1.3 A DISTRIBUTED RAINFALL RUNOFF MODEL TO USE IN MEDITERRANEAN BASINS WITH RADAR RAINFALL ESTIMATES

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1. INTRODUCTION

Floods are the most important natural hazard in the Mediterranean area. Meteorological, morphological and urbanisation features make difficult the anticipation of floods in this zone. Particularly, high variability of rainfall exists both in time and space, and river basins have in general fast response times. Therefore, hydrological models taking into account the rainfall variability should play an important role in flood alert systems in the Mediterranean.

In this sense, radar information is a key element in flood forecasting. A number of works have shown that this is an essential information to provide accurate flow estimates using a rainfall runoff model, even when a dense raingauge network exists (see Sempere Torres *et al.* (1999)). In fact, a density of about 1 raingauge per 200 km^2, that is the case of Catalonia, is insufficient to reproduce the spatial pattern of most of the storms.

A conceptual distributed rainfall runoff model is developed, seeking to incorporate spatial rainfall fields, particularly from weather radar. The simplicity of ideas (looking for intuitive and physical sense) as well as a useful conception (like a little computation time, or a manageable set of parameters) are the main purposes of the model, in order to design a tool adapted to real time flood forecasting. A case study in Besos catchment (1020 km^2) is presented here.

2. THE BESOS CATCHMENT

The Besos catchment (1020 km^2) is located in Barcelona area, and it is a typical example of Mediterranean complex catchments. It is quite heterogeneous, from mountains over 1000 m to rural planes that have been suffering a continuous urbanisation process during the last decades. After a serious flood in 1962, a great investment was done in order to monitor the cathcment for hydrological purposes. It is now instrumented by several telemetered rain and streamflow gauges (see figure 1), and the area is well covered by the National Weather Service radar (the maximum distance to the radar site is 60 km). Regarding the quality of the radar information, some problems have been detected in the basin area, being the most important the ground clutter detection in the mountainous zone. Parallel studies are being carried out to improve the quality of radar images thinking in their hydrological applicability (see Sánchez-Diezma *et al.* (2001)).

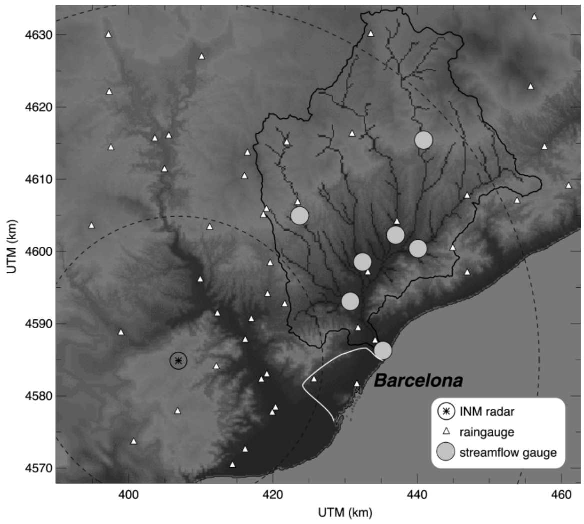

Figure 1. Telemetered gauges in the Besos catchment. The radar belongs to the National Weather Service (INM), and it is located in the Puig de les Agulles (650 m a.s.l).

3. THE RAINFALL RUNOFF MODEL

The presented model is based in a model developed by Hermida and Sempere Torres (1997) from the previous work of the previous work of Garrote and Bras (1995), where the catchment is split into hydrological cells (1x1 or 2x2 km^2). Each cell is treated as a hydrological unit, where a lumped model is applied. Once the cell runoff is computed, it is routed to the outlet following a single unit hydrograph process, which is obtained from the definition of a simplified drainage network. Finally, the sum of all the cell runoffs provides the total discharges at the outlet.

Rainfall input is different in each hydrological cell, and it is derived from a rainfall field with the same resolution as the hydrological cell. The model is also able to include evaporation estimates.

3.1. The loss function at cell scale

Two models are selected to reproduce the rainfall runoff transformation at cell scale, depending on the degree of urbanisation: *TOPMODEL* (Beven and Kirkby (1979)) is a model that performs well in rural and permeable catchments, and it is applied in rural cells. On the other hand, an alternative model more adapted to non-permeable soils is applied in highly urbanised cells: the *SCS* loss function (see McCuen (1982)).

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The two parameters needed in the *SCS* model are obtained directly from tables (see Chow *et al.* (1988)) for each hydrological cell, basically from the urbanisation degree.

The *TOPMODEL* version used in rural cells has some important particularities that make it different to that commonly used (Beven *et al.* (1995)). This version does not include the runoff routing from the source area to the outlet because it will be done inside the routing module in a distributed manner. Then, both excess and base flows are assumed to come to surface in the middle of the hydrological cell, ready to be routed.

The topographic index is derived from DEM analysis. The computation is made for the entire catchment using a multidirectional algorithm that computes the source area for each pixel. Then, inside each hydrological cell, a different density function of the topographic index is provided for each one, in order to apply the model.

This version is leaded by 3 parameters, according to the two classic *TOPMODEL* stores: the Root Zone (1st store) and the Saturated Zone (2nd store). The initial deficit of the 1st store (Sr_0) is considered an event parameter. In the 2nd store, the exponential storage emptying parameter (m), and the transmissivity at saturation (T_0) have to be fixed. Finally, the initialisation of this 2nd store is done from the initial value of the observed runoff.

3.2. The routing model.

A water pathway to the basin outlet is defined for each hydrological cell, derived from topography. The pathway is divided in two kinds of paths: hillslope path (slow response) and river path (fast and channelled response). The separation is made by imposing that a cell belongs to river if its draining area is at least greater than a threshold. Figure 2 shows the drainage system used by the model in the Besos catchment, where the threshold has been fixed in 24 km^2.

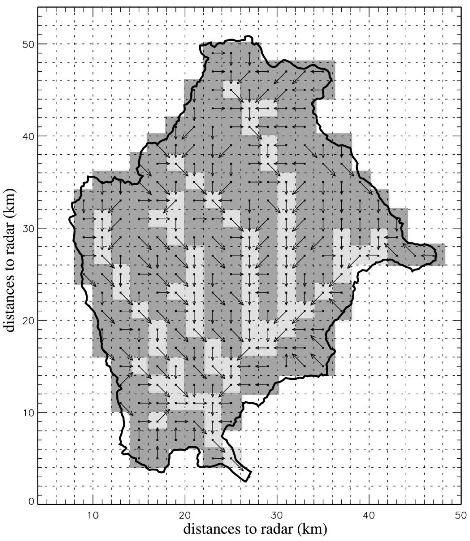

Figure 2. Drainage system in the Besos basin. Division in river cells (soft grey) and hillslope cells (dark grey).

In the hillslope path, a little lamination is considered. The Gamma function $G(n,K)$ of the Nash's Unit Hydrograph (Nash (1957)) is applied. This function is leaded by 2 parameters: n is the number of cells of the hillslope path, and K is the storage constant (a model parameter).

In the travel over river cells, a time delay is applied supposing that water travels to the outlet with a constant velocity. This time delay (t_r) depends on the length of the river path (l_r), derived from topographic analysis, and on the river velocity (v_r), that is the last parameter of the model. No further propagation effects are carried out. The resulting unit hydrograph becomes the same Nash's Unit Hydrograph obtained before, but delayed in a time (figure 3).

A working scheme of the model is shown in figure 4. The model has to optimise 5 parameters, what is currently done by minimizing the root mean square error using the Rosenbrock's method (Rosenbrock (1960)).

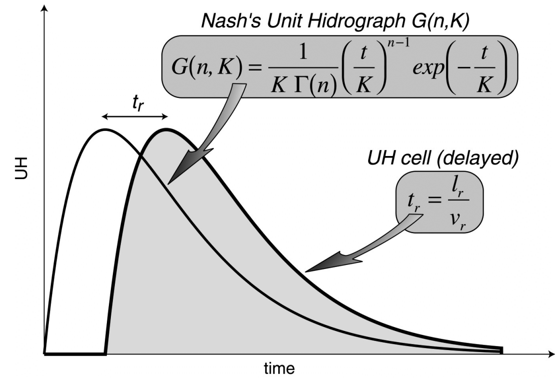

Figure 3. Example of a unit hydrograph used to propagate the runoff from the cell to the outlet, after the application of the Nash's UH in the hillslope path, and a time delay in the river path.

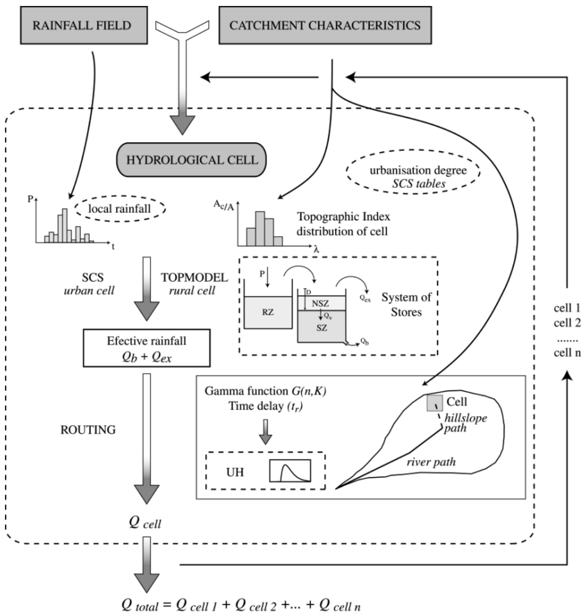

Figure 4. Scheme of the proposed model.

4. RESULTS

The available streamflow and rainfall data from the last 5 years are used to fit the model. Because of not having available radar information during all the flood events, in some cases the raingauge data is the only information used to build the rainfall fields (using the thin plate spline method (Duchon (1976)).

An example of partial results is shown in figure 5, where the resulting hydrographs (using raingauges and radar information) for a single event optimization are shown. In this event, radar images have only suffered a single correction process (reflectivity substitution in ground clutter areas), and the reflectivity conversion to rain intensity has been simply done using the Marshall-Palmer relationship (Marshall and Palmer (1948)). Although the images processing is insufficient to reproduce accurately the spatial rainfall fields, the effectiveness of using rainfall estimates by radar is evident, because the general shape of the hydrographs (including both peaks) and the quality parameters (Nash efficiency) are better than those obtained using rainfall from raingauges.

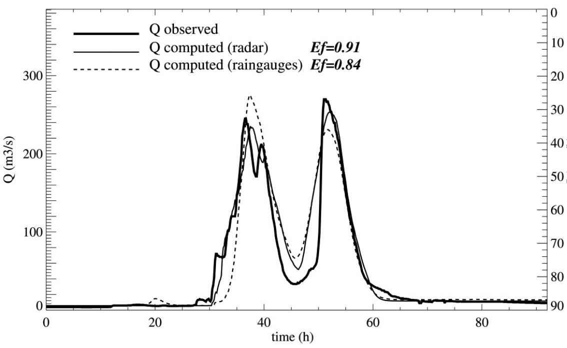

Figure 5. Results obtained in the optimisation for the 10/14/1996 event.

5. CONCLUSIONS

A distributed conceptual rainfall runoff model, able to incorporate the spatial variability of rainfall, is presented. It is based on the application of the TOPMODEL and SCS equations at the square cell scale (1 or 4 km^2), and the integration of the generated runoff using a conceptual Unit Hydrograph derived from the cell location into the simplified drainage system of the basin.

A calibration process using the available distributed data is used to fit the model. When possible, processed radar pictures are used as the best rainfall field estimates.

The results in the Besos catchment show the importance of using radar information to improve flow reconstitutions and to achieve better model adjustments.

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References

Beven, K., and M.J. Kirkby, 1979, A physically-based variable-contributing area model of basin hydrology, *Hydrol. Sci. Bull*, *24* (27-53), 27-53.

Beven, K., R. Lamb, P. Quinn, R. Romanowicz, and J. Freer, 1995, TOPMODEL, in *Computer models of watershed hydrology*, edited by V.P. Singh, pp. 627-668, Water Resour. Publ., Littleton, CO (USA).

Chow, V.T., D.R. Maidment, and L.W. Mays, 1988, *Applied Hydrology*, 572 pp., McGraw-Hill, Singapoore.

Duchon, J., 1976, Interpolation des fonctions de 2 variables suivant le principe de la flexion des plaques minces., *Rev. Automat. Inf. Rech. Oper.*, *10* (12), 5-12.

Garrote, L., and R.L. Bras, 1995, A distributed model for real-time forecasting using digital elevation models, *J. Hydrol.*, *167*, 279-306.

Hermida, J., and D. Sempere Torres, 1997, A rainfall-runoff model to use spatial fields in Mediterranean basins, in *WMO-INM International Conference on cyclones and hazardous weather in the Mediterranean area*, pp. 101-106, Instituto Nacional de Meteorología, Palma de Mallorca.

Marshall, J.S., and W.M. Palmer, 1948, The distribution of raindrop with size, *Journal of Meteorology*, *5*, 165-166.

McCuen, R.H., 1982, *A guide to hydrologic analysis using SCS methods*, 110 pp., Prentice-Hall.

Nash, J.E., 1957, The form of instantaneous unit hydrograph, *Hydrol. Sci. Bull.*, *3*, 114-121.

Rosenbrock, H.H., 1960, An automatic method for finding the greatest or least value of a function, *Comput. J.*, *3*, 175-180.

Sánchez-Diezma, R., D. Sempere-Torres, G. Delrieu, and I. Zawadzki, 2001, An Improved Methodology for Ground Clutter Substitution Based on a Pre-Classification of Precipitation Types, in *30th International Conference on Radar Meteorology*, Munich, Germany, 19—24 July 2001. (*This volume*).

Sempere Torres, D., C. Corral, P. Malgrat, and J. Raso, 1999, Use of weather radar for combined sewer overflows monitoring and control, *J. Env. Eng.*, *125* (4), 372-380.