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# Regionalization in surface runoff and soil erosion risk evaluation

**C. RENSCHLER, B. DIEKKRÜGER**
*Geographische Institute der Universität Bonn, Meckenheimer Allee 166, D-53115 Bonn, Germany*
e-mail: renschler@uni-bonn.de

**C. MANNAERTS**
*International Institute for Aerospace Survey and Earth Sciences (ITC), PO Box 6, 7514 AE Enschede, The Netherlands*

**Abstract** The Agricultural Non-Point Source Pollution Model (AgNPS) and the Revised Universal Soil Loss Equation (RUSLE) were used as tools to predict spatial and temporal variability in surface runoff and soil erosion risk. The distributed model AgNPS allows the spatial evaluation of runoff and soil loss for single storm events. The Integrated Land and Water Information System (ILWIS) was used in a GIS-model link to determine and handle the distributed model input and output of AgNPS. This paper focuses on the regionalization of topographic input parameters and the application of the AgNPS hydrological model for six different spatial resolutions ranging from 200 m to 1 km. The test area is the 211 km$^2$ Guadalteba River basin located in the province of Malaga, Spain. This drainage basin was chosen because there is much surface runoff and soil erosion in this region.

## INTRODUCTION

Since the Universal Soil Loss Equation (USLE) was developed by Wischmeier & Smith (1958), the USLE and modified versions such as the Revised Universal Soil Loss Equation (RUSLE) by Renard *et al.* (1991) have been widely used as tools for predicting soil erosion in many parts of the world. The application of the empirical USLE for other regions has rarely been validated in a satisfactorily scientific way and is therefore still a controversial subject among scientists. But USLE components are also found in deterministic hydrological models, such as the Agricultural Non-Point Source Pollution Model (AgNPS) for predicting surface runoff, erosion and water quality developed by Young *et al.* (1989). This spatially distributed model allows the prediction and evaluation of runoff and soil loss for single storm events and a regional estimation of erosion and sedimentation based on a raster of different grid sizes. The definition of the optimum grid size, the determination of variables within these grid cells, and the effects on the grid oriented model AgNPS is discussed in this paper (see also Braun *et al.*, 1996; Grunwald, 1997). The model input and output are handled with the Integrated Land and Water Information System (ILWIS) developed by the International Institute for Aerospace Survey and Earth Sciences ITC (Meijerink *et al.*, 1988).

## STUDY AREA

The study area (37′N, 5′W) is located 100 km northwest of Malaga in the region of Andalucia, Spain (Fig. 1). The Guadalteba drainage basin is a part of the Guadalhorce River basin, which drains southwards to the Mediterranean Sea. The study area covers 211 km$^2$, and varies in altitude from 1430 m a.m.s.l. down to 368 m a.m.s.l. at the maximum level of the Guadalhorce reservoir. Annual precipitation varies strongly with an average of 472 mm (Conde Guadalhorce station, 1950–1993) and has reached extremes from 224 mm (hydrological year 1983) up to 1195 mm (1990). Monthly precipitation amounts also vary markedly and indicate a typical Mediterranean climate of a warm, dry season from May to September followed by a cool, wet season from October to April.

The analysis of precipitation data is based on eight weather stations (Fig. 1) with daily and hourly observations, and shows a significant correlation of elevation and long-term annual precipitation. Both sided Mann-Whitney tests based on hourly measurements, have shown that the distribution of event-based energy-intensities and maximum 1 h intensities observed for all erosive storm events are highly correlated between four of the five stations and belongs therefore to the same origin (Conde G./19 years/175 erosive events; Cuevas/6 years/56, El Burgo/5 years/37; Almargen/2 years/24). A landscape analysis using terrain mapping units and the field

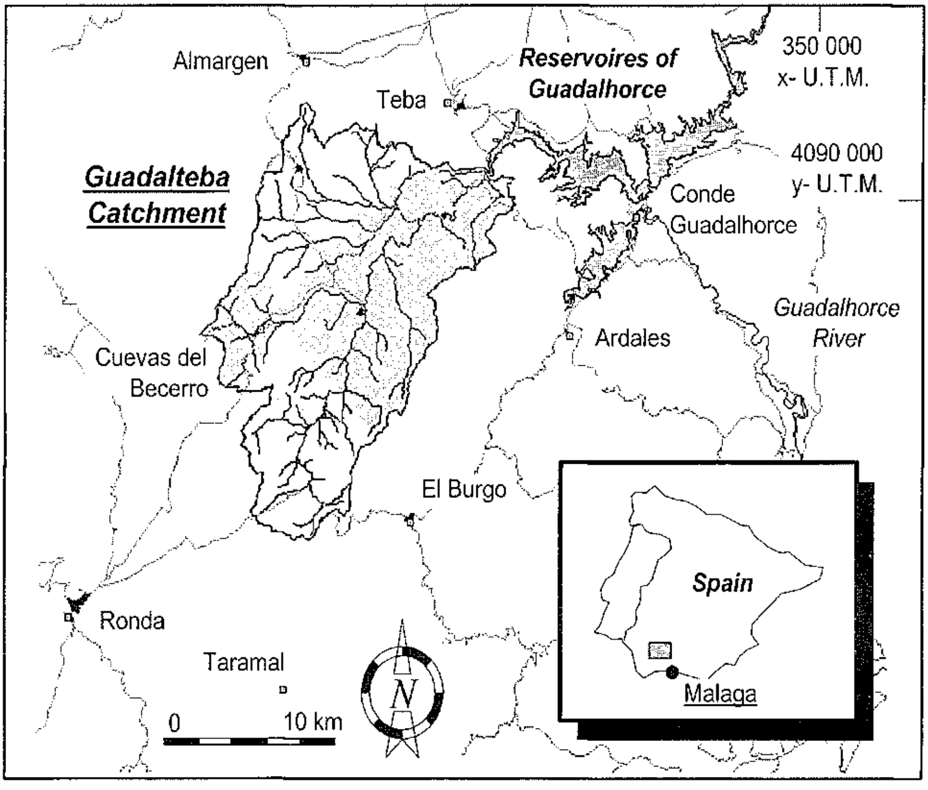

**Fig. 1** Location map of Guadalteba drainage basin and weather stations (▫) in the Province of Malaga, Spain.

soil texture, showed a strong relationship between the lithology, the geomorphology and the soils in the area. Taking into account that similar soil genesis has taken place on the same lithologic units in the Guadalteba basin, the soil type distribution was based on six lithologic units found in the area: Triassic and Jurassic limestone, Cretaceous Capas Rojas (reddish limestone), Tertiary clayey and sandy Flysch, Neogene and Quaternary deposits. Multi-spectral and temporal remote sensing (three LANDSAT TM 1990/1991), with ground truth observations of selected test areas in the field, enabled differentiation between eight vegetation and land use types by a maximum likelihood method: durum wheat, other crops in crop rotation with durum wheat, orchards, shrubs and woodland, grassland, rock outcrops, settlements and unclassified areas.

## METHOD AND DATA PREPARATION

The Revised Universal Soil Loss Equation (RUSLE) in combination with the Agricultural Non-Point Source Pollution Model (AgNPS) permits the evaluation of seasonal changes in four of the five erosion factors and their influence on soil loss rates: rainfall erosivity, soil erodibility, soil loss ratio and supporting practice factor. The regionalization of the temporal invariant slope length and slope gradient factor representing the topography is described in the following. The data flowchart (Fig. 2) gives an overview of the structure of the ILWIS-AgNPS link used in the spatial erosion risk mapping. Except for the input variables related to rainfall, which are not considered by AgNPS as spatially distributed, all model input parameters and seasonal relevant variables were prepared as raster maps in ILWIS.

For deriving topographic input parameters, the Digital Elevation Model (DEM) capabilities of ILWIS were used. The DEM was based on segment lines describing 20 m contour lines on 1:50 000 toposheets of the Guadalteba area. The contour line segment map was rasterized with a pixel resolution of 10 m and the DEM was calculated by linear interpolation between the two nearest contour lines. The influence of scale when using six different grid sizes showed tremendous effects on the values of the topographic parameters for AgNPS. Table 1 lists the number of cells running AgNPS 4.03 for different grid sizes where the 200 m grid with a total of 5264 cells comprised the maximum number of cells.

The slope length is defined either as the distance on a homogeneous slope needed either for surface runoff to concentrate in rills and channels, or to enter a well defined channel, which may either be part of a natural drainage network or a constructed channel (Wischmeier & Smith, 1978). ILWIS enables the user to derive the field slope length as the distance from each point to the channelled flow of an ephemeral or perennial channel. The upper limit of the field slope length was set to 90 m due to AgNPS limitations and was reduced if the average distance in a grid to a channel was smaller. As grid size decreases, slope lengths smaller than 70 m play a more important role than at larger grid sizes (Fig. 3(a)).

The slope gradient for each pixel in the DEM was determined using the information of the first derivative in the $x$ and $y$ directions of the pixel environment. The square root of the sum of both squared derivatives divided by the pixel size was assumed to be the slope gradient, expressed as a percentage, of each pixel. The average

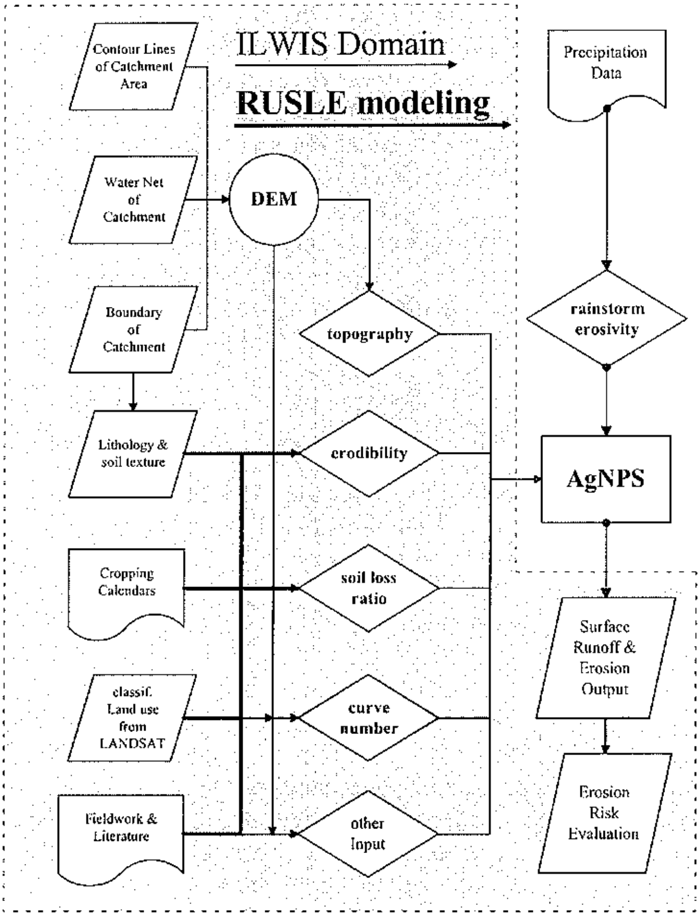

**Fig. 2** Flow chart of ILWIS-AgNPS link for surface runoff and erosion risk evaluation.

**Table 1** Representing drainage basin input characteristics and simulated peak flow results at the outlet cell for six grid sizes.

| Grid size (m) | Raster size (ha) | Total number of cells | Drainage basin area (km$^2$) | Area weighted upland erosion [d] (t ha$^{-1}$) | Area weighted curve number [c] | Area weighted runoff volume (mm) | Peak flow rate [b] at outlet (m$^3$ s$^{-1}$) | Spec. peak flow rate [b] at outlet (m$^3$ s$^{-1}$ km$^{-2}$) |
|---|---|---|---|---|---|---|---|---|
| 200 | 4.00 | 5264 | 210.56 | 5.78 | 73.68 | 11.4 | 147.44 | 0.700 |
| 250 | 6.25 | 3373 | 210.81 | 5.76 | 73.65 | 11.4 | 150.59 | 0.714 |
| 400 | 16.00 | 1323 | 211.68 | 5.61 | 73.13 | 11.2 | 146.68 | 0.693 |
| 500 | 25.00 | 845 | 211.25 | 5.65 | 73.14 | 11.2 | 148.89 [a] | 0.705 [a] |
| 800 | 64.00 | 329 | 210.56 | 5.47 | 72.50 | 10.9 | 157.56 [a] | 0.748 [a] |
| 1000 | 100.00 | 212 | 212.00 | 5.47 | 72.51 | 10.9 | 165.42 [a] | 0.780 [a] |

The scenarios were based on soil moisture conditions corresponding to one week without rainfall and an erosive storm event with a return period of five years (43 mm and 95 MJ mm ha$^{-2}$ h$^{-1}$).

[a] spatial AgNPS simulation validated for cell sizes of 0.4 to 16 ha (USDA-ARS, 1990);

[b] peak flow calculation: AgNPS standard method with non-geomorphic correction;

[c] here arithmetic mean of all cells and not the characteristic curve number for the whole basin;

[d] arithmetic mean of all slopes (also overestimated slopes >30%).

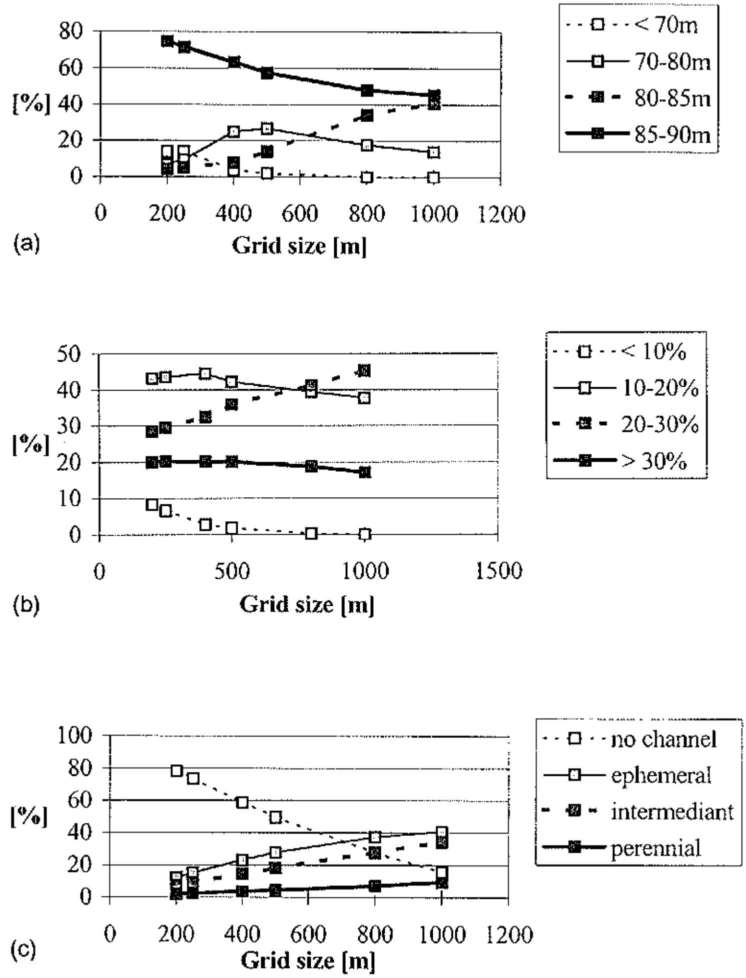

**Fig. 3** Distribution of (a) slope lengths, (b) slope gradients and (c) AgNPS channel indicators as a function of grid cell resolution.

slope gradient in a grid cell was formulated by averaging the slope gradient values of all pixels belonging to a common drainage basin. The calculation of the slope gradients is very important, because the soil losses calculated by AgNPS are highly sensitive to this parameter (USDA-ARS, 1990). In contrast to the slope length, which is less sensitive than every other USLE factor, a 10% error in the slope gradient gives about a 20% error in computed soil loss (Renard *et al.*, 1994). The slope gradient tends to the average slope gradient of the basin with increasing grid size (Fig. 3(b)).

The channel parameters were linked with river orders according to Strahler's scheme. The predominant river order of the two highest orders recognized as present in a cell, was taken as representative for this specific cell. The rivers were assigned as ephemeral streams (first order), intermittent (second and third order) and perennial streams (fourth and fifth order) according to the AgNPS definition. The comparison between the portions of the channel indicators based on different grid sizes has shown that the calculation procedure tends to underestimate the portion of no channel cells with increasing grid size (Fig. 3(c)). This means, with a larger grid size the runoff calculations were performed on the channels and depend more on the channel characteristics than on the field slopes.

To remove the occurrence of scale dependent sink holes in the DEM, newly created advanced calculation procedures in the ILWIS domain (see also Gorte, 1994) were performed on the DEM producing an exact definition of all the flow paths to only one outlet cell. These adapted procedures took into account the scale independent rasterized stream net digitized from the toposheets and the flow directions derived for larger grid sizes. The upstream drainage area for each cell represents flow paths in the basin for different grid sizes (Fig. 4). The larger the cell size, the rougher the stream net is represented for the basin. Stream lines on grid sizes of more than 250 m show erroneous connections to neighbouring streams resulting in errors in the upstream drainage area of neighbouring drainage basins.

The calculation of runoff portion in the AgNPS model is based on the curve number method (USDA-SCS, 1972). To derive a representative curve number (*CN*) for the soil-vegetation-cover-complex of a grid cell, the combination of the dominant lithologic and land use units in a cell were evaluated by a list of classes describing land use treatment or practice with their time variant characteristic hydrological conditions (Rawls & Brakensiek, 1986; USDA-SCS, 1986). The new time developed evaluation system that takes into account the time variance of the antecedent soil moisture is advanced for the conditions in the Guadalteba area and these conformed with previous observations and experiences. As Table 1 shows, the averaged *CN* value for the basin did not change remarkably with the grid size. Therefore the influence of spatial distribution of soil and vegetation information on runoff production due to grid size is negligible. It should be noted that not the average *CN* but the spatial distribution of *CN* was used in simulating the surface runoff with AgNPS.

## SIMULATION RESULTS

The peak flow calculation obtained from the standard AgNPS method (USDA-ARS, 1990) was analysed for a storm event in October with a return period of five years and antecedent moisture conditions which were assumed to be representative for conditions one week after a heavy rainfall period. The simulated peak flow for the outlet cell of the basin increased with larger cell sizes in contrast to a decreasing average runoff volume in the basin (Table 1). This increase is caused by the proportional increase of cells representing channels, in comparison to overland runoff (Fig. 3(c)). The spatial distribution of the area weighted runoff volume and the peak flow simulation results for cells within the basin for larger grid sizes, was highly under or overestimated for some raster cells in comparison to smaller grids. This was caused by the differences in the flow paths and corresponding upstream drainage areas for larger grid sizes (Fig. 4). The aggregation of relief information leads to flow paths cutting through the long narrow hill ranges which actually separate the parallel flow paths in the central northern flat area. These errors in the flow path characteristics cause different spatial distribution in calculated runoff volume and peak flow rates for certain locations, between simulation results of grid sizes larger than 250 m.

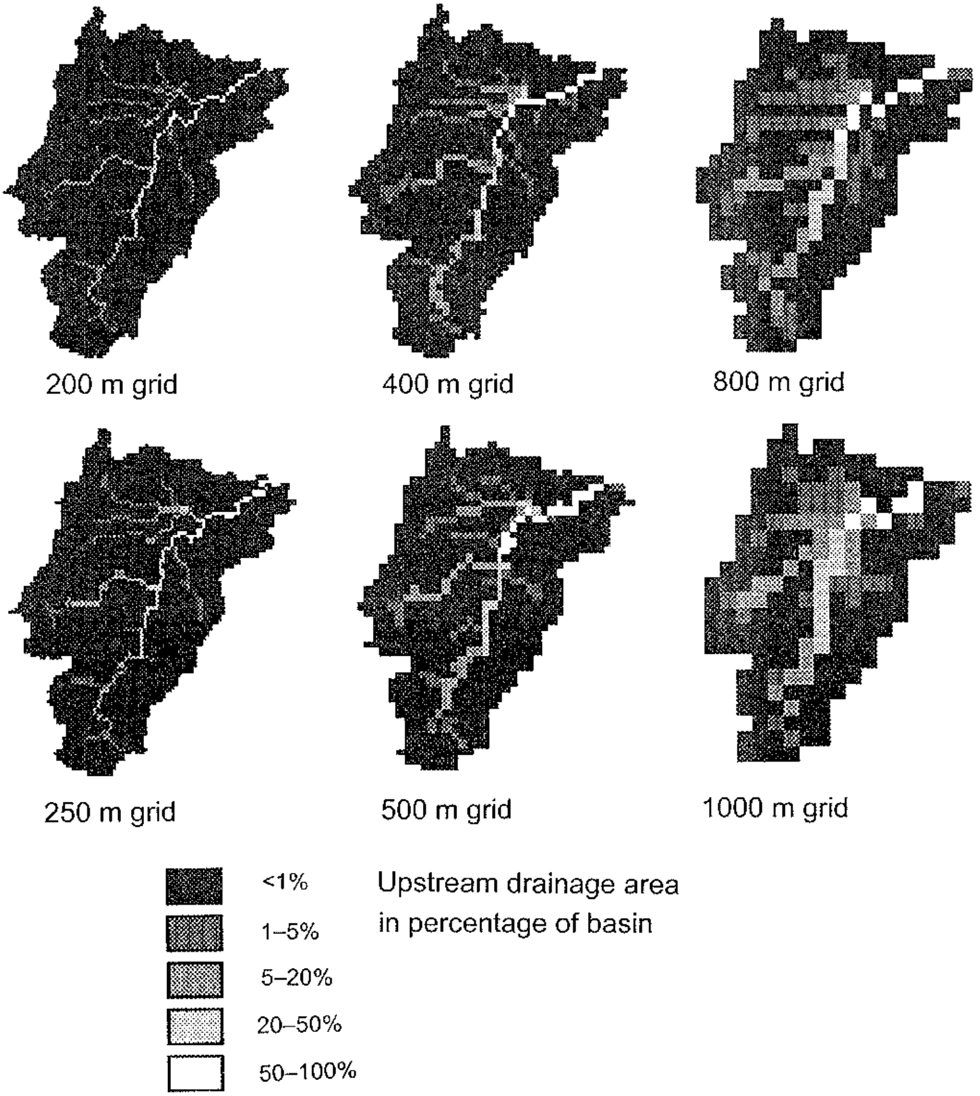

**Fig. 4** Comparison of the upstream drainage area based on six different grid sizes; the upstream drainage area is computed as a proportion of the whole drainage basin (211 $km^2$).

Wischmeier & Smith (1978) described the soil loss tolerance as a value denoting the maximum level of soil erosion that will permit a level of crop productivity to be sustained economically and indefinitely. Schertz (1983) mentioned that the off-site sediment damage on water quality of streams and lakes by eroded soil and sediment fixed nutrients, fertilizer or pesticides, has to be evaluated in respect to soil loss tolerances. Further, an evaluation of the off-site effects of sediments on wildlife and ecosystems is needed. According to tables given by Schertz (1983), the assumption of a soil loss tolerance of about 5 to 10 t $ha^{-1}$ soil loss per year is acceptable for the soils of the Guadalteba drainage basin.

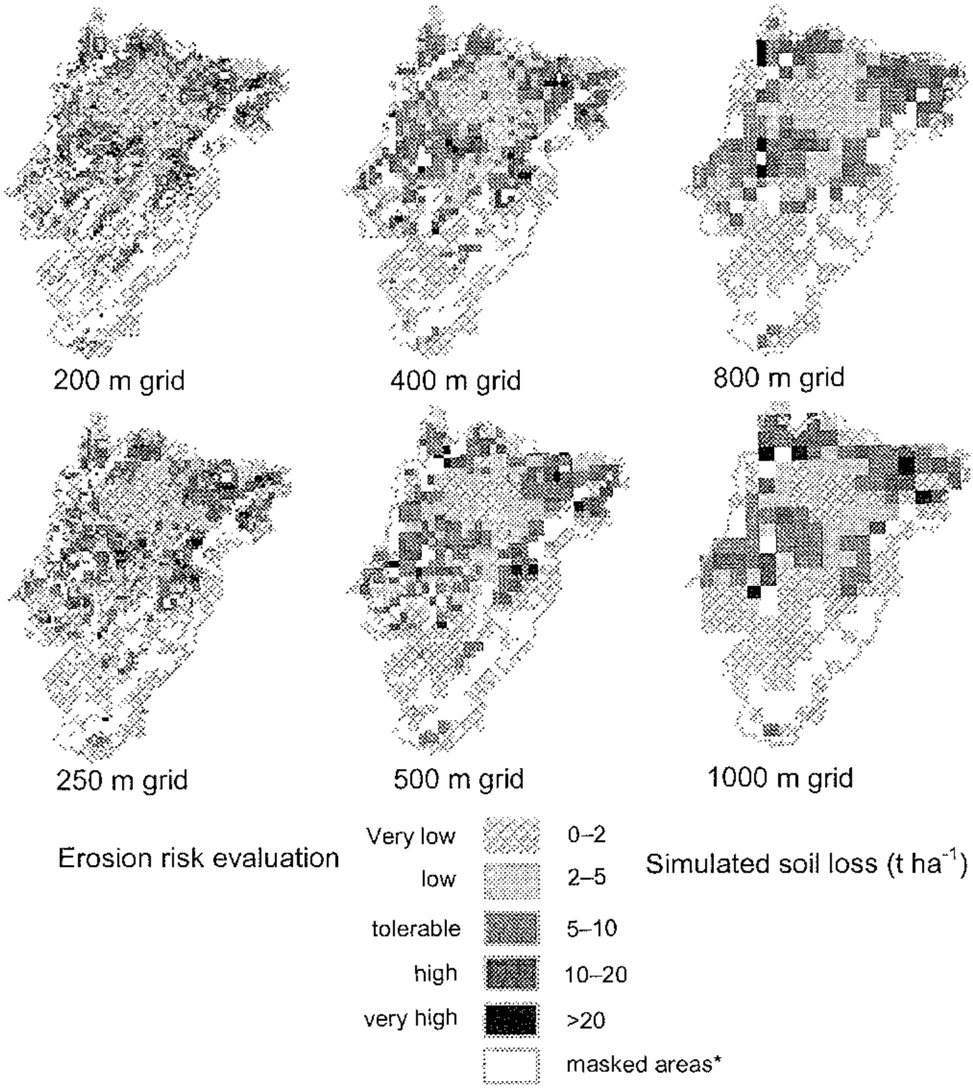

**Fig. 5** Comparison of erosion rates and risk due to different grid sizes calculated for a worst case scenario with the energy-intensity of a 5 year storm event in October (*slope gradients >30% are masked due to over estimation by AgNPS).

On the basis of this tolerable level, the soil erosion losses were computed for each storm event scenario. A durum wheat and sunflower rotation was used for storm events with a five year return period. The simulated averaged upland soil loss due to sheet and rill erosion in the basin varies little with the grid size (Table 1). With respect to spatial distribution, larger grid sizes give a very rough impression of the erosion risk evaluation and differences in soil loss become obvious if the locations of the "hot spots" with an erosion risk of more than 10 t ha$^{-1}$ are compared for different grid sizes (Fig. 5). These relative errors in the location were apparent in all erosion simulations performed for grid sizes equal to or larger than 400 m. Further, the 200 and 250 m grid gave the best localization of each condition in the area.

## CONCLUSIONS

The analysis showed that the performance of the RUSLE-AgNPS-ILWIS-link for a geo-referenced evaluation of erosion and runoff risk for the conditions in the Guadalteba area is promising. The optimum grid size for undistorted simulation results for the whole 211 $km^2$ drainage basin with AgNPS is 200–250 m. The differences between calculated topographical input characteristics were indicated as very low for these grid sizes. Therefore the simulated erosion risk maps for these grid sizes, were assumed to give the best simulation of erosion losses in the area. The inputs relevant to the hydrological model components of AgNPS were determined using scale independent methods. Hydrological simulation results for the outlet were more or less constant for smaller grid sizes, in contrast to spatially distributed results within the basin. The flow paths and upstream drainage areas indicated remarkable changes, especially in the flat areas, for grid sizes larger than 250 m. These caused differences in the simulated spatial distribution of results such as runoff volumes and peak flow rates within the watershed.

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