Testing hydraulic efficiency of three pressure-difference samplers while varying flows and bag properties (mesh size, weave density, fill level)

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1. Introduction

Pressure-difference bedload samplers have a flared opening that is designed to accelerate flow velocity as it enters the sampler in order to counteract a deceleration of flow that occurs during the sampling process as the sampler bag fills with captured bedload and mesh pores become clogged by small particles. The ratio of flow velocity at the sampler entrance to the flow velocity measured when no sampler is present denotes a sampler's hydraulic efficiency. Maintaining a hydraulic efficiency of 100% in a sampler over all flows as well as for different nets and their varying levels of fill and clogging is considered an ideal (though probably unattainable) goal.

To meet the various sampling tasks in sand and gravel-bed streams, pressure-difference samplers are used with a variety of sampler bags that differ in length, shape, and netting fabric. While several studies have noted effect of bag clogging on hydraulic or sampling efficiency (Druffel et al., 1976; Johnson et al., 1977; Edwards, 1980; O'Leary and Beschta, 1981; Beschta, 1981), only a few preliminary studies (Bunte et al. 2009, 2015) started to investigate how netting properties, including fabric details such as thread and mesh width, affect a sampler's hydraulic efficiency. Ultimately, effects on the hydraulic efficiency extend to sampling efficiency which is the ratio of a transport rate measured in the sampler to the transport rate that occurs in the sampler's absence. This study evaluated the effects of various netting properties on the hydraulic efficiency of three pressure-difference samplers. The details of this study and its results are described in Bunte et al. (2017).

2. Methods

2.1 Flume experiments

Flume experiments for this study were conducted in a large flume at the Engineering Research Center at Colorado State University. The flow was 6 ft wide and 2.2 ft deep for all runs, ensuring that all samplers were well submerged and wall effects were minimized near the flume center. Three pressure-difference samplers with 1.4 expansion ratios were tested: The Toutle River 2 (TR2) sampler with a 12-by-6 inch opening, the similarly shaped but smaller Elwha sampler with the 8-by-4 inch opening, and the BL-84 sampler with its square 3-by-3 inch opening (Figure 1). Bags with four different mesh widths were tested for the TR2: 0.55, 1, 2, and 3.6 mm (Figure 2). Three bags with mesh widths of 0.55, 1, and 3.6 mm were tested for the Elwha sampler and two bags with 0.25 and a 0.5 mm bag for the BL-84. The custom-sewn bags available for the study differed in size and shape; their bag surface areas were equalized by adjusting the clamping location at the bag ends. Each bag was tested empty, and two of the bags for each sampler were tested filled to 30 and 50% of its volumetric capacity with gravel. In addition to the gravel fill, those bags were also tested clad with an inner plastic liner that blocked 30 and 50% of the net surface and simulated bag clogging by organic debris or sediment particles.

Figure 1: The three pressure-difference samplers used for testing (viewed from the front and with no bags attached).

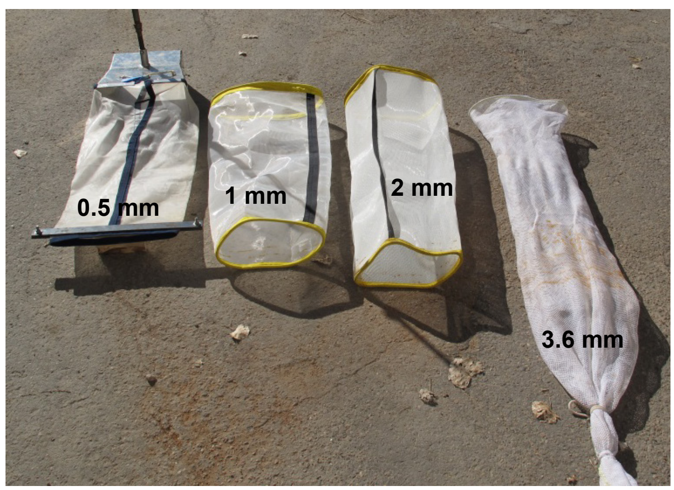

Figure 2: Bags with four different mesh widths were used for testing with the TR2 sampler. The 0.55 mm net is shown attached to the TR2 sampler and with a clamp at the end.

Each sampler and its different net configurations were tested with three target velocities of 1.5, 2.5, and 3.5 ft/s. Together with runs for each sampler when no net was attached and measurements of flow velocity in the absence of a sampler, testing amounted to about 80 runs. Flow velocities were measured using an ADV at 7-9 locations along a line about 1 inch in front of each sampler per run. Velocity was either measured at a constant height of 2" above ground ($v_{x,2}$) or computed for that height from measured velocity profiles.

2.2 Data analyses

2.2.1 Relation between mesh width and the density of the netting weave:

The study examined the relation between mesh width w, i.e., the distance from the edge of one thread to the next, and the density of the netting weave that may be characterized by the fabric's percent open area (*%Ao*). The *%Ao* is determined by a ratio of thread width *d* to mesh width *w* and computed as $\%Ao = w^2 \cdot 100/(\underline{w}+d)^2$. A net's *%Ao*, and hence the net's throughflow capacity, generally increases with mesh width, as was shown for wide range netting material with mesh widths between 0.5 and 10 mm, but thread width contributes as well such that a thinly-threaded net with a 0.5 mm mesh width may have the same *%Ao* as a thickly-threaded net with a 2 mm mesh width (Figure 3).

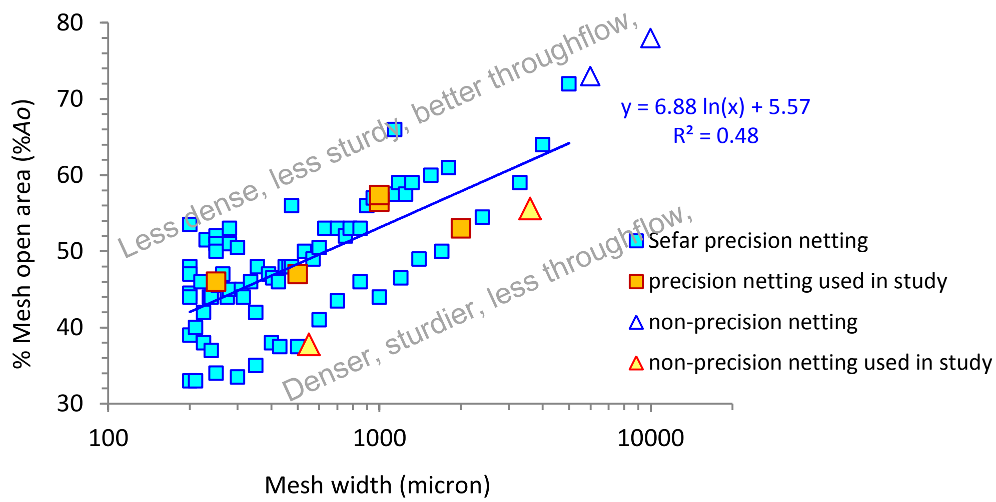

Figure 3: Relation of % mesh open area (*%Ao*) to mesh width *w* for Sefar precision netting. Data from the Sefar (2006) product catalogue. Data for the netting used in this study and for other netting materials are included.

A net's throughflow rate is not only determined by the *%Ao* but also by other blockages of the sampler bag such as bag surface area blocked by seams, by gravel fill, and by clogged mesh pores. The various sources of net blockage are likely additive, hence, this study mathematically combined the various bag parameters (bag size, seam width, *%Ao*, and the degree of bag clogging or filling) into a single parameter denoted as the final percent bag open area

$$\%Ao_{final} = (\%Ao_{tot} - \%Ao_{clogged} - \%Ao_{seam}) \cdot (\%Ao) \quad \text{Eq. (1)}$$

where $\%Ao_{tot}$ is set to 100. For a net that is 50% clogged, has 4% of its surface covered by seams, and has a *%Ao of 57*, the $\%Ao_{final}$ is computed as (100-50-4)·57% = 26.2. Measured flow velocities and computed hydraulic parameters were then related to the $\%Ao_{final}$.

2.2.2 Matrix of velocity measurements condensed to single parameters:

Flow velocities measured at multiple locations along the front of the samplers during the various runs were condensed into a few hydraulic parameters that could subsequently be related to the combined parameter for net openness $\%Ao_{final}$. Velocities measured at 2 inches above ground ($v_{x,2}$) or interpolated for that height from measured velocity profiles were analyzed as lateral averages over all locations measured directly in front of the sampler entrance ($v_{xin,2}$), within the central part of the sampler width ($v_{xctr,2}$), as well as the ratio of inside to outside of the sampler ($x_{xin,2}/v_{xout,2}$). Discharge passing through the sampler (Q_{in}) was computed from the velocity profiles. Hydraulic efficiency (HE) was computed from the flow velocity measured right in front of the sampler opening ($v_{xin,2}$) divided by the $v_{xin,2}$ measured at the same locations when no sampler was in the flume and was accordingly termed $HE_{in,2}$.

3. Results

3.1 Relations of flow velocity and discharge to *%Ao_{final}*

For each sampler and each target velocity, flow velocity in front of the sampler ($v_{xin,2}$) was positively related to the percent bag open area ($\%Ao_{final}$) (Figure 4). Logarithmic functions best described the trend of the relations that were characterized by an initial steep increase from low to moderate values of $\%Ao_{final}$ (basically from clogged to empty bags) and subsequent flattening from moderate to high values of $\%Ao_{final}$ (basically from empty nets to a sampler with no net attached).

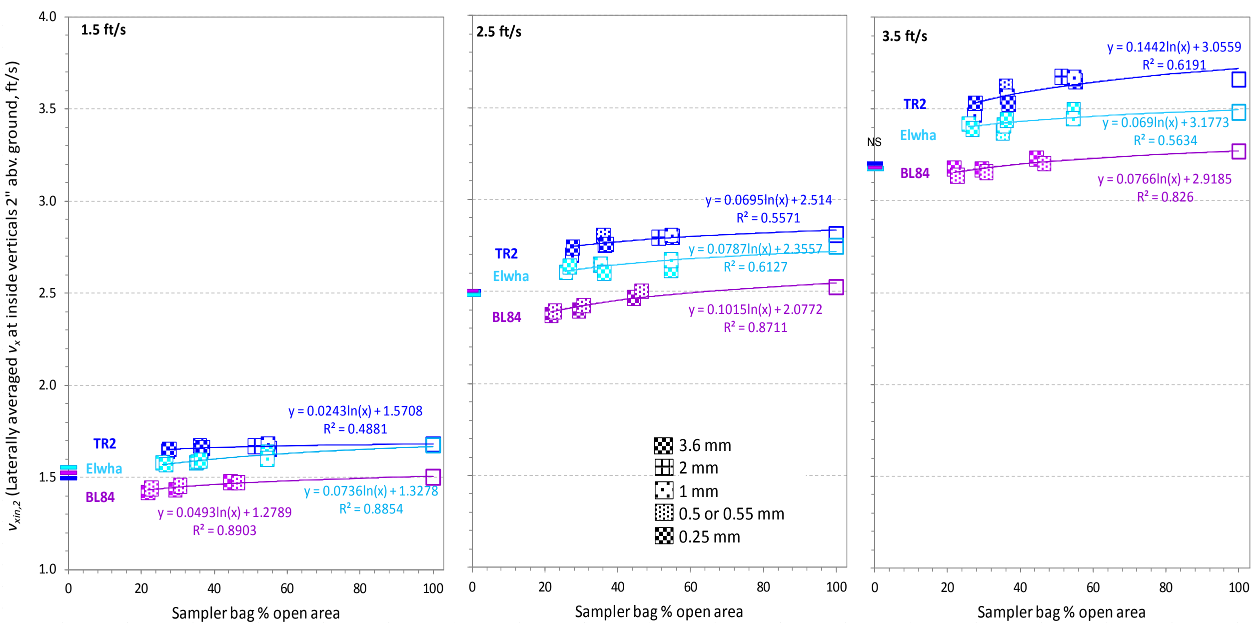

Figure 4: Logarithmic regression functions fitted to the relations of $v_{xin,2} = f(\%Ao_{final})$ computed for the $v_{xin,2}$ averaged over the measurement locations directly in front of the sampler entrance. To improve the visual comparison of $v_{xin,2}$ among target velocities and samplers, all data were plotted in the same scale for $v_{xin,2}$. The legend in the center panel indicates mesh width and refers to all panels.

Figure 4 shows that sampler type (i.e., the size of the entrance area), target velocity, and the $\%Ao_{final}$ all affected $v_{xin,2}$. The relative magnitude with which those three parameters affected $v_{xin,2}$ as well as the other hydraulic parameters was analyzed by comparing the $v_{xin,2}$ associated with a specified percentage of net openness, which was selected as 50% Ao_{final}. The velocity $v_{xin,2}$ was mostly controlled by the target velocity of a run, while sampler entrance area and net openness had minor influences. Several studies had reported that HE increases with ambient velocity (e.g., Kuhnle, 1992), while other studies reported that HE differs among pressure-difference samplers (Hubbell et al., 1987; Pitlick, 1988; Gray et al., 1991; Ryan and Porth, 1999; Childers, 1991, 1999; Ryan, 2005; Vericat et al., 2006). An unexpected discovery in this study was the effect of sampler width on $v_{xin,2}$. The BL-84 and the Elwha samplers differ by just one inch in sampler height, but the notably larger $v_{xin,2}$ for the Elwha suggested that $v_{xin,2}$ was not only influenced by a sampler's protrusion into fast flow but also by the sampler's width.

3.2 Hydraulic efficiency

Similar to the results obtained for near-bed flow velocity $v_{xin,2}$, hydraulic efficiency computed from $v_{xin,2}$ ($HE_{in,2}$) increased with sampler entrance area, with target velocity, and with the % bag open area $\%Ao_{final}$ (Figure 5). Hwever, while target velocity had exerted a large influence when measured $v_{xin,2}$ was compared among samplers, the dominating influence of the target velocity parameter dropped out when analyzing the effect of HE, because hydraulic efficiency is calculated as a velocity ratio. Instead, all three parameters, sampler entrance area, target velocity, and $\%Ao_{final}$ each exerted relatively equal controls on hydraulic efficiency. However, the way in which the three parameters affected HE was complex and not uniform among the samplers.

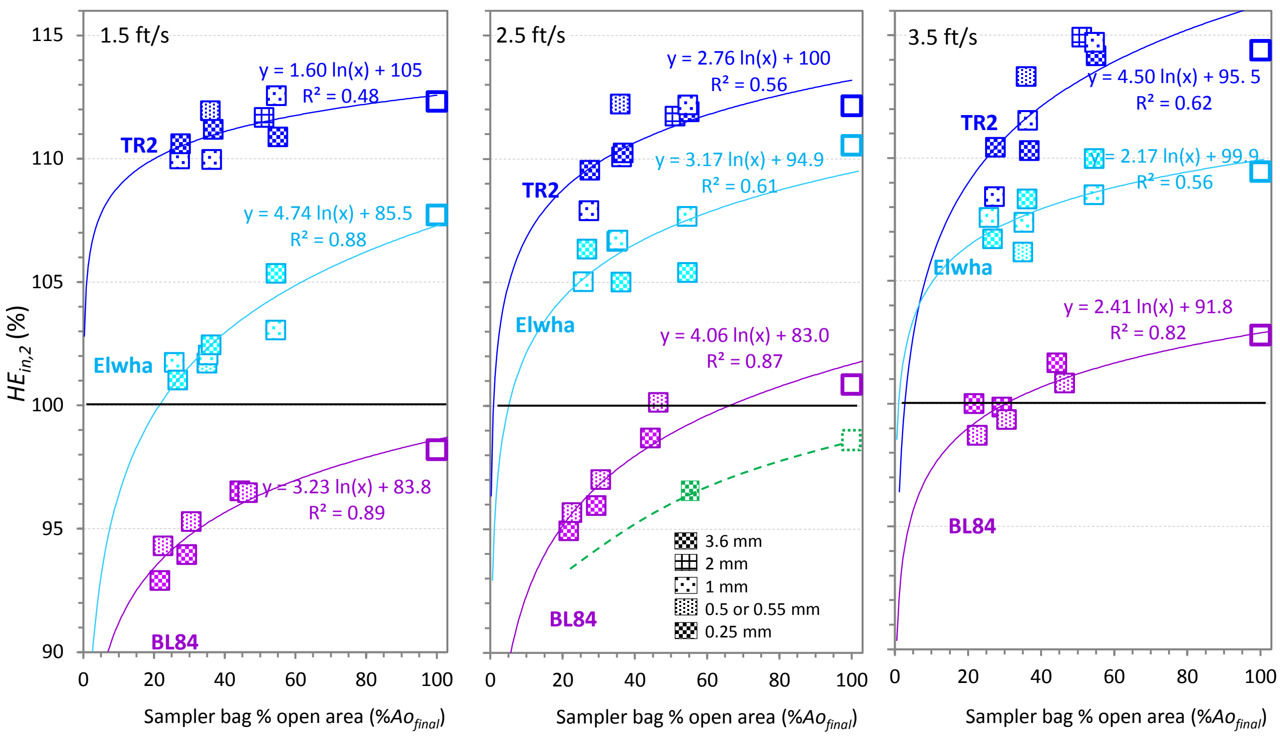

Figure 5: Hydraulic efficiency $HE_{in,2}$ for the three samplers and three target velocities. All panels are plotted in the same scale. The legend in the center panel refers to all panels. The green data point in the central panel indicates $HE_{in,2}$ measured for a bedload trap with an empty 3.6 mm net.

3.2.1 Sampler size affects *HE* most, target velocity and $\%Ao_{final}$ come next:

Absolute values of hydraulic efficiency for the TR2 and Elwha samplers were within 101 to 115%, showing that flow was sucked into those two pressure-difference samplers for all target velocities and all net configurations, even for clogged nets. The $HE_{in,2}$ for the BL-84 was below 100% (93-98%) for the slowest flow tested and ranged around 100% in the fastest test runs.

A TR2 sampler half filled with gravel had a higher hydraulic efficiency than an Elwha with empty bags, and an Elwha with half-clogged nets has a higher efficiency than an empty BL-84 sampler, showing that on average, sampler entrance size affected hydraulic efficiency slightly more than target velocity, while the overall percent bag openness ($\%Ao_{final}$) ranked third. A single test run with an unflared bedload trap (Bunte et al., 2004, 2007) yielded a hydraulic efficiency of 97%, showing that a sampler's expansion ratios affects hydraulic efficiency much more than either target velocity, sampler entrance area, or bag opening.

3.2.2 Complex effects of %Ao_{final} on hydraulic efficiency: The effects of %Ao_{final} on hydraulic efficiency were complex and differed among samplers, among bags, and among target velocities. Coarse-meshed nets (with Ao_{final} >50%) that were empty did not reduce hydraulic efficiency for the TR2 sampler, but clogged nets did, indicating that the choice of bag mattered little for the TR2 sampler as long as the bag was not filled to 50%, especially not in faster flow and not for the shape-retaining 1-mm bag. For the BL-84 sampler, the choice among coarse nets was likewise less important for hydraulic efficiency than avoiding filling the bag to 50%, especially in slower flow. By contrast for the Elwha sampler, gravel fill and the sheer presence of a coarse net equally reduced $HE_{in,2}$, particularly at slower flow.

3.2.3 Bag clogging vs gravel fill: Comparison of runs in which bag were filled to 30 and 50% of their volumes with gravel to those in which 30 and 50% of the bag volume was clogged showed that bag clogging reduced hydraulic efficiency notably more than gravel fills of similar volumes. This is because water could easily exit the bags above the gravel wedges, whereas complete clogging of the backward portion of the net caused turbulence and redirection of the flow within the net and that reduced $HE_{in,2}$. Further, net shape was found to exert a notable influence on how net openness affected hydraulic efficiency.

3.2.4 From hydraulic efficiency to sampling efficiency: In order to use multiple bedload samplers interchangeably, or to compare results between studies that used different samplers, all samplers should have the same HE, and ideally, that value should be near 100% for a wide range of sampler bag configurations.

However, HE is not a straightforward measure of sampling efficiency. Instead, the relation between flow hydraulics at the sampler entrance and bedload transport is highly complex, and even estimating a possible relation requires several assumptions. Consequently, rather than assuming a direct or fixed relation between HE and sampling efficiency, the sediment transport mode and processes at the sampler entrance need to be evaluated. A high HE more likely causes pronounced over-sampling under specific conditions: 1) When sand and fine gravel or organic material is transported in suspended mode rather than as true bedload, 2) When sandy or fine gravel bed material is entrained due to turbulence and vortices at the sampler entrance, such as when pushing the sampler through the water column t the stream bed, and then sucked into the sampler, 3) When gravel particles are dislodged during sampler placement on the bed and then sucked into sampler (Bunte et al., 2019, *this volume*).

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