Role of spatial aggregation over runoff calculations on southeast France catchments

NABIL J. EID[1,2], FLAVIE CERNESSON[2], NATHALIE FOLTON[3] & PASCAL KOSUTH[2]

1 *Depto. Eng. Civil e Ambiental/FT/UnB, 70910-900 Brasília-DF, Brazil*
njeid@unb.br

2 *UMR TETIS Cemagref, ENGREF-CIRAD, Maison de la Télédétection, 500 rue JF Breton, 34093 Montpellier Cedex 5, France*

3 *UR Ouvrages Hydrauliques et Equipements pour l'Irrigation, CEMAGREF BP31, Le Tholonet, 13612 Aix on Provence Cedex 1, France*

Abstract The paper investigates the catchment area extension calculations as a function of the adopted spatial resolution and the effect of these spatial resolutions on the runoff calculations, for a number of catchments. Calculations were done with hypothetical and constant amounts of precipitation over space. Adopted grid size varied from 3000 to 2 m. Area estimate errors were computed in respect to 2 m grid resolution and the SCS method used for excess precipitation calculations. Results have shown that 75% of the catchments have errors of <15% of its area at any resolution and that the surface estimation errors are < ±1% for a 200 m spatial resolution. For any catchment effective precipitation presented, small variations occurred when 300 m spatial resolution was used and at 100 m spatial resolution almost no variations were observed.

Key words Corine Land Cover; French Mediterranean catchments; SCS; spatial resolution

INTRODUCTION

The ability of Geographical Information Systems to handle spatial data and the current extended storage and processing ability of personal computers make it very easy to refine grid size with almost no additional requirements. The advantages or disadvantages of the grid choice are still objects of discussion in different scientific scopes. On water resources these discussions lead with volumes or peak discharge generated on the catchments.

When a spatial resolution is adopted to accomplish geographical operations requested by a simulation model, the choice of this spatial resolution introduces errors on the results associated with the catchment surface estimations.

Burian *et al.* (2002) compared different data sets of land cover with different spatial resolutions at three urban catchments in the USA to investigate the relative difference in annual runoff volumes. For the three catchments, the errors varied from 8 to 14%, but no relationship with the catchment size could be established.

The analysis by Yang *et al.* (2001) to evaluate the spatial resolution sensitivity of 15 catchments in Japan ranging from 464 to 3049 km^2 was based on thresholds areas for the river network definition. River networks were extracted from various resolutions of digital elevation model (DEM). The original DEM used has 250 m resolution. Two others resolutions were generated: 500 m and 1000 m. When a single

DEM is analysed, they found that the river network generated with larger threshold area tends to loss of the detailed scaling information. Also, increasing the DEM mesh size leads to losing the detailed scaling information in a catchment. For the runoff analysis, only tendencies could be identified, leading to a decrease of the total runoff with increasing coarseness of the DEM grid size.

Booij (2005) brings a similar focus to the question. In his work, a Swedish hydrological model was evaluated for three different spatial resolutions aiming to represent the Meuse River basin (surface area about 20 000 km^2) in western Europe. The three spatial resolutions resulted in model schematizations, based on DEM, with thresholds that resulted on 118, 15 and 1 (sub-) basins. Average and extreme discharges were well reproduced by the three discretizations in calibration and validation. The results become somewhat better with increasing model resolution.

The behaviour of spatial resolution in distributed hydrological modelling was investigated by Shrestha *et al*. (2003) evaluating the ratio between catchment area and input data resolution. Test simulations were conducted on two catchments in China for discharge simulation. Results showed a rapid improvement of model results with finer resolutions.

The present paper reflects the discussion presented by Schumann & Geyer (2000): if the hydrological model used is unable to differentiate in its output between area elements, it seems unnecessary to differentiate between them in the model resolution. The concept of entropy is the way suggested by Schumann & Geyer to do this kind of differentiation between grid cells.

In this work, 97 independent watersheds were submitted to one single precipitation event and the SCS CN model was applied. Different grid spatial resolutions were superposed to the catchment boundaries and to the soil cover defined by the so-called Corine Land Cover (CLC). The original CLC scale was defined by means of the least detectable surface. This was taken as 25 ha (IFEN, 1988).

OBJECTIVES

Our analysis had two targets. The first one is evident and leads with the influence over the catchment surface. Border effects are evaluated by means of the computed surface when different grid sizes are superimposed since a fixed origin X–Y reference axes. The second one deals with each class of land cover surface, determined using different grid sizes, and how much these grid sizes influence the runoff calculated by means of the SCS model for a uniform rainfall over any studied catchment.

MATERIALS AND METHODS

Independent catchments were selected. The catchment boundaries employed on this evaluation came from a digital vector map. This map has been reprojected to the Lambert II Extended projection system (related to the whole of France). This is the same projection system for the CLC product, also in a vector digital format (IFEN, 1988). In Fig. 1(a), the green polygons represent classes at CLC level 3 mapping, positioned in the French Mediterranean area. The 97 basin boundaries are superimposed on the CLC polygons and represented in grey scale polygons. Figure 1(b) shows the 97 catchments and the respective class 3 CLC land cover.

(a)

(b)

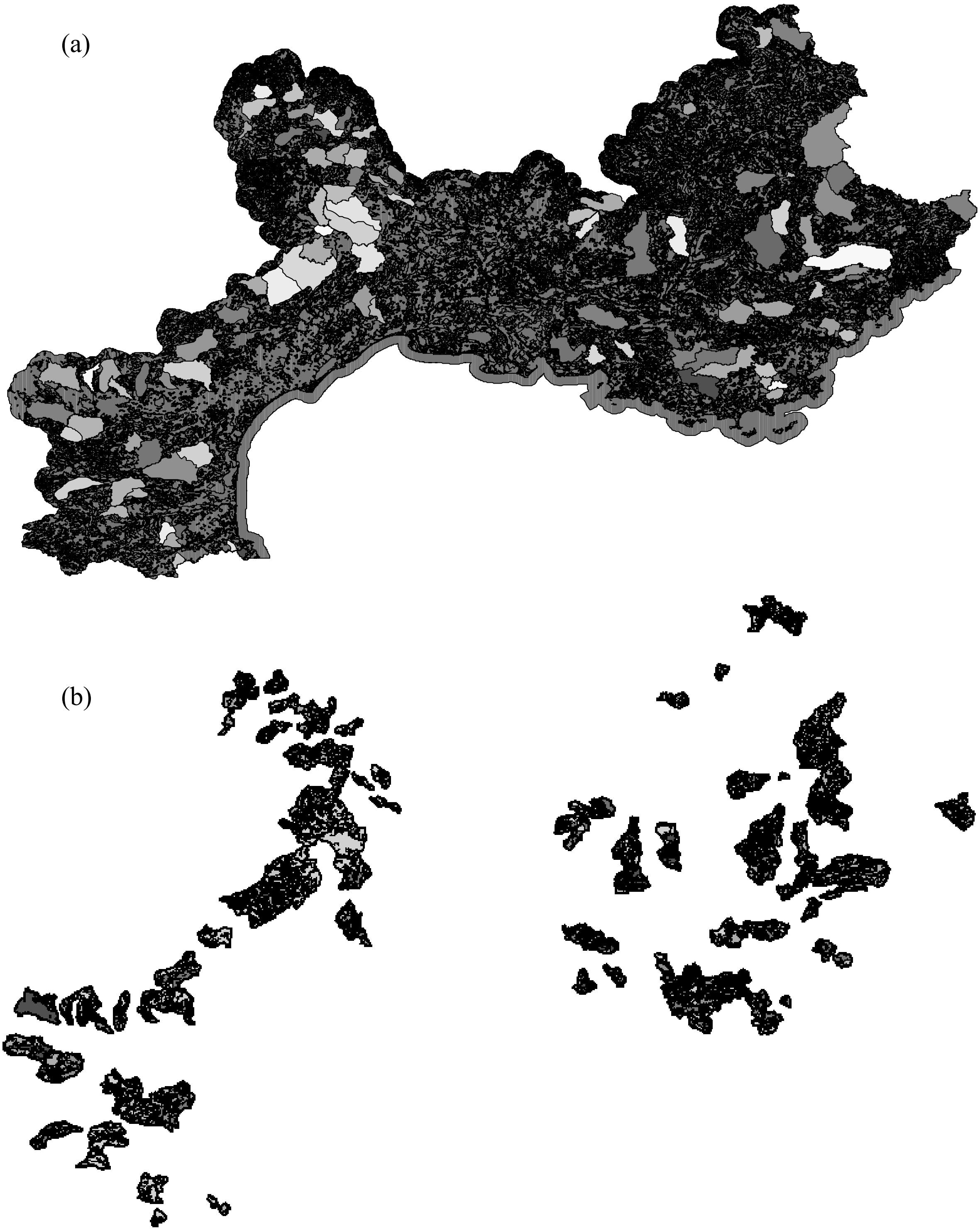


Fig. 1 97 watersheds and the CLC; (a) CLC for the French Mediterranean region; and (b) CLC on the 97 basins.

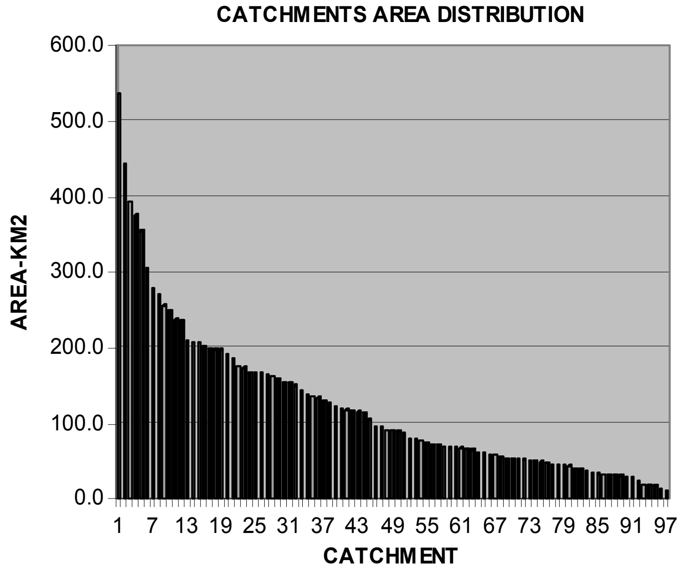


Fig. 2 Catchment area distribution.

Catchments areas varied from 10.55 to 536.60 km^2 , with a mean of 122.84 and standard deviation of 99.87 km^2. The catchment size distribution is represented in Fig. 2.

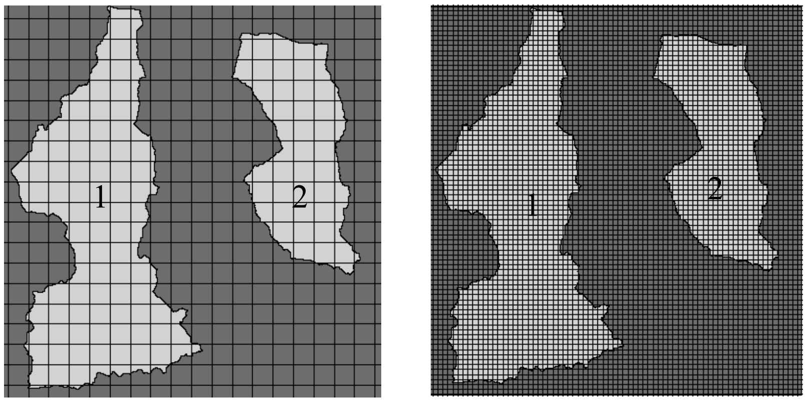
Thirteen spatial resolutions have been adopted to evaluate the influence over the effective rainfall calculated with the SCS model: 3000, 2000, 1000, 500, 400, 300, 200, 100, 50, 20, 10, 5, and 2 m. The 2 m limit was due to the software and hardware, 32 bits limitation concerning the complete surface area.

To maintain the same origin a fixed window with all the catchments has been displayed. From the origin and axes defined by this way, grids with the stipulated size were superimposed onto the CLC and catchments boundaries layers. The 97 catchment polygons had their surfaces tabulated by land cover for each grid size. The sum of the CLC classes present on each catchment defined its total surface, variable with the spatial resolution. Figure 3 presents the grid superposition over two of the catchments and shows the estimated surface of two catchments for two different grid sizes.

RESULTS

Relative errors on surface areas were calculated for reference areas (2 m spatial resolution). The worst value was observed for a 40 km^2 catchment which reached almost 50%. The third quartile was selected to summarize the distribution of the errors, indicating that 75% of the catchments have an error of <15% for all resolutions. The errors drop very fast when refining the spatial resolution. Figure 4 presents the relative errors for selected groups of catchments.

Figure 5 shows the successive surface area differences between the finest adopted spatial resolutions. Stabilization of the computed surface converges quickly and the differences from the 200 m to 100 m estimates are 1 km^2. For the 97 catchments analysed, the 2 m spatial resolution is admitted as the truth, and almost no differences



2000 m grid
Surface1 = 352.00 km^2
Surface2 = 184.00 km^2

500 m grid
Surface1 = 351.25 km^2
Surface2 = 175.50 km^2

Fig. 3 Two grid sizes superposed over two catchments.

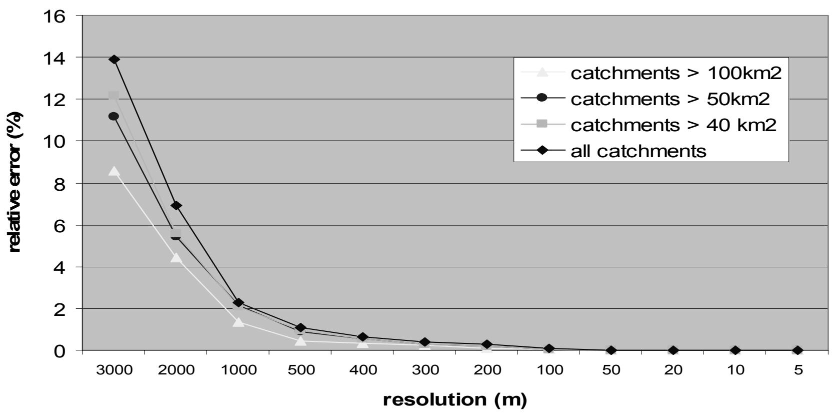


Fig. 4 Relative errors for the third quartile related to spatial resolutions.

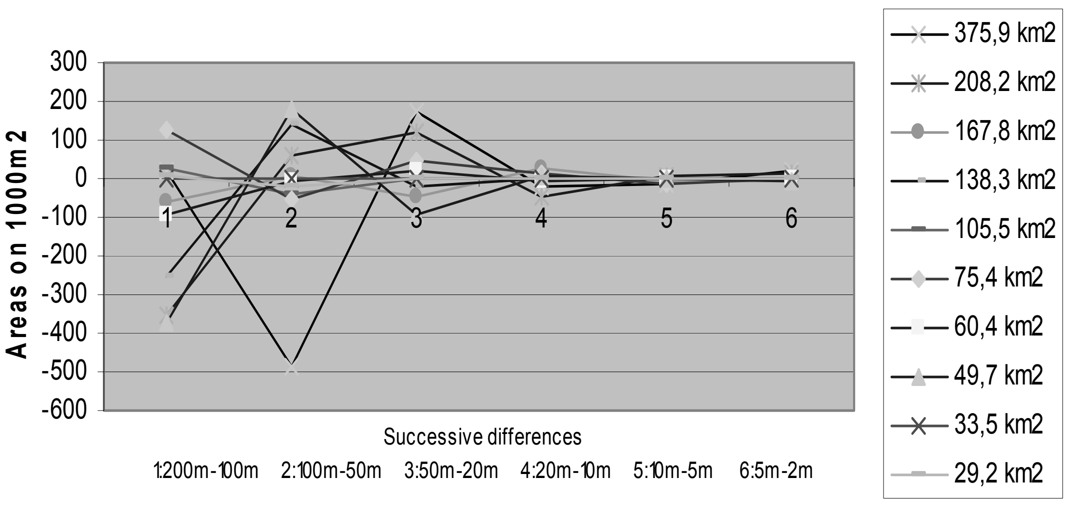


Fig. 5 Differences on computed area with successive spatial resolutions on selected catchments.

can be observed between the 5 and 2 m spatial resolutions. For the selected group of catchments Fig. 5 shows that the expected error on the surface estimations are less than ±1% for a 200 m spatial resolution. The same can be said for all other catchments.

The calculated values came from a procedure like the rasterization of a vector map. They are not the result of a DEM manipulation, which can take with different conclusions. The work of Armstrong & Martz (2003) can be used to evaluate the grid aggregation of DEMs.

To test the SCS model a hypothetical 80 mm precipitation, distributed uniformly in time and space over any of the catchments was considered. Hydrological soil group C and AMC class II were considered for all catchments.

The relationship between CLC class 3 land cover and the CN values has been done by means of Table 1. The table values have not been verified for hydrological sound

Table 1 Relationship between CLC class 3 and CN values.

CLC class 3	Class Description	CN value
111	Continuous urban fabric	95
112	Discontinuous urban fabric	85
121	Industrial or commercial units	91
122	Road and rail networks and associated land	98
124	Airports	98
131	Mineral extraction sites	89
132	Dump sites	89
133	Construction sites	89
142	Sport and leisure facilities	85
211	Non-irrigated arable land	88
221	Vineyards	88
222	Fruit trees and berry plantations	78
223	Olive grows	82
231	Pastures	86
241	Annual crops associated with permanent crops	88
242	Complex cultivation patterns	75
243	Land principally occupied by agriculture, with significant area	75
244	Agro-forestry areas	75
311	Broad-leaved forest	70
312	Coniferous forest	75
313	Mixed forest	72
321	Natural grassland	65
322	Moors and heathland	82
323	Sclerophyllous vegetation	82
324	Transitional woodland-shrub	82
331	Beaches, dunes, and sand plains	0
332	Bare rock	100
333	Sparsely vegetated areas	89
334	Burnt areas	89
335	Glaciers and perpetual snow	100
411	Inland marshes	100
412	Peat bogs	65
512	Water	100

use. Values in the Table have been arbitrated by the authors in order to give numerical sense to the CLC class 3 land cover for the SCS model.

Effective precipitation calculations for each catchment and spatial resolution were done as follows: (a) for each catchment the CLC vector map has been clipped at catchment boundaries; (b) a fixed origin of any desired spatial resolution grid has been superimposed to both catchment boundaries and clipped CLC vector maps; (c) the number of grid cells for each land cover has been tabulated for each catchment; (d) effective precipitation has been calculated according to the SCS model and Table 1 associations for each of the land covers; (e) the overall catchment effective precipitation has been calculated, weighting the values computed on; (d) by the respective fraction of grid cells respect the total number of grid cells on the catchment and adding these values.

The results presented in Fig. 6 shows that for low spatial resolutions the variations on the effective precipitation for a generic catchment are quite important, and for 300 m spatial resolution only slight variations on effective precipitations can be seen. At 100 m spatial resolution, it can be considered that a steady condition has been reached for all catchments.

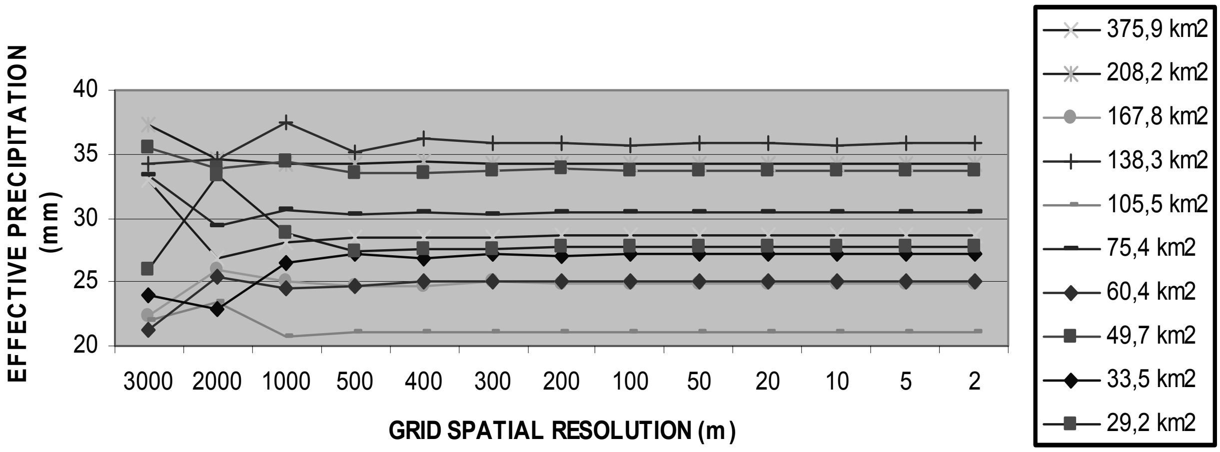


Fig. 6 Effective precipitation calculated for different spatial resolutions on selected catchments.

CONCLUSIONS

- The analyses of the evolution of the estimated area and of the effective precipitations are coherent for the studied range of catchment area: 10–500 km^2. Deviations that are more important are expected at smaller catchment sizes.
- From 300 to 200 m spatial resolution, the error on the choice of the grid can be less important than the error for the definition of the catchments boundaries.
- Surface estimates stabilization can be achieved only with very fine resolutions.
- Consideration of land cover description according to spatial resolution is taken account of by the model predictions but not specifically studied on this paper. It is necessary to analyse it for a better knowledge of the scale issues.

Acknowledgement To the French-Brazilian Cooperation (Project CAPES-COFECUB 474-04) for the support given.

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