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and Deposition of Sediments"
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Debris flows and sediment transport in steep catchments

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Debris flows + sediment transport in torrents

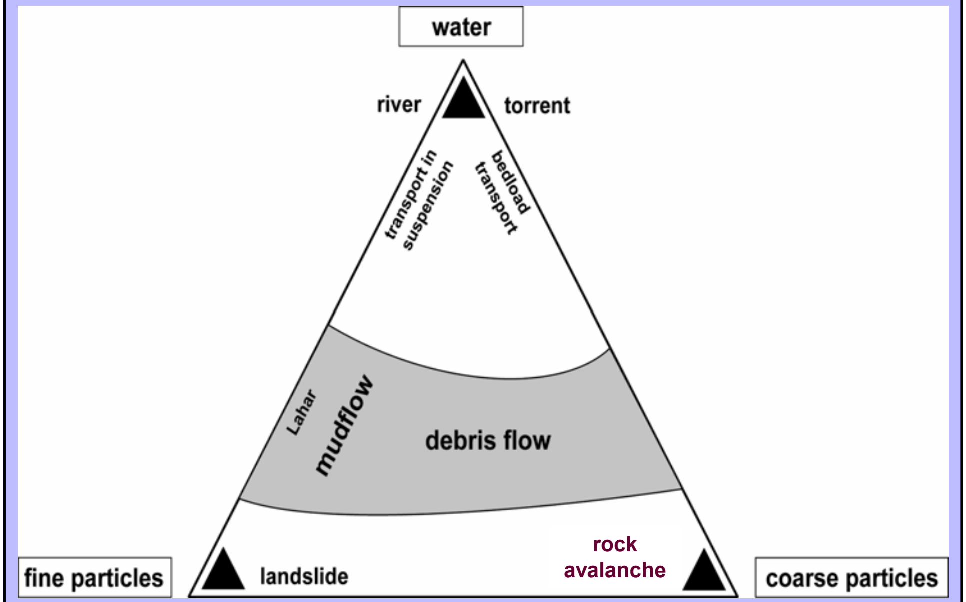
Sediment transport processes in torrent channels

Sediment transport

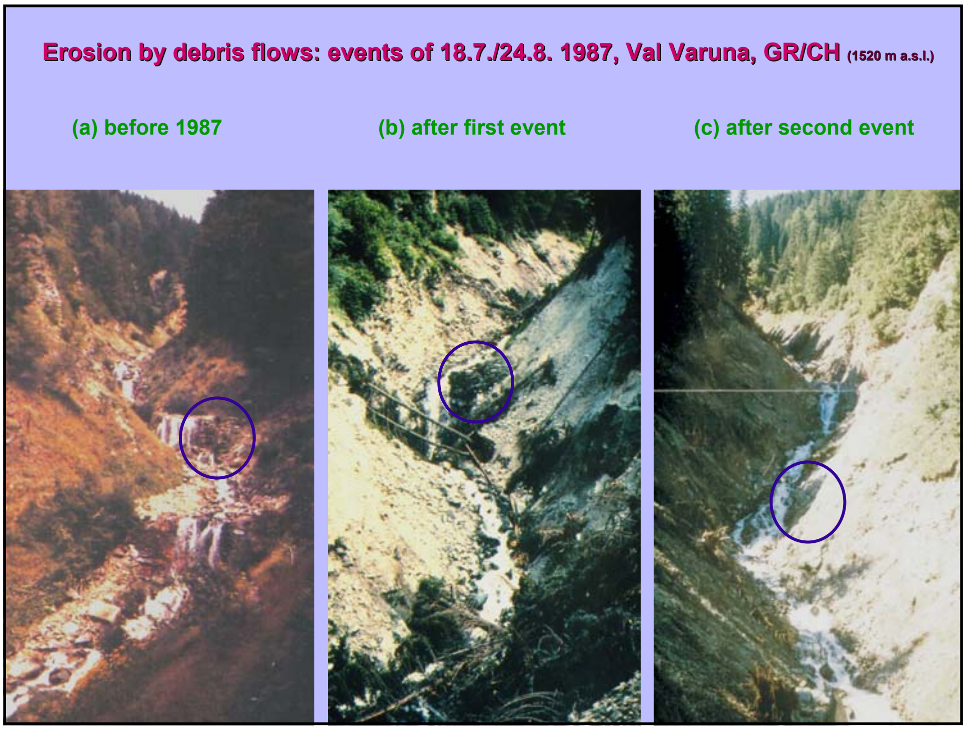
Debris flow

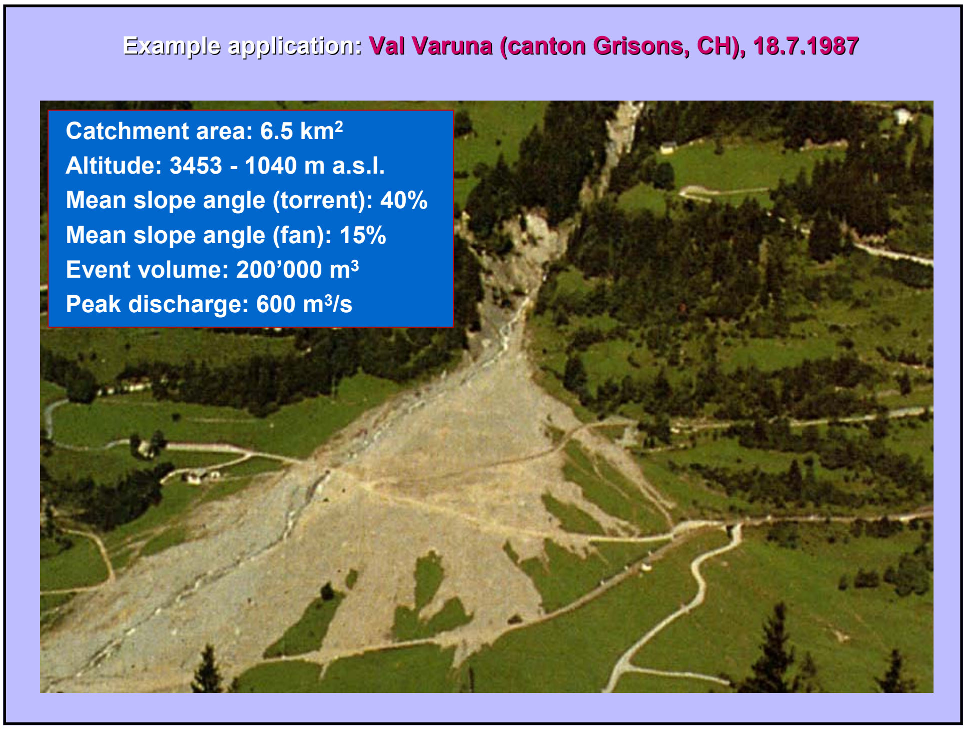
Structure of content

Fast mass movements: variability of material composition

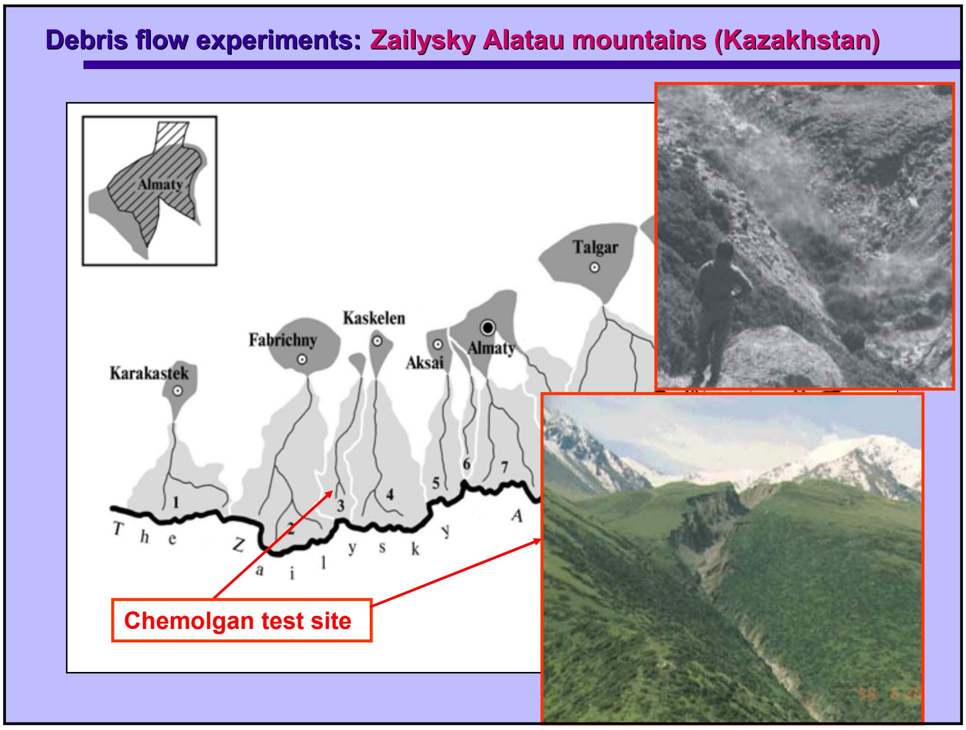


Debris flow initiation by landsliding


Erosion by debris flows: events of 18.7./24.8. 1987, Val Varuna, GR/CH (1520 m a.s.l.)
(a) before 1987
(b) after first event
(c) after second event


Example application: Val Varuna (canton Grisons, CH), 18.7.1987
Catchment area: 6.5 km²
Altitude: 3453 - 1040 m a.s.l.
Mean slope angle (torrent): 40%
Mean slope angle (fan): 15%
Event volume: 200'000 m³
Peak discharge: 600 m³/s


Flooding due to aggradation (Poschiavino/Val Varuna, CH, 18.7.87)
debris flow


Debris flow experiments: Zailysky Alatau mountains (Kazakhstan)
Almaty
Talgar
Kaskelen
Fabrichny
Aksai
Almaty
Karakastek
1
2
3
4
5
6
7
The Zailysky A
Chemolgan test site

Transition sediment transport - debris flows

Takahashi (1991), equilibrium sediment concentration in debris flows (theory + experiments):

$$C_s / C^* = (s - 1) \tan\theta / [(\tan\phi - \tan\theta) / C^*]$$

(Rickenmann 1990), bedload transport experiments:

$$Q_b = 6.8\, Q_m\, S^{2.1} \implies C_s / C^* = 6.8\, S^{2.1} / (6.8\, S^{2.1} + 1)$$

Tognacca (1999), laboratory experiments on debris flows + bedload transport experiments of Smart/Jäggi:

$$C_s / C^* = [\tanh(9.0\, S_e^{0.85} - 2.4) / 2.3] + 0.43$$

C_s : volume sediment concentration of the flow

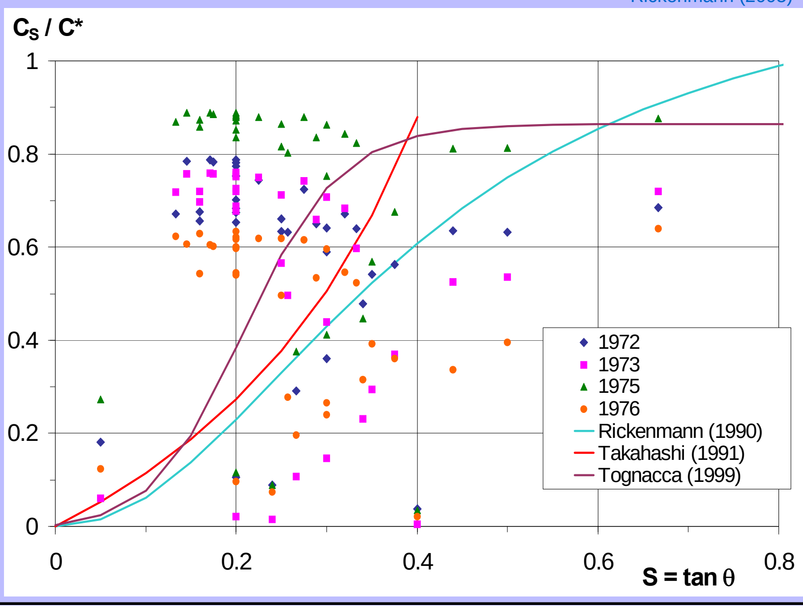
C^* : maximum packing density of the bed material

$S_e \approx S$: energy slope or bedslope ($\tan\theta \approx \sin\theta$)

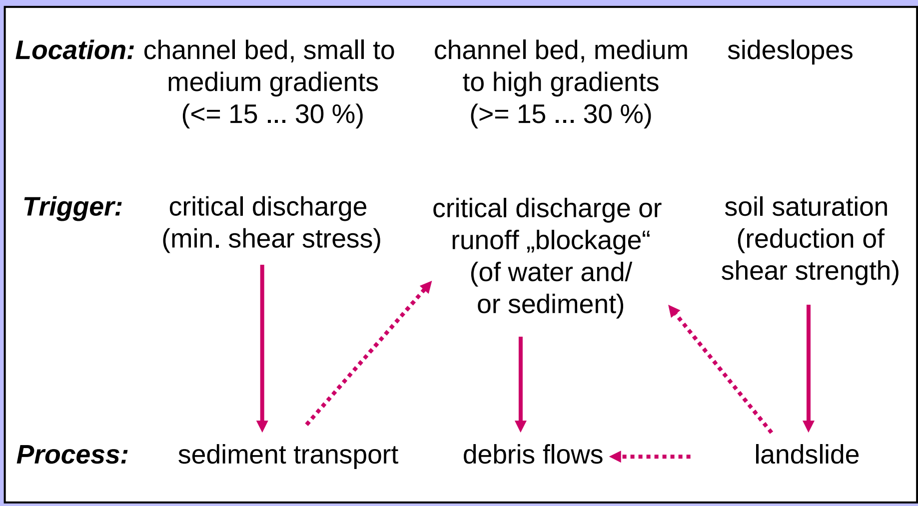
Transition sediment transport - debris flows

Comparison of equations for sediment concentration estimates, with data from Chemolgan-experiments

Rickenmann (2005)



Headwater catchments: interaction of runoff processes, shallow landslides, sediment transport and debris flows



Structure of content

1) Introduction
2) Debris flows: hazard and sediment delivery
3) **Bedload transport in torrents and mountain rivers**
4) Example of floods 2005, Swiss Alps
5) Conclusions

Sediment transport: equation of Meyer-Peter & Müller (1948)

For gravel bed rivers, based on laboratory experiments with channel slopes S in the range: $0.0002 \leq S \leq 0.023$

exponent ≈ 2 is more likely for steep slopes

$$\phi_b = 8\,(m'\theta - \theta_c)^{1.5}$$

later corrections
(e.g. Wong & Parker, 2006)

strong reduction for pronounced bed forms in torrent channels

ϕ_b = *dimensionless sediment transport rate*
θ = *dimensionless bed shear stress*
θ_c = *critical dimensionless bed shear stress at initiation of transport*
m' = *losses due to form resistance*

$$\phi_b = \frac{q_b}{(s-1)\,g\,d_m{}^3}$$

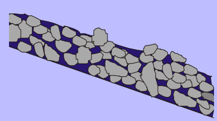
$$\theta = \frac{hS}{(s-1)\,d_m}$$

Sediment transport in steep channels: equations

Basis: laboratory experiments at ETH Zürich of Meyer-Peter & Müller (1948), Smart & Jäggi (1983) and Rickenmann (1990).

Here: simplified equations are shown only, for s = 2.68 and $(d_{90}/d_{30})^{0.2} = 1.05$.

Steep channel slopes, $0.03 \leq S \leq 0.20$

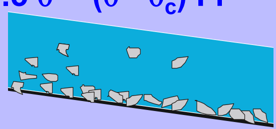


$$q_b = 5.8\,S^2\,(q - q_c) \qquad (1)$$

All channel slopes, $0.0002 \leq S \leq 0.20$

$$\phi_b = 2.5\,\theta^{0.5}\,(\theta - \theta_c)\,Fr^{1.1} \cong 2.5\,\theta^{0.5}\,(\theta - \theta_c)\,Fr \qquad (2)$$

$$q_b = 1.5\,S^{1.5}\,(q - q_c) \qquad (3)$$



Remark: (3) is exactly equivalent with (2)
only for small sediment concentrations and approximative similarity between q_c and θ_c.

q_b = transport rate (per m'); q = discharge (per m'); q_c = critical q at initiation of transport;
S = channel slope; ϕ_b = dimensionless transport rate; θ = dimensionless bed shear stress;
Fr = Froude number

Comparison of sediment transport in torrents and gravel bed streams

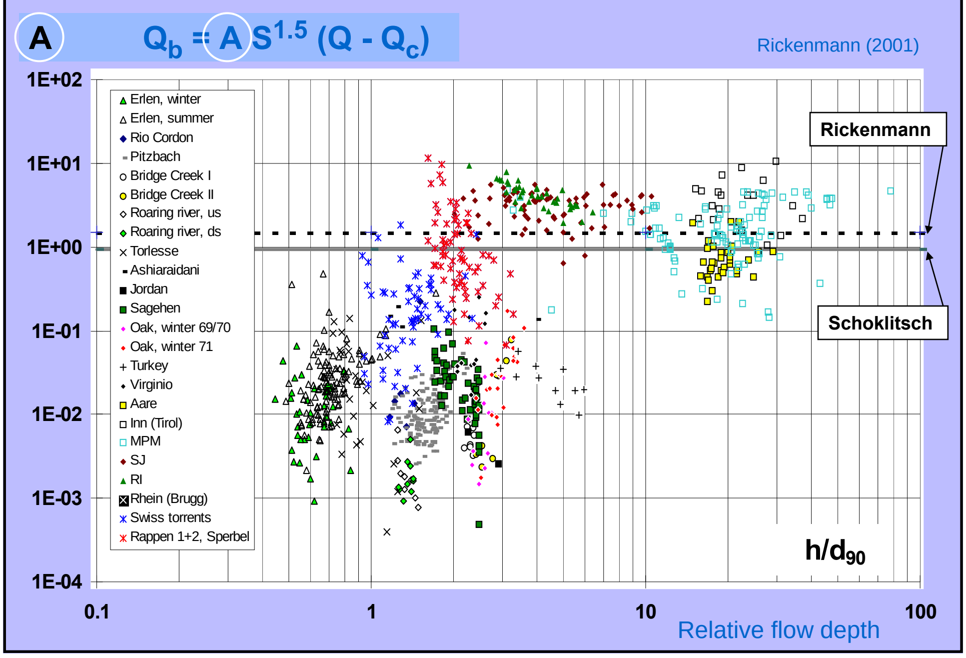
No.	Stream	Slope, S	EG [km2]	Qc [m3/s]	Qp [m3/s]	Observation period	Measuring method
1	Erlenbach	0.17	0.7	0.5	12	1982-93	SRB, Sensors
2	Melera	0.17	1.06	0.5	8	1936-51	SRB
3	Rio Cordon	0.13	5	2	13	1987-94	Metall grill, ST
4	Rappengraben 2	0.11	0.6	0.3	2.6	1928-57	ST
5	Sperbelgraben	0.11	0.56	0.28	1.2	1903-54	ST
6	Pitzbach	0.08	27	2	12	1994/1995	SB
7	Bas Arolla	0.07	7.6	2.4	--	1986-87	SB
8	Bridge Creek	0.067	15.8	0.42	1.5	1971	BLS
9	Rappengraben 1	0.060	0.7	0.35	2.2	1903-27	ST
10	Torlesse Stream	0.057	3.85	0.3	3	1973-77, 1980	VTS
11	Schwändlibach	0.055	1.38	1.5	8.5	1953-58, 1976-92	SRB
12	Rotenbach	0.050	1.66	2.5	17.6	1955-58, 1975-93	SRB
13	Ashiraidani	0.050	6.5	1	6.5	1978	CVC
14	Jordan (Kinneret)	0.035	1590	60	210	1969, 1974, 1975	Dep
15	Sagehen Creek	0.010	27.2	1	1.68	1982-84	BLS(HS)
16	Oak Creek	0.0090	6.7	1	3.4	1969-71	VTS
17	Turkey Brook	0.0086	(7)	0.27	16.6	1978-80	BLP
18	Virginio Stream	0.0080	40	1.8	7.5	1983-85, 1988	VTS
19	Aare (Brienz)	0.00280	554	44	190	1936-37	BLS
20	Inn (Tirol)	0.00126	9316	100	1436	1931-32	BLS
21	Rhein (Brugg)	0.00085		200	(1400)	1936	BLS

Rickenmann (2001)

Comparison of sediment transport in torrents and gravel bed streams

$$Q_b = A\, S^{1.5} (Q - Q_c)$$

Rickenmann (2001)



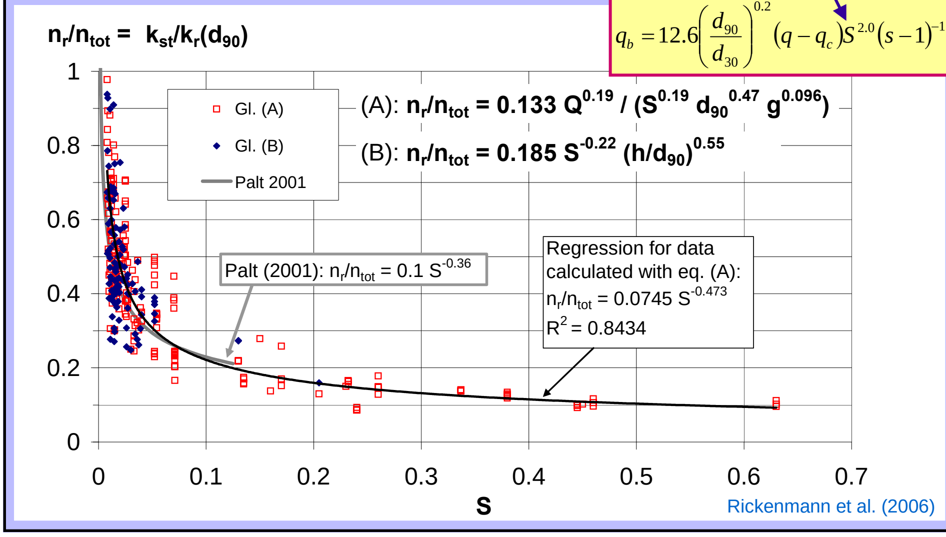
Form resistance in torrent channels

- Total resistance k_{st} from Rickenmann (1996), based on field data
- Grain roughness k_r according to Wong & Parker (2006): $k_r = \frac{23.2}{\sqrt[6]{d_{90}}}$

$$S_{red} = S\left[\frac{n_r}{n}\right]^a$$

$$q_b = 12.6\left(\frac{d_{90}}{d_{30}}\right)^{0.2}(q-q_c)S^{2.0}(s-1)^{-1.6}$$

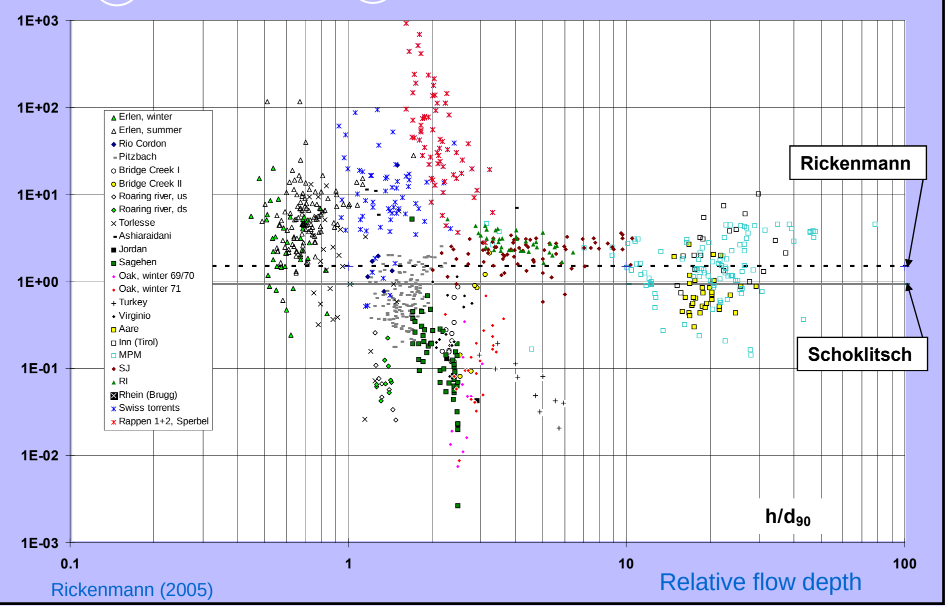
$n_r/n_{tot} = k_{st}/k_r(d_{90})$



Comparison of sediment transport in torrents and gravel bed streams

$A = Q_b/[S_{red,k}^{1.5}(Q_m-Q_c)]$ bzw. $G_E/[V_{re}\ S_{red,k}^{1.5}]$

Sred = f(J, h/d90), Sk = slope correction Abrahams (2003)



Sediment transport simulation model: SETRAC

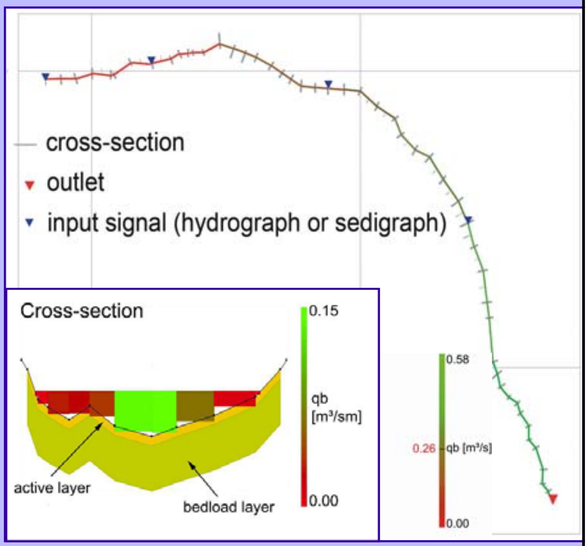
SETRAC

= Sediment Transport Model for Alpine Catchments [developed at BOKU Univ. in Vienna]

• Accounting for form flow resistance losses in steep channels

• Inclusion of fractional transport (multiple grain sizes) and bed level changes

► Testing of the simulation model for flood events in torrents and mountain rivers



Rickenmann et al. (2006)

Example: Sediment transport in Luetschine

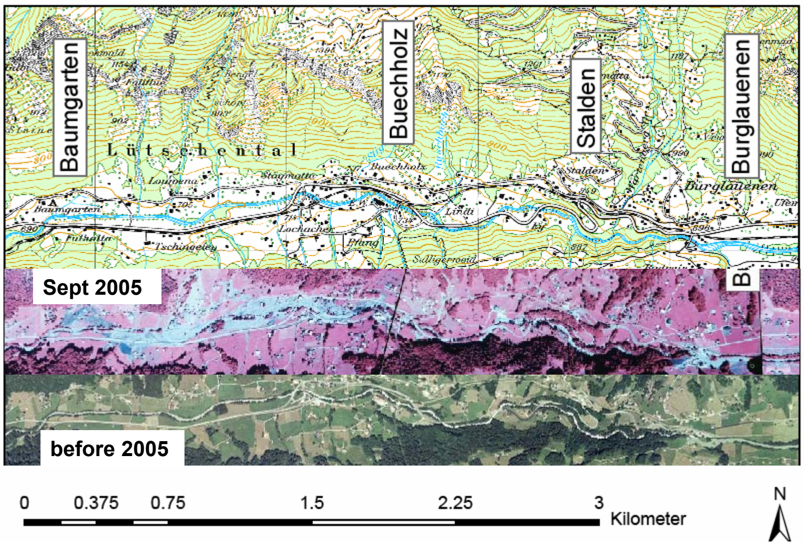
Flood event of 20 to 23 August 2005, Lütschine mountain river, canton Berne, Switzerland

Deposition along a flat river reach (Buechholz – Baumgarten)

Erosion along a steep river reach (Stalden - Buechholz)

Example: Sediment transport in Luetschine

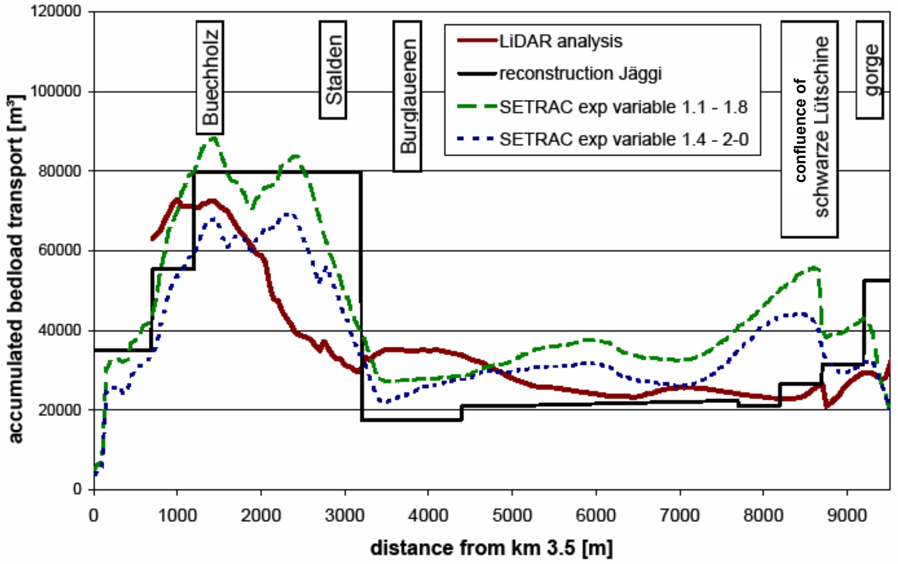
Flood event of 20 to 23 August 2005, Lütschine mountain river, canton Berne, Switzerland



Flow is from right to left on this map

Sediment transport simulation with SETRAC

Flood event of 20 to 23 August 2005, Lütschine mountain river, canton Berne, Switzerland



Flow is from right to left on this diagram

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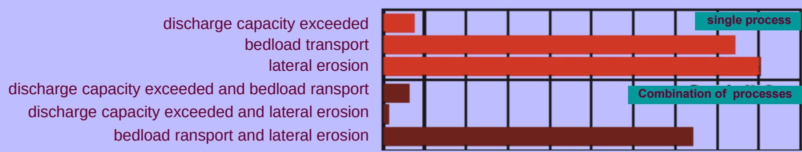
Floods 2005: main processes in torrents

- not extremely high flows („water flow excluding sediment") in small torrent catchments
- for some events large landslides were important triggers
- partly very high channel erosion rates
- insufficient discharge capacity and blockage of flow cross-sections

Floods 2005: main processes in mountain rivers

- high sediment (bedload) transport
- importance of lateral erosion and channel migration
- blockage of flow cross-sections

- high damage to infrastructure (e.g. traffic routes)



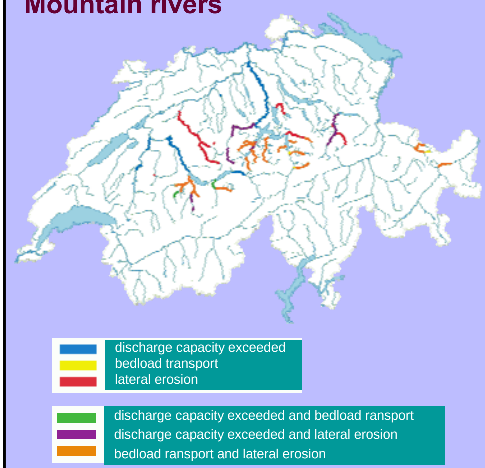
Example of overload situation

Sediment transporting flood: overloading of retention basin

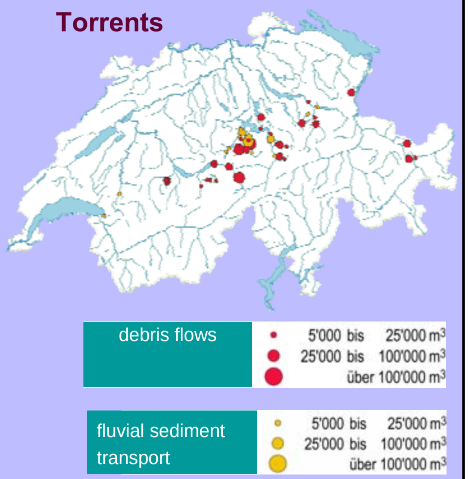
Buoholzbach (NW), 70'000 m3

Floods 2005: documentation of channel processes

Mountain rivers



Torrents



2005 Events: Observations on transported sediment volumes for
- **34 debris flow events**
- **39 flood events with fluvial bedload transport**

Analysis with simple bedload transport equation

Integration over duration of flood event (or observation period):

Q_b = bedload transport capacity

S = channel slope

Q = discharge

Q_{cr} = threshold discharge at beginning of bedload transport

$$Q_b = 1.5\,(Q - Q_{cr})\,S^{1.5}$$

Q_b: bedload volume

$(Q - Q_{cr})$:

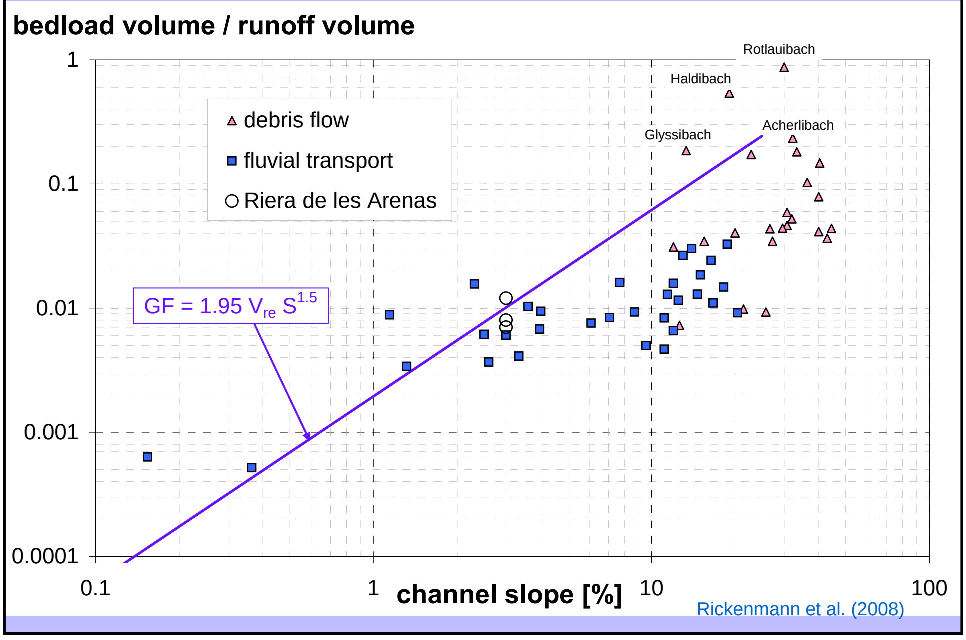
rainfall-volume 20. - 22. 8. 05 (ψ = 1)

runoff volume 20. - 22. 8. 05 (ψ = 0.41 - 0.86)

reduced runoff volume (main rainfall period)

(neglecting effect of Q_{cr})

Floods 2005: comparison of bedload transport



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Conclusions

1. Debris flows may supply large sediment loads to receiving streams
2. Fluvial sediment transport during floods 2005 is in agreement with simple transport equation – but at channel slopes above ~ 5% transport is reduced
   (form resistance losses / limited sediment availability)
3. Sediment volume of debris flows 2005:
   - sediment load is affected by channel slope and runoff volume (similar to fluvial b.l.t.)
   - some very large events due to landslide input
4. Continuous transition from debris flows to bedload transport