Evaluation in the laboratory of the influence of storm movement on the hydrologic response of small areas

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Introduction

Moving storms are natural phenomena which affect the rainfall-runoff process. Ignoring the storm movement can lead to considerable over- or under-estimation of runoff volumes and peaks. The rainfall runoff process has to be understood for a variety of engineering studies, such as the design of urban drainage systems, the analysis of pollutant and soil transport, water resources management, and flood defense and flood management systems. Most methods used in hydrologic studies assume a constant rate of rainfall whereas natural rainfall is highly variable in both time and space. Thus the effect on the runoff response to the movement of storms across the drainage area is not taken into account. The aim of this study is to quantify the hydrologic response of drainage systems in terms of discharges and soil loss caused by both non-moving and moving rainstorms. Laboratory experiments were conducted in the last few years, employing different set-ups to gain insight into this issue.

Materials and methods

The experiments used several soil flumes (Fig.1), a physical scale model (1:100 scale) representing an impermeable downtown urban area with high rise buildings (Fig.2) and a movable sprinkling-type (full cone nozzle) rainfall simulator (Figs. 1 and 2). Moving rainstorms were simulated by moving the rainfall simulator upstream and downstream over the soil surface and the physical scale model at different speeds and from different directions. Overland flow and sediment transport were monitorized over time, during the runoff events.

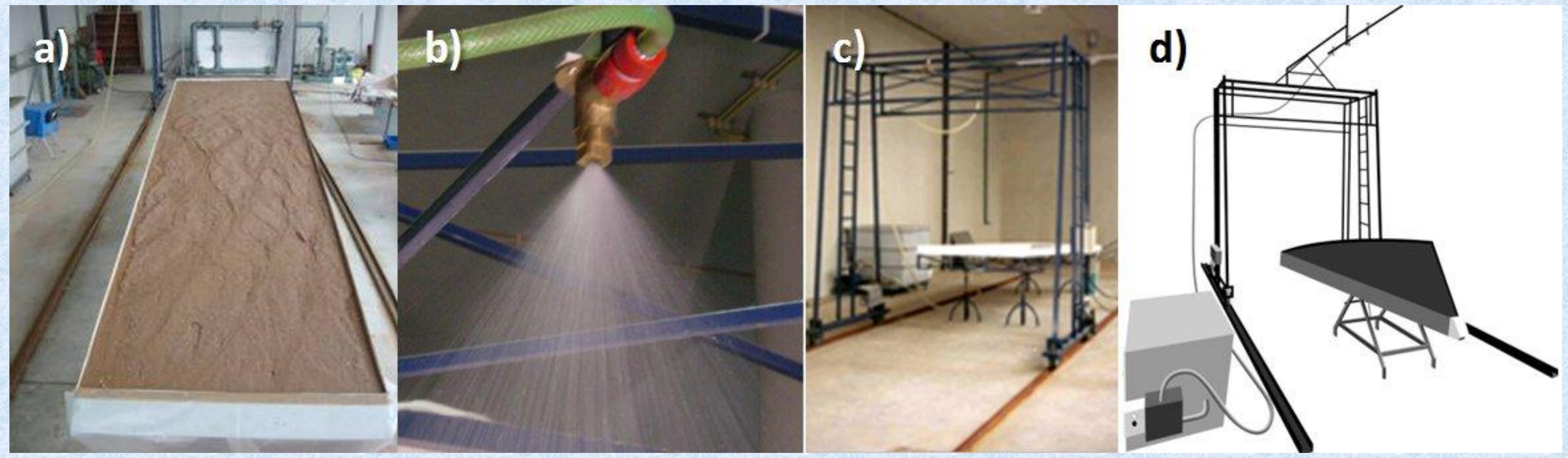

Fig. 1 – Photographs of a) flume, b) full-cone nozzle spray, c) rainfall simulator installed on a structure that is electrically driven along rails and d) sketch of the laboratory set-up with a converging flume surface.

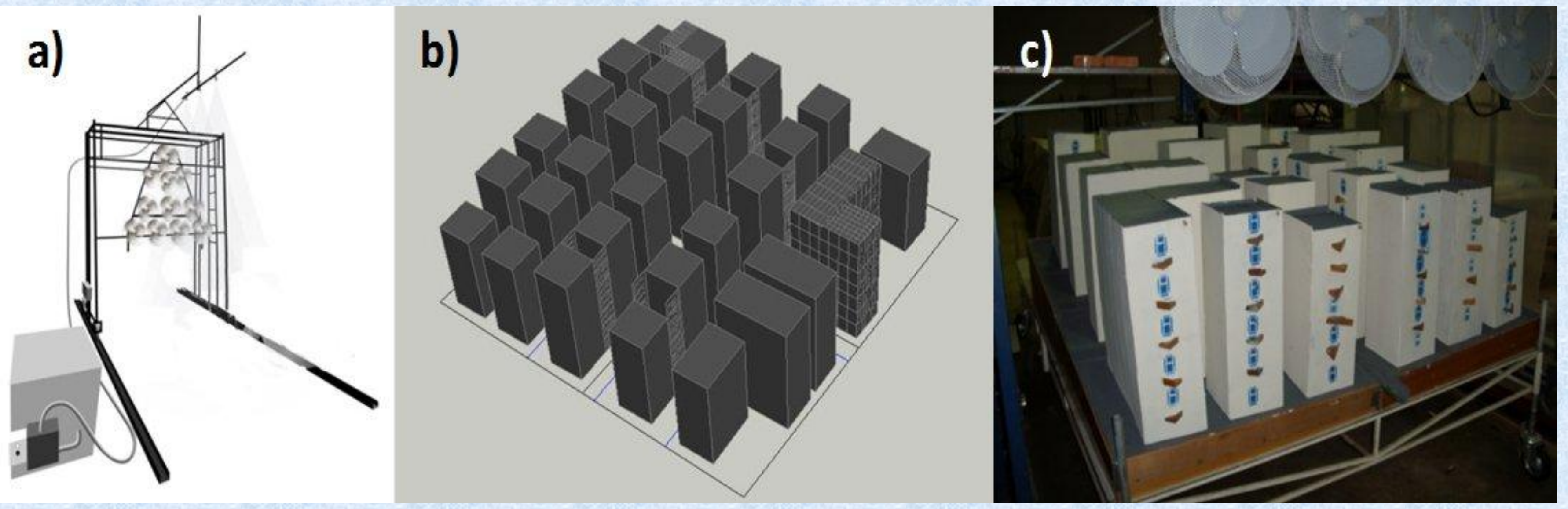

Fig. 2 – Laboratory set-up: a) sketch of the rainfall simulator structure with wind generator device, b) conceptual model of an urban system, c) photograph of the 1:100 scale model of an impermeable downtown urban area.

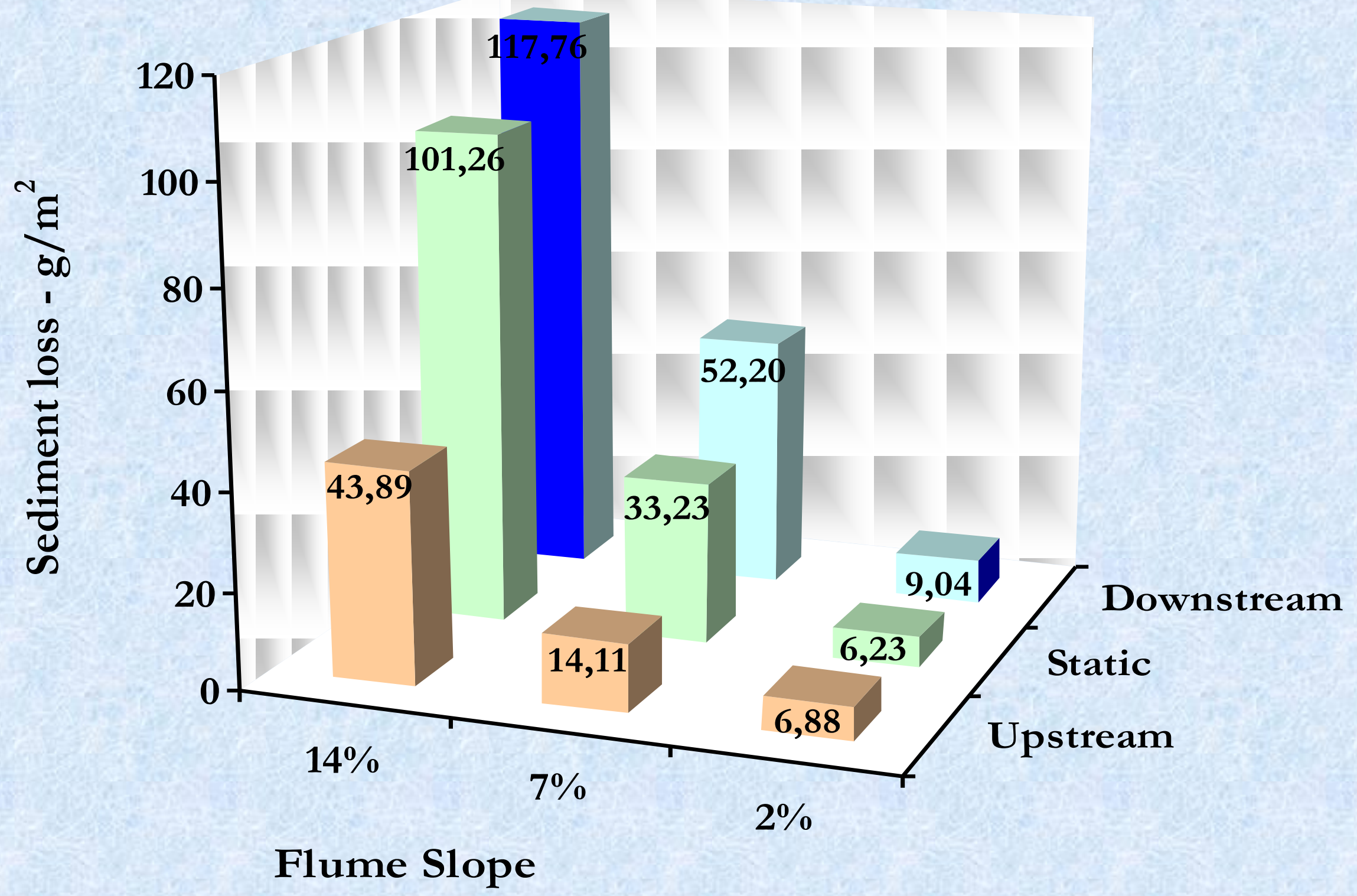

Fig. 3 – Total soil loss caused by different rainfall events as a function of slope and storm type, for three slopes (2%, 7% and 14%) and three types of storms (downstream, upstream and static). The soil flume was made of zinc-coated iron and was 3.00m long, 0.30m wide and 0.10m deep.

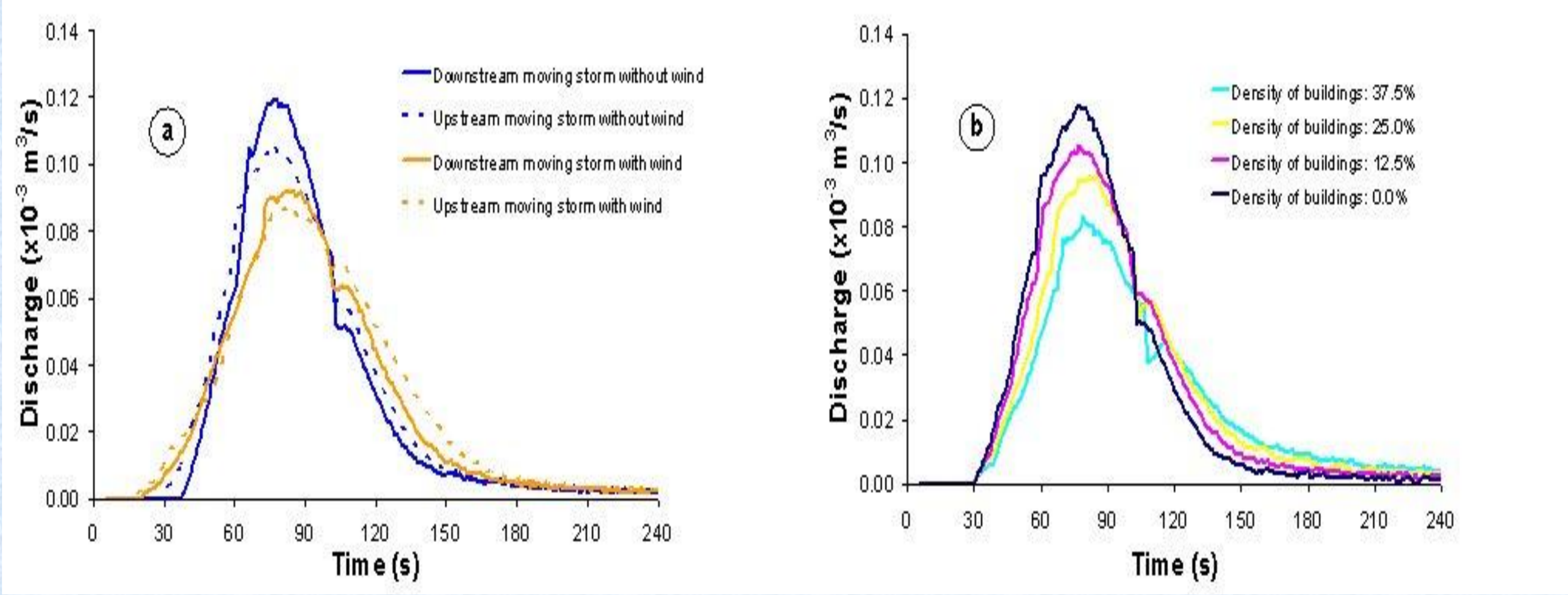

Fig. 4 – Hydrographs obtained from the 1:100 scale physical model of an urban area: a) For the 12.5% building density, comparison of hydrographs for upstream and downstream moving storms, with and without wind b) Hydrographs for downstream moving storms for different building densities.

Results

Figure 3 shows results from soil flume experiments. Significant differences in runoff and soil loss between identical simulated rainstorms moving downstream and upstream were clearly observed; we define identical rainstorms those that yield the same water volume over the drainage area. Downstream moving storms yielded higher soil loss than did upstream moving storms. A similar behavior was observed for other speeds and slopes.

Figure 4 shows results from scale model experiments. Downstream moving storms produce higher peak flows than upstream storms. Wind effect reduces this difference because more rain is intercepted by the lateral walls of the buildings. The increase in building density reduces peak flow for downstream moving storms, in comparison with an initial impermeable surface.

Conclusions

Laboratory experiments with soil flumes and a physical scale-model of an urban area showed that the direction of storm movement, especially for very high intensity rainfall events, significantly affected runoff and water erosion processes, at different scales. Distinct hydrologic responses for storms moving upstream and downstream were identified. Downstream-moving storms caused considerably higher peak runoff and erosion than did upstream-moving storms. The hydrograph shapes were also different: when compared to upstream moving storms, downstream-moving storms yielded runoff that started later and the rising limb was steeper.

The differences observed between static and moving rainstorms should be taken into consideration for small drainage basins, which means that design procedures need careful evaluation.

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