WATER BALANCE IN NATURAL BASINS. A PRACTICAL CASE: RIVER MOROS IN SEGOVIA (SPAIN).

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SUMMARY

In this work a water-balance model was tested when applied to a natural pilot basin, and the results being contrasted with those given by the measurements in a hydrometric station in El Espinar (Segovia, Spain) located at the basin outlet.

On the other hand, the main watery basin flows have been identified and assessed accurately, both through their numeric and cartographic parameters.

By means of software ESTCLIMA, the average monthly climatic parameters for every spot in the land were obtained, using a land base held by a Digital Elevation Model (DEM). The graphic result was a number of maps matched to annual average temperature, annual rainfall, number of rain-days in a year and maximum month average storm.

It was also determined the water retention capacity of soils in every point in the basin, getting a graphic output which shows the quantity of water (in litres) for every m^2 in surface and 1,25 m in depth.

Finally, and in every spot in the basin, the values of the main parameters in the water balance were obtained, both numerical and graphically, that is: net water volume infiltrated, runoff flow, internal drainage water volume and average water volume soil-retained. All these values were compared to the total water volume measured at the basin final point.

1 INTRODUCTION.

Research has been historically done of parameters such as rainfall regimes, infiltration/runoff ratios and water volumes available in streams and rivers. In the thirties, research by R.E. Horton (1933, 1940) connecting infiltration capacity, rainfall and superficial runoff was the best-known and more influential for many hydrologists. Later experimental tests started to show the importance of the sub-superficial and subterranean cycling. Also, the close relation between infiltration ratios, previous soil humidity and its physical characteristics was clearly shown.

In recent years, some authors (Sánchez & Blanco, 1985; Gandullo, 1985) established indirect methods based on parametrical techniques for calculating soil water retention, through physical, organic and structural variables. These estimations opened up for water balance calculation referred to weather-soil complex in a station, and thus to the whole land, whose logical unit is the basin. Water balances (Thornthwaite, 1948; Thornthwaite & Mather, 1955, 1957; Cerezuela, 1977; Montero de Burgos & González Rebollar, 1974; Gandullo, 1985, 1994) allow getting the water percentages which suffer evaporo-transpiration, stay retained to the soil, or get infiltrated into the aquifer, all through the average climatic year.

Another main factor which held researchers attraction was the role of vegetal covers on the water basin dynamics. It was fairly evident that a soil correctly vegetated had higher infiltration ratios and lower runoff rate.

The main problem is runoff rate calculation. Many authors have set methods, tables and expressions trying to evaluate runoff coefficients. Perhaps, the most widely-spread method was proposed by Soil Conservation Service (S.C.S., USDA, 1978). This method goes for the superficial runoff in the origin of a concrete storm or aisled rainfall whose intensity is known. However, research in water balance of a basin needs longer time, and not only the duration of a storm. This fact makes hard the utilisation of Curve Number in water balances, which must be referred to annual periods, and ideally, to the average climatic year.

This work is trying to adapt Curve Number method to the classic water balance systems. The expected target is getting a global water balance for the whole basin through available or easily acquirable data (edited cartography, weather data in meteorological registers, soil-vegetation data from tests and tabulated data).

Advantages of the method are the important reductions in required costs and time to study the water basin balance (Blanco *et al.*, 1998, 2000). (It must be regarded that the setting of equipments capable of measuring timely and spatially the water flows and answer times in a basin, oblige to the monitoring of phenomena throughout many years, given the natural weather irregularity).

2 MATERIALS AND METHODS.

The model was tested experimentally in a natural basin (minimally altered by human beings) located at Guadarrama Sierra (North Madrid, Spain). The area belongs to the upper basin of River Moros (El Espinar, Segovia) and has a total size of 35 km^2. There is a hydrometric station at the basin outlet, which has registered flows in the period 1952-1995. Its control is duty of Duero Water Office (Civil Works Ministry).

The main *items* on which the work was based were:

- By means of software ESTCLIMA (Sánchez Palomares *et al.*, 1999) -which monitors, among others, the average month climatic parameters for every spot within a land, defined by three coordinates X, Y, HEIGHT- a representation of temperatures and rainfalls in the basin was obtained. Land base used was a DEM consisting of 25 x 25 m^2 cells in real scale. Graphic result was maps for average annual temperatures, annual rainfall, number of rainfall days in a year and maximum average month storm.

- By using an experimental inventory, very simple in the number of collected samples (45 samples from 15 soil profiles), the water soil retention capacity was determined for every point in the basin. This process was made thanks to the correct segregation criteria in homogenous zones used and to the statistical means utilized (TWINSPAN analysis based on hierarchic divisive methods for samples) (Hill, 1975, 1979). A graphic result was obtained showing litres of water for every m^2 in surface and 1,25 m in depth (standard depth of the vegetal soils) which soils are capable of retaining in every point within the basin (see Map in Addendum titled: Soil Water Retention Capacity).

- Also, and both numerical and graphically, and for every point within the basin, the values of the main parameters in the water balance were obtained, that is: net water volume infiltrated (once discounted losses due to evaporation and vegetation-consumption), superficial runoff volumes, internal drainage water volume (classified in sub-superficial drainage water and deep drainage water) and average water volume retained by soils. Graphic results got were: annual infiltration, annual superficial runoff, annual internal drainage, average water reservoir in the soils (for instance, see Map in Addendum titled: Annual Superficial Runoff).

- Computer development consisted of ARC-VIEW and ARC-INFO. Cartography was edited by means of COREL DRAW 10.

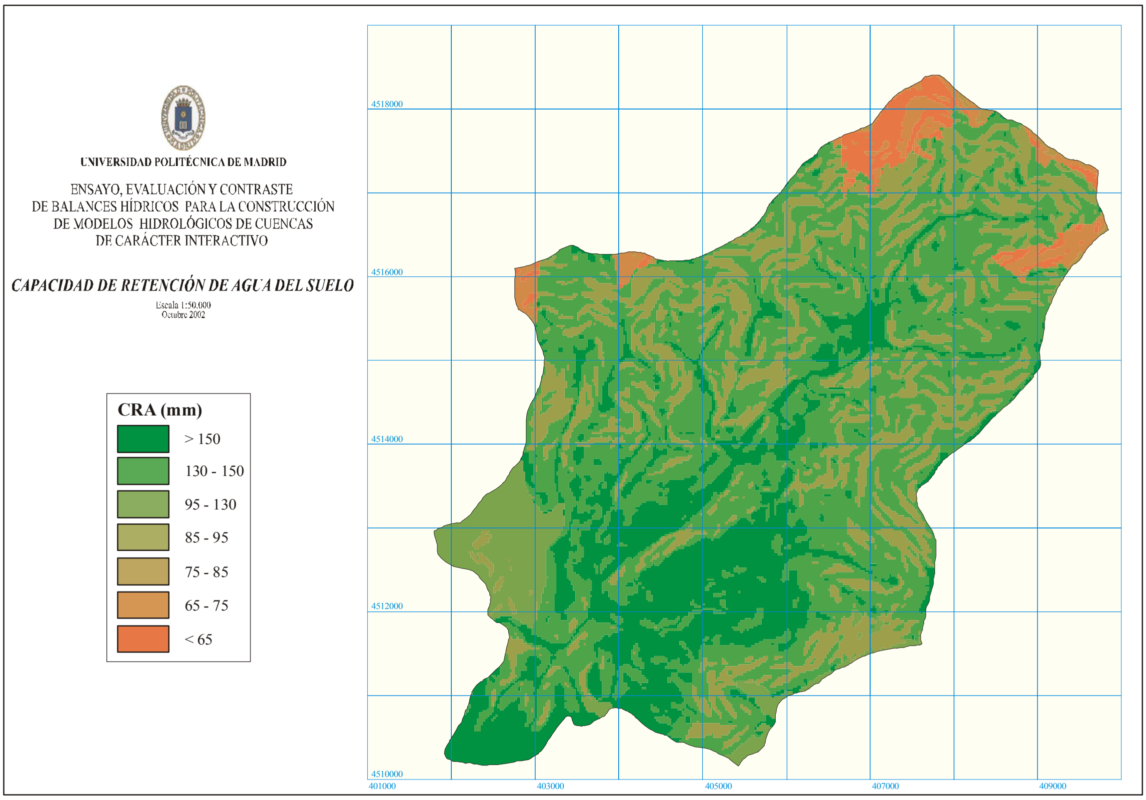
3 DISCUSSION AND RESULTS.

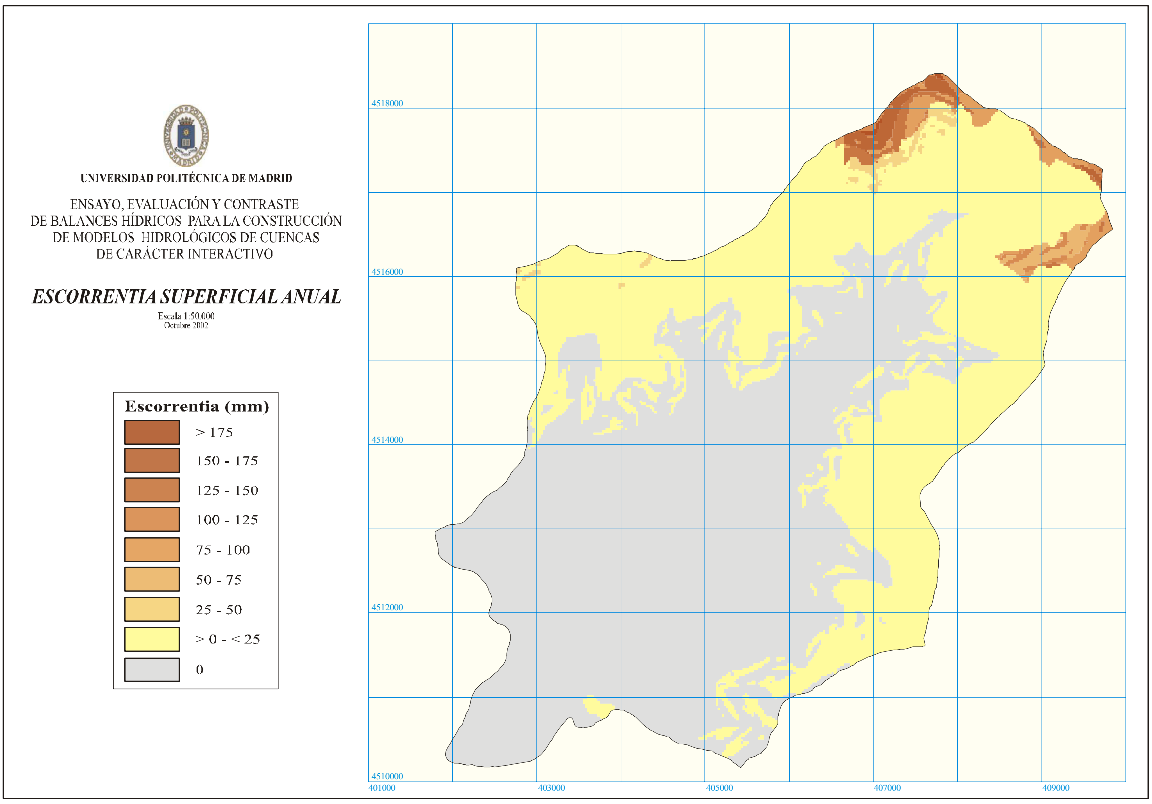
Application of hydrologic model for every turn in the basin (25 x 25 m^2) and its integration into the whole basin (basin surface, 35 km^2) gave as a result the following global water balance:

<table>
<tr><th colspan="5">ANNUAL WATER BALANCE IN THE BASIN (35 km²)*</th></tr>
<tr><th colspan="2">HYDROLOGIC PARAMETERS</th><th>m³</th><th colspan="2">% REFERRED TO RAINFALL**</th></tr>
<tr><td colspan="2">RAINFALL</td><td>39.009.219</td><td colspan="2">100</td></tr>
<tr><td colspan="2">INFILTRATION</td><td>38.832.972</td><td>99,5</td><td rowspan="2">100</td></tr>
<tr><td colspan="2">SUPERFICIAL RUNOFF</td><td>176.247</td><td>0,5</td></tr>
<tr><td colspan="2">INTERNAL DRAINAGE</td><td>22.606.513</td><td colspan="2">58</td></tr>
<tr><td></td><td>SUBSUPERFICIAL DRAINAGE</td><td>20.993.753</td><td>53,8</td><td rowspan="2">58</td></tr>
<tr><td></td><td>DRAINAGE IN DEPTHS</td><td>1.612.760</td><td>4,2</td></tr>
<tr><td colspan="2">SOIL RESERVOIR</td><td>3.889.224</td><td colspan="2">10</td></tr>
<tr><td colspan="2">REAL EVAPORO-TRANSPIRATION</td><td>16.226.459</td><td colspan="2">41,6</td></tr>
<tr><td colspan="2">MEASURED WATER</td><td>21.170.000</td><td colspan="2">54,3</td></tr>
</table>

* Water balance in the average climatic year.

** All percentages are calculated for total rainfall, but only infiltration and runoff must sum up 100 (all other parameters are sub-lots of infiltration)


UNIVERSIDAD POLITÉCNICA DE MADRID
ENSAYO, EVALUACIÓN Y CONTRASTE
DE BALANCES HÍDRICOS PARA LA CONSTRUCCIÓN
DE MODELOS HIDROLÓGICOS DE CUENCAS
DE CARÁCTER INTERACTIVO
CAPACIDAD DE RETENCIÓN DE AGUA DEL SUELO
Escala 1:50.000
Octubre 2002
CRA (mm)
> 150
130 - 150
95 - 130
85 - 95
75 - 85
65 - 75
< 65
4518000
4516000
4514000
4512000
4510000
401000
403000
405000
407000
409000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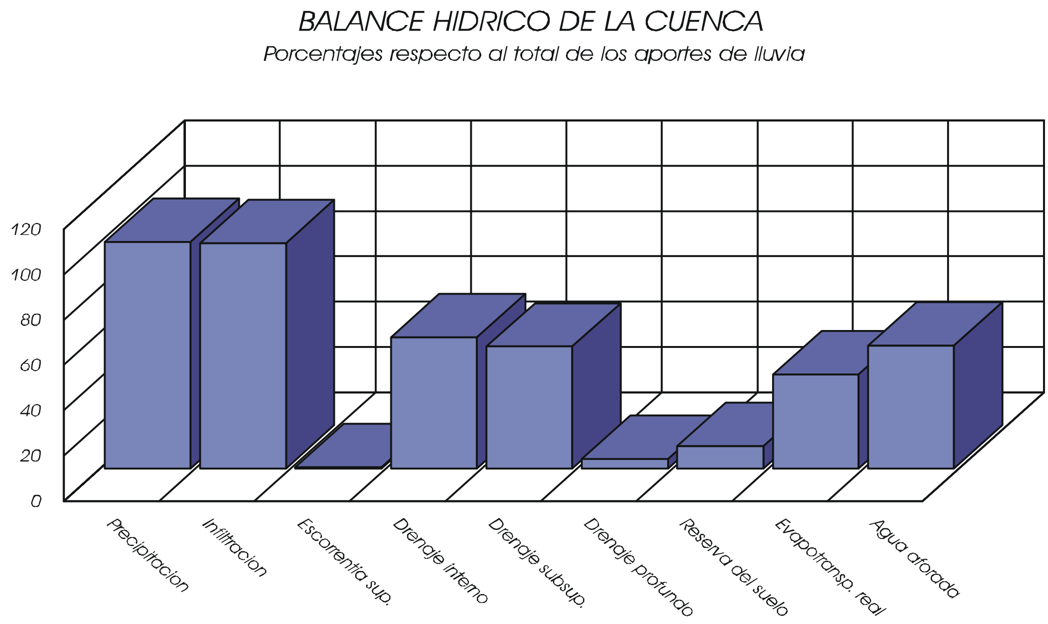
DE MODELOS HIDROLÓGICOS DE CUENCAS
DE CARÁCTER INTERACTIVO
ESCORRENTIA SUPERFICIAL ANUAL
Escala 1:50.000
Octubre 2002
Escorrentia (mm)
> 175
150 - 175
125 - 150
100 - 125
75 - 100
50 - 75
25 - 50
> 0 - < 25
0
4518000
4516000
4514000
4512000
4510000
401000
403000
405000
407000
409000

In the following blocks-diagram all different concepts are merely represented in percentages, showing clearly the more than evident lack of equality between them:



Main aspects in this diagram are:

- Almost all rainfall water gets infiltrated into the soil (99,5 %).
- About half of rainfall water is evaporated into the atmosphere or transpirated by vegetation (41,6 %).
- About half of rainfall water goes through the soil (58 %), sub-superficially (53,8 %) or in depths (42,2 %).
- Almost all water going through soil feeds outlet basin flow, that is, the flow measured at the hydrometric station.
- Just a small portion of rainfall feeds deep aquifers (4,2 %).
- Water measured in the watershed in the basin outlet is about half rainfall in the basin (54,3 %).

So, theoretician model tests carried out in a non-altered pilot basin as the one used in this work are very clarifying akin to the behaviour of the main hydrologic parameters. Moreover, they have allowed us to calculate with accuracy the main water cycles existing in the basin.

However, we could also find important limitations:

- The model is designed so as to know the water flows in average climatologic years. It is not valid for irregular climatologic years, since its good results are based on the absence of extreme processes (violent storms which originate peak flows, etc.).
- Also, the theoretician model carried out was insufficient to extrapolate the results to other basins existing in different geo-climatic environments. In fact, thanks to the

computerization of all calculation processes, through feed-back exercises, some trial and error was made, modifying the value of some variables, and noticing significant changes in the balance results.

In other words, it would be really important to go on the research testing the model in different non-altered basins in different settings.

4 CONCLUSIONS.

- The hydrologic model tested showed high accuracy and coherence in its results, once contrasted with data from the hydrometric station in the pilot basin.

- It was found out that densely vegetated basin, such as this one, consume a large quantity of available rainfall due to evaporation and transpiration through vegetation (up to 50 % of total rainfall). However, almost all remaining water going through the soil goes sub-superficially, feeding river flow. Thus, it cannot be said that increase in water consumption, due to reforestation, in basins lacking cover, means decreasing in river flows. Global balance could even invert: less available water in land, but more available water in rivers, and anyway, a more constant flow.

- Also, superficial runoff, in these non-altered basins is almost null (0,5 % of total rainfall), which must be understood in the sense of all water erosion damages being irrelevant.

- Furthermore, the quantity of water infiltrating into eventual aquifers through deep drainage is also really small (less than 5 % of all rainfall). This fact, must be specially related to the physiographic and lithological characteristics of the basin, really much over the former parameters. Thus it is estimated as having further less relevance in its global balance.

- However, the hydrologic model tested, despite being fully clarifying, lacks inevitably for having been contrasted in just one basin. Its extrapolation to other geographic environments must be done cautiously, until the research is widened to basins with different geo-climatic conditions.

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