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Integrative bedload monitoring station - URSLAU

Станица за интегрисани мониторинг вученог наноса - УРСЛАУ

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Abstract

An integrative bedload monitoring station was installed at the middle reach of the Urslau torrent in 2010 in collaboration of the Austrian Service for Torrent and Avalanche Control and the University of Natural Resources and Life Sciences Vienna / Institute of Water management, Hydrology and Hydraulic Engineering. At this monitoring station direct (mobile basket sampler, bedload trap) and indirect (geophone device) bedload monitoring methods are applied. The combination of selected monitoring methods enables a comprehensive measurement and assessment of the bedload transport process. This article presents the integrative monitoring system and explains the single used direct and indirect monitoring methods. Advantages and restrictions in bedload measurement of the applied devices are discussed. Selected results concerning spatial and temporal variability, initiation of motion, (specific) bedload rates, grain size distribution and bedload yields of three years of bedload monitoring at the Urslau torrent are presented.

Key words: Integrative Bedload monitoring system, Basket sampler, Bedload trap, Geophones

Извод

Станица за интегрисани мониторинг вученог наноса инсталисана је у средини бујичног водотока Урслау 2010. године у сарадњи са аустријском Службом за заштиту од бујица и лавина и Универзитетом за природне ресурсе и бионауке – Институтом за водопривреду, хидрологију и хидраулику. На овој станици су примењене директне (покретни хватач вученог наноса) и индиректне (геофон уређај) методе. Комбинација одабраних метода мониторинга омогућава свеобухватна мерења и оцену транспорта вученог наноса. У раду се презентује интегративни мониторинг сустем и појединачно објашњавају директне и индиректне методе мониторинга. Дискутоване су предности и ограничења примењених уређаја за мерења вученог наноса. Презентовани су одабрани резултати просторне и временске промењљивости, иницирана кретања, специфичне количине вученог наноса, крупноћа и продукција наноса за три године осматрања бујичног водотока Урслау.

Кључне речи: Интегрисани систем осматрања вученог наноса, хватач вученог наноса, геофони.

Introduction

The knowledge of bedload transport in downstream sections of mountain torrents is important for the analyses and assessment of floods with sediment transport and for the design and implementation of measures. Bedload monitoring is an essential step to improve the understanding of the natural process and forms the basis to apply and calibrate bedload transport formulas and numerical models. Being aware of the importance of bedload monitoring data, the project "Monitoring and Calculation of bedload transport at downstream sections of mountain torrents at the case study Urslau torrent" was started in 2010 by the University of Natural Resources and Life Sciences Vienna / Institute of Water management, Hydrology and Hydraulic Engineering, financed and supported by the Austrian Service for Torrent and Avalanche Control (Habersack et al., 2012; Kreisler et al., 2012). The aims of the project are the development of an applicable method to asses bedload transport at downstream sections of mountain torrents and the measurement and analyses of the bedload transport at the Urslau torrent over four years. This article presents the developed and installed integrative bedload monitoring. Possibilities and restrictions of applied monitoring methods are pointed out. A choice of results of the bedload load monitoring program at the Urslau River is given and discussed.

Study Site

The Urslau torrent is located in the alpine region of the province Salzburg in Austria (figure 1b). It encompasses a drainage basin of 121.8 km2 and is characterized by an average bed slope of 11.7%. In Saalfelden the Urslau discharges into the Saalach River, which is a tributary of the Salzach River. The catchment area is situated in the Upper Eastern Alps. The southern part of the project area lies within the Greywacke Zone and the northern part in the Northern Limestone Alps. The bedload monitoring station is situated near the town Maria Alm at the downstream section of the Urslau torrent. The drainage area upstream the measurement station is 56 km2, bed width equals 8.2 m and the average bed slope near the station is 2%. The mean annual discharge at the gauging station Saalfelden (5 km downstream the measurement station) is 4.39 m3s-1. Pictures of the monitoring site are shown in figure 1a and 1c.

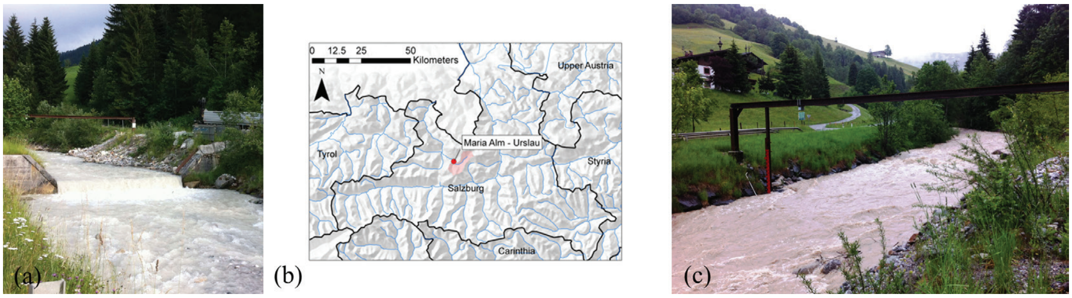


Figure 1 Site of bedload monitoring station (a,c), Location of catchment area (b)

Слика 1 *Положај станице за мониторинг вученог наноса (а, ц), локација слива (б)*

Materials and Methods

To describe the bedload transport process adequately a certain set of measured parameters is demanded. Following, these main parameters of interest and the common units are listed (after Habersack et al., 2010): Specific bedload rate [kgm-1s-1], Bedload rate [kg s-1], Bedload yield [kg], Spatial variability of bedload transport, Temporal variability of bedload transport, Initiation of motion [m; m3s-1m, Nm-2], Grain size distribution, Transport path / transport velocity [m; ms 1]

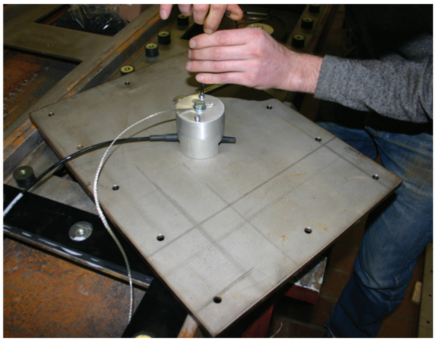
There are several monitoring methods in use, which have their specific possibilities and restriction in bedload measurement. There is no single bedload monitoring device, which enables to measure the whole set of main parameters of interest. The main objective of the integrative bedload monitoring system at the Urslau Torrent (also presented in Habersack et al., in prep) is to combine the advantages of a selection of monitoring methods. This combination of several single techniques allows monitoring the bedload transport process entirely. The integrative bedload monitoring station at the Urslau torrent combines indirect (geophone device) and indirect (mobile basket sampler, bedload trap) measurement methods. Following the single measurement devices are presented.

Geophone Device

Geophone plates allow a qualitative, indirect monitoring of the bedload transport. Geophones are vibration sensors, which are used originally in seismic subsurface exploration. To detect bedload transport at the Urslau torrent the geophone are mounted on the underside in the middle of 0.36m long, 0.5m wide and 0.015m thick steel plates (figure 2.a). These steel plates are installed horizontally, bed parallel over the whole river cross-section (figure 2.b). At the Urslau torrent seven geophones are distributed equally over a torrent profile width of eight meters.

Bedload particles, which move over the steel plates, create vibrations of the steel plates. These vibrations are detected by the geophones. A software program analyses and processes the raw data signal of the geophones automatically and continuously. Following parameters are computed and stored (Habersack et al., 2012): number of impulses per minute (threshold value of 0.1V), maximum amplitude per minute and quadratic integral of the signal per minute. If required the raw data signal and number of impulses, maximum amplitude and quadratic integral per second can be recorded.

(a)



(b)

Figure 2 Geophone mounted on steel plate (a), Geophone device (b)

Слика 2 *Монтиран геофон на челичној подлози (а), геофон уређај (б)*

The continuous and automatic data recording offers information of the bedload transport which are high in spatial and temporal resolution. The spatial distribution of the transported material over the torrent profile is determined, as well as the temporal course of the bedload transport process. Further, the critical flow for the initiation of bedload material can be ascertained. The direct assessment of bedload transport rates in weight respectively volume and the texture of the transported material is not possible. Therefore calibration measurements with direct monitoring devices (mobile basket sampler, bedload trap) are required.

Mobile Basket Sampler

The concept of the used mobile basket sampler is based on a mobile bedload trap presented in Bunte and Abt, 2003. The sampler was built for bedload measurements in mountain streams with intense bedload transport (Habersack et al., 2012). The basket sampler consists of a rectangular steel frame, which is 0.4m wide and 0.3m high, a sampler bag and a steel bar. The sample bag has a mesh size of 4mm x 7mm. The steel bar is attached at the intake frame using a uniaxial rotary joint, which causes the sample intake to turn into mean flow direction in response to the fluvial forces. The sampler can be mounted on a mobile crane at the upper end of the steel bar. Two tensioning ropes, which are fixed on either side of the steel frame and on both riverbanks, prevent the sampler form drifting downstream. Figure 3a and 3b show the mobile basket sampler respectively pictures of the measuring procedure.

For bedload transport measurements the mobile basket sampler is lowered at given measurement verticals onto the streambed and raised again after a defined measurement time, which depends on bedload transport intensity. Measurements are performed downstream of the geophone device, allowing a calibration relation between the data of the geophone device and the result of the basket sampler measurements.

(a)

(b)

Figure 3 Mobile basket sampler, Measuring procedure (a,b)

Слика 3 *Покретни хватач наноса, поступак мерења (а, б)*

There are two possible measurement procedures – Cross-section Measurements and Permanent Measurements. At Cross-sections Measurements bedload samples are taken at three predefined verticals in the stream profile. Temporal variability of bedload transport is obtained by performing three measurements at one vertical consecutively. Specific bedload transport is calculated by determining the average value of these three subsequent measurements. Sample taking at several measurement verticals allows the calculation of the prevailing bedload transport in the stream profile. Performing Permanent Measurements, bedload samples are taken at one vertical repeatedly. This measurement procedure is undertaken to analyse the temporal variability of the bedload transport process.

Advantages of mobile basket sampler measurements are the possibility to take spatial and temporal variable bedload samples. The spatial distribution of bedload transport within the stream profile as well as the temporal variability can be investigated. A sieving analysis of the measured material gives the grain size distribution respectively the characteristic grain sizes of the transported material. Bedload measurements with the basket sampler at the Urslau torrent are restricted to low and medium discharges. At high water flow the lowering of the sampler on the riverbed is problematic due to high hydraulic flow pressure. Additionally, occurring woody debris make the measurement procedure difficult. Further, at high flow and therefore, at very intense bedload transport rates, measurement time hast do be reduced strongly which can cause uncertainties within the measuring process.

Bedload Trap

The bedload trap is mounted directly downstream of the geophone device in the middle of the stream profile (Figure 4a). It consists of a sampling box, which is placed on load cells. The volume of the sampling box is 1.13 m3. The trap is covered by a lid with a longitudinal sampling slot (1.6m long and 0.5m wide). In rest position the slot is closed and flush with the streambed. When starting with bedload sampling, the slot is opened hydraulically via manual control, allowing for bedload material to be trapped in the container. The load cells commence recording automatically the bedload mass increase within the trap. To analyze the sampled bedload material an excavator withdraws the filled sampling box and places it on the riverbank (Figure 4b). After the box is emptied it has to be reinserted. This maintenance work is restricted to low flow conditions.

(a)

(b)

Figure 4 Bedload trap downstream geophone device (a), Sampling box (b)

Слика 4 *Низводни хватач за вучени нанос са геофон уређајем (a), сандук за узорке наноса*

Bedload monitoring using a bedload trap is possible at all water stages, even at high flow conditions and intense bedload transport. It enables a relative long-lasting direct bedload measurement. Specific bedload transport, temporal variability, texture of the transported material and also initiation of motion can be determined. As the bedload trap is fixed downstream the geophone device, bedload trap measurements serve as well as the mobile basket sampler measurements to calibrate the geophone data. The fixed position of the bedload trap in the stream profile prohibits the analyses of the spatial variability of the transport process.

Integrative bedload monitoring system

Geophone device, mobile basket sampler and bedload trap form together the integrative bedload monitoring system. The combination of these methods takes advantage of the possibilities of the mentioned single monitoring methods and compensates their specific restrictions in bedload measuring. Table 1 shows the suitability for measuring the parameters of interest of all measurement devices, which are applied at the Urslau torrent. The last raw of the table represents the integrative monitoring system and its possibilities in bedload monitoring.

Suitability Table	Specific bedload rate	Bedload rate	Spatial variability	Temporal variability	Initiation of motion	Grain size distribution	Transport process
Mobile Basket Sampler	**3**	**3**	**2**	**1**	**1**	**2**	**-**
Bedload Trap	**3**	**1**	**-**	**2**	**3**	**3**	**-**
Geophone Device	**1**	**1**	**3**	**3**	**3**	**1**	**-**
Integrative Monitoring System	**3**	**3**	**3**	**3**	**3**	**3**	**-**

3	Highly suited for measuring this parameter
2	Suited for measuring this parameter
1	Partially suited for measuring this parameter
-	Not suited for measuring this parameter

Table 1 Integrative Monitoring System - Suitability table (after Habersack et al., 2012)

Табела 1 *Интегрисани мониторинг систем - Табела погодности (према Хаберзак-у et al., 2012)*

Results

Bedload transport measurements are operated at the Urslau torrent since 2011. Several mobile basket sampler and seven bedload trap measurements have been performed already. Geophone recordings are available continuously since January 2011. In this chapter a selection of these bedload monitoring results is presented.

At the Urslau torrent bedload transport intensity is recorded continuously due to the geophone device. This enables a comprehensive analysis of the bedload transport process.

Considering bedload transport at the Urslau torrent on a large time scale gives the diagram in figure 5. Here the course of the sum of all installed geophone impulses and discharge, exemplarily illustrated for the year 2012, is shown. Bedload transport intensity tends to follow the course of water discharge. At high flow conditions the number of recorded geophone impulses is high too.

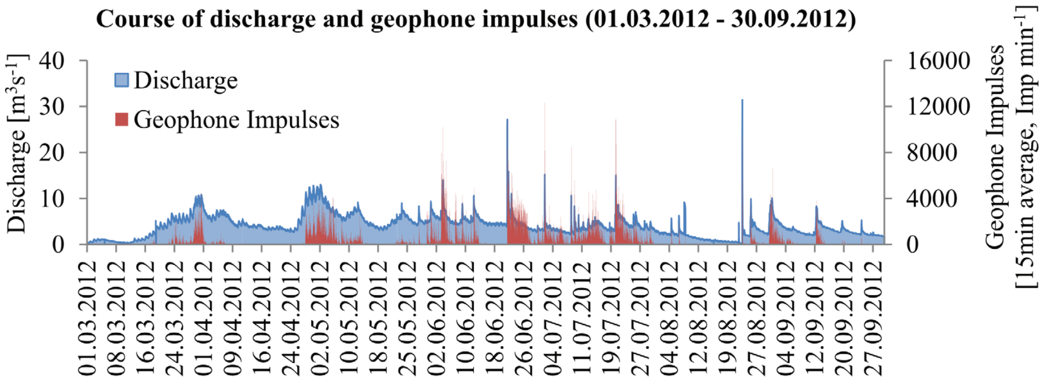


Figure 5 Course of Geophone Impulses (15min average value) and discharge – Urslau 2012

Слика 5 *Курс геофон импулса (15 минутна средња вредност) и протицај – Урслау 2012*

Figure 6 shows the daily course of geophone Impulses at the Urslau torrent. The strong temporal variability of bedload transport is apparent. Although hydraulic conditions are relative stable bedload transport intensity differs from an average value of 1 to nearly 400 geophone impulses per 15 minutes.

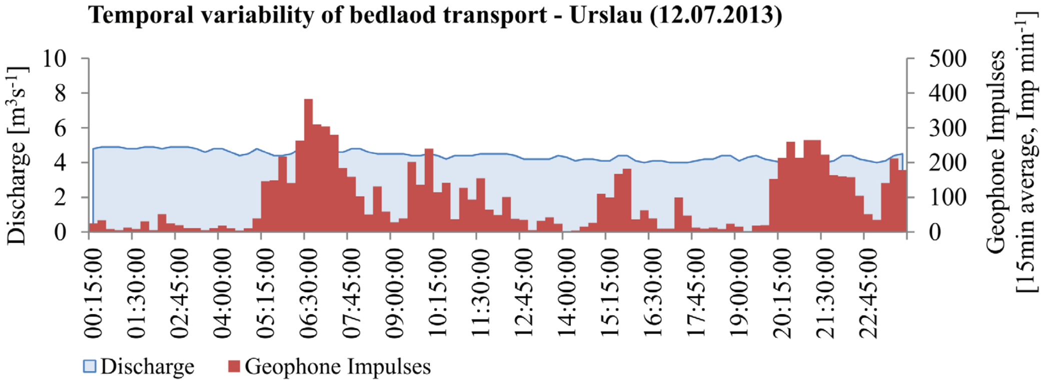


Figure 6 Temporal variability of bedload transport (Urslau 12.07.2013)

Слика 6 Временска варијабилност транспорта вученог наноса (Урслау 12.07.2013)

Bedload transport exhibits not alone temporal variability of bedload transport, but also varies spatially within the stream profile. Figure 7 shows the temporal and spatial distribution of geophone impulses for 01.05.2012 – 31.10.2012.

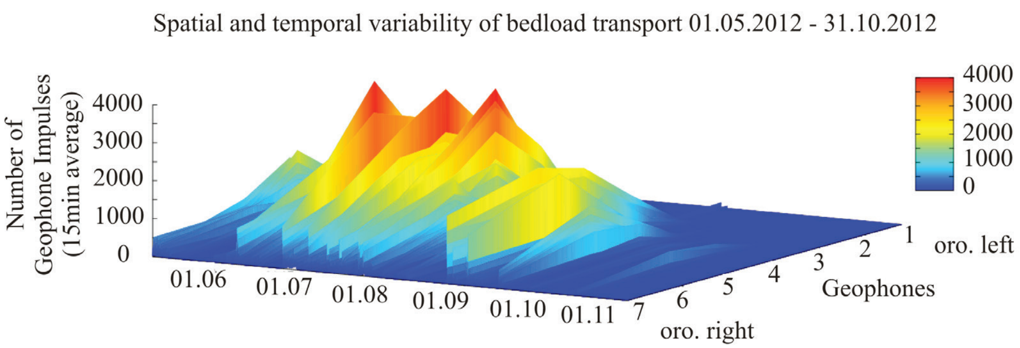


Figure 7 Spatial and temporal variability of bedload transport

Слика 7 *Просторна и временска варијабилност транспорта вученог наноса*

For the determination of the critical flow for initiation of motion the average number of geophone impulses is calculated for the corresponding discharge categories. Figure 8 shows the result of this analysis. For the Urlsau River, in the section of the monitoring station the lower limit of the critical flow for the initiation of bedload transport is in the range of 3-5m3s-1.

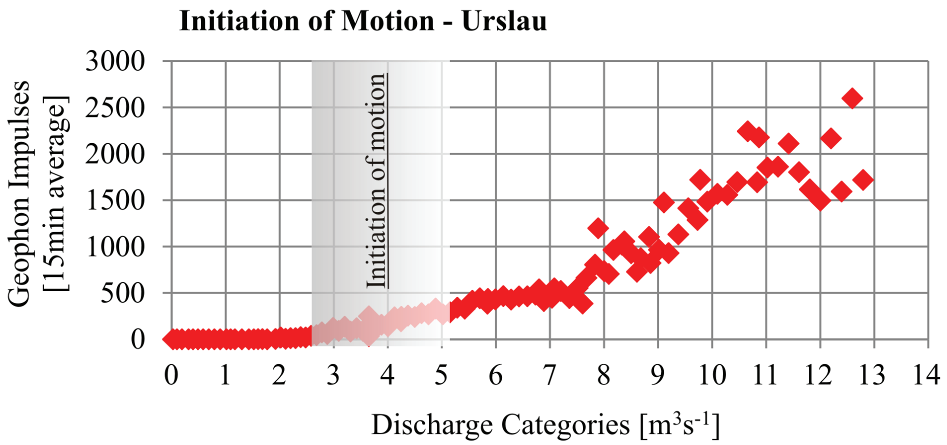


Figure 8 Initiation of motion

Слика 8 *Почетак кретања*

Direct bedload transport measurements allow the determination of transported bedload mass respectively volume and the texture of the transported material. Figure 9 gives an example of a measurement with the mobile basket sampler. At this cross-section measurement specific bedload rates and texture of the transported material at each measuring vertical are illustrated. The highest specifc bedload rate (2.8 kgm-1s-1) was measured in the middle of the cross-section. Extrapolating these point measurements on the stream profile yields a bedload transport rate of 7.2 kg s-1.

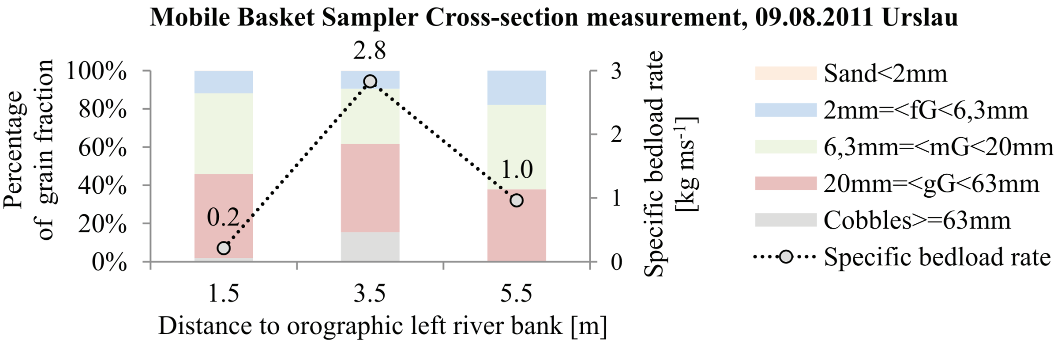


Figure 9 Cross-section measurement (09.08.2011)

Слика 9 *Мерни профил (09.08.2011)*

The result of a bedload trap measurement (01.06.2013) is given in figure 10. The course of mass increase of the sampled bedload material in the trap is shown. The cumulative curve of registered geophone impulses of the geophone directly upstream the bedload trap is illustrated too. The similarity of these two courses is evident.

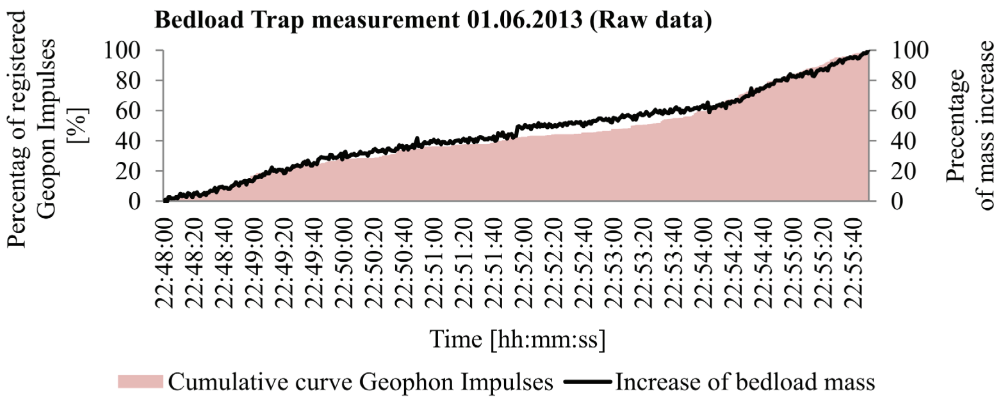


Figure 10 Bedload trap measurement 01.06.2013

Слика 10 *Мерење проноса вученог наноса 01.06.2013*

Direct bedload transport measurements are undertaken directly upstream of the geophone device, enabling the comparison of geophone data and direct measured transport rates. Geophon data are calibrated by relating the measured specific bedload rates to geophone impulses, which were recorded in the corresponding time period. This relation gives the opportunity to calculate bedload yields for chosen time periods. The correlation of direct measured specific bedload rates and geophone data is given in figure 11.

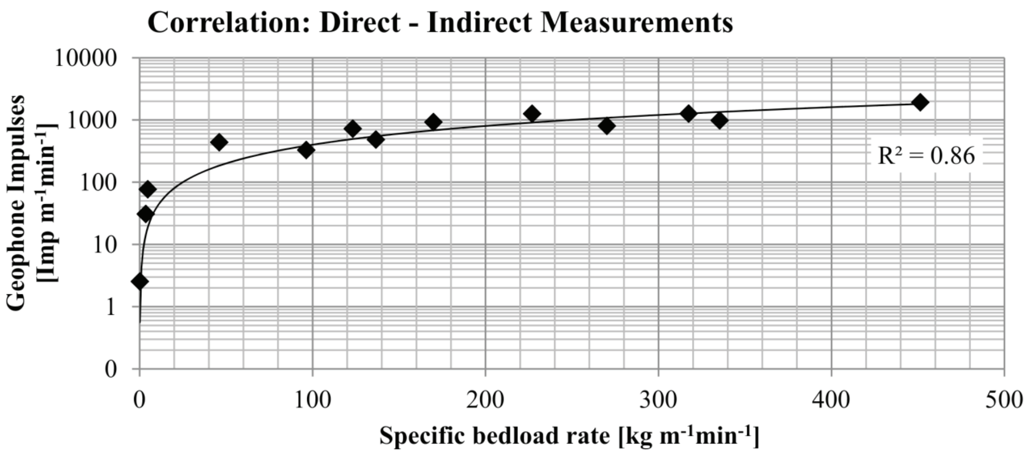


Figure 11 Correlation of direct and indirect bedload measurements

Слика 11 *Корелација директних и индиректних мерења вученог наноса*

Discussion

This article shows that the integrative bedload monitoring system, applied at the Urslau torrent gives satisfactory monitoring results. The suitability table (Table 1) and the given examples of monitoring results (figure 5 – 11) demonstrate that all main parameters of interest (after Habersack et al. 2012), except the parameters “transport path and transport velocity” can be determined. For the detection of transport path and transport velocity of single bedload particles the further application of tracer stones is needed (for example Liedermann et al., 2012).

Due to the high spatial and temporal variability of bedload transport, a continuous monitoring of the bedload process using indirect monitoring methods is required. The high temporal variability of bedload transport in figure 6 underlines the temporal variability of the transport process. This example reveals also that bedload transport is not alone dependent on prevalent water flow. It is recommended to consider further determining factor when assessing bedload transport events. Exemplarily bedload material supply, activity of tributaries and material input out of slope processes, previous bedload transport events and armouring processes are listed here.

The application of direct monitoring methods gives information of mass and volume of transported bedload material. The mobile basket sampler is applied and established for low and medium flow rates at the Urslau torrent. At high flow and high intensities of bedload transport measurements with the mobile basket sampler are not feasible. Bedload transport measurements using the bedload trap are operating satisfactorily for higher discharges, as illustrated in the example of the bedload trap measurement of the 01.06.2013 in figure 10.

The calibration of geophone data is an essential issue of direct bedload measurements. The relation between geophone data and measured bedload rates in figure 11 provides a strong correlation (correlation coefficient of 0.86). As already mentioned this relation enables the determination of bedload yields.

Measured bedload data of the Urslau torrent form an essential basis to review existing approaches to calculate bedload transport. Further work will concentrate on the applicability of established bedload transport formulas by comparing calculated results with measured bedload data. Possibilities to calibrate and adjust bedload transport formulas will be compiled.

Summary

Bedload transport has been measured at the Urslau torrent for three years. Direct and indirect bedload monitoring methods have been applied. The presented results highlight the importance of an integrative monitoring system to detect the bedload transport process entirely. Selected results concerning the main parameters of interest are shown. Measured bedload data of the Urslau torrent form an important basis for future work relating the review and adaption of existing bedload transport formulas.

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