Velocity gauging with ADCP in rivers with bedload and sediment transport

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The ADCP technique is generally accepted as an instrument for velocity gauging in rivers. But still there are many challenges to deal with: (1) In rivers with high sediment transport, like in many streams in the foothills of the Alps, ADCP gauging of velocities is insufficient and sometimes even impossible to be carried out satisfactorily. (2) Rivers with bedload make it difficult to validate the measured data, if the position of the ADCP is fixed by the Bottom-Tracking-Method. (3) Sediment transport is also responsible for inaccurate measurement readings of some gauging stations. Due to streambed erosion during floods, the supposed rating-curve is not valid during peak flow. It has to be adjusted to measured velocity data as well as shape and depth of the riverbed. During a two-year research project, these problems were investigated in detail at two typical rivers in Southern Bavaria: First, the major river *Inn* with high sediment transport rates and considerable erosion and aggradation processes during flood and second, the much smaller river *Tiroler Achen*, flowing into Lake *Chiemsee*. Although no erosion occurs here, considerable bedload requires additional measurement techniques to get exact position data during ADCP measurements.

Keywords: Velocity gauging, flow metering, sediment transport, bedload, differential GPS

1 INTRODUCTION

The knowledge of discharges in rivers is of high importance for many hydrologic tasks and investigations in water resources engineering. Accurate values are the crucial input data for all hydrodynamic-numerical modeling schemes; and in flood frequency analysis, a reliable evaluation of extreme discharges is only possible, if the data from river gauging stations is precise and available in a wide range of different runoffs [1].

In the presented research study the authors tried to detect the supposed erosion processes in the river Inn. The original idea was that if the riverbed erodes during flood, the cross section for runoff increases which of course will have a positive effect on the remaining freeboard in the river. While studying the erosion process through ADCP and echo sounder at the river Inn, the authors faced some unknown problems, which are described in this article.

The extreme flood in May 1999

The extremely high water in May 1999 was caused by a Vb meteorologic scheme, hitting wide areas in Bavaria, Austria and the Czech republic. Figure 1 shows the hydrograph of this major flood.

While studying the runoff we realized, that the bottom of the river bed at three gauging stations near the city of Rosenheim must have been eroded by several meters during the runoff of the peak of the wave. Using the 1d-model HEC-RAS and assuming a constant river bed before and during the flood event [2], the calculated water levels did not fit to the observed water levels (fig. 1).

The reason for this obviously must lie in the eroded riverbed during flood. Astonishingly, the deviation from measurement and calculation corresponded very closely to the hydrograph. It seemed as if erosion increased with higher discharges, and after the peak the riverbed was filled up with sediments almost simultaneous with the descending discharge.

In this article we will concentrate on our investigations at the river *Inn.* The results we found at the *Tiroler Achen* are presented in detail in [3].

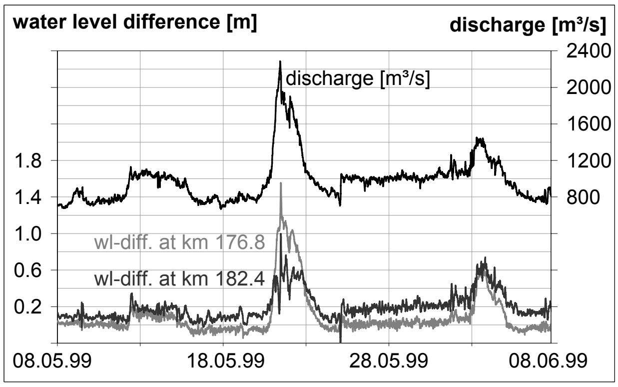

Figure 1: Hydrograph of the flood in May 1999

2 MEASUREMENTS AT THE RIVER INN

Encouraged by this simple insights in the mechanism of erosion processes the authors tried to get more information about erosion and sedimentation coming along with high runoffs. Therefore, during the exceptional flood in August 2005, several measurements have been taken at the Inn near the village of Nußdorf using amongst others also the ADCP technique [2].

2.1 ADCP in use

Acoustic Doppler Current Profiler use the well-known Doppler Effect to measure relative velocities between transducer (= measuring device) and reflectors (= particles in water column). For the here presented investigations ADCP model "Workhorse RioGrande", developed by RD Instruments, with a frequency of 1200 kHz was used.

The carrier device is a self made catamaran in aluminium with 20 kilograms of weight. It contains a waterproof box hosting the battery, the modem device and a laptop, and also a GPS antenna used for external recording of position coordinates (fig. 2). Using a second, stationary GPS antenna on the river bank allowed the use of the so-called *differential GPS-technique* and improved the accuracy up to few centimetres.

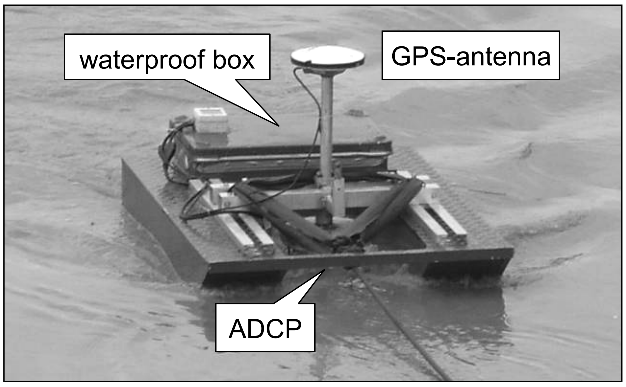

Figure 2: Carrier device with ADCP and onboard GPS

2.2 Situation

The following information is given for better understanding the situation at the gauging station, where the investigations took place.

<u>Geography, catchment area:</u>

The river *Inn* rises in Switzerland, at an altitude of 2484 meters above sea level. After 517 covered river kilometres and 2193 metres of difference in altitude, the river mounts into the Danube near the Bavarian city of Passau. Of its total catchment area of some 26.000 km², about 16.360 km² fall upon Bavarian territory, which the river drains along its final course of 213 kilometers before flowing into the major river *Danube* at Passau. Because of the high alpine catchment area of its upper reaches, the river *Inn* transports heaps of very fine sediment, coming from the glaciers in Switzerland and Austria.

<u>History:</u>

Due to the construction of 16 power plants along the Bavarian Inn during the last 80 years and the declining energy slope of the river, a huge amount of sediment was deposited in the reservoirs and river bed levels ascended up to several metres. Today, these sedimentations already are included in water management studies, but the temporal eroding effect of high floods, often linked with drawdown of retention water level elevation, is still unknown [2].

<u>Measurement site:</u>

Measurements were carried out at river kilometre 199.2, only 500 metres above the hydro power plant Nußdorf, where a road bridge crosses the river. Water level at retention water level elevation is about 120 metres wide and mean depth is six metres.

<u>Discharge situation:</u>

During the summer months 2005, five measurements could be carried out – three during normal flow conditions and two during high flood (fig. 3).

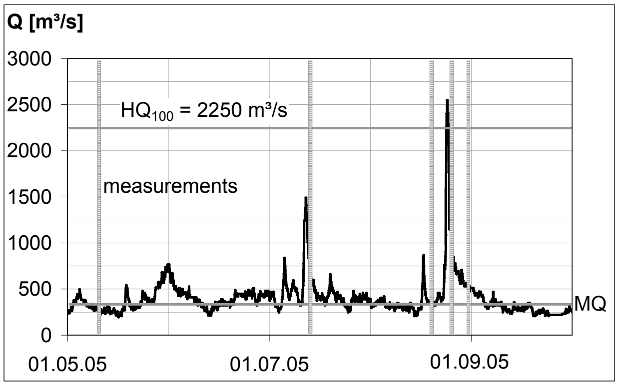

Figure 3: Discharge situation in summer 2005

2.3 Measurements during high flood

Carrying out the measurements was a big challenge for the executing personnel.

<u>Problems:</u>

- A huge amount of branches, trees, parts of wood etc., floating with the current, put the measuring devices at great risk (fig. 4).
- High flowing velocities caused high flow resistance of the ADCP carrying device and great exertion was necessary to keep the boat in position as well as to move it across the river.
- Turbulences at the water surface and stationary waves, induced by the two pillars of the bridge, also made the movement across the river very difficult.
- High suspended sediment concentrations partially made it impossible for the ADCP to collect data.

Figure 4: Driftwood flowing down the river *Inn*

2.4 Results of the measurements

The following explanations include only the results of the high-flood measurements during August 2005. The Peak of the flood wave occurred from 23rd to 24th of August during night time, which avoided the acquisition of data during peak flow. Measurements were possible not until the following afternoon, while the decelerating branch of the flood wave. Six crossings could be carried out successfully, their data sets were analysed and interpreted [2].

Bottom Track versus dGPS:

Because of sediment transport near the river bed, bottom track was biased upstream (fig. 5).

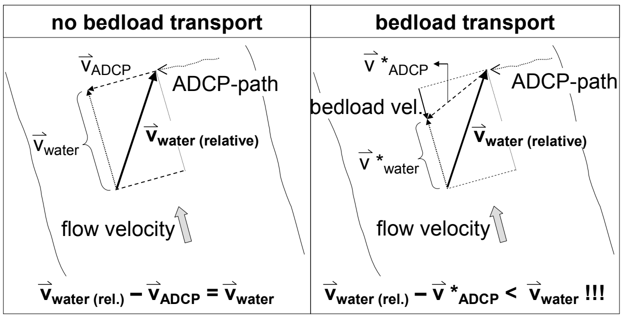

Figure 5: Biased bottom track due to bedload transport

As figure 5 shows, upstream biased bottom track is responsible for underestimating flowing velocities with ADCP measurements [3]. Therefore the calculated discharge is also too small, when referencing ADCP data on bottom track in cross sections with bedload transport. Referencing measurement data on dGPS data produced satisfying results, comparing them with available reference values (fig. 6).

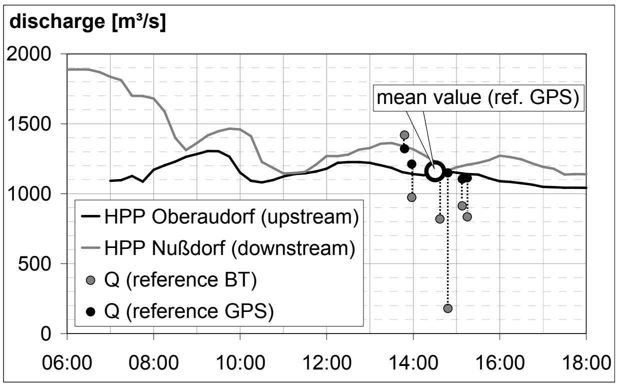

Figure 6: Discharge calculated by the ADCP with reference on bottom track as well as on dGPS

Due to high suspended sediment concentrations, the bottom track signal often lost contact to the river bed. Therefore river width was detected insufficiently, which also could be improved by referencing the data on dGPS information.

Erosion of the river bed:

For the first time known, temporal erosion of the river bed during high flood could be detected with ADCP measurements. The results show an erosion of up to two metres in comparison with the river profile during normal flow conditions (fig. 7).

Because it was the first time, that the temporal erosion could be detected and documented, this information is very important and is an extremely useful contribution to the ongoing attempts trying to improve the understanding of hydromorphological processes during high floods [2].

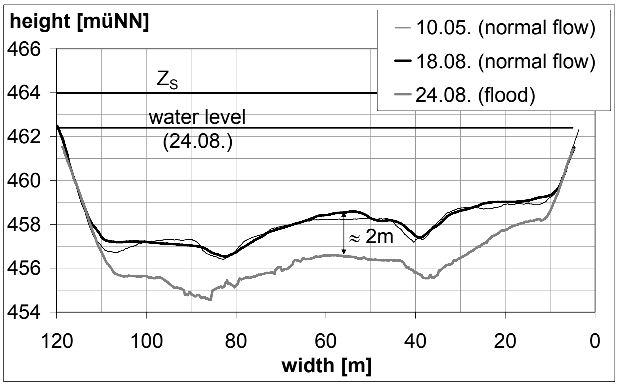

Figure 7: Detected bed erosion during flood

Bedload velocities:

In addition to measuring streambed depths, discharge and flowing velocities, the attempt was made to analyse the ADCP data in respect to bedload velocities [3]. Therefore the phenomenon of upstream biased bottom tracking due to bedload transport was utilised. For each transit, the boat velocities, calculated from the bottom track data of the ADCP, were extracted out of the ASCII files. Using trigonometric relations, the velocities in direction north-south and east-west were transformed into components parallel to the crossing direction and components rectangular to it. Under normal conditions, the components rectangular to the crossing direction should converge to zero. In case of bedload transport these values will be biased, which can be used to estimate the amount of bedload velocity. Figure 8 shows the components of the boat velocities parallel to the crossing direction.

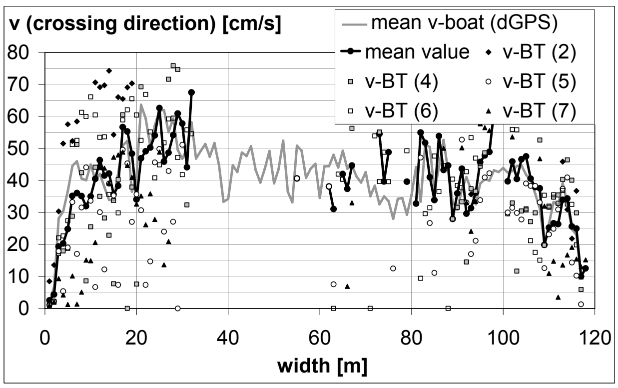

Figure 8: Components of boat velocities parallel to the crossing direction

The grey line represents the mean boat velocity of all five crossings, calculated from the dGPS-data. The huge fluctuations resulted from the manual trailing of the ADCP and the problems faced during the measurements. It can be seen, that despite the scattering of the individual crossings, the mean velocity of the boat calculated from the bottom track data (black line) corresponds well with the actual velocities. The lack of bottom track data in the middle region of the cross section is also eye-catching and emphasizes the need of external positioning data.

Figure 9 contains the illustration of the second components of the boat velocities, in this case rectangular to the crossing direction, which is parallel to the main flow direction.

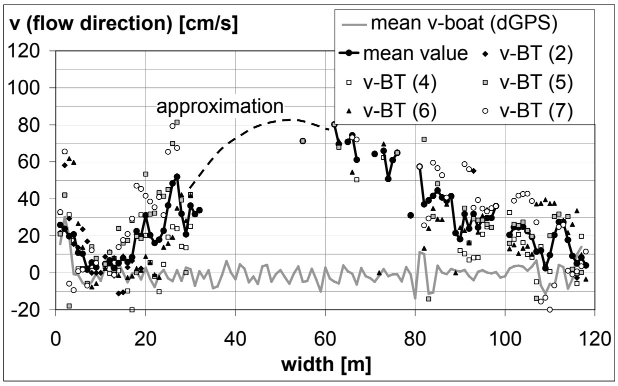

Figure 9: Components of boat velocities rectangular to the crossing direction

The mean value calculated from dGPS-data is fluctuating around zero which means, that besides very small, locally restricted movements up- and downstream the river, there were no components of boat velocities rectangular to the crossing direction. But if you look at the run of the curve, representing the values calculated from the bottom track data, they range between zero and 80 cm/s. That means that bedload moves through the cross section with a velocity up to 80 cm/s.

3 CONCLUSIONS

Various measurements during the extreme flood of August 2005 at the river Inn near the border of Austria and Germany gave us a good insight into a set of problems which can arise, when one tries to use the ADCP technique during high waters.

The challenges in conducting and interpreting the measurements lay in

- extreme driftwood, which compromises the carrier device as well as the expensive measuring devices onboard
- high suspended sediment concentrations, which make it difficult to get sufficient data for interpretation

Consequently, the hydraulic laboratory of the Institute of Hydraulic and Water Resources Engineering at the Technische Universität München (Oskar-von-Miller Institute in Obernach) will try to improve the carrier device, so that debris and driftwood will be kept away from the ADCP device reliably. Besides, we have plans to investigate the effect of suspension load – in respect of concentrations as well as grain size distributions – on the reflected acoustical signal of the ADCP. The successful interpretation of bottom track data regarding bedload velocities encouraged us to continue this work and to enhance the used procedure.

So our main goal, to describe the erosion process during flood, is still not achieved completely. There is still a lot of investigation to do, but with the aid of the herein presented measurements, we luckily got a lot of important insights, which will help us to reach the original objectives.

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