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PHD. THESYS

- summary -

Indirect estimation of soil moisture, using GIS, for modelling the high floods generated by rain. Applications in Apuseni Mountains

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1. INTRODUCTION

During the time, Romania faced a lot of problems regarding the high flood manifestation. It is known that the hills areas (with a low afforestation degree, with a favorable terrain for production and transfer of alluvial materials) presented high flood vulnerability for a long time, in the last 10 years we frequently assist to an increase of the cases characterized by this extrem hydrologic event in the mountain areas also. A explanation could be the important decrease of deforestation areas having an impact to runoff speed, time of concentration, runoff coefficient etc. In the same time there is an other factor, the frecquent high intensity rain (especially during the summery).

The soil moisture has an important role in estimating the runoff depth generated by rain. The moment of surface runoff initiation depends of soil water saturation degree, wich is related to the antecedent precipitation and physical soil characteristics (texture, structure, soil profile depth, porosity, permeability, retention capacity, infiltration capacity etc.).

The purpose of this study is to develop a GIS methodology for indirect estimation of soil moisture which can help to anticipate the runoff depth in real time and than to hillslope runoff integration. The focus is to estimate the runoff for high flood generation, by knowing the meteorological forecasting for day *i*, antecedent moisture and by computing the infiltration depth.

The thesys contains eight chapters, a synthesys could include the next steps for elaborating the research theme: establish the objectives – study of current status of research – selection of methods – database generation – development and automatisation of GIS algorithms for infiltration and soil moisture estimation - development and automatisation of GIS algorithm for runoff high flood modeling taking into account the soil moisture conditions – validation of GIS algorithm for runoff high flood modeling taking into account the soil moisture conditions.

2. MOTIVATION, OBJECTIVES OF RESEARCH AND GEOGRAPHICAL LOCALIZATION OF STUDIED WATERSHEDS

2.2 Objectives of research

From the title we can deduce two principal objectives of the research theme:

a). development of a GIS algorithm that would permit the indirect estimation of soil moisture and daily infiltration generated by rain; b). development of a GIS algorithm for modeling both the surface runoff and the eventually high flood by taking into consideration the soil hydrological conditions.

Starting from these two objectives, there are some complementary ones tht can be deducted, such as: 1) creating an ArcGIS module in order to implement automatically the indirect estimation of soil moisture using the balance method; 2) finding an ArcGIS module for automatic implementation of indirect estimation algorithm for cumulative infiltration based n SCS method; 3) integrating the infiltration and soil moisture in the algorithm of estimating the surface runoff; 4) realizing digital maps regarding the infiltration and soil moisture in some small basins from Apuseni Mountains; 5) creating digital maps for surface runoff (net precipitation, runoff coefficient, runoff volume), by presenting some areas menaced by high flood, in some small basins from Apuseni Mountains; 6) establish the maximum debts by generating the runoff hydrograph in different sections of some small basins from Apuseni Mountains.

2.3 The elements of geographical localization of the studied watersheads

For the applications regarding the indirect estimation of soil moisture and surface runoff that can generate the high flood, there had been selected four small hydrographical basins from Apuseni Mountains. In the selection of these basins were taken into account the complexity of physic-geographical factors, the different elevation levels , the existence of settlements and meteorological data available.

These hydrographic basins are: *Albac Watershead; Beliş Watershead upstream of Beliş-Fântânele Lake; Poşaga Watershead; Călata Watershead upstream of Călata town*.

In the section of validating the GIS model for estimating the high flood, based on the soil moisture conditions, the case study was done on two hydrographic basins from Apuseni Mountains: *Beliş Watershead* amonte of Poiana Horea and *Somesul Cald Watershead* upstream of Smida; only for these two basins were available the hydrometrical data necessary for validation.

Related to the research theme, on the occasion of different scientific publications/manifestations, there had been elaborated studies for other hydrographic basins: Săcuieu, Iada, Drăgan, Căpuş, Pârâul Mare, Nadăş, Stolna, Râşca, Neagra, Valea Mare, Ampoi.

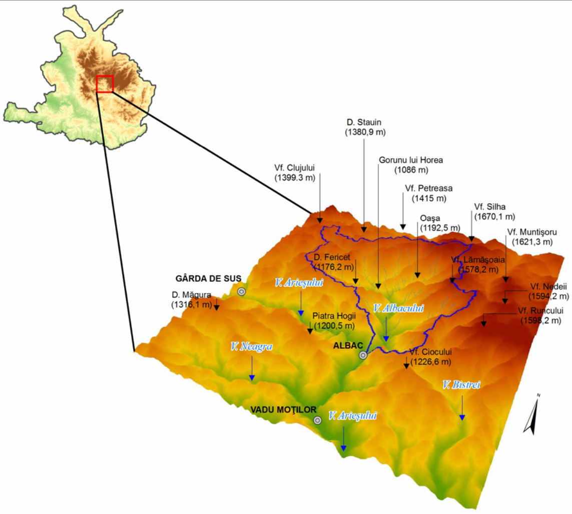


Fig. 2.1. Elements of geographic location of Albac watershed

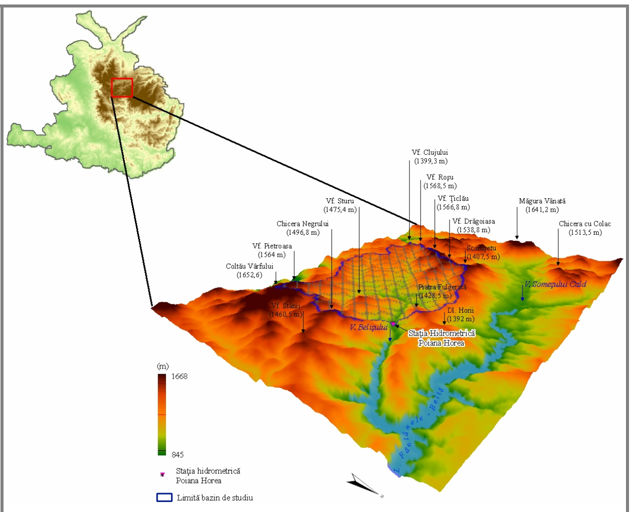


Fig. 2.2. Elements of geographic location of Beliş watershed

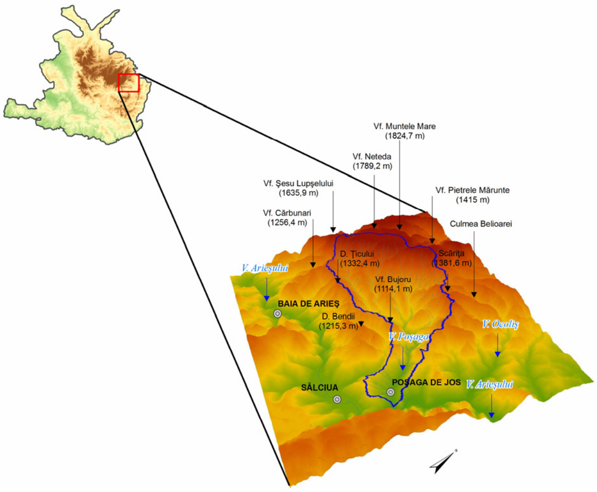


Fig. 2.3. Elements of geographic location of Poşaga watershed

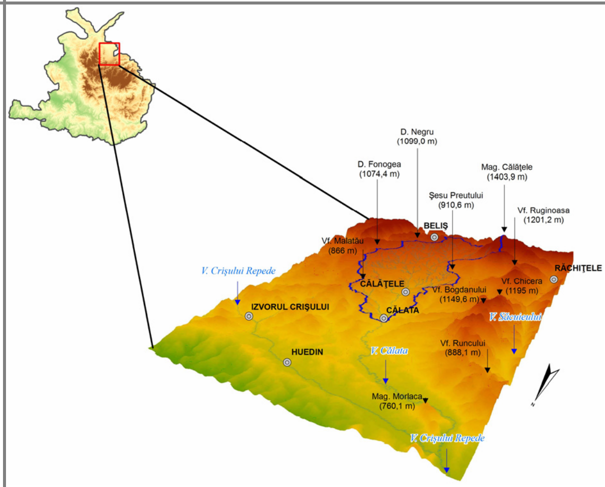


Fig. 2.4. Elements of geographic location of Călata watershed upstream of Călata settlement

3. THE CURRENT NATIONAL AND INTERNATIONAL STATUS OF RESEARCH OF THE PRESENT THEME

3.1. Soil moisture research at national and international level

In Romania there are a very few studies regarding the use soil moisture in high flood evaluation models. The most of these analyses were focues either on characterizing the terrain moisture condition to a large temporally scale (seasonal, annual or multinannual scale), either on studing the soils hidrophysical characteristics for agricultural purpose. *Ujvari I. (1972)*, in the paper *Geografia apelor României,* takes into account, in order to determine the runoff through the balance method, the total mean soil moisture (W_o). The author mentions the fact that the value of total soil moisture hardly depends on the clime humidity, studing, in the same time, the relation between the total soil moisture humidity by basin and mean elevation of th basins (**Fig. 3.1**). The relation W_o is based on the altimetric regional zonality of evapotranspiration components (which decrease with the altitude), respective groundwater (which increase with the altitude). *Haidu I. et colab. (2003)* analyse the soil moisture in the rapport with the risk of production of the extreme event (moisture excess or hydrological drought). To express the seasonality of water balance parameters and dynamics of rainfall-runoff relationship in monthly scale *Vandewiele et al. (1993)*, cited by *Haidu I. et al. (2003)* have developed so called VUB (Vrije Universiteit Brussels) models. These are deterministic models with concentrated parameters simulating basin-scale water balance components. *Simota M. and Mic Rodica (1993)* quoted by *Rodica Mic, Corbuş C. (1999)* developed a calculation relation based on balance, which takes into account past precipitation amount, average daily rainfall, evapotraspiration, the number of days without precipitation, drainage coefficient (dependent on a series of physical and geographical characteristics: slope, soil texture, landuse, etc.).

At an international level, studies on fluid characteristics of the soil have evolved quite profound, traditional methods being complemented by a number of indirect methods based on numeric models, specialized equipment or remote sensing techniques. *Hillel D. (1988)* deals in considerable detail in his paper, all fluid processes occurring in soil. The paper begins with an analysis of soil physical properties (texture, size distribution, structure, etc.) and water properties (molecular structure, density, vapor pressure, capillarity, osmotic pressure, viscosity, etc.), then proceeds to an analysis of processes which compose the water cycle at pedogeographic level (infiltration, soil water redistribution after infiltration, underground drainage, evapotranspiration, water use by plants, etc.). For modeling of infiltration, *Musy A., (1998)* presents two types of models: *models based on empirical relationships with two, three, four parameters* and *physical models*. USDA has proposed, through the *National SCS Handbook (1972)*, to estimate *cumulative infiltration (mm)*, a relationship depending on the amount of precipitation received by a river basin, the initial losses, the maximum retention potential *(Musy A., 1998)*. Estimating the degree of wetting of the soil by means of remote sensing represents subject of many international research projects *(Pardé M., (2003), H. Gao et al., (2004), M. Susan Moran et. Al., (2004), Baghdadi N . et al. (2005), Maria Jose Escorihuela (2006), Tischler M. et al., (2007), etc.*

3.2. The study of flash flood modelling at the national and international level

Therefore, there have been developed, a series of models to simulate the behavior of a river basin for various rainfall conditions. There are, at international level, many researchers that have treated their works related to drainage problems in slope basins, such as: *Roche M., (1963)*, *Ven te Chow Ph. D. (1964), Dubreuil P. (1974)*, *Klemeš V. (1975)*, *Ritzema H. P., (1994)*, *Ambroise B. (1998)*, *Musy A., Higy C. (1998), Bois P.H. (2000)*, *Laborde J. P., (2000)*, *Beven J. K., (2001), Belfort B. (2006), Okonski, B. et al.(2007), Lenar-Matyas A. et al. (2009), Ghanshyam Das (2009),* etc.

Musy A., (1998) describes the main types of models, separated as: physical models, mathematical models, deterministic models, stochastic models. *Ven te Chow Ph. D. (1964),* shows to highlight rainfall-runoff relationship two methods: flow correlation with prior precipitation index (API) and rational formula. *Sherman (1932)* proposes in order to determine the flood hydrograph a method based only on net rainfall intensity curve - *unit hydrograph method* (HU) analyzed and used extensively (*Roche M., 1963; Ven te Chow Ph. D. 1964;Dubreuil P. ,1974; Şerban P. Et al., 1989; Musy A., 1998; Haidu I. 2006*).

Ogden L. F. et. colab. (2001), conducts an analysis of GIS modules developed for the application of hydrological models such as: ARC/INFO Hydrologic Routines, GRASS, GIS/HEC-1, HEC-Geo HMS, WMS (Watershed Modeling Systems), MMS / PRMS (Modular Modeling System, Precipitation Runoff Modeling System), etc. Other hydrological models implemented in GIS: HEC-HMS (Hydrologic Modeling System), SHE (Système Hydrologique Européen), TOPMODEL, SCS-CN (Soil Conservation Services - Curve Number); LTHIA-GIS (Long-Term Hydrologic Impact Assessments); AGWA (Automated Geospatial Watershed Assessment), KINEROS (Kinematic Runoff and Erosion Model), SWAT (Soil Water Assessment Tool); HydroTools; ArcHydro etc.

4. THE DATABASE

4.1 Cartographic database

In what it may concern the cartographic data base, for the soil moisture and high flood study is necessary to use the following types of maps:

a). *topographical maps 1:50.000; 1:25.000* as support for digitizing the next elements:

- contour lines;
- rivers;
- settlements;

b). *soil maps 1:200.000*

These represent the support for generating a digital database for the soil type, texture, structure, using the maps purchase from ICPA Bucharest.

c). ***C**orine **L**and **C**over 2000 database* for landuse analysis, realized in 1:100.000 scale.

d). *geological maps 1:200.000*

The geological maps are important for describing the role of rocks in soil genesis. So, there had been vectorized the rock types for the watershed studied.

4.2 Numerical database

Numerical database necessary for elaborating the thesys has the following structure:

a). *meteorological data* registred to meteorological stations and pluviometrical points located inside and/or neighborhood basins. The main meteorological data necessary for soil moisture and high flood estimation are:

- *daily precipitation*;
- *daily mean temperature*;
- *daily maximum and minimum temperature*;
- *monthly mean air preasure*;

b). *Hydrological data* (*maximum discharge*) registered from hydrometrical stations. These data are necessary to validate the maximum runoff model.

4.3 Primary GIS dataset

a). For some applications, ***elevation*** informations, necessary in spatial analysis of terrain configuration, was based on topographical 1:50:000 and 1:25.000. The maps were georeferenced using , **Stereo 1970** projection, later it was realized contour lines vectorizing (**Fig. 4.3**).

b). ***The rivers*** had been vectorized using topographical maps 1:25.000; the attribute database contains the next information: rivers name, rivers length, rivers type (permanently, temporary) (**Fig. 4.4**). For analysis the rivers evolution level was generated the stream order, using **S**tream**O**rder extension.

Using topgraphical maps 1:25:000 it was created, also, a polygon vector database for ***the settlements*** in the four studied watersheds.

c). As for the ***geological layer***, it was created a polygon vector GIS database, with attribute “rock type”. The vectorizing was realized using the geological maps 1:200.000.

c). As for ***the soils***, it was realized a polygon vector GIS database (**Fig. 4.6, 4.7, 4.8, 4.9**), using the soil maps 1:200.000 and other papers. Attribute database contains the next information: soil types, SRTS 2003 symbols, texture, structure, hydrologic soil group (HSG).

d). For the analysis of landuse it was used the **C**orine **L**and **C**over 2000 database. The polygon vector layer has a spatial detail comparable with a topographical map 1:100.000.

4.4. Derived GIS database

This chapter present the raster database generation, focused by the morphometric characteristics of watershed (Digital Elevation Model, slope, slope lenght, aspect, hillshade, plan curvature, vertical curvature etc.).

Digital Elevation Model (DEM), known frequently as Numerical Terrain Model (MNT) or Digital Terrain Model (DTM) describes the spatial continuous terrain configuration (*Moore I. D. et colab., 1991; Hengl T. et colab., 2003*). The cartographic representation of altitude and, indeed, of relief configuration is named hypsometric map. For the study applications it was prefer to use a DEM obtained from ASTER (**A**dvanced **S**paceborne **T**hermal **E**mission and **R**eflection **R**adiometer) database with 21,5 m spatial resolution. This Digital Elevation Model has an accuracy comparable with the topographic maps 1:25.000.

The land slope is the major morphometric element with high degree of importance in the hydrological system, influencing the complex of parameters such as: infiltration velocity, capilary flow, soil water retention capacity, subsurface runoff, flow speed and flow direction, hillslope runoff, lag time, time of concentration.

5. CLASSICAL METHODOLOGY FOR INDIRECT SOIL MOISTURE ESTIMATION

5.1. General methodological context

a). Direct methods based on soils sampling and laboratory research. These methods can be applied either extracting the water from soil sample (metoda uscării le temperaturi ridicate – *metoda gravimetrică*, metoda arderii cu alcool, metoda reacţiilor chimice – cu acid sulfuric sau nitrat de amoniu) either by using the procedures based on the difference between water and soil density or the procedures based on the absorption of different radiations.

b). The indirect methods can be applied “in situ”, using apparatus, either at a distance, by remote sensing techniques or numerical models based on physical parameters research of soil moisture process. These section contain methods such as: *tensiometric method; electroconductometric method; reflectometric method* (TDR – **T**ime **D**omain **R**eflectometry or

FDR – **F**requency **D**omain **R**eflectometry)*; neutronic method; remote sensing techniques; soil moisture conditions indices; numerical models; procedures based on GIS analysis.*

5.2. Indices for characterizing soil moisture

Used to highlight the water extremes phenomena - drought and excess moisture, most rely on weather information over the study area at monthly, annual or multiannual scale and such indices as: soil hydro-physical indices (coefficient of hygroscopic, wilting coefficient, etc.) , De Martonne index, Thornthwaite global moisture index, Seleaninov-Budîco moisture index, Koncek index, Lang index, Palmer index to assess severity of drought (PDSI), the standardized precipitation index (SPI), rainfall infiltration index, etc.

5.3. Metoda SCS pentru estimarea indirectă a infiltraţiei cumulative

SCS (Soil Conservation Service) has proposed, for estimating infiltration - *cumulative infiltration (Musy A., C. Higy, 1998),* a relationship depending on the amount of precipitation received by the basin, the initial losses, and the maximum retention potential:

$$F = \frac{S \cdot (P - I_a)}{P - I_a + S} \qquad (5.20)$$

-where:

F - cumulative infiltration (mm)

P - rainfall (mm)

I_a - initial abstraction (evapotranspiration, retention in the canopy);

S - maximum capacity of retention;

Following numerous experiments, SCS proposed for estimating the initial losses (I_a) an empirical relationship (*USDA, 1997; Mishra, S. K., Singh, V. P., 2003, Baltas E. A. et al., 2007*):

$$I_a = 0{,}2 \cdot S \qquad (5.22)$$

The computation of parameters for water retention is made by applying the following relations:

$S = \frac{1000}{CN} - 10$ (when the quantity of water is expressed in inches); *(5.23)*

$S = \frac{25.400}{CN} - 254$ (when the quantity of water is expressed in mm); *(5.2*

- where: CN = f (soil, vegetation, soil recovery mode, land use, antecedent soisture conditions)

In a first stage, indices CN_{II} are taken into account for normal moisture conditions, so that, where appropriate, an adjustment to take place in relation to their previous moisture conditions (AMC I, II or III).

5.4. Balance method for indirect soil moisture estimation

A method for characterizing the state of wetting of the pedosphere layer is proposed by *Simota M. and Mic Rodica* (1993), and used subsequently in a study to estimate the maximum flow for large floods (*Mic Rodica, Corbuş C., 1999*). This method is based on a balance equation that takes into account the following parameters: flow rate, evapotranspiration, the sum of daily average rainfall for ten days before the day of calculation, the number of days without rain:

$$U = (1-\alpha)\cdot(\sum_{i=1}^{10} Pi) - N \cdot E_t \quad (5.27)$$

-where:

Pi - average daily rainfall amount

N - number of days without precipitation

α - coefficient of discharge

Et – evapotranspiration

6. GIS METHODOLOGY FOR INDIRECT ESTIMATION OF SOIL MOISTURE

6.1. GIS functions used for the study of soil moisture

In this chapter, it is analyzed issues regarding the contribution of GIS technology in developing the study: a. creating a GIS database related to the parameters that influence soil moisture, b. generating new data sets from the original stored data (eg DEM generation using the digitized contours on topographic maps or using elevation points obtained through GPS techniques) c. integration equations for calculating soil moisture GIS d. allowing the construction of modules for automatic calculation of infiltration, moisture soil drainage e. mapping results), then provides a summary table on the main GIS functions can be used in the study of soil moisture (Table 6.1).

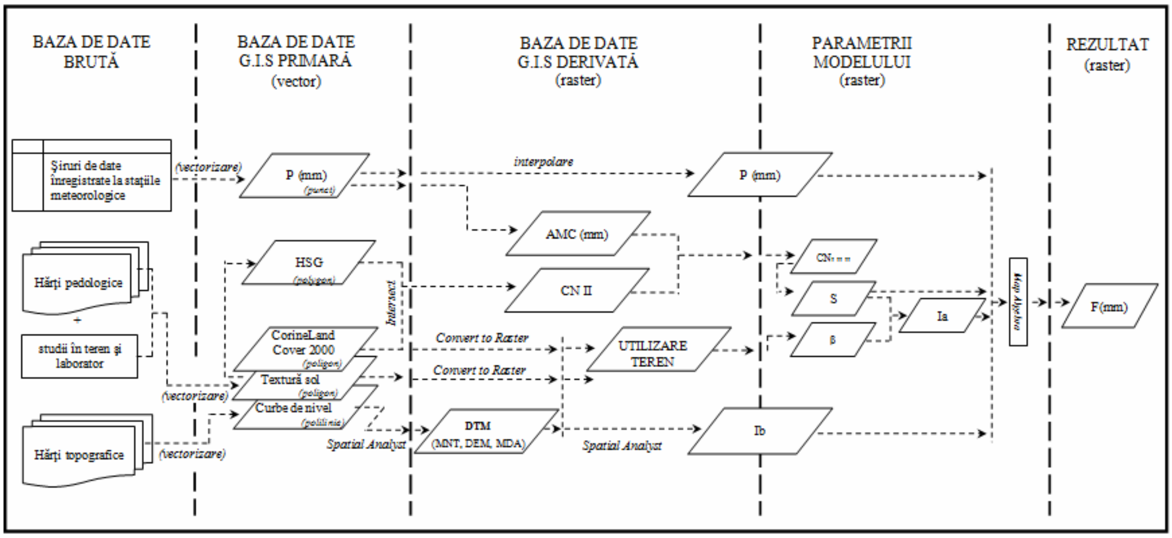
6.2. Algoritm GIS de estimare a infiltraţiei cumulative utilizând metoda SCS

6.2.1 General considerations

Studying the SCS model it have been seen some weaknesses that have imposed some improvements, we believe, the method described in subsection 5.3. Most important problem is the failure to take into account the slope and hence the ability to characterize each surface drainage. Including this parameter's mathematical relation to calculate the cumulative infiltration will take the following form:

$$F = \frac{S\cdot(P-I_a)}{P-I_a+S}\cdot(1-Ib/100) \quad (6.1)$$

- unde: Ib – slope (degree)



[P (mm) – suma zilnică a precipitaţiilor; HSG – clasa hidrologică de sol; CN II – indicii Curve Number pentru condiţii normale de umezeală anterioară; AMC – condiţiile anterioare de umezeală în funcţie de precipitaţiile pe ultimele 5 zile; $CN_{I,II,III}$ – indicii Curve Number adaptaţii condiţiilor anterioare de umezeală; S – potenţialul maxim de retenţie; β – capacitatea vegetaţiei de a întârzia drenarea către sol a apei interceptată iniţial; Ia – pierderile iniţiale; Ib – panta (grade); F (mm) – infiltraţia cumulativă]

Fig. 6.1. GIS algorithm to estimate the cumulative infiltration using the SCS method

GIS algorithm developed for indirect determination of the infiltration of rain is based on GIS integration of all parameters that define the SCS method. The sequence of operations to be performed to calculate the cumulative infiltration is shown in **fig. 6.1**.

6.2.2 The developed GIS module

For synthesising the steps for implementing the algorithm and reducing the volume of work and of time we have built an ArcGIS module able to perform automatically the calculation of cumulative infiltration. F**ig. 6.2** represents the graphical interface developed. Due to seasonal differentiation regarding on the one hand the influence of the past rainfall on the establishment of past moisture conditions (AMC), and on the other hand the influence of vegetation on the coefficient β, the module has been divided into two sub-modules: a sub-module for the calculation of cumulative infiltration for the period with vegetation (March-September), a sub-module for calculating cumulative infiltration during winter (October-February).

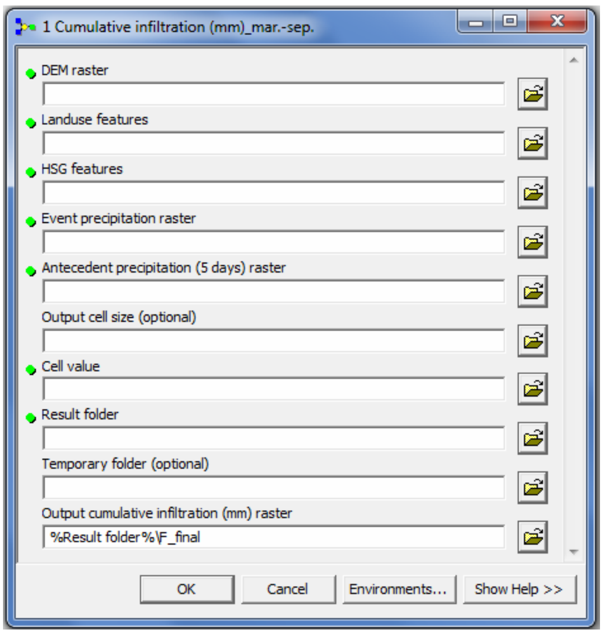


Fig. 6.2. Interfaţa grafică a modulului de calcul a infiltratiei cumulative

After entering the above metioned data and the running of the module, in addition to cumulative infiltration final result, a series of intermediate results of layer type will be obtained as well, namely: the Curve Number index, coefficient β, the maximum retention capacity, initial losses, the slope of the land. The working time of the module is of several minutes, depending on computer performance, on the basin area or the study area and the spatial resolution.

6.2.3 Spatial representation of algorithm's parameters

At this stage it is intended that for each parameter consisted by SCS method to achieve a raster format layer, and then, using map algebra operations lead to obtain maps of cumulative infiltration for different rainfall events. **Fig. 6.3** shows the primary and derived set of layers for the analysis of spatial cumulative infiltration.

Spatialization of the daily amount of precipitation

For the spatial representation of daily precipitation amounts in the Apuseni Mountains area we used an algorithm based on the Kriging method taking in account the relief, as a key factor in the spatial distribution of precipitation values. This model can be classified as a residual Kriging, a so-called trend model.

Raster layers of the other parameters of the model (*Curve Number index, the potential maximum retention, initial abstraction*) were obtained automatically when running the computation module for infiltration.

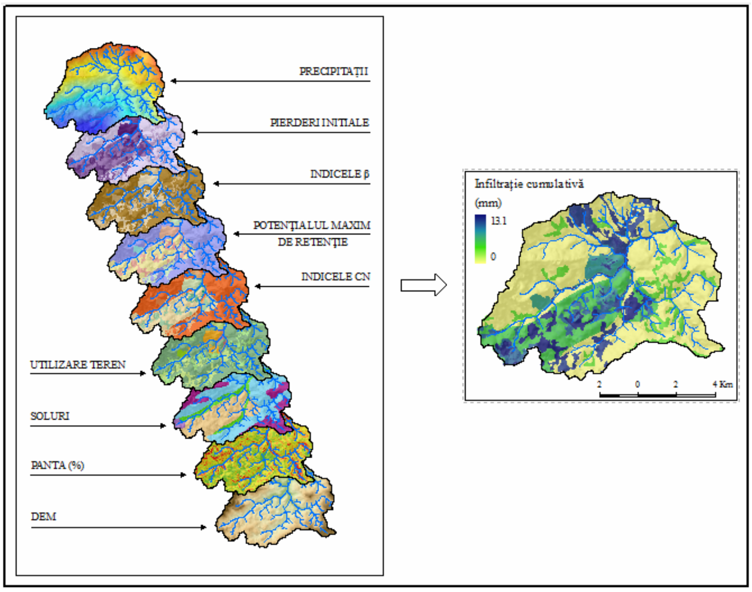


Fig. 6.3. Layere necesare pentru spaţializarea infiltraţiei cumulative

6.2.4 Applications and results

In this part of the paper, there ar presented the results of the cumulative infiltration for a few rainfall events recorded in the study area. Two of the selected intervals were applied to all four study basins: the interval 16 to 19 July 2002 and 7 to 10 August 2006. At other studies (articles, PhD reports) were made applications to the presented methodology for estimating cumulative infiltration and other successive periods of rain. Such an application was made in Beliş basin from 18 to 30 October 1992. Another application was made in the Poşaga Basin and hinted the month June 1997. The following is an example only for the result for the period 16 to 19 July, 2002 for Beliş and Albac basins.

Albac watershed. On July 16, 2002, although precipitation in some places exceeded 20 mm/m2, infiltration has been estimated at less than 6 mm on wide areas in a few cases were > 6-8 mm (**Fig. 6.19**). Infiltration areas > 2 mm generally overlap the perimeter of unwooded areas from settlements' perimeter: Mătişeşti, Dirleşti, Petreasa, Giurgiuţ, Buteşti, Horea, Manceşti,Albac. On July 17, due mainly rainfall > 30 mm/m2, characterized by the infiltration area > 6-8 mm extends a lot, values below 2 mm remain only in the area occupied by coniferous forests and are characterized by greater interception capacity.

Beliş watershed. On July 16, 2002 the water layer affected by infiltration process on small areas exceeded the value of 6 mm. Most of the basin was characterized by the infiltration values below 2 mm, even 0 mm (**Fig. 6.20**).

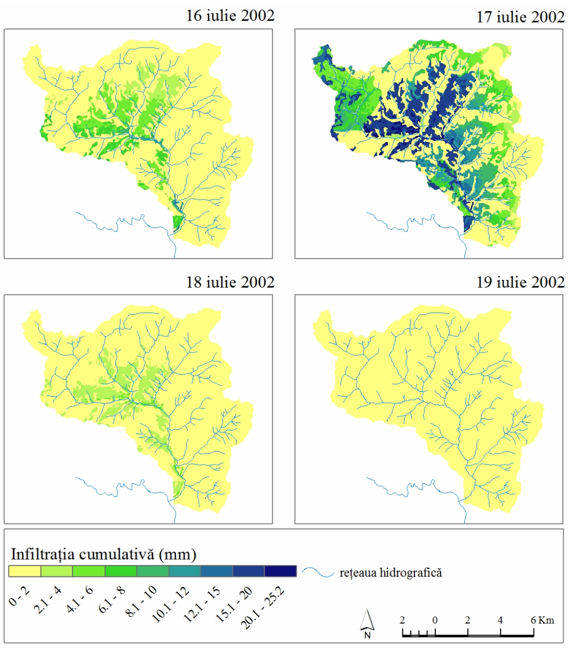


Fig. 6.1. Albac Basin. Spatial distribution of cumulative infiltration from 16 to19 July 2002

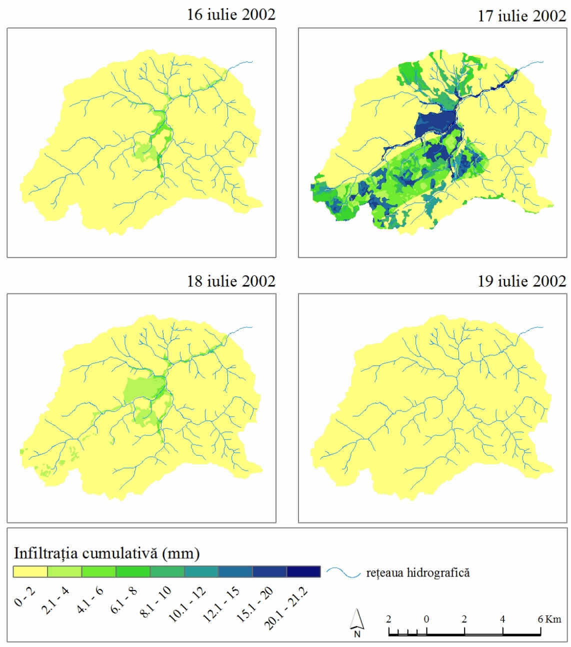


Fig. 6.20. Beliş Basin. Spatial distribution of cumulative infiltration from 16 to19 July 2002

Weak expression of infiltration process can be put primarily on account of not very high amounts of rainfall at the basin level (2-6 mm/m2 in the middle and lower basin, namely 6 to 12 in the upper mm/m2). O course, the genetic factor, low infiltration, or even absent on large areas is explained by physical and geographical conditions of the basin (coefficient of afforestation ≈ 0.8 and the presence of soil texture mainly clay loam and sandy loam with medium capacity, even low infiltration).

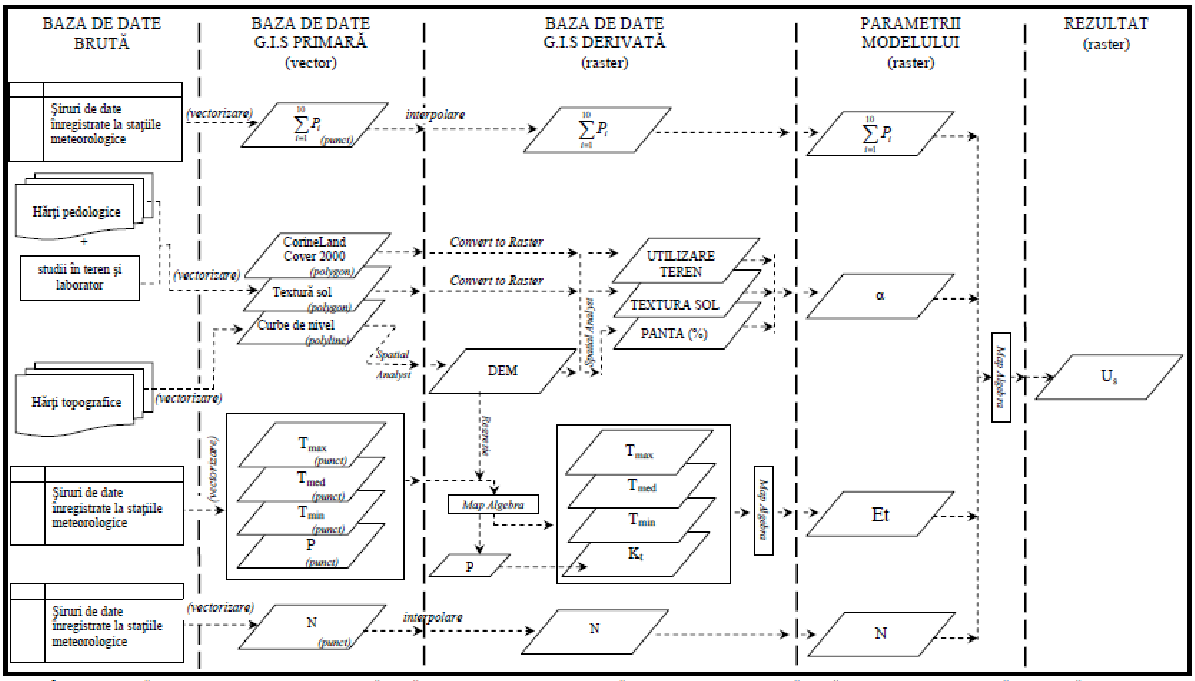
On 17 July 2002 its is exposed an expansion of the area showing the process of infiltration. Cumulative infiltration values border quite large surfaces between 6-10 mm, sometimes even surpassing the 20 mm. Physic-geographical characteristics of the land being unchanged, this increase is explained by the infiltration of rainfall event that exceeded 20 -30 mm/m2. The highest values in overlapping areas are unwooded in the perimeter of Poiana Horea village (Fig. 6.20). In the days following rainfall decrease leads to reduced water intake to pedosphere environment.

6.3. GIS algorithm for estimating soil moisture using the balance method

6.3.1 General considerations

The purpose of this chapter is the development of a GIS algorithm is supported using the balance method described in Section 5.4 to check for soil moisture characterization.

Similar with the algorithm for calculating the cumulative infiltration there were taken in consideration all five components for designing the GIS algorithm to estimate soil moisture. The chain of operations to be performed is presented in graphical form in the general scheme of the GIS methodology for estimating soil moisture using the balance method (**Fig. 6.31**).



[P_i – suma zilnică de precipitaţii; T_{max} – temperatura maximă zilnică (°C); T_{med} – temperatura medie zilnică (°C); T_{min} – temperatura minimă zilnică (°C); P – presiunea atmosferică medie lunară (hPa); K_t – coeficient empiric; N – numărul de zile fără precipitaţii; α – capacitatea de scurgere (coeficientul de scurgere theoretic); Et – evapotranspiraţia zilnică (mm); U_s – umezeala solului]

Fig. 6.31. Schematizarea algoritmului GIS de estimare a umezelii solului folosind metoda bilanţului

6.3.2 The developed GIS module

For the method for determining the cumulative infiltration, was built a module, a toolbox in ArcGIS able to automatically calculate the scale soil moisture using daily balance method described above. The module or toolbox was developed in ArcGIS Model Builder and had three parts (Fig. 6.32):

1. a sub-module for determining daily evapotranspiration (*Daily Evapotranspiraţion*)
2. a sub-module for determining the theoretical coefficient of leakage (*Frevert runoff coefficient*);
3. a sub-module for determining soil moisture (*Soil Moisture*);

In **Fig. 6.33** Soil Moisture sub-module interface is presented, the other sub, because it addresses two of the model parameters (flow rate, ie evapotranspiration), will be described in next section *Representation of spatial parameters of the algorithm*).

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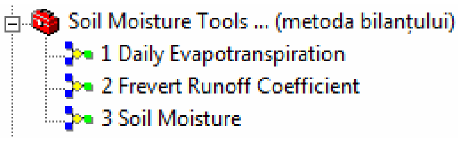

Fig. 6.32. The toolbox structure developed for ArcGIS for soil moisture estimation using the balance method

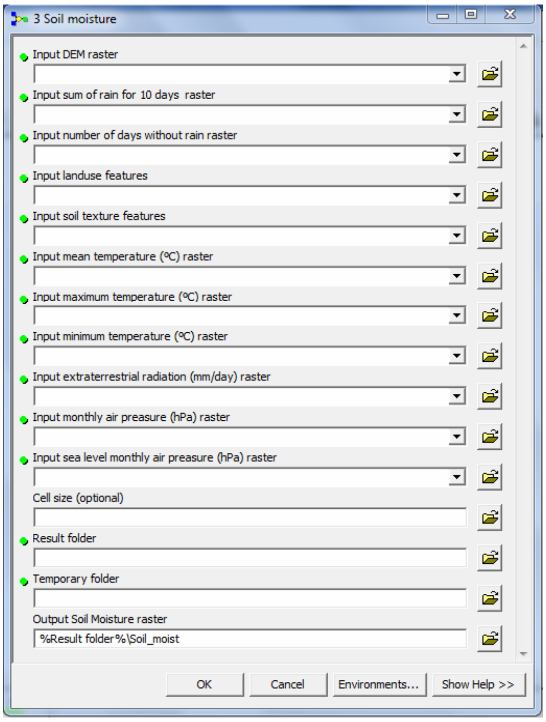

Fig. 6.2. Interfața grafică a modulului GIS dezvoltat pentru calculul umezelii solului folosind metoda bilanțului

6.3.3. Spatial representation of the number of days without precipitation (N)

The chapter focuses, as with SCS model, the presentation of the methodology of GIS spatial analysis of all variables necessary application of balance method, is about parameters such as: daily rainfall, number of days without precipitation (for 10 days prior) average temperature, daily maximum and minimum, monthly average atmospheric pressure, daily evapotranspiration, surface flow potential (theoretical flow coefficient).

Reprezentarea spațială a numărului de zile fără precipitații (N)

Parameter N provides an insight into reducing the stock of soil water content due to an increased number of days without precipitation the dominant process remains evapotranspiration.

Generating raster layer on the numbers of days without precipitation was made using **Ordinary Kriging** interpolation method.

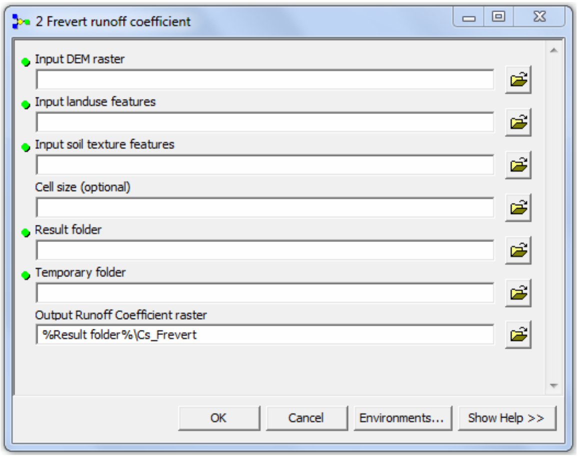

Fig. 6.35. GIS interface sub-module for estimating Frevert leakage coefficients

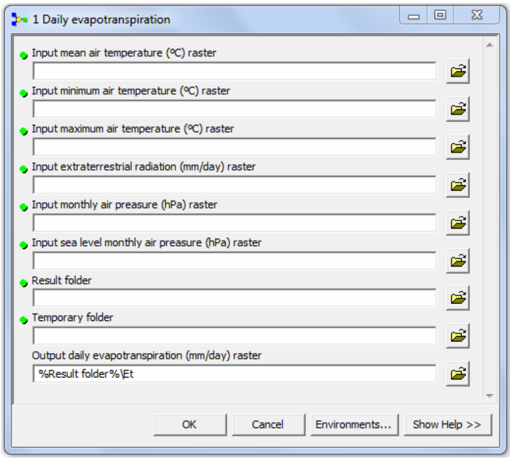

Fig. 6.38. GIS graphical user interface sub-module developed to calculate evapotranspiration

Spatial representation of the theoretical flow coefficient (α)

To support the spatial representation of the theoretical flow coefficient was achieved running the computation module of soil moisture, a sub-module (Fig. 6.35) using Frevert synthesis and is based on a case type procedure named Overlay Unique Conditions.

Spatial representation of daily evapotranspiration

Spatial representation of daily evapotranspiration was achieved through integration into GIS Hargreaves- Samani method. Developed through a sub-module (Daily Evapotranspiration), the calculations can be done automatically for every day. In Fig. 6.38 it can be seen the graphical user interface of the present sub-module.

For its implementation it is necessary previously to achieve the raster database for: average temperature, minimum and maximum for air, monthly average atmospheric pressure, the

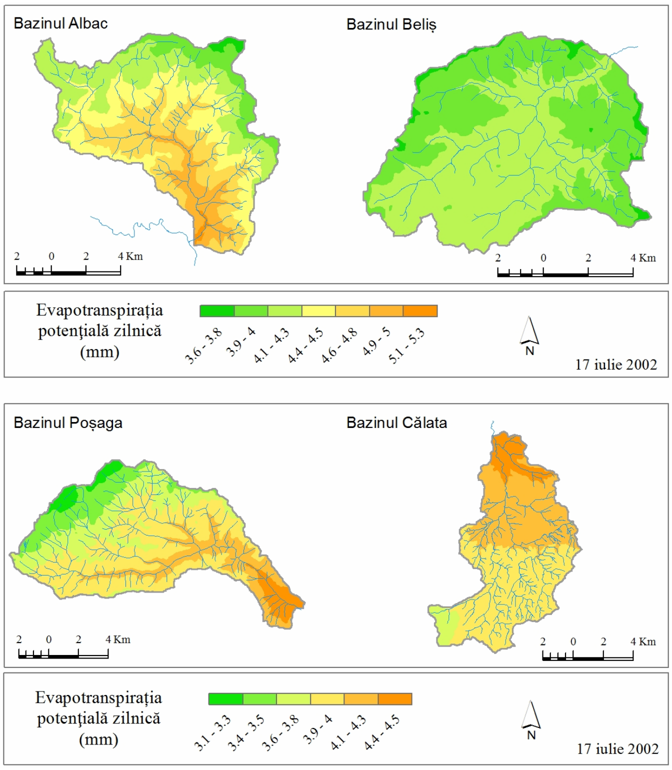

Fig. 6.47. Distribuţia spaţială a evapotranspiraţiei potenţiale zilnice la nivelul celor patru bazine de studiu (exemplu: 17 iulie 2002)

average atmospheric pressure at sea level in that month, the incident radiation from outside the atmosphere. Regarding the spatial distribution of potential evapotranspiration in the present four study basins for example, in Fig. 6.47can be seen the results obtained on 17 July 2002.

There are, however, days, especially during summer, the water reserve tank is below the potential evapotranspiration. Under these conditions real evapotranspiration will be represented by the value of the stock of existing water inside the tank at the time. It is, of course, the case of water intercepted by vegetation and soil water reserve. In order to determine the actual evapotranspiration was developed an algorithm that works as an ArcGIS module to achieve automated calculations. Applying this algorithm for the day provided an example for the spatial distribution of potential evapotranspiration (Fig. 6.47) it has been revealed that for this case the actual evapotranspiration corresponds with the potential evapotranspiration.

6.3.4. Applications and results

Several applications have been made for the algorithm for calculating the moisture from the four study basins, but we will present only the results for days 17 and 18 July 2002 for Belis and Albac basins.

Under spatial reference, it is shown an increase of moisture in relation to altitude, also an increasing within soil moisture in areas characterized by fine textured (clay-loam) in those with coarse texture (sandy-loam). However, it should be noted that fine-textured soils, although they are known as having a low infiltration capacity, have more retention capacity instead. During a heavy rain, the volume of water infiltrated into the upper unwooded soil horizons is greater, due to lower interception, but exposure to evapotranspiration is higher. This would be the explanation for the lower estimated values model, sometimes the lack of moisture in the land occupied by pastures or meadows.

In **Albac watershed**, the highest values of soil moisture estimated overlap the clay-loam textured soils characterized by a high capacity of infiltration. These maximum values correspond, however, to areas of convergence of the drainage network, due to reduction of land slope (Fig. 6.50). Low capacity of water disposal in clay-textured soils from the upper basin, upstream of the confluence with the main river course Coşului Valley, completed and well by significant quantities of precipitation, explaining the increase of moisture in the area on the 18th of July 2002.

In case of **Belis watershed**, significant enough moisture on the 18th of July 2002 (Fig. 6.53) can be attributed to rainfall interception and infiltration generated the previous day, rainfall whose activity continues on the 18th of July 2002 to values of 10-12 mm.

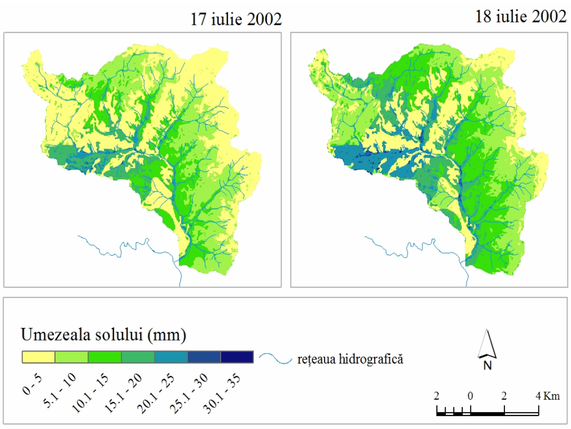

Fig. 6.3. Albac watershed. The spatial distribution of moisture soil estimated by balance method

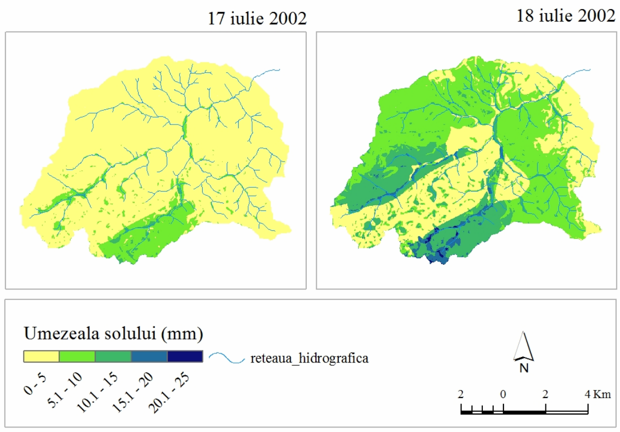

Fig. 6.4. Belis watershed. The spatial distribution of moisture soil estimated by balance method

7. HIDROPEDOLOGICAL STUDY FOR AN EXPERIMENTAL BASIN

In addition to the application of numerical computational models, determining soil moisture conditions can be achieved both directly, by collecting soil samples and studying them in the laboratory, and indirectly through the use of specific equipment. In our country, one of the most known and used procedures for characterizing the soil hydrological point of view is based on sampling the soil profile and their study in the laboratory. This procedure has the advantage of high accuracy, but the disadvantage of highlighting only a momentary situation with regard to soil moisture conditions, being practically impossible to determine the moisture before each rain event forecasted.

It was realized, however, an applied field study with a team of researchers from OSPA Cluj deployed in a campaign in summer 2009 at the contact Gilău Massif-Muntele Mare with Transilvnia Hollow, the study being focused on the right side of the Basin Hăşdate. The field study consisted in the development of soil profiles, soil taxonomic classification, sampling of soil core profiles. Subsequently, laboratory analysis and boundaries of soil units were made by OSPA Cluj staff. In the area of study we selected a small basin area approx. 8 km2 (Hăşmaş basin) in which, on the basis of the observed field and laboratory elements, we proceeded to:

- creating a digital database on primary delineated soil units and soil profiles;
- calculation of key hydro - physical soil indicators and their spatial representation;

7.2 Pedological data collection in the field

7.2.1 Implementation of the soil profiles

The basin area Hăşmaş it have been made in the summer of 2009 a total of more than 50 soil profiles and for 10 of these samples have been taken to carry out laboratory analysis. In Fig. 7.4 we can see the spatial distribution of primary and secondary profiles made in the experimental basin and adjacent area.

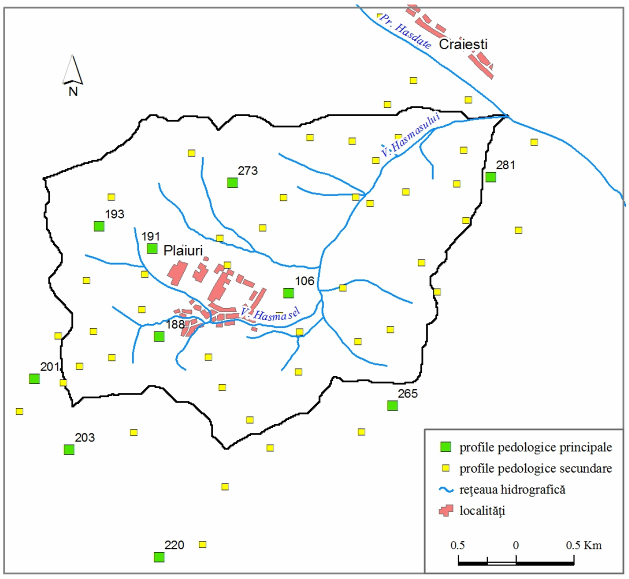

Fig. 7.4. Hăşmaş watershed. Spatial distribution of soil profiles

7.2.2 Soil profile description and sampling

The morphological features of the soil are studied and noted in the ground job profile: horizons or sub horizons depth, horizon designation, color, frequency and spot size, texture, etc. In Fig. 7.6 shows the characteristics of some pedological soil profiles made in the basin.

7.3 Pedogeographic features with a role in determination of ground water reserve

Moisten of the soil can be easier or harder, water gives up faster or slower according to several features that are interrelated: texture, structure, soil profile thickness, porosity, permeability, infiltration rate, capillary ascent, etc. (**Fig. 7.7**).

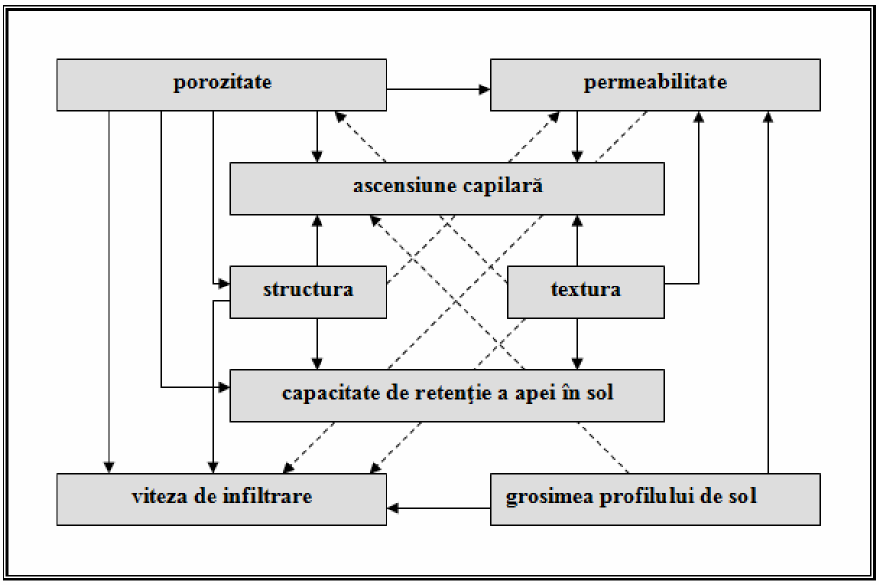

Fig. 7.7. Inter-relationships of the main pedogeographic features with role in the distribution of soil water reserve

7.4 GIS database for the specific field collected pedological elements

Pedological data collected from field work and then the results from laboratory tests were used to generate a GIS database on the elements of importance in the study of water characteristics of soil. It is therefore, about the development of digital maps, vector polygon format, representing soil types, as well as the database of digital point vector format (Fig. 7.15), and the profiles of soil samples collected for analysis laboratory. The database of soil profiles is composed of the following attributes (Fig. 7.15b): name of soil type, clay content (average field), the wettability index (average profile), density (mean profile). These elements created a base for determining the total porosity of soil and then hydro-indices of the soil (wilting coefficient, field capacity, total capacity for water, moisture equivalent.

7.5 Determination of hydro-phisical soil indices

At this stage hydro-indices were calculated for each soil horizons corresponding to the 10 main sections. They were subsequently spatially interpolated average values of these indices by Ordinary Kriging method (Fig. 7.18). Of utmost importance hydro indices for the study of soil moisture belong to the total capacity for water (CT) and moisture equivalent (EU). Knowing the total water capacity may determine the degree of saturation of soil in water, and this should help a lot in anticipation of a flood, and highlight areas with high vulnerability to floods. Equivalent humidity shows the capacity of a soil to retain water, giving importance to the development of the infiltrated layer from one rainfall event to another.

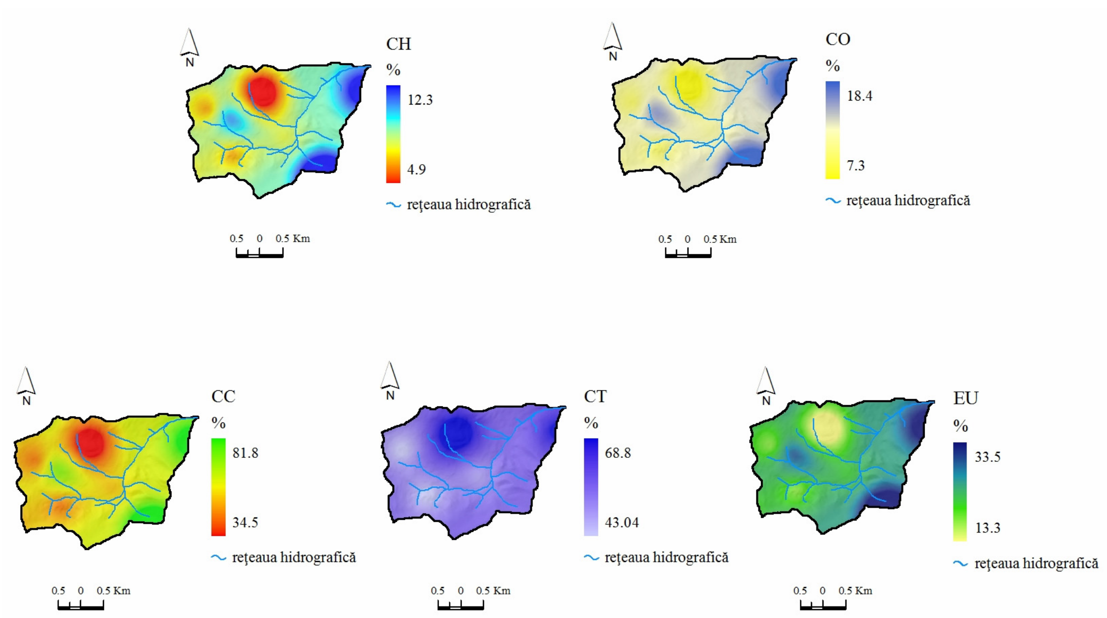

Fig. 7.1. The spatial distribution of key hydro-physical soil indices

8. MODELING OF HIGH FLOOD GENERATED BY RAIN TAKING IN ACCOUNT SOIL MOISTURE CONDITIONS

If a rain event likely trigger a flood, soil plays a buffer between the size of gross rainfall and net rainfall. Previous soil moisture conditions will put their mark on both the volume of water available for drainage and the flow rate or time of concentration of slope basins. In Fig. 8.1 is presented schematically where soil moisture can be placed inside rainfall-runoff processes.

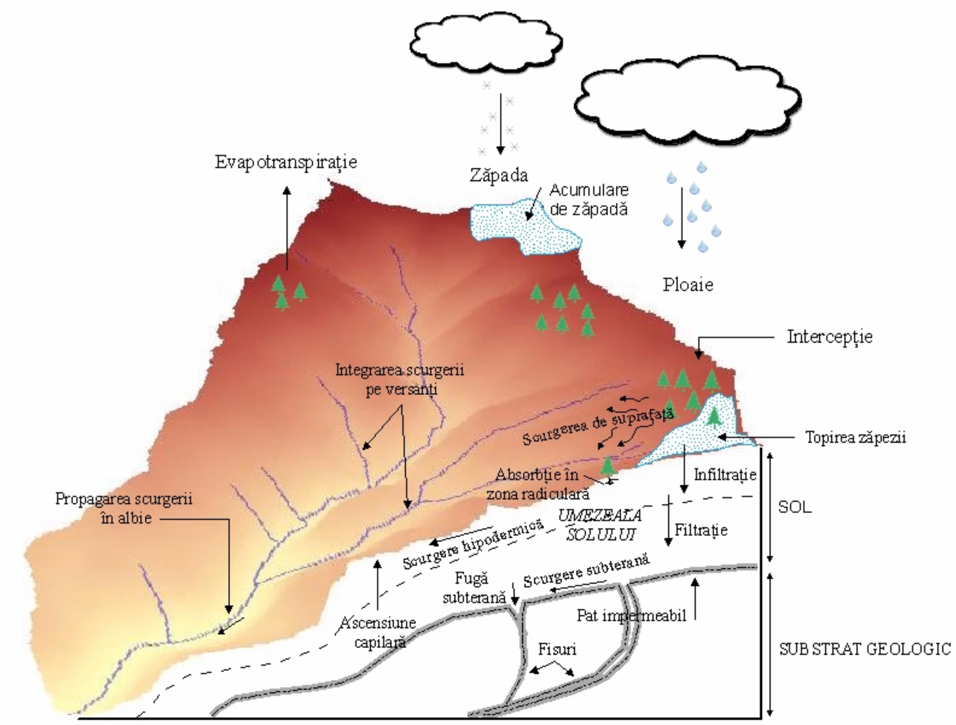

Fig. 8.1. Location of soil moisture in rain-runoff process

8.1 General methodological background on flood modeling

In this chapter a summary was made on the most known models for anticipating floods, being realized a classical description of both methods on flood modeling and models which operates by means of GIS techniques.

8.2 GIS flood modeling algorithm knowing the soil water content

This chapter aims to strengthen the methodology, based on the use of geographic information systems, regarding flood modeling. Emphasis will be on:

a). estimate the quantity of water available to drain (net rainfall) knowing prior conditions of soil moisture and water infiltrated layer;

b). determining drainage coefficients for different rain seasons;

c). Integration of slopes flow and determination of runoff hydrograph in different sections of the basin;

In **Fig. 8.3** it is shown the sequence of steps that compose the GIS flood modeling algorithm when the water infiltration layer is known.

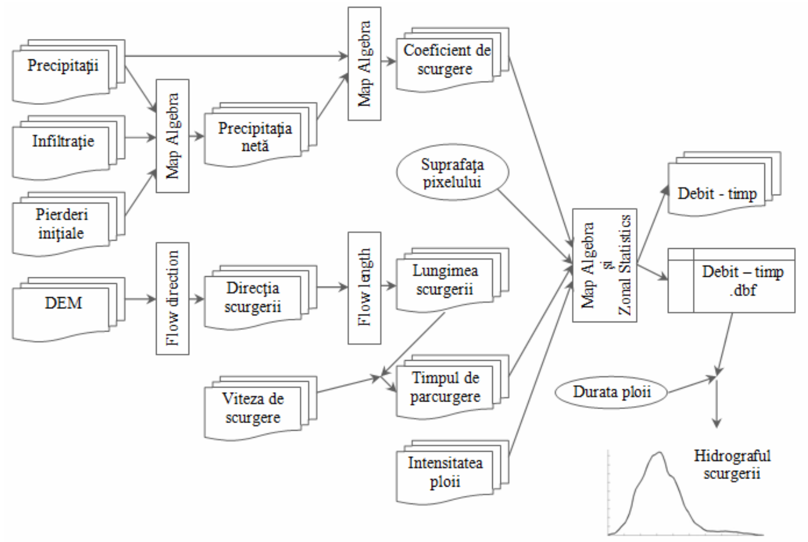

Fig. 8.2. GIS flood modeling algorithm schema taking in account soil water infiltration

8.2.1 Estimating net rainfall and the runoff coefficient

8.2.1.1 Calculation Equations

One of the most famous equation for calculating the flow layer upon which SCS model does not account directly for the amount of water infiltrated. This equation is as follows: (*USDA, 1997; Mishra, S. K., Singh, V. P., 2003; Mishra S. K. et al., 2006, Mihalik N. Elizabeth et al., 2008*).

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad (8.3)$$

- where:

Q - drained layer (mm)
P - the amount of precipitation (rain and snow) (mm)
I_a - initial abstraction (evapotranspiration, retention in the canopy, other retentions);
S - potential maximum retention;

For the current study, water layer available for proper drainage (Q (mm)) was estimated using an equation that takes into account directly infiltrated water layer (Musy A., C. Higy, 1998):

$$Q = P - I_a - F \qquad (8.5)$$

- where:
P - rainfall (mm)
I_a- Initial abstraction (mm)
F - cumulative infiltration (mm)

8.2.1.2 GIS Methodology

This part of the study is to present GIS methodology which was the basis for estimating net rainfall and the coefficient of drainage. Note that the algorithms were developed for the determination of net rainfall from both the SCS-CN method and the balance method. In Fig. 8.4 it is presented schematically the procedure for obtaining a map layer available for discharge using SCS-CN method.

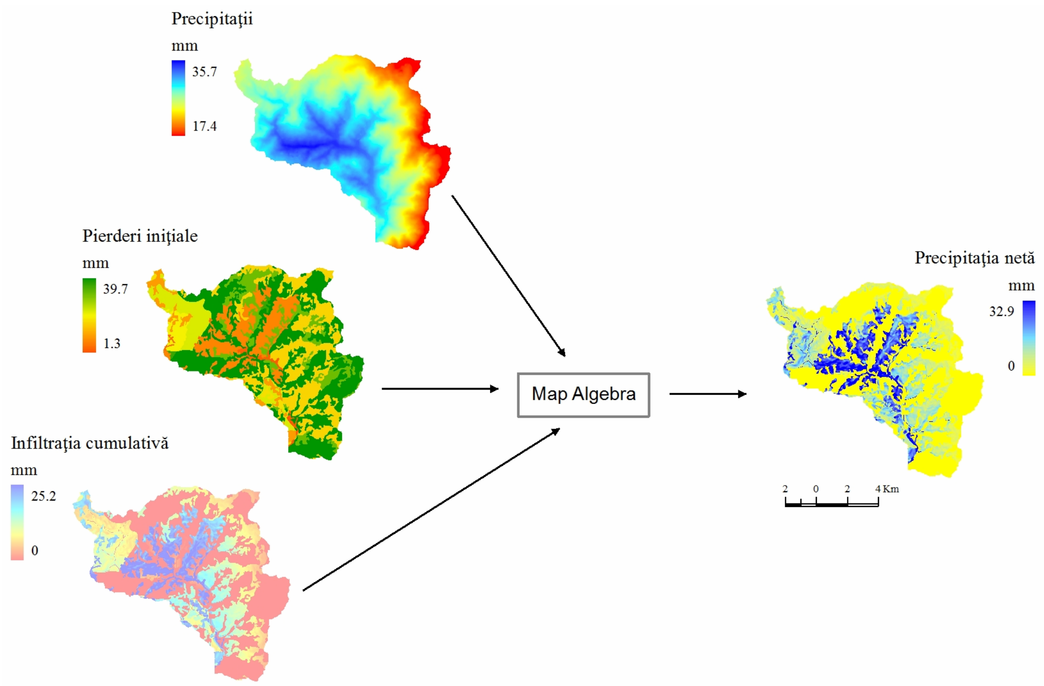

Fig. 8.3. Spatialization schematization algorithm of net rainfall using SCS-CN method

8.2.1.3 Applications and results

In Fig. 8.7 there are presented the results available for drainage layer (for example on July 17, 2002) obtained from applying the algorithm based on SCS-CN method. It is generally found increases in net precipitation in relation to the level of deforestation and the sandy or sandy-silty soils (hydrologic class A), to those characterized by high content of clay, water is assigned the class C or D.

A more conclusive hydrological situation of the day July 17, 2002 offers the spatial distribution of flow coefficients, obtained from the ratio of the layer available for runoff and precipitation (equation 8. 8). The results shown in Fig. 8.8. Areas with the highest lift coefficient values reveal the leak is Albac basin, respectively Calata situation was explained, on one hand, quite significant amounts of rainfall in this day and on the other hand, a lower coefficient of afforestation for these two basins. For Belis Basin, although the rainfall was quite heavy dominance of coniferous forests, generally overlapping of clayey-sandy soils with good infiltration capacity of rainfall interception that manages to exceed the threshold, leads to extremely low values of coefficient drain.

Another application in the same four basins was carried out for between 7 to 10 August 2006. There was also a study on the flow of the basin upstream Belis hydrometric Poiana Korea station, in the event of rainfall from the second decade of October 1992.

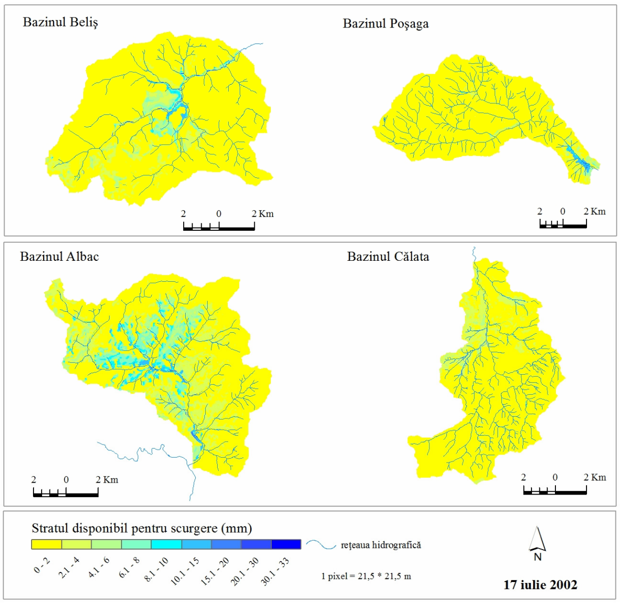

Fig. 8.7. Spatial distribution of drainage available layer obtained using SCS-CN method (example: 17 July 2002)

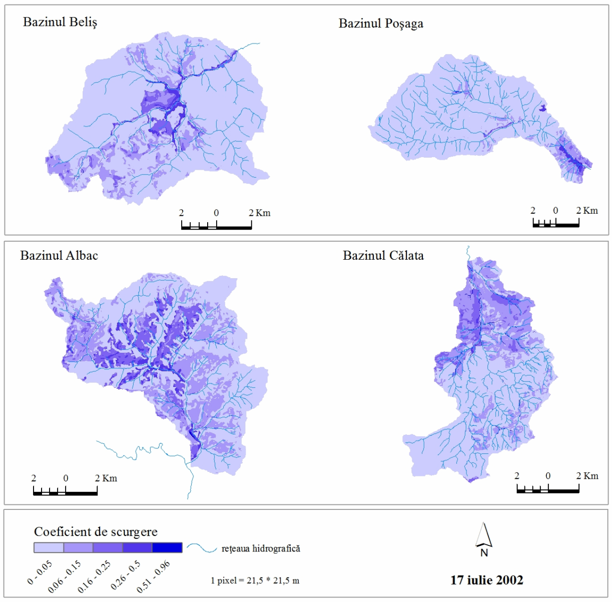

Fig. 8.8. The spatial distribution of flow coefficients from the parameters determined by the SCS-CN method (example: 17 July 2002)

8.2.2 Integration of hillslopes runoff method using digital izochrone method.

Slopes runoff formation and its integration with the river network (transfer function) is characterized by great complexity due to the temporal-spatial variation of rainfall, infiltration and physico-geographical factors basin.

In this study, runoff slopes integration will be analyzed through an *isochronous type model*. Steps should be done in three main directions:

- *Determining the digital izochrones*;
- *Flow calculation* for each partial surface (Fi) between two isochronous;
- *Surface flow hydrograph generation*;

8.2.2.1. GIS methodology for estimating time of travel / concentration

Estimated travel time, respectively time of concentration for the selected river basins for the study, was conducted through GIS by using as input data: Digital Elevation Model (DEM), slope, surface that water can leak in each pixel (Catchment Area) Curve Number index, Manning's N roughness coefficient (*Al-Smadi M., 1998; Gebremeskel S. et al., 2002*).

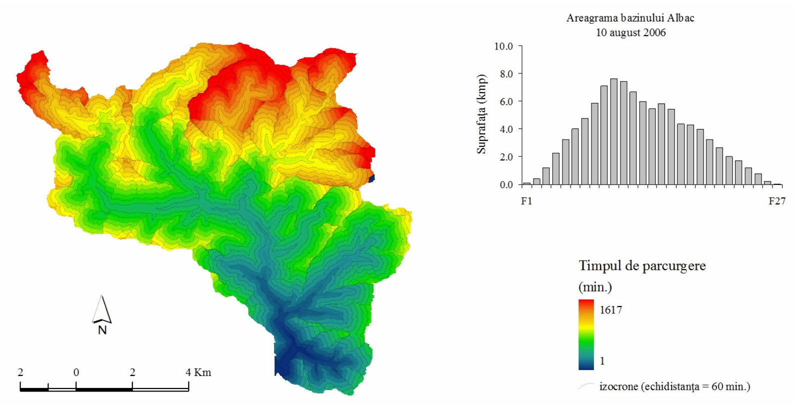

Fig. 8.4. Travel time and areagraphic for Albac basin (example: 10 August 2006)

Two elements are important for determining the travel time and time of concentration: the slope and bed flow rate and flow length. For spatial analysis of *flow velocity* there is an algorithm developed by Olaya V. and Al Smadi M. (2004) in SAGA GIS, based on Manning method and which allows to produce a raster of flow velocity in an interactive way by selecting which input pixel upstream to which calculations to be made. For automatic generation of the travel time raster, it has been made, an ArcGIS sub – module (*Domniţa M. et al., 2010*). In Fig. 8.16. there are results presented as an example by running the sub-module in Albac watershed.

8.2.2.2 Calculation of maximum discharges resulted in sections without measurements

Once the layer of water available for discharge (through excess capacity of interception-infiltration), drainage coefficients at pixel level and basin areagraph for physical and geographical conditions existing at the time of the rainfall event, next phase of the algorithm was to calculate flow in each F_i area, with 1 minute equidistance between two consecutive isochronous and its extraction of the flow-time data string in a .dbf table by using zonal statistics functions from GIS. Flow calculation was performed by means of rational method, commonly used in our country for small basins (*Şerban P., Diaconu, 1995; Păcurar V., 2006; Bilaşco Şt., 2008; Magyari Saska Zs., 2008* etc.) . Further, due to limited representation of graphs in ArcGIS, the generation of flow hydrograph can be achieved by means of a tabular and graphic analysis software (Excel, SPSS, Matlab etc.).

8.2.2.3. Applications and results

In this part of the paper it is presented the obtained results by applying the algorithm to the four study basins for different rainfall events. For the four basins, there were selected for three sections for calculating, generally located in areas with human settlements. We will limit ourselves to further illustrate just the rainfall flow hydrographs produced by modeling on 17th of July 2002, for Albac si Călata watersheds.

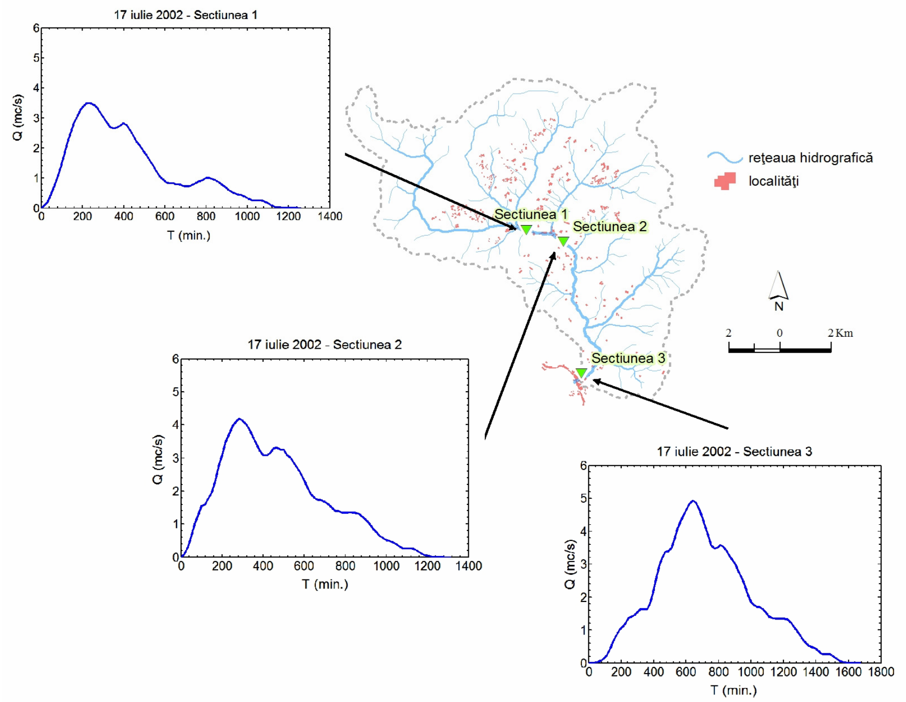

Fig. 8.5. Albac Watershed. Flow hydrograph generated by rain on the day of July 17, 2002

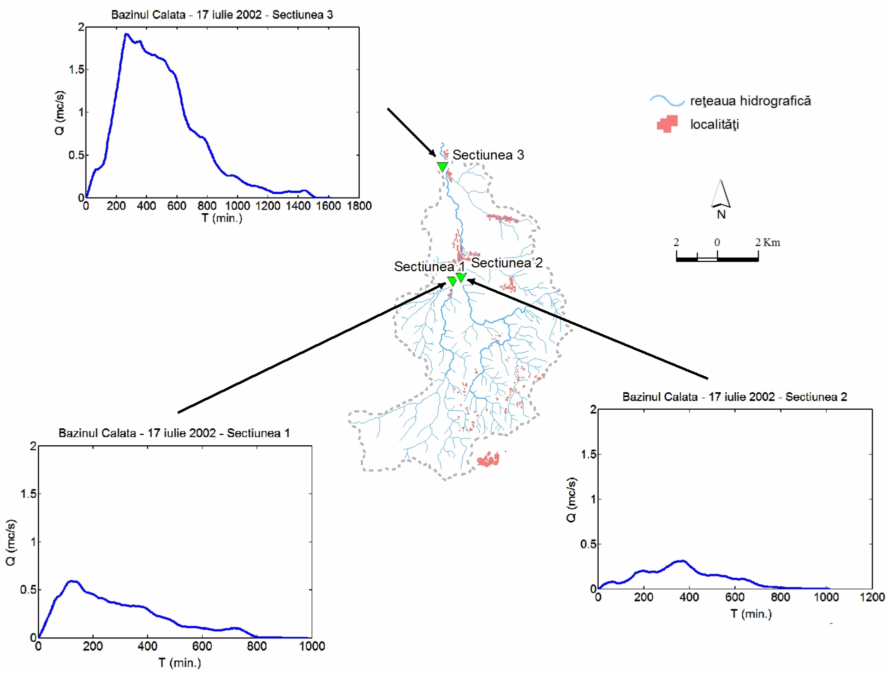

Fig. 8.6. Călata Watershed. Flow hydrograph generated by rain on the day of July 17, 2002

9. VALIDATION OF HIGH FLOODS, GENERATED BY RAIN, GIS ESTIMATION MODEL BASED ON THE STUDY OF SOIL MOISTURE CONDITIONS

Objective: possible correlation with the calculated hydrograph obtained from measurements is not only a self-validation but the validation of the whole model as the representation of spatial variation of soil moisture co-participate to the flow mechanism holding an important role in the balance equation .

In this paper we try to make a distinction between soil humidity and soil moisture. Soil moisture can not be confirmed by field measurements, because it should be considered two separate things in terms of perception of moisture phenomena:

- Soil humidity measured on field work and evaluated in the laboratory, which sees utility in particular in soil or agropedology research;
- Soil moisture occurs in the real flow mechanism and is calculated from the equations.

9.1. Validation procedures. General aspects.

In this study, the validation of the GIS flood simulation model, the procedure consisted of comparing the modeled flood hydrographs with flood hydrographs obtained by measurements from hydrometric stations Poiana Horea and Smida. The developed GIS model estimates only surface runoff from rain, not taking into account the basic flow of the river, hypodermic drainage or underground drainage.

It may, therefore, be applied only to very small basins or on slopes and torrents where, obviously, groundwater flow is very small compared with that resulting one from torrential rains.

9.2 Case study: July 2005 flood of the rivers Someşul Cald and Beliş

9.2.2. Analysis of hydrographs obtained from measurements at hydrometric station

For both study basins, the highest rates correspond to 12 July, when it was recorded 30.5 m3/s on the river Someşul Cald at Smida hydrometric station and 16 m3/s on the River Beliş at Poiana Horea hydrometric station.

Regarding the flood on the river Beliş (Fig. 9.4), there is a sudden increase in flow in the relevant section at Poiana Horea hydrometric station on July 12, in 8 hours increasing rates over 11.5 m3 / s (from 4 , 36 m3 / s at 6:00 to 16 m3 / s at 14.00). Taking into account as a starting point at 6:00 on July 11, increasing time (T_{cr}) for the flood reaching peak flow was 32 hours, and the decrease time (TSC) was 100 hours (12 July, 14:00 - July 16, 18:00). After the 16th of July, reveals a general trend of declining flows.

Regarding the Someşul Cald river flood (Fig. 9.5), it highlights a somewhat sudden increase in the flow of 4.12 m3 / s (beginning on 11 July) to over 25 m3 / s (in the following afternoon of July 12). After reaching a flood peak on the evening of July 12, flows gradually decreased reaching values of approx. 6 m3 / s on 16 July, related to reduced rainfall. As a result, increasing time (TCR) of the flood was 36 hours, and the decrease time (TSC) for 96 hours.

9.2.3. GIS implementation model

For modeling the two floods, in addition to the layers of daily precipitation amounts, there were prepared the rest of spatial data input: soil texture, the land use, previous conditions of moisture, Digital Elevation Model, flow rate etc.. Based on raster infiltration, net precipitation, flow ratios, flow rate layers and taking into account the duration, rainfall intensity from Vlădeasa and Băişoara (weather stations closest to the basins of the study), there were obtained flow-time strings time and then flow hydrographs.

9.2.4. Modeled flood hydrograph vs. measured flood hydrograph

We call into question the measured rates obtained by modeling does not include the appropriate hypodermic flow fraction, or groundwater flow or the past river flow, as if from flow measurements. Under these conditions, separation of groundwater drainage and surface drainage is not an easy action, being necessary to find a function to fit the best curve of 'cutting the hydrograph'.

In case of the flood of the river Someşul Cald, the attention has focused also on the flood peak (range 11 to 15 July 2005). With no information about the start of the rains that have caused these increases in flow, was taken into account the situation recorded by the meteorological station Vlădeasa (station located at the shortest distance from the basin).

From Fig. 9.11 is observed a discrepancy regarding the time aspect between measured and calculated hydrograph, which sends us to launch the following hypothesis: *What if in the Someşul Cald basin the rain / rains actually began several hours earlier than at station Vlădeasa?!*

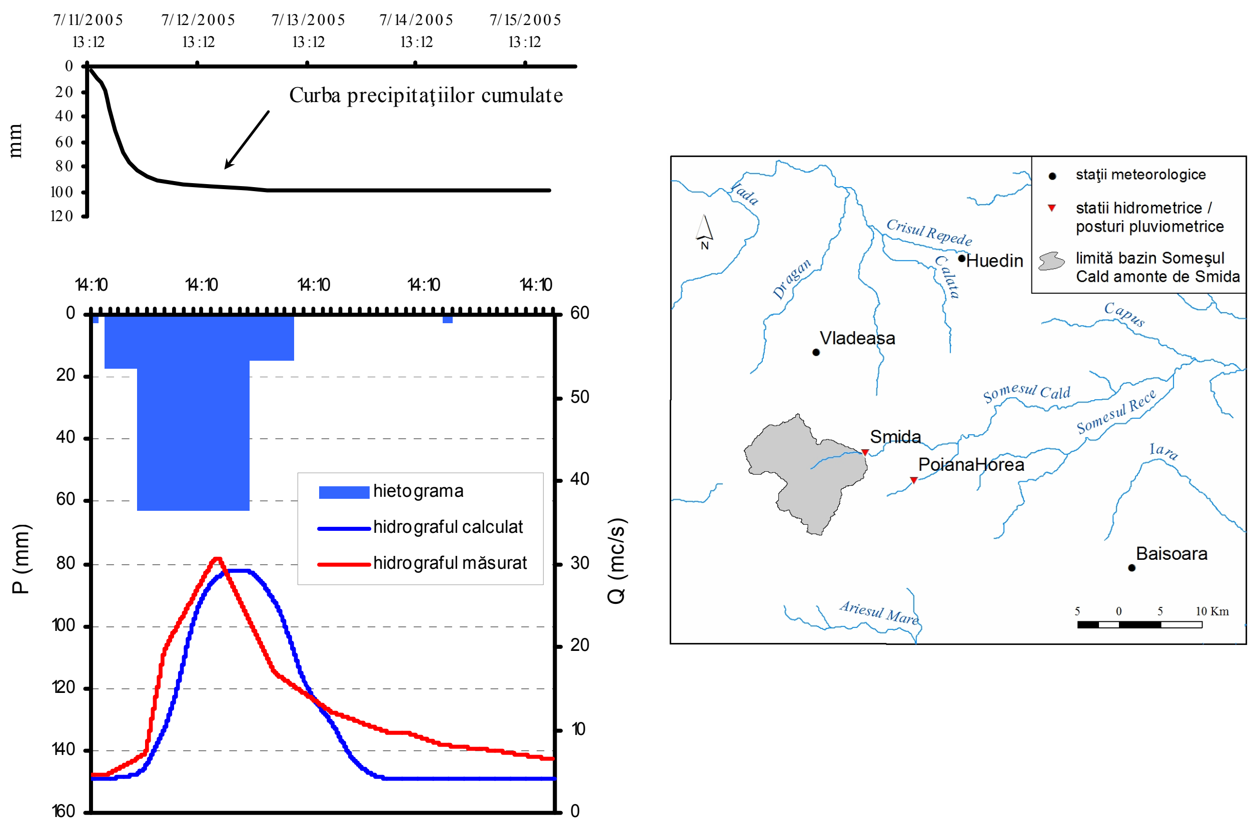

Fig. 9.1. Modeled vs. measured hydrograph for the flood peak in July 2005 Smida hydrometric station (11 to 15 July 2005). Measured flow data have a time resolution min. 2 - max. 5 measurements per day, and modeled flow have time resolution of 1 calculation / min (1440 calculations / day). At the top of the chart are the average rainfall per the basin (it is heavy rainfall proper each rainfall extracted from the precipitation maps generated by interpolating the data from meteorological stations: Vlădeasa, Băişoara, Huedin Zalău Dej, Cluj-Napoca Turda and hydrometric stations: Smida and Poiana Horea).

However, measured hydrograph shows somehow a sharp decrease in the flow after reaching the peak flow (30.5 m3 / s) compared with the simulated hydrograph, but bear in mind that on 12 July at 18:00 (when there was maximum) until 6:00 am on July 13, there are no other measurements. In these conditions may be released following hypothesis: *it is possible that during this period of 12 hours to have maintained high rates for some time after measuring the maximum flow and their decrease was not so "steep"?!*

In the absence of measurements of groundwater flow, flow separation procedure of surface and groundwater flow based on widely used by hydrologists in our country is drawing a line between *the first value of the flow increasing part of the hydrograph and the final value of the flow decreasing part of the hydrograph* (Fig. 9.11). After the separation of groundwater flow under this procedure there is a decrease in maximum flow measured up to 5 m3 / s; in these conditions modeled flows are higher than those measured in particular on the flow decreasing part of the hydrograph (Fig. 9.13).

Of course, the start time, duration, intensity of rainfall in the basin being uncertain, the shape and quantitative differences between the two hydrographs maintain their position. These differences can be reduced, as mentioned above, primarily by increasing the temporal-spatial resolution of rainfall data base.

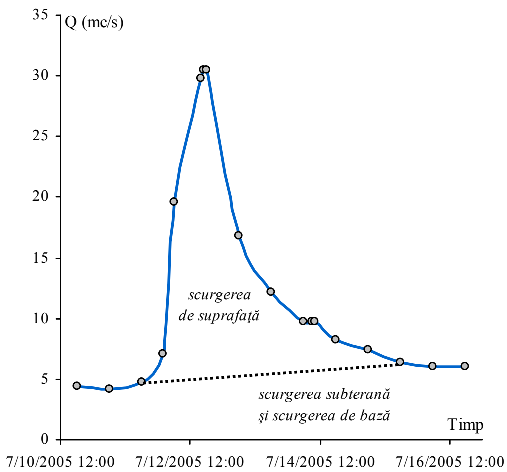

Fig. 9. 2. Procedură de separare a scurgerii de suprafaţă de scurgerea subterană utilizată în România

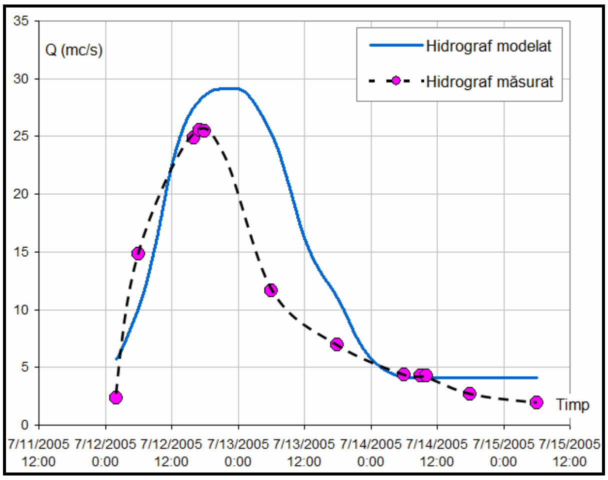

Fig. 9. 3. Hidrograf măsurat vs hidrograf modelat după separarea scurgerii de suprafaţă de scurgerea subterană şi de bază. Studiu de caz: viitura din iulie 2005 (Bazinul Someşului Cald, staţia hidrometrică Smida)

Of course, not exclude any modeling inaccuracies in the algorithm, but as long as the input data, respectively comparison data that raises some problems, it is difficult to quantify model errors. Despite poor data resolution temporal-spatial aspect, the analyzed examples confirm that the model for estimating runoff in small basins is good and offers an alternative in prognosis of rain floods.

10. CONCLUSIONS

For developing the research theme were considered two main objectives: a). development of a GIS algorithm to allow indirect estimation of soil moisture and rainfall infiltration on a daily scale, b). development of a GIS algorithm to model the rain floods taking in account the soil hydrological conditions.

a). In terms of meeting the first major objective, the entire GIS methodology has been automated through the creation if of two toolboxes or ArcGIS modules:

1. ArcGIS module to calculate the cumulative infiltration using SCS method - *Cumulative Infiltration Tools.*

2. ArcGIS module to calculate the soil moisture using balance method - *Soil Moisture Tools*, with three sub-modules: *1. Daily Evapotranspiration, 2. Frevert Runoff Coefficient, 3. Soil Moisture*

b). In terms of meeting the second objective (development of a GIS algorithm to model the rain floods taking in account the soil hydrological conditions), GIS methodology has also been automated. Using as input data layers generated when applying the first algorithm was automatically obtained the following result set:

a) *maps*: net precipitation map, flow coefficients map, volume of water drained from each pixel map, flow direction map, flow length of drainage map, travel time map.

b). *tabular results*: tables with stored flow-time strings.

c). *graphic results*: rain flow hydrograph.

The validation phase of the GIS floods estimation model based on the study of previous moisture conditions, the observed differences between measured and calculated hydrographs can be made, largely, on account of insufficient input data consistency (especially rainfall data) but also the inconsistency in terms of time density of measured flows (max. 4-5 measurements / day) vs. calculated flow (minutely).

Despite poor data resolution from temporal-spatial aspect, the analyzed examples confirm that the model for estimating runoff in small basins is good and offers an alternative in prognosis of rain floods.

11. SELECTIVE REFERENCES

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