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Measurement of sand transport with a submerged pump: presentation of the results of a test campaign carried out on the Isère River in July 2019

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ABSTRACT: In alpine and piedmont gravel bed Rivers, sand can be transported as bed load or as suspended load over a coarser bed. This explains why most of the monitoring tools, which have been developed for bed load or suspended load, do not adequately measure the sand fraction, which is mainly transported at the transition between these two modes. This difficulty in measuring the sand fraction is a real problem because sand is a major component of the total load transferred from the mountain to the sea. Some techniques have been specially designed for sand measurement; they can be effective but not always easy to deploy. That is why we propose here to test a new method, based on a submerged pump initially developed for hostile environments such as drilling operations, and capable of withstanding high loads of fine sediments. The pumping tests were carried out in the Isère River during July 2019, and compared to a isokinetic flux sampler: the Delft bottle. We present the results and limitations of the method.

1 INTRODUCTION

Rivers transport sediments from the mountain to the sea, as bedload or suspension. Bedload comprises coarse sediments transported in contact with the bed, whereas suspension comprises fine sediments transported in the main flow. These definitions may appear simple, but it is no longer the case as soon as one questions what is ‘coarse’ and what is ‘fine’? The sand fraction (often defined in the range [63 μ m-2mm]) is usually used as a limit. But, obviously there is no strictly speaking a size limit between the two mode of transport, and sand can be present both in bedload and suspended load. Because sand does not clearly be associated with one or the other mode of transport it is usually excluded from sampling operations: bedload is often measured for the coarse fraction (considering sizes > 2mm for avoiding samplers clogging) whereas suspension is usually measured for the finest fraction (excluding coarse sands). As a result sediment budgets do not include a confident estimate of the sand fraction, which is clearly a problem, because anyone could observe that sand is far to be negligible in deposition zones (dams..). Sand is present in all parts of the river system. It controls the mobility of the bed, is a support for ecosystems and sand carried by rivers plays a key role in coastal morphodynamics [Bendixen *et al.*, 2019].

To overcome this problem, samplers were specifically designed for measuring sand transport. Some bedload samplers are adapted for bedload measurement in presence of small bedforms (the Arnhem BTMA, the Nile sampler [L C Van Rijn and Gaweesh, 1992]), but they are not adapted for measuring sand transported in the water column. Other samplers such as the P61 or P72 [Davis, 2005] are more adapted for the water column, but cannot measure very close to the bed. The Delft bottle sampler [Beverage and Williams, 1989] was designed for measuring both close to the bed and in the water column. These samplers were specifically designed for not per-

turbing the flow: they are supposed to be isokinetic, which means that their presence is transparent for the local flow and that they sample at the same velocity than ambient flow velocity.

However all these samplers are heavy devices designed to be stable in highly turbulent flows and must be handled with a winched cable from a truck or a boat. As a consequence measurements are time and money consuming and sampling a large river section can take several hours (usually one day for the whole section). This can induce a real bias because in the same time discharge and sediment rate can vary greatly. In addition, such devices are not adapted to sand transport measurement in small energetic alpine rivers (with low flow depth, but important sand load). As an alternative, other technics such as pump-samplers have been tested in the past [L C Van Rijn and Schaafsma, 1986]. These approaches were however limited by the available technology limiting the pumping height and velocities. In this paper we present new tests performed with a submerged pump specifically developed for large pumping height in drilling operations. The tests were done in the Isère River during July 2019 in comparison with the Delft bottle. We present the results and limitations of the method.

2 MATERIAL AND METHOD

2.1 The pumping device

After a review of available pumping systems, we finally chose to test a submerged pump which allows, in comparison with other solutions (such as peristaltic pumps), higher intake velocities and pumping height. We used the 12 Volt Stainless Steel Monsoon XL distributed by Proactive Environmental Products. It is a centrifugal, single-cell, submerged pump initially developed for hostile environments such as drilling operations, and capable of withstanding high loads of fine sediments up to 35m. The pump is controlled by a separate servo amplifier, allowing to adapt the intake velocity to the ambient flow velocity.

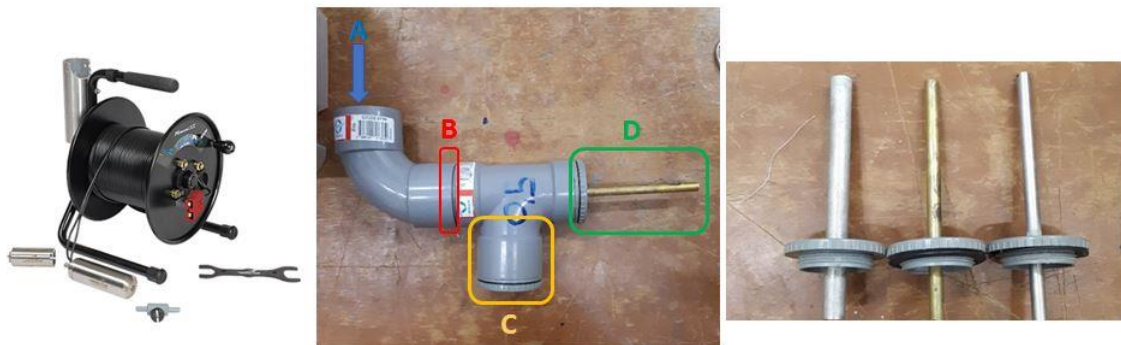


Figure 1. The pump (left photo) and its support (middle photo): A) emplacement for the pump B) filter C) settling reservoir and D) intake nozzle with diameters 10/7/6 mm (right photo)

A series of trial and error tests were required to adapt the pump to our objectives, and we finally designed the PVC support shown in middle panel of Figure 1: after entering the device through the intake nozzle (Figure 1D), the water is filtered with a 1 mm mesh (Figure 1B) in order to protect the pump (Figure 1A) from the coarsest grains which settle in a little reservoir (Figure 1C). We used an intake nozzle of 7 mm in order to increase the intake velocities up to 2.5m/s.

2.2 Method

For comparison we also used a Delft Bottle sampler which permits a direct measurement of the local average sand transport. The bottle geometry causes a strong reduction of the flow velocity inside the bottle and settling of the sand particles larger than about 50 μm . Because the capture and settling are not fully efficient, a calibration coefficient must be applied to the measured mass depending on the nozzle intake, the local flow velocity and the mean sand diameter.

For the tests the instruments (pump and Delft Bottle) were mounted on the Delft Bottle metallic support, which was handled with a winched cable from a truck positioned on a bridge.

Some tests were done with both the Delft Bottle and the pump, and other tests were done with the pump only (Figure 2). The Delft Bottle can measure at a height of 5cm above the bed. The pump was installed above the bottle nozzle which means that the first measurement was possible at 35 cm above the bed only. When the pump was considered alone it could be positioned closer to the bed.

The water was pumped to the surface through a 8 mm flexible hose. Because we could observe partial obstruction of the pump nozzle with small particle of vegetation during the preliminary tests, we regularly stopped very shortly the pump during sampling which permits to clean the filter and intake nozzle by a backwash effect (due to the water column pressure). After each sampling, the pumped sediment was mixed with the sediments collected in the settling reservoir.

All samples (from the pump and the Delft Bottle) were sieved with a 50 μ m size mesh, oven dried, weighed and analyzed in the laboratory.



Figure 2: The pump mounted on the Delft Bottle (left); the pump mounted on the Delft Bottle support (middle) and sieving at 50 μ (right)

Because the objective was to be closer to the isokinetic conditions, we also measured the ambient mean flow velocity using an ADCP. This permitted to adapt the intake nozzle for both Delft Bottle and the pump.

3 MEASUREMENT CAMPAIGN

3.1 *Study site*

A two days field campaign was done in the Isere river in 2019 (June 27 and July 4), at a location called the Campus bridge. At this location, the watershed is about 5700km², the river width is 60m and the slope is approximately 0.0005 m/m. The morphology shows alternate bars, where a Wolman count indicates a gravel bed with $D_{50}=1.4$ cm and $D_{84}=2.5$ cm. The Isere river has a pluvionival type hydrological regime, and it transports a lot of sand both as bedload and suspension. We measured from a bridge located approximately 10 m above the water surface.

3.2 *Measurements*

Measurements were done on July 4 (a first set not presented here was done on June 27 and allowed us to adjust the protocol and to do a first comparison between the DB and the pump). During the day the discharge varied in the range 280-295 m³/s. The vertical profile was considered at 13m from the left bank where the ADCP indicate a surface flow velocity of approximately 1.5 m/s and a near bed flow velocity of 0.7 m/s. The average flow velocity was 1.25 m/s and the flow depth was approximately 2.5m.

We performed 3 runs summarized in Table 1. In Run 1 we measured simultaneously with both the Delft Bottle (used with the small straight nozzle) and the pump for comparison. In run 2 and 3 the pump was used alone. In Run 2 we stopped the run between each sample on the vertical to collect the coarse sand settled in the reservoir (Figure 1C). In Run 3, we did a continuous meas-

urement on the vertical and the coarse sand collected at the end of the run in the settling reservoir (Figure 1C) was considered representative for the whole vertical.

Table1: summary of the runs performed on July 4

Run	Device	Distance to the bed (m)	Sampling duration DB (min)	Sampling duration pump (min)	Local time	Sample volume (l)
1	DB + pump	0.35	10.0	8.50	10h00	34.5
		0.50	10.3	7.50	to	29
		0.99	10.0	7.50	12h30	29
		1.33	10.2	7.67		32
		1.49	10.0	9.50		37.8
2	Pump alone	0.10		1.30	14h30	5
		1.15		2.55	to 15h	10
		1.53		2.63		10
		1.70		2.75		10
		2.07		3.08		10
3	Pump alone	0.10		2.42	16h to	10
		0.64		2.52	16h20	10
		1.14		2.65		10
		1.40		2.75		10
		1.88		2.60		10

4 RESULTS

Considering that we used the small straight nozzle, that the median sand diameter was coarse ($>130 \mu\text{m}$) and that the average velocity was 1.25 m/s, a coefficient of 0.7 was deduced from the abacus provided with the sampler and applied to each Delft Bottle measurements. Concerning the pump, all measurements were done with an intake velocity of 2-2.5 m/s considering preliminary results with the ADCP. Actually, after analysis of the ADCP data, the flow velocity on the vertical was rather around 1.25 m/s, which means that we did not pump with isokinetic conditions.

Figure 3 presents the sand concentrations measured for the 3 runs. In Figure3a fluxes measured with the Delft Bottle in Run1 are converted to concentrations using the ADCP flow velocities, and are compared to the concentrations measured with the pump. The results are consistent (with slightly larger values observed for the pump), keeping in mind the large uncertainties associated with the abacus coefficient and with the non-isokinetic conditions for the pump.

Figure 3b compares the concentration profiles measured for each runs. An uncertainty exists for run3 because the coarse sand fraction collected in the settling reservoir was affected proportionally to each sample over the profile. However, we observe that the general shape of the concentration profile is conserved, and also that concentrations increase and decrease during the day, and information which was confirmed by independent measurements with a turbidimeter (supposing it can be used as a proxy for the transport dynamics) measuring on the left bank not far downstream.

The median diameters D_{50} measured for samples of Run1 are compared in Figure 4. The diameters are consistent, and indicate relatively coarse sand. The figure also shows that sediments collected with the Delft Bottle are coarser than sediments collected with the pump. This can be explained by the fact that the pump collects integrality of the sand present in the flow, whereas the Delft Bottle collects only the part that actually settles in the bottle, with a capture efficiency which is less for the finest fraction $<100\mu\text{m}$ [Beverage and Williams, 1989].

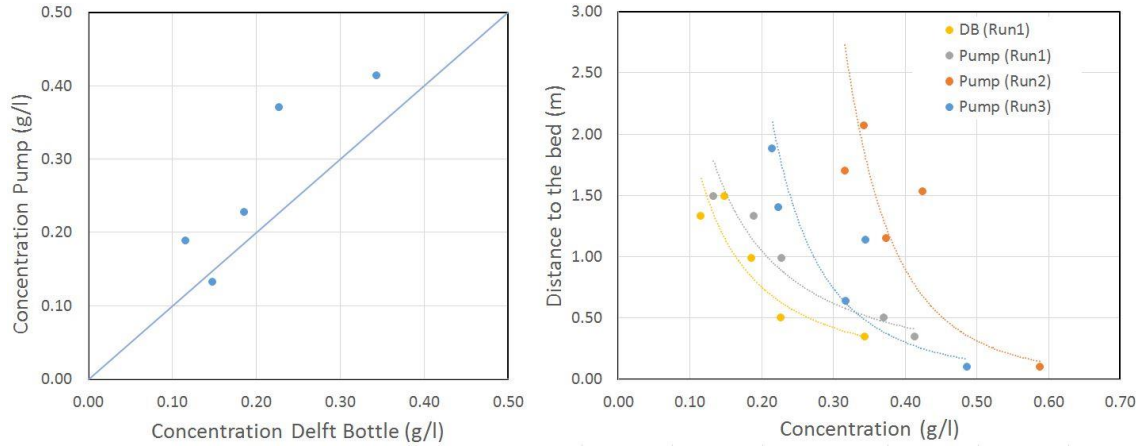


Figure 3: Comparison between concentrations measured on the vertical profile of Run1 with the DB and the pump (left panel); concentration profiles measured for each run (right panel)

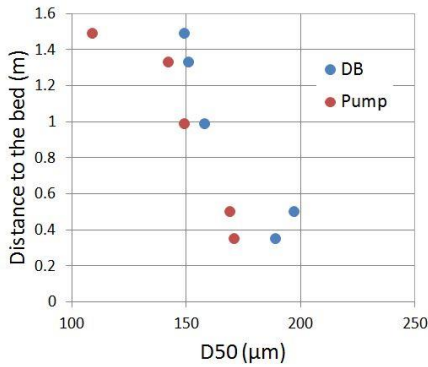


Figure 3: Comparison of median diameter D_{50} measured for each samples of Run1 with the pump and the Delft Bottle on the vertical profile

5 DISCUSSION AND CONCLUSION

The results of these preliminary tests are very encouraging because we found a good consistency between the pump and the Delft Bottle. However it must be acknowledged that these results are associated with large uncertainties. The first uncertainty concerns the Delft Bottle measurements we used here as a reference. This system does not measure a concentration but a mass settled in the bottle, which supposes that what leaves the sampler is negligible. Several studies (recalled in [Beverage and Williams, 1989; L C Van Rijn and Schaafsma, 1986]) have compared the Delft Bottle with other samplers (such as the P61 measuring directly a concentration instead of a mass) and concluded that it was inefficient to capture diameters smaller than $100\mu\text{m}$, and as a consequence underestimate sand transport [$63\mu\text{m}$ - 2mm] in a ratio of approximately 1:2. Uncertainties also exist with the correction coefficients we applied to the Delft Bottle measurements [J Dijkman, 1978; J. Dijkman and Milisic, 1982], and with additional sampling during raising and lowering of the instrument [L Van Rijn and Roberti, 2019].

Another source of uncertainties concerns the hydraulics conditions. Despite the ADCP measurements, we could not respect isokinetic conditions. How the sampling efficiency is impacted when the velocity inside the intake nozzle is larger or smaller than the ambient flow velocity is largely unknown. Available studies [Gray and Landers, 2014; Starosolszky, 1981] suggest that relative sampling rates (ratio of intake velocity to ambient flow velocity) larger than 1 leads to underestimation of the actual sand concentration and that inversely relative sampling rate smaller than 1 leads to overestimation; this error increases with coarse sands. But flume analysis [Nelson and Benedict, 1950] suggest that deviating intake velocity does not results in large error

(<20%) provided that sampling rates are in the range [0.8-2] [L C Van Rijn and Schaafsma, 1986].

Uncertainties also exist for the distance to the bed: the Delft Bottle support was handled with a winched cable from a truck, from the surface to the bed, and we considered the sampler was positioned on the bed when the tension exerted on the cable was relaxed; which is very imprecise and subjective.

It will probably be impossible to have an exact reference for estimating the pump efficiency (this is actually the problem encountered for all sediment sampler validation). However, because the pump allows long sampling with a perfect timing control, and gives direct access to the local concentration, it seems to be a promising unbiased technic for measuring sand transport. In addition because samples are collected in real time at the surface it could represent a real gain of time compared to heavy standard instruments requiring removing the apparatus from the water between each sample. Several questions are still challenging and will motivate new field campaigns as for instance how to measure the exact flow velocity at the nozzle entrance, or how to sample the coarsest grains (captured in the entrance reservoir) during a continuous measurement?

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