Bundesanstalt für Gewässerkunde

Universität Stuttgart

Uncertainty assessment on erosion of cohesive sediment in the Upper Rhine: Implications for sediment management

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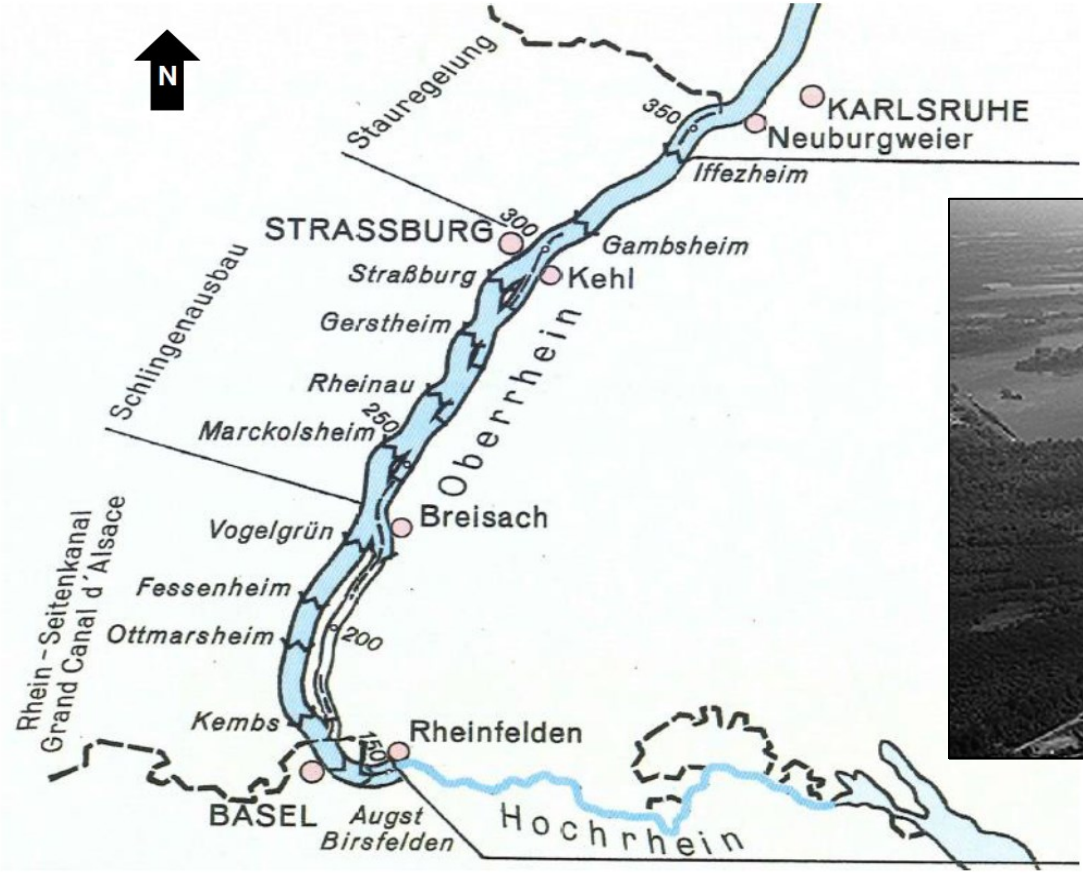
SedNet, Genoa
June 14th – 17th 2017

Upper Rhine

Construction of 10 dams in the southern Upper Rhine…

… to control water levels and improve navigation

… for hydropower purposes



Figures: Frings (2014)

Sediment retention

Construction of 10 dams in the southern Upper Rhine…

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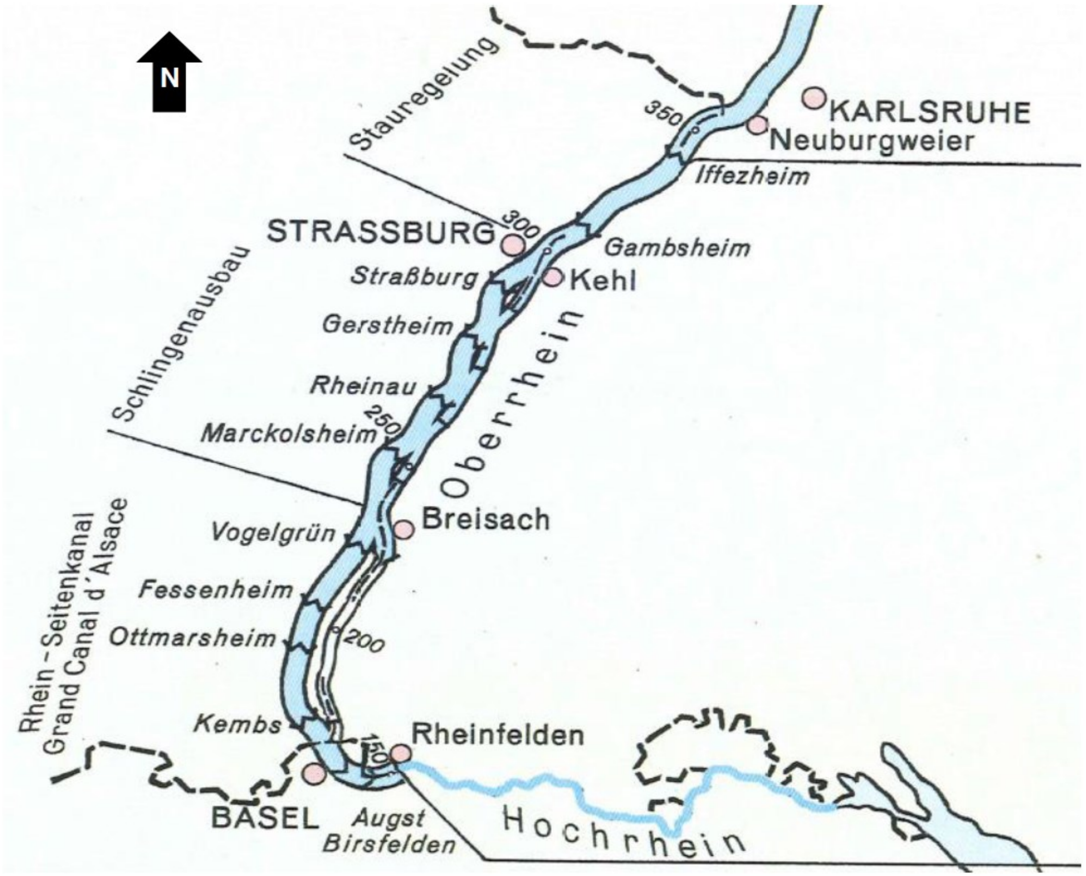
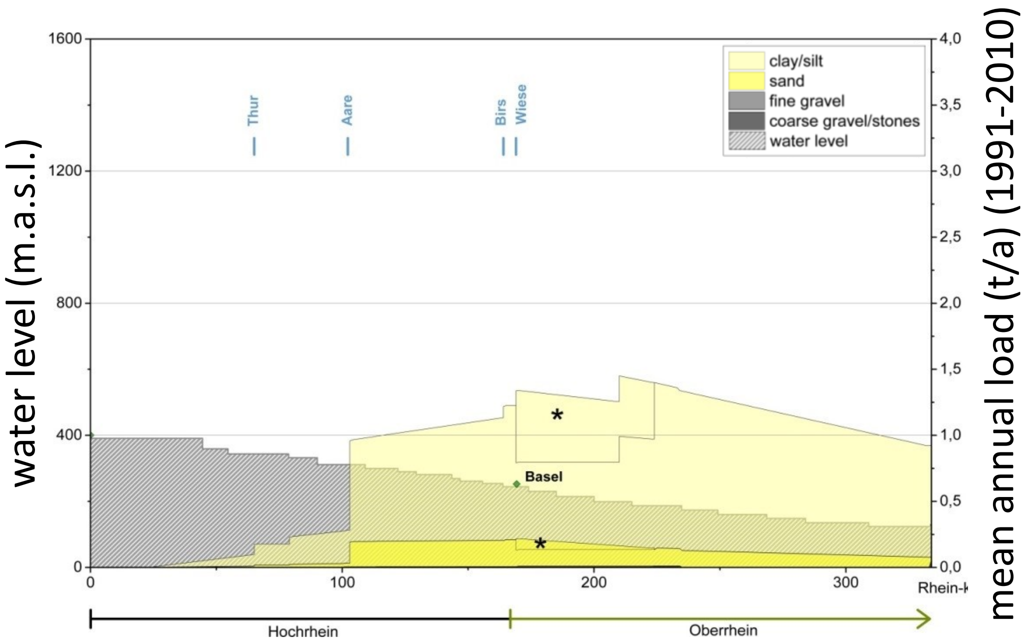
Reservoirs upstream of the dams retain 100 % of bed load (sand/gravel) and ~ 15 % of suspended load





Frings & Hillebrand (2017)

HCB contamination

Construction of 10 dams in the southern Upper Rhine…

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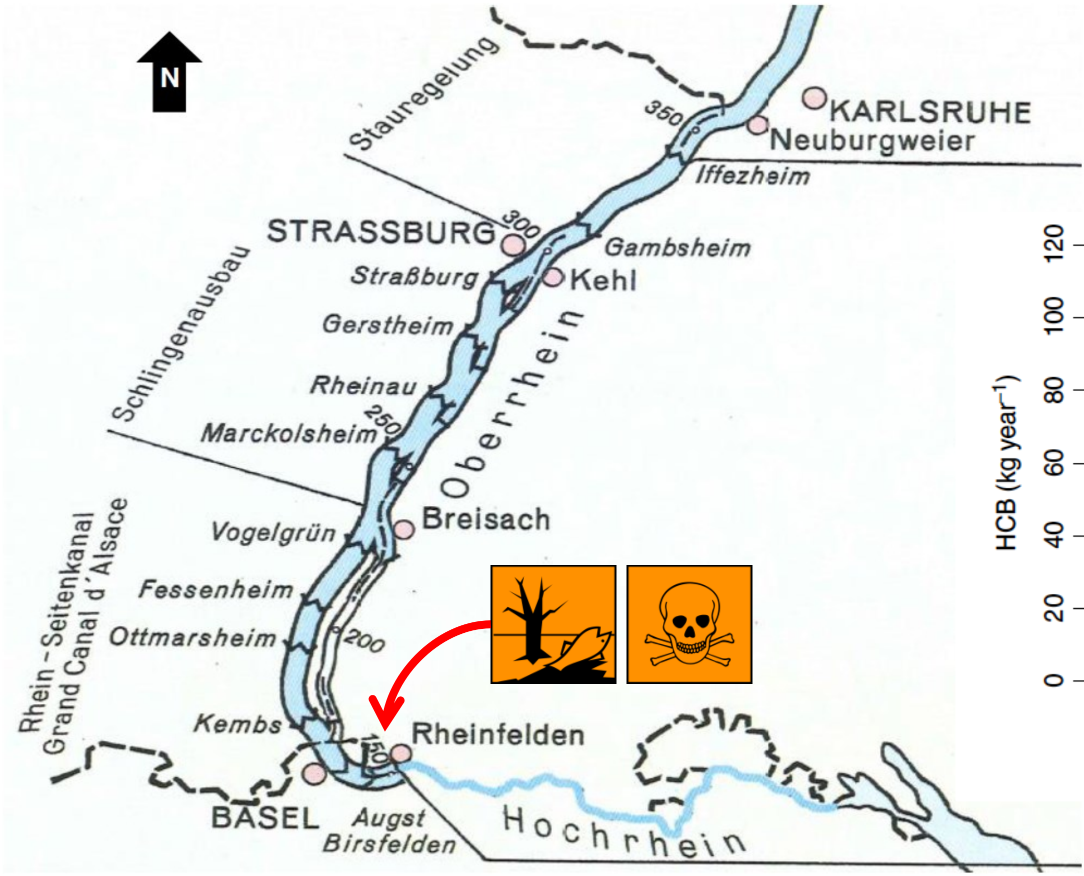
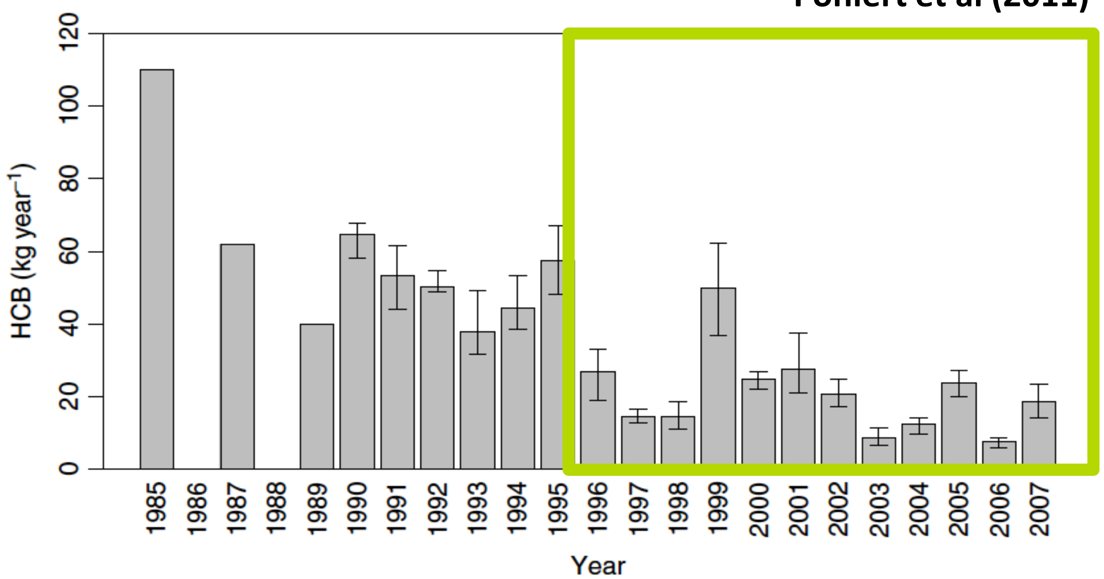


Hexachlorbenzene emission into the Upper Rhine (1970-1990)

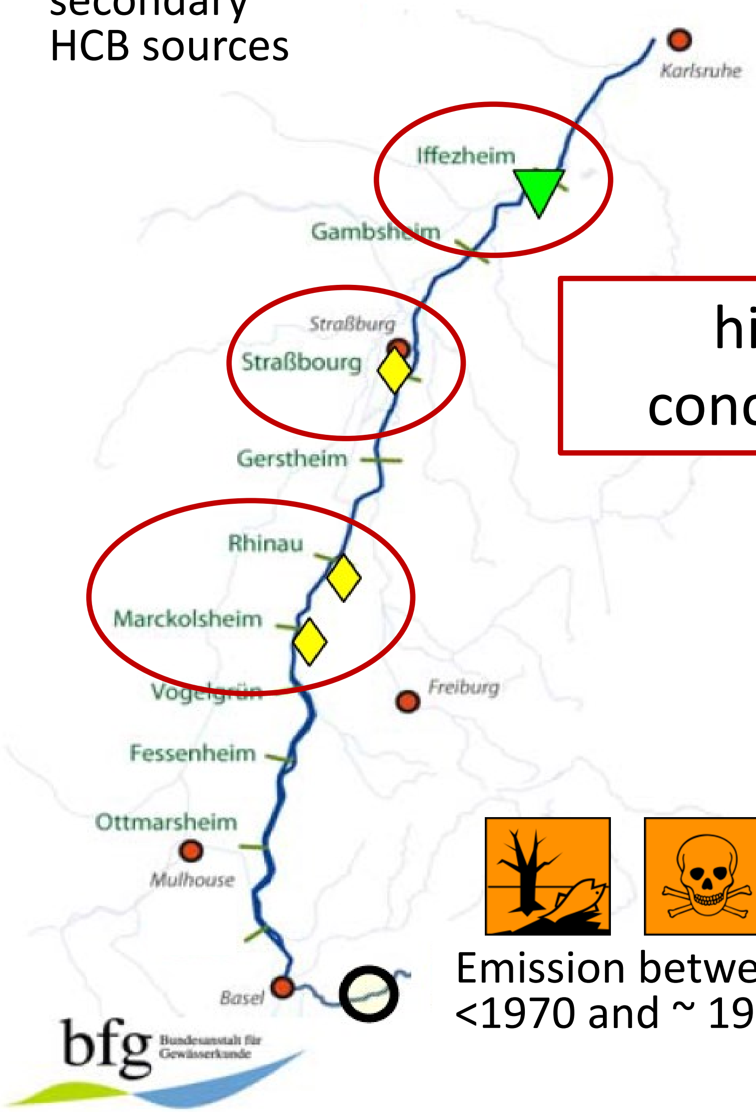
Highly toxic aromatic compound (dirty dozen) strongly associated to fine sediment

Pohlert et al (2011)



HCB contamination

◇ Location of secondary HCB sources



high HCB-concentrations

Emission between <1970 and ~ 1990

BfG (Report 1717 + 1787)

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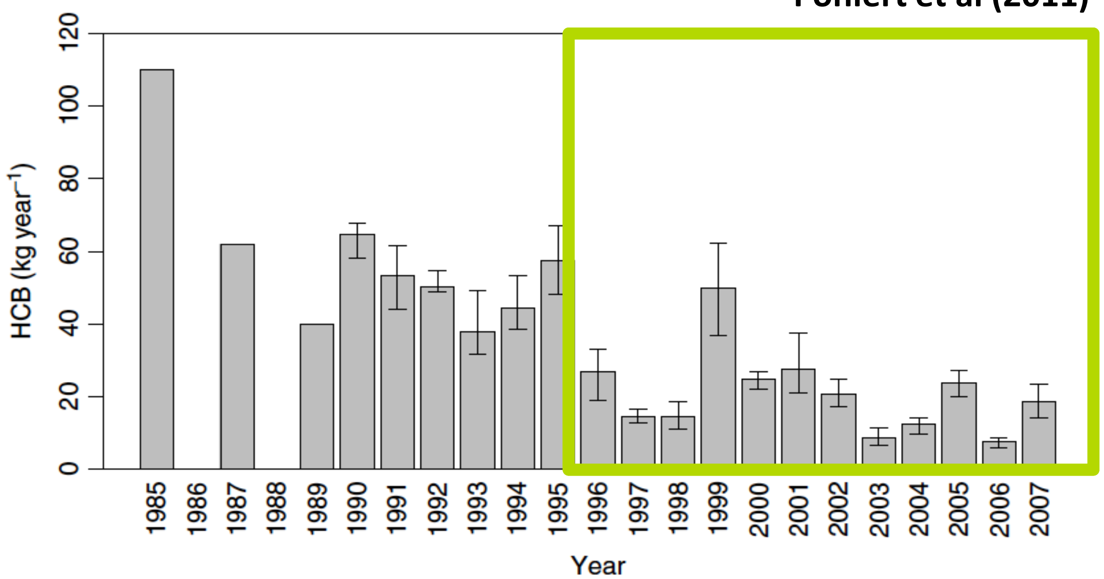
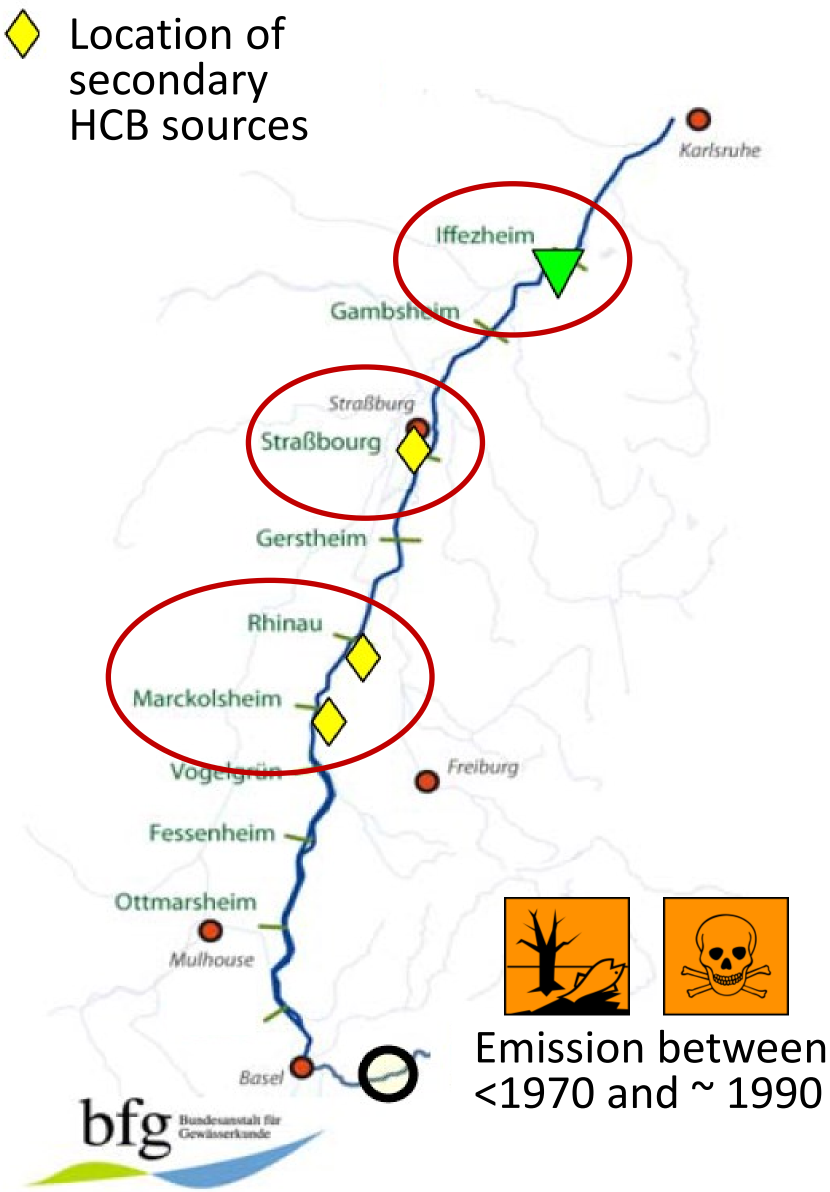


Erosion modelling



BfG (Report 1717 + 1787)

Risk of erosion of contaminated and cohesive sediments

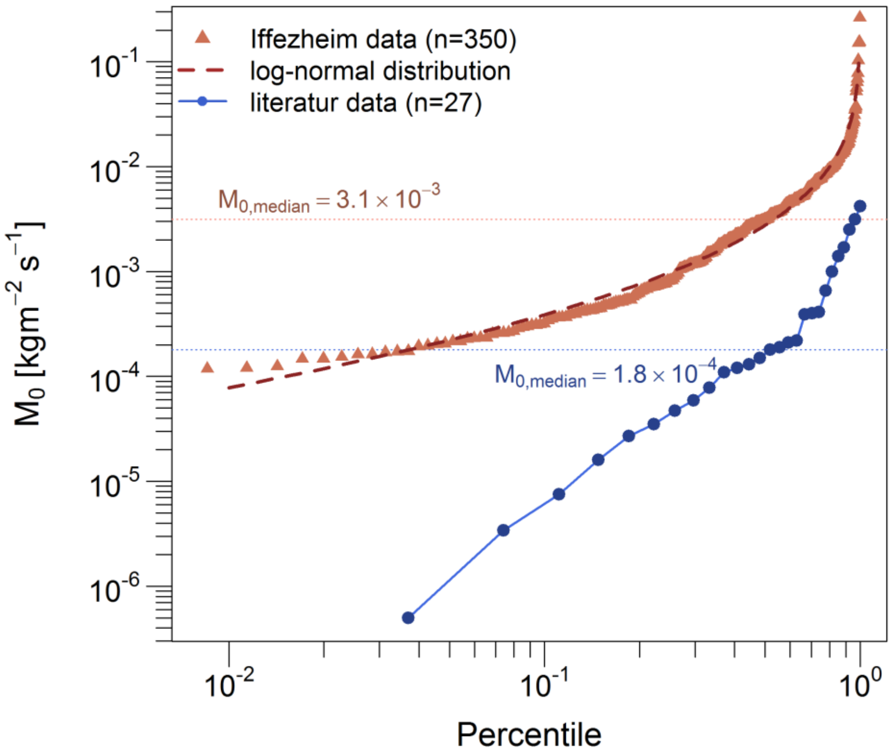
Widely-used erosion law:

$$M = M_0 \times \left(\tau_b / \tau_c - 1\right)$$

M = *erosion rate*
M_0 = *erodibility*
τ_b = *bed shear stress*
τ_c = *critical shear stress*

Erosion modelling

Hoffmann et al (subm, JRBM)



Risk of erosion of contaminated and cohesive sediments

<u>Widely-used erosion law:</u>

$$M = M_0 \times (\tau_b / \tau_c - 1)$$

large uncertainty & variability

➢ **no universal law to predict**

Aims

① Model the long-term (approx. 60 to 100 years) erosion and deposition dynamic in the 10 reservoirs of the Upper Rhine

② Evaluate the uncertainty of the model results

Risk of erosion of contaminated and cohesive sediments

Widely-used erosion law:

$$M = M_0 \times \left(\tau_b / \tau_c - 1\right)$$

Scale not appropriate for complex CFD-models

large uncertainty & variability
➢ no universal law to predict

Methods

① Find statistical models to predict M_0 and τ_c

② Evaluate uncertainty of erosion model: $M=M_0(\tau_b/\tau_c-1)$

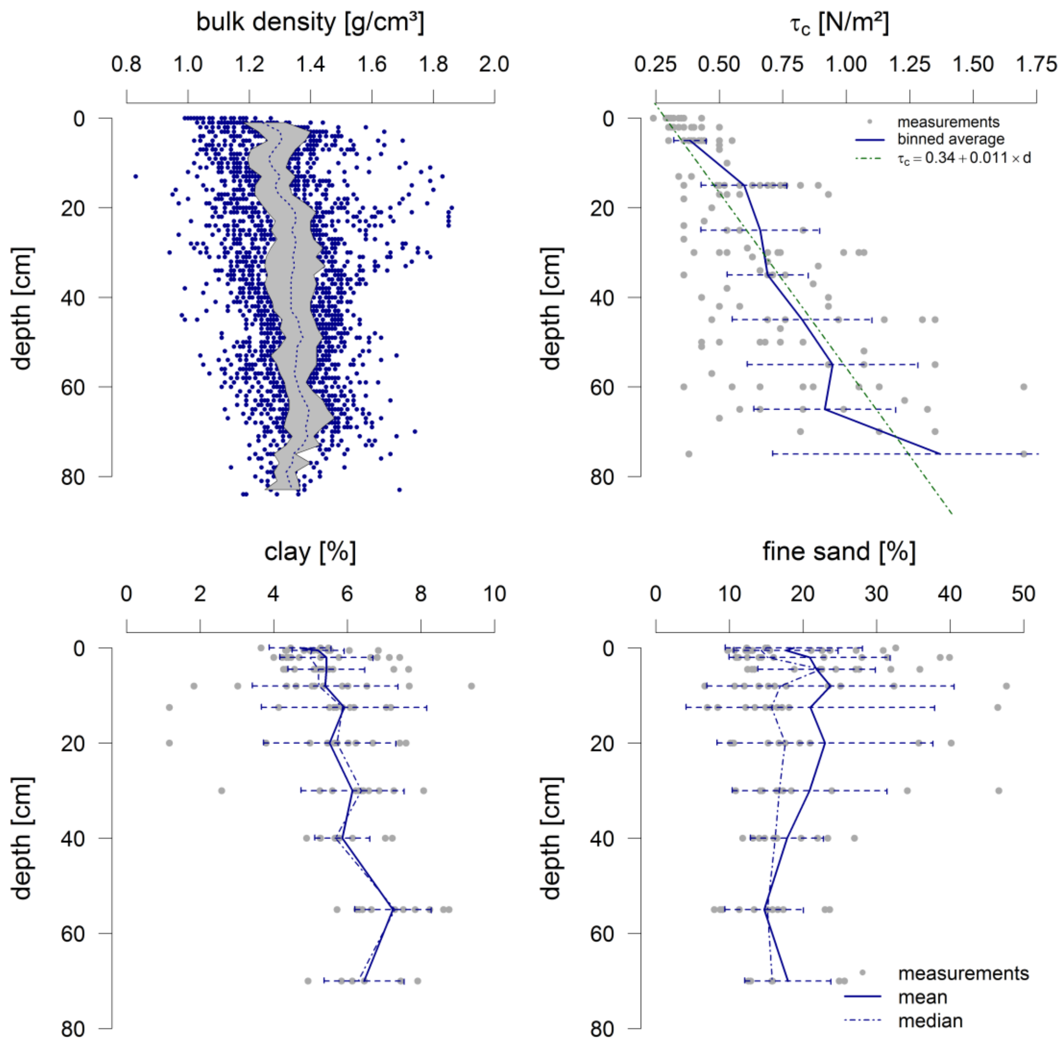
③ Develop and apply sedimentation/erosion model to predict dynamics of cohesive sediment in reservoirs

1. Prediction: M, τ_c

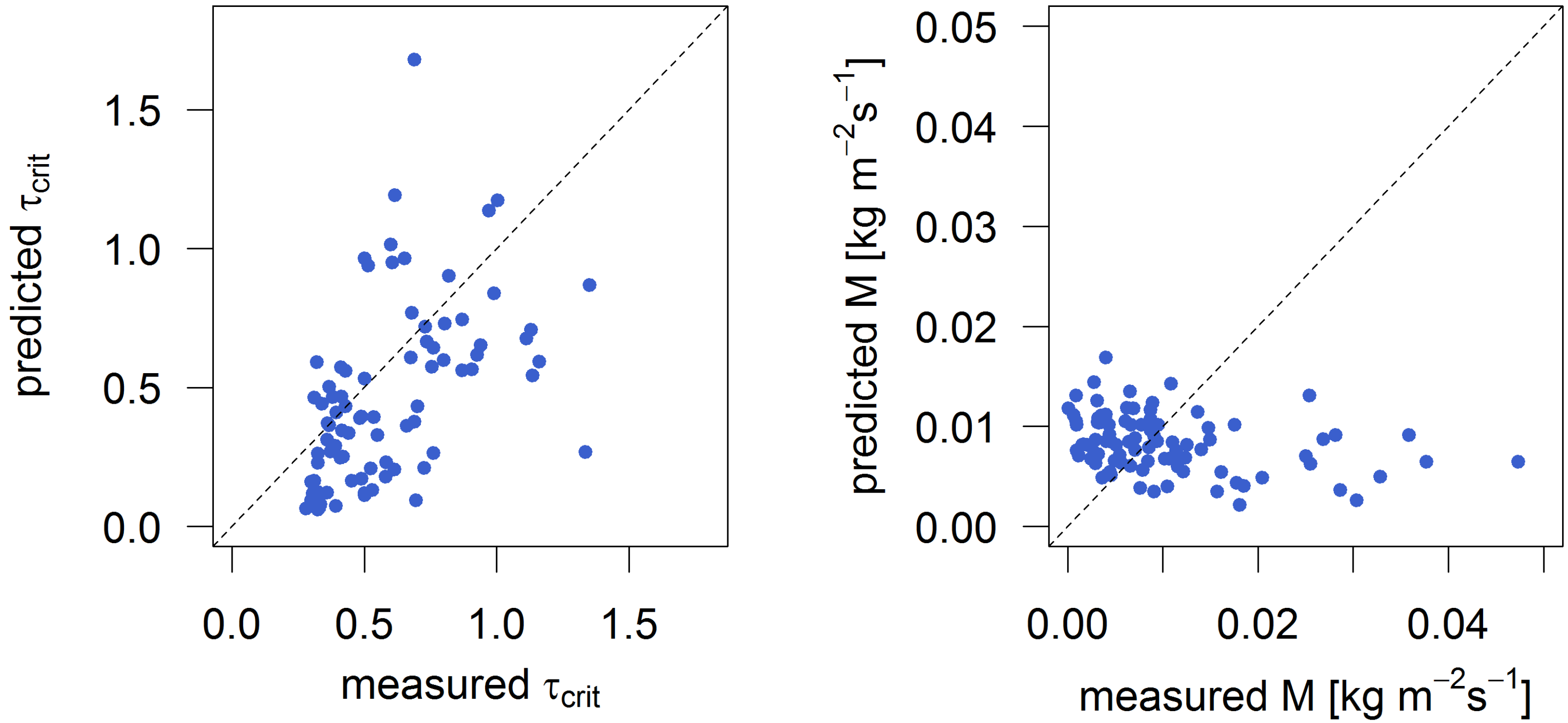
- 12 × 1m-drillings in Iffezheim reservoir
- Estimates of grain size, bulk density, critical shear stress & erosion rate (Noack et al 2014)
- Bootstrap regression:

$$\tau_c = \frac{1}{77.5}\left[3.2(\rho_s - \rho_w)gd_{50} + \left(\frac{\rho}{\rho_{con}}\right)^{10} \frac{k}{d_{50}}\right]$$

$$M = M_0 \times (\tau_b / \tau_c - 1)$$



1. Prediction: M, τ_c

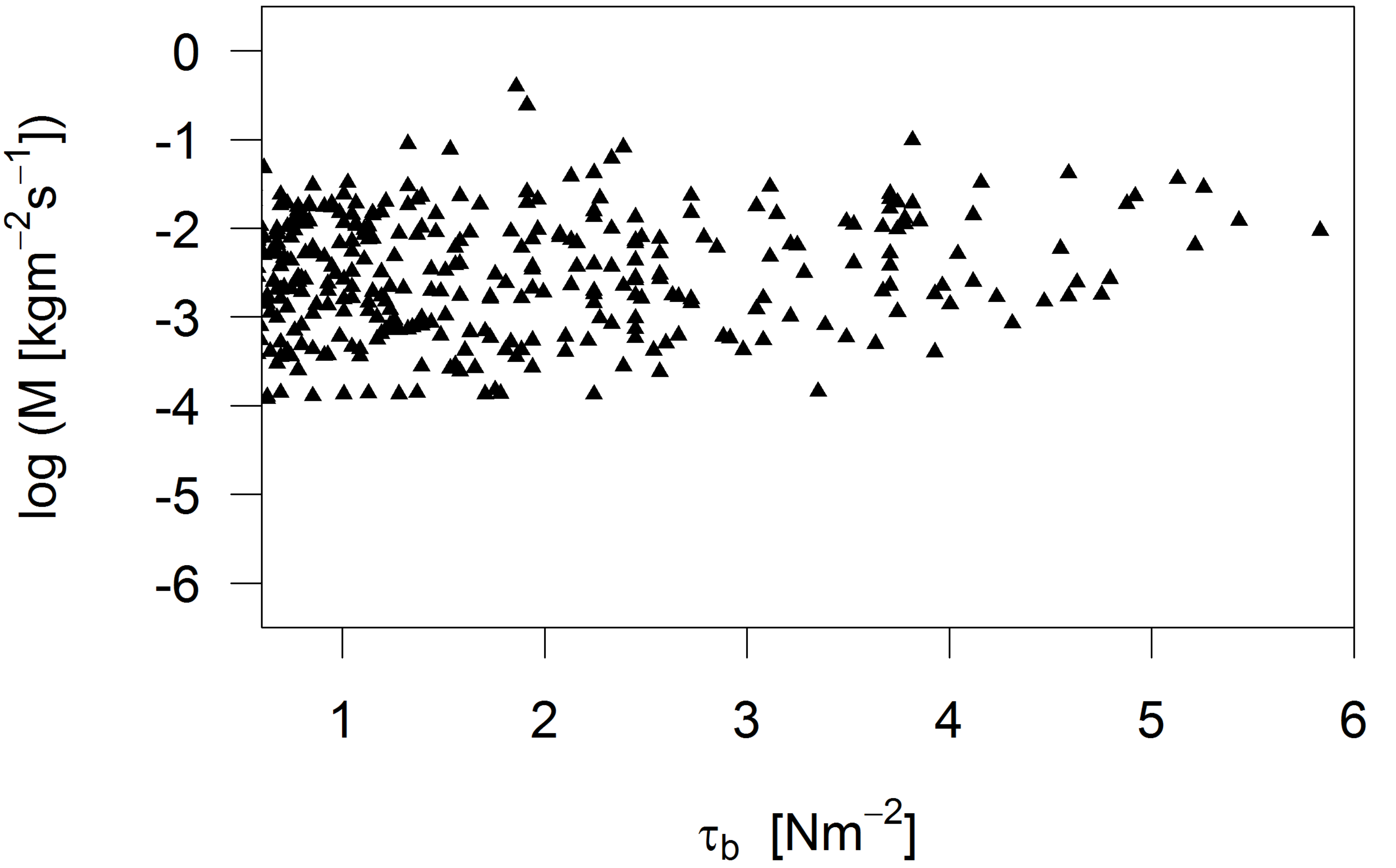


	τ_c	M
RMSE	0.32 Nm^{-2}	10.8×10^{-3} kg m^{-2} s^{-1}
Coef. of variation	0.51	1.01

2. Uncertainty of modeled M

$$M = M_0 \times (\tau_b / \tau_c - 1)$$

$M_0 = (5.53 \pm 0.6) \times 10^{-3}$ kg $m^{-2}s^{-1}$
$\tau_c = 0.62 \pm 0.32$ Nm^{-2}



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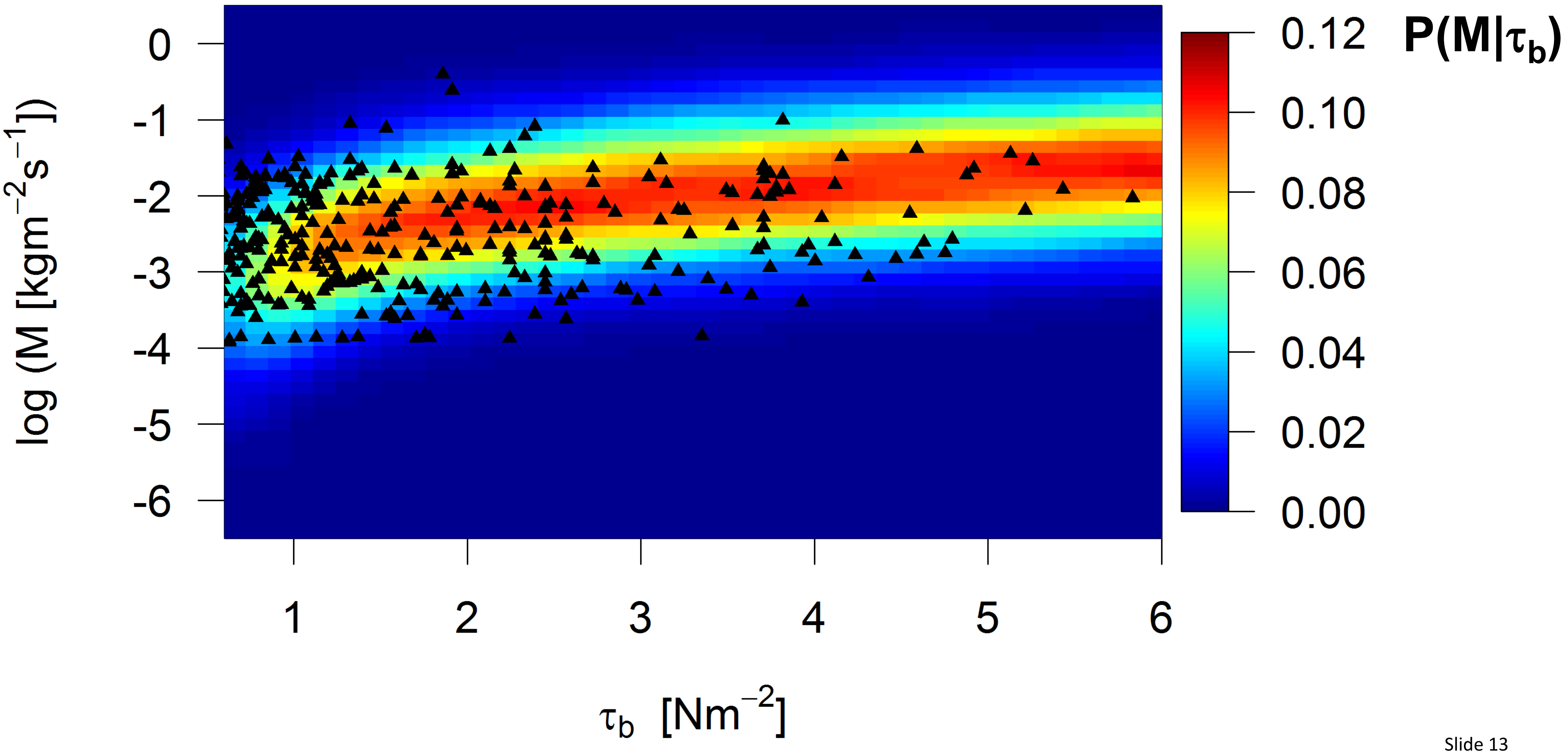

2. Settling/erosion dynamics

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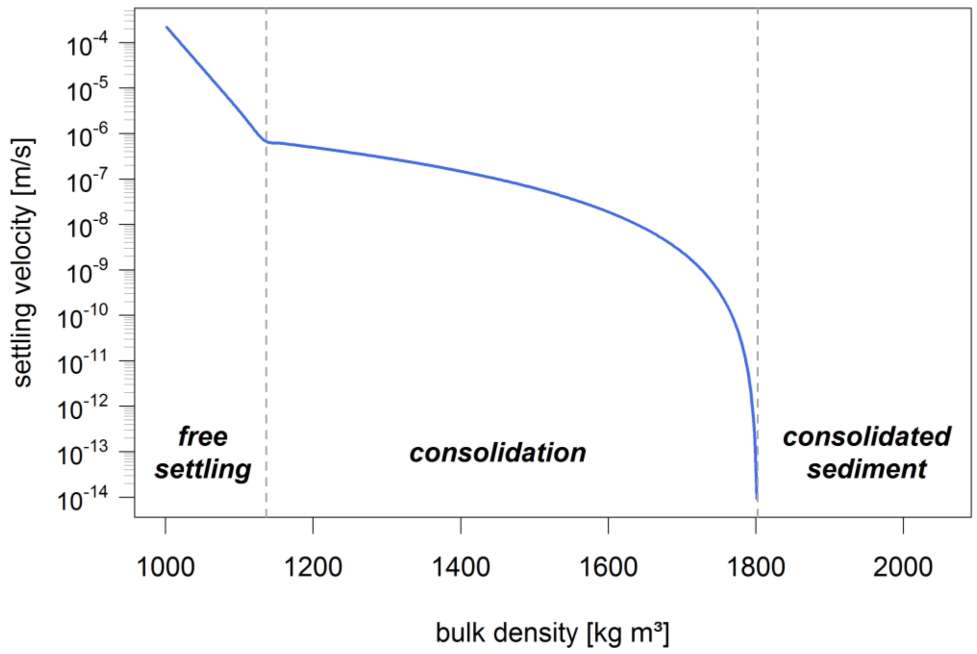
1D settling/erosion model

① Sedimentation: hindered settling approach

② Erosion: $M = M_0(\tau_b/\tau_c - 1)$ for $\tau_b > \tau_c$



③ Application to Iffezheim reservoir

- Main deposition = weir
- Weir through flow at $Q > 1100 m^3/s$
- $\tau_b = f(Q)$

2. Settling/erosion dynamics

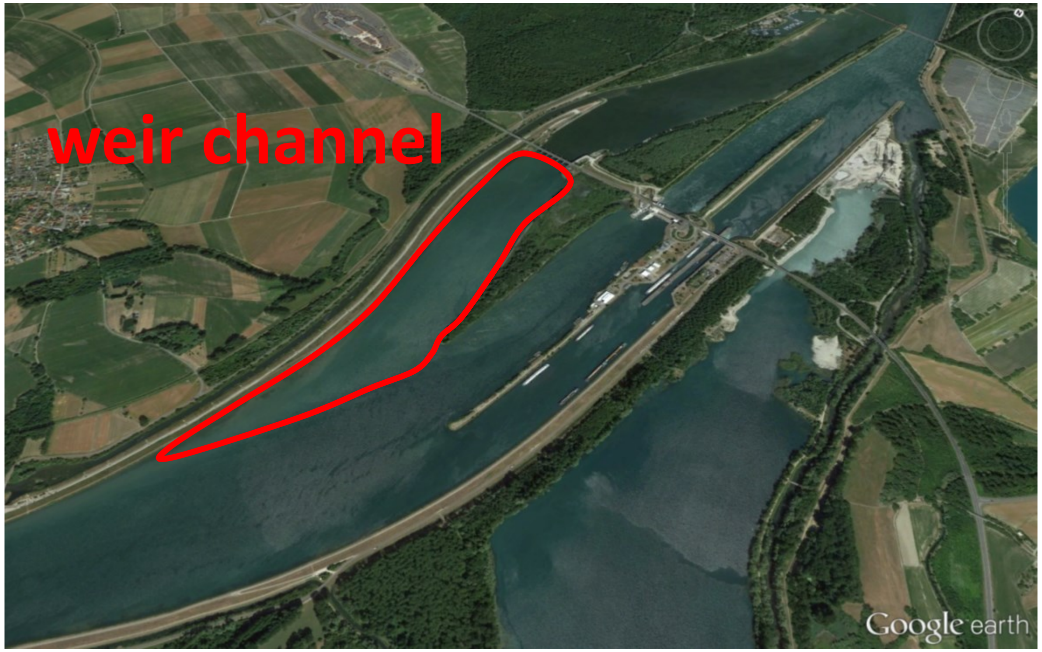
1D settling/erosion model

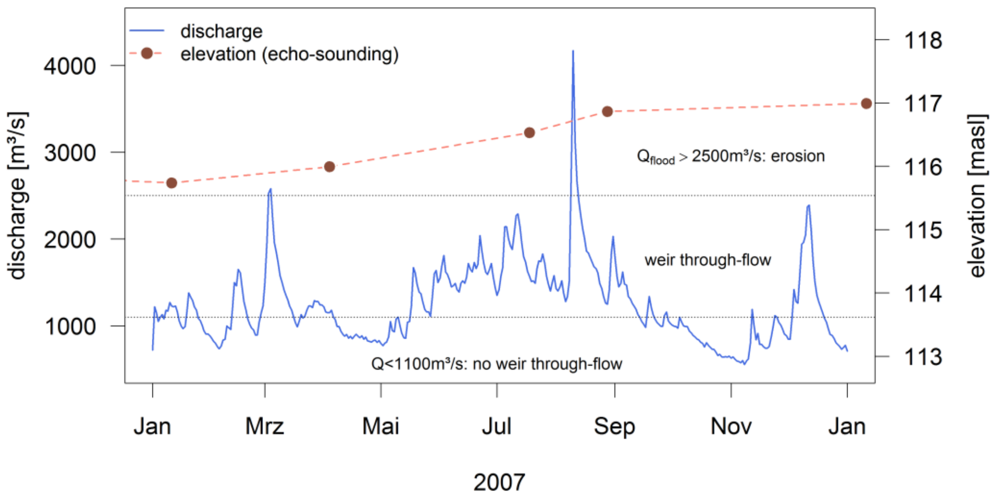
① Sedimentation: hindered settling approach

② Erosion: $M = M_0(\tau_b/\tau_c-1)$ for $\tau_b > \tau_c$

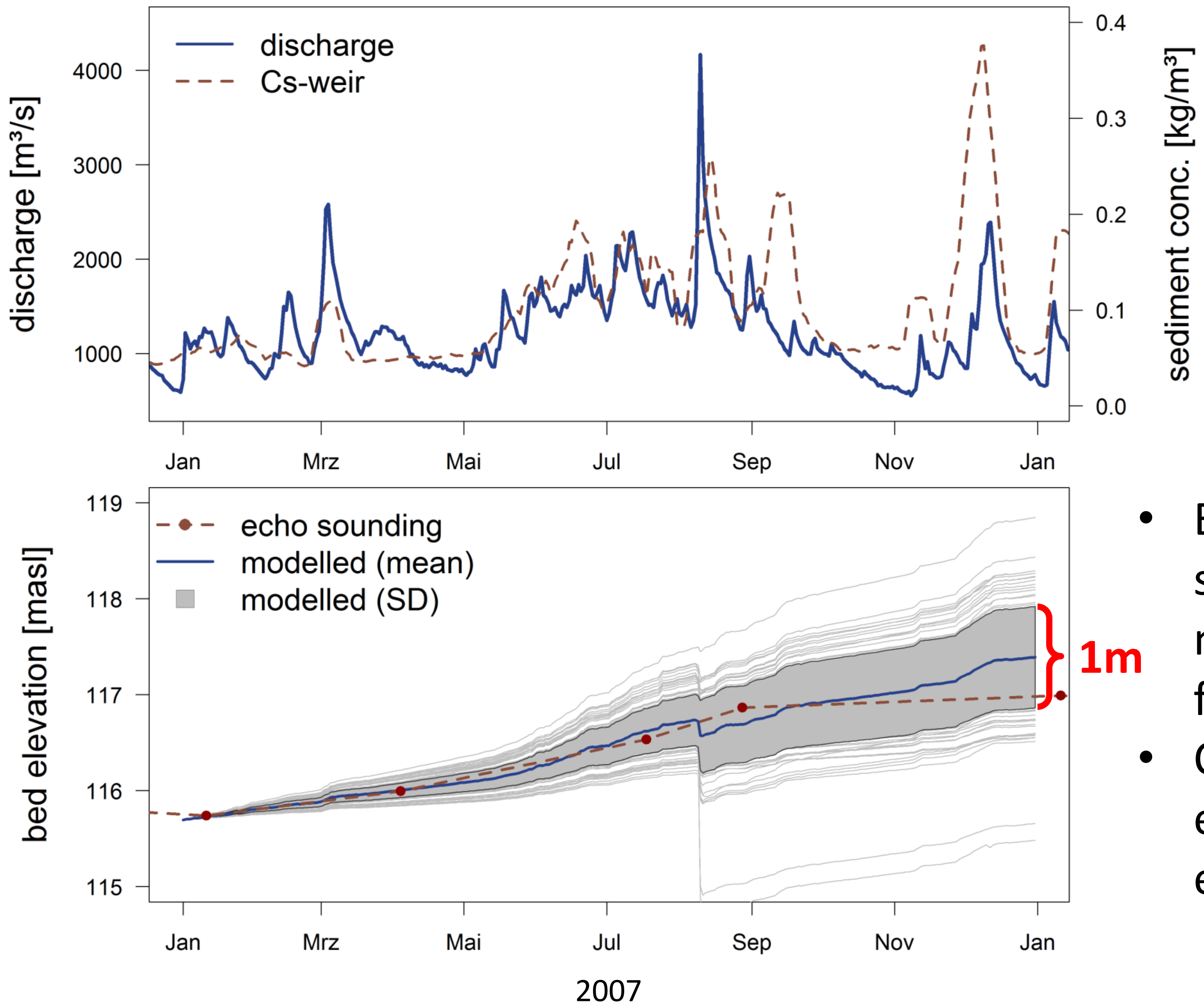
③ Application to Iffezheim reservoir (Example: 2007)

- Main deposition = weir channel
- Weir discharge at $Q > 1100 m^3/s$
- $\tau_b = f(Q)$





3. Settling/erosion dynamics



- Echo-sounding: strongest sedi-mentation during flood (τ_b~6 Nm²)
- Contradicts evidences from erosion modelling

3. Conclusion

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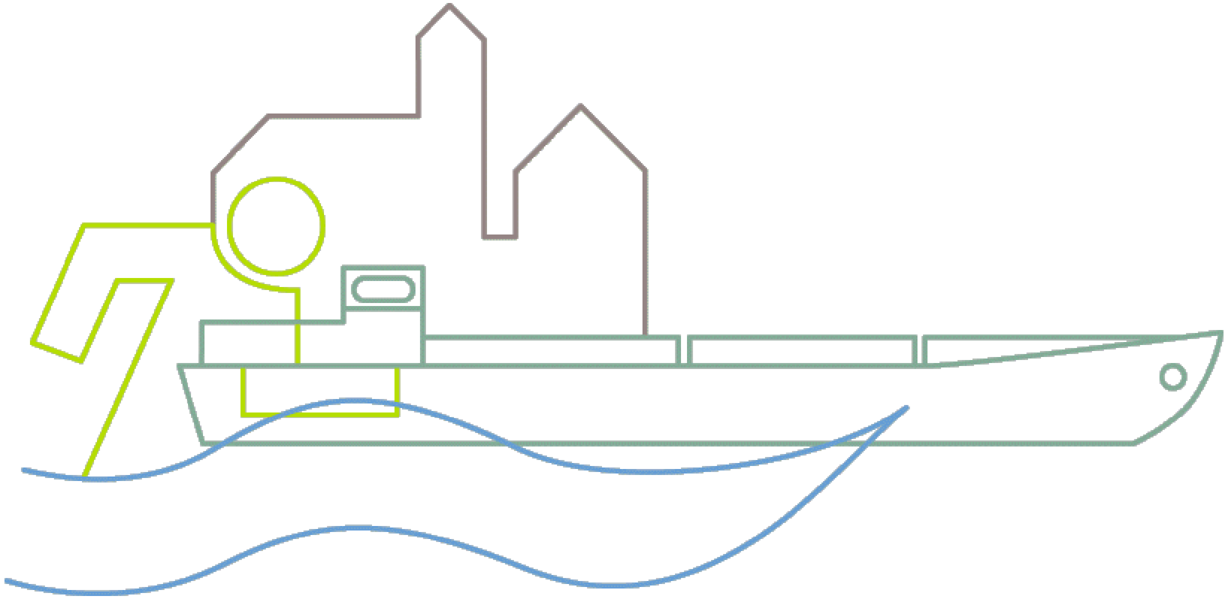
① Prediction of τ_c and M in the order of 50% and 100%, respectively.

② Vertical 1D model covers general behavior of dynamics of cohesive sediment in reservoirs

- ➢ Appropriate to model long-term evolution!

③ But large uncertainty

- ➢ Improved erosion model required
- ➢ Stochastic approach required



Thank you!

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