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12th International Conference on Hydroscience & Engineering
Hydro-Science & Engineering for Environmental Resilience
November 6-10, 2016, Tainan, Taiwan.

Integrative Bedload Measurement Systems in Austria - Development and Evaluation of Bedload Transport Measurement Techniques and Optimization of Calculations

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ABSTRACT

Many different techniques to determine bedload discharge in rivers exist. The "integrative bed load measurement system" includes several of these techniques to comprehensively analyze bedload transport processes. We are aiming is to better understand these processes and to determine bedload discharge. Therefore we clustered different techniques like calibrated geophones, Reid slot samplers and basket samplers. In was found that the formulae we applied underestimate bedload transport at high discharges and initiation of bedload motion starts at lower discharges than estimated. Relevant new parameters - such as the effective transport width could be implemented for the optimization of calculations

KEY WORDS: bedload transport, geophone, bedload slot sampler, integrative bedload measurement system

INTRODUCTION

Bedload transport data form an essential basis for the planning of river engineering works, flood protection, torrent control and waterway management. This information is further needed for issues concerning ecology and hydropower. Bedload monitoring is a prerequisite to extend the understanding of natural processes and to select, apply, calibrate and validate bedload transport formulas (Habersack & Laronne, 2002). Nevertheless, it remains difficult to predict and to monitor bedload transport in nature (Rickenmann et al., 2012). Many bedload transport formulas were developed by using data of laboratory investigations with controlled boundary conditions, equilibrium transport and bed level stability (Habersack & Laronne, 2002).

Comparisons with monitoring data showed that measured transport rates differed from the calculated values (Bathurst, 1978, Haddadchi et al., 2013). There are many known adverse effects like the temporal and spatial variability (Habersack et al., 2008), varying grain sizes, high flow velocities, turbid flow (Lucía et al., 2013) and different modes of movements that complicate the measurement and also calculation of bedload transport.

The first integrative bedload monitoring system was built in 2006 and has been installed at the straight river section of the Drau River. Since 2007, bedload transport monitoring is performed at this site. An "integrative bed load measurement system" combines several bedload monitoring techniques and therefore facilitates the determination of the initiation of motion of bedload particles, bedload transport rates and total bedload yields. Furthermore, the bedload texture and the spatial and temporal variability of the transport process can be examined.

At the measuring stations direct (mobile basket samplers, bedload traps) and indirect (geophone devices, hydrophones) methods are applied. Each of these measurement techniques has its deficits, which are compensated by combining the different methods. This offers the opportunity to comprehensively monitor the bedload transport process. Mobile basket samplers allow many opportunities in bedload monitoring but they also have disadvantages in quantifying the underlying bedload transport processes. For example, at a specific range of discharges and flow velocity, the lowering of the sampler on the streambed is limited (Kreisler et al., 2011).

Further problems arise from the measurement itself, when sampling disturbes the flow field (Gray et al., 2010). With bedload traps, which are installed at the stream bed, direct measurements of the bedload transport become possible at all water levels (Kreisler et al., 2014) and do not impact the flow field until the filling stage reaches 80% (Habersack et al., 2001). Longer sampling durations and continuous recording of the bedload transport process are feasible with bedload traps (Reid et al., 1980, Habersack et al., 2001, Kreisler et al., 2016).

Indirect bedload monitoring methods have the advantage of continuously recording the bedload transport processes over time and over the channel width (Reid et al., 1980, Aigner et al., 2016). For the calibration of indirect measurement devices direct measurements are indispensable and therefore the employment of traditional basket samples will increase (Gray et al., 2010, Kreisler et al., 2016).The monitoring results of the Drau River from 2009 to 2015 enable a useful comparison of measured bedload data with commonly used bedload transport equations.

The aim of this paper is to present the integrative monitoring system, the results of the different measurement results and a comparison between the calculated and measured results. Further, different ways to optimize the calculation results are shown.

STUDY SIDE

Figure 1 gives an overview of the Austrian river network where all integrative measurement stations, deployed by BOKU are tagged. The station Dellach - Drau is highlighted, as this paper presents its results.

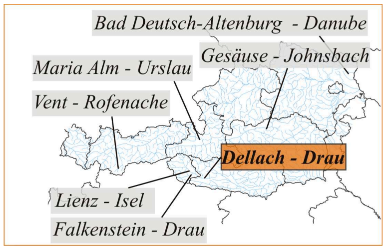

Fig. 1 Overview of the integrative measurement stations in Austria

The Drau River is a large alpine river. Altogether, it drains an area of 41.000 km^2. The catchment area upstream of the gauging station in Dellach encompasses 2.131 km^2. The Drau River displays a nivo-glacial water regime with a discharge maximum in June. Discharge is dominated by snow- and glacial melting processes as well as by precipitation. The mean annual discharge at the gauging station Oberdrauburg is 63 m^{3}s^{-1}.The study site at the Drau River is placed at a straight river section. Riverbanks are protected by riprap and there is almost no vegetation that influences the flow up to bank-full discharge. The bed width of the Drau River at the study site extents to 50 m with a bed slope of 0.18 %. The bedload monitoring station was built in 2006 and extended with a hydraulically liftable slot trap in 2008. The measuring station is situated at the mid-course of the Drau River near the town Dellach. A stream gauging station is located directly at the station and is operated by the hydrographic survey of Carinthia. Water levels are measured using hydrostatic pressure sensors. Flow velocity measurements are conducted by a calibrated hydrometric impeller and a radar based flow velocimeter. An array of geophones is embedded in the stream bed, where 40 geophones are installed equidistantly, in intervals of one meter at the orographic right half of the river and every two meters at the left half of the river. The bedload traps are mounted in the right section of the river directly upstream from geophone 19, 25 and 32. Measurements using the Large Helley-Smith sampler (LHS-sampler) are conducted with a mobile crane from a bridge. Figure 2 provides an overview of the arrangement of instruments at the measurement site.

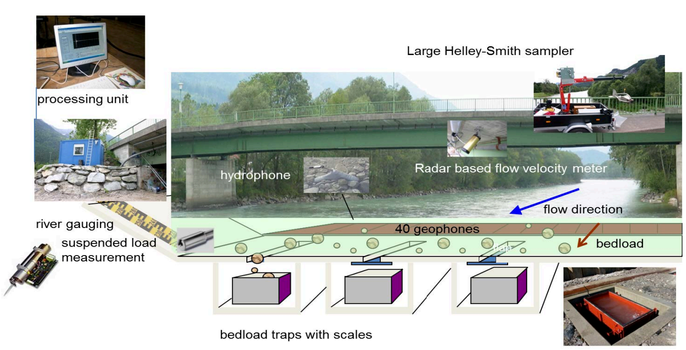

Fig. 2 Integrated automatic and continuous bedload monitoring station Dellach at the Drau River in Austria, view upstream. The station contains mobile basket samplers, 3 slot-type bedload samplers, 40 plate geophones, 1 hydrophone and additional suspended sediment and gauging station equipment.

INTEGRATIVE BEDLOAD MONITORING METHODS

The suitability of several bedload monitoring devices to measure selected parameters of interest was recently described (Habersack et al., 2010). It is not possible to monitor bedload transport processes satisfactorily using one single measurement device, as each method has its specific advantages and restrictions (Habersack et al., in prep.). Hence the integrative bedload monitoring system was developed consisting of a basket sampler, bedload traps and geophone devices. (see arrangement in Figure 2) As the deficits can be compensated by combining the different methods, the monitoring system offers the possibility to entirely monitor the bedload transport processes.

Direct bedload monitoring methods enable the determination of (specific) bedload rates and the texture of the bedload material. In the following the basket sampler and the bedload trap, both part of the integrative monitoring system at the Drau, are introduced. Mobile basket samplers have been applied in bedload monitoring for decades (Mühlhofer, 1933, Van Rijn, 1986). At the Drau River a LHS-Sampler with an intake width of 0.152 meters and a 0.5 mm net is deployed. Using a cable winch, the sampler is lowered from a bridge onto the riverbed. Measurements are conducted at 10 defined verticals and are conducted three times consecutively (Emmett, 1981, Habersack & Laronne, 2001). The measuring time is depending on the prevailing bedload transport rate.

At the bedload traps the sample box is covered by a lid with a longitudinal sampling slot. The sampling slots are 1.6 m long and 0.25 m wide at the two fix traps and 0.5 m wide at the hydraulically liftable trap. When starting the monitoring, the slot is opened hydraulically via manual control, the transported bed material gets trapped in the sample box and load cells automatically record the mass increase within the box. Bedload traps enable measurements at all discharge stages and thereby also bedload monitoring at flood events can be performed. Habersack et al. (2001) presented that both hydraulic and sampling efficiency are high. Furthermore the measurement of bedload rates and the determination of bedload texture is possible. Disadvantages of the bedload trap are its fixed position in the stream bed and the high maintenance effort.

Geophones are vibration sensors originating from seismic technology. To detect bedload transport, the geophone sensors are mounted on the underside of 0.36m long, 0.5m wide and 0.015m thick steel plates (Figure 4a). These steel plates are embedded on the same level as the stream bed (Figure 4b).

Bedload particles moving over the steel plates produce vibrations which are registered by the geophone sensors. The geophone signal is sampled continuously at a rate of 10 kHz. Good correlations are found for the geophone data and bedload mass, when bedload material is larger than 10-30mm (Rickenmann & McArdell, 2007).

For the comparison of measured bedload data and calculated bedload rates, bedload transport equations were selected with an application range fitting to the Drau River. The applied formulae were Meyer-Peter and Müller (1948), Formula of Wu et al. (2000) and the Formula of Recking (2013).

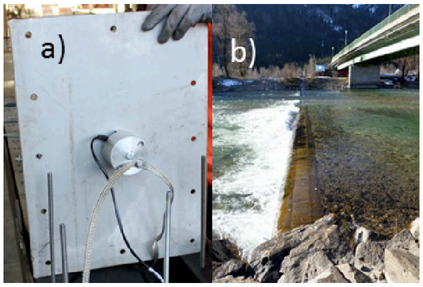

Fig. 3 a: Mounting of the geophone sensor at the steel plate, b: Arrangement of the geophones at the measuring site

RESULTS

Since 2006, Bedload transport monitoring is operated at the Drau River. Several direct measurements using the mobile basket sampler and the bedload trap have been performed and geophone data is available continuously since 2006. In the following, some results of the bedload monitoring program are presented. Thereafter, measured bedload rates at the Drau River are compared to calculation values.

From 2006 to 2016, direct measurements were conducted at different discharges (Figure 4) The blue diamonds represent all LHS-samples and the red triangles represent all bedload trap measurements.

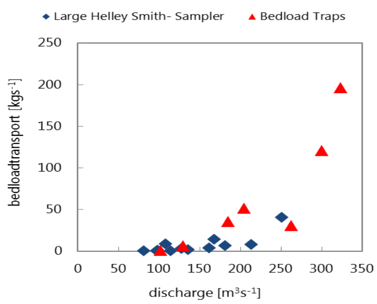

Fig. 4 Overview of performed direct measurements

The application of geophones in the Drau River produces high-resolution data of the bedload transport process. The temporal and spatial distribution of geophone impulses from 24.06.2016 to 22.06.2016 at the Drau River is shown in Figure 5. In the illustrated time period, various bedload peaks occurred and most bedload transport was registered in the middle of the channel between geophone 7 and 35. We observed areas within the cross-section, where bedload transport rates are comparably higher (peaks are located between geophone 16 and 23 on 17.06.2016). The graph in Figure 5 highlights possibilities of continuous data coming from geophone records.

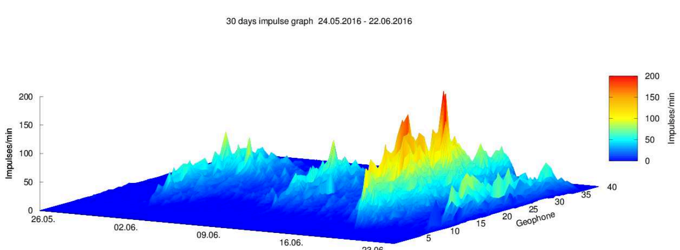

Fig. 5 Spatial and temporal distribution of geophone impulses (24.05.2016-22.06.2016)

A critical flow value for the initiation of motion is determined by comparing geophone data from the years 2010 to 2014 to flow discharge. The diagram, showing the discharge categories at the x-axes and the average geophone impulses at the y-axes, is depicted in Figure 6. It shows that at the measuring site sediment material starts to move between discharges between 60 and 80 m^3s^{-1}.

The back line displays the effective transport width, which increases from the point of motion until bank full discharge. The transport width is calculated by considering the influence width of every impinged geophon and increases from 0.5 m up to 40 m. This means that at discharges higher than 300 m^3s^{-1} bedload transport occurs within the total river cross-section. The effective transport width could also be observed in Figure 5 where the variance of the local transport is shown.

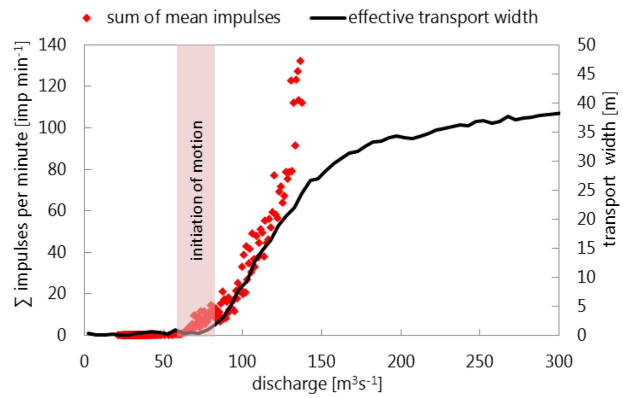

Fig. 6 Initiation of motion and effective transport width

Bedload monitoring over a period of 7 years at the Drau torrent showed that transported bedload mass does not solely depend on hydraulic conditions. Availability of sediment is another point affecting the bedload transport process. This information coming from measured data is crucial to interpret the results of calculated bedload data.

In Figure 7 the directly measured specific bedload transport rates using bedload traps and the LHS sampler are related to the calculated specific bedload transport rates and are presented in dependence of discharge. For this comparison the three listed bedload transport formulae were used.

The red squares indicate the comparison of measured data with the equation of Meyer-Peter and Müller. The formula underestimates measured bedload rates at discharges ~150m^3s^{-1} and for high discharges. The comparison shows a good fit at a discharge around 200 m^3s^{-1}. The blue diamonds show the comparison with the formulae of Wu et al. (2010). It properly reflects initation of motion, overestimates until a discharge of 160 m^3s^{-1} and underestimates bedload transport above a discharge of 260 m^3s^{-1}. The comparison with the formula introduced by Recking (2013) is represented by green triangles. It also shows a fit regarding initiation of motion, overestimates until a discharge of 160 m^3s^{-1}, and underestimates the bedload transport over a discharge of 260 m^3s^{-1}.

The mobile basket sampler is an appropriate tool for direct bedload measurements at the River Drau but measurements with these samplers are limited for high discharges as woody debris impedes a safe handling and measurements can only be performed during daytime.

Measurements with a mobile basket sampler are only possible up to a discharge of 250 m^3s^{-1} wherefore bedload traps are used for high flow rates. The highest measured bedload transport was 196.6 kg s^{-1} at a discharge of 323 m^3s^{-1}. The geophone device shows the variable spatial and temporal distribution of bedload transport. This variability favors the combination of direct and indirect methods in order to eliminate the variance of bedload transport in the calculation. When comparing Figure 4 and Figure 6 it can be seen that direct and indirect measurement devices are indicating a equal value for initiation of motion. Calculating specific bedload transports with formulas of Wu et al. (2010) or Recking (2013) the initiation of motion for the River Drau was shown to be reproduced accordingly. Only the formula of Meyer-Peter and Müller (1948) failed in calculating the point of initiation of motion accordingly. Generally, all used formulae, overestimated bedload transport at low discharges and underestimated the transport for high flow conditions. These findings are consistent with literature, where calculated values of bedload transport formulas were shown to be higher than the measured bedload data at low to middle flow conditions (Bathurst, 1978, Nitsche et al., 2011, Rickenmann & Recking, 2011). The measured bedload transport rates during high flow conditions showed that this effect changes for discharges above about 230 m^3 s^{-1}. As rarely bedload data for high discharges is encountered, this phenomenon is not found in literature.

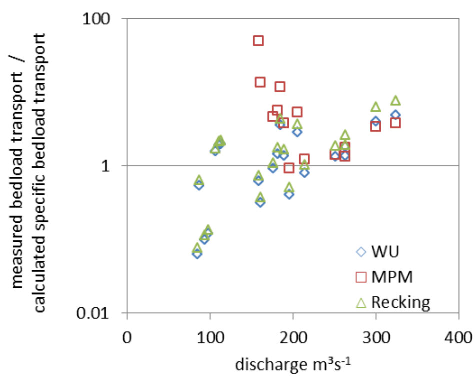

Fig. 7 measured bedload transport compared to the calculated specific bedload transport in dependence of the discharge

DISCUSSION

The effective transport width, which is shown in Figure 6, could be used to optimize the transport calculations as it could be increased with discharge. Hence the comparison of measured and calculated results is essential for optimizing the application of the bedload transport formulae, and therefore increasing the reliability for engineers.

CONCLUSIONS

The monitoring experiences showed, that an integrative monitoring system is crucial to obtain comprehensive bedload transport data. Only by combining different measurement methods disadvantages of single devices can be compensated. The comparison of calculated and measured bedload data for all measured events since 2009 and the thorough analysis of these data allowed for the enhancement in application bedload transport formulae. One promising aspect for further optimization is the effective transport width but still additional work is needed for detailed analysis and improvements in application of bedload transport formulas

ACKNOWLEDGMENTS

The financial support by the Austrian Federal Ministry of Economy, Family and Youth and the National Foundation for Research, Technology and Development is gratefully acknowledged. This research was financed by the Federal Ministry of Agriculture, Forestry, Environment and Water Management of Austria and the Federal governments of Carinthia and Tyrol.

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