

MARSEILLE  
DU 27 MAI  
AU 3 JUIN  
**2022**



ICOLD  
27<sup>TH</sup> CONGRESS  
90<sup>TH</sup> ANNUAL  
MEETING



CIGB  
27<sup>ÈME</sup> CONGRÈS  
90<sup>ÈME</sup> RÉUNION  
ANNUELLE



Committee J – Reservoir Sedimentation  
Workshop « SEDIMENT BYPASSING AND TRANSFER »

# Hydraulics & Sediment transport

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# Tunnel hydraulics

Bypasses sediment during floods

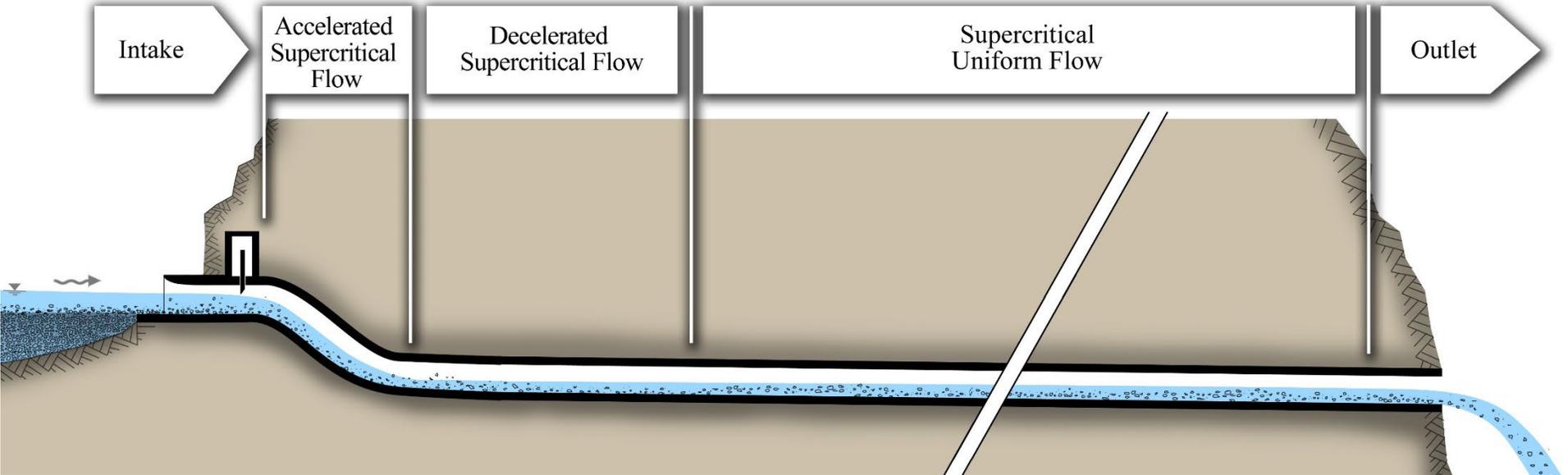
Free – surface open channel flow  
Exceptional: pressurized flow

supercritical flow

Most time of the year closed

Hydraulic jumps, pressure fluctuations,  
pulsations & subatmospheric depressions

enough sediment transport capacity &  
economic tunnel cross section

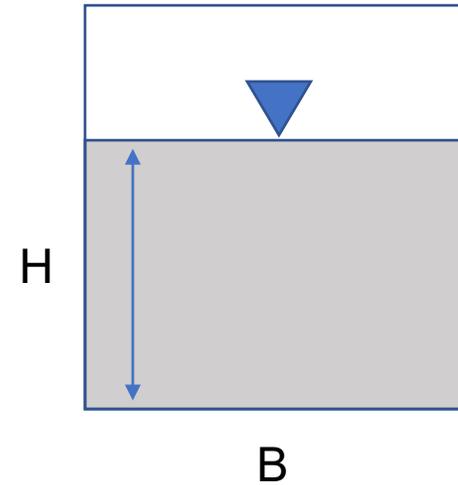


# Tunnel hydraulics

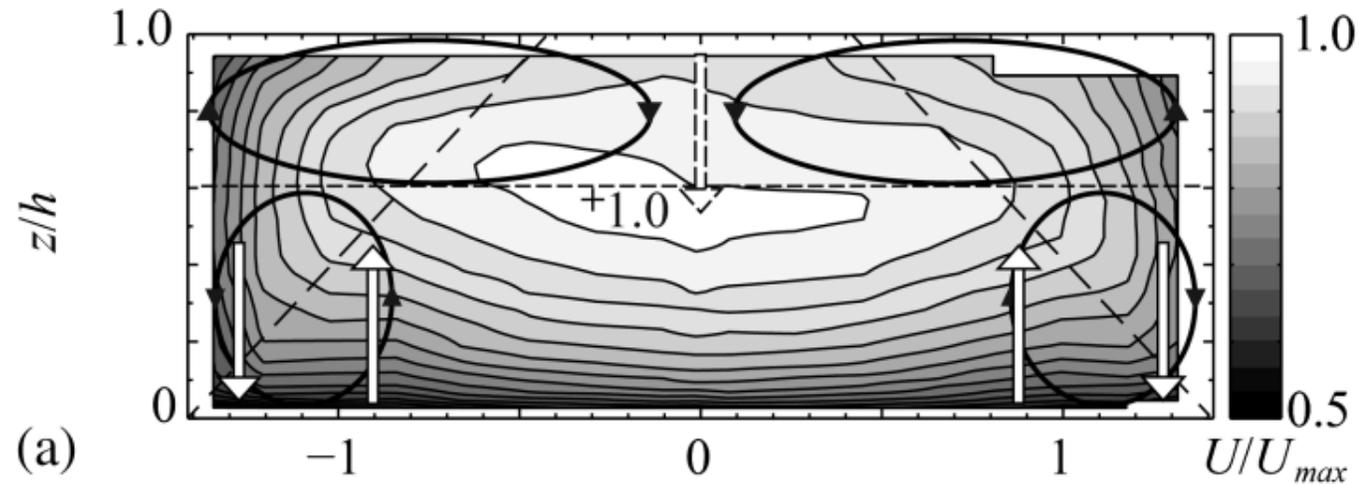
Low aspect ratio  $B/H$

$B$  = Width,  $H$  = flow depth

$B/H$  between about 6 and 1 depending on discharge



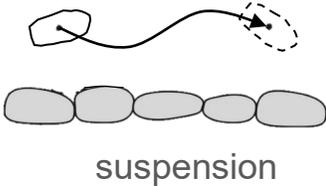
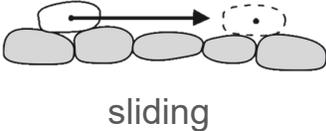
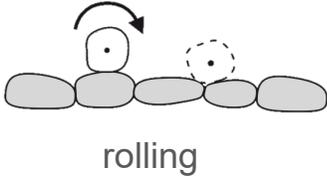
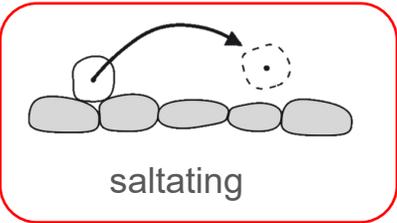
$B/H = 2.8$



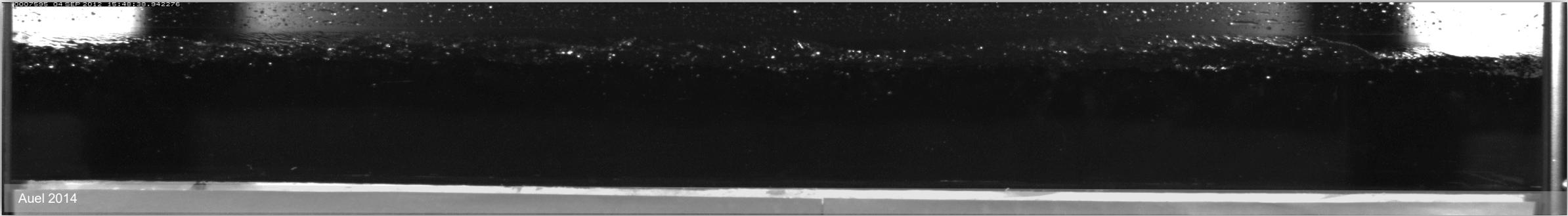
# Sediment transport

Sediment is transported in saltating, rolling, sliding motion or suspension

## Main abrasion process



high speed flow



# Sediment transport

locations where bed shear stress is high

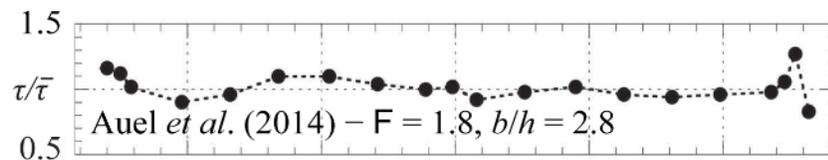
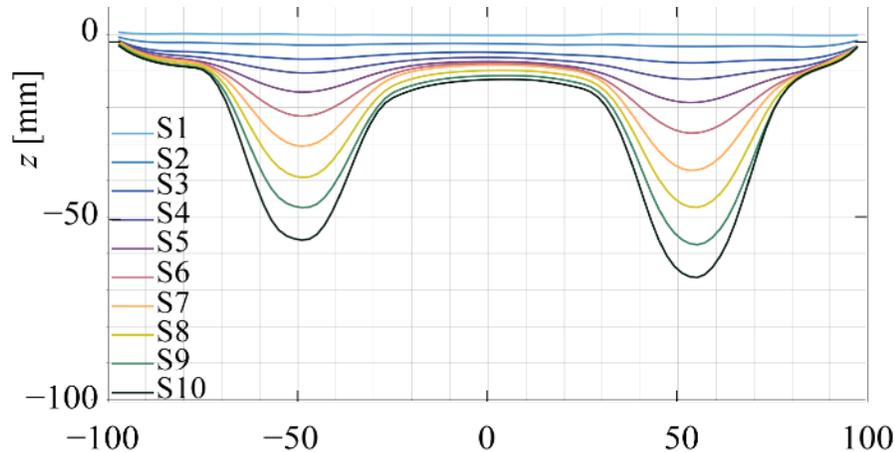
1 channel for  $B/H < 2$

2 channels for  $2 < B/H < 3$

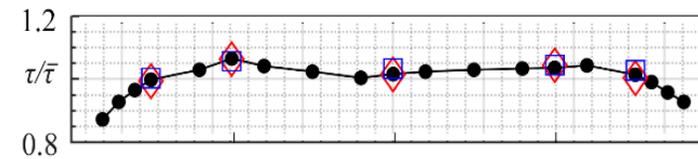
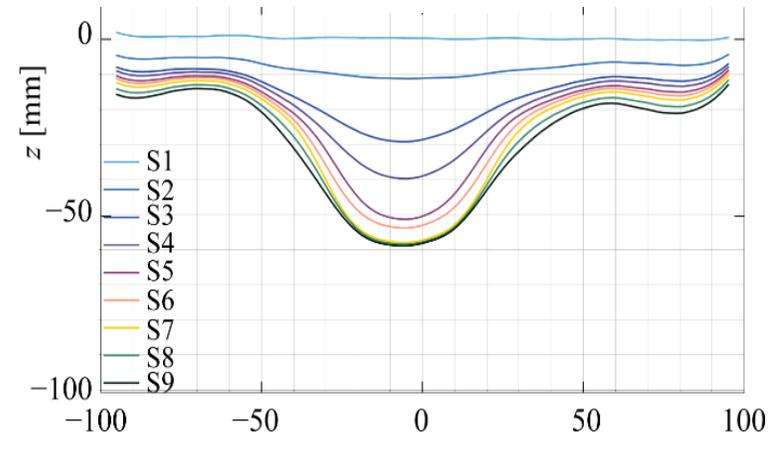


random potholes for  $B/H > 4$

$B/H = 2.2$

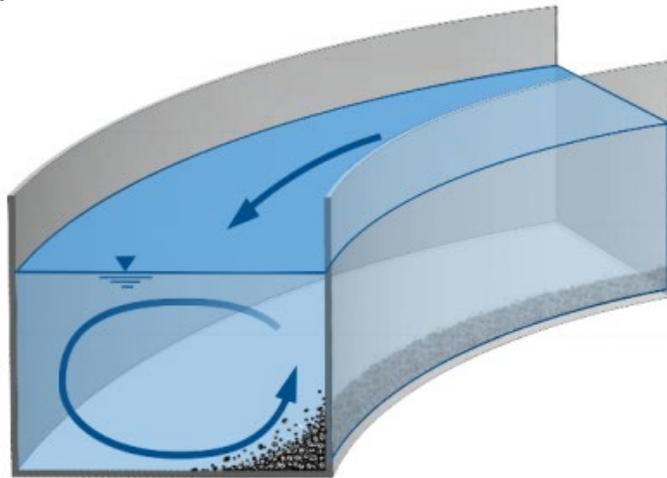


$B/H = 1.6$

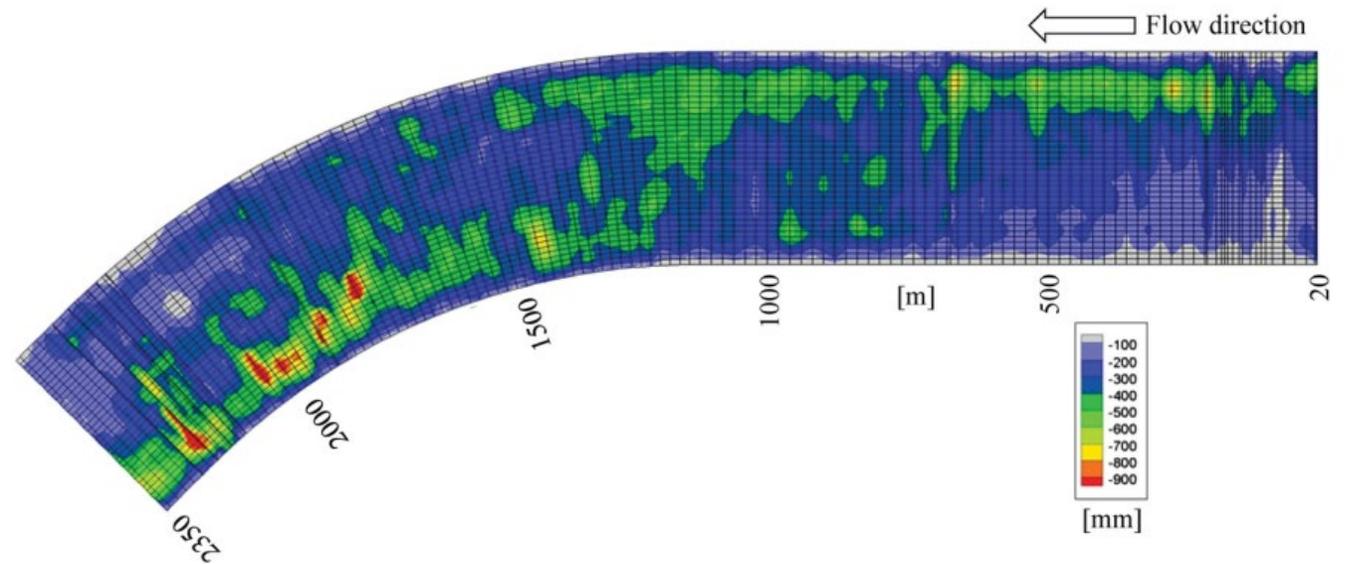


# Sediment transport

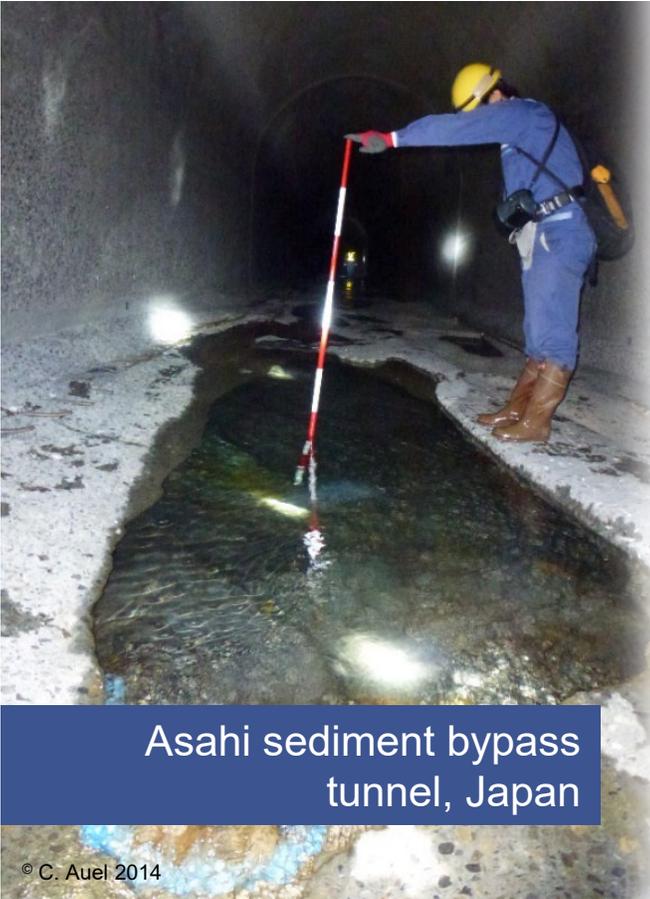
Curve: secondary currents



sediment transported in the inner curve



# Abrasion - a common problem in infrastructure



Asahi sediment bypass tunnel, Japan

© C. Auel 2014

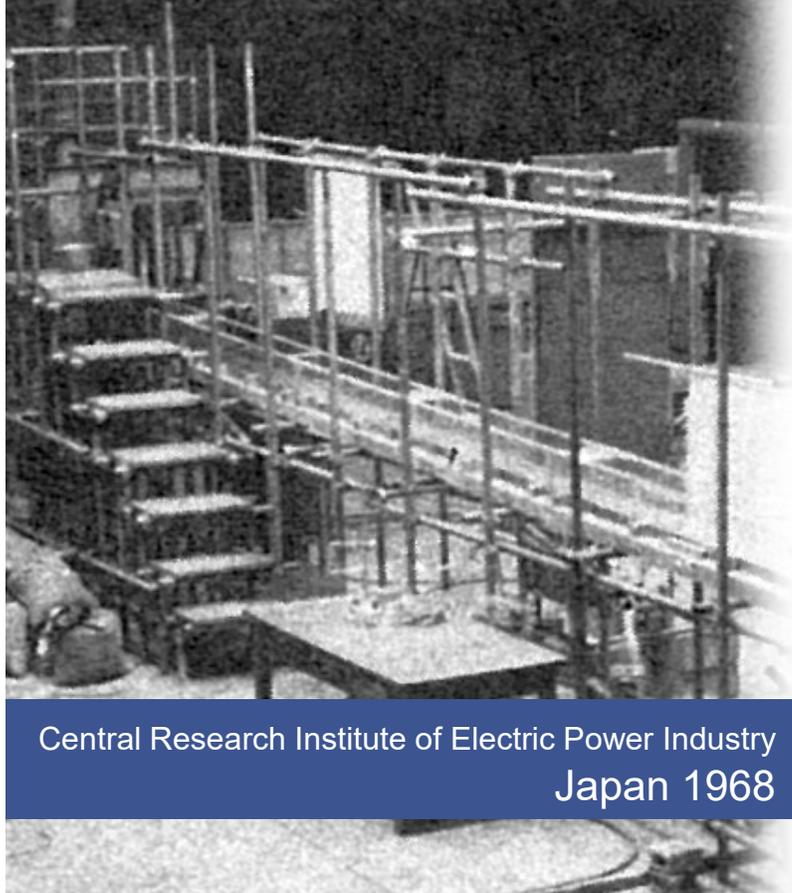


Palagnedra sediment bypass tunnel, Switzerland

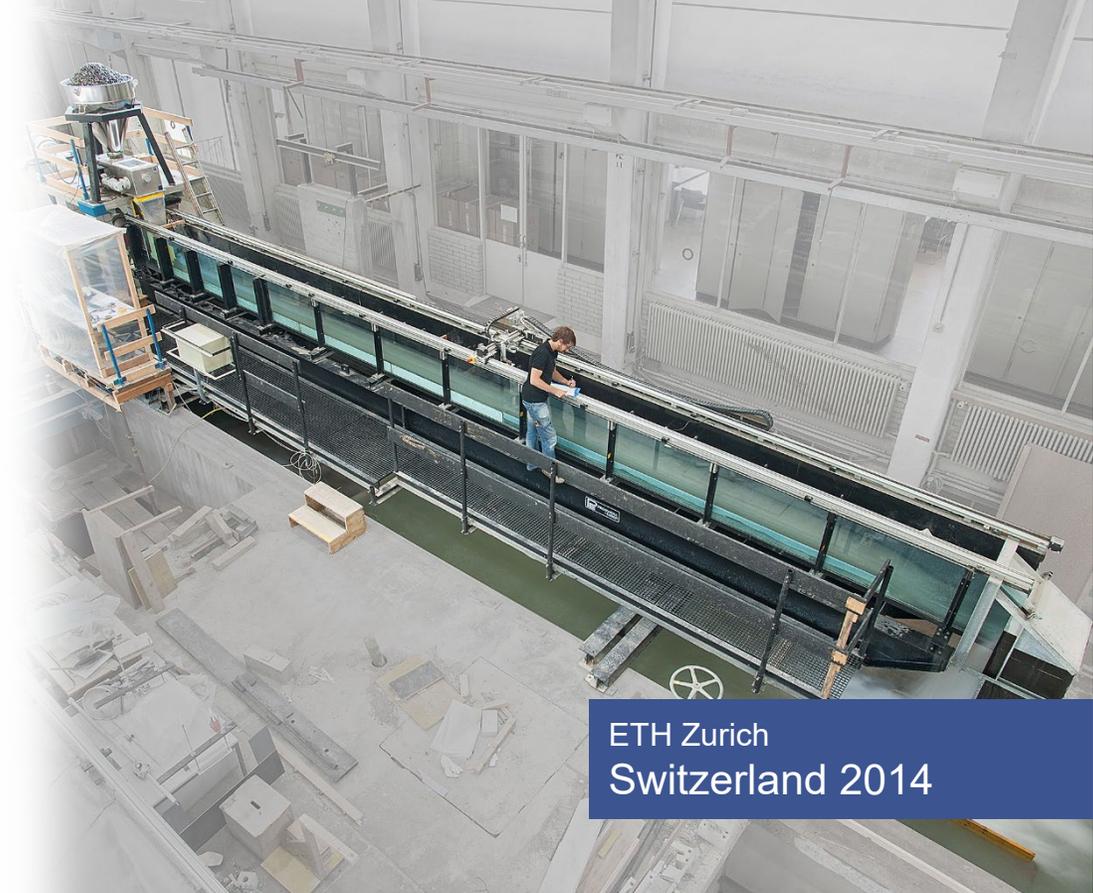
© C. Auel 2011



# Laboratory research on abrasion



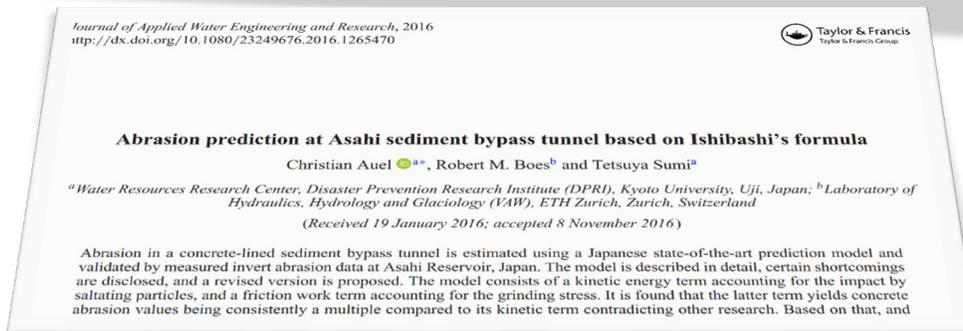
Central Research Institute of Electric Power Industry  
Japan 1968



ETH Zurich  
Switzerland 2014



# Abrasion prediction Models



*Ishibashi model*  
Ishibashi 1983 Proc. JSCE  
Auel et al. 2018 JAWER



*Auel model*  
Auel et al. 2017 ESPL





# Estimation of abrasion resistance

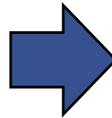
*Input*  
Discharge  
Sediment flux  
Sediment diameter  
Material properties



*Modelling*  
Ishibashi

$$V_a = 1.5 C_1 Y_{ts} \sum E_i N_i n_i$$

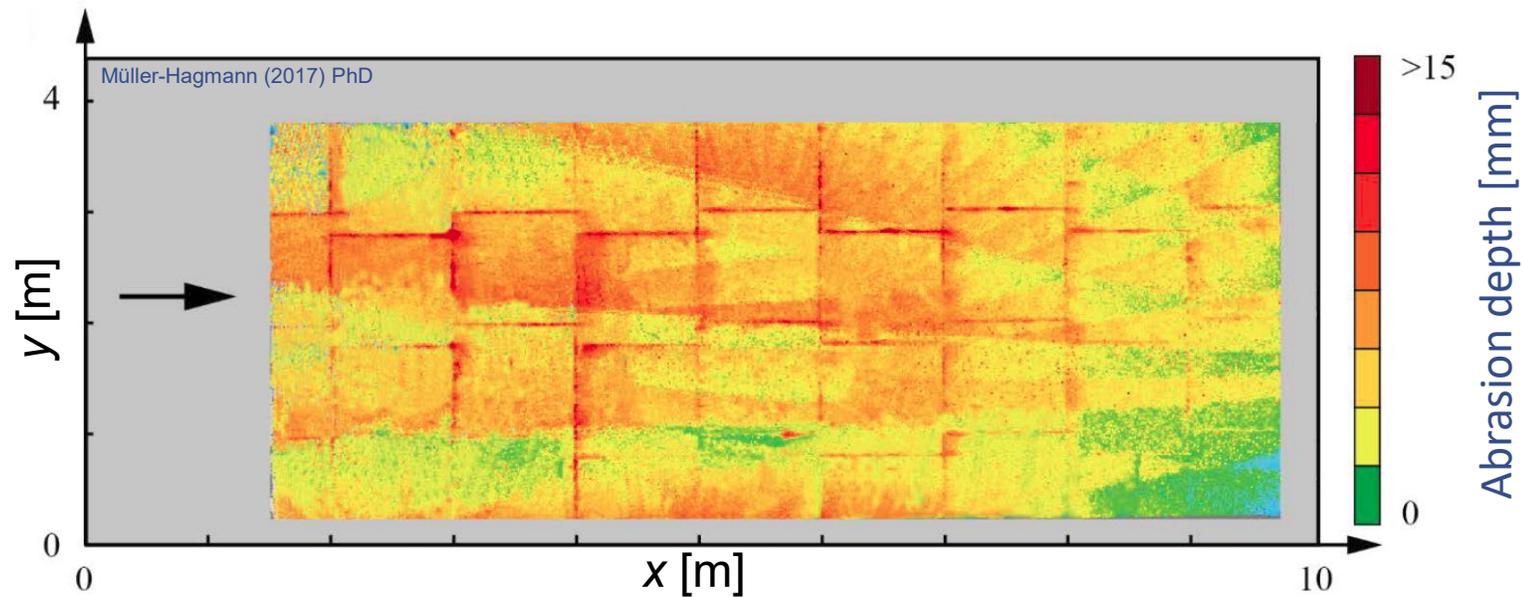
*Auel*

$$A_r = \frac{1}{k_v} \frac{Y_M (s-1)g}{f^2 t} q_s$$


Calibration with real data

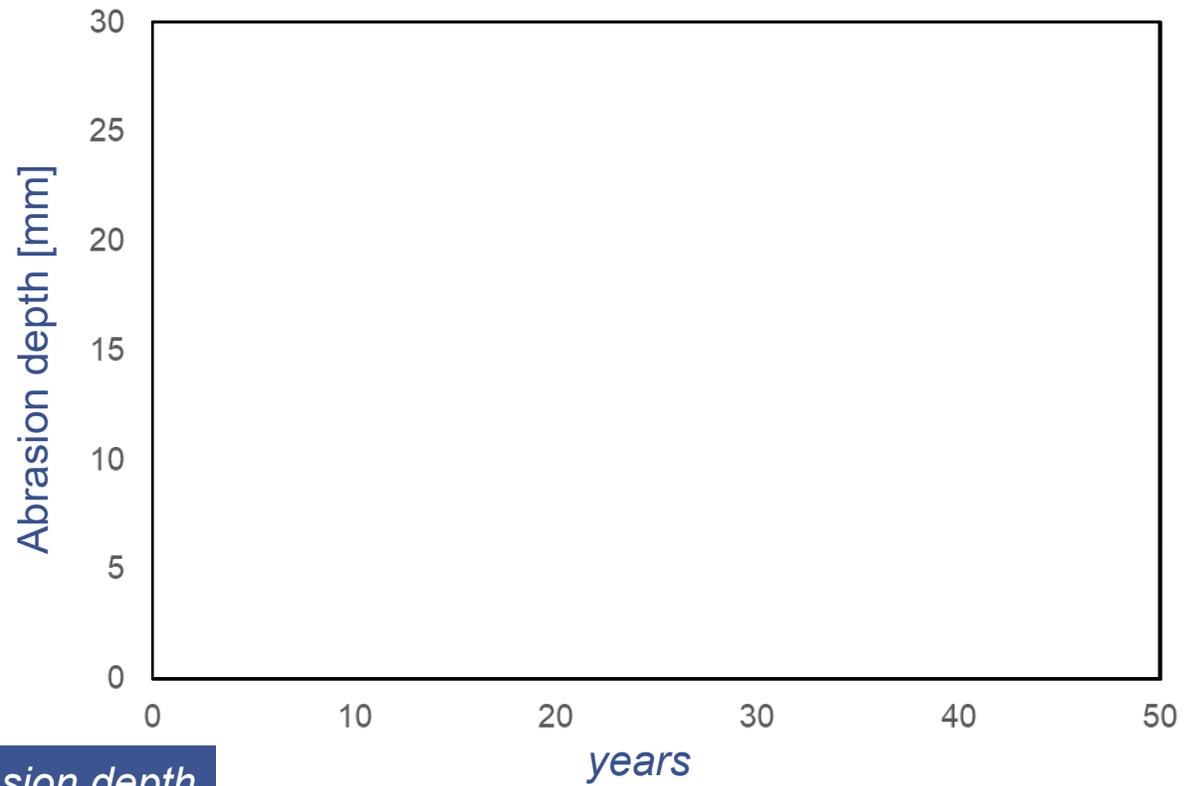


# Model calibration

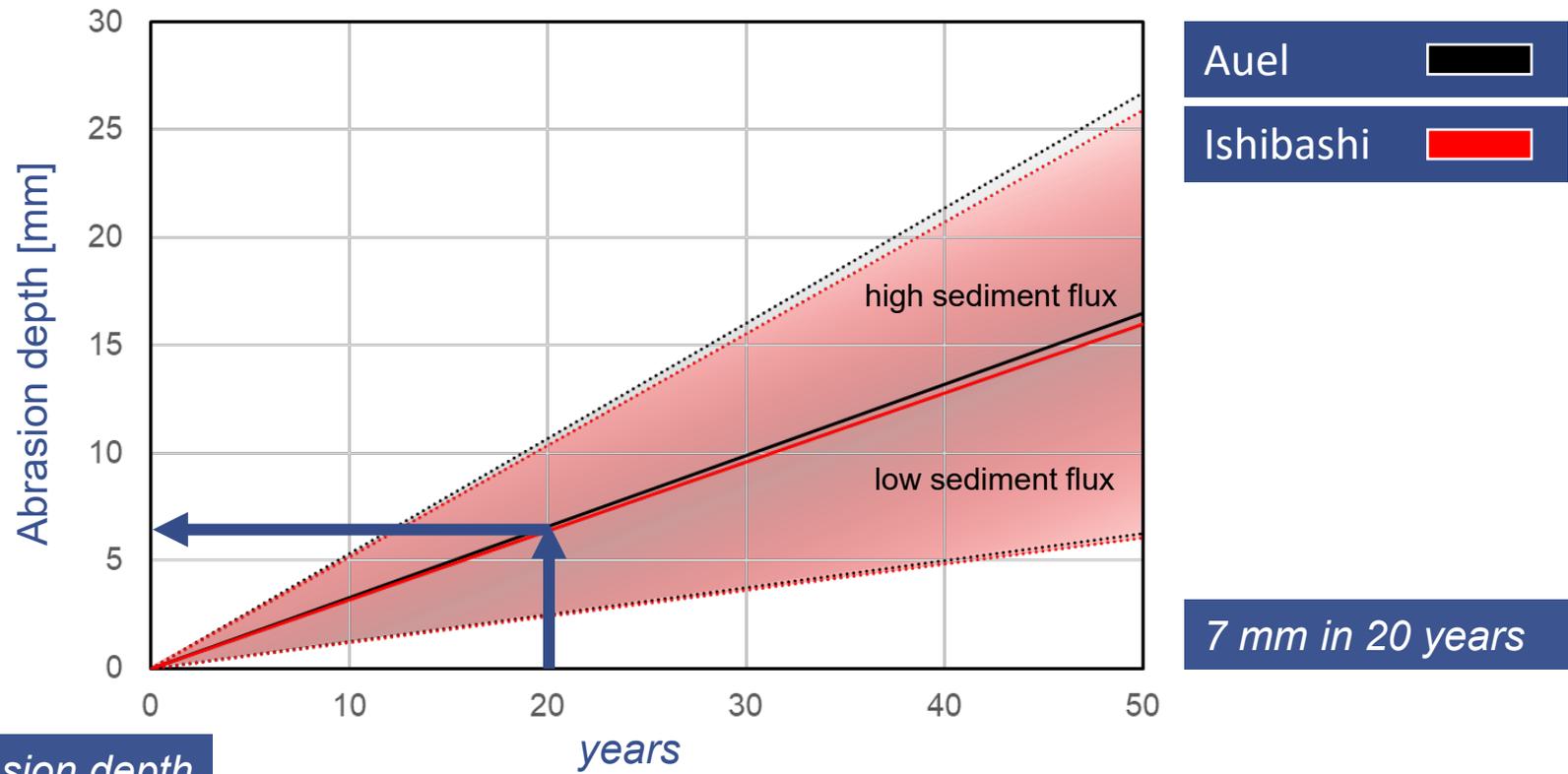


Measure abrasion depth with laser scan  
Know material parameters  
Estimate sediment flux  
→ obtain new  $C_1$  and  $k_v$

# Exemplary Results (granite)



# Exemplary Results (granite)



*Averaged abrasion depth*

*7 mm in 20 years*

