Four Years of Bedload Transport Measurements in the Albula River upstream of the Hydropower Dam Solis

Dieter Rickenmann, Stefan Boss, Tobias Nicoller, Alexandre Badoux

WSL - Swiss Federal Research Institute
Mountain Hydrology and Mass Movements
Birmensdorf, Switzerland
1) Swiss plate geophone (SPG) system

2) The measuring system at the Albula River

3) Direct bedload sampling for calibration

4) Bedload transport in the Albula River

5) Concluding remarks
Swiss plate geophone (calibration) measurements at various sites

<table>
<thead>
<tr>
<th>Stream</th>
<th>Location</th>
<th>Drainage area [km²]</th>
<th>Operation period (sensor type)</th>
<th>Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erlenbach (basin)</td>
<td>Alptal, Schwyz, CH</td>
<td>0.7</td>
<td>1986-1999 (PBIS), 2000+ (GS)</td>
<td>yes</td>
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<tr>
<td>Erlenbach (bridge)</td>
<td>Alptal, Schwyz, CH</td>
<td>0.5</td>
<td>1995-1997 (PBIS), 2002+ (GS)</td>
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<td>Vogelbach</td>
<td>Alptal, Schwyz, CH</td>
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<td>1999+ (GS)</td>
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<td>Pitzbach</td>
<td>Pitztal, Tyrol, AT</td>
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<td>1994-1995 (PBIS)</td>
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<td>Spissibach</td>
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<td>Rofenache</td>
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<tr>
<td>Drau</td>
<td>Lienz, Tyrol, AT</td>
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<td>2006+ (GS)</td>
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<tr>
<td>Isel</td>
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<td>1199</td>
<td>2006+ (GS)</td>
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<tr>
<td>Schweibbach</td>
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<td>Fischbach</td>
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<tr>
<td>Ruetz</td>
<td>Mutterbergalm, Tyrol, AT</td>
<td>28</td>
<td>2008+ (GS)</td>
<td>yes</td>
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<tr>
<td>Riedbach</td>
<td>Grächen, Valais, CH</td>
<td>18.7</td>
<td>2009+ (GS)</td>
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<tr>
<td>Nahal Eshtemoa</td>
<td>Negev Desert, Israel</td>
<td>119</td>
<td>2009+ (GS)</td>
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<tr>
<td>Elwha River</td>
<td>Washington, USA</td>
<td>833</td>
<td>2009+ (GS)</td>
<td>yes</td>
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<tr>
<td>Navisence</td>
<td>Zinal, Valais, CH</td>
<td>82</td>
<td>2011+ (GS)</td>
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<tr>
<td>Ötztaler Aache</td>
<td>Sölden, AT</td>
<td>444</td>
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<tr>
<td>Unsau</td>
<td>Maria Alm, Salzburg, AT</td>
<td>55</td>
<td>2011+ (GS)</td>
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<tr>
<td>Suggadainbach</td>
<td>St. Gallenkirch, AT</td>
<td>75</td>
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<td>Asahiaraidani</td>
<td>Hodako Observatory, JIP</td>
<td>6.5</td>
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<td>Solda River</td>
<td>Valle Venosta, I</td>
<td>130</td>
<td>2014+ (GS)</td>
<td>yes</td>
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<tr>
<td>Albula River</td>
<td>Tiefencastel, CH</td>
<td>529</td>
<td>2015+ (GS, AS)</td>
<td>yes</td>
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<tr>
<td>Avancon de Nant</td>
<td>Pont de Nant, Vaud, CH</td>
<td>13.5</td>
<td>2015+ (GS)</td>
<td>yes</td>
</tr>
</tbody>
</table>

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

(Rickenmann 2017, JHE)
Swiss plate geophone: Example of signal, summary values

Impulses are recorded whenever the signal exceeds a predefined threshold value (on positive amplitude range), typically $A_{\text{min}} = 0.1$ 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)
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Bedload transport measuring system at the Albula River

Sediment bypass tunnel of hydropower lake Solis

BAFU Flow gauging station Albula

Outlet of turbined water of ALK

Beload Transport Measuring Station of WSL
The view on the photos is upstream. (a) Both geophone (orange) and accelerometer (violet) sensors are installed. (b) medium flow conditions on 7 May 2015 with a discharge of about 8 m³/s.

(Rickenmann et al. 2017, PIAHS)

<table>
<thead>
<tr>
<th></th>
<th>Albula at Tiefencastel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment size</td>
<td>529 km²</td>
</tr>
<tr>
<td>Channel slope</td>
<td>0.007</td>
</tr>
<tr>
<td>Channel width</td>
<td>15 m</td>
</tr>
<tr>
<td>Grain size D₈₄</td>
<td>0.16 m</td>
</tr>
<tr>
<td>Grain size D₅₀</td>
<td>0.065 m</td>
</tr>
<tr>
<td>10-year peak discharge</td>
<td>107 m³/s</td>
</tr>
<tr>
<td>100-year peak discharge</td>
<td>128 m³/s</td>
</tr>
</tbody>
</table>
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Bedload transport measuring system at the Albula River

\[ y = 0.0867x^{0.95} \]
\[ R^2 = 0.96 \]

Unit bedload transport rate \( q_b \) (kg m\(^{-1}\)s\(^{-1}\))

Impulse rate \( IMPT \) (m\(^{-1}\)s\(^{-1}\))

\[ y = 0.0848x \]
\[ R^2 = 0.862 \]

IMPT vs. \( qb \) for \( D > 19.5 \text{mm} \)

IMPT vs. \( qb \) for \( D > 9.5 \text{mm} \)

G5  
G6  
G7

SNFS-DFG Research Project with TU Munich; calibration measurements in the Albula River
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Bedload transport measuring system at the Albula River

(Rickenmann et al. 2017, PIAHS)

Swiss Federal Research Institute WSL
Bedload transport at the Albula River 2015 - 2018

$Q_c = \text{critical discharge at initiation of bedload transport}$
Bedload transport $Q_b$: observations and calculation

Observations with SPG
- Bedload transport rate $Q_b$: Albula Summer 2016
- linear calibration with $k_b = 11.7$ for $D > 9.5$mm
- $Q_{bm\_bin}$: binned data

Calculations
- Use two methods described in Schneider et al. (2015, WRR, eq. 13, eq. 14), modified equation of Wilcock & Crowe (2003)
  - $Q_{btot}$: using total shear stress, combined with reference shear stress of 0.051 (slope dependent)
  - $Q_{bred}$: using reduced shear stress with method of Rickenmann & Recking (2011), combined with reference shear stress of 0.03 (slope independent)
Comparison: deposits in Solis lake; other mountain rivers

From surveys of the sediment deposits in the hydropower lake, on average the total annual volume of sediment transported into lake Solis is about 80 000 m$^3$ (Oertli and Auel, 2015), which is largely input from the Albula River.

A comparison is made here with the mean value of coarse bedload transport (over three years 2015, 2016, 2018) for particles with D > 9.5 mm:

<table>
<thead>
<tr>
<th>Albula river</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>mean Bedload mass</td>
<td>9937 t</td>
</tr>
<tr>
<td>Bulk deposit density</td>
<td>1800 kg/m$^3$</td>
</tr>
<tr>
<td>Bedload deposit volume</td>
<td>5521 m$^3$</td>
</tr>
<tr>
<td>Annual deposit lake Solis</td>
<td>80’000 m$^3$</td>
</tr>
<tr>
<td>Bedload/Total load</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Flood 2014: about 80 000 m$^3$ transported through bypass tunnel (SPG measurements) (Hagmann et al., 2015)

Mountain rivers in Austria (A):
- Bedload measurements with SPG system (of WSL);
- All data courtesy of TIWAG hydropower company, Innsbruck

\[
V_{re} = \int (Q - Q_c) \, dt = \text{effective runoff volume}
\]

\[
Q_p = \text{annual peak discharge}
\]
Content

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Concluding remarks

• The Swiss plate geophone (SPG) system has been successfully calibrated to determine bedload flux in the Albula River

• Annual bedload (and suspended load) can be estimated roughly as a function of the effective runoff volume and the (annual) peak discharge

• Along with a similar measuring system installed at the outlet of the sediment bypass tunnel, a sediment budget for the Solis lake can be established

• The SPG measurements are used by the EWZ hydropower company to optimize the duration of flushing operations through the bypass tunnel

• SPG or similar acoustic bedload transport measurements are helpful to improve the process understanding of bedload transport
Thank you for your attention