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An efficient, self-orienting, vertical-array, sand trap

Michael Hilton [a,*], Bill Nickling [b], Sarah Wakes [c], Douglas Sherman [d], Teresa Konlechner [e], Mark Jermy [f], Patrick Geoghegan [f]

[a] Department of Geography, University of Otago, PO Box 56, Dunedin 9054, New Zealand
[b] Department of Geography, University of Guelph, Guelph, Canada
[c] Department of Applied Sciences, University of Otago, Dunedin, New Zealand
[d] Department of Geography, University of Alabama, Tuscaloosa, Alabama, United States
[e] National Centre for Coasts and Climate, University of Melbourne, Australia
[f] College of Engineering, University of Canterbury, Christchurch, New Zealand

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ABSTRACT

There remains a need for an efficient, low-cost, portable, passive sand trap, which can provide estimates of vertical sand flux over topography and within vegetation and which self-orients into the wind. We present a design for a stacked vertical trap that has been modelled (computational fluid dynamics, CFD) and evaluated in the field and in the wind tunnel. The 'swinging' trap orients to within 10° of the flow in the wind tunnel at 8 m s^{-1}, and more rapidly in the field, where natural variability in wind direction accelerates orientation. The CFD analysis indicates flow is steered into the trap during incident wind flow. The trap has a low profile and there is only a small decrease in mass flow rate for multiple traps, poles and rows of poles. The efficiency of the trap was evaluated against an isokinetic sampler and found to be greater than 95%. The centre pole is a key element of the design, minimally decreasing trap efficiency. Finally, field comparisons with the trap of Sherman et al. (2014) yielded comparable estimates of vertical sand flux. The trap described in this paper provides accurate estimates of sand transport in a wide range of field conditions.

1. Introduction

There have been many attempts to design a passive sand trap for use in aeolian geomorphology. These include traps that integrate the vertical sand flux (e.g. Bagnold, 1938; Leatherman, 1978; Fryberger et al., 1984; Greeley et al., 1996) and segmented traps that provide estimates of sand flux as a function of height above the surface (e.g. Wilson and Cooke, 1980; Borówka, 1990; Dong et al., 2004; Basaran et al., 2011; Rotnicka, 2013; Sherman et al., 2014). It seems that few aeolian geomorphologists involved in empirical work have avoided the temptation to design a better trap, with the primary focus on trap efficiency. There has been less emphasis paid to cost, durability, portability and practicality in a range of field conditions.

All traps are solid structures and inevitably affect the air stream in front of the trap, which may in turn affect the trajectory of saltating grains and result in underestimates of sand flux (Pye and Tsoar, 1990; Rasmussen and Mikkelsen, 1998; Li and Ni, 2003). The efficiency of many traps has been assessed in wind tunnel or field conditions, with reported efficiencies ranging from 30% to over 90%. There are inevitable compromises, however. For example, Nickling and McKenna Neuman (1997) report a passive wedge-shaped sand trap that is efficient (>90%) over a range of wind velocities, provided incident winds angles remain <5°, a condition that is rare in the field. Other traps are efficient, the VTRAP (Namikas, 2002), for example, but require significant excavation of the bed to install the subterranean chamber.

Sand transport is highly variable over small temporal and spatial scales, particularly during near-threshold conditions and low transport rates (Ellis et al., 2012). It is difficult to imagine the larger and more complex and more expensive passive sand traps, the continuously weighing traps of Jackson (1996), or Bauer and Namikas (1998), for example, being deployed in spatial arrays adequate to account for this variation. The large footprints of some traps may render them unsuitable for use within or near vegetation in some situations (e.g. measuring sand flux on the stoss face of a foredune within *Ammophila arenaria*). Moreover, most of the traps described in the literature have been intended for use on relatively flat surfaces. Obtaining reliable estimates of sand flux

* Corresponding author.
E-mail address: mjh@geography.otago.ac.nz (M. Hilton).

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between and within coastal dunes and dune systems requires traps that can be mass-produced and that are capable of providing estimates of sand transport in conditions of variable wind direction and speed.

Most passive sand traps are secured to the ground (e.g. the 'streamer-type' trap of Sherman et al., 2014), dug into the bed (e.g. the VTRAP and HTRAP of Namikas, 2002) or pressed into the bed (e.g. the segmented, unventilated trap used by Borówka (1990)) to attain stability. They are oriented into the wind with the assumption the wind field is unidirectional, or are deployed in sets intended (typically) to quarter the wind, such as the deployment of cylindrical traps (e.g. the 'vertical rod sand trap' of Leatherman, 1978). In fact, wind is not unidirectional at any time scale, and only meets assumptions of statistical (e.g., non-trending) unidirectionality over relatively short time scales. To accommodate changes in wind direction without direct intervention to reorient a trap, it must be able to orientate to variations in wind direction over seconds or minutes. A few traps of this type have been constructed (e.g. the Fryberger orientating trap, Fryberger et al., 1984) or can be partially rotated so they align with the 'mean wind' (e.g. the continuously-weighing, tipping-bucket T-BASS trap of Bauer and Namikas, 1998), but these are large traps that have a substantial foot-print and typically produce scour at their base (e.g. Greeley et al., 1996). This problem was largely overcome by the Wilson and Cook trap (WAC), developed by S.J. Wilson and R.U. Cooke in 1980, which has remained popular because of its simplicity, its efficiency (Goosens et al., 2000) and because it can be deployed at height on a mast (Petersen et al., 2011). The cyclone-style traps are efficient at a range of wind speeds and grain sizes (Basaran et al., 2011). Finally, omni-directional traps (e.g. Arens and van der Lee, 1995) appear advantageous, but have not yielded good results in coastal field conditions at very low or high speeds.

The current paper describes a new style of passive sand trap designed to overcome the limitations described above. It is simple and inexpensive to construct, easy to deploy, extremely durable, is highly efficient and self-orientating, and it has a small footprint. It can be used within or over a vegetation canopy and is suitable for use over complex dune morphologies and during light rain.

2. Design & materials

The traps are manufactured from a PVC non-pressure water pipe (Fig. 1) (42 mm external diameter, 2 mm wall thickness), cut into 210 mm lengths. Thinner pipe could be used. One end of the pipe is warmed using a 2000 W hot air gun (or similar), then moulded by inserting a wooden die (turned on a lathe from a 38 × 38 mm square-section) to achieve a round to square section transition. A 10 mm hole is drilled through the top and bottom of the moulded section, 20 mm (centre) from the square opening. This hole accommodates the vertical rod that will allow the trap to rotate in the horizontal plane. Part of the rear section of the pipe (160 mm in length) is then cut away with a band-saw. The catch-bag hangs off this section. Finally, a 3 mm wide section of a slightly larger PVC pipe, (42 mm internal diameter) is cut, slid over the rear of the trap, and glued in place. This strip helps ensure that the catch-bag does not slide off the trap when secured with a rubber band. A rigid, 10 mm diameter fibreglass rod is used to support each set of traps. Traps are supported by a rubber O-ring slid over this rod. Friction between the trap and the washer is reduced by sitting a polished stainless steel washer over each O-ring. The catch-bags are manufactured from 63micron, square-cell, nylon mesh, by folding and sewing the mesh along two sides, then cutting the edges using pinking shears (to prevent unravelling), to achieve internal bag dimensions of 200 × 80 mm. The bags are slipped over and secured to the trap, above the flange, with a rubber band. The traps weigh approximately 47 g. Each trap costs about $US4 in materials and can be manufactured in approximately 10 min.

We have used the traps in a range of beach-foredune settings, with each pole supporting a vertical array of 3–8 traps. The catch-bags can be removed from the traps at the end of each sand-flux run, but it is much easier to assemble multiple poles and to simply remove the whole pole from the station and remove and seal each catch-bag. The traps hang vertically when the pole is removed from the ground and held horizontally, at which point it is straightforward for a second person to remove each bag and use the rubber band to seal the bags for later drying and weighing. It is usually easy to push the poles 30–40 cm into the beach or dune substrate, with the aid of a small spirit level to ensure the pole is vertical, or to gently tap the poles into the ground with a rubber mallet. We have also inserted the poles into sections of metal pipe, pre-inserted into a stony deflation surface.

The traps do not intercept bedload. In practice, the bottom edge of the lowest trap is usually 1 cm above the bed, however, the trap can be set at any elevation. Unlike the Sherman et al. (2014) mesh traps, and some other trap types, the assembly does not provide a continuous sample of the vertical sand flux. This could be achieved with the swinging traps, but the 'swinging' attribute would be lost and the lowest trap would rapidly fill in most transport conditions because of its small size.

We have generally deployed the traps in moderate to high sand transport conditions, for periods between 90 and 600 s. Significant changes in bed level, caused by the formation or migration of bedforms, or interactions between the flow and the trap (scour) have not been observed, but the lowest trap might be raised higher up the pivot pole if necessary.

Traps must be placed at least 10 mm apart on the rod – the thickness of the rubber ring and washer. When installing a trap array on a steep slope it is necessary to excavate a level terrace below the rear corner of the catch-bag of the lowest trap to ensure it can swing freely. This excavation should not affect flow in front of the trap entrance. Finally, while the trap continues to function during light rain, particular in strong wind conditions, the combination of high sand flux and heavy rain results in sand sticking between the stainless steel washer and the trap, which impedes or prevents trap swinging. Wet sand may also stick to the support pole. Any sand sticking to the entrance of the trap, the pole, or the underside of the catch-bag support, can be washed into the catch-bag with a light spray of water.

3. Methods

3.1. Orientation and catch-bag resilience

The trap assembly was tested in the University of Canterbury's open circuit wind tunnel facility to determine (i) the tendency for the trap to orient to the flow and (ii) the resilience of the catch-bag assembly. Traps were placed at 45° to the air flow and flow speed through the tunnel increased in 2 m s^{-1} increments (Fig. 2). Each experiment was videoed (from above), with a range of angles marked on the floor of the wind tunnel, to allow the alignment of the trap to be associated with wind speed. This test was first undertaken with an empty trap, then repeated with the catch-bags containing weights between 10 and 60 g. These values are typical of sand weights captured during field trials. As described below, our field experiments were terminated when the lowest trap contained around 150 g of sand. At this time the higher traps (traps 2–8) contained less than 60 g of sand. The trap and catch-bag assembly was tested in flows up to 40 m s^{-1} to identify a threshold above which the bag might detach from the trap.