GENERATION OF A CURVE NUMBER MAP WITH CONTINUOUS VALUES BASED ON SATURATED HYDRAULIC CONDUCTIVITY

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ABSTRACT

The curve number is a hydrological model well-know around the technical and scientific world. One of its limitations are the errors produced by a misclassification of the hydrological soil groups, a variable that defines (among others) the model's parameter. The goal of this article is to minimize this error. For this reason a saturated hydraulic conductivity value has been chosen as a representative value of each soil group. From these averaged values, regression curves for each soil-use complex are defined in order to estimate the value of the curve number parameter. In this way, the curve number parameter does not present step-wise variations between hydrological soil groups but present continuous values from the saturated hydraulic conductivity.

RESUMEN

El número de curva es un modelo hidrológico que se utiliza ampliamente en el mundo técnico y científico. Una de las limitaciones que presenta, y que se minimizan utilizando el método propuesto, son los errores que se producen en la clasificación de una de las variables que definen al parámetro número de curva: los grupos hidrológicos de suelo. Para ello, se ha asignado un valor representativo de conductividad hidráulica saturada a cada uno de dichos grupos de suelo y se han estimado diversas curvas de regresión para las características del terreno que diferencia el modelo. Con estas curvas, el parámetro del número de curva deja de presentar variaciones escalonadas entre grupos hidrológicos para presentar valores continuos a partir de valores de conductividad hidráulica saturada.

Keywords: curve number, saturated hydraulic conductivity, hydrologic soil group, Spain

INTRODUCTION

The curve number is a well-known model developed by the Soil Conservation Service (SCS) of United States in the 1950's decade. Its main objective was to estimate the runoff in small basins with a predominant agricultural land use in order to analyse the influence in hydrological processes of land treatments and changes of land use. Later on, it was adjusted to urban basins and at this moment it is one of the widest applied models in the world. The main reason of this expansion is due to the following characteristics:

- its simplicity (it only depends on one parameter)
- it is guaranteed by an international recognized institution, the SCS (Ponce and Hawkins, 1996)
- it needs very few data and they are easy to obtain

The only parameter that the model needs is called the curve number. Its value ranges from 0 to 100. The lowest numbers are those lands that allow a higher infiltration, while the highest numbers are those ones representing the most impermeable surfaces.

The curve number parameter is defined from different variables: land use, land treatment, hydrologic conditions, hydrologic soil group and antecedent soil moisture condition (AMC). The first four variables are related among them in a tabular way (Table 1) being the curve number values those ones corresponding to medium AMC. If soil moisture conditions are different (wetter or dryer), the following equations 1 and 2 allows to convert this medium curve number to the new condition (Hawkins et al., 1985):

$$NC_I = \frac{NC_{II}}{2.281 - 0.01281 NC_{II}} \qquad (1)$$

$$NC_{III} = \frac{NC_{II}}{0.427 + 0.00573 NC_{II}} \qquad (2)$$

where NC_I value corresponds to the curve number in dry conditions and NC_{III} to the curve number in wet conditions. In this article, this variable is not a goal of research.

In Spain, Témez (1987) adapted the variables that define the curve number to the physical Spanish conditions and available data (table 1). In this research, curve number parameter is estimated from this last table.

LAND USE AND TREATMENT	SLOPE (%)	A	B	C	D
Fallow R	>= 3	77	86	89	93
Fallow N	>= 3	75	82	86	89
Fallow R/N	< 3	72	78	82	86
Row crops R	>= 3	69	80	86	89
Row crops N	>= 3	67	76	82	86
Row crops R/N	< 3	64	73	78	82
Small grain R	>= 3	64	75	84	86
Small grain N	>= 3	61	73	81	84
Small grain R/N	< 3	60	71	78	81
Poor rotation crops R	>= 3	66	77	85	89
Poor rotation crops N	>= 3	64	75	82	86
Poor rotation crops R/N	< 3	63	73	80	84
Dense rotation crops R	>= 3	58	72	81	85
Dense rotation crops N	>= 3	55	69	78	82
Dense rotation crops R/N	< 3	52	67	76	80
Pasture	>= 3	68	78	86	89
Medium meadow	>= 3	49	69	78	85
Dense meadow	>= 3	42	61	74	80
Very dense meadow	>= 3	39	55	70	77
Pasture	< 3	47	67	81	88
Medium meadow	< 3	39	59	75	84
Dense meadow	< 3	30	48	70	78
Very dense meadow	< 3	17	34	67	76

Sparse orchard or tree farm	>= 3	45	66	77	84
Medium orchard or tree farm	>= 3	39	60	73	78
Dense orchard or tree farm	>= 3	34	55	70	77
Sparse orchard or tree farm	< 3	40	60	73	78
Medium orchard or tree farm	< 3	35	55	70	77
Dense orchard or tree farm	< 3	25	50	67	76
Very sparse wood or forest land (trees, brushes, …)		56	75	86	91
Sparse wood or forest land (trees, brushes, …)		46	68	78	84
Medium wood or forest land (trees, brushes, …)		40	60	70	76
Dense wood or forest land (trees, brushes, …)		36	52	62	69
Very dense wood or forest land (trees, brushes, …)		30	44	54	61
Permeable rocks	>= 3	94	94	94	94
Permeable rocks	< 3	91	91	91	91
Impermeable rocks	>= 3	96	96	96	96
Impermeable rocks	< 3	93	93	93	93

Table 1. Curve number parameter adapted to physical Spanish conditions and available data, where R are those crops cultivated following the maximum slope and N are those crops cultivated following contour lines

As table 1 shows, the curve number parameter does not present continuous values among the different soil-land complexes but stepwise values. This means that a mistake in the classification of one of the 4 variables that define the parameter can represent an important error when estimating its value. Its variation will depend on the type of variable that shows the error.

The goal of the present research is to establish a method to estimate a continuous curve number depending on the variation of the hydrological soil groups. To reach it, this last variable must be related to a quantitative soil property: the saturated hydraulic conductivity (K_s).

METHOD

Following, there is a description of the above mentioned method. Firstly, there is a brief description of the method used to estimate the slope and land use and treatment, all of them variables needed to define the curve number. Secondly, the method to classify the soil groups based on saturated hydraulic conductivity and to estimate a continuous curve number parameter is presented. To acquire this, a saturated hydraulic conductivity map of the study area obtained by Ferrer (2002) is used with 1x1 km spatial resolution (figure 1).

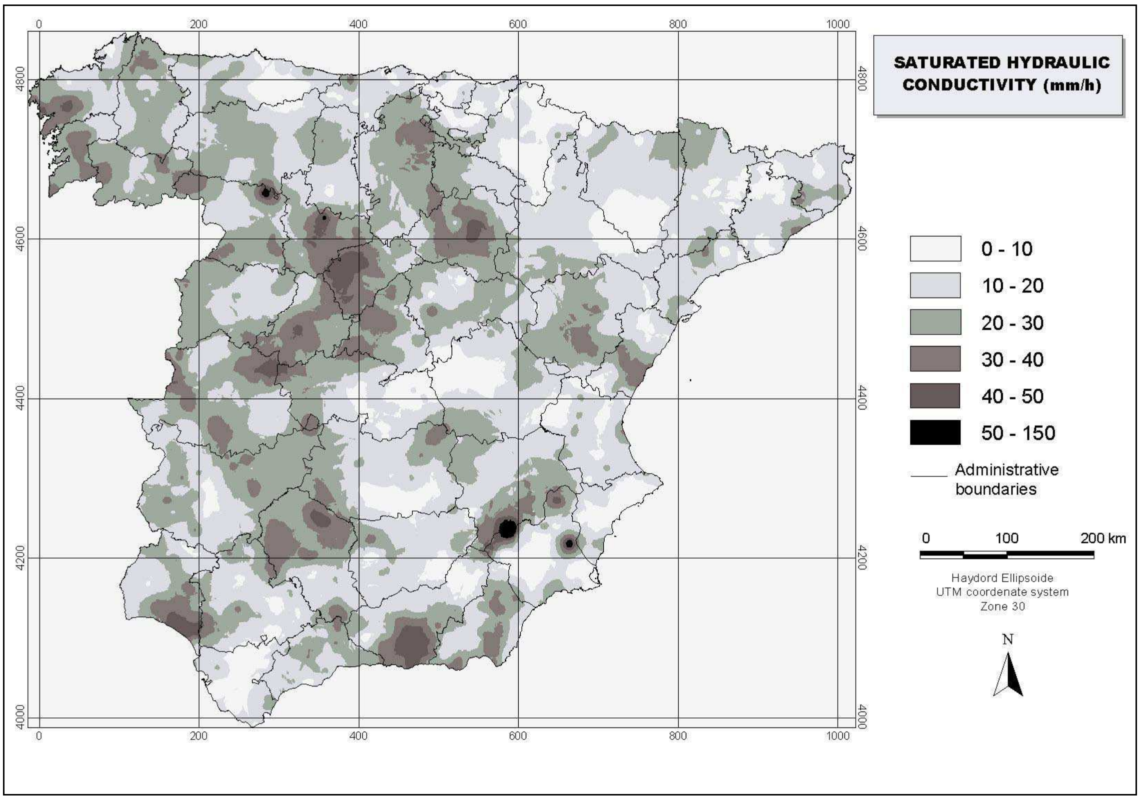

Figure 1.Saturated hydraulic conductivity for the study area with 1 x 1 km spatial resolution

Slope map

The variable of slope is a new variable in the curve number method and was incorporated by Témez (1987) in order to estimate those areas that have terraces as land treatment.

The slope map was derived from a 80 x 80 m spatial resolution DEM available in the Spanish Administration (Centro de Estudios Hidrográficos, CEDEX). It was generated using the 8-neighborhood method (Horn 1981). Afterwards, the map was classified in two groups: those pixels with slope less than 3% and those ones with slope equal or higher than 3% (figure 2) and the resulting map was transformed to a 1x1 km cell size map.

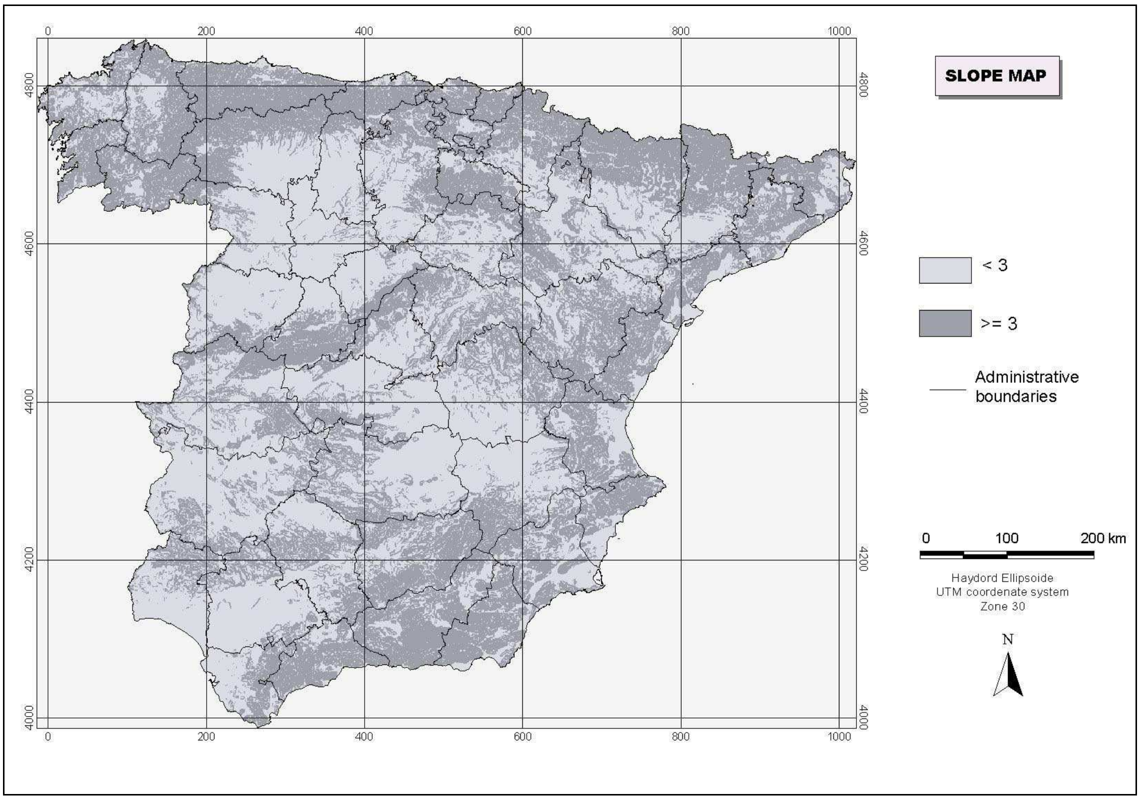

Figure 2. Slope map to estimate the curve number parameter

Land use and treatment map

The land use map was the one generated by CORINE Land Cover project at the beginning of 1990. The equivalences between its legend and curve number land use classes were those ones proposed by Ferrer et al. (1995) and CEDEX (1997) with small modifications (figure 3).

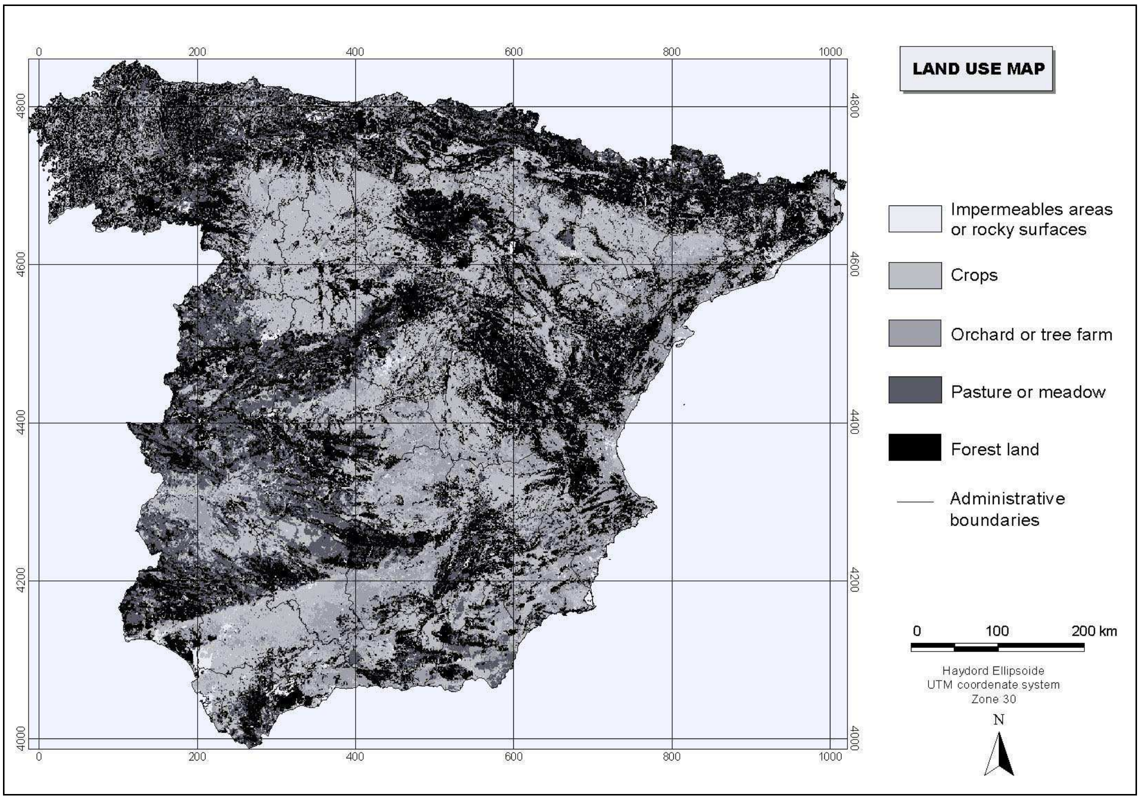

Figure 3. Land use curve number classes for the study area

With respect to the land treatment, due to the extension of the study area it was not possible to analysed it with detail. Therefore, the most often treatment applied has been considered as uniform for all the area: crops cultivated following the maximum slope.

Equivalences between hydrologic soil groups and K_s

Up to now, different authors have established different equivalences between hydrologic soil groups and K_s (table 2).

Hydrological soil group	SCS (1986)	NRCS (1993)	Nearing et al. (1996)
A	7.62 – 11.43	≥ 180	≥ 28.36
B	3.81 – 7.62	18 – 180	2.34-16.74
C	1.27 – 3.81	1.8 - 18	1-7.4
D	0 – 1.27	≤ 1.8	≤ 0.68

Table 2. Equivalences between soil groups and Ks values, based on SCS (1986), NRCS (1993) and Nearing et al. (1996)

As this table shows, there are important differences in authors' criteria. After applying these three equivalences to the K_s map of the studied area, any of the resulting maps presented completely satisfactory data. For this reason new equivalences based in criteria introduced by Spanish soil experts (Porta et al., 1999; Trueba et al., 2000) were established, remaining as table 3 shows.

Qualitative infiltration	*Ks* (mm/h)	Hydrological soil group

Very high	$f_c > 50$	A
High	$20 < f_c \leq 50$	B
Medium	$5 < f_c \leq 20$	C
Low	$1 < f_c \leq 5$	C
Very low	$f_c =<1$	D

Table 3. Proposed equivalences between K_s and hydrologic soil groups

Continuous curve number parameter

Once the intervals of saturated hydraulic conductivity were assigned to each soil group (table 3), a regression curve was estimated for each soil-land use complex described in Table 1. The objective of these curves was to estimate the value of the curve number parameter from K_s data. Thus, the four curve number values of each soil-land use complex were related to the four representative K_s values of each hydrologic soil group (table 4).

Hydrologic soil group	**K_s representative value (mm/h)**
A	50
B	35
C	10
D	0.5

Table 4. K_s representative values (mm/h) for each of the hydrological soil groups, based on the K_s ranges assigned in table 3.

As this table shows, the K_s representative value for groups B, C and D is the mean value of the K_s range assigned in table 3. As in group A there is not upper limit in K_s values, the representative value is its minimum value, 50 mm/h.

In this way, for instance, the regression equation estimated for the *Medium wood or forest land* would be the fitting curve represented in figure 4.

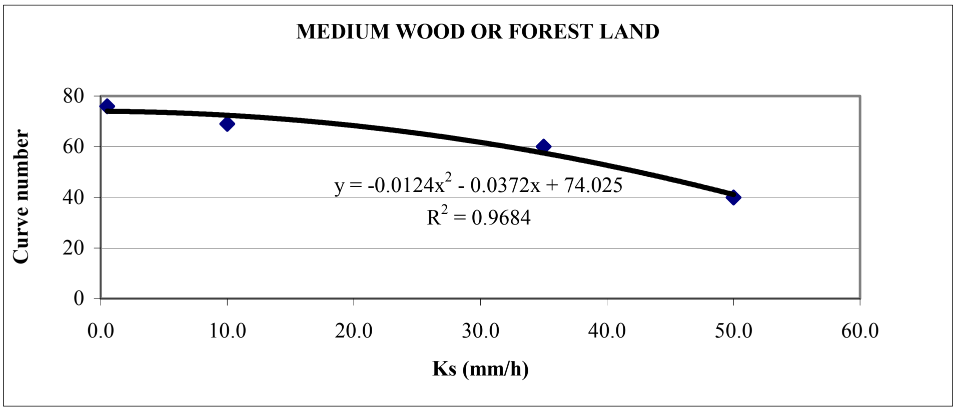

Figura 4. Regression curve representing the relation between the curve number and Ks values in the soil-land use complex "Medium wood or forest land"

All the equations estimated for each soil-land use complex were applied to generate a curve number map, once the maps of the slope and land use maps were overlaid by means of GIS operations.

RESULTS

As table 5 shows, the different regression equations obtained for each land use and treatment and slope give high R^2 values. Their application taking into account the slope and the land use maps gave the curve number map shown in figure 5.

LAND USE AND TREATMENT	SLOPE (%)	REGRESSION EQUATIONS	R^2
Fallow R	>= 3	$nc = -0.005Ks^2 - 0.034Ks + 91.844$	0,9425
Fallow N	>= 3	$nc = -0.0047Ks^2 - 0.0433Ks + 88.239$	0,9719
Fallow R/N	< 3	$nc = -0.0025Ks^2 - 0.1487Ks + 85.212$	0,9649
Row crops R	>= 3	$nc = -0.0061Ks^2 - 0.0795Ks + 88.435$	0,991
Row crops N	>= 3	$nc = -0.0042Ks^2 - 0.1471Ks + 85.268$	0,9816
Row crops R/N	< 3	$nc = -0.0045Ks^2 - 0.1094Ks + 81.127$	0,9724
Small grain R	>= 3	$nc = -0.008Ks^2 - 0.0402Ks + 85.349$	0,9917
Small grain N	>= 3	$nc = -0.009Ks^2 - 0.0267Ks + 82.489$	0,9952
Small grain R/N	< 3	$nc = -0.0069Ks^2 - 0.0787Ks + 80.463$	0,9933
Poor rotation crops R	>= 3	$nc = -0.0059Ks^2 - 0.1455Ks + 88.323$	0,9894
Poor rotation crops N	>= 3	$nc = -0.0061Ks^2 - 0.1078Ks + 85.182$	0,9842
Poor rotation crops R/N	< 3	$nc = -0.0053Ks^2 - 0.1086Ks + 82.154$	0,9793
Dense rotation crops R	>= 3	$nc = -0.0075Ks^2 - 0.1439Ks + 84.379$	0,9936
Dense rotation crops N	>= 3	$nc = -0.01Ks^2 - 0.0292Ks + 81.011$	0,9873
Dense rotation crops R/N	< 3	$nc = -0.011Ks^2 - 0.0376Ks + 78.15$	0,9909
Pasture	>= 3	$nc = -0.0058Ks^2 - 0.1172Ks + 88.576$	0,9949
Medium meadow	>= 3	$nc = -0.0124Ks^2 - 0.0372Ks + 83.025$	0,9684
Dense meadow	>= 3	$nc = -0.0109Ks^2 - 0.1691Ks + 78.236$	0,9949
Very dense meadow	>= 3	$nc = -0.0056Ks^2 - 0.4466Ks + 76.044$	0,9904
Pasture	< 3	$nc = -0.0122Ks^2 - 0.1873Ks + 86.617$	0,9877
Medium meadow	< 3	$nc = -0.0095Ks^2 - 0.368Ks + 81.873$	0,9912
Dense meadow	< 3	$nc = -0.006Ks^2 - 0.6618Ks + 77.552$	0,9976
Very dense meadow	< 3	$nc = 0.0008Ks^2 - 1.2674Ks + 77.726$	0,997
Sparse orchard or tree farm	>= 3	$nc = -0.014Ks^2 - 0.0073Ks + 81.334$	0,9807
Medium orchard or tree farm	>= 3	$nc = -0.0145Ks^2 - 0.0159Ks + 76.755$	0,99
Dense orchard or tree farm	>= 3	$nc = -0.0109Ks^2 - 0.2918Ks + 75.619$	0,9879
Sparse orchard or tree farm	< 3	$nc = -0.0134Ks^2 - 0.0544Ks + 76.869$	0,9909
Medium orchard or tree farm	< 3	$nc = -0.0087Ks^2 - 0.3688Ks + 75.845$	0,9898
Dense orchard or tree farm	< 3	$nc = -0.0137Ks^2 - 0.28Ks + 74.308$	0,9871
Very sparse wood or forest land (trees, brushes, …)		$nc = -0.0128Ks^2 - 0.0175Ks + 89.7$	0,9862
Sparse wood or forest land (trees, brushes, …)		$nc = -0.0164Ks^2 - 0.1357Ks + 81.219$	0,9788
Medium wood or forest land (trees,		$nc = -0.0124Ks^2 - 0.0372Ks + 74.025$	0,9684

brushes, …)			
Dense wood or forest land (trees, brushes, …)		$nc = -0.0077Ks^2 - 0.2289Ks + 67.62$	0,9789
Very dense wood or forest land (trees, brushes, …)		$nc = -0.0077Ks^2 - 0.2006Ks + 58.873$	0,9841
Permeable rocks	>= 3	$\boldsymbol{nc} = 94$	
Permeable rocks	< 3	$\boldsymbol{nc} = 91$	
Impermeable rocks	>= 3	$\boldsymbol{nc} = 96$	
Impermeable rocks	< 3	$\boldsymbol{nc} = 93$	

Table 5. Regression equations for each soil-land use complex to estimate curve number parameter

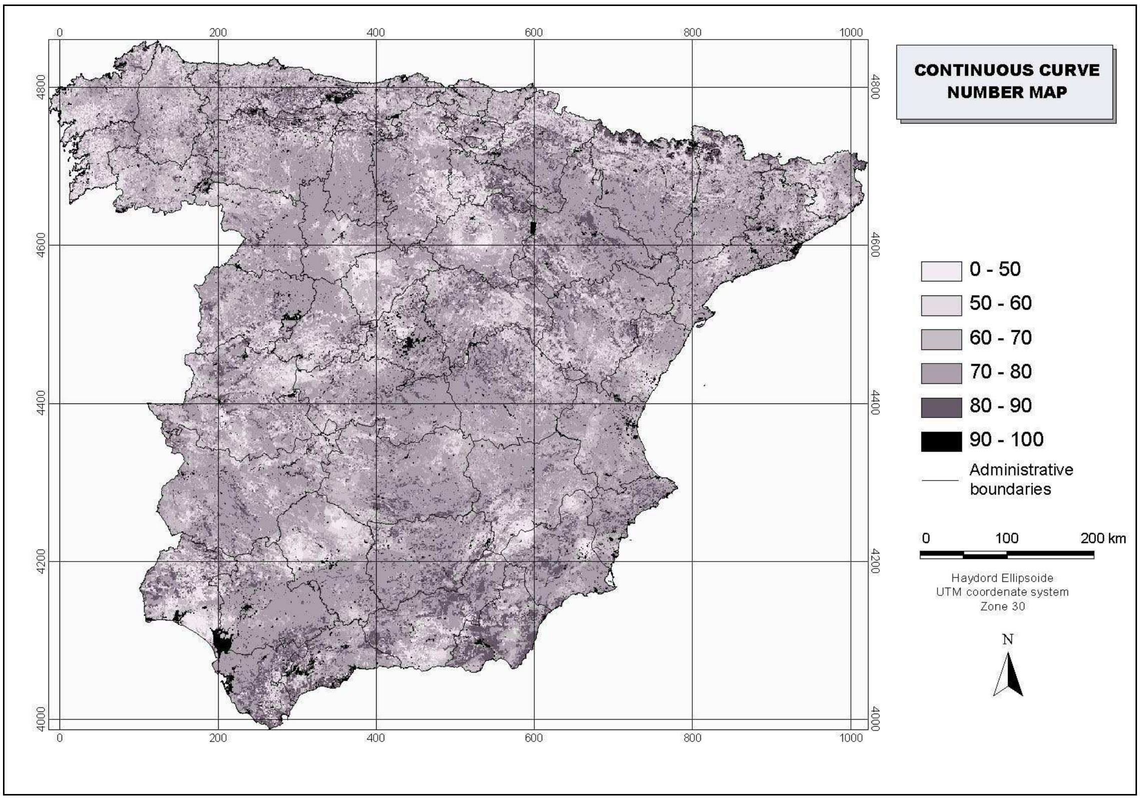

Figure 5. The continuous curve number parameter for all the study area

As it can be observed, the highest curve number values are associated to the impermeable areas: urban areas, salt marshes, lakes, important rivers and areas with high mountains where rock appear at the land surface. The medium curve number values (from 70 to 90) are the majority over the study area. They almost form a continuous area from the south to the north. The low medium curve number values (from 50 to 70) are located in areas where forest is the most often land use. Generally it coincides with main mountain chains. The lowest curve number values coincide forest areas with high infiltration rates (hydrologic soil group A) as was expected from table 1. In some cases these values are too low (they can reach negative values). The reason is that the regression equations have been assuming a mean K_s value of 50 mm/h for group A), when in some areas this rate is higher (around 100 mm/h).

CONCLUSIONS

The main conclusions that can be derived from the above data and results are the following ones:

1. It is possible to estimate a continuous curve number based on a quantitative variable that defines hydrologic soil groups.
2. There are good adjustments in all the regression equations used to estimate a continuous curve number, so saturated hydraulic conductivity is a good variable to estimate hydrologic soil groups.
3. The main problems estimating the continuous curve number are in those areas where there are very high saturated hydraulic conductivity.

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