Flood modelling in river basins with highly variable runoff

5th EGU Leonardo Conference – Hydrofractals 2013 – STAHY '13, Kos Island, Greece, 17–19 October 2013

E.-M. Michailidi, Th. Mastrotheodoros, A. Efstratiadis, A. Koukouvinos, & D. Koutsoyiannis

Department of Water Resources & Environmental Engineering, National Technical University of Athens, Greece (http://itia.ntua.gr/1385/)

1. Abstract

In the Mediterranean there are numerous small to medium-scale basins that exhibit highly-variable runoff, intermittent or ephemeral. Typically, these are affected by flash floods, for which effective modelling is more difficult than in large basins with permanent runoff, as shown in two representative catchments in Greece and Cyprus. First we employ the widespread SCS-CN method with a synthetic unit hydrograph, whose parameters are calibrated against a number of observed flood events, which generally fails to reproduce the observed hydrographs. Next, we test different modelling structures, using conceptual tanks to represent the storage and interflow processes, which are dominant in all types of basins. The significant variability of the optimized parameter values reflects the complexity of the involved processes. In addition, it reveals the crucial role of flood measurements, in order to build realistic models and provide consistent estimations of the related uncertainties.

2. Study basins and their characteristics

Study basins are Sarantapotamos (Eastern Greece, 144.6 km^2) and Peristerona (Cyprus, 77.0 km^2). Semi-arid climatic conditions prevail in both areas, yet these basins exhibit substantially different hydrological behaviour, due to their geological characteristics. Sarantapotamos basin has ephemeral flow, since it is underlain entirely by limestone and dolomite, which strongly favour deep percolation instead of runoff. Peristerona basin is mainly underlain diabas and basalt (parts of Troodos ophiolite), as well as agricultural uses, which favor surface runoff. Although the flow regime is intermittent, floods with significant peak flows (the highest in Cyprus) often occur.

3. Validation of SCS-CN & SUH approach

The combined SCS-CN and synthetic unit hydrograph (SUH) approach is of the most typical flood design method. Its key assumption is the dominance of overland flow, while soil moisture accounting is not explicitly represented.

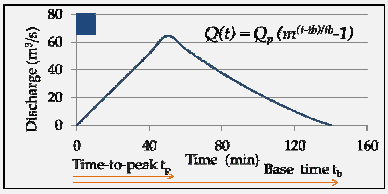

Fig. 1: Outline of the parametric SUH.

In order to validate this method in the two study basins, we developed a parametric SUH, with a single parameter that expresses the time to peak as percentage of the time of concentration, as estimated by the Giandotti formula (6.5 h for Sarantapotamos, 3.5 h for Peristerona). The model parameters were calibrated against each flood event to ensure the closest, in terms of volume and peak flow, fitting to the observed hydrographs (7 in Sarantapotamos and 17 in Peristerona). The entire computational procedure was implemented in Matlab. As shown in Fig. 2, the method generally failed to represent the observed events.

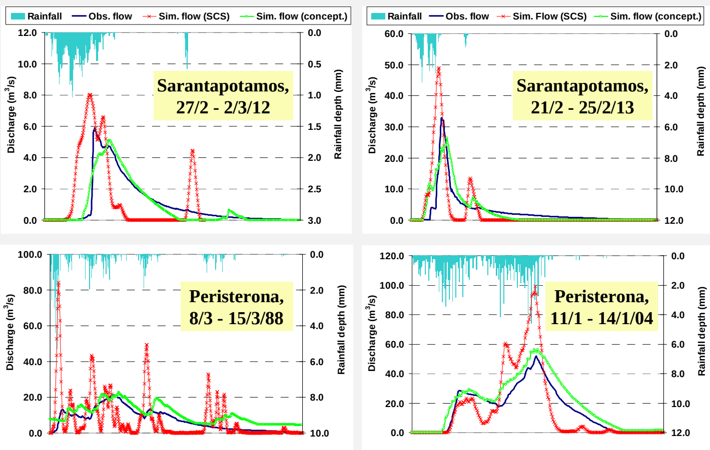

Fig. 2. Simulated (with the SCS-CN & SUH method as well as the conceptual tank model) vs. observed hydrographs and corresponding rainfall, for characteristic flood events in Sarantapotamos (upper charts) and Peristerona (lower charts).

4. Conceptual modelling

In order to represent the soil processes we tested alternative models of hydraulic analogues. The final version comprises two interconnected tanks that represent the unsaturated (upper tank) and saturated (lower tank) zones, with capacities K_1 and K_2, and initial soil moisture storage S_{01} and S_{02}, respectively. Three recession parameters are applied, i.e. l_1 and l_2, which control interflow and baseflow (horizontal flows), and m, which controls percolation (vertical flow from upper to lower tank).

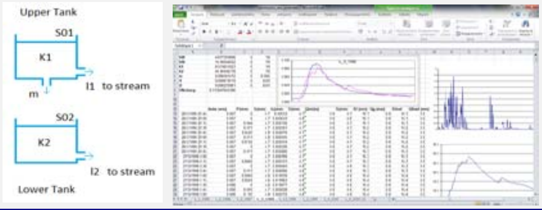

Fig. 3: Graphical representation of model structure and parameters (left) and its implementation to a spreadsheet interface (right).

5. Statistical analysis of parameters

For each flood event in Peristerona we carried out multiple calibrations, since we found that quite different parameter sets (e.g., Table 1) exhibit similarly good performance (Fig. 2).

Table 1: Five "equifinal" parameter sets for the flood event of 3/1988 in Peristerona.

	Set 1	Set 2	Set 3	Set 4	Set 5
K_1 (mm)	52.9	43.0	45.7	37.9	45.9
K_2 (mm)	27.4	37.0	40.6	37.1	35.8
m	0.0010	0.0012	0.0012	0.0012	0.0011
l_1	0.0140	0.0150	0.0154	0.0143	0.0148
l_2	0.0052	0.0060	0.0050	0.0060	0.0060
Efficiency	0.809	0.813	0.809	0.810	0.813

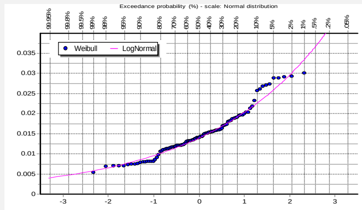

Fig. 4: Statistical analysis for parameter l_1.

Next, we fitted a suitable theoretical statistical distribution to each sample of parameter values (100 values, in total) that correspond to multiple "equifinal" sets over all simulated events (Fig. 4).

6. Monte Carlo simulation

For the 17 flood events in Peristerona, we generated 10 000 synthetic parameter sets from the corresponding statistical distributions, and next we applied the tank model to obtain 10 000 synthetic hydrographs. We examined two cases, with constant and random initial conditions. At each time step we calculated the mean flow and several quantiles (0.5, 2.5, 5.0, 95.0, 97.5, 99.5%).

In general, the mean flows are close to the observed ones, while the initial conditions slightly only affect the results of the MC procedure. In all but two events the actual flows are within the envelopes 2.5 and 97.5%.

Characteristic examples are shown in Fig. 5. In the upper graph, the mean discharge almost matches the actual one, while in the middle and lower graphs the mean discharge under- and overestimate the actual flows.

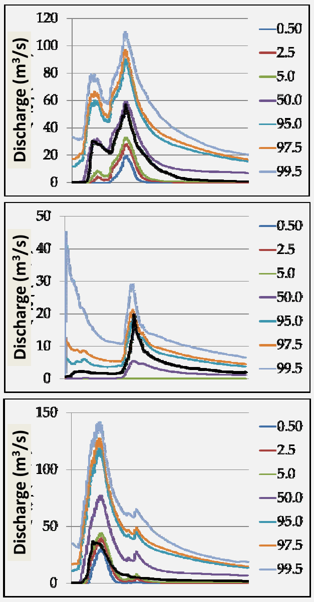

Fig. 5: Observed hydrographs and characteristic quantiles of simulated flows.

7. Conclusions

- The widely used SCS-CN & SUH approach, even with calibrated parameters, cannot represent the flood regime of small semi-arid Mediterranean catchments, where interflow is the dominant process.
- Parsimonious conceptual models based on hydraulic analogues are much more flexible for representing complex flood regimes.
- Model parameters should be treated as random variables, since they exhibit significant variability across different events, and also for different setups of the calibration problem (due to equifinality).
- Monte Carlo simulation is a powerful technique to deal with uncertainty, which is present in all aspects of flood modelling.