MODELLING THE IMPACT OF URBANIZATION ON HYDROLOGICAL EXTREMES

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Introduction

Urbanization can induce significant changes to the hydrological regimes of small catchments, leading to flash floods which can provoke significant damage and put local populations at risk. This impact could be enhanced by climate change, especially since urbanization could lead to major hydrometeorological changes over cities and potentially increase extreme rainfall events.

Ongoing research projects aim to study of the impact of urbanization on hydrological processes in small catchments. This is being achieved by: (i) installing a detailed monitoring network in a study area, the Covões catchment (small urban basin in the city of Coimbra, Portugal); and (ii) modelling storm runoff and use it to study the impact of different urbanization patterns on hydrology at both the slope and catchment scales. This paper presents the first results of the modelling exercise performed during these ongoing projects.

Covões Catchment

The Covões catchment (6.2 km^2; Figure 1) is located in the centre of mainland Portugal. In 2000, 21% of the catchment's surface was occupied with discontinuous urban fabric (55 % built-up areas interspersed with 45% agricultural and woodlandland cover); the remainder of the catchment was mostly forested (Figure 1, right). Between 1987 and 2000, the percentage of impervious areas in the catchment increased from approximately 3.5 % to 10%; this trend is expected to continue, and new urban areas are currently being developed further upstream. This situation has been indicated as one cause of a major flood in late 2006, underlining the need for a modelling approach to study the impact of further urbanization on the catchment's hydrological processes and analyze the effectiveness of different mitigation measures.

Modelling approach

The MEFIDIS model (Nunes *et al.*, 2005) was selected to be applied to the Covões catchment. The model is a process-based, spatially-distributed and dynamic hydrological model for extreme rainfall events. Hydrological simulation is based on the St. Venant equations (Chow *et al.*, 1988). Simulated processes include interception, infiltration, surface retention and runoff generation through either infiltration or saturation excess. The spatial distribution of saturated areas and soil moisture deficits can be calculated using a topographic wetness approach (Beven, 2000). Runoff routing is handled using a kinematic wave approach (Singh, 1996).

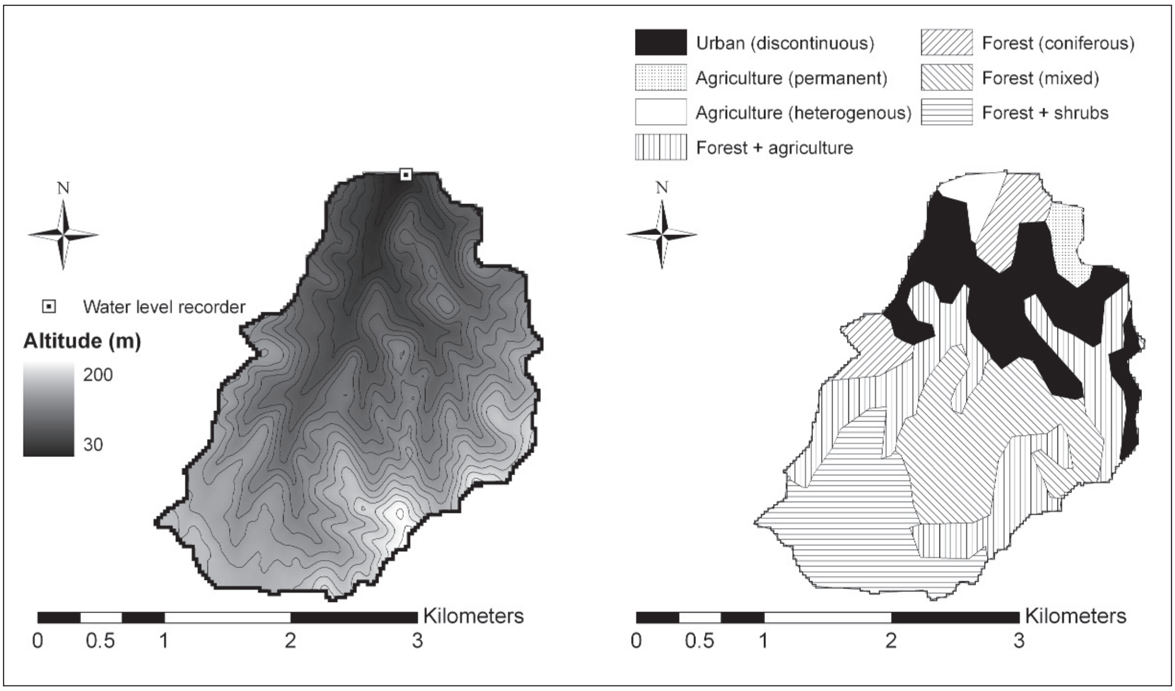

Figure 1. Map of the Covões catchment showing altimetry and location of the water level recorder (left); land cover according to the CORINE 2000 map (right)

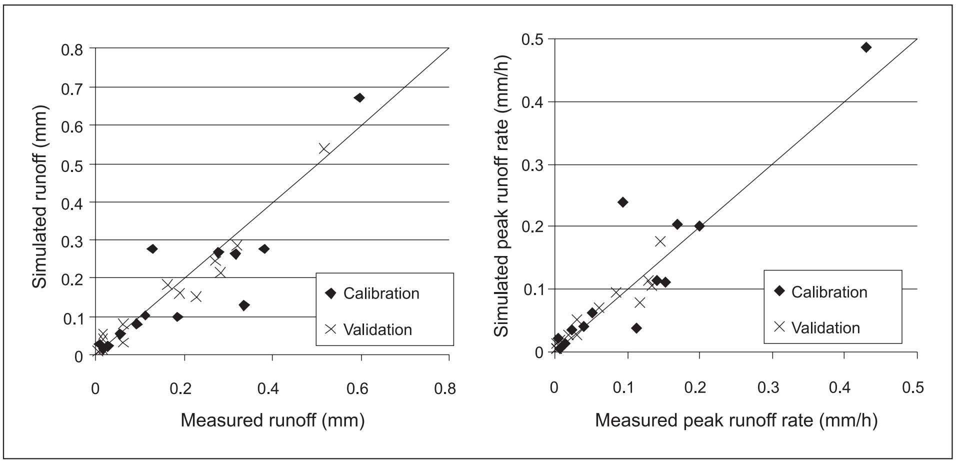

Figure 2. Comparison between simulated and observed results for storm runoff and peak runoff rates for selected storms in 2005

The model was applied to the Covões catchment using existing topographic (25×25 m), landcover and soil maps; landcover and soil parameters were taken from the scientific literature. The model was calibrated and validated by means of a split-sample approach, using 26 storms which occurred in 2005 and for which rainfall was measured at 15-minute intervals. Calibration and validation for storm runoff and peak runoff rates are shown in figure 2; the Nash-Sutcliffe model efficiency index (Beven, 2000) was 0.83 in both cases (r^2 = 0.85 and 0.87, respectively), showing a good agreement between simulated and observed results.

Modelling exercise

MEFIDIS was applied to the Covões catchment to assess the impact of different urbanization densities in the study area. The effects of no urbanization, 1987 conditions (catchment with 3.5% imperviousness) and future expectations (catchment with 14.5 to 16.5% imperviousness) were evaluated by running the model for a selection of storms (with total rainfall volume above 10 mm), changing only the urbanization density inside the urban area shown in figure 1. The results are shown in figure 3.

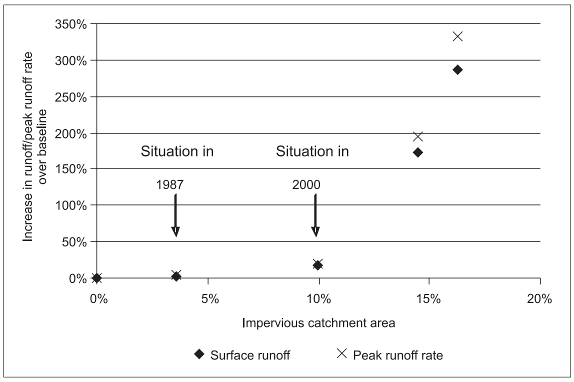

Figure 3. Average increase in surface runoff and peak runoff rate over baseline conditions (0% impervious catchment area) in the Covões catchment

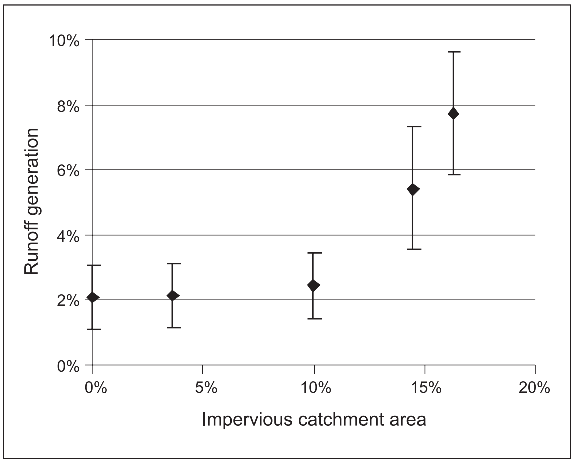

Figure 4. Increase in the runoff coefficient due to urbanization in the Covões catchment

Model results indicate that in 1987 urbanization had not led to any significant impact on runoff volume and peak runoff rates in Covões. In 2000, however, urbanization had already led to an increase of 17.5% and 19 % respectively for runoff and peaks. Simulations also revealed the non-linear relationship between runoff response and urbanization, which can be attributed to an increase in the catchment's hydrological connectivity as urbanization density increases, allowing for more of the runoff generated in impervious areas to reach the hydrological network more quickly.

Model results also show the potential for further impacts of urbanization on runoff generation in this catchment, as shown in figure 4. Even with the significant increase in runoff and peak runoff rates with a 16.5% impervious catchment area (equivalent to an urban density of 90% inside the urban area shown in figure 1), simulated runoff generation is only 8%, implying that a significant part of rainfall still infiltrates or is retained in surface depression storage.

A follow-up modelling exercise is currently underway, simulating both the impact of rainfall intensity changes on runoff generation and the effects of combined changed rainfall intensity and urbanization (due to climate and land use changes). The results of this work will also be presented.

Conclusions

This study shows how a modelling approach can help urban planning by estimating the hydrological impact of urbanization. The expansion of the urban area can be studied while storm conditions remain unchanged, allowing the impact of urbanization to be separated from that of different storm rainfall patterns. With MEFIDIS it is also possible to change storm patterns in line with climate change predictions, while keeping urban areas constant; and both changes can be simulated simultaneously to study positive feedback between increases in storm intensity and the imperviousness of the catchment's surface.

Acknowledgments

This work has been financed by the Portuguese Foundation for Science and Technology, through project URBHI (POCI/CLI/60421/2004) and project CANAIS (PPCDT/AMB/58429/2004).

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