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The contribution of GIS to hydrological modelling

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Abstract In this communication, we aim to show our contribution towards the building of a grid containing the water holding capacity (WHC) parameter of the soils. This parameter is used as input data in a hydrological balance type model running at the scale of half a square degree for estimating the soil water reservoir. The Digital Soil Map of the World drawn and edited by FAO is the soil map we used to determine the WHC parameter.

Key words hydrological balance model; water holding capacity; grid; FAO; soil classes; West and Central Africa

OBJECTIVES

A key objective of the research lead by the Vahyne group of the Joint Research Unit HydroSciences Montpellier is to determine the impact of a climatic variability on water resources in West and Central Africa in an arid and semiarid context. This research is being achieved through the application of semi-distributed modelling to determine the water balance. The studied area being over 6 million km^2, the scale for studying this impact is using the half-degree grid. The time step for the data of discharge, rainfall and evapotranspiration is monthly.

The chronological data base managed in the Environmental Information System for Water Resources and Modelling (SIEREM) enabled the selection of 356 measurement sites observed on a period long enough to calibrate the model. For all these sites we delineated the drained basin. Before this delineation, we had to build GIS entities of the hydrological network (one file per major river). The basins on which this modelling process was carried out exceed 5000 km^2.

To delineate the drainage basins, we used GTOPO30 DEM provided by USGS. This choice was made mainly because of the size of our study area. No other DEM existed over such a surface area. (SRTM and SRTM30 were not available at that time.) From this DEM, we ran ArcInfo programs that calculate the flow direction and the flow accumulation and then the program delineates the basins. This was the automated procedure, but on our study area, the nature of the topography is such that additional human interpretation is required based on existing published studies of IRD hydrologists for the region.

The next step was to determine the WHC for every delineated basin, within each of the cells within the model.

To calculate the soil reservoir of the model, we needed a soil cover information data base mapped for the whole modelled region. We found only one map fitting this need: the Digital Soil Map of the World distributed by the FAO (1995) in a numeric format. This digitized version is of particular interest in that it covers most of the globe and makes our operating method more applicable everywhere.

THE SOIL UNITS DEFINED BY FAO

On the worldwide map cover, FAO defined 4930 soil units. A unit does not correspond to a homogeneous soil type and the symbol used to identify a soil unit is made of:

– the symbol of the dominant soil type;
– a numeric digit that qualifies the soil associations (dominant soil unit, associated soil units and inclusions);
– a numeric digit that qualifies the texture of the dominant soil of the unit (1 stands for rough, 2 for mean and 3 for thin);
– a lower case letter that qualifies the slope of the soil unit (*a* for flat to wavy, *b* for undulating to uneven, *c* for hilly to mountainous).

Here are two examples of soil units of the map:

(1) *Ag1-3a*: gleyic acrisoils t(*Ag*), with thin texture (*3*) and plinthic acrisoil, flat to wavy (*a*).

(2) *Lc6-3b*: chromic luvisoils (*Lc*), thin (*3*), chromic litho soils and vertisoils with orthic solonetz, hilly to mountainous (*b*).

This description can only be found at the back of the paper maps published by FAO in 1973.

THE INFILTRATION DEPTH VALUES DETERMINED BY FAO

Within the corresponding CD of the FAO soil map (one ArcInfo cover per continent), a file called SMAX.ASC is provided. In this file are stored the pieces of information that permitted us to calculate the WHC parameter. FAO defined seven classes, each one corresponding to a depth of infiltration of water in the soil, depth that is calculated according to granulometric values, characteristic of the soil types which make up each soil unit. In the SMAX.ASC file, in front of every soil unit symbol, are listed seven values corresponding to the percentage of occupation of the current soil unit in the class. A program called image.exe located on the CD permits one to view this map by continent.

The seven classes Every class corresponds to a range of depth of water storage in the soil unit. At every soil unit are associated seven values in percentage, one for each class. The total for every soil unit must be 100%.

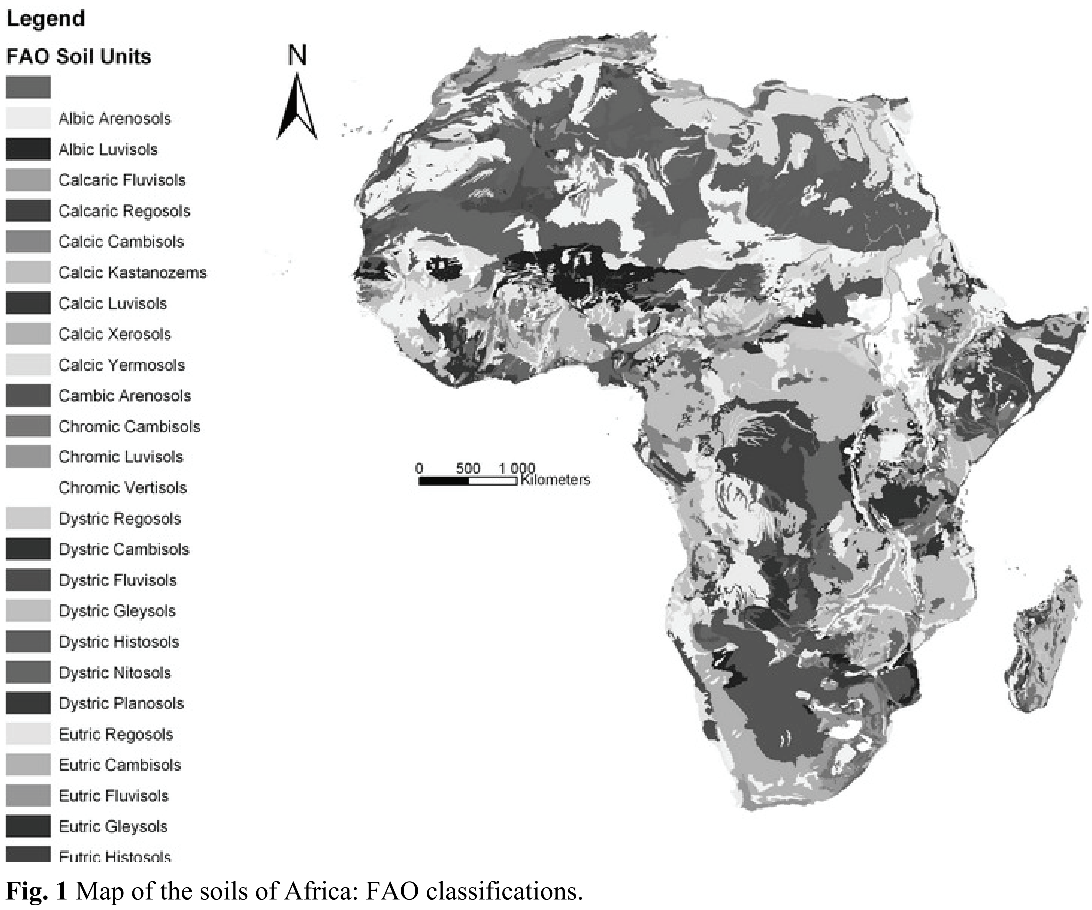

Fig. 1 Map of the soils of Africa: FAO classifications.

Table 1 FAO classes defined in the SMAX.ASC FAO file.

Wetlands	A	B	C	D	E	F
NC (mm)	200/300	150/200	100/150	60/100	20/60	0/20

For instance, lets take the Albic Arenosoil soil unit whose FAO symbol is Qa5-1a, the values stored in the SMAX.ASC file are: 860, Qa5-1a, 10, 0, 0, 40, 25, 25, 0.

860 is the "unit code" given for that soil unit; Qa5-1a is the FAO soil codification, and the seven values, 10, 0, 0, 40, 25, 25, 0, are the percentage of occupation of this soil unit in the classes wetlands (10%), A (0%), B (0%), C (0%), D (25%), E (25%) and F (0%), respectively.

THE GIS PROCESSES TO OBTAIN THE WHC PARAMETER

For every class in the FAO files, the depth of infiltration is given for a range of values (except for the wetland class which is not quantified). For instance, class F stands for a depth going from 0 to 20 mm. The first tests done with the WHC parameter in modelling were carried out by Mahaman Ouedraogo (2001) who used the mean value of the FAO range, i.e. taking again the example of class F, he gave it the value 10 mm.

We decided to improve this model input and chose to calculate the WHC parameter for the limit and mean values, so we calculated three values for every class which we expressed as SMIN (for the F class, it was 0), SMOY (for the F class, it took the value 10) and SMAX (20 for F class). The class called wetlands had no digital value in the FAO classification, it is affected by swampy soils and we gave it a single very high value: 1000 mm.

We then calculated three absolute depth values for every soil unit, using the following operating procedure. Every soil unit had seven percentage values, ranging from 0 to 100 in every class, we calculated a depth for every class of each soil unit, for instance, 10% in class A (ranging from 200 to 300 mm in SMAX.ASC FAO file) was calculated as 20 mm for SMIN (10% of 200 mm), 25 mm for SMOY (10% of 250 mm) and 30 mm for SMAX (10% of 300 mm). This was done for every class of every soil unit and we then summed the seven minimum values to get one SMIN value, then the seven mean values to obtain SMOY and the seven highest values to get SMAX. Such a procedure was done for the 4930 soil units of the FAO file. We give in the following table the example of the calculation for the soil unit called *Qa5-1a*.

Table 2 WHC parameter calculation from percentages to absolute values: SMIN in roman characters, SMOY in italic and SMAX in bold.

Qa5-1a	Wetlands 1000	A 200–300	B 150–200	C 100–150	D 60–100	E 20–60	F 0–20	Total
SMAX.ASC (%)	10	0	0	40	25	25	0	100
Abs. Min	100	0	0	40	15	5	0	160
Moy	*100*	*0*	*0*	*50*	*20*	*10*	*0*	*180*
Max	**100**	**0**	**0**	**60**	**25**	**15**	**0**	**200**

This calculation was repeated on the 4930 soil units, for the respective seven classes for every soil unit and for the three limit values of every class, i.e. a total of 103 530 values.

Reynolds (1999) recalculated the SMAX.ASC file from the FAO taking account other pedo-transfer of the soil functions (Saxton model, 1986). We added the results of this recalculation as a fourth value we called Saxton in the attribute table of the GIS cover of the soil unit map of Africa. With the specific GIS commands we added the four SMIN, SMOY, SMAX and SAXTON values to every polygon of the African soil cover (Fig. 2). Once this new cover was built, we intersected it with a half a square degree grid layer to obtain a map at the step of the model (Fig. 3).

The soil map of FAO over Africa was made up of 4985 polygons, and after the intersection with the grid, we got 36 849 polygons, that is an average of 7.3921 soil units per cell of the grid. In fact, there are from 1 to 23 units per cell, and the most frequent case is 3 units per cell, 1981 cells are in this case on the African continent (see distribution in Fig. 4).

Every cell contains several polygons of soil units; these have the SMIN, SMOY, SMAX and SAXTON values of the soil unit. We then decided to weigh these WHC values at the surface area of each polygon within the cell. We then obtained SMINP, SMOYP, SMAXP and SAXTONP

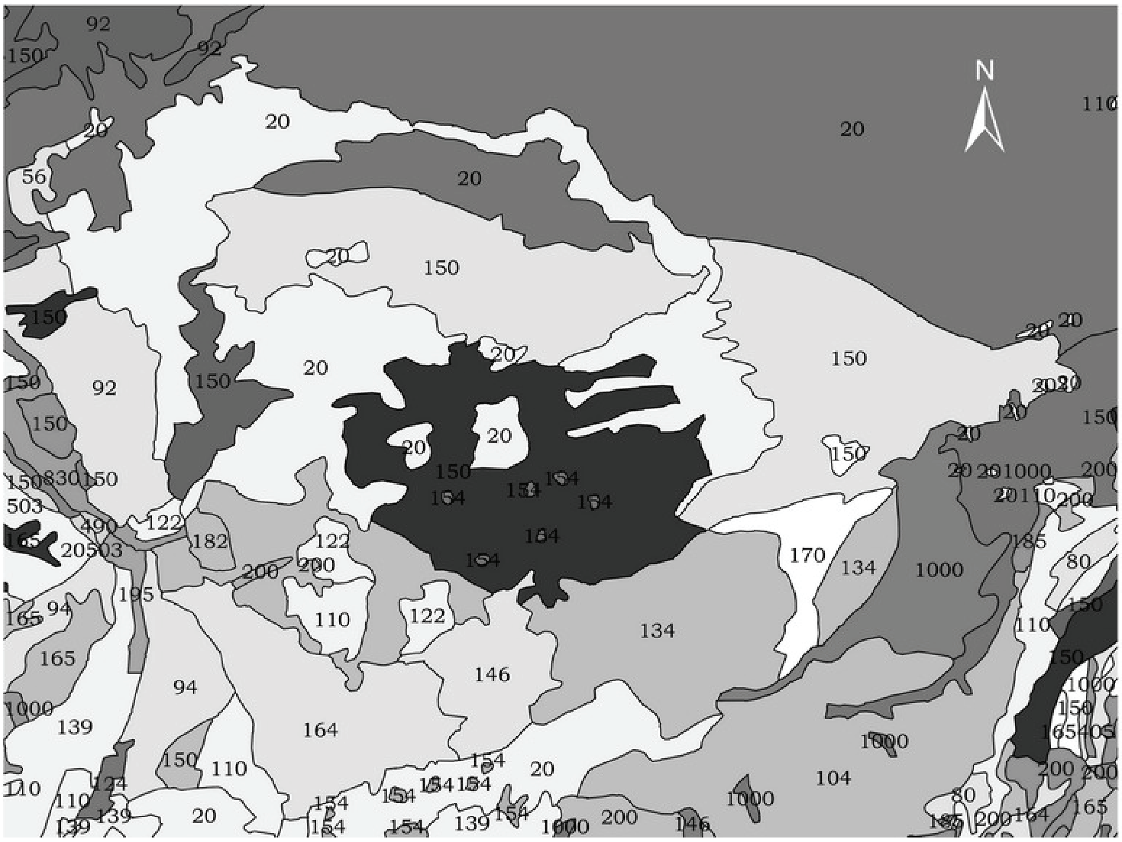

Fig. 2 Smax value for every soil unit, before being weighted.

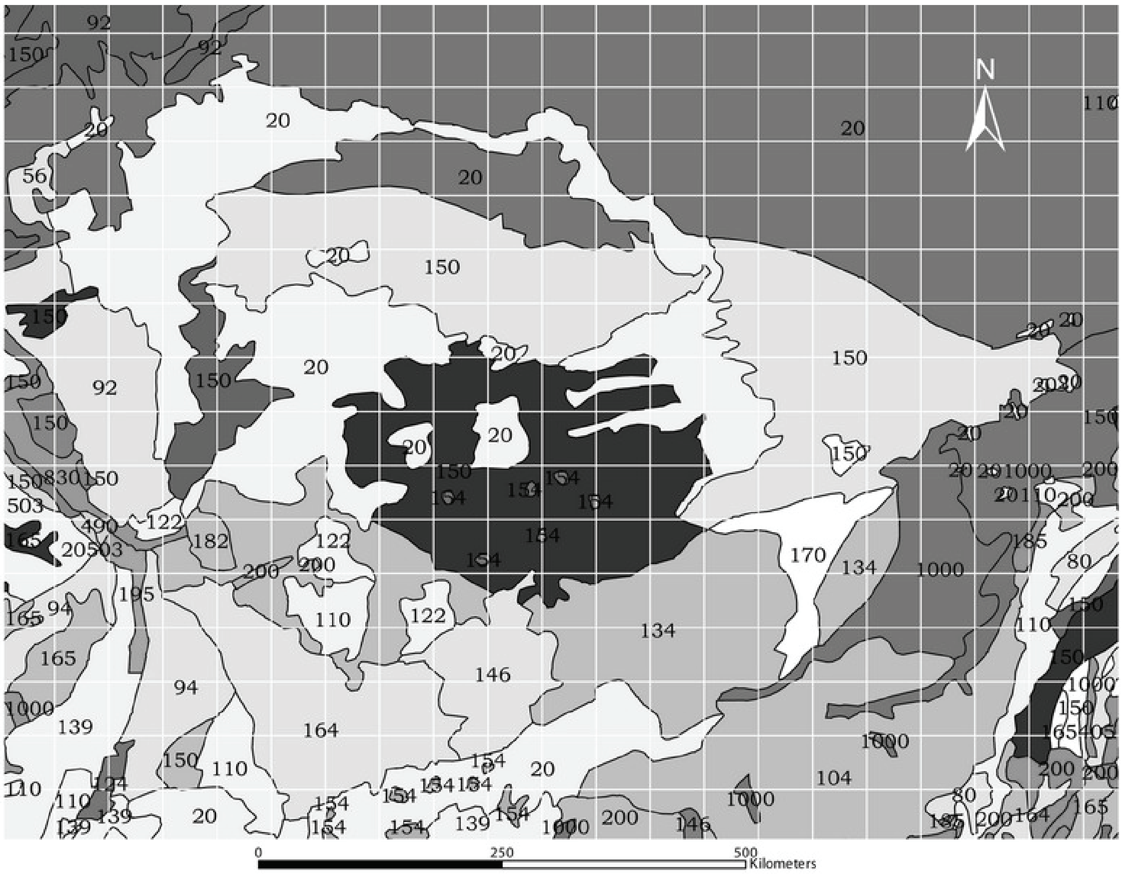

Fig. 3 The cover of the soil map intersected with a half of a square degree grid.

values. Once this calculation ran, we summed these values to get only one value per cell. In a first series of tests, we used these values and “cut” the map of Africa with the polygons of each basin that was to be modelled.

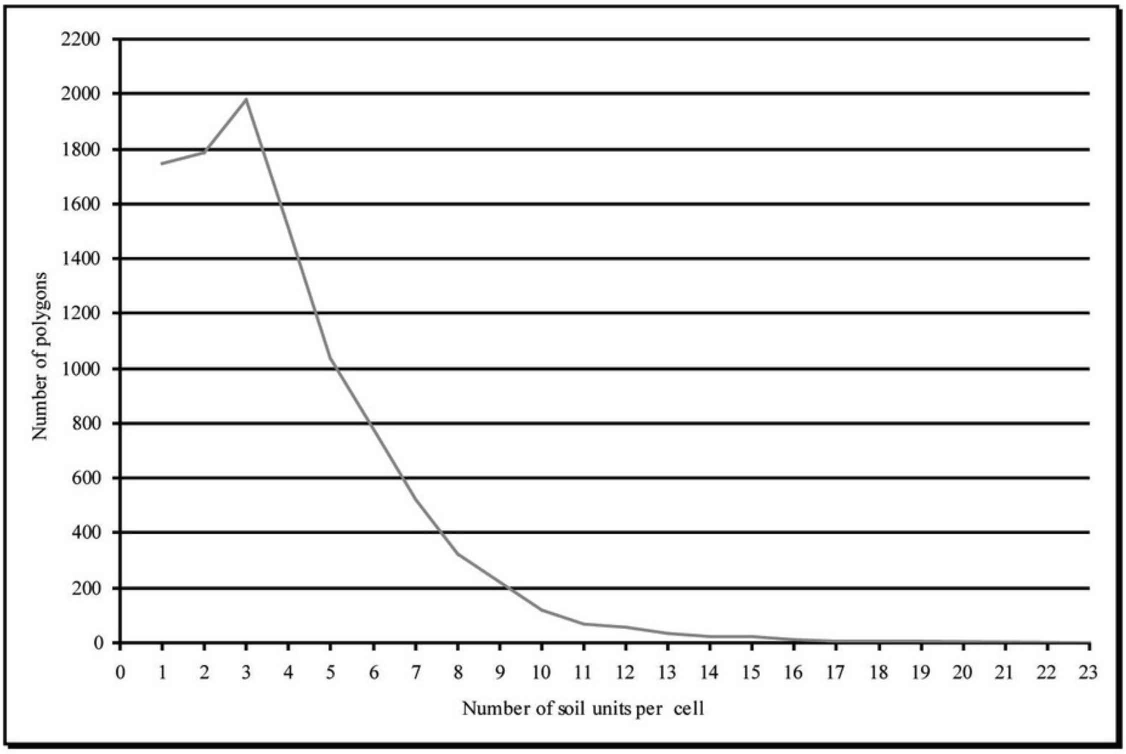

Fig. 4 Distribution of the number of soil units per cell over the whole map of Africa.

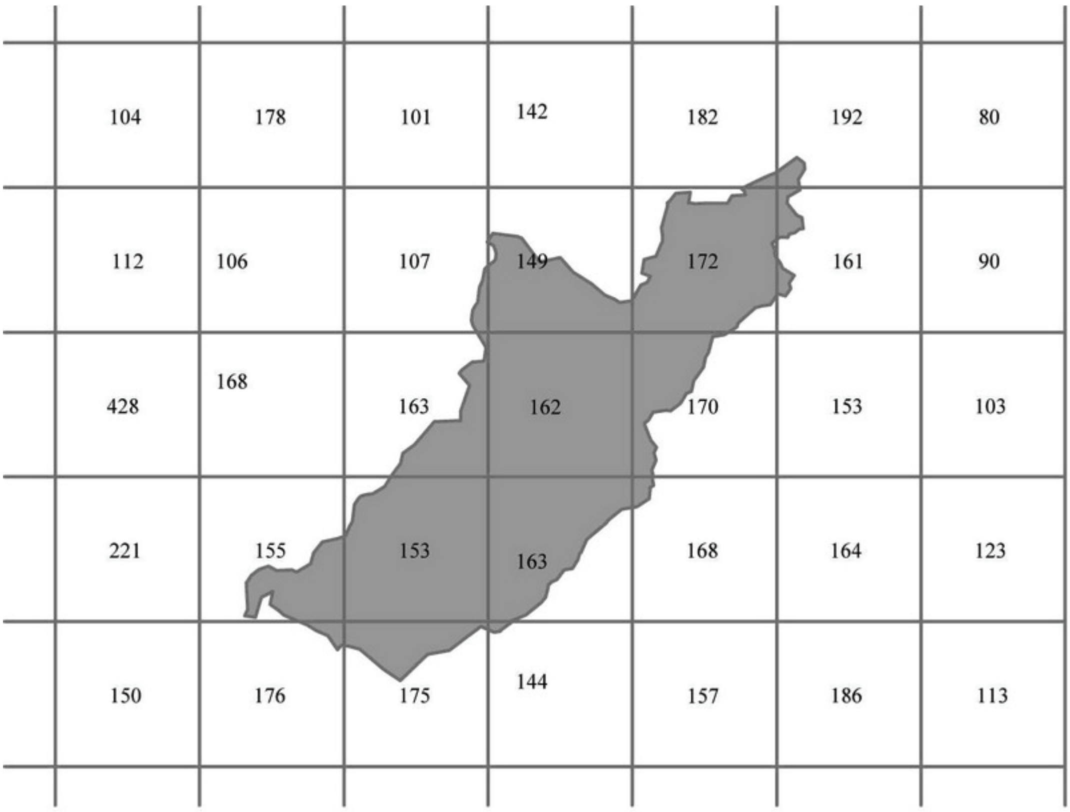

Fig. 5 WHC values of the first tests.

FINAL CALCULATIONS TO ENHANCE THE WHC PARAMETER

But, we noticed that the cells at the edge of the basins were not complete cells and even some were very small parts of a cell and thus, the calculated WHC were not representative of the "real" ones. We then decided to "cut" the grid at the limits of the basins before weighting the WHC values to obtain the most accurate possible value. The final procedure we adopted is the following one:

– intersect the FAO soil map with the 0.5 square grid
– "cut" this grid with the basin polygons
– calculate the SMINP, SMOYP, SMAXP and SAXTONP values for every soil unit in every cell by multiplying the SMIN, SMOY, SMAX and SAXTON values by the surface area of the polygon in the cell
– calculate a SMINPM, SMOYPM, SMAXPM and SAXTONPM values by adding the different values of the n polygons in the cell. Figure 6 shows the differences in the results obtained with the two calculations we tried.

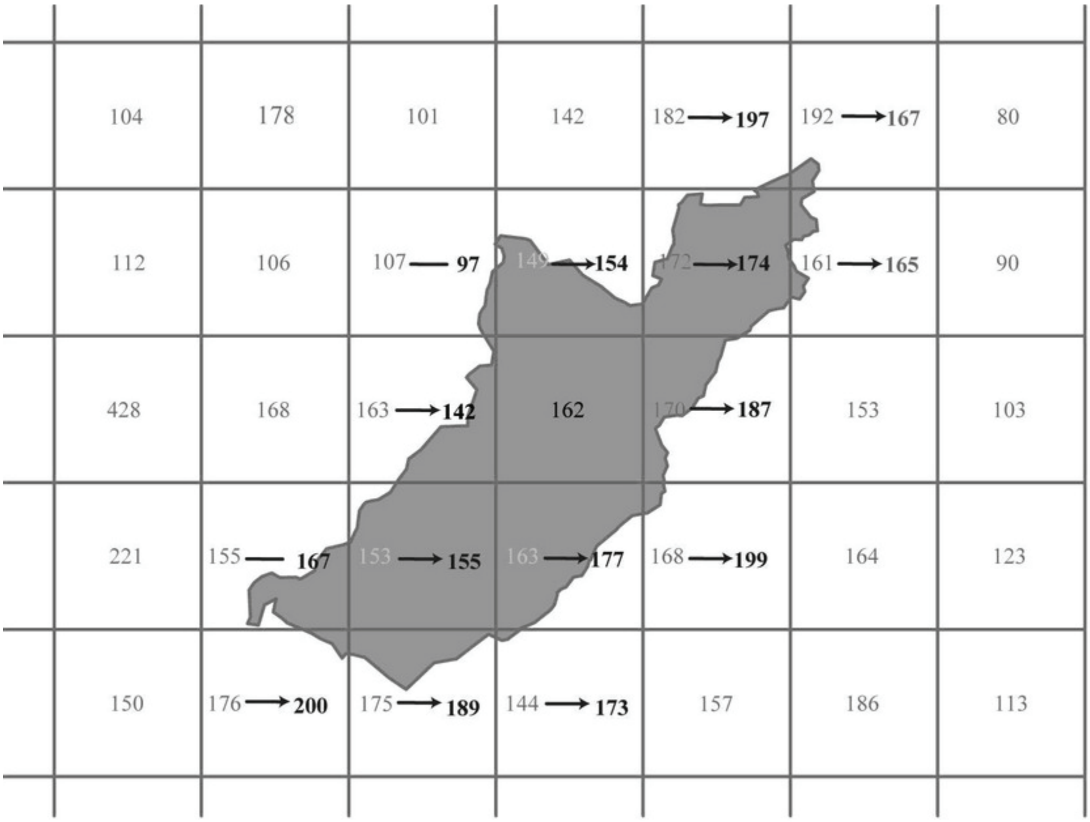

Fig. 6 Final WHC values (here SMAXPM) recalculated after having been "cut" with the basin delineation. Previous value, arrow and then new value in bold.

PROSPECTIVE

The first tests we carried out were done on the occasion of the thesis of Sandra Ardoin-Bardin (2004) and were positive in the improvement provided by this parameter. We took as a postulate that the WHC value was steady over the 20-year period of calibration of the model. But, in fact, depending on the intensity of human pressure such as agriculture practices, erosion; this parameter varies. Our future investigations will be to estimate the variation of this value based on human activity in the basins and the modification of the basins behaviour depending on the anthropogenic pressure.

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