Bedload transport monitoring and modelling: state of the art

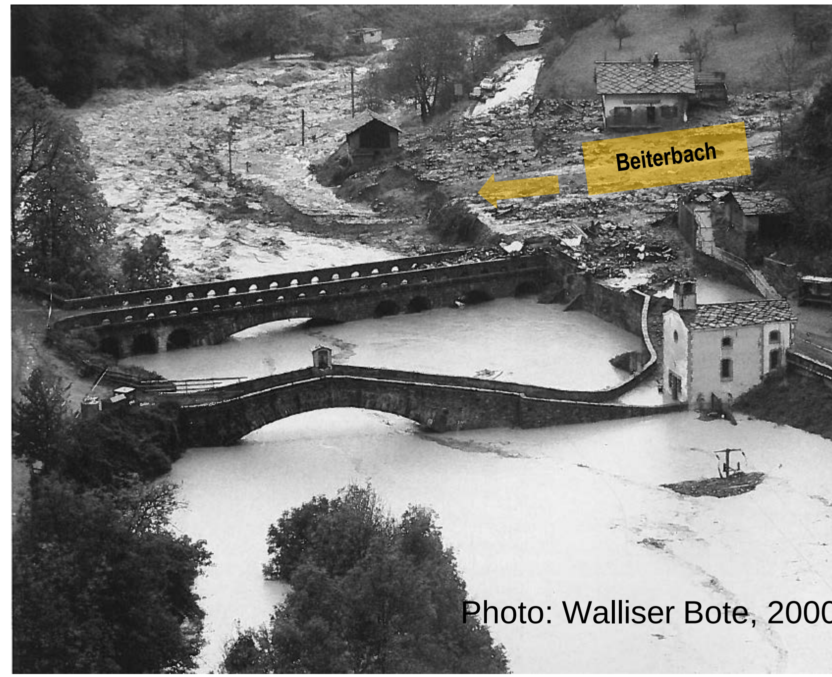

Photo: Walliser Bote, 2000

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Content

1) Direct bedload transport measurements

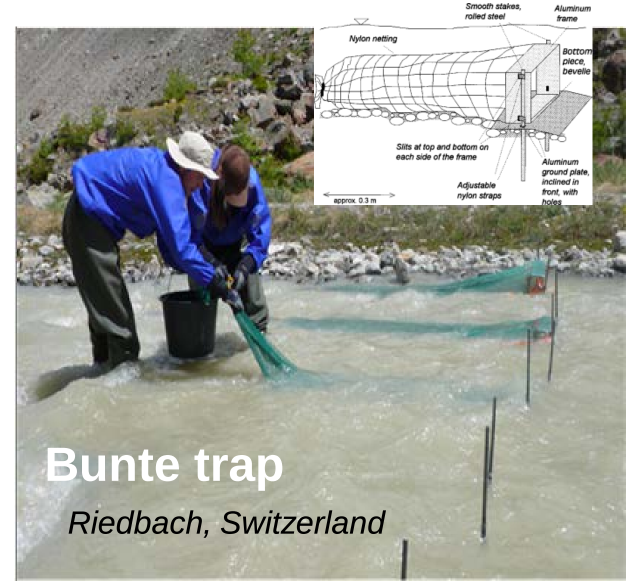
2) Surrogate bedload transport measurements
with acoustic systems

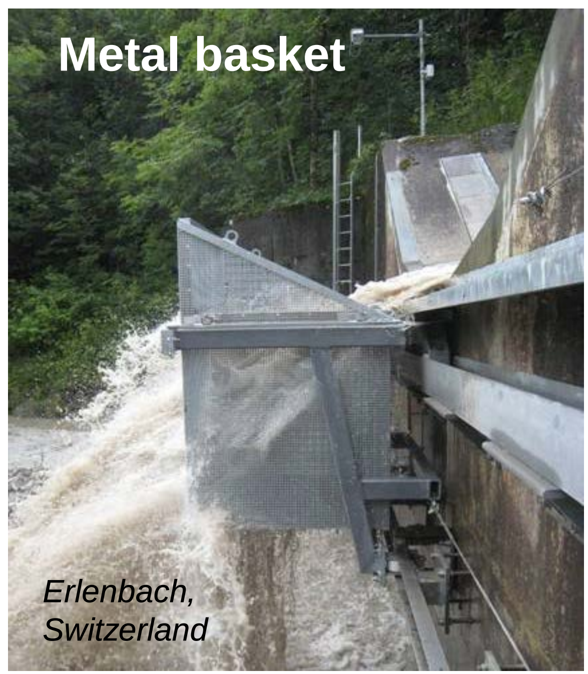
3) Bedload transport modelling: example
applications of the „sedFlow“ code

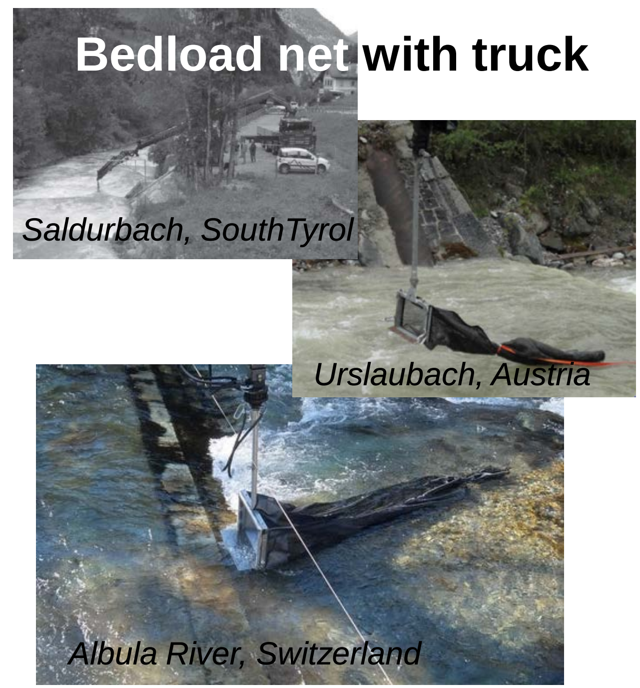
4) Concluding remarks

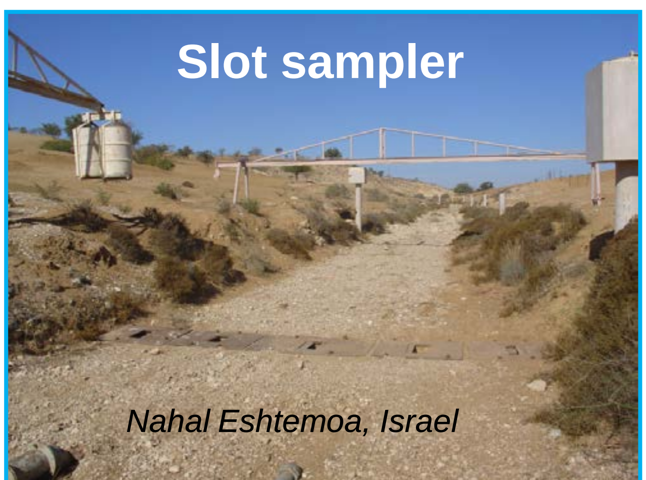
Direct measurements of bedload transport

Helley-Smith and pressure difference samplers

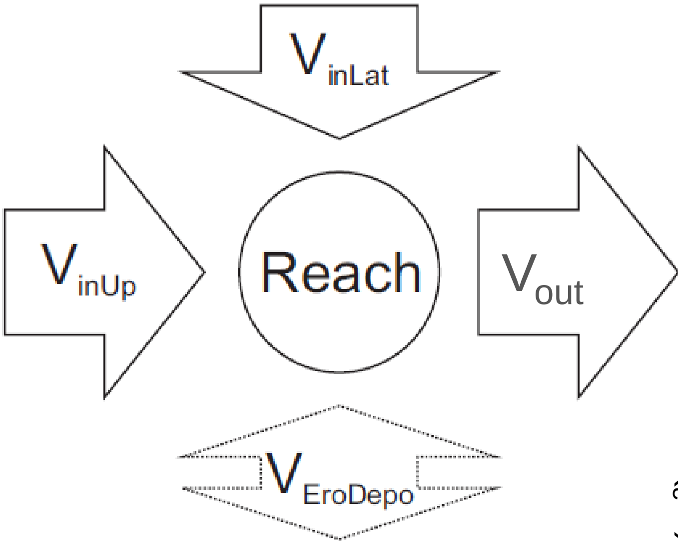


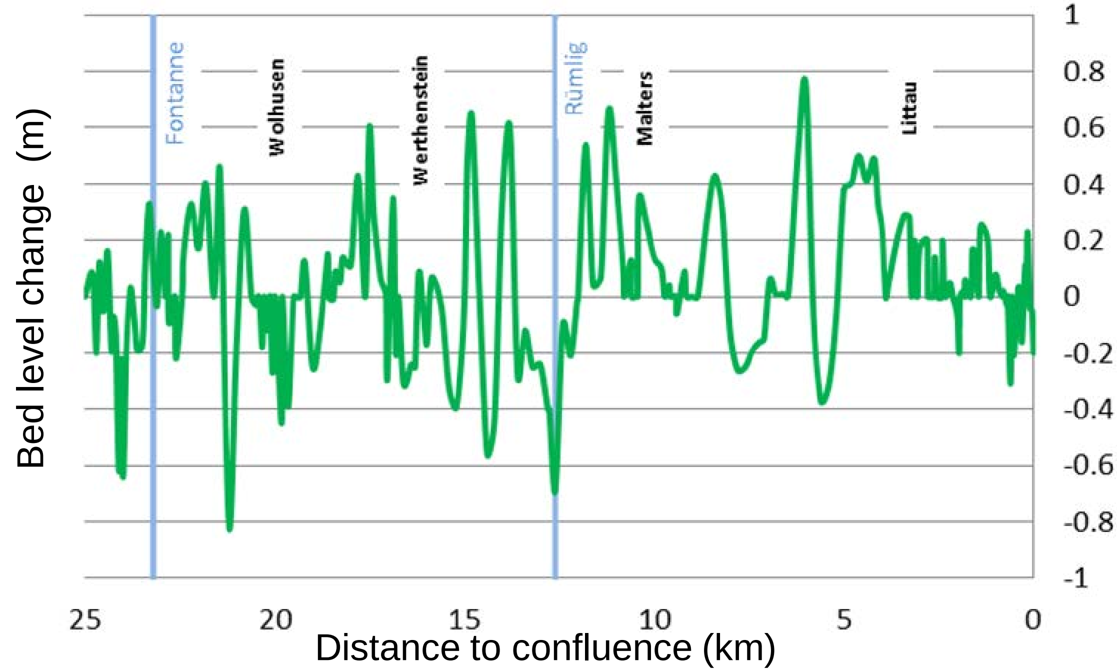


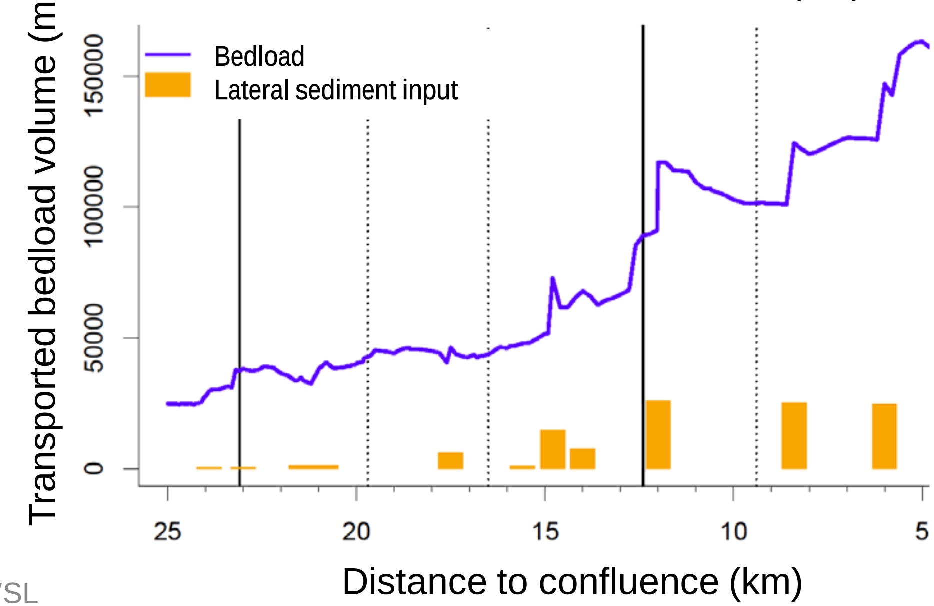




Sediment budget from repeated cross-section surveys

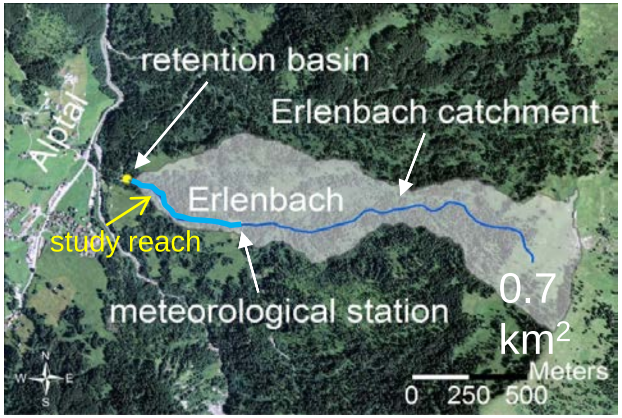






Example of Emme River
(sedFlow simulation)

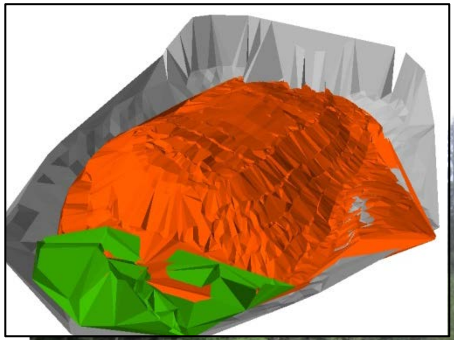
The Erlenbach bedload observatory



- small catchment (0.7 km^2)
- long-term sediment transport observations (>30 years)
- step-pool morphology
- channel slope: 0.17 mean; 0.105 us of station

Acoustic bedload measurements

(Swiss impact plate geophone)



Surveys of sediment deposits

Automatic bedload sampling with moving baskets (2009 ff)

Automatic bedload sampling with moving baskets (video)

video moving basket

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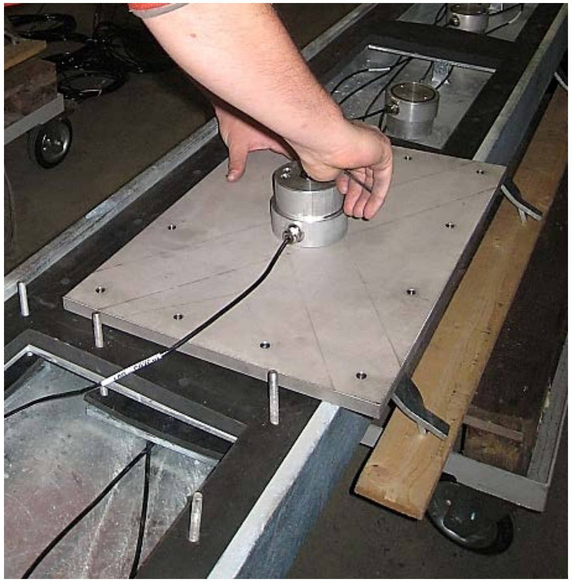
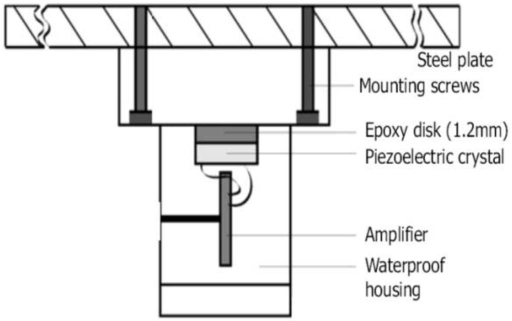
Different generations of acoustic systems

- Steel plates with standard dimensions (36 cm x 50 cm)
- acoustic isolation (elastomer)
- sensor mounted in aluminum housing, fixed in center of plate
- sensor records deformation velocity of steel plate



1986 – 1999
piezoelectric bedload impact sensor



2000 ff
geophone sensor

2016 ff
Miniplate accelerometer

2013 ff
Japanese pipe microphone

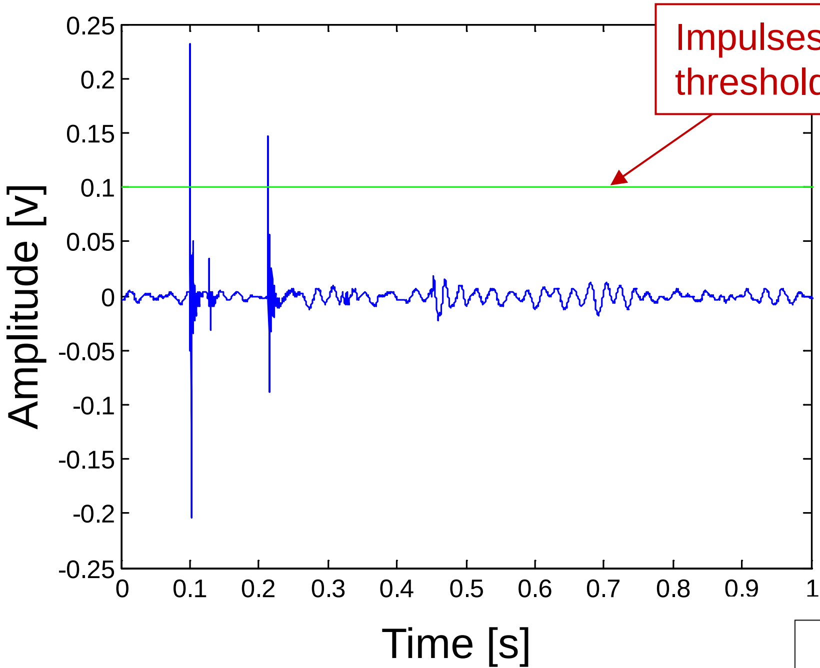
Swiss plate geophone measurements at various sites

Stream	Location	Drainage area (km^2)	Operation period (sensor type)	Calibration
Erlenbach (basin)	Alptal, Schwyz, CH	0.7	1986-1999 (PBIS), 2000+ (GS)	yes
Erlenbach (bridge)	Alptal, Schwyz, CH	0.5	1995-1997 (PBIS), 2002+ (GS)	–
Vogelbach	Alptal, Schwyz, CH	1.6	1999+ (GS)	–
Pitzbach	Pitztal, Tyrol, AT	27	1994-1995 (PBIS)	yes
Spissibach	Leissigen, Berne, CH	2.5	1998-2010 (PBIS)	yes
Rofenache	Vent, Tyrol, AT	98	2000+ (GS)	yes
Drau	Lienz, Tyrol, AT	1876	2002+ (GS)	yes
Drau	Dellach, Carynthia, AT	2300	2006+ (GS)	yes
Isel	Lienz, Tyrol, AT	1199	2006+ (GS)	yes
Schweibbach	Eisten, Valais, CH	9.7	2007+ (GS)	–
Fischbach	Mühlau, Tyrol, AT	71	2008+ (GS)	yes
Ruetz	Mutterbergalm, Tyrol, AT	28	2008+ (GS)	yes
Riedbach	Grächen, Valais, CH	18.7	2009+ (GS)	yes
Nahal Eshtemoa	Negev Desert, Israel	119	2009+ (GS)	yes
Elwha River	Washington, USA	833	2009+ (GS)	yes
Navisence	Zinal, Valais, CH	82	2011+ (GS)	yes
Ötztaler Ache	Sölden, AT	197	2011+ (GS)	yes
Urslau	Maria Alm, Salzburg, AT	55	2011+ (GS)	yes
Suggadinbach	St. Gallenkirch, AT	75	2013+ (GS)	yes
Ashiaraidani	Hodako Observatory, JP	6.5	2013+ (GS)	yes
Solda River	Valle Venosta, I	130	2014+ (GS)	yes
Albula River	Tiefencastel, CH	529	2015+ (GS, AS)	(yes)
Avancon de Nant	Pont de Nant, Vaud, CH	13.5	2015+ (GS)	(yes)

GS = geophone sensor, AS = Acceleration Sensor, PBIS = piezoelectric bedload impact sensor

(Rickenmann 2017, JHE)

Swiss plate geophone (SPG): Example of signal, Impuls counts

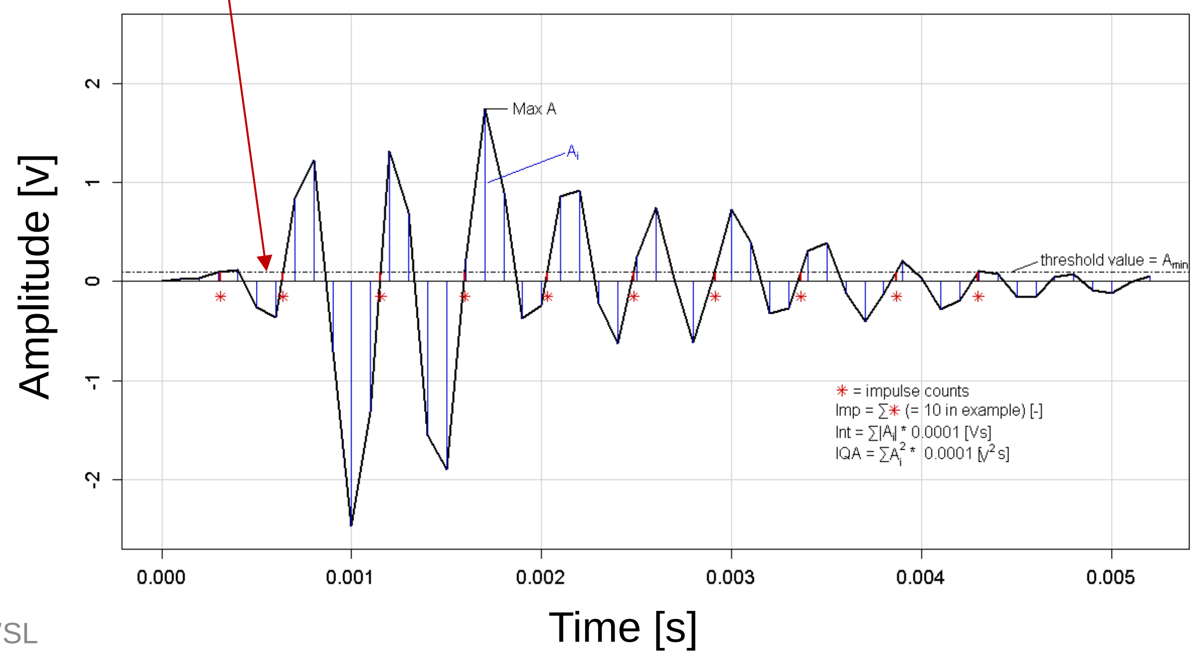


Impulses are recorded whenever the signal exceeds a predefined threshold value (on positive amplitude range), typically A_{min} = 0.1 V

Triggering and number of impulses depends on:

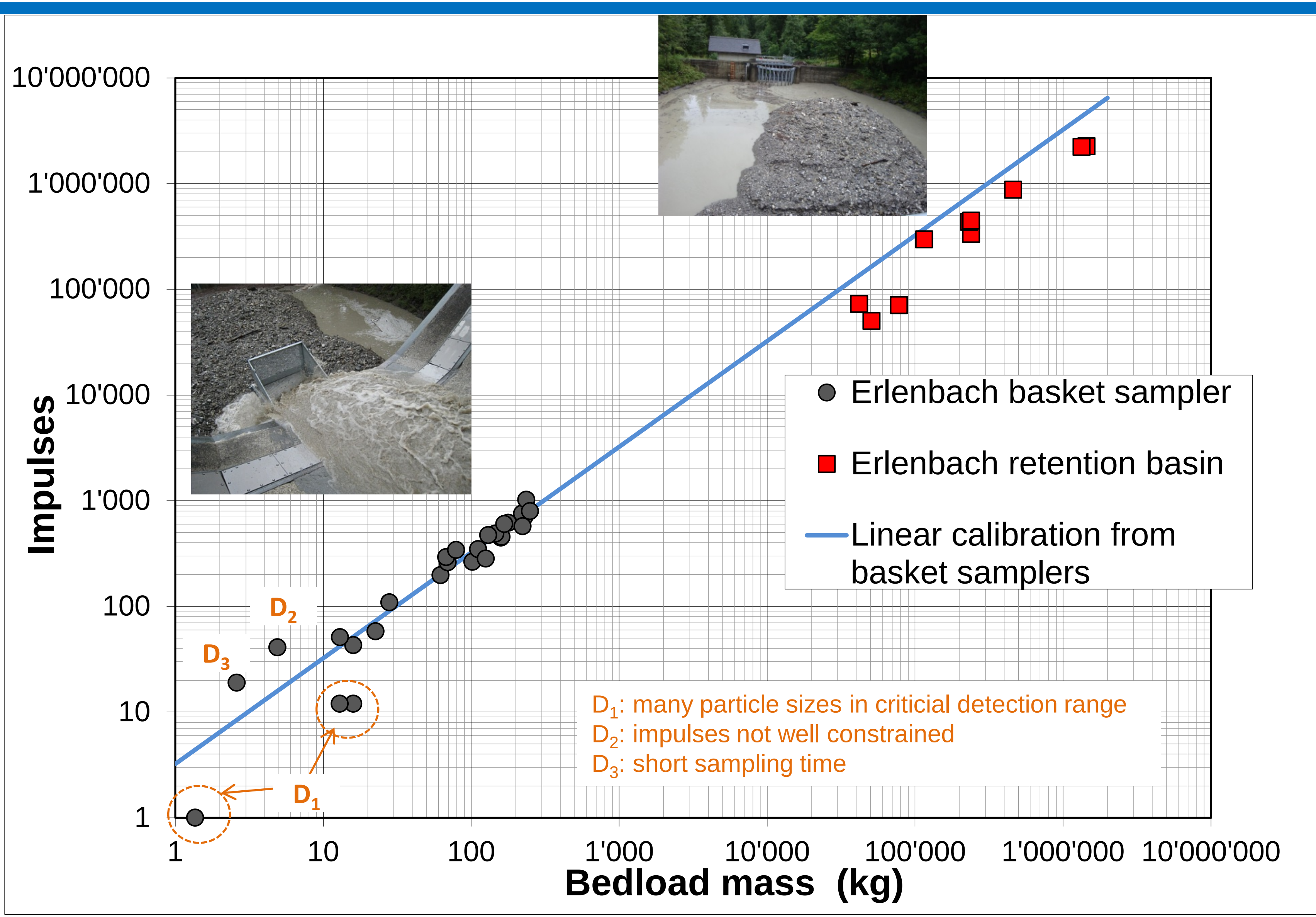
- grain size, grain shape, type of movement, number of grains, grain velocity
- limiting grain size is about 10 - 20 mm

Raw signal is recorded only at a few sites during the calibration measurements.



(Rickenmann et al. 2014, ESPL)

Calibration of the Swiss plate geophon system at the Erlenbach

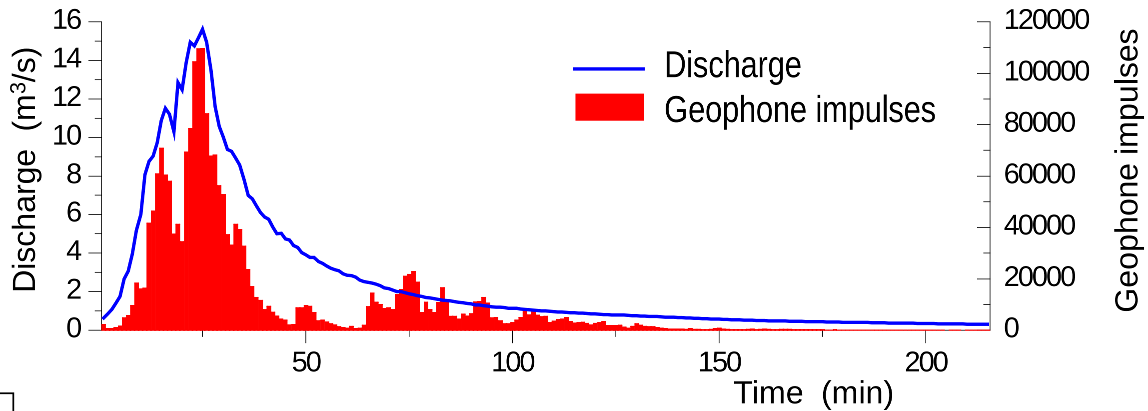


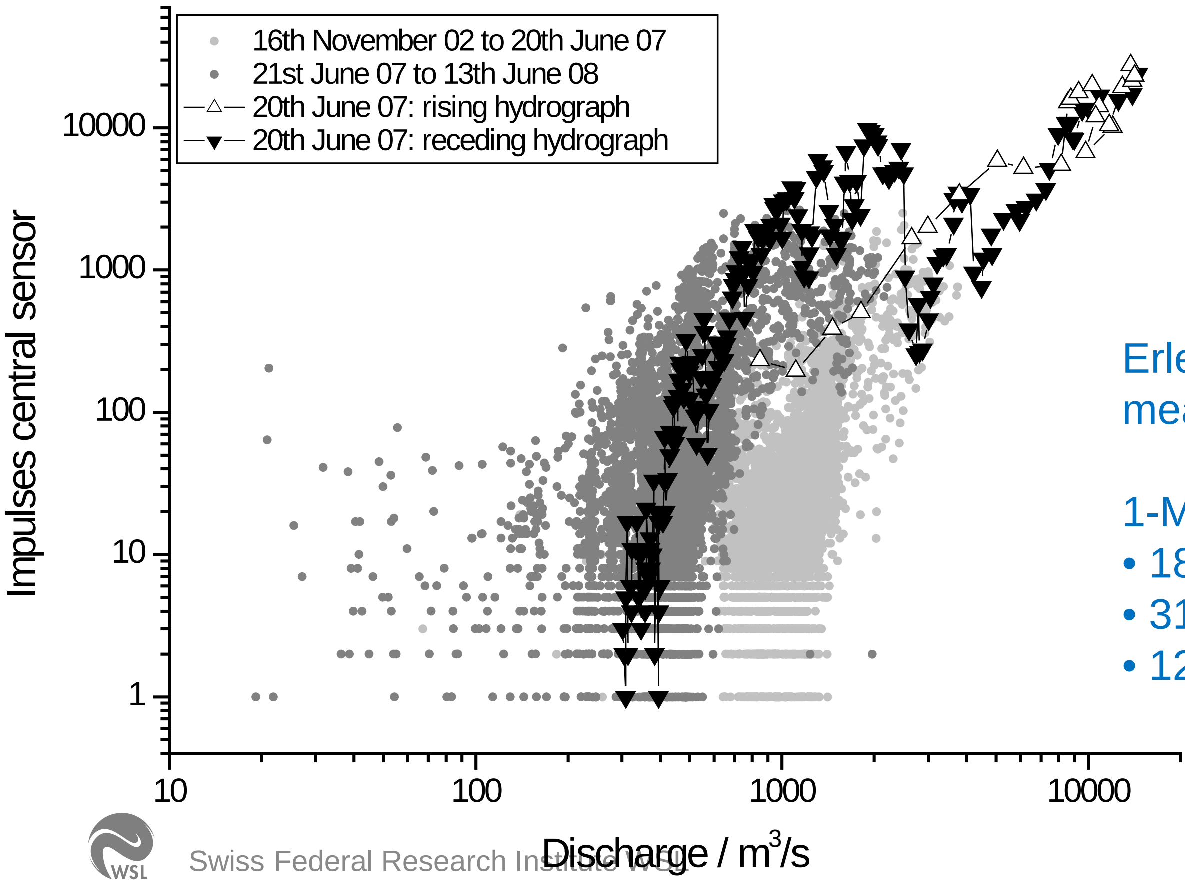
→ **Linear calibration between impulses and bedload mass works well at Erlenbach**

(Rickenmann et al. 2012 , ESPL)

Effect of extreme flood event (20 June 2007) on transport

- Large events influence bedload transport for several years
- Shift both in
  - Transport efficiency
  - Threshold of motion



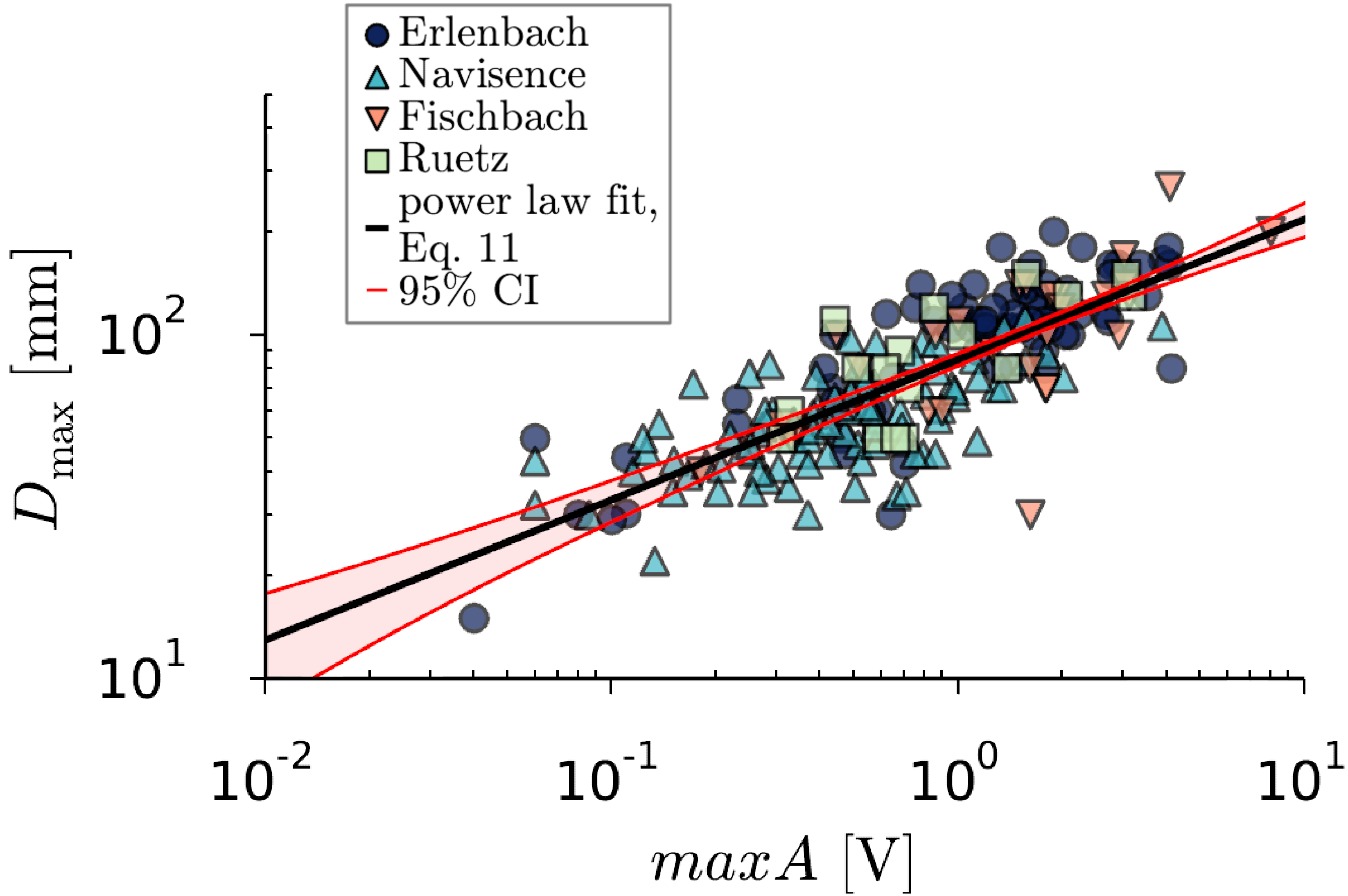


Erlenbach: Bedload transport measurement 2002-2010

1-Minute data
- 18990 data points
- 316.5 hours
- 128 individual events

(Turowski et al. 2009 , ESPL)

Comparison of SPG signal response at different sites



→ **Maximum grain size correlates with signal strength, almost independent of site**

(Rickenmann et al. 2014, ESPL; Wyss et al. 2016, WRR)

Grain size identification and flux estimation with the SPG

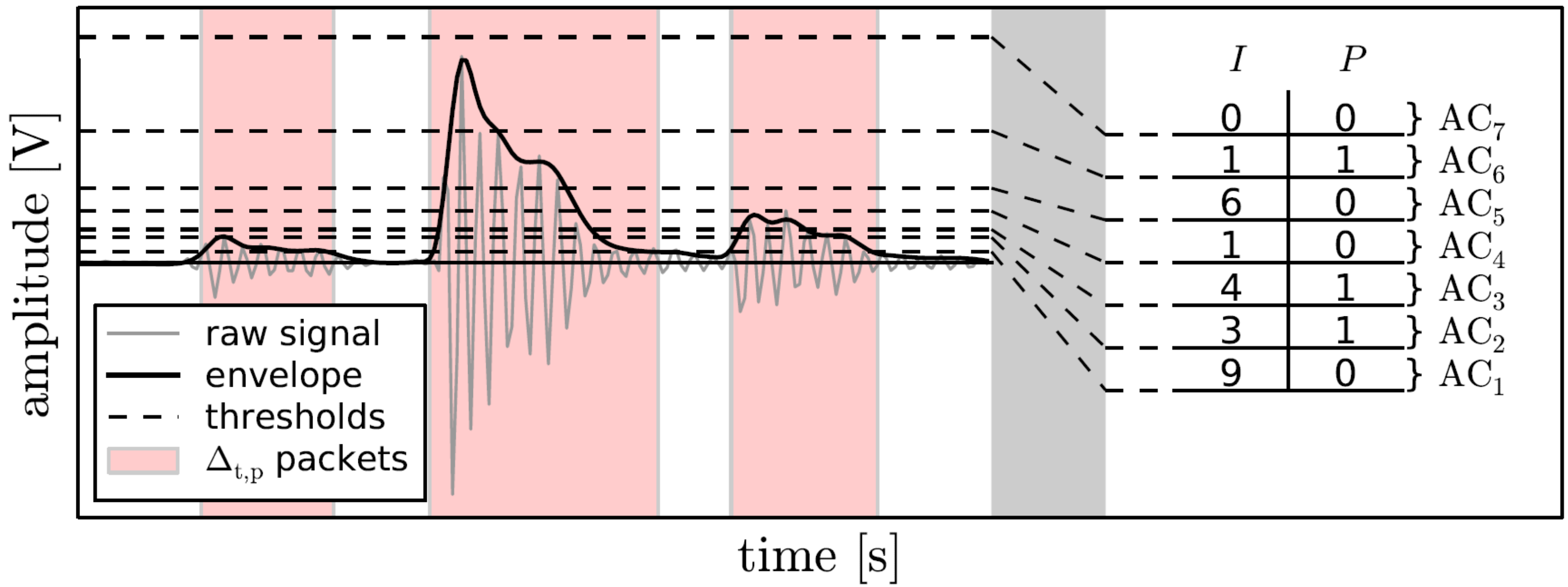
→ Amplitude Histogram method

Hypothesis:

→ signal amplitude is a function of the size of the transported particle

→ every particles collides only once against the steel plate

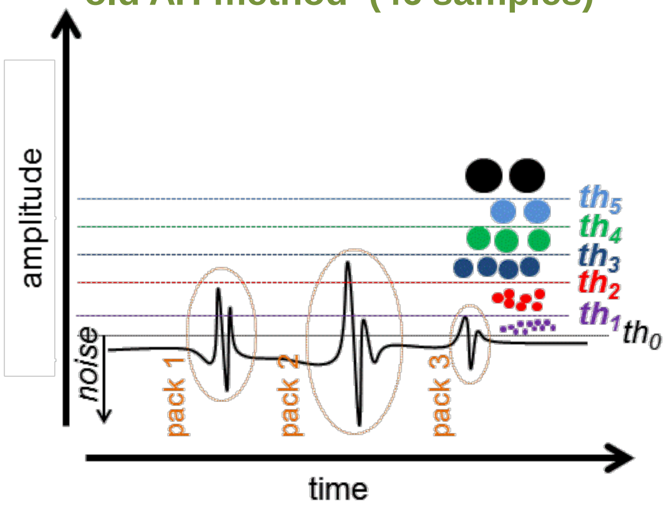
→ amplitude thresholds can discriminate between grain-size classes



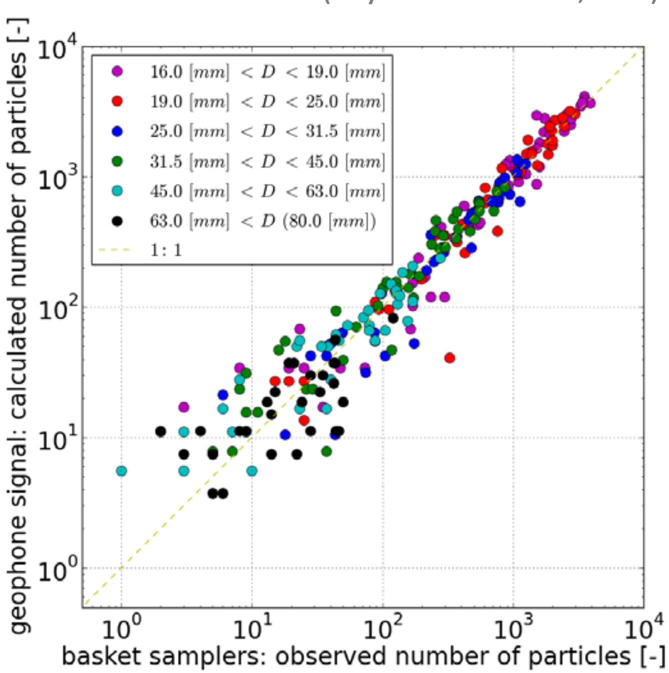
(Wyss et al. 2015, JHE)

Grain size identification: Amplitude Histogram (AH) method

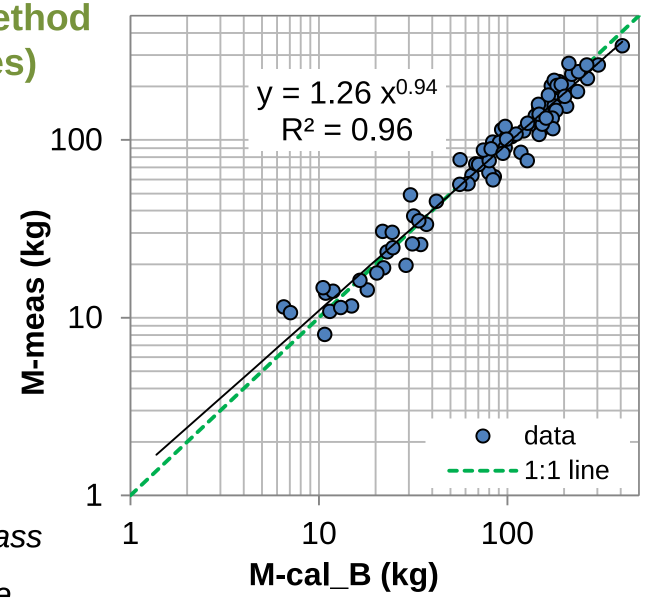
old AH method (46 samples)



(Wyss et al. 2016, JHE)

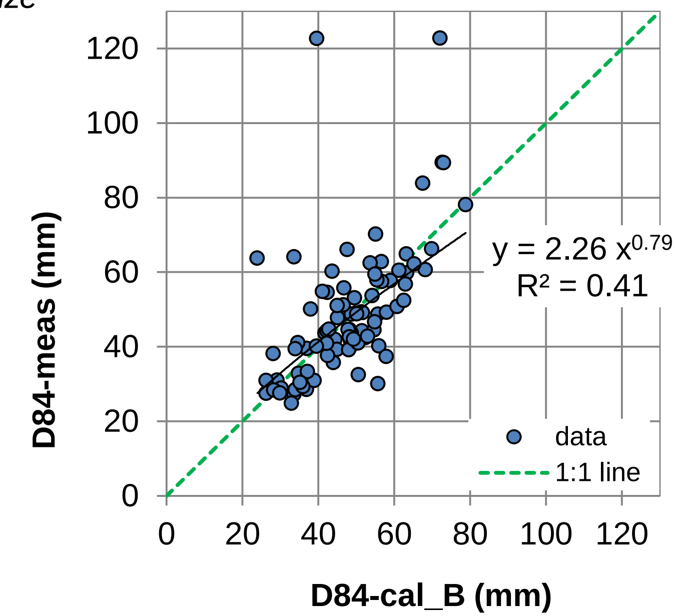


new AH method (88 samples)



M = bedload mass

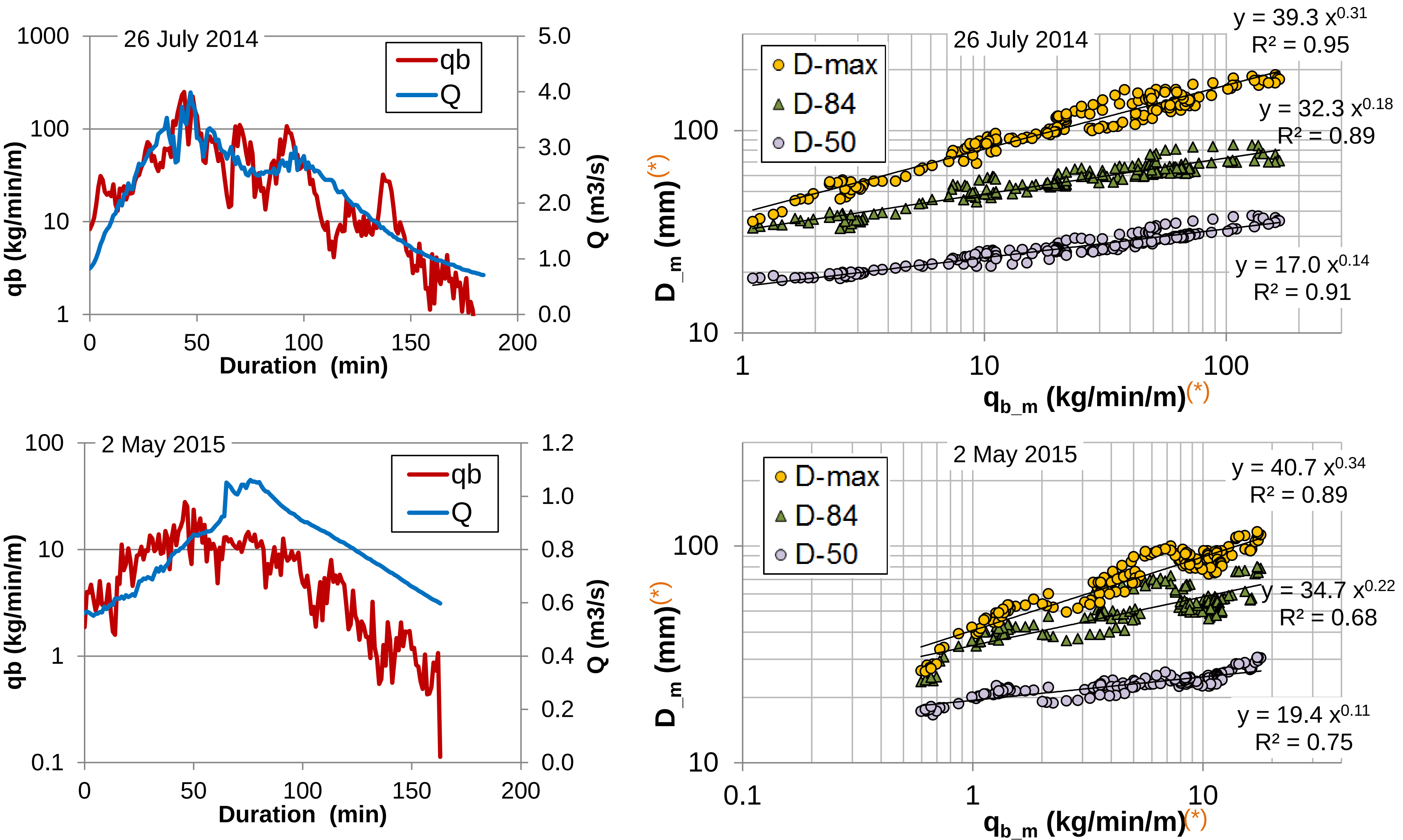
D84 = grain size



(Rickenmann et al. 2018, River Flow)

Application of AH method to Erlenbach

(*) moving average over 10 min



→ Grain sizes correlate with bedload flux (over 2 orders of magnitude)

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sedFlow-WSL: 1d bedload transport simulation

Main objectives

Application to mountain rivers, fast computations (multiple scenarios)

Key elements

- rectangular cross section, 1-dimensional calculation (hydraulics and bedload transport)
- fractional bedload transport calculations, active layer, evolution of longitudinal profile
- optional limitation of erosion depth (bedrock, large boulders)
- channel network, lateral water and or sediment input (fluvial or debris flows)

Hydraulics

- kinematic wave (explicit, implicit with analytic approximation after Liu & Todini 2002)
- simplified hydraulics (no flow routing), also allowing for adverse bed slopes
- variable power equation of Ferguson (2007) for steep and shallow flows

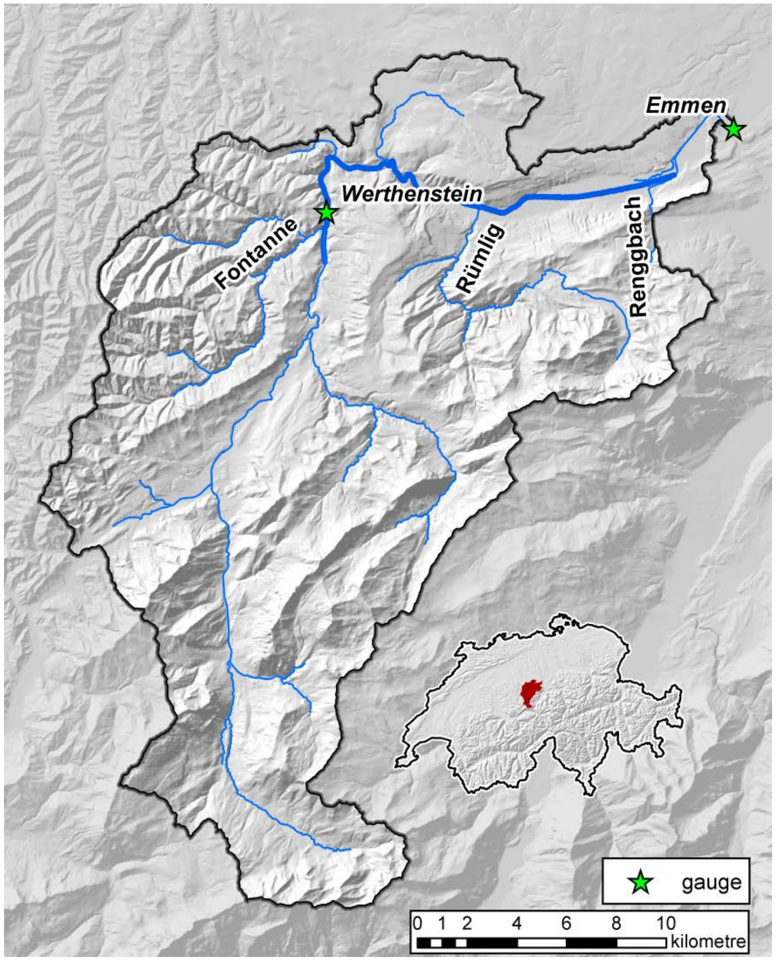
Bedload transport

- Lamb et al. (2008) for initiation of motion
- Rickenmann (2001) or Wilcock-Crowe (2003) for transport
- use of reduced energy slope to account for macro-roughness (Rickenmann-Recking 2011)

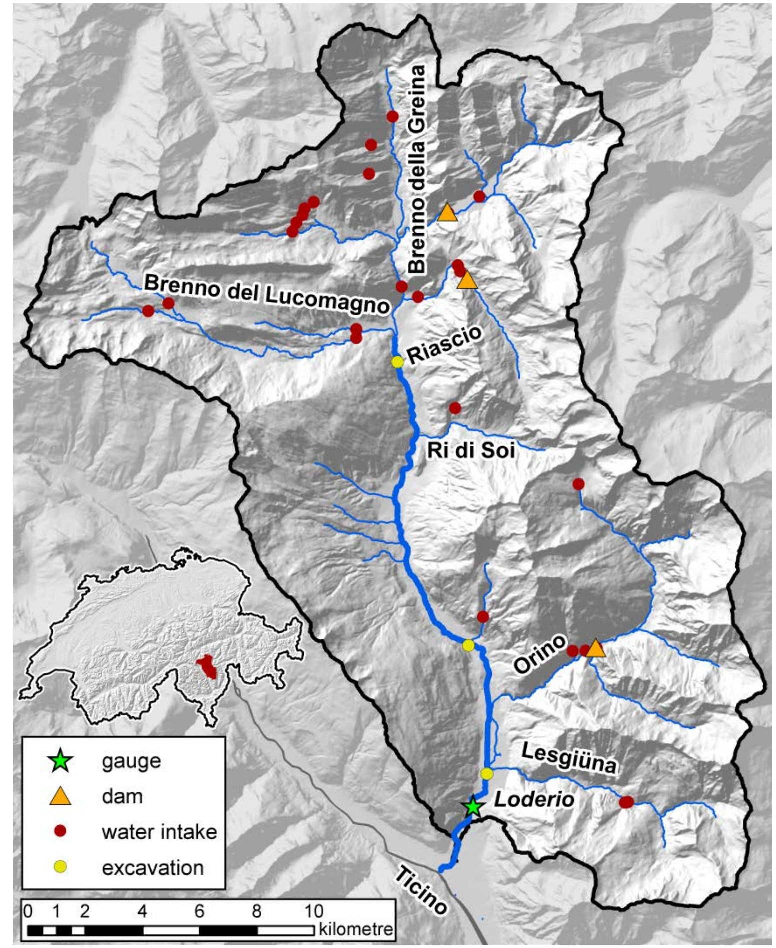
(Heimann et al. 2015a, 2015b)

sedFlow: calibration in Swiss mountain rivers

Kleine Emmer River



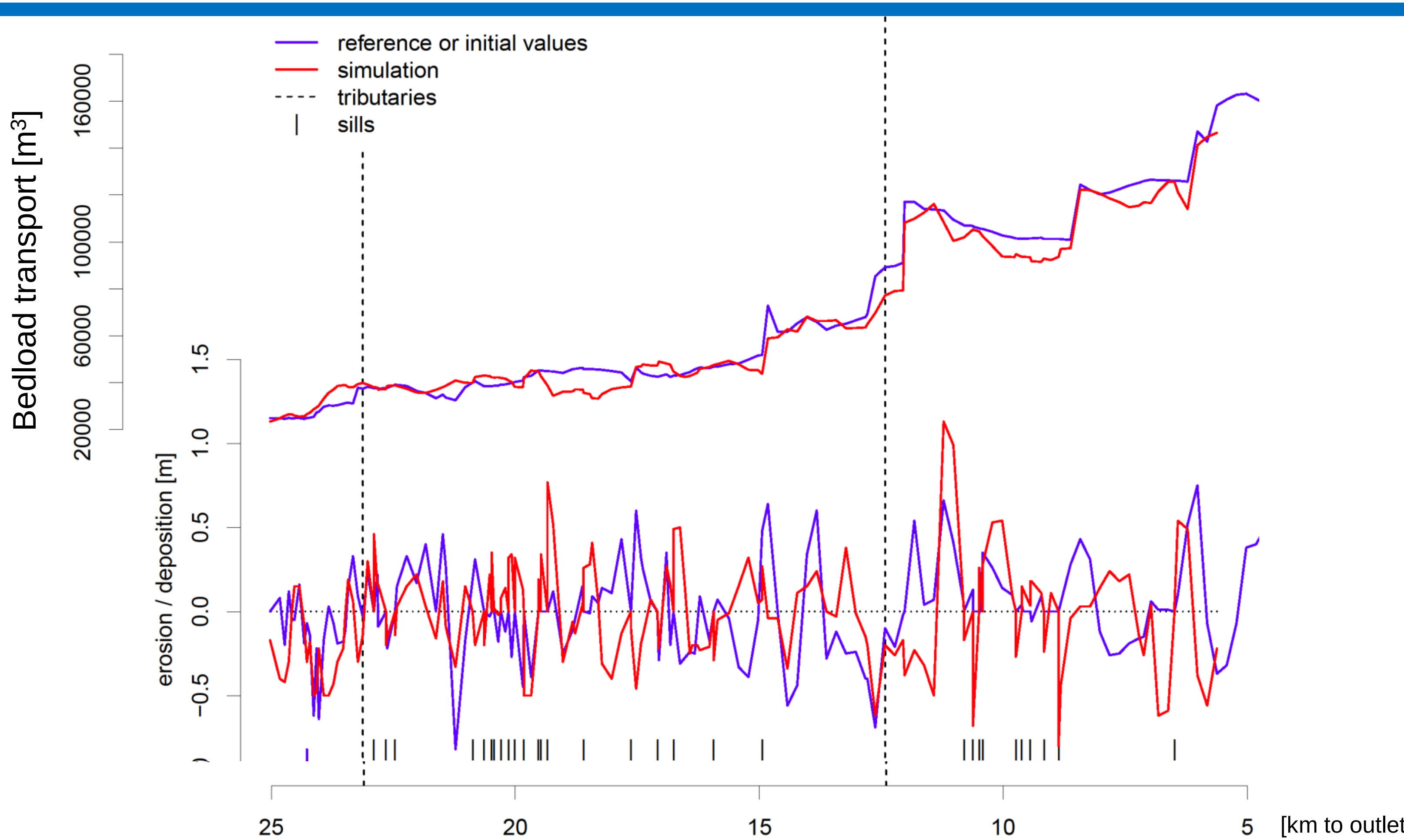
Brenno River

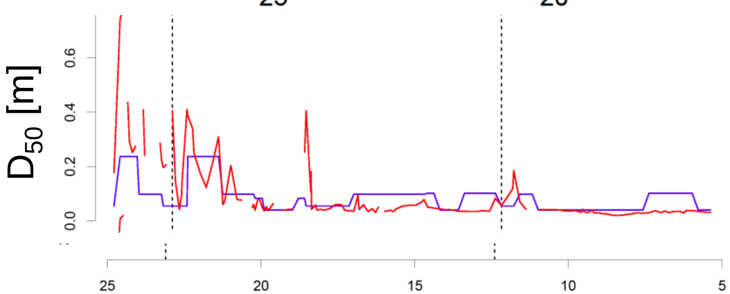


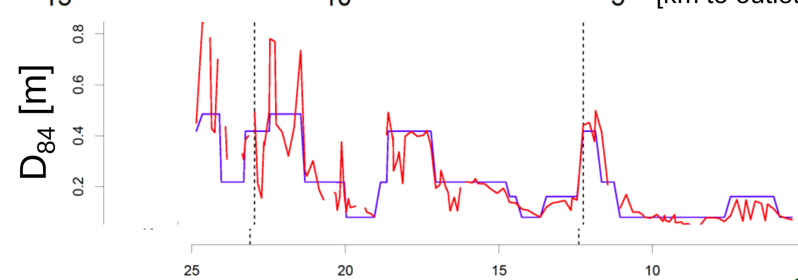
Kleine Emmer River		Brenno River
480 km²	catchment size	**400 km²**
2000 - 2005	cross-section surveys	**1999 - 2009**

(Heimann et al. 2015a, 2015b)

sedFlow calibration: Kleine Emme River

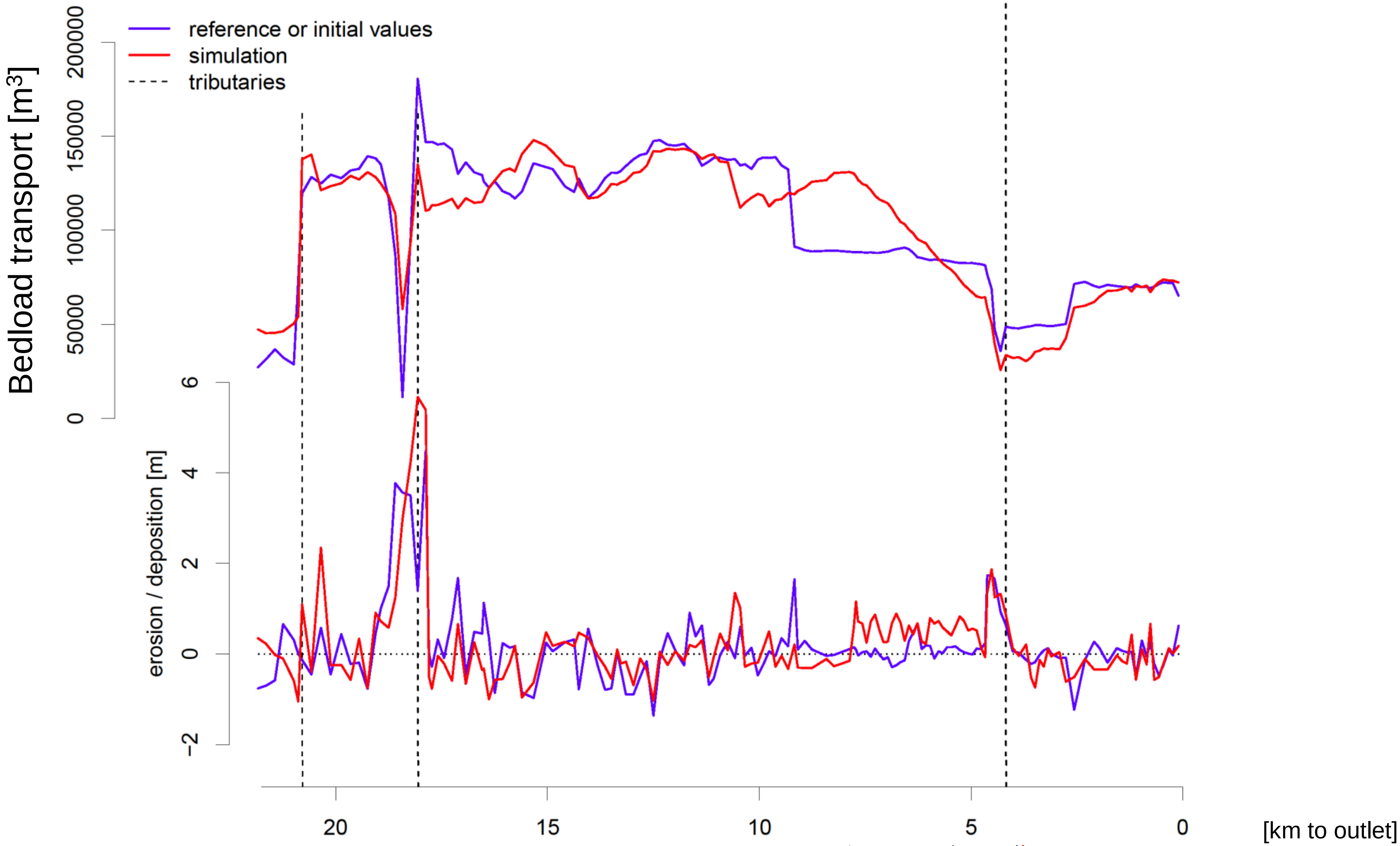


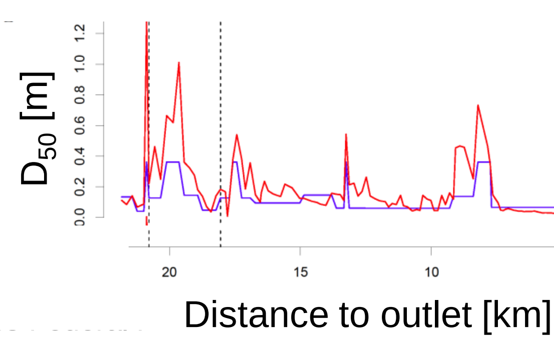


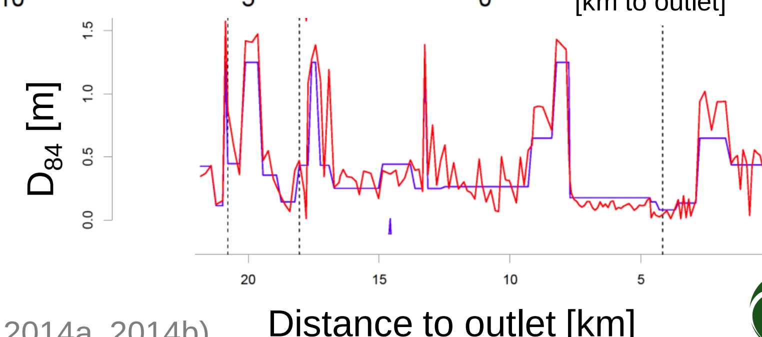


Distance to outlet [km] (Heimann et al. 2015a, 2015b) Distance to outlet [km]

sedFlow calibration: Brenno River

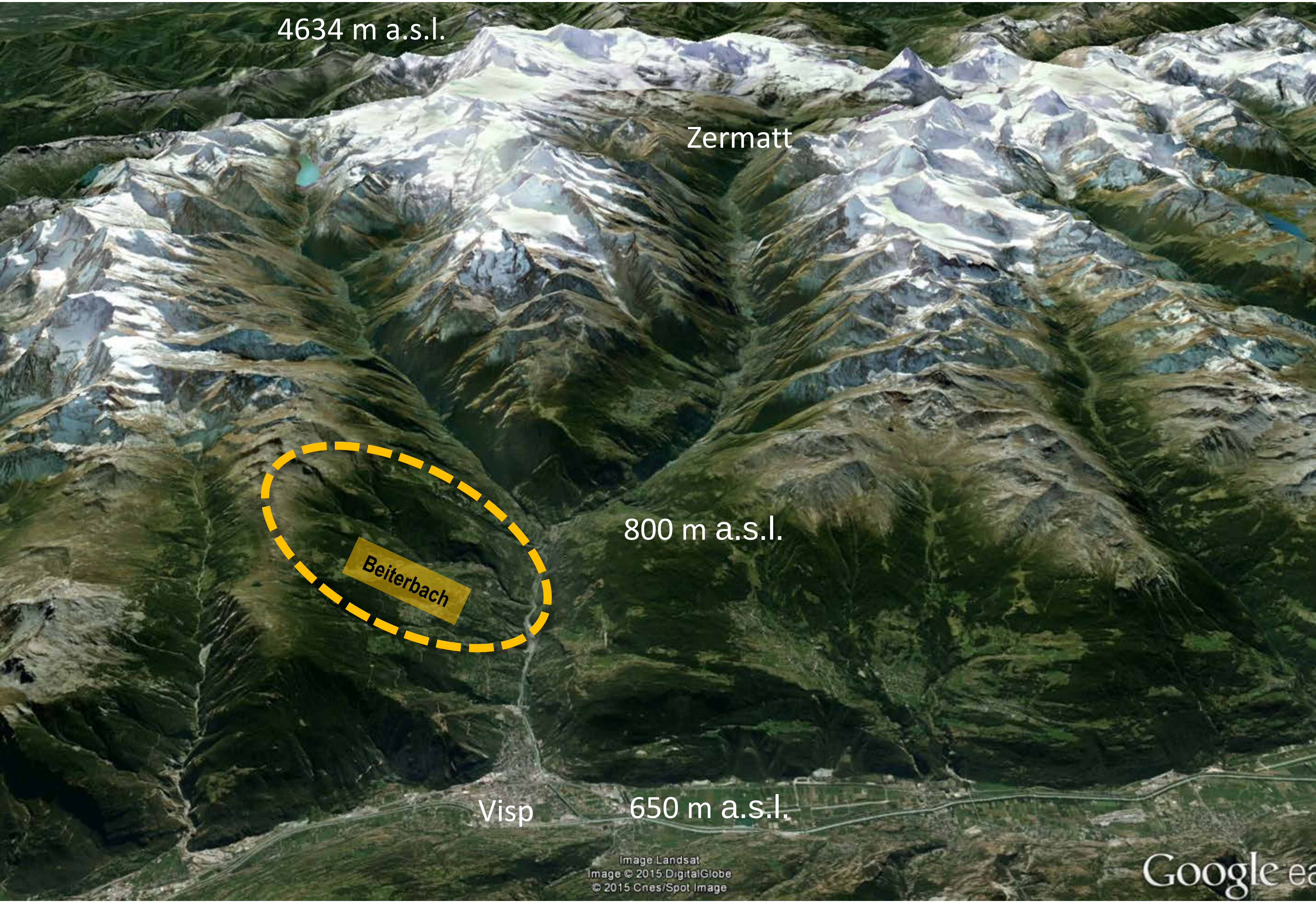






Heimann et al. 2014a, 2014b)

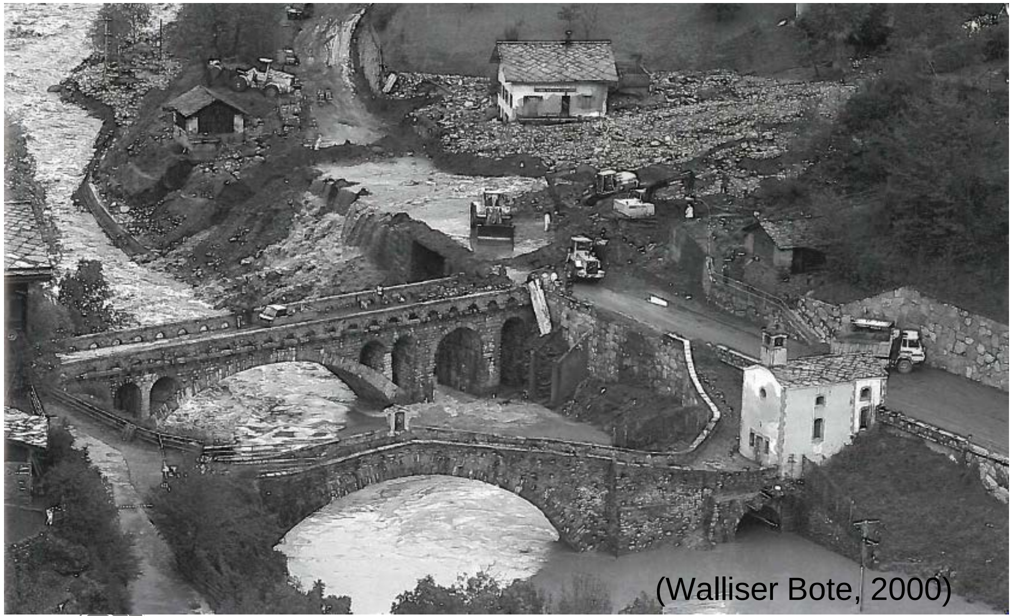
Application of sedFlow + BASEMENT: Vispa + debris flow



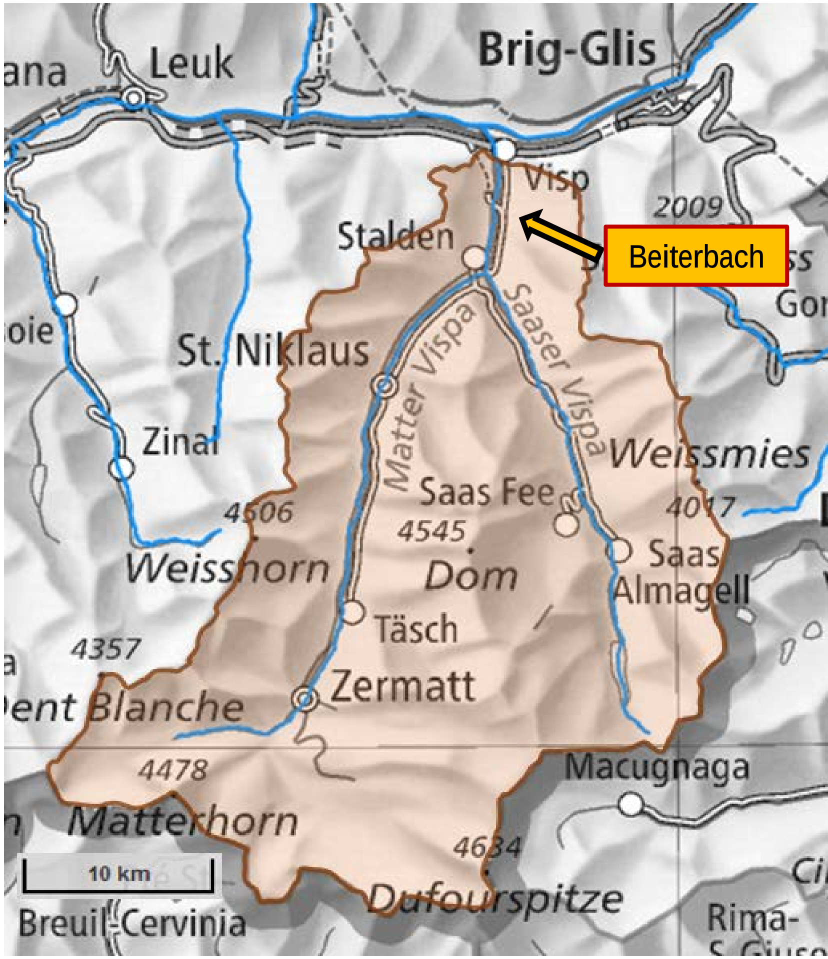
sedFlow application: Vispa River + debris flow input

Flood event of 14-16 October 2000

- Debris flow event on 15 October near Neubrück (north of Stalden)
- Debris flow Beiterbach: sediment input into Vispa River: 60,000 – 80,000 m^3, in three surges
- Two fatalities, damage to (railroad) infrastructure, damming of Vispa River, changes of channel morphology

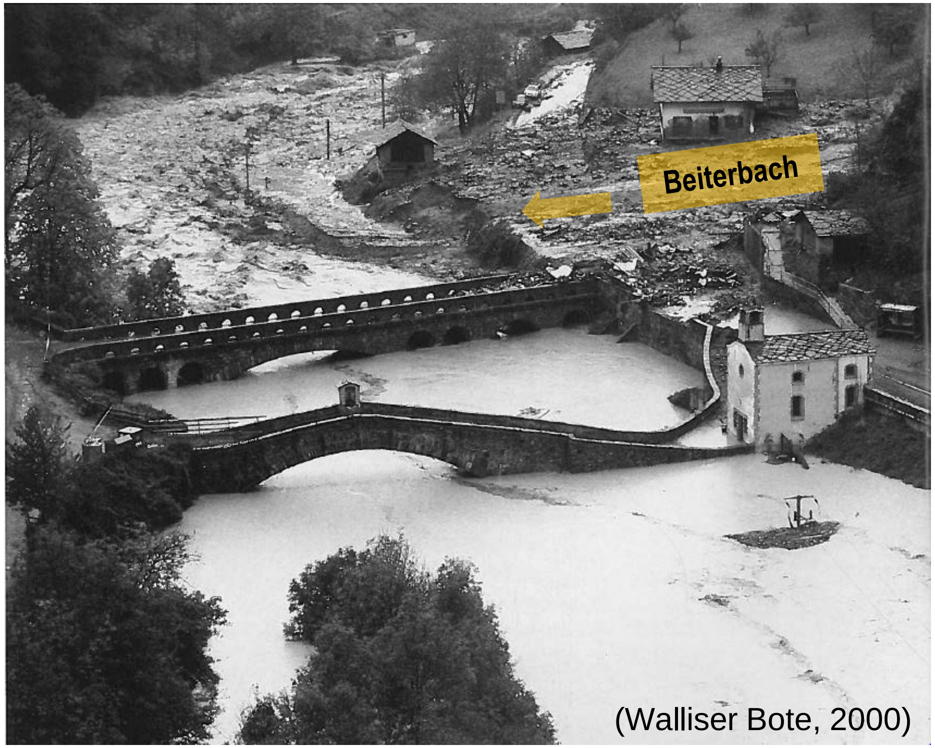


(Walliser Bote, 2000)

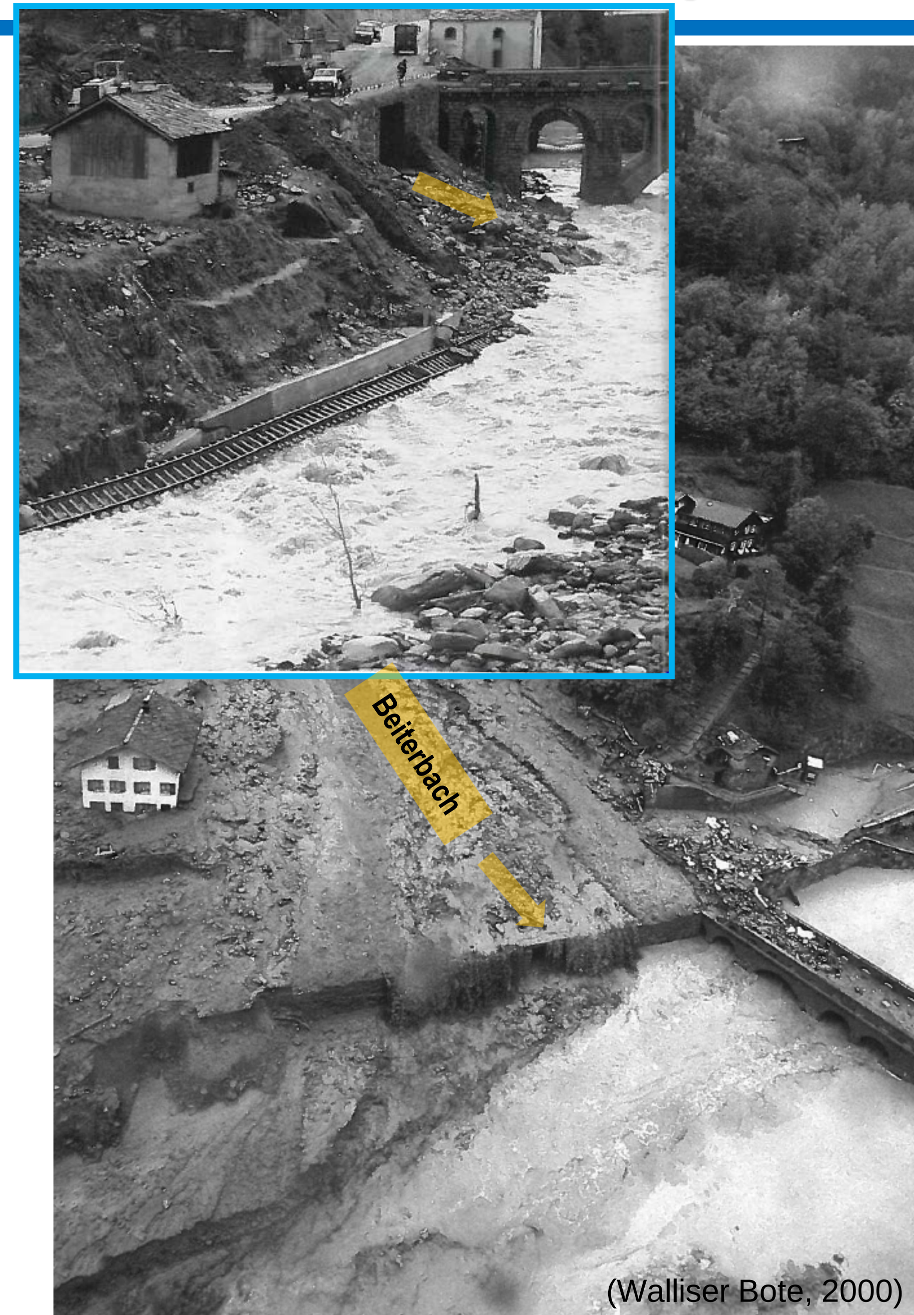


(Briner 2016)

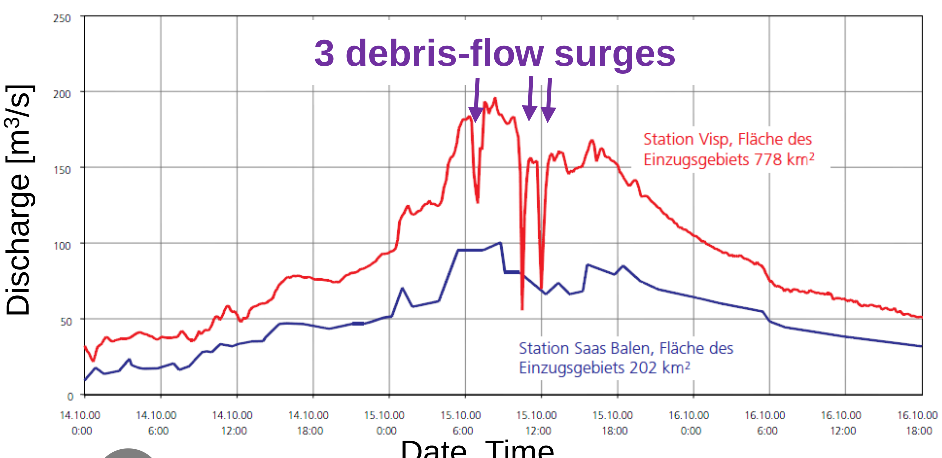
sedFlow application: Vispa River + debris flow input



(Walliser Bote, 2000)



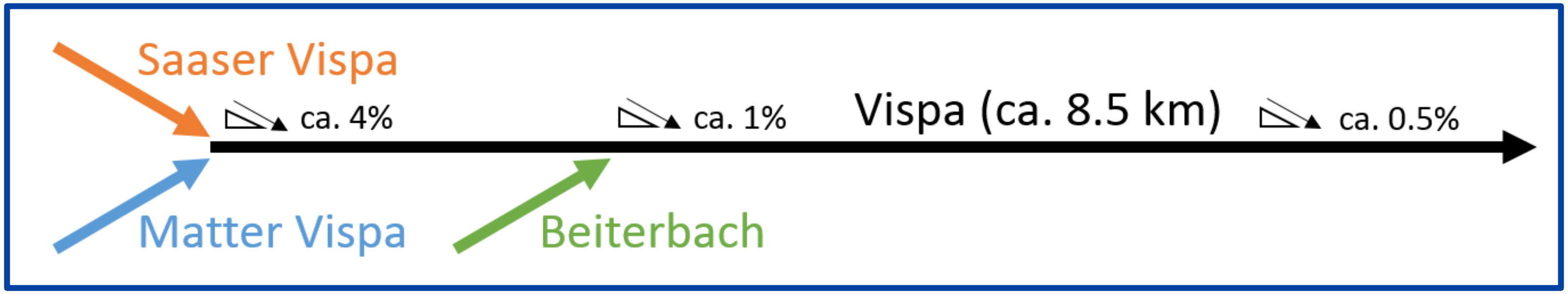
(Walliser Bote, 2000)

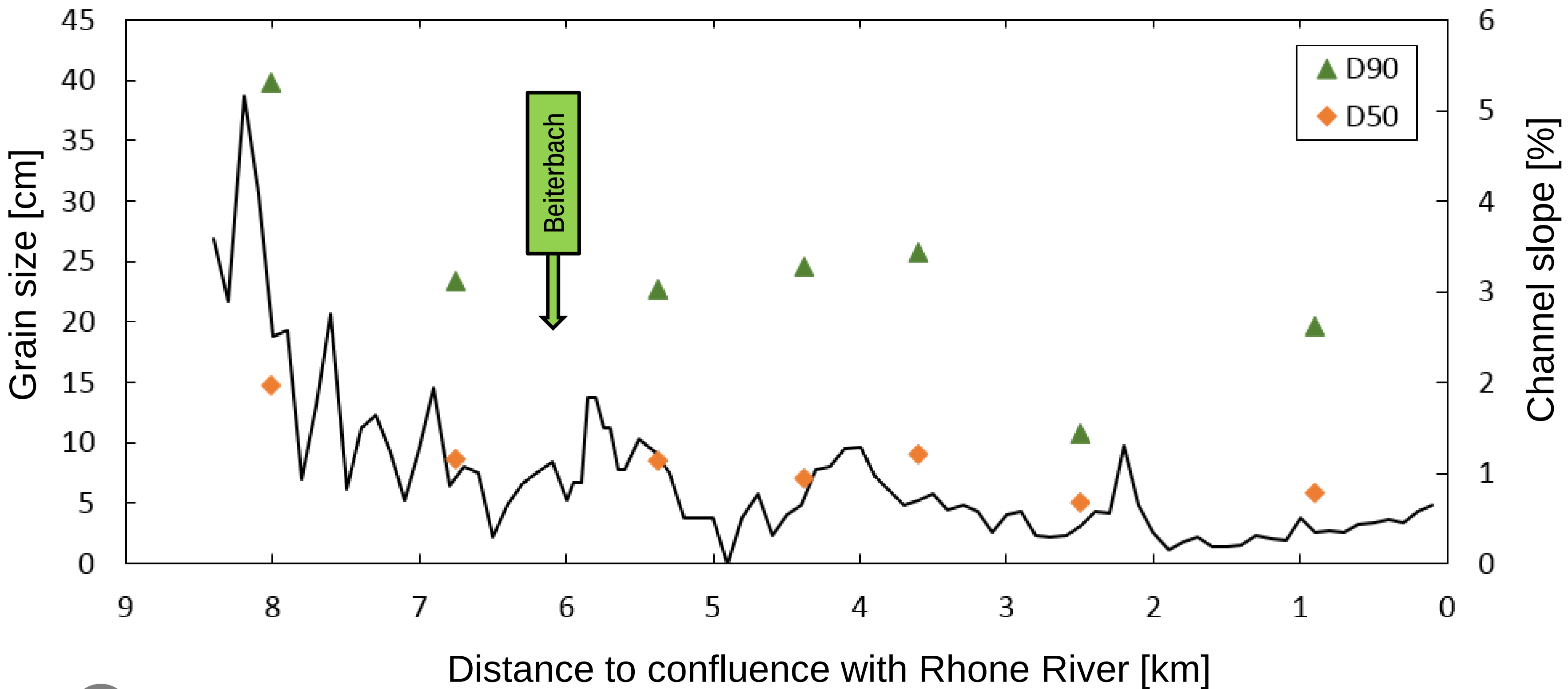


(Teysseire & Nigg, 2002)

sedFlow application: Vispa River + debris flow input

Flood event of 14-15 October 2000

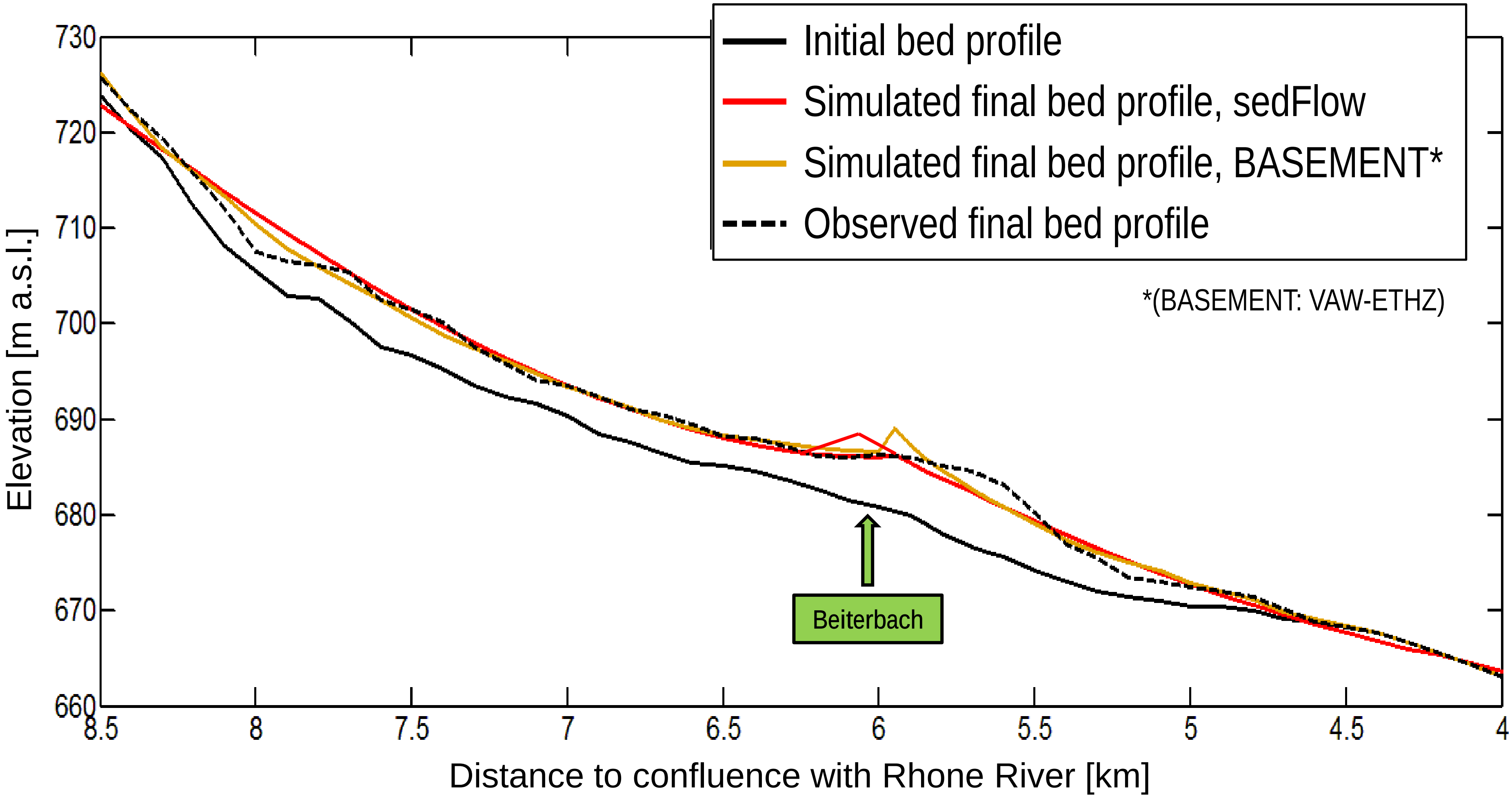




(Briner 2016; Rickenmann 2017)

sedFlow application: Vispa River + debris flow input

Flood event of 14-15 October 2000



(Briner 2016; Rickenmann 2017)

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Concluding remarks

Bedload transport monitoring in steep rivers

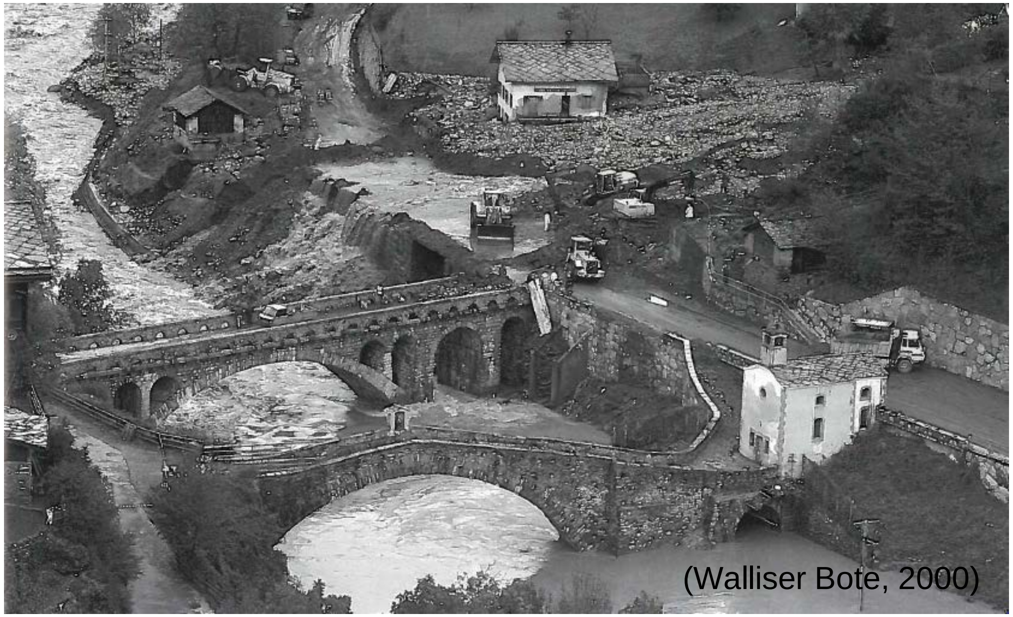
- **Direct bedload sampling in mountain rivers is possible (up to mean flow intensities) but challenging**
- **The Swiss plate geophone (SPG) system can be used to determine both total bedload flux and fractional bedload transport rates**
- **SPG or similar acoustic bedload transport measurements are helpful to improve the process understanding of bedload transport**

Bedload transport simulations in mountain rivers

- **for example cases: bed level changes and sediment budget is rather well constrained**
- **simulated changes (sedFlow examples) in bed level and total transported bedload agree reasonably well with observations**
- **note calibrated components: GSD (Kleine Emme), channel width (Brenno), channel slopes of tributaries (Vispa,** sedFlow**), selection of bedload equation (**BASEMENT**)**

Thank you for the attention.

Questions?



(Walliser Bote, 2000)