

# Laboratory Measurement of Bedload with an ADCP

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## Abstract

Moving bottom bias in acoustic Doppler current profiler (aDcp) bottom tracking has been used by several researchers as an estimate of apparent bedload velocity. However, it remains unknown if the apparent bedload velocity is an unbiased estimate of average bedload particle velocity. This paper presents a controlled laboratory calibration of ADCP apparent bedload velocity, which was performed in the Main Test Channel at the St. Anthony Falls Laboratory (SAFL) as part of the National Center for Earth-Surface Dynamics (NCED) SedT project.

The length of the sediment-recirculating mobile bed test section was 20 m. Both sand-bed ( $d_{50} = 0.98$  mm) and gravel-bed ( $d_{50} = 11.06$  mm) bedload transport experiments were conducted, with five flow rates tested for each sediment. Bottom track data were collected with both 600 kHz and 1200 kHz Rio Grande ADCPs, and over a range of bottom track pulse lengths from &R20 to &R40. Actual bedload transport rates were measured using 1) conventional samplers, 2) five automatic weigh pans distributed laterally across the channel at the end of the test section, 3) dune tracking by means of eight sonars, and 4) high speed digital videography. In this paper, measured apparent bedload velocity is compared to bedload transport rate from the weigh pans and dune tracking. In addition, the influence of bottom track pulse length and operating frequency on measured bedload velocity is assessed. The results show reasonable correlation between ADCP bedload transport and measured bedload transport rates, with coefficient of determination ( $r^2$ ) ranging from 0.59 to 0.93 with RMSE (root mean square error) ranges from 0.059 m/s to 0.106 m/s for sand bed. For the gravel bed, correlation was found between capture rates and dune tracking with  $r^2$  ranging from 0.52 to 0.97. However, correlations of ADCP apparent bedload velocity and transport rates were lower in gravel bed runs, with  $r^2$  ranging from 0.22 to 0.73. This was probably due to the relatively sporadic nature of gravel bedload transport (Rennie and Villard 2004), but may possibly also have been due to insufficient flow depths for the operation of the ADCP during gravel-bed runs.

## Introduction

Bedload measurements in rivers are required to assess sediment load for the design of structures such as bridges and pipelines, river training works, reservoir silting problems, and assessment of aquatic habitat. Knowledge of bed material transport is essential for understanding river morphology and channel change, which depend on the pattern of sediment transfer along a river reach through local erosion and deposition. Fluvial phenomena, such as river meandering, development of bars and ripples,

and dune migration all depend on the erosion and deposition of bed material in rivers. Understanding of bedload is thus required for design of engineering projects.

A reliable bedload measurement technique is essential for development of improved predictive models, but bedload measurement is still a challenge. Traditional physical samplers are difficult and dangerous to deploy in high channel-forming flows. Traditional sampling is also expensive, time-consuming, and measurement error is high. Pit-traps are another common method for bedload measurement. The shortcoming of pit-traps is that it is not certain whether all the bedload has been trapped. Relatively fine bed material (sand) may saltate over the trap and very large events may fill the trap.

Rennie and others (2002) introduced a bedload measurement technique using the bottom tracking capability of an acoustic Doppler current profiler (aDcp) for a reliable and easy means to measure bedload during high flow in rivers. Bottom tracking provides aDcp velocity, assuming that the river bed is stationary. However, in mobile river beds, such as during floods, bottom tracking is biased by particles moving on or near the river bed.

This bias is a measure of apparent bedload velocity ( $v_a$ ), and has been found to correlate with measured bedload transport rate (Rennie and others 2002, Rennie and Villard 2004, Gaeuman and Jacobson 2006, Gaeuman and Rennie 2006). The bias can be extracted during moving boat applications by comparing bottom track velocity ( $v_{BT}$ ) with Differential Global Positioning System (DGPS) velocity ( $v_{DGPS}$ ):

$$v_a = v_{DGPS} - v_{BT} \quad (1)$$

The acoustic method permits continuous measurement of coarse particle apparent velocity during flood events, which is a direct reflection of the magnitude of bedload movement. Furthermore, this technique has been used to map the spatial distribution of bedload in both sand bed and gravel bed reaches of river (Rennie and Millar 2004, Rennie and Church 2010). However, the method has not been calibrated in a controlled laboratory setting, and thus bedload velocity precision and bias remain unknown. It is uncertain if the apparent bedload velocity is an unbiased estimate of average bedload particle velocity.

It should be acknowledged that an aDcp is an expensive instrument, with prices ranging from about US\$15K to US\$25K. A DGPS unit can be obtained for a few hundred dollars, although best quality Real Time Kinematic DGPS systems with O(cm) accuracy cost tens of thousands of dollars (see Rennie and Rainville (2006) for an evaluation of the precision of various DGPS systems during an ADCP survey). However, despite these costs, aDcp-DGPS systems are routinely deployed by national water survey organizations to measure river discharge, thus there is tremendous opportunity to utilize aDcps for bedload surveys.

## Research Objectives

Apparent bedload velocity measured by the aDcp has unknown precision and bias. There remain two uncertainties that could lead to bias. First, particularly in sand-bed environments with a concentrated near-bed suspended layer, the precise location of reflection of a bottom track pulse and the corresponding location of measurement has not been determined. Assuming a velocity gradient from the bed, measurement near the top of the near-bed suspended layer would result in positive bias of the measured bedload velocity. Second, thus far it has been assumed that the measured velocity is a spatial average of surface particle velocities, including immobile particles. Particle velocities are actually weighted by backscatter intensity. Smaller isolated particles are more likely to be de-emphasized due to Rayleigh scattering (refraction) instead of specular scattering (reflection). In the case of 1200 kHz and 600 kHz ADCPs, particles with diameters < 0.8 mm and <1.6 mm, respectively, may be less weighted

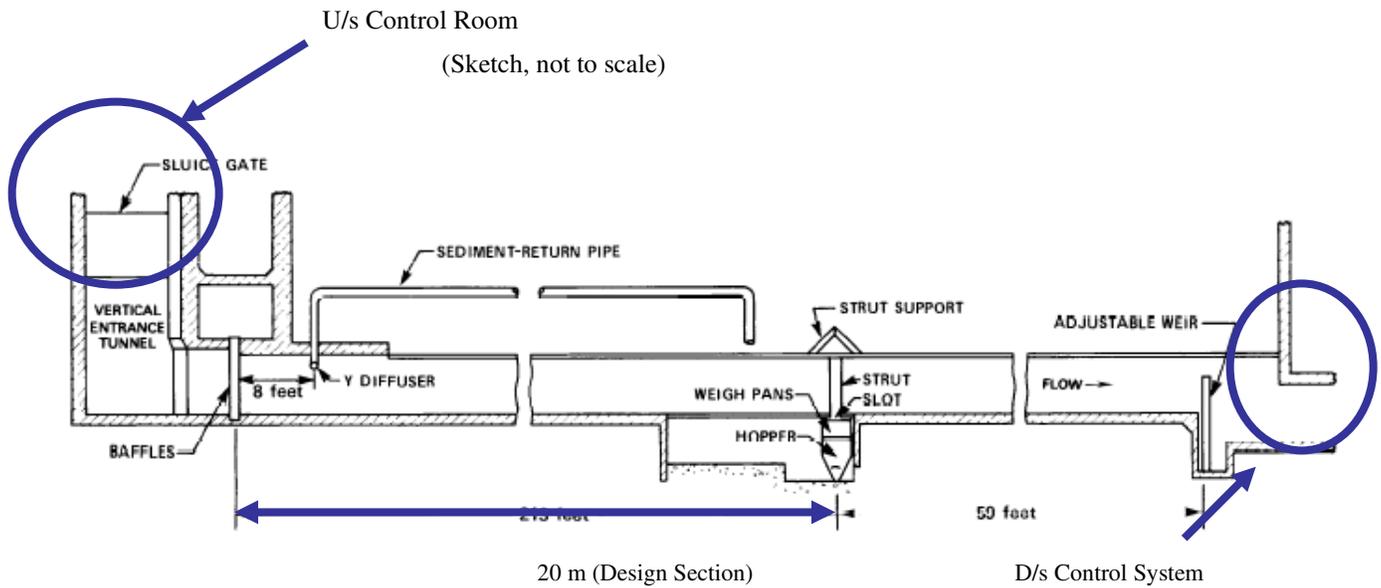
(see Thorne and Hanes 2002 Figure 3a). Thus, measured apparent bedload velocity of fine sediments over a solid bed may be negatively biased. Gaeuman and Jacobson (2006) presented a model to estimate the relative scatter from mobile and immobile particles. They suggested that in their study of transport of fine to medium sand measured with a 600 kHz ADCP, the backscatter intensity from the immobile bed was approximately 10 times greater than from mobile particles, which would negatively bias the observed spatially averaged bedload velocity. However, this estimate was based on the ADCP water profile backscatter (as opposed to scattering of the bottom track ping) and an estimated vertical distribution of suspended sediment concentration. The relative weighting of backscatter intensity from sand, gravel, and immobile bed remains uncertain.

ADCP calibration in a controlled laboratory setting requires a sufficiently large flume. Typical ADCPs require greater than 1 meter flow depth and width. The present work involved a laboratory calibration of the apparent bed velocity technique over a period of three months (January to March 2006) in the Main Test Channel (2.75 m wide, 1.8 m deep, 85 m long) at the Saint Anthony Falls Laboratory (SAFL). The intent of this study was to evaluate the ability of an ADCP to resolve particle motion in the bedload transport layer. In particular, the goal was to determine measured bedload velocity precision and bias and bias sources in different fluvial conditions (sand bed and gravel bed). A secondary goal was to examine patch scale particle-flow interactions relevant to bedload transport. Measurements included synchronous bedload particle velocity by ADCP and digital videography, simultaneous bedload transport rates collected in traps that spanned the flume, bedload transport rates by dune tracking, and water velocity measurements using Acoustic Doppler Velocimeters (ADVs). Two four-beam ADCPs of different operating frequencies were evaluated: 600 kHz and 1200 kHz RDI Rio Grande ADCPs. Lower frequency instruments are less sensitive to smaller particles and undergo less signal attenuation, thus operating frequency may influence measured bedload velocity. Three different bottom track pulse lengths were tested:  $\approx 20$ ,  $\approx 30$ , and  $\approx 40$ . A pulse length of  $\approx 20$  means that the bottom track acoustic pulse length equaled 20% of the distance between the ADCP and the bed. Longer pulse lengths permit greater influence of near-bed suspended scatterers on the measured apparent bedload velocity (Rennie and Villard 2004).

This report describes the experimental set-up and presents some of the preliminary results. The influence of bottom track pulse length and operating frequency on measured apparent bedload velocity is evaluated, and the measured apparent bedload velocity is compared with bedload transport rate measured by both weigh pans and dune tracking. Total boundary shear stress and grain shear stress have been estimated from measured vertical velocity profiles for each flow, but these results are not presented herein. Similarly, the digital videos of particle velocity have not yet been analyzed, thus the full calibration of the technique is still in progress.

## Experimental Set-Up

The Main Test Channel was refurbished by SAFL staff for the SedT project. The SedT project was a multi-investigator bedload and channel dynamics research initiative of the National Center for Earth Surface Dynamics (NCED) performed in the SAFL Main Test Channel during 2006. For the current research, a mobile-bed test section of 20 m length was created in the flume using the existing sediment recirculation infrastructure and new bedload traps. The bedload traps consisted of five automatically recording weigh pans distributed across the width of the flume downstream of the mobile-bed test section, at a distance of 18 meters upstream of the downstream gate (Figure 1). Transported bed material was captured in the weigh pans, weighed automatically, and re-circulated. Bedload data from the traps were recorded at 0.9 Hz. Nominal sediment depths were 30 cm and 45 cm for the sand-bed and gravel-bed experiments, respectively.

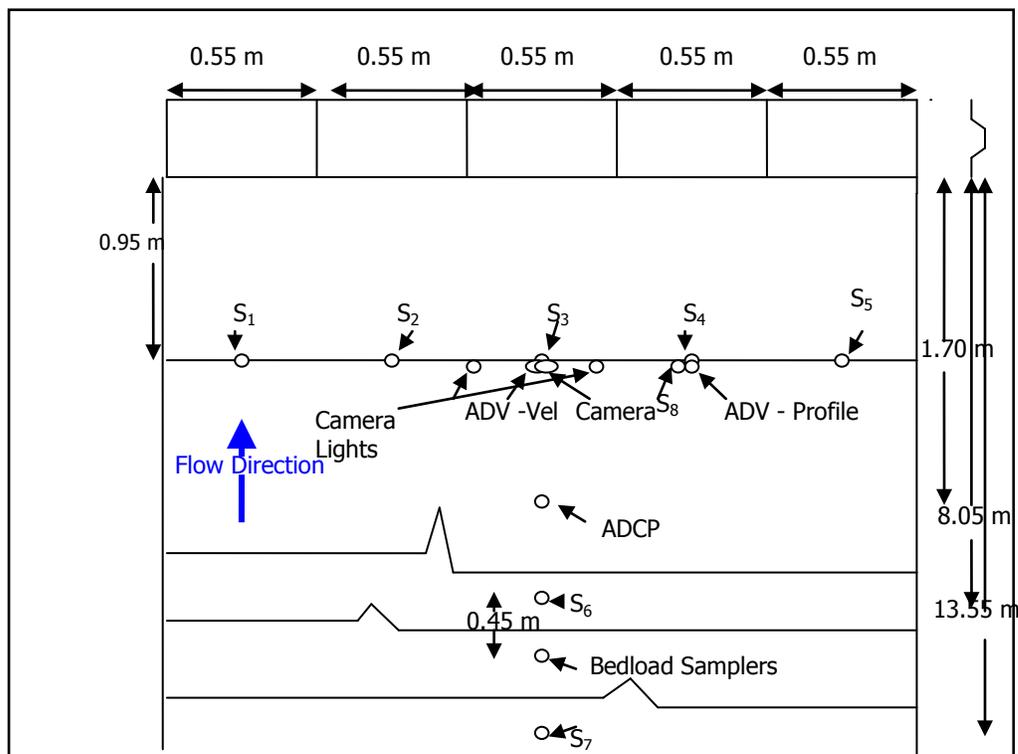


**Figure 1.** Sketch of Main Flume at St. Anthony Falls Laboratory (Adapted from sketch provided by Jeffrey D.G. Marr).

The ADCP was mounted in the center of the channel at a distance of 1.7 m upstream of the weigh pans (Figures 2, 3). The location of the ADCP fore and aft beams (beams 3 and 4, respectively) depended on the instantaneous bed level, but were centered at 0.50 m upstream and downstream of the ADCP for the nominal sand-bed depth of 0.3 m (Figure 4).



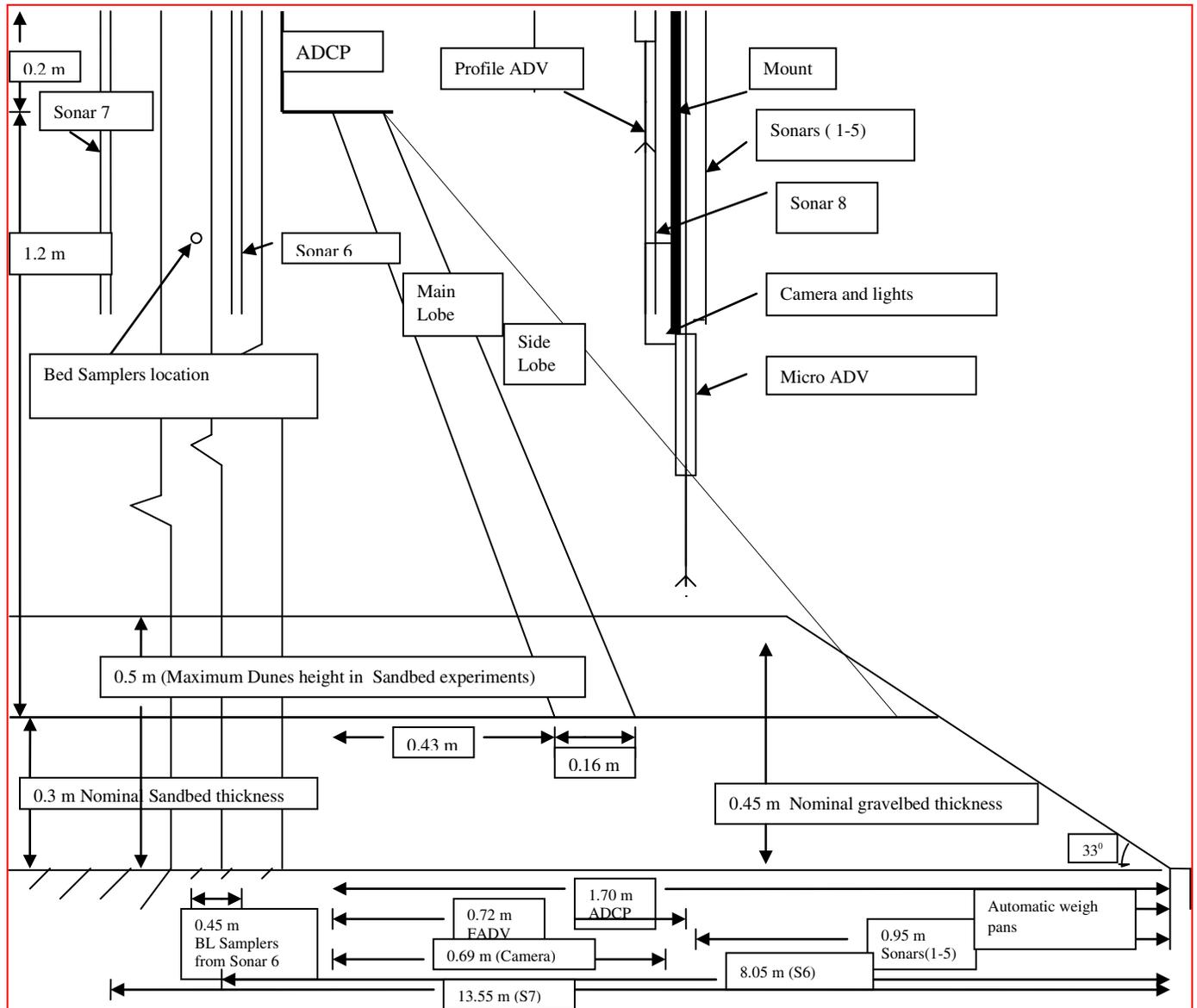
**Figure 2.** a) 1200 (left) and 600 (right) kHz ADCPs; b) Installed 1200 kHz ADCP and bedload trap weigh pans under construction (2 completed), looking d/s.



**Figure 3.** Schematic diagram of the Experimental Set-up (Plan View); S = Sonars, ADCP = Acoustic Doppler Current Profiler, ADV = Acoustic Doppler Velocimeter.

A total of 8 sonars were placed by SAFL staff to measure the dune heights, including five placed at the center of each weigh pan at a distance of 95 cm upstream of the weigh pans. Sonars 6 and 7 were respectively at a distance of 8.05 m and 13.55 m upstream of the central weigh pan 3.

Other instruments were deployed during the experiment. A 16 MHz microADV, which recorded near-bed velocity during ADCP runs. A 10 MHz field ADV, which was used to measure vertical velocity profiles. Finally, an underwater digital video collection system was developed and deployed by SAFL staff to capture plan-view digital video images of transport in the vicinity of theinsonified area of beam 4 of the ADCP. Data from these instruments will be presented elsewhere. Various bedload samplers tested by the U.S. Geological Survey (USGS) were deployed at a distance of 8.5 m upstream of the weigh pans, and were not operated concurrently with other instruments during high flows when wake from the samplers propagated downstream.



**Figure 4.** Schematic diagram of the Experimental Set-up (Sectional View). Flow is from left to right. The sediment fell into the weigh pan at the angle of repose.

## Experimental Procedure

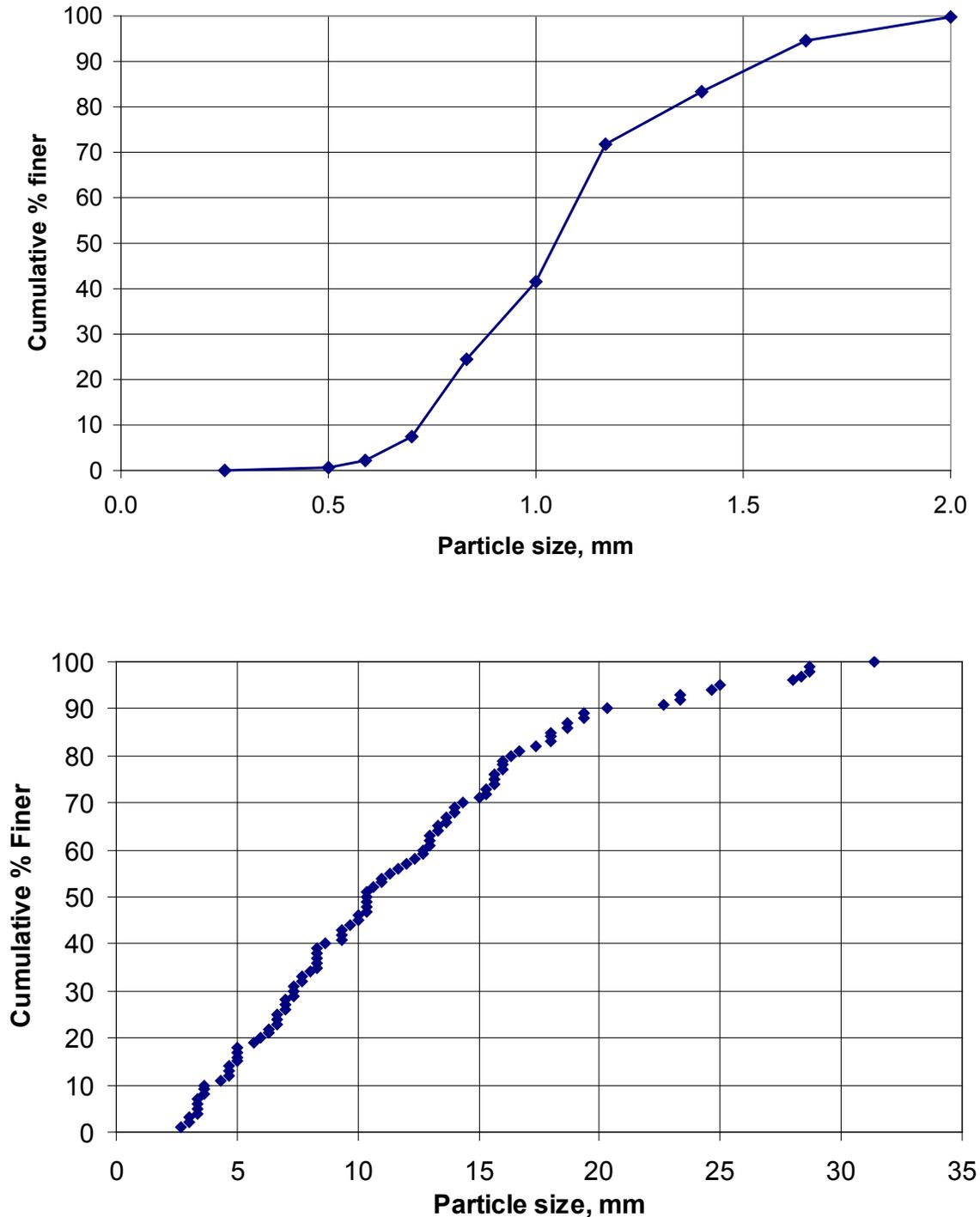
Data were collected during five different steady discharges in each of the sand and gravel beds using all of the instruments described above. For each flow, between 30 min. and 2 hours of ADCP data were collected at 5 Hz for each of &R20, &R30 and &R40 bottom track pulse lengths for the 1200 kHz ADCP and &R40 bottom track pulse length for the 600 kHz ADCP. Bedload transport rate was measured continuously at the weigh pans at 0.9 Hz, and a time integrated measurement of bedload transport rate was achieved through analysis of sonar data (see below). Except for the lowest transport rates with exceptionally slow dune migration (the 2.0 m<sup>3</sup>/s sand-bed runs), each ADCP data collection period was sufficiently long that average transport at the ADCP should have been equivalent to average

contemporaneous transport at the weigh pans. Transport from dune migration was calculated based on transport between sonars 3 and 6, which were spaced further apart, thus the sonar time series for an entire day was utilized to calculate dune celerity and corresponding bedload transport due to dune migration.

For each test flow rate the flume was run for several hours prior to data collection. However, an equilibrium bed state was not always achieved, particularly for runs with dune transport. Regardless, apparent bedload velocity measured by the ADCP was collected simultaneously with corresponding measurements of particle velocity (digital video) and transport rate (weigh pans and sonars).

### **Sand-bed and Gravel-bed Experiments**

For the sandbed experiments, the channel was loaded by SAFL staff with nearly uniform sand to a depth of 30 cm. The sand was purchased as graded to 0.8 mm but random sampling suggested that  $d_{50}$  and  $d_{90}$  were 1.05 mm and 1.55 mm respectively (Figure 5a). A total of five different discharges from 2.0 to 3.6 m<sup>3</sup>/s were used for the experiments.



**Figure 5.** (a, top) Sand-bed grain size distribution by bulk sieve analysis; (b, bottom) Gravel-bed surface particle distribution by Wolman particle count (5.5 m<sup>3</sup>/s)

The nominal gravel bed was 45 cm deep, which was greater than expected for the present research, but conformed to gravel volume requirements for the second stage of SedT experiments. Five runs with varying discharges (from 3.4 to a maximum of 5.5 m<sup>3</sup>/s) were conducted. Wolman pebble

counts through the sample area were carried out after each run. The surface particle size distribution following the 5.5 m<sup>3</sup>/s discharge is depicted in Figure 5b, with D50 and D90 equal to 10.3 mm and 20.3 mm, respectively.

## Analytical Methods

ADCP data were analyzed using MATLAB. For each run, mean and standard deviation of apparent bedload velocity were calculated in the X (downstream) and Y (cross-stream) directions using the full four-beam solution. In the four-beam solution, the X component is derived from the velocities measured in the fore and aft beams, and the Y component from the port and starboard beams. Furthermore, the mean and standard deviation for the downstream component of apparent bedload velocity in beam 3 and in beam 4 were calculated by projecting the measured beam velocity on the horizontal axis, based on the assumption that vertical particle velocity was zero. Beam 3 and 4 insonified areas were upstream and downstream of the installed ADCP, respectively. Means and standard deviations of apparent bedload velocity were calculated for each run, without prior data filtering. In this paper, the mean downstream apparent bedload velocity in beam 4 has been used in sand-bed runs, but the full four-beam solution for apparent bedload velocity has been used in gravel-bed runs. Apparent bedload velocity is compared to measured bedload transport rates, and the influence of bottom pulse length and operating frequency on measured bedload velocity is assessed.

Bedload transport rates ( $g_b$ ) were estimated for sand-bed runs from the ADCP apparent bedload velocity using the kinematic approach (van Rijn 1984):

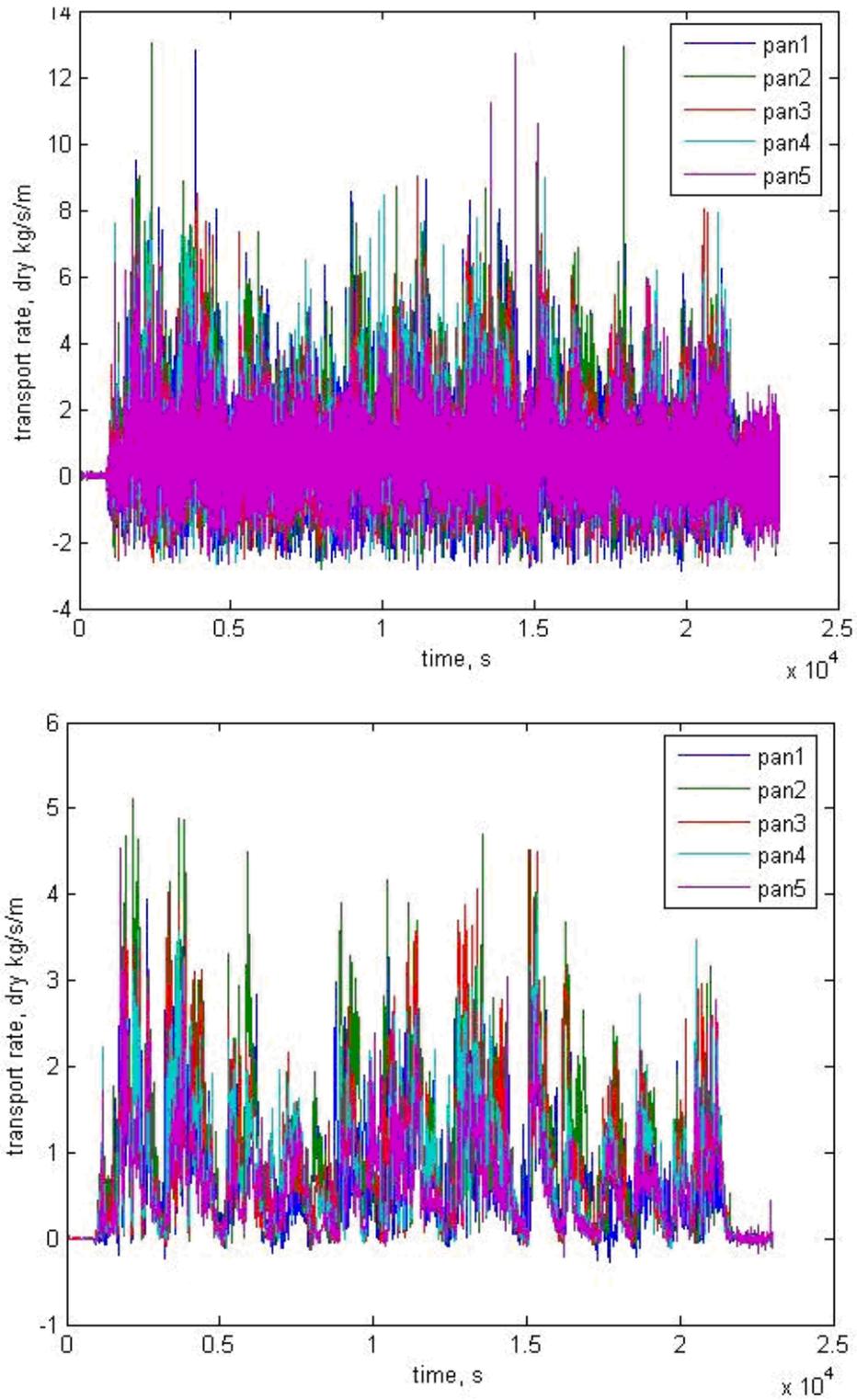
$$g_b = \rho_s (C_b u_b \delta_b) \quad (2)$$

where  $\rho_s$  was sediment density,  $u_b$  was the mean downstream ADCP apparent bedload velocity measured in beam 4, which was closest to Pan 3. The bedload layer thickness ( $\delta_b$ ) was estimated visually for two different discharges of 3.2 m<sup>3</sup>/s and 3.18 m<sup>3</sup>/s on 9<sup>th</sup> and 14<sup>th</sup> of February, 2006 to be 1.3 cm and 1.2 cm respectively. The bedload concentration ( $C_b$ ) was evaluated using an empirical expression from Van Rijn (1984):

$$C_b = 0.18C_0 \frac{T}{D_*} \quad (3)$$

where  $C_b$  is the bedload concentration by volume,  $C_0$  is the maximum (bed) concentration = 0.65,  $T$  is the transport stage parameter (dimensionless excess shear stress), and  $D_*$  is the dimensionless particle parameter. Improved estimates of bedload layer thickness and concentration may be developed from the video data.

MATLAB codes were developed to calculate the mean and standard deviation of bedload transport rate measured in five weigh pans during an ADCP run. The bedload time series were excessively noisy, thus a boxcar average method was used to smooth the bedload time series for all five weigh pans. A filter analysis was performed to determine the optimum averaging time and number of points to delete after a weigh pan tip. The optimization was based on elimination of negative bedload transport rates without excessive smoothing of the time series (Figure 6). Two runs were analyzed, one for gravel and the second for sand. Optimum filter parameters were 15 second box-car averages with deletion and subsequent interpolation of 6 points after a tip. Sediment specific gravity ( $S_s$ ) was measured by SAFL staff to be 2.63 and 2.69 for sand and gravel, respectively. Finally, for bedload estimation, submerged weights were converted to dry weights.



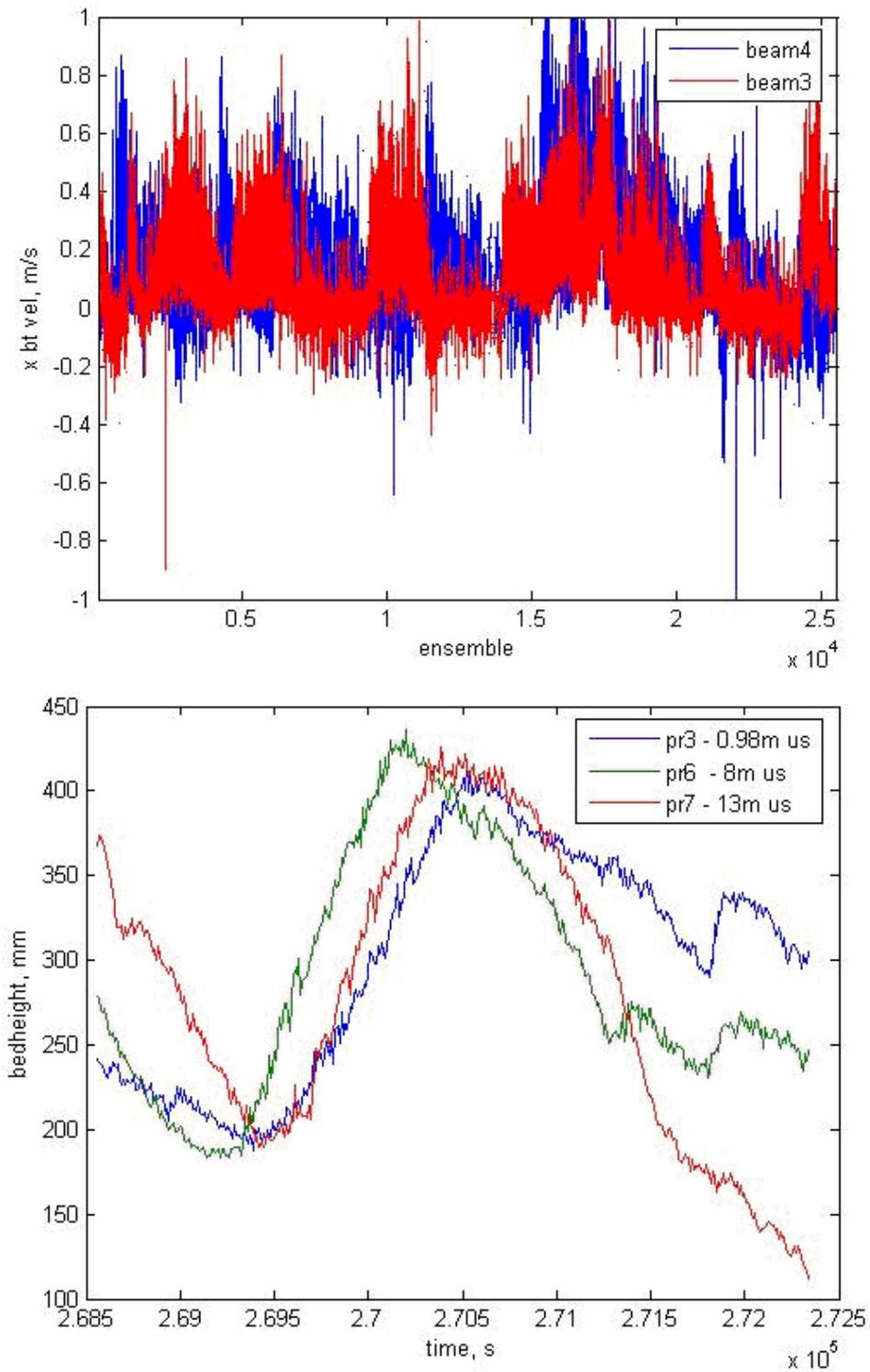
**Figure 6.** Gravel-bed 5.5 run ( $Q = 5.5 \text{ m}^3/\text{s}$ ) weigh pan bedload transport rates: (a, top) 1 s averaging and 0 point skip after pan tip; (b, bottom) 15 s averaging time and 6 point skip after pan tip.

The sonar data were used to estimate the dune celerity between beams 3 & 4 of ADCP and sonars 3 & 6 and 6 & 7. The distance between sonars ( $\Delta x$ ) was known. The time of dune travel between two sonars ( $\Delta t$ ) was calculated from the cross-correlation function between the bed elevations measured by the two sonars. The time lag that gave the peak correlation was equated to  $\Delta t$  assuming that the peak correlation corresponds to passage of the same phase of a dune. The dune celerity ( $V_c$ ) was simply

$V_c = \frac{\Delta x}{\Delta t}$ . The average dune amplitude ( $h$ ) was estimated manually from the observed bed elevation time series (Figure 7b). Finally, bedload transport rate ( $g_b$ ) was estimated from dune celerity, amplitude, and wavelength using Simons and others (1965).

$$g_b = \rho_s \left[ \frac{(1 - \lambda)V_c h}{2} \right] \quad (4)$$

where  $\lambda$  is the bed porosity (39% for sand and 43% for gravel). It should be emphasized that dune tracking provided a single time-integrated estimate of bedload transport for each run.



**Figure 7.** (a, top) Time series of raw ADCP bottom track velocity in d/s direction in beams 3 and 4 during a sand-bed run ( $Q = 3.6 \text{ m}^3/\text{s}$ ). Periodicity is due to passage of dunes. (b, bottom) Bed height variations with time in sandbed experiments measured by sonars along center line of the flume.

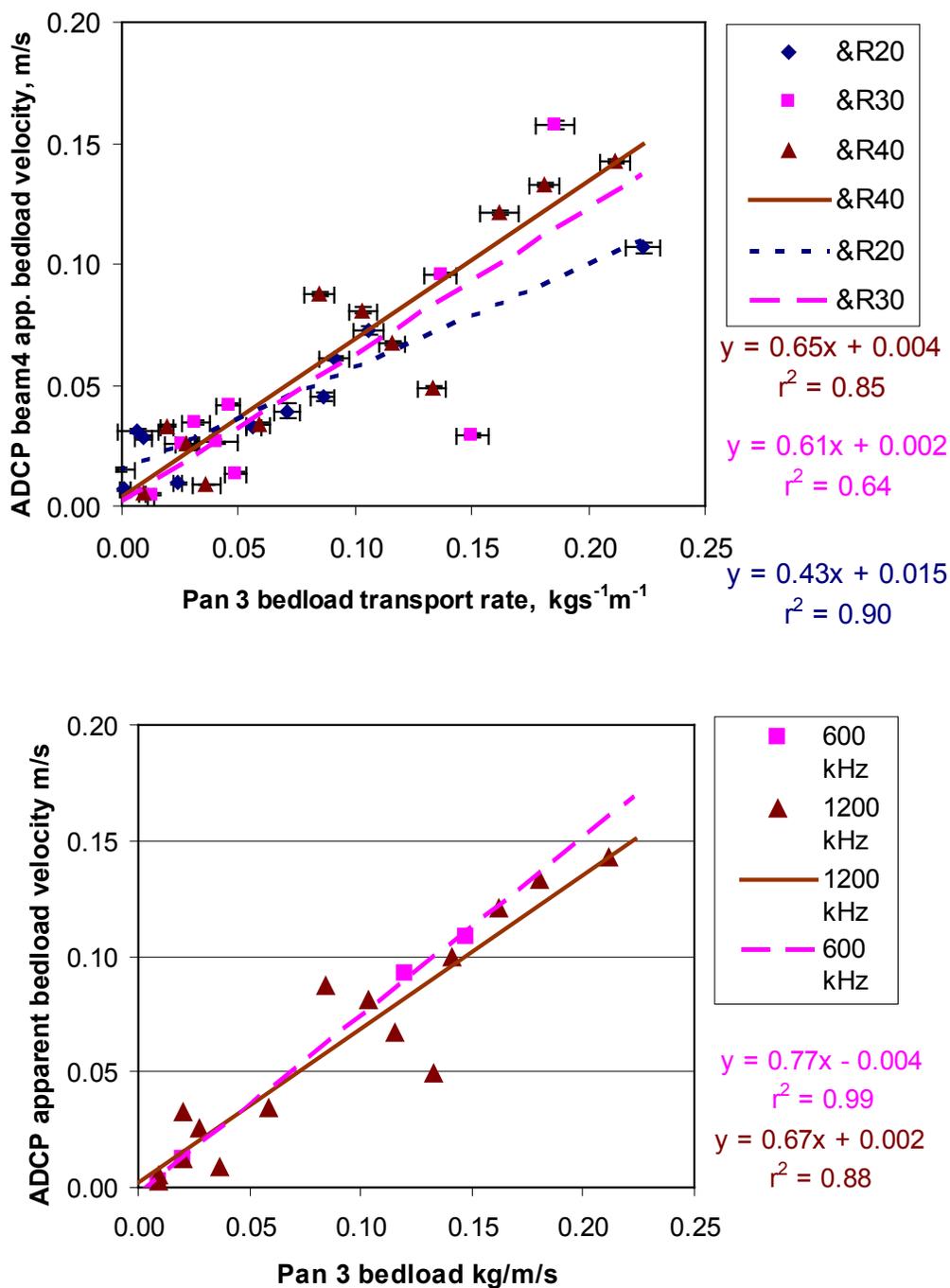
## Preliminary Results

Synchronous bedload measurements by ADCP, weigh pan, and sonar data were compared. ADCP bedload measurements appeared to be more reliable for sand-bed than gravel-bed runs, possibly because the increased nominal bed level during gravel runs reduced the flow depth beyond the operating range of the instrument, but also possibly because stochastic gravel transport increases the variability of particle velocity within a beam sample volume (Rennie and Millar 2004, Rennie and Villard 2004). Analysis of the video data will help clarify this issue.

### Bottom Track Pulse Length and Operating Frequency Sensitivity Analysis

Figure 8a shows ADCP beam 4 apparent bedload velocity results for different pulse lengths with respect to pan 3 capture rates during sand-bed runs. Pulse length &R20 displayed better correlation ( $r^2 = 0.90$ ) as compared with pulse length &R30 ( $r^2 = 0.64$ ) and pulse length &R40 ( $r^2 = 0.85$ ). Furthermore, as expected, longer pulse lengths measured greater apparent bedload velocity due to increased positive bias from suspended particles. Figure 8a includes error bars ( $\pm$  one standard error) for both the apparent bedload velocity and the bedload transport rate. The standard errors are small, largely due to the large number of samples collected using the ADCP (sampling rate 5 Hz for 1200 kHz ADCP) and the weigh pans (sampling rate 0.93 Hz) during each run. The mean standard deviations for beam 4 ADCP raw apparent bedload velocity and weigh pan 3 raw transport rates in the sand bed runs were 0.125 m/s and 0.31 kg/s/m, respectively.

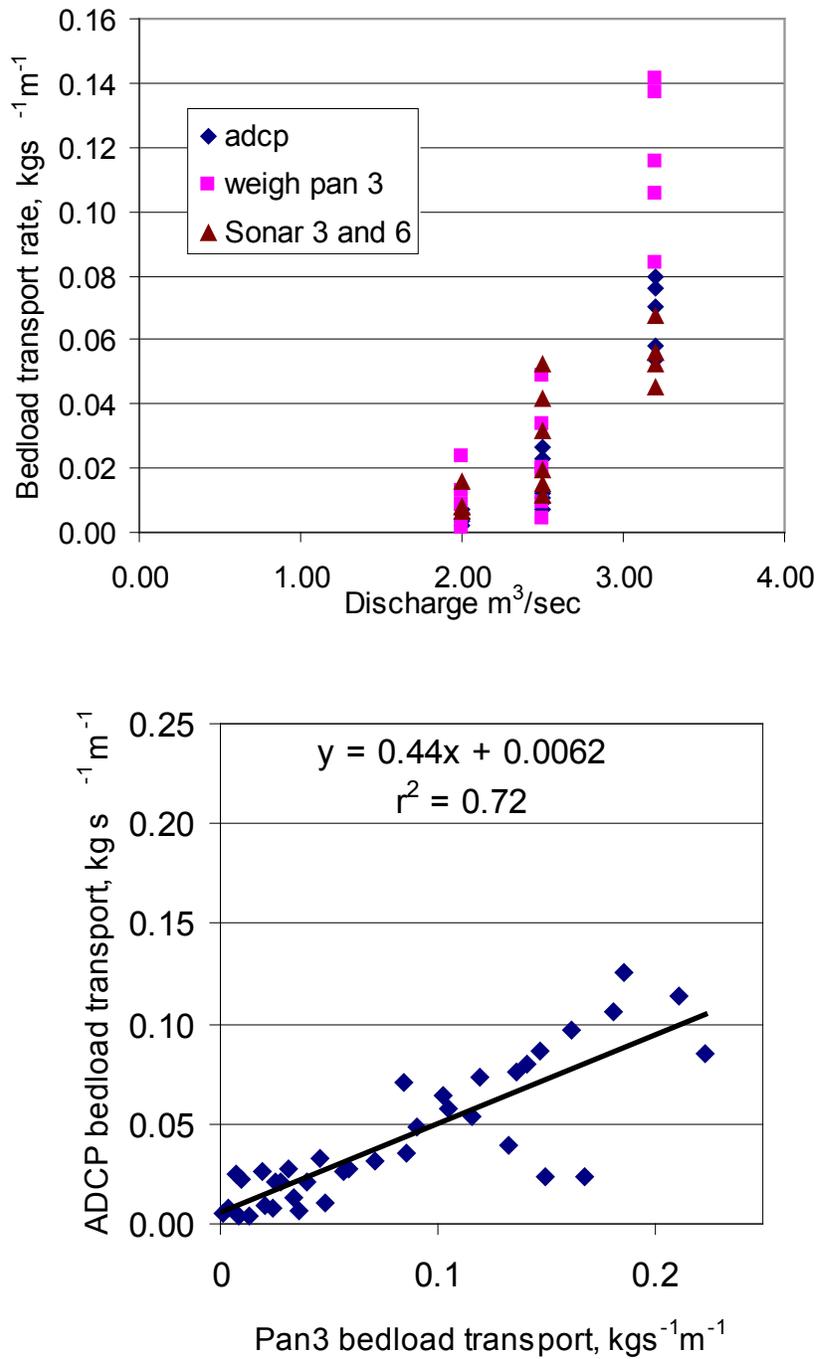
A sensitivity analysis for instrument operating frequency was also performed (Figure 8b). Using &R40 for pulse length, the 600 kHz ADCP displayed a smoother trend of increasing apparent bedload velocity with increasing discharge than the 1200 kHz ADCP. However, the 600 kHz ADCP gave poor results with &R20 and &R30. ADCP pulse length and frequency sensitivity analysis confirmed that there is variation of ADCP bedload measurements when using different pulse lengths and/or operating frequency (Rennie and Villard 2004).



**Figure 8.** ADCP beam 4 mean apparent bedload velocity versus mean bedload transport rate measured immediately downstream central weigh pan 3 for each data run: (a, top) ADCP bottom track pulse length sensitivity analysis for 1200 kHz ADCP during sand-bed runs. Error bars represent  $\pm$  one standard error, wherein ADCP beam 4 apparent bedload velocity standard errors are smaller than the data symbols; (b, bottom) sensitivity analysis for frequency during sand-bed runs at &R40 pulse length.

## **Comparison of Bedload ADCP's Measurements with Capture rates and Dune Tracking**

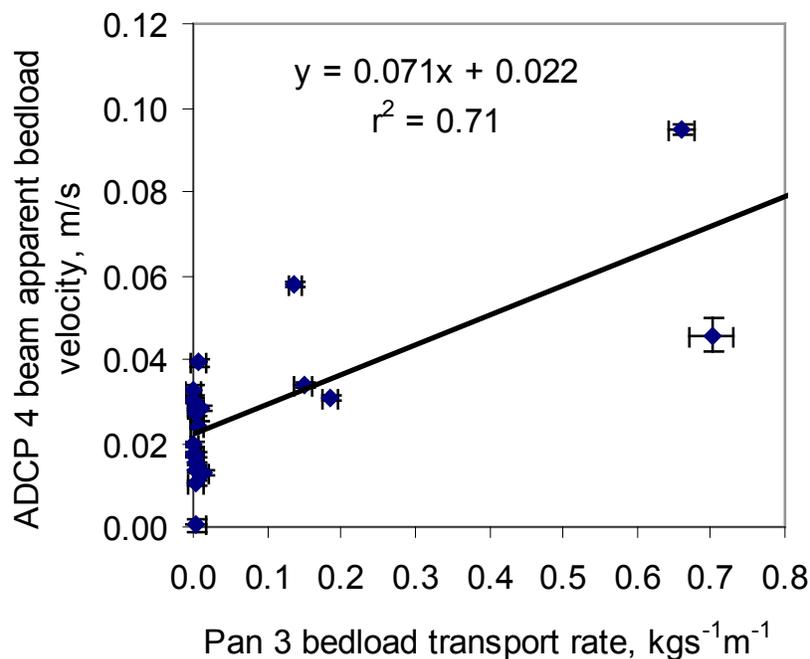
Reasonable correlation was observed between bedload estimated from ADCP apparent bedload velocity and pan measured bedload transport rates during sand-bed runs (Table 1, Figure 9b). All available data for individual ADCP runs are shown in Figure 9. For individual sand-bed data sets segregated by ADCP operating frequency and bottom track pulse length, coefficients of determination ( $r^2$ ) ranged from 0.59 to 0.93 with RMSE (root mean square error) ranging from 0.059  $\text{kg}\cdot\text{s}^{-1}\cdot\text{m}^{-1}$  to 0.106  $\text{kg}\cdot\text{s}^{-1}\cdot\text{m}^{-1}$  (Table 2).



**Figure 9.** Sand-bed: (a, top) variation of mean bedload by ADCP, weigh pan 3 capture rates, and dune tracking at various discharges; (b, bottom) correlation of ADCP mean bedload and weigh pan 3 mean capture rates (both plots use all operating frequencies and pulse lengths).

For gravel-bed data sets, due to the non-availability of bedload volumetric concentration and active bedload layer thickness, bedload transport was not estimated using Equation 2. Instead, ADCP

bedload velocity was compared directly with pan 3 capture rates and dune tracking. Lower correlation between ADCP bedload velocity and weigh pan capture rates was observed in gravel-bed runs. Poor results were achieved with the 1200 kHz ADCP at &R40, thus only data for the 1200 kHz ADCP at &R20 and &R30 are shown in Figure 10. The mean standard deviations for the four-beam solution ADCP raw apparent bedload velocity and weigh pan 3 raw transport rates in these gravel-bed runs were 0.101 m/s and  $0.55 \text{ kg}\cdot\text{s}^{-1}\cdot\text{m}^{-1}$ , respectively. It appears that the ADCP registered an apparent bedload velocity at low transport rates. This may have been due to water bias (i.e. influence of suspended scatterers on bottom track), although minimal sediment suspension was observed during the gravel bed runs. For individual operating frequency and pulse lengths, values of  $r^2$  ranged from 0.22 to 0.73 (Table 2). It is noteworthy that reasonable correlation was obtained between gravel bedload transport estimates from dune tracking and the weigh pans, although the dune tracking predictions were only 58% of the measured capture rates (Table 1).



**Figure 10.** Gravel-bed mean ADCP four-beam solution bedload velocity (without &R40) versus pan 3 mean capture rates. Error bars represent  $\pm$  one standard error.

**Table 1.** Comparison of ADCP, capture rates, and dune tracking.

Sediment	Method <sup>1</sup>	Regression Analysis	r <sup>2</sup>	RMSE kg·s <sup>-1</sup> ·m <sup>-1</sup>	n
Sand-bed	g <sub>A</sub> vs g <sub>C</sub>	0.443x + 0.006	0.72	0.062	39
	g <sub>A</sub> vs g <sub>D</sub>	1.125x + 0.007	0.69	0.018	16
	g <sub>D</sub> vs g <sub>C</sub>	0.343x + 0.015	0.67	0.023	15
Gravel-bed	V <sub>A</sub> vs g <sub>C</sub>	0.090x - 0.056	0.18		38
	V <sub>A</sub> vs g <sub>D</sub>	0.127x + 0.060	0.19		34
	g <sub>D</sub> vs g <sub>C</sub>	0.579x + 0.022	0.80	0.153	47
Gravel-bed without &R40	V <sub>A</sub> vs g <sub>C</sub>	0.072x + 0.022	0.55		20
	V <sub>A</sub> vs g <sub>D</sub>	0.126x + 0.022	0.62		19

1 g<sub>A</sub> = ADCP bedload measured using Van Rijn model in kg·s<sup>-1</sup>·m<sup>-1</sup>

g<sub>C</sub> = Measured Capture Rate for weigh Pan 3 in kg·s<sup>-1</sup>·m<sup>-1</sup>

g<sub>D</sub> = Estimated bedload using Simons dune tracking model in kg·s<sup>-1</sup>·m<sup>-1</sup>

V<sub>A</sub> = Measured bed velocity of ADCP in m/s

RMSE = Root mean square error

**Table 2.** Comparison of ADCP, capture rates, and dune tracking; sensitivity analysis for ADCP pulse lengths and operating frequency

ADCP	Pulse length	Method <sup>1</sup>	Regression Analysis	r <sup>2</sup>	RMSE kg·s <sup>-1</sup> ·m <sup>-1</sup>	n
Sand-bed: Capture rates and ADCP bedload transport						
1200	40	g <sub>A</sub> vs g <sub>C</sub>	0.056x - 0.010	0.84	0.062	12
	30	g <sub>A</sub> vs g <sub>C</sub>	0.496x - 0.008	0.59	0.046	9
	20	g <sub>A</sub> vs g <sub>C</sub>	0.384x - 0.001	0.93	0.043	11
600	40	g <sub>A</sub> vs g <sub>C</sub>	0.545x - 0.011	0.86	0.032	4
Sand-bed: Dune tracking and ADCP bedload transport						
1200	40	g <sub>A</sub> vs g <sub>D</sub>	1.149x - 0.022	0.72	0.020	4
	30	g <sub>A</sub> vs g <sub>D</sub>	0.543x - 0.001	0.17	0.029	3
	20	g <sub>A</sub> vs g <sub>D</sub>	0.815x - 0.008	0.89	0.014	4
600	40	g <sub>A</sub> vs g <sub>D</sub>			0.023	2
Gravel-bed: Capture rates and ADCP bedload velocity						
1200	40	V <sub>A</sub> vs g <sub>C</sub>	0.048x + 0.713	0.22		11
	30	V <sub>A</sub> vs g <sub>C</sub>	0.092x + 0.017	0.70		9
	20	V <sub>A</sub> vs g <sub>C</sub>	0.066x + 0.072	0.52		11
600	40	V <sub>A</sub> vs g <sub>C</sub>	0.265x + 0.11	0.73		7
Gravel-bed: Dune tracking and ADCP bedload velocity						
1200	40	V <sub>A</sub> vs g <sub>D</sub>	0.043x + 0.085	0.17		9
	30	V <sub>A</sub> vs g <sub>D</sub>	0.202x + 0.014	0.93		10
	20	V <sub>A</sub> vs g <sub>D</sub>	0.112x + 0.029	0.66		10
600	40	V <sub>A</sub> vs g <sub>D</sub>	0.426x + 0.115	0.97		6

<sup>1</sup> Notation as in Table 1.

## CONCLUSIONS

Initial experimental test results verified that moving bottom bias in acoustic Doppler current profiler (ADCP) bottom tracking provides an estimate of apparent bedload velocity. Bedload transport rates measured by ADCP, weigh pans, and dune tracking were reasonably comparable. The preliminary results were particularly promising for sand bed experiments. Measurement of apparent bedload velocity was less successful in the gravel-bed experiments, which displayed high apparent bedload velocity even for low transport rate runs. Of the operating parameters tested, the 1200 kHz ADCP with bottom track pulse length &R20 gave the most reliable results. This configuration yielded the highest correlation with measured transport rates in the sand-bed runs, and was least sensitive to positive bias at low transport rates in the gravel-bed runs.

The digital video of particle movements remains to be analyzed. Precision and accuracy of ADCP bedload velocity measurement will be evaluated by comparing synchronous instantaneous particle velocities and ADCP bedload velocity signals. In particular, the relative weighting of mobile sand, mobile gravel and immobile bed in individual ADCP bedload velocity measurements will be determined.

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