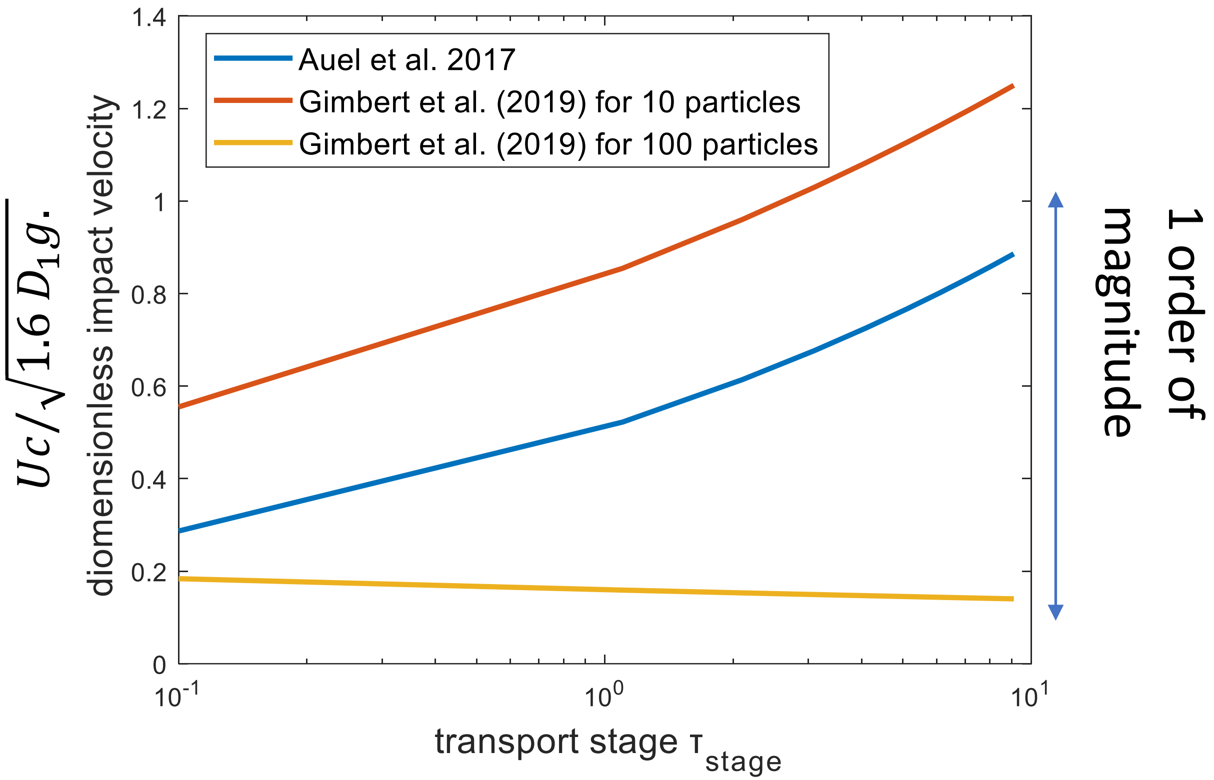
Investigator	Impact Velocity Formula	Comments
Auel et al. (2017 b)	$U_c = 0.84\sqrt{D\, g\delta\tau^*_{stage}}^{\,0.18}$	-
Gimbert et al. (2019)	$U_c = 0.51\sqrt{D\, g\delta\tau^*_{stage}}^{\,0.25}$	10
	$U_c = 0.16\sqrt{D\, g\delta\tau^*_{stage}}^{\,-0.06}$	100

$$\delta = \frac{\rho_s - \rho}{\rho}$$

- Particle density (ρ_s)
- Fluid density (ρ)

Impact Velocity Formulas

- Multiple formulas exit based on physical or experimental studies.



$$\tau_{stage} = \frac{\tau}{\tau_c} - 1$$

High variability

Impact Velocity Additional Formulas

- Multiple formulas exit based on physical or experimental studies.

$$U_c = U_{st} \cos\beta \sqrt{1 - e^{-\widehat{H}_b}}$$ (Lamb et al., 2008)

- β is the riverbed slope.
- $U_{st}(D) = \sqrt{4\delta g D / (3C_d)}$ is the terminal settling velocity.
- C_d is the drag coefficient dependent on particle shape and size (Dietrich, 1982).
- $\widehat{H}_b(D) = 3C_d \rho_f H_b(D) / 2\rho_s D_k \cos\beta$.
- The particle hop height (H_b) is given $H_b(D) = 1.44 D {\tau^*_{stage}}^{0.5}(D)$.

Impact Rate

- Multiple formulas exit based on physical or experimental studies.
- n is dependent mainly hydraulic condition and particles diameter and bedload flux.

Impact Rate Formulas

- Multiple formulas exit based on physical or experimental studies.

The impact rate per diameter (n) is computed by Gimbert et al. (2019) as the ratio between the number of moving particles of diameter D (N_D) and the time between consecutive impacts ($\bar{t}$) of the particles:

$$n(\bar{q}_s, D) = \frac{N_{D_k}(\bar{q}_s, D)}{\bar{t}(D)},$$

The time between consecutive impacts ($\bar{t}$) is given by Gimbert et al. (2019):

- $\bar{t}\,(D_k) = 0.14\tau_{stage}^{*}{}^{0.28}(D_k)$, 10 Particles
- $\bar{t}\,(D_k) = 0.04\tau_{stage}^{*}{}^{0.03}(D_k)$, 100 Particles

Impact Rate Formulas

- Multiple formulas exit based on physical or experimental studies.

The impact rate per diameter (n) is computed by Auel et al. (2017 b) :

$$n(\bar{q}_s, D) = \frac{\bar{q}_s(D)}{V\ (D\ ).L(D)},$$

Where:

- V is the volume of particle of diameter D.
- L is the hope length of particle of diameter D.
- L defined by Auel et al., (2017 b):

$$L = 2.3D{\tau_{stage}^{*}}^{0.8}$$

Impact Rate Formulas

- Multiple formulas exit based on physical or experimental studies.

The impact rate per diameter (n) is computed by Lamb et al., (2008):

$$n(\bar{q}_s, D) = \frac{\bar{q}_s . U_s(D)}{V\ (D\ ). H_b(D). U_b(D)},$$

Where:

- H_b is the bedload height.
- U_b is the bedload particle stream wise velocity.
- U_s The average settling velocity through the bed load layer.
- V is the volume of particle of diameter D.

Impact Rate Formulas

- Multiple formulas exit based on physical or experimental studies.

The impact rate per diameter (n) is computed by Lamb et al., (2008):

$$n(\bar{q}_s, D) = \frac{\bar{q}_s . u_s(D)}{V\,(D\,). H_b(D). U_b(D)},$$

$$u_s = \frac{\hat{H}_b . U_{st} . \beta}{2\log\left[e^{\hat{H}_b/2} + \sqrt{e^{\hat{H}_b/2} - 1}\right]}$$

$$U_b = 1.56\sqrt{D\,g\delta\tau^{*}_{stage}}^{\,0.56}$$