Bed load measurements with a new passive ultrasonic sensor

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Introduction

Sound generated by particle impacts has been employed for detecting bed load movement for some time (Mulhofer 1933), but the development of this approach has been slow in spite of its advantage in producing a continuous record.

Richards and Milne (1979) applied a piezo-electric transducer to convert acoustic energy to electric signals. They concluded that the method was potentially useful for identifying bed load transport thresholds.

Banziger and Burch (1991) and Rickenmann et al. (1997) describe a system where impacts caused by bed load passing over a metal plate are detected by a hydrophone. Impacts above a certain threshold amplitude are recorded by a pulse counter. The volume of material deposited in an adjacent sediment trap was found to correlate with the number of pulses counted per minute.

The present paper discusses the results of experiments and field work carried out to test the suitability of a passive ultrasonic sensor recording in a narrow frequency band. It had initially been developed to monitor the amount of sand carried in suspension by oil pumped up from reservoirs below the Norwegian continental shelf. The sensor detected the sound of particles impacting the pipeline wall at a bend. These collisions generate a characteristic frequency pattern which was analysed to estimate the total mass of sand.

Clampon (1998) adapted this pipeline instrument for NVE so that it could also record the impact of gravel- and cobble-sized material. The first generation model of the resultant bed load sensor was installed and tested in three rivers in Norway.

Sensor design and mode of operation.

The sensor consists of an acoustic sensing device, a signal amplifier and, a low-pass / high-pass filter and a digital signal processor (DSP). The signal filter removes all frequency components outside a narrow ultrasonic frequency band. The remaining signal is integrated over a period of one second and the amplitude value output in digital form as a numeric string. The water turbulence generates very little acoustic energy in the selected frequency band. The processed data thus almost entirely represents variations in bed load transport with very little ambient noise present in the record. The sensor is fitted onto the underside of a 500x500x10 mm steel plate which is fixed to the riverbed. Particles sliding or rolling over the plate create a vibration, which in turn is picked up by the sensor.

The sensor has been connected to a Sutron 8210 datalogger (RTU). To conserve data storage space and reduce communication time when downloading, one random sample in every 5 second interval is recorded; the remainder are discarded. In addition to the bed-load reading, the logger measures water stage at 5 minute intervals. The stored data is transmitted to the office once a day, using a combination of line-of-sight radio and fixed line modems. Of the two sites operational today, one is solar powered and the other uses mains power.

The sensor runs on a 12V power supply using 300 mA and communicates readings through an RS-485 serial interface. The cylindrical sensor-head is 20 cm high and 10 cm in diameter. All electrical components are mounted in a robust and watertight stainless steel housing.

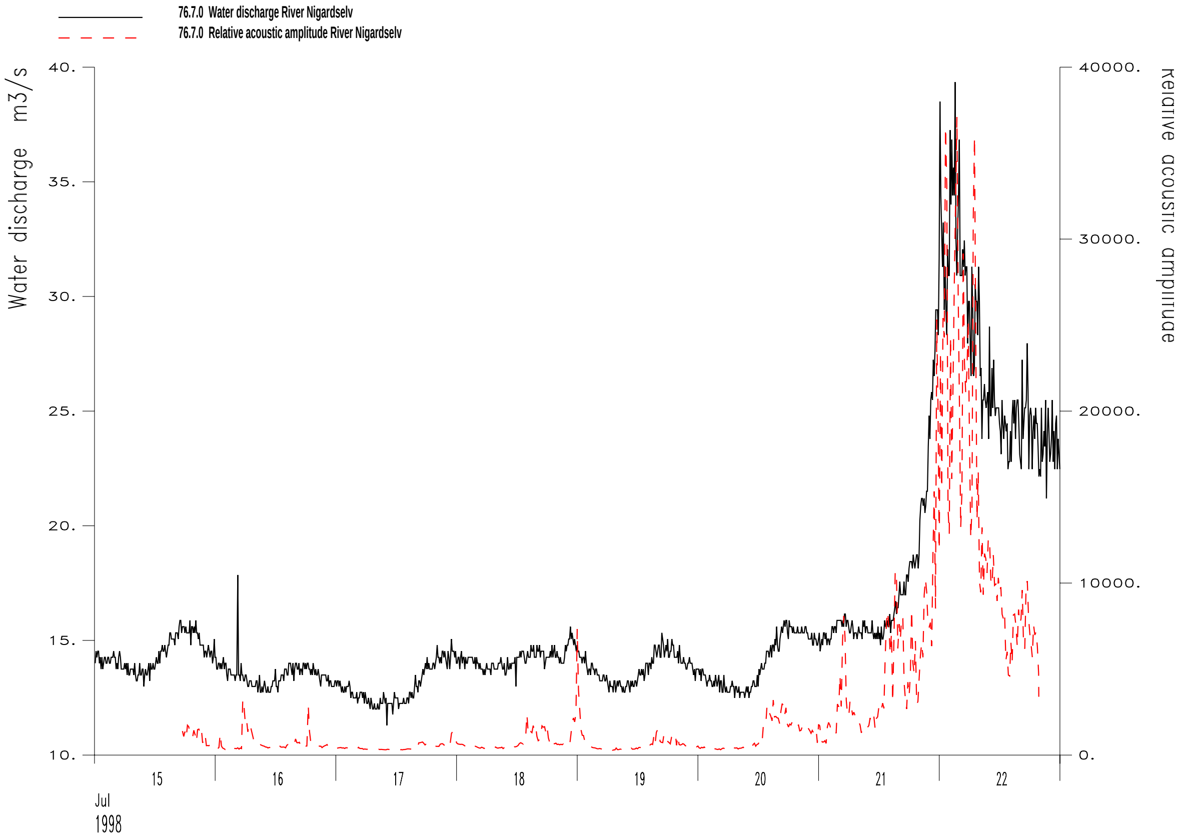

Fig. 1 Maximum relative acoustic amplitude and water discharge in river Nigardsbreelv 15 – 22 July 1998.

Nigardsbreelv

Nigardsbreelv is the meltwater river from the Nigardsbre glacier and its flow is characterised by a high degree of turbulence. The river occupies a bedrock channel and the bed load carried by the river is derived from sediments supplied by the glacier. The bed load is composed of relatively coarse material; gravel fractions dominate but there is also a large proportion of cobbles and boulders. Clasts are often well rounded.

The annual transport rates have been calculated from measurements of the annual rate of deposition on the delta in lake Nigardsvatn, 0.6 km downstream from the glacier terminus. The mean annual transport rate amounts to 8000 t/yr, though up to 20 000 t/yr have been measured during years with particularly intense runoff.

In May 1998 a sensor was installed in a rock surface cavity on the riverbed ca 0.5 km downstream from the glacier. The cavity was covered with a steel plate, connected to the datalogger by a cable.

A record covering 15-22 May 1998 is shown in Fig 1. This indicates mean values during successive 5 minute periods. During the first seven days, the discharge was subject to daily fluctuations of around 12-15 m3/s because of snowmelt. The acoustic record shows little bed load activity, except for some minor peaks triggerd by short term blocking of subglacial tunnels. The acoustic activity increased considerably, however, during a flood at the end of the period of measurement but fell back to a low level during the recession phase even though discharge remained high for some time. No direct sampling of bed load was carried out. However a high transport rate of cobbles and boulders during the flood is indicated by the fact that the cable was heavily abraded, and eventually broken.

Gråelva

In November 1999 a sensor was installed in the river Gråelva, a lowland river in Trøndelag in central Norway. The sensor and the corresponding plate were built into the weir of the water discharge monitoring station. Gråelva represents a low energy environment when compared to Nigardsbreelv . The bed load is derived from a layer of gravel and cobbles on the river bed upstream of the monitoring station.

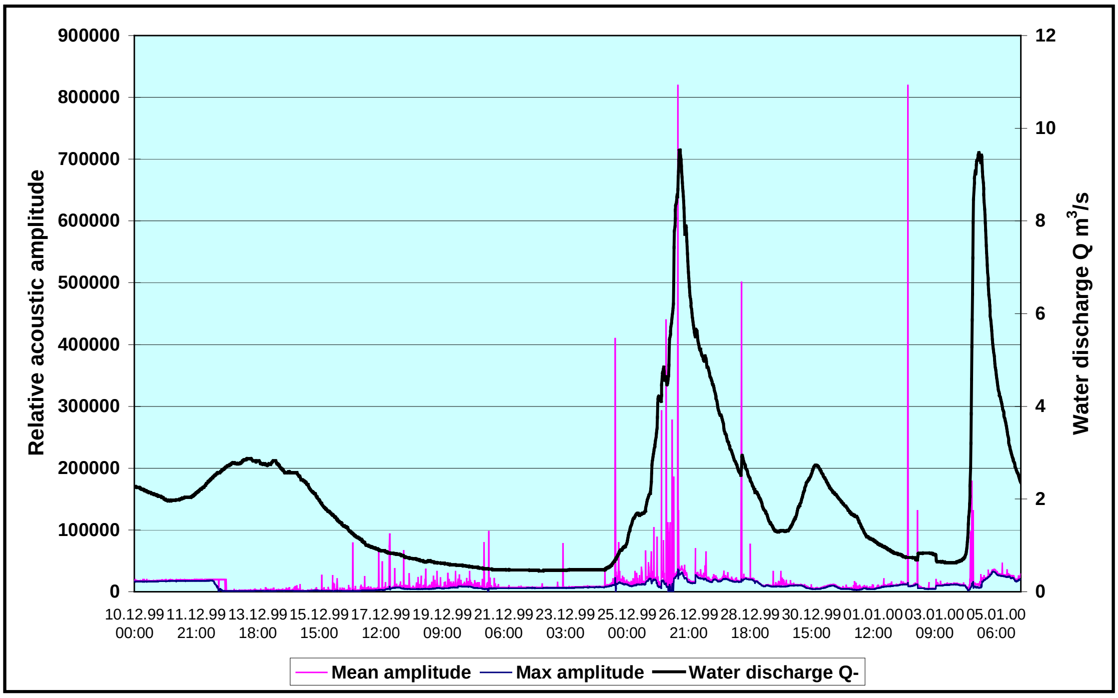

Fig. 2 Relative acoustic amplitude and water discharge in river Gråelva 10 December - 5 January 1999.

A record covering the period 10 December 1999 to 5 January 2000 is shown in fig 2. The measurements reveal a transport pattern essentially in agreement with general bed load observations. The bed load passes in pulses, but these do not always correlate with high water discharge.

If we exclude the anomalous measurement of 2 January the largest maximum amplitudes were recorded during the rising water stage of the flood event on 25 og 26 December. During the falling stage of the same flood there is apparently little bed load activity except on the 28 December when a small rise in discharge was accompanied by a major acoustic peak. The mean amplitude, however, remained low throughout the whole measurement period. In contrast, during the flood on 4 January there was only a small increase in acoustic amplitude. No high amplitude events were registered after the flood had culminated.

Bayelva

Bayelva is located near Ny Ålesund on Svalbard in the high Arctic. Most of the sediments are supplied by the Austre and Vestre Brøggerbre glaciers and erosion in the glacier forefield.

Sediment transport and water discharge are measured at a composite Crump weir near the river outlet in the fjord. Between the the monitoring station and the glaciers the river passes through several sandurs. The sediments on the riverbed are dominated by gravel and cobble fractions. They are derived from sandstones and are in general more angular than the clasts in the two other rivers.

Results from the acoustic record for 14 – 25 July 2000 are given in Fig.3 Water discharge variations during the period were mainly caused by temperature fluctuations giving rise to variations in snow and glacier melt. The highest acoustic amplitudes were recorded during the rising stage of the 17 June flood event. A similar pattern occurs during each of the daily discharge fluctuations during the period. However, the amplitude of the acoustic peaks does not always match the water discharge amplitudes. During low discharges of 3 – 6 m3/s for 24 – 27 July, the acoustic amplitudes are higher than the ones of the preceeding days despite significantly lower water discharges.

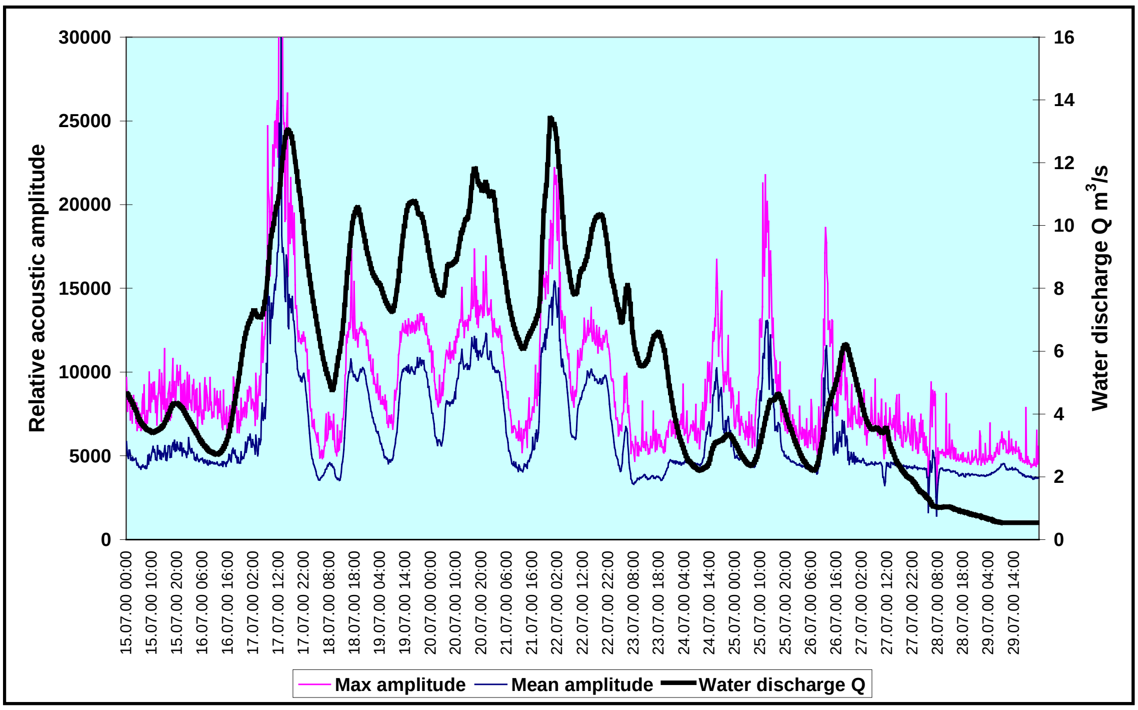

Fig. 3 Relative acoustic amplitude and water discharge in river Bayelva 15 – 29 July 2000.

A plot of bed load samples obtained with a Helley–Smith sampler vs acoustic amplitude is shown in Fig. 4. More data need to be collected to confirm this correlation. It is however apparent that the amount of bed load trapped by the sampler increased when the acoustic amplitude peaked.

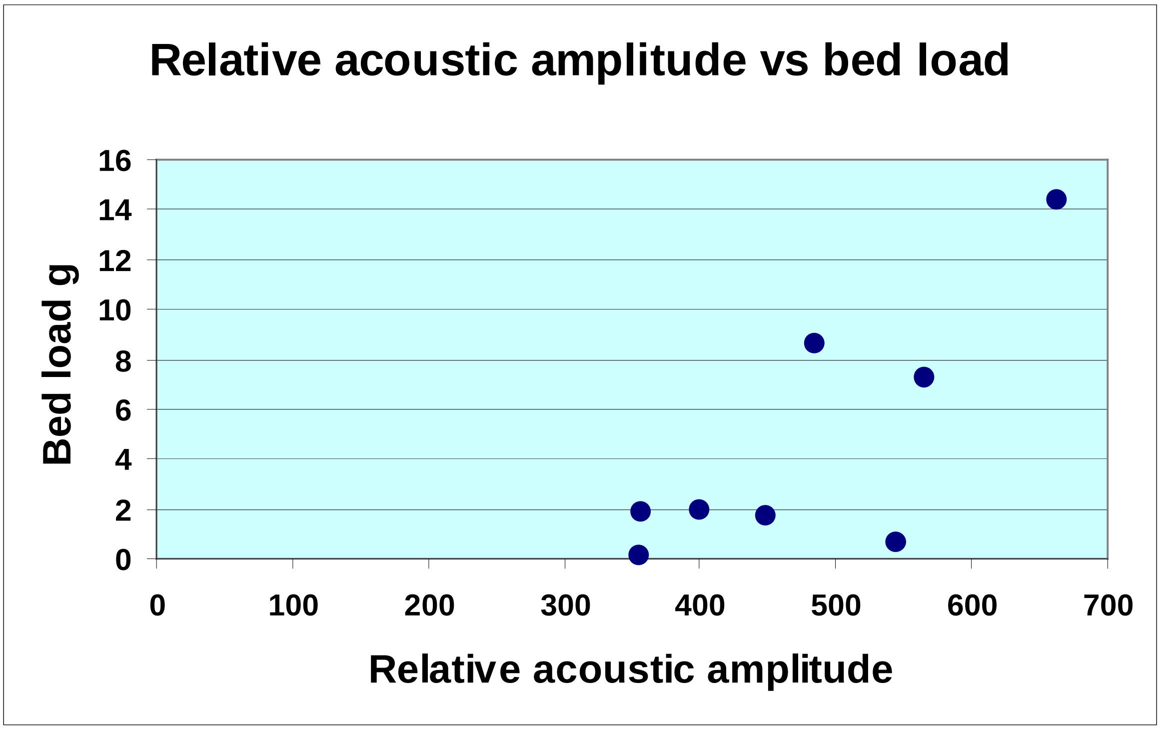

Fig 4. Relative acoustic amplitude vs bed load trapped by Helley – Smith sampler for 20 min.

Conclusions

The experiments and field tests of the acoustic bed load sensor indicate that this system successfully monitors temporal variations in the rate of bed load transport.

The system must be calibrated to direct samples of bed load for each measuring site.

The field measurements reveal a markedly irregular pattern of bed load transport rates in the studied rivers. There is some similarity to suspended load transport in the way that an hysteresis effect is present, namely the transport rate is much larger on the rising stage than on the falling stage of a flood.

The small difference between max and mean acoustic amplitudes recorded in the high energy rivers Bayelva and Nigardsbreelv most probably indicates continuous movement of fairly coarse bed load. In the quieter river Gråelva there is a very large difference between the mean and max amplitudes. This probably represents a continuous flow of small amounts of sand with only sporadic transport of cobbles or boulders during the observation period.

References

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