VARIATIONS IN FLOW RESISTANCE IN SMALL AGRICULTURAL STREAMS DUE TO IDEALIZED AQUATIC VEGETATION DISTRIBUTIONS

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The work reported here considers flow resistance due to vegetation in the smallest of surface water drainage channels – streams and agricultural drainage ditches of the order of 1m wide and 10cm deep. The second investigation explored the way in which the spatial distribution of obstacles to the flow affected flow resistance in these small channels. In practice, such obstacles in these channels are usually patches of aquatic vegetation. However, vegetation has complex hydraulic properties. Therefore, to elucidate the specific effects of the spatial pattern of obstacles, we used arrays of hydraulically-simpler obstacles, namely sandbags. We found that the maximum efficiency of energy conversion from potential energy to kinetic energy in the flow occurred when the sandbags covered 50% of the total area they occupied. If they were more spread out than this, it allowed the creation of individual wakes, which between them increased energy dissipation; if they were more piled up, this caused plunging of the flow over them, which also increased energy dissipation, though to a much lesser extent that individual wake formation.

1 INTRODUCTION

Conveyance channels – including rivers, streams and manmade drainage channels – provide two primary services. Firstly, they convey water, and the material it carries with it. Most importantly, this can mitigate flood risk, or alleviate drought (depending on the climatic setting), and can also provide a source of energy and leisure amenity. They can also support rich biodiversity and ecological health, not only within their own channels, but throughout their catchments [2]. Channels in which flow conveyance is prioritized, for example by extensive dredging, often have their ecological value concomitantly degraded by this process, while channels in which ecological health is prioritized, for example by allowing aquatic vegetation to grow freely, often have their ability to convey water degraded because they become blocked. Thus, while these two functions may not be entirely mutually exclusive, the question does often arise as to where the optimum balance lies between maximizing the conveyance capacity of surface water drainage channels, and ensuring that they are resilient supporters of biodiversity and ecological health. This has become a prominent issue, given the increased occurrence of flood events and the increased value of the damage that they cause, together with the increased interest in river restoration and improving their ecological value. This issue can be particularly problematic in the smallest of conveyance channels – agricultural ditches and streams – where vegetation and other obstacles can block the flow of water very effectively.

Blockage or increased resistance to flow due to in-stream vegetation has been studied extensively in recent decades [1]. This work has focused on channels where the water surface is at least of the order of metres wide and the water depth is at least several tens of centimetres. In this paper, the focus is on the very extensive category of channels that are an order of magnitude smaller than this – with widths of tens of centimetres and depths of up to a few tens of centimetres. In many settings, these are the first conveyance channels that water enters after falling to the ground, and are thus crucial controls on its transport.

The aim of the study reported here was to explore the way in which the spatial distribution of obstacles to the flow (which, in practice, will often be patches of vegetation) affected flow resistance in these small channels. To do this, we adopted an approach that was intended as a halfway house between laboratory flume experiments and field measurements. Laboratory flume studies of flow resistance are carried out in conditions which are deliberately simplified, so that the values of the parameters of interest can be tightly controlled and extraneous, unmeasured influences on the data can be minimized. Field experiments are carried out in conditions where the full complexity of the natural system is present, so that the “real thing” can be measured, but with limited control on parameter values and the influence of extraneous factors. There have been attempts to bridge this gap by introducing real plants into laboratory flumes [4], or by using field flumes, which allow for some control of variables associated with the flow and channel morphology [3]. Here, we chose to take an alternative approach, using a natural channel with uncontrolled discharge, but using sandbags, whose locations we could adjust as the primary elements of flow resistance. In this way, we were able to investigate the effects of gradual spreading of these roughness elements on the flow characteristics.

2 METHODS

The experiment was carried out in a small tributary of the River Ribble at Sawley in NW England (53.9114N, 2.3440W). Fifteen sandbags were each filled to their capacity with 10kg of sand. Six runs of the experiment were carried out. In the first – the control case – the sandbags were not placed in the stream. In the remaining five, they were placed in five different spatial distributions (Figure 1). These six distributions were characterized in terms of the relative coverage of the channel bed by the sandbags, which varied from 0% to 300% (in the 300% case, the sandbags were stacked three high across the channel).

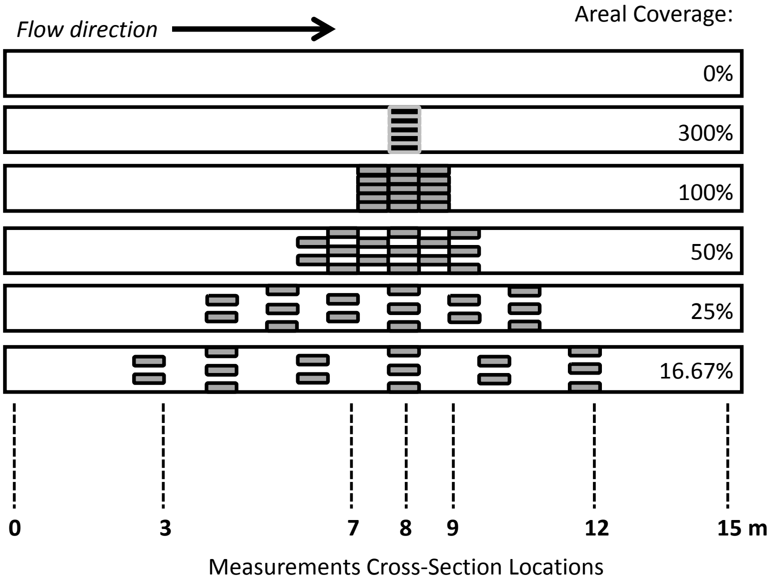

Figure 1: Spatial distributions of sandbags used in the six experimental runs, and locations of measurement cross-sections. Black-filled rectangles indicate sandbags piled 3 high; grey-filled rectangles indicate single bags.

The width of the water surface in this stream varied from 1-1.5m, and the channel was approximately straight for a distance of ≈30m, within which the 15m section containing the sandbags (Figure 1) was located centrally. Measurements of channel bed and water surface elevation were taken at 10cm intervals at seven locations along the 15m long section. These were 1-1.5m wide at the water surface. Flow speed at approximately 60% of the full depth was also recorded at each of these intervals in each cross-section using a Sontek 2D flowmeter. Since the flow depths were only a few centimetres for several of the measurement positions, and the measuring head of the flowmeter is itself a couple of centimetres in depth, measurements of flow at different depths were not feasible. However, the limited depth of the flows also indicates that vertical variations in flow speed would have been limited, so measurement of flow speed at a single, intermediate depth at each point in each cross-section was considered to be justified. The morphology of these cross-sections is shown in Figure 2, which also shows their relative elevations and a typical water surface position. The measurements were taken over the course of three days, during which the discharge varied little.

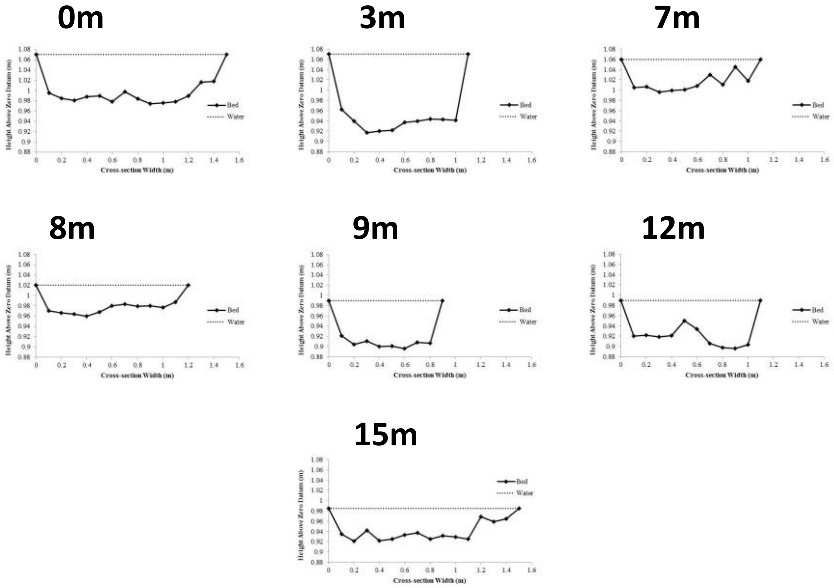

Figure 2: Cross-sections of the channel at the seven measurement locations

3 RESULTS

The longitudinal variation in the water height for the six different treatments is shown in Figure 3

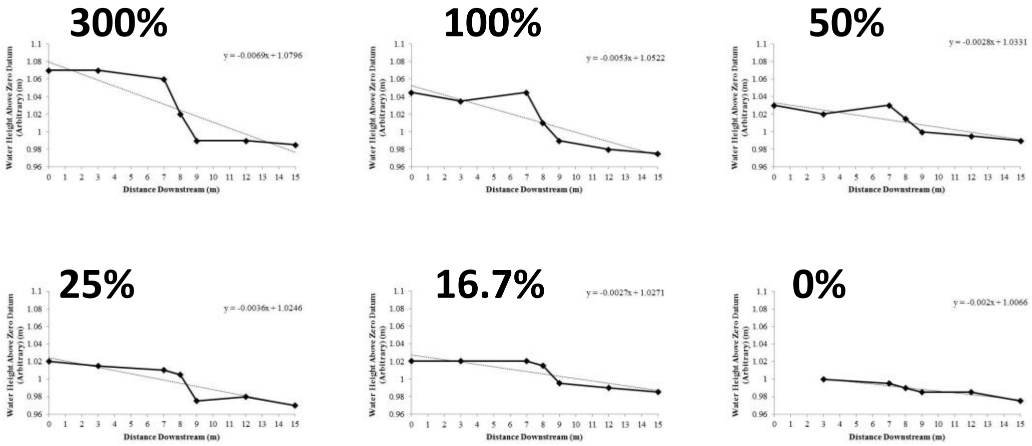

Figure 3: Longitudinal water height variation for each sandbag coverage pattern (Figure 1)

Manning's coefficients decreased with the downstream position of the cross-section whose data was used to calculate them. This indicates that the flow was not in equilibrium within the channel: rather than there being uniform steady flow with the drag forces equaling the gravitational forces, the latter were greater and the flow accelerated down the measured stretch, resulting in a net gain of kinetic energy. Given this, the results of the experiments are presented in terms of energy gains and losses (Figure 4).

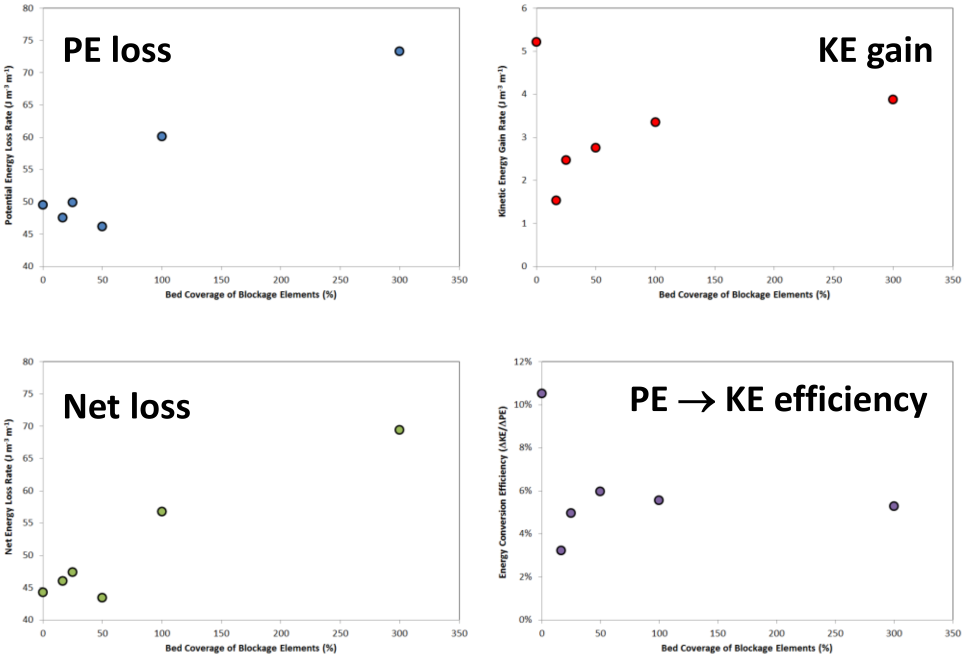

Figure 4: Energy gains and losses down the measured channel, as a function of sandbag bed coverage.

These results indicate that the net loss (PE loss – KE gain, potential energy that is dissipated rather than transferred to kinetic energy) increases approximately linearly with bed coverage, and that this pattern persists even for coverages of >100% i.e. whether the coverage is piled up or spread out across the bed. They also indicated an interesting and potentially significant pattern in terms of their efficiency of PE conversion to KE. Whilst, as expected, this efficiency is highest (approximately 10.5%) in the control case where there are no sandbags in the channel, it is lowest for the most spread out distribution of sandbags. It then reaches a peak at an intermediate coverage (50%) and then retains a value slightly lower than this for higher coverage values. This suggests that the creation of wakes in the gaps between the sandbags in the lower coverage value cases reduces the energy conversion efficiency. Where this is not possible because the obstacles are too tightly packed together (50% coverage and above) there is less dissipation to turbulent energy in the wakes, and more efficient conversion to KE. The slight reduction in efficiency at the highest coverage values compared to that at 50% coverage is (from the graphs of PE and KE themselves) due to only a slight extra gain in KE despite a significant increase in PE, evidently due to the piling up of the water behind the highest coverage value cases. The longitudinal water surface height changes (Figure 3) suggest that energy loss due to the water plunging over the downstream edge of the highest coverage distributions may be the cause of this. Thus maximal energy conversion efficiency, and the most efficient conveyance of water occurs when the obstacles have an areal coverage of 50% - if they are more spread out, this allows the creation of individual wakes, which between them increase energy dissipation; if they are more piled up, this can cause plunging of the flow over them, which again increases energy dissipation.

REFERENCES

[1] Nepf H. “Hydrodynamics of vegetated channels”, *Journal of Hydraulic Research*, Vol. 50, No. 3 (2012) pp 262-279.

[2] Reimchen T., Mathewson D., Hocking M., Moran J. and Harris D. “Isotopic evidence for enrichment of salmon-derived nutrients in vegetation, soil and insects in riparian zones in coastal British Columbia”, *American Fisheries Society Symposium*, Vol. 34 (2003) pp 59-69.

[3] Schoelynck J., Meire D., Bal K., Buis K., Troch P., Bouma T., Meire P. and Temmerman S. “Submerged macrophytes avoiding a negative feedback in reaction to hydrodynamic stress”, *Limnologica - Ecology and Management of Inland Waters*, Vol. 43, No. 5, (2013) pp 371-380.

[4] Shucksmith J., Boxall J. and Guymer I. “Bulk Flow Resistance in Vegetated Channels: Analysis of Momentum Balance Approaches Based on Data Obtained in Aging Live Vegetation”, *Journal of Hydraulic Engineering (ASCE)* Vol. 137, No. 12 (2011) pp 1624-1635.