Monitoring of bed load transport by use of acoustic and magnetic device

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The high energy and active morphodynamic environment associated with mountain streams introduce important technical constraints in the application of classical techniques to measurements of bed load transport. Direct classical methods for investigating bed load transport are for the most part expensive to apply, in terms of both equipment and manpower requirements. As a result, most studies applying such methods have addresses very limited objectives and involving short periods of records. In addition, it is difficult to use short-term monitoring in the interpretation of longer-term sediment yield and contemporary fluvial system changes. Most attention has centred on bed load versus suspended load because this determination is important to subsequent evaluations of transport rates. Studies of sediment transport indicate, that bed load constituting a substantial part of the total load and is generally much more important than suspended load in forming and changing the channel system of a mountain stream.

Direct measurements particularly during floods are extremely difficult because of many problems such as high flow velocity, large quantities of sediment, the wide range of grain size and dangerous field conditions. Any sampler placed in the flow may perturb local hydraulics conditions. Numerous studies have attempted to measure bed load using acoustic device (e.g. Bedeus & Ivicsics, 1964; Tywonivk & Warnock, 1973; Richards & Milne, 1979; Froehlich, 1982; Bänzinger & Burch, 1990; Rickenmann, 1994). Geomorphologists and hydrologists are constantly seeking improved methods for measuring bed load transport in order to more accurately quantify sediment yield from drainage basins. Field studies are difficult to compare because of a variety of measurement techniques and sampling procedures. Therefore it is necessary to develop appropriate techniques to monitoring bed load transport in the mountain streams.

The work reported was undertaken in the Homerka instrumented catchment in the Polish Flysch Carpathians, where different monitoring techniques of sediment transport have been applied over the past 30 years. The area is characterized by highly active erosion, sediment transport and fluvial sedimentation processes. Fluvial processes are dominant, and the channel network is being actively deepened. The extreme floods has a decisive determines the formation of the fluvial system, being a geomorphologically effective event. The armoured surface layer consists of grain sizes with a D_{50} of 55 mm. The coarsest fractions (> 600 mm) of the bed material only becomes mobile during extreme floods. But transport rate and mechanisms of this material are still poorly understood. Little is currently known about large particles moving through the drainage system of catchment basins of different scales.

Grain sizes that normally move as bed load are transported at high rates during extreme flood as part of the suspended load. During low and intermediate magnitude flood events, when a stream is not competent to transport the coarser fractions of the bed material, the finer, mobile fractions are selectively removed from the active layer. When the tractive force is larger than the critical value for the maximum grain size, all fractions are transported.

In instrumented catchment of Homerka stream bed load transport is measurement using the acoustic and magnetic methods. The Homerka stream draining a catchment area of 19.6 km^2 with a longitudinal slope of 53,3 ‰, mean discharge of 0.350 $m^3 s^{-1}$, annual flood discharge of 9.15 $m^3 s^{-1}$ and a mean annual rainfall of 909 mm. Diverse bed load transport along the Homerka stream is associated with differing sediment supply developing in response to bedrock erosion, bed armouring and hillslope mass movements.

The acoustic device was made by author and has been installed at gauging station of Bacza stream, which is tributary of Homerka stream. It enables the continual detection of coarse particle movement during flood events as indicator of the magnitude of bed load movement. Early experimental investigations started in 1972 and an upgraded recording system has been working since 1975. In the past 29 years, 75 events have been recorded.

The acoustic device consists of a three steel-pipes with a microphones placed horizontally on a bed channel, a signal processing unit, oscilloscopes, recorders and a computer. These recording systems have been installed in a straight reach in the lower part of the stream. This type of sensor does not interfere with the natural hydraulic conditions. Each steel-pipe has 6 m in length and 42 mm diameter and have been installed on bed channel at 10 m distance from each other. Each microphone is a small capacitive one and has a flat frequency response from 20 Hz to 35 kHz. Author tested different microphones as also different diameter of pipes both steel and plastic.

The microphones catches sound (acoustic waves) transferred through the pipes after its generation due to percussion of gravels. The acoustic noise has a frequency in the range from 20 Hz to 60 Hz. The signal-processing unit have a low frequency amplifier and six noise filters. Data logging system are based on the recording current signal whose amplitude is a measure. Power is supplied from external high-capacity lead-acid batteries connected to power. The above device is still experimental and has their own advantages and disadvantages.

The relationship between water discharge and rate of bed load transport is analysed from the continuous recording of water discharge and the continuous measurement of acoustic signals of coarse sediment. In general, sound intensity increases with transport rate and the frequency of sound is inversely proportional to the diameter of the moving particles. The pattern of signals has a complicated hierarchic system reflecting bed load transport pulsed nature and noise. The initiation of sediment particle movement is an important factor of the bed load transport process. There were observed different threshold discharge, the passing of which causes initial motion of bed load.

The transport rate increases rapidly and achieves its maximum value very soon after an increase in the magnitude of the flow renders the bed unstable. The threshold discharge varies during each flood events. It is possible to recognise the discharge threshold for initiation motion of the bed load transport during the rising limb of flood and the second one, during the falling limb, which sediment transport stops. In general, bed load transport reaches a peak more rapidly than the discharge. For a given flood discharge, intensity of bed load transport vary according to whether they are associated with the rising or the falling stage. This is reflected in the shape of the loop describing the discharge and bed load transport relationship (e.g. Froehlich, 1982; Schöberl, 1991; Rickenmann, 1994; Moog & Whiting, 1998). Each flood is characterized by a loop with a different shape in a manner similar to the hysteresis curve analogous as suspended sediment load (Froehlich, 1982). The device also has a possibility of estimating the amount of discharge of bed load. Calculation of the amount of bed load moved it be bases on periodic surveying or emptying of the sedimentary basin on above concrete weir and drop dam. The particle size distributions of the sediment were determined using large sieve.

Usually more bed load was transported by discharges preceding the first annual occurrence of a threshold rate of initial motion. A very important role is played by the sequence of floods and interarrival time. The role of the relaxation time has still been poorly understood.

Applications of the magnetic tracer technique allow to obtain the fractional bed load transport rate, in compliance with the grain fractions, transported during flood (e. g. Ergenzinger & Conrady, 1982; Ergenzinger & Custer, 1983; Hassan et al., 1984; Reid, et. al., 1984; Ergenzinger, et al., 1994;). The first continuous measurement of the passage of naturally magnetic coarse material bed load transport was done by Ergenzinger and Custer (1982).

Coarse material bed load transport is measured at Homerka stream at use magnets cemented into holes drilled into gravels and an electromagnetic device that acts like as a classical metal detector. The system was made by author and has been installed at gauging station of the Homerka stream. Early experimental investigations started in 1982. The device consists of a two elongate magnetically sensitive coils (copper windings on an iron core), each of 4 m length. Coils have been installed across bed channel at 30 m distance from each other. The motion of traced gravels during a flood is registered by their passage over the coil, which affects the magnetic field causing a change in the inductance of the coils. According to the Faraday principle a voltage peak is induced and the signal is detected, amplified and transmitted to a receiver and then to recorder. The median bed material in the experimental reach is 64 mm in size. Different size of magnets are inserted to different sizes of gravels and protected with epoxy. A paint cover helps to visually identify the traced coarse particles on the stream channel. After every flood gravels were searched with a portable metal detector and reseeded**.** Recovery rates range from 12 to 85%.

Transfer of gravel particles through the Homerka channel system appeared to be influenced by flood magnitude and duration. The first event after the injection of the traced gravels into the channel may not representative. It is almost not possible to relocate labelled particle in the exactly identical position it had occupied prior to treatment. The transport distances of single traced gravels range from 5 - 140 meters during annual flood. The small gravels have significantly lower transport lengths than the larger particles.

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