Monitoring sediment fluxes in Alpine rivers: the AQUASED project

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ABSTRACT
Monitoring activities in Alpine rivers is normally focused on water discharge measurements; sediment transport measurements have recently gained interest for several reasons, such as flood protection, research purposes, sediment budget and continuity. A new monitoring station has been designed and deployed in the Sulden/Solda river (South Tyrol, Italy) to address these needs. The watershed is characterized by large glacier areas and steep slopes feeding the river with sediments. The station is equipped with a 4m-rack of geophone plates and an acoustic pipe-hydrophone. Bedload is measured along with suspended load, water stage, water conductivity and temperature. This work presents the installation and the results collected during a high flood event and compares them to values derived from bedload equations obtained by other authors.

KEYWORDS
monitoring, bed load, geophone, alpine rivers

INTRODUCTION
The traditional monitoring in Alpine rivers is focused on water discharge measurements. Recently the monitoring activities have focused both on water discharge and on sediment load (bedload + suspended load). Sediments move across the channel network transported by water according to two main mechanisms: as suspended sediment and as bed load. The first mechanism involves small size sediments (silt and sand), which are lifted by the water turbulence; the second involves the larger sediments (pebbles and cobbles), which move by rolling, sliding and saltation close to the riverbed. Mountain river hydraulic and morphology are strictly linked through bedload transport processes (Gomez, 2006); monitoring bedload is important to engineers, scientists, public authorities and people/institutions/enterprises operative in water resources. Measuring and understanding sediment transport phenomena is the key point for further investigation on the morphodynamic evolution of alpine rivers and on their response to natural and anthropic forcing. Suspended sediment transport monitoring is a consolidated activity and requires one or more turbidity meter to be installed in a river

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cross section. Bedload monitoring is a more challenging activity in mountain streams because of the complexity of the process. In the last decades both direct and indirect approaches for bedload monitoring have been applied in Europe (Lenzi et al., 1999; Rickenmann et al., 2012; Rickenmann et al., 2014; Dell'Agnese et al., 2014; Mao et al., 2014) and in Japan (Mizuyama et al.,2010). Within the AQUASED (which stands for the latin AQUA=water and SEDiments) project a new monitoring station has been set up along the Solda river to measure water and sediment fluxes. This work describes the set up of the new station and presents the instruments calibration and results related to bedload monitoring.

THE AQUASED PROJECT

Within the AQUASED project a new monitoring station (Figure 1) has been designed and set up in South Tyrol (Italy), along the Solda river. The project partners encompass two SMEs, two universities and the local authorities. The Solda river drains a 145 km^2 wide watershed with many glacial areas (18 km^2), which strongly affect the hydrological regime and the sediment availability. The new station has been designed with the aim of monitoring both water and sediment fluxes (suspended- and bedload). Suspended sediment monitoring is performed using a standard turbidity meter, bedload is indirectly measured by a rack of 8 Swiss-plate geophones, installed on the downstream end of a check dam. The minimum plates sensitivity is 2, 3 cm-grain size . The plates rack is 4m long and covers half the river width (8m), from the river center to the right bank. Water discharge is measured by means of water level measurements and the estimation of a suitable rating curve, derived from several direct water discharge measurements, performed using the salt dilution method. This consists in dumping a known amount of salt (NaCl) into the stream so that its base conductivity is increased. This increment is indirectly measured with a conductivity meter and a thermometer installed on the river bank. The whole station is the result of a large cooperation: the SMEs provided part of the measuring instruments and the design activities, the universities provided the scientific support and the local authorities (Water Department of the Province of Bolzano) provided the necessary support to make the project be operative.

Figure 1: (left) the measuring station: the array of geophones is installed on half width on the downstream end of the check dam and (right) a detail of the turbidimeter installation system

The monitoring station has been installed during winter 2013-14 and completed at the beginning of May 2014; the collected data include: water level, turbidity, temperature and conductivity and geophone impact data. One of the novelties of this installation is the geophones data recording system, which saves continuously the whole raw plate velocity (cm/s) data sampled at 5kHz, without loss of information, adopting a signal/noise detecting algorithm and an on-the-fly compression. This system can save a year of 5 kHz data in about 20 GB of disk space for each plate. The saved data can be elaborated both counting the number of impulses above given thresholds (i.e. the "traditional" plate signal elaboration described in Rickenmann et al. 2014) and applying any type of signal process algorithm. The traditional signal elaboration consists in fixing a threshold and counting the number of recurrences (called impulses) the signal exceeds it. Here six different thresholds are used; the signal intensity depends on the sediment grain size, vibrations due to larger cobbles are typically higher, therefore the upper threshold can be related to large-size sediments, while the lower are related to smaller sediments. In the following the number of impulses are collected by six channels, the first (channel n. 1) refers to the lower threshold and channel n.6 refers to the higher threshold.
In 2014 the monitoring station was equipped with an acoustic pipe sensor ("Japanese pipe hydrophone", Mizuyama et al., 2010) for bedload sampling, with the main aim of performing inter-comparison between the two indirect bedload measuring systems (plate geophone and pipe hydrophone), but unfortunately on August 13th 2014 a high intensity flood heavily damaged the pipe.

Figure 2: bedload sampling using a crane mounted trap (left), the sediment trap (right)

CALIBRATION

The geophone plates carry out indirect measurement of the bedload discharge. Basically, recorded data are a measure of the vibrations induced by the sediments moving on the plates. Suitable rating curves are needed to correlate the specific bedload transport (measured in kg/(m s)) to the number of impulses recorded by the system. Calibration measurements have

been performed using a heavy bedload trap, handled by a crane. The trap is made by a net characterized by an opening size of 3.6 mm anchored to a metal frame. It is lowered into the stream flow just downstream of a plate and held by a crane and four ropes, which help in the trap positioning. The trap is kept in the sampling position for 5 to 10 minute, depending on the bedload transport intensity. The net retains sediment particles larger than 3.6 mm in diameter. The collected material is then sieved using four sieves (Figure 3), characterized by net dimensions of 64mm, 45mm, 32mm and 22mm. The five separated samples are weighed, the four larger size samples are then released back into the stream and the grain size distribution of the finest size fraction (<22mm) is determined via laboratory sieving. This procedure allows to carry to the laboratory a reduced amount of sediments, which means reduced sampling costs.
Rating curves for bedload are obtained comparing the bedload direct measurements to the geophone impulses. Figure 4 shows an example of a rating curve obtained after the first sampling in 2014.

Figure 3: (left) sieves used to separate coarse pebbles (64mm, 45mm, 32mm and 22mm) from medium-fine pebbles (<22mm), (right) a detail of the 64mm sieve

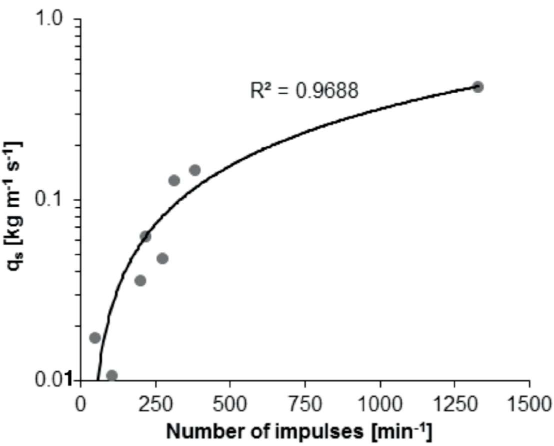

Figure 4: specific bedload discharge versus number of impulses exceeding the voltage threshold relative to channel 4 (rating curve). Each point on this graph represents a direct measurement of bedload taken with the sampler as shown in Figure 2

RESULTS

Since its installation the station worked regularly, recording a high intensity flood occurred on August 13th 2014. Figure 5 (upper part) shows the water discharge data recorded in the summer season 2015: the Solda river is characterized by a snow melting period during May and June, followed by a glacier melting period, during July and August. Figure 5 (lower part) shows the plate signal measured by plate n.2, located close to the river center. The number of impulses recorded on channel 2 is high, especially during high flows and during the glacier melting period. During the low flow periods channel 2 impulses never drop below 100 impulses/h, since during the summer bedload is always active. The number of impulses recorded on channel 4 refers to larger sediments and during low flow conditions (end of May, June and August) it is very low, showing that in those periods large-size sediment transport is not observed.

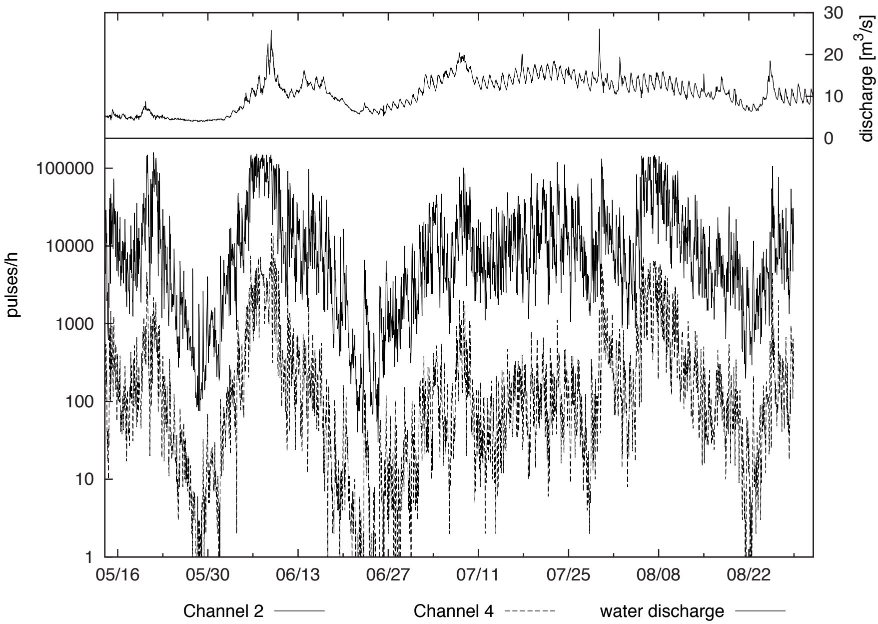

Figure 5: water discharge (above) and bedload impulses (below) during summer 2015, data from plate 2, located near the river center

Figure 6 shows the flood of August 13th 2014, which was characterized by a peak of 72 m^3/s (specific discharge 0.5 $m^3/s/km^2$), and by an intense sediment transport, which attains values up to 1000 kg/s, (preliminarily estimate using data from only one geophone plate). The computation of the total amount of sediments transported across the measuring station during the entire flood event was 7100 tons. Impulses on channel 6 were recorded mainly during this intense flood event, characterized by large boulder transport. Water and sediment fluxes seems to be well correlated at the beginning of the flood; on the contrary the water discharge dropped rapidly at the end of the event whereas the sediment discharge kept high values for several hours. Unfortunately the acoustic pipe was damaged during this event because it was impacted by large boulders (up to 1m) transported by the flow. In contrast, the geophone plates were not damaged. Data show that the actual bedload is significantly lower compared to values estimated applying the Schocklitsch (1962) and Rickenmann (1990 and 2001) equations, even after accounting for form drag correction. Sediment transport equations approximately match the bedload rates recorded by the geophone plates only at the peak of the transport event. This confirms that using formulas to estimate bedload in steep gravel-bed rivers can lead to large errors (Gray and Simões, 2008) especially at normal flows.

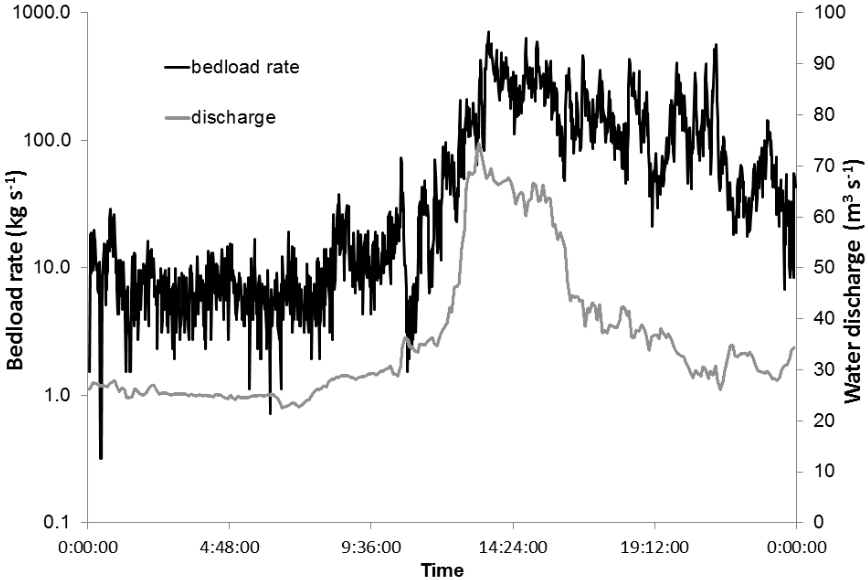

Figure 6: bedload rate (thick black line) and water discharge data (grey line) data collected during the August 13th 2014 event

Figure 7 shows the number of impulses recorded during summer 2015 on channel 4 versus the water discharge. Data show a complex pattern: the bedload transport intensity seems to be not well correlated to water discharge. High bedload rates have been measured whereas water discharge values never exceeded 7-8 m^3/s especially in May; high bedload rates have been recorded during high flow conditions in June; in July the bedload transport rates did not reach the values observed in June-even though the water discharge reached a similar peak value; finally in August, high bedload transport intensities have been measured for intermediate flow conditions. Bedload intensity reflects both sediment availability (in the catchment as well as within the riverbed) and the sediment transport capacity of a given river reach. For example the high bedload transport rate measured in May could be related to high sediment availability within the riverbed; the high bedload transport rate measured in August is probably related to the sediments coming from the glaciers located in the upper part of the catchment.

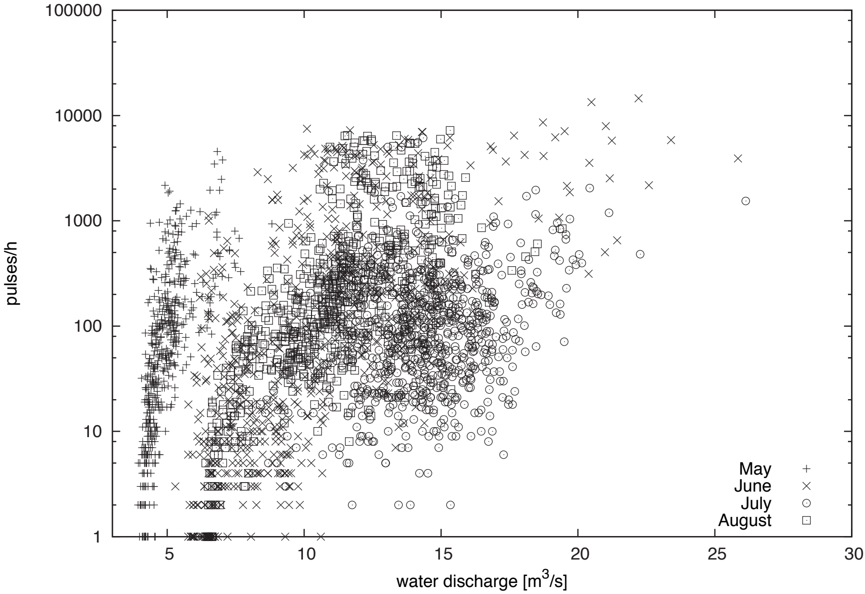

Figure 7: 2015 measured channel 4-impulses are plotted versus water discharge, data from plate 2, located near the river center

CONCLUSIONS

A new sediment transport monitoring station in a glacierized and active watershed has been designed and installed. The collected parameters are bedload, suspended load, water stage, water conductivty and temperature. Bedload is indirectly measured using a rack of 8 geophone- plates. Data are recorded using an innovative signal/noise recognition system and a compression algorithm, which allows to save the whole high-frequency signal, with an acceptable amount of storage usage. Calibration was performed using a bedload sampling device with a mobile crane support.

A complete data set of bedload and water discharge values was collected during 2014 and 2015. The Solda river behaviour is characterized by a glacial runoff regime, with a very low water discharge during winter, a snow melting period between March and June and a glacier melting period from July to August-September. Sediment transport data show higher bedload values during the glacier melting period and very low sediment transport rates during the snow melting phase, probably due to considerable difference in the sediment availability. Flood event data analyses and the comparison with bedload formulas confirm the complexity of bedload estimation in steep gravel bed rivers.

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