

## SWAT-Based Runoff Modeling in Complex Catchment Areas – Theoretical Background and Numerical Procedures

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### Abstract

This paper shows the structure of the SWAT-based model used in modeling of the “rainfall-runoff” process. The SWAT model is hydro-dynamic and physically-based model for application in complex and large basins. Model inputs are as follows: rainfall, air temperature, soil characteristics, topography, vegetation, hydrogeology and other relevant physical parameters. The model is based on five linear reservoirs as follows: reservoir of the vegetation cover, snow accumulation and melting, surface reservoir, underground reservoir and surface runoff reservoir. The model uses GIS tools for preprocessing and post-processing. The basic modeling unit is the hydrologic response unit (HRU), defined as the network of elementary hydrologic areas with the selected discretization, measure of which is dependent upon the desired accuracy, as well as upon data accuracy. The total runoff on the exit profile of the catchment is computed by convolution of the sum of runoffs (surface and base runoffs). The model can be applied at the daily and hourly level of discretization and used for multiannual simulations. Illustration of operation of the SWAT based model will be presented on a selected part of the River Drina basin (with the total area of around 20.000 km<sup>2</sup>).

**Keywords:** Rainfall-runoff model, linear reservoirs, GIS tools, snow accumulation and melting, potential and real evapotranspiration, total catchment runoff, surface runoff, underground runoff.

### 1. Introduction

The most important objects of complex management of catchment waters are numerous large multi-user storages capturing the basin inflow for the purpose of water supply to urban areas or irrigation for agricultural areas, flood protection, recreation or electricity generation. As fresh and clean water is becoming scarcer and water pollution by human beings grows, a better distribution of demand coming from a growing number of water consumers is becoming the imperative.

Paper Divac et al. (2009) shows that in order to create the highest possible power of the hydropower plants and achieve best possible water management, it is necessary to know or

evaluate basin water circulation at the daily, weekly, monthly or annual level. If the evaluations are based on incomplete information, relevant evaluated water discharge in the basin may be fairly incorrect. For example, if the water inflow to storage has been forecasted, advance emptying can be performed so it can to receive potential flood. But, if the emptying in advance is not necessary, then certain water volume would be spilled uselessly (without electricity generation), although it could be precious during the dry seasons.

Water circulation modeling in mathematical model, i.e. hydro-information systems, is not possible without modeling of transformation of rainfall into runoff. Water falls in the form of rain or snow, then the part of it stays on the vegetation, then evapotranspiration and sublimation processes occur, and available water off and forms the river watercourses. These processes are the starting point for modeling of water use for hydropower, management of water resources and other purposes. Present paper describes the use of SWAT model in majority of Serbian hydro-information systems ("Drina" HIS, "Vlasina" HIS and others).

SWAT is the abbreviation for the Soil and Water Assessment Tool model, developed in USDA, (Neitsch et al., 2005). SWAT was designed to make possible the testing and further forecast of water circulation in soil, sediments and farming pesticides and herbicides in large basins with diverse soil and vegetation classes in long time periods. In order to meet these requirements, the model is physically-based and regression equations are used to describe relations between input and output values. SWAT model includes physical patterns which describe the water circulation, sediment circulation, vegetation growth and nutrients circulation by applying required input data on climate, soil characteristics, terrain topography, vegetation topography and land use in the catchment area. SWAT is the continuous time model usable in long-term simulations. The model is not envisaged for simulation of details such as flood wave episodes and similar.

## 2. Historical development of SWAT model

SWAT model development is an ongoing process, taking place at USDA *Agricultural Research Service* (ARS) for almost 30 years now. Current version of the SWAT model is the successor of "the Simulator for Water Resources in Rural Basins" model (SWRRB) (Arnold and Williams, 1987), created to simulate water management and sediment transport in non-investigated (non-gauged) basins in the USA. SWRRB model development started in early 80's in the form of CREAMS, (Arnold et al., 1995b) hydrologic model modification, which was then used to develop *Routing Outputs to Outlet* (ROTO) model in early 90's of the last century. This was a support toll for the management of the underground flow in the basins of Indian countryside in Arizona and New Mexico that covers the area of several thousands of square kilometers. ROTO model development was demanded by the US Bureau of Indian Affairs.

Further important step was the integration of the two models, SWRRB and ROTO, into a single model (SWAT model). SWAT preserved all SWRRB model options, as a very useful simulation model for simulation of processes in very extensive areas.

Then, SWAT model was exposed to constant critique and simultaneous development. Crucial improvements of earlier model versions (SWAT 94.2, 96.2, 98.1, 99.2, and 2000) were described by Arnold and Fohrer (2005) and Neitsch et al. (2005).

Presently, SWAT model is a complex physically-based model with a daily discretization step, used to model circulation of water in the basin, including the sediments circulation and agricultural production with chemicals in unanalyzed basins. The model is the efficient in computing terms with the ability to perform long simulations. SWAT model divides the

catchment into numerous sub-catchments, which are further divided in the elementary hydrologic response units (HRU), the land use, vegetation and soil characteristics of which are homogenous. Multiple HRUs in a single area make a sub-catchment (with clear watersheds and areas), while HRUs are not recognizable space-wise, but they exist only in simulations.

SWAT model uses the following inputs: daily rainfall, the maximum and minimum air temperature, solar radiation, relative air humidity, wind speed. They inputs originate either from the metering stations or they were computed beforehand.

Green-Ampt infiltration method is used for application of daily measured or generated rainfall (Green and Ampt, 1911).

Snowfall is determined on the basis of precipitation and the mean daily air temperatures.

The model uses maximum and minimum daily air temperatures for computations.

Application of climate inputs includes the following: (1) up to ten elevation zones are simulated for calculation of rainfall distribution per elevation and/or snowmelt process, (2) climate inputs are adapted to simulation model requirements, and (3) forecast of weather conditions is performed as a new option of the SWAT 2005.

Full hydrologic balance of each HRU includes accumulation and evaporation off the plants, determination of effective rainfall, snowmelt, water exchange between surface runoff and soil layer, water penetration into deeper layers, evapotranspiration, sub-surface flow and underground flow and water accumulation.

Estimation of snow-covered area, snow cover temperature and volume of snowmelt is based on the principles described in Fontaine et al. (2002).

SWAT model includes options for estimation of surface runoff from HRUs, which combine daily or hourly rainfall and USDA *Natural Resources Conservation Service* (NRCS) *curve number* (CN) method (USDA-NRCS, 2004) or Green-Ampt method. Water retention on plants is computed by the implicit CN method, while explicit water retention is simulated by Green-Ampt method. Water collection in soil and its runoff lag are computed by the techniques of water redistribution between the soil layers.

Sub-surface flow simulation is described in Arnold et al. (2005) for fissured soil classes. SWAT 2005 also offers new options for simulations of water level change in soil on HRUs with seasonal oscillations.

Three methods are used for estimation of potential and real evapotranspiration: Penman-Monteith, Priestly-Taylor and Hargreaves (Hargreaves et al., 1985). Water exchange between the soil and the deeper layers occurs through the sub-surface soil layer. Sub-surface flow is fed by the water not used by plants or water that does not evaporate, which can penetrate to sub-surface reservoirs. Water which penetrates to the deepest reservoirs is considered lost for the system, i.e. it is considered a system output.

### 3. Model in general

SWAT model is comprised of numerous diverse physical processes in the basin to be modeled. Catchment has to be divided into sub-catchments for the purpose of modeling. Sub-catchment utilization in simulations is very useful in the environment with catchment parts having significantly different characteristics of vegetation or soil, what has an impact on hydrologic processes. Division of basic catchment areas within the sub-catchments allows the user to distinguish between relevant catchment areas and analyze them. Input data for each sub-

catchment are grouped or organized into the following categories: climate, HRUs, storages/lakes, underground, river network and catchment runoff. Elementary hydrologic response units are mainly of square shape on land within the sub-catchments where the vegetation, soil and land use classes are homogenous.

Regardless of the type of problem being modeled and analyzed by the model, background of the method is the water balance of the catchment area. In order to achieve precise forecast of circulation of the pesticides, sediments or nutrients, hydrologic cycle is simulated by the model which integrates overall water circulation in the catchment area. Hydrologic simulations in the catchment area can be divided into two groups. In the soil phase of the hydrologic cycle the processes on the surface and in the sub-surface soil occur, as well as the circulation of sediments, nutrients and pesticides through the water flows in all sub-catchments. In the second phase, the circulation of water and sediment through the river network up to the exit profile are observed.

Hydrologic cycle is simulated by SWAT model, which is based on the following balance equation:

$$SW_t = SW_0 + \sum_{i=1}^t (R_{\text{day}} - Q_{\text{surf}} - w_{\text{seep}} - E_a - Q_{\text{gw}}) \quad (1)$$

where  $SW_t$  is the humidity of the soil (mm H<sub>2</sub>O),  $SW_0$  is the base humidity of the soil (mm H<sub>2</sub>O),  $t$  is time (days),  $R_{\text{day}}$  is rainfall volume (mm H<sub>2</sub>O),  $Q_{\text{surf}}$  is the value of surface runoff (mm H<sub>2</sub>O),  $E_a$  is the value of evapotranspiration (mm H<sub>2</sub>O),  $w_{\text{seep}}$  is the value of seepage of water from soil into deeper layers (mm H<sub>2</sub>O) and  $Q_{\text{gw}}$  is the value of underground runoff (mm H<sub>2</sub>O).

SWAT model uses the following climate and hydrologic inputs: rainfall, air temperature and solar radiation, wind speed, relative air humidity, snow pack, snowmelt, elevation zones, water volume on plants, infiltration, water seepage into deeper soil layers, evapotranspiration, sub-surface flow, surface flow, lakes, river network, underground flow and other inputs related to vegetation growth and development, erosion on the catchment area, nutrients, pesticides and land use.

### 3.1. Strengths and limitations of the model

Borah and Bera (2003, 2004) have compared SWAT model with several other models of the same type. Their 2003 study showed that all models (*the Dynamic Watershed Simulation Model* (DWSM) (Borah and Bera, 2004), *Hydrologic Simulation Program – Fortran* (HSPF) (Bicknell et al., 1997) and SWAT model) treat the hydrologic processes, sediments circulation and chemical processes applicable in the catchment areas divided into smaller basic sub-catchments. They have concluded that SWAT model is a promising model for long-term simulations, primarily of agricultural basins. They showed in their 2004 study that SWAT and HSPF models can forecast annual volumes of waters and pollution with adequate monthly forecasts, except in months of storms and under unusual hydrologic circumstances (flood waves), when simulation results turn to be considerably worse.

Van Liew and Garbrecht (2003) compared the basin outlet hydrographs produced by SWAT and HSPF models on 8 catchment areas in Little Washita River basin in south-east Oklahoma. The conclusion was that SWAT model is better than HSPF model in terms of runoff forecast for different climate conditions and it may be even better for long-term simulations in the case of the impact of changeable climate factors upon surface water resources.

In El-Nasr (2005) SWAT and MIKE-SHE models (Refsgaard and Storm, 1995) were used in parallel for hydrologic analyses of the Belgium's Jeker River basin and it turned out that

MIKE-SHE model produced slightly better results. In Srinivasan et al. (2005), it was concluded that SWAT model gave discharges approximately similar to the ones obtained by the *Soil Moisture Distribution and Routing* (SMDR) model (Cornell, 2003) in FD-36 experimental basin in east-central Pennsylvania (total area of 39.5 ha) and that SWAT model can perform good calculations of seasonal changes. In Srivastava et al. (2006), it was determined that the model of synthetic neural networks (*artificial neural network* ANN) is better model than SWAT model in calculation of the runoff from the small basins in south-eastern Pennsylvania.

### 3.2. Previous model adaptations

SWAT model development was accompanied by numerous modifications, adaptations and improvements of specific processes which were in certain cases focused on specific regions. The most recent examples are the models SWAT-G, Extended SWAT (ESWAT), and *the Soil and Water Integrated Model* (SWIM). The initial SWAT-G model was developed by modification of certain parts of the SWAT 99.2 model, wherein percolation, hydraulic permeability and functions related to water seepage were improved for usual conditions that exist in hill and mountain regions in Germany (Lenhart et al., 2002). ESWAT model (van Griensven and Bauwens, 2003, 2005) brought in several new modifications to the original SWAT model: (1) within-hourly rainfall as inputs and infiltration, discharge and forecast of losses due to the erosion, based on the user time discretization of one hour, (2) water flow through the river network based on one-hour time step and the link with water quality, based on the kinematic wave and functions used in QUAL2E model as additional improvement, (3) multiple (multi-space and/or multi-parameter) calibration and auto-calibration (similar components are built into the SWAT 2005 model). SWIM model is based primarily on hydrologic components of the SWAT model and nutrients circulation from the MATSALU model (Krysanova et al., 1998, 2005) and it was created to simulate processes in the middle range of basin areas (from 100 to 100.000 km<sup>2</sup>). The latest SWIM model improvements include the integration of the dynamic sub-model of underground waters (Hatterman et al., 2004) that increases the capacity of simulation of forest systems (Wattenbach et al., 2005) and develops the use of much more realistic simulations in humid and riparian regions (Hatterman et al., 2006).

### 3.3. Reasons for development of the new model

As shown here, the SWAT model is complex and applicable under various conditions and for various purposes. It has also been shown that the model had experienced many adaptations and additional developments related to modeling of phenomena in specific basins. After the analysis of the original and numerous adapted models, the Project Team of the Belgrade Institute “Jaroslav Černi” has decided to perform additional development of SWAT model and its adaptation to specific basins in the wider area that includes Serbia (Serbia, Montenegro and Bosnia and Herzegovina) (Prodanović et al., 2009).

## 4. Theoretical background of the new SWAT model

### 4.1. Model structure and mathematical background

As mentioned above, SWAT model is physically-based and the water balance is modeled by five linear reservoirs shown in Figure 1. For each of the reservoirs, a set of applied equations of water balance and links between reservoirs that represent possible water routes, either surface or underground, will be presented.

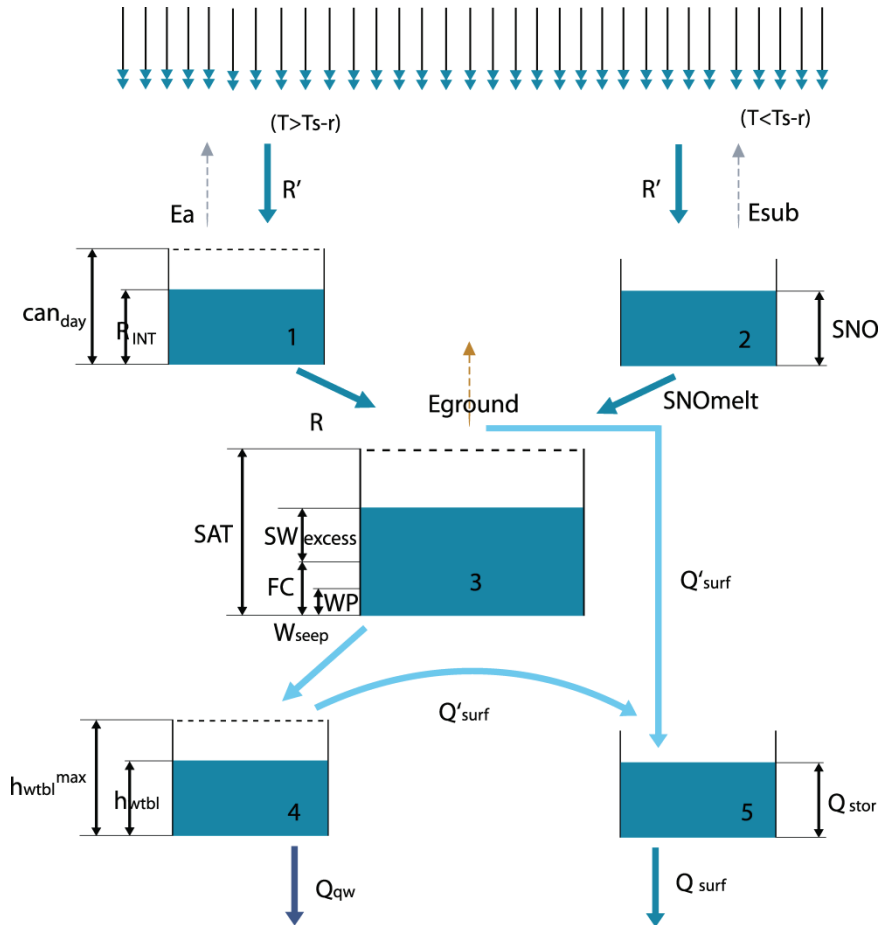


Fig. 1. Scheme of linear reservoirs in SWAT model

**First reservoir** represents the approximation of the first vertical layer when precipitation is in the form of rain. It represents the layer of vegetation cover of the terrain surface. It is used to simulate water retention on the plant cover.

**Second layer** also represents the layer above the terrain surface, but when precipitation is in the form of snow. In addition to water retention on plants, in this layer is also simulated water retention in the snow blanket. The outlet of this reservoir is the snowmelt transferred to the following reservoir.

**Third reservoir** represents the unsaturated soil layer. The inlets of this reservoir are the outlets of the previous two, i.e. effective precipitation and snowmelt. Simulated here is the surface runoff, as well as the seepage to deeper soil layers.

After the soil is saturated and water spilled from the previous reservoir, one part of the water runs to the underground aquifer that the underground or base runoff originates from (**fourth reservoir**).

**Fifth reservoir** is the reservoir of surface runoff that actually represents the retention capacity of surface and the layer lying immediately under the land surface.

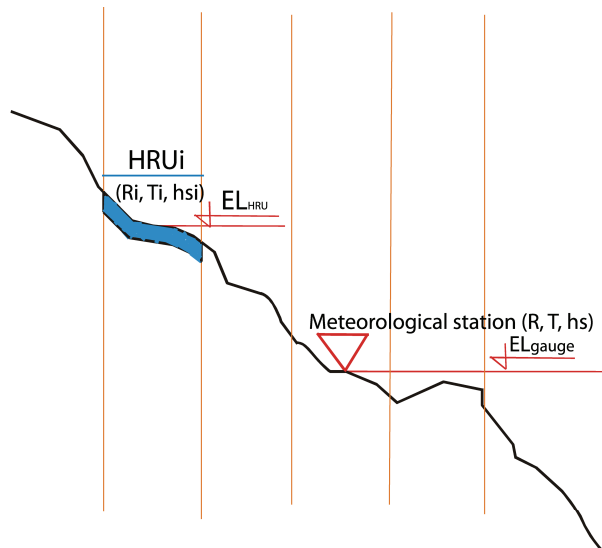
Climate inputs are the constants (radiation at the atmosphere boundary and other time constants) and variables (air temperature, rainfall and other) that change in time and space. The elevations of each HRU (obtained by the application of GIS techniques), as well as the areas and other performances, determined for model purposes, are also taken into consideration. Mean rainfall, air temperatures and snow pack height are computed for each HRU.

### Mean rainfall

Calculation of referent rainfall values for each HRU by the means of formula (2) is performed because in the case of the sloped terrain the meteorological values change with the change in elevation:

$$R'_{HRU} = \sum_{k=1}^n \left\{ R_{gauge} + (EL_{HRU}^k - EL_{gauge}) \cdot \frac{p_{laps}}{1000} \right\} \cdot p_R^k \quad (2)$$

The calculation of referent rainfall values in HRUs is linked to rainfall stations, which are grouped (assigned to sub-catchment) according to the rule of Thiessen polygons (Figure 2).



**Fig. 2.** Illustration of the sloped terrain

In Equation (2),  $R_{gauge}$  is rainfall (mm),  $EL$  is elevation (m), ( $EL_{gauge}$  is the elevation of the location where the rainfall was recorded (on the rainfall station),  $EL_{HRU}$  is the elevation of the HRU and  $p_{laps}$  is the rainfall gradient (mm/km). This is the measure of rainfall growth per elevation growth and  $p_R^k$  is weight. The following condition is to be met for  $p_R^k$ :

$$\sum_{k=1}^n p_R^k = 1 \quad (3)$$

where  $k$  is the number of rainfall stations which were grouped (assigned to sub-catchment).

### Mean Temperatures

Calculation of referent temperatures in HRUs is linked to meteorological stations assigned to HRUs according to the division of Thiessen polygons. The calculation (described above) is

performed for mean, minimum and maximum temperatures within the discretization period of calculation:

$$T_{HRU} = \sum_{k=1}^n \left\{ T_{gauge} + (EL_{HRU}^k - EL_{gauge}) \cdot \frac{t_{laps}}{1000} \right\} \cdot p_T^k \quad (4)$$

where T are the minimum, maximum and mean air temperatures,  $t_{laps}$  is the temperature gradient ( $^{\circ}C/km$ ) and  $p_T^k$  is the weight. The following condition is to be met:

$$\sum_{k=1}^n p_T^k = 1 \quad (5)$$

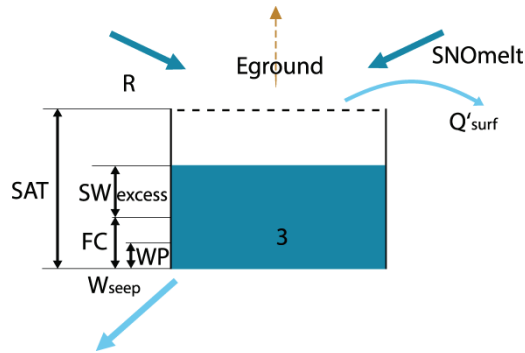
where k is the number of rainfall stations which were grouped (assigned to sub-catchment).

#### 4.2. Water balance through the unsaturated environment

Hydrologic cycle within a HRU, simulated by this model, is defined by the balance equation (6):

$$SW^i = SW^{i-1} + (R^i + SNO_{melt}^i) - Q_{surf}^i - w_{seep}^{i-1} - E_{t-soil}^i \quad (6)$$

where  $SW^i$  is the water volume in soil in time  $t_i$  (mm),  $SW^{i-1}$  the water volume in soil in time  $t^{i-1}$  (mm),  $R^i$  the rainfall volume in discretization period  $i$  (mm),  $SNO_{melt}^i$  – water equivalent of snowmelt (mm),  $Q_{surf}^i$  the volume of surface runoff (mm),  $E_{t-soil}^i$  the evapotranspiration of soil (mm) and  $w_{seep}^{j-1}$  filtration (water penetration to deeper soil layers) (mm).



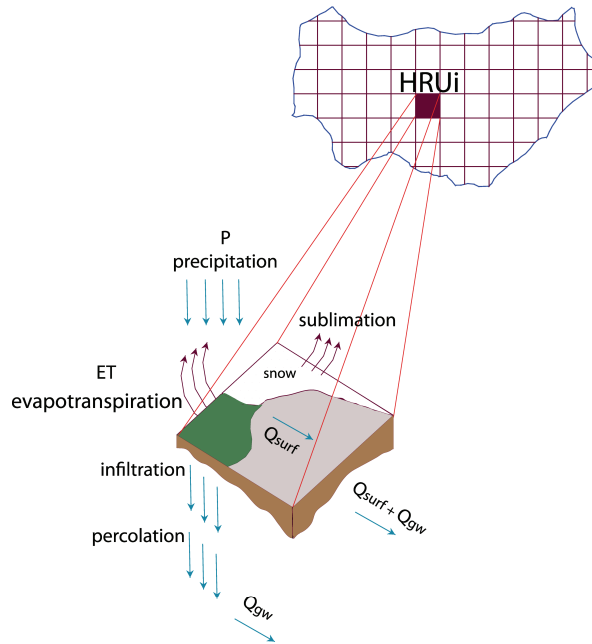
**Fig. 3.** Reservoir in unsaturated environments (3)

Elements of the Equation (6) are illustrated in Figure 4.

#### 4.3. Snow accumulation and snowmelt

The model separates rainfall into rain and snow depending on the boundary temperature  $T_s$ . This boundary temperature is not automatically equal to zero degrees of Celsius, but usually it is either equal or very close to zero ( $\pm 1^{\circ}C$ ). The snowmelt process is modeled for each HRU individually by determination of the reference elevation for each HRU and computation of the water volume of snow blanket for that given elevation and size of HRU at any moment of time.





**Fig. 4.** Balance scheme of SWAT model

Value corresponding to snowmelt is computed according to the following equation:

$$SNO_{melt}^i = b_{melt}^i \cdot sno_{cov} \left[ \frac{T_{snow}^i + T_{max}^i}{2} - T_{melt} \right] \quad (7)$$

where  $SNO_{melt}$  is the water equivalent of the snowmelt (mm),  $sno_{cov}$  the snow coverage of the HRU (%),  $b_{melt}$  the degree-day factor of snowmelt (mm/day °C),  $T_{snow}$  snow temperature (°C),  $T_{max}$  the maximum temperature value recorded during the discretization period (°C) and  $T_{melt}$  is the base (referent) temperature of snowmelt (close or equal to zero) (°C).  $b_{melt}$  is computed from the following expression:

$$b_{melt} = \frac{(b_{melt6} + b_{melt12})}{2} + \frac{(b_{melt6} - b_{melt12})}{2} \cdot \sin\left(\frac{2\pi}{365} \cdot (d_n - 81)\right) \quad (8)$$

where  $b_{melt6}$  is the degree-day factor of snowmelt (mm/day °C) on June 21<sup>st</sup> of the current year (mm/day °C),  $b_{melt12}$  is the degree-day factor of snowmelt on December 21<sup>st</sup> of the current year (mm/day °C),  $d_n$  is the day of the calendar year (1-365). In years with 366 days, the  $b_{melt}$  value for December 31<sup>st</sup> is equal to the value on December 30<sup>th</sup>.

The following condition is to be met:

$$0 \leq SNO_{melt}^i \leq SNO^i + E_{sub}^i \quad (9)$$

where  $E_{sub}$  is the sublimation of water from solid state (snow) to vaporous state, computed only when  $T > T_{melt}$  is applicable, according to the following formula:

$$E_{sub} = \frac{E_s}{1 + cov_{sol}} \quad (10)$$

where  $\text{cov}_{\text{sol}}$  is the index of vegetation and soil albedo (for snow-pack  $> 0.5$  mm,  $\text{cov}_{\text{sol}} = 0.5$ ) and  $E_s$  is the maximum sublimation (soil evapotranspiration):

$$E_s = E'_o \cdot \text{cov}_{\text{sol}} \quad (11)$$

Potential evapotranspiration is computed out of the canopy storage (there are two possible cases):

$$E'_o = E_o - E_{\text{can}}, \quad \text{if } E_o > E_{\text{can}} \quad (12)$$

$$E'_o = E_o, \quad \text{if } E_o < E_{\text{can}} \quad (13)$$

where  $E_o$  is potential evapotranspiration,  $E_{\text{can}} = R_{\text{INT}}$  the value of evaporation of canopy storage waters and  $\text{sno}_{\text{cov}}$  is the part of HRU covered by the snow.

Notion of the spatial curve of reduction of snow pack height is defined as:

$$\text{sno}_{\text{cov}} = \frac{\text{SNO}}{\text{SNO}_{100}} \cdot \left[ \frac{\text{SNO}}{\text{SNO}_{100}} + \exp(1 - \text{sno}_{50\text{cov}} \cdot \frac{\text{SNO}}{\text{SNO}_{100}}) \right]^{-1} \quad (14)$$

where  $\text{SNO}_{100}$  is the minimum measure of snow pack height for snow coverage of HRU of 100% and  $\text{sno}_{50\text{cov}}$  is the percentage of  $\text{SNO}_{100}$  for snow coverage of 50% (the possible range of values is between 0 and 1).

The following condition is to be met:

$$\text{sno}_{\text{cov}} \leq 1.0 \quad (15)$$

Snow temperature is computed according to the following equation:

$$T_{\text{snow}}^i = T_{\text{snow}}^{i-1} \cdot (1 - l_{\text{sno}}) + \overline{T_{\text{dn}}^i} \cdot l_{\text{sno}} \quad (16)$$

where  $l_{\text{sno}}$  is the impact of the snow temperature during the previous days and  $\overline{T_{\text{dn}}}$  is the mean daily temperature.

The value of sublimation is computed according to the following equation:

$$E_{\text{sub}} = \frac{E_s}{1.5} \quad (17)$$

and the following condition is to be met:

$$\overline{T_{\text{dn}}} > T_{\text{melt}} \quad (18)$$

The maximum sublimation (soil evaporation)  $E_s$  is the maximum value of sublimation off the plants during the current day that depends upon canopy storage and is computed as follows:

$$E_s = E'_o \cdot 0.5 \quad (19)$$

The potential evapotranspiration is computed on the basis of canopy storage (there are two possible cases):

$$E'_o = E_o - R_{\text{int}}, \quad \text{if } E_o > R_{\text{int}} \quad (20)$$

$$E'_o = E_o, \quad \text{if } E_o < R_{\text{int}} \quad (21)$$

where  $E'_o$  is the potential evapotranspiration (mm) and  $R_{\text{int}}$  is the canopy storage (mm). There are two possible ways to compute the water equivalent for snow pack height:

$$SNO^i = SNO^{i-1} + R^i - SNO_{melt}^{i-1} - E_{sub}^{i-1}, \quad \text{when } T^i < T_{s-r} \quad (22)$$

$$SNO^i = SNO^{i-1} - SNO_{melt}^{i-1} - E_{sub}^{i-1}, \quad \text{when } T^i > T_{s-r} \quad (23)$$

where SNO is the water equivalent of snow pack height (mm) and  $SNO_{melt}$  is the water equivalent of the snowmelt (mm). Snow temperature is calculated as follows:

$$T_{snow}^i = T_{snow}^{i-1} \cdot (1 - I_{sno}) + \overline{T_{dn}} \cdot I_{sno} \quad (24)$$

where  $\overline{T_{dn}}$  is the mean daily air temperature ( $^{\circ}C$ ) and  $T_{snow}^{i-1}$  is the snow temperature for the previous day.

#### 4.4. Calculation of potential surface runoff

Rainfall value (rain) is computed in the following two ways:

$$R'_{int} = 0, \quad \text{when } T^i < T_{s-r} \quad (25)$$

$$R'_{int} = R'_{HRU}, \quad \text{when } T^i > T_{s-r} \quad (26)$$

In the first case, the rainfall (25) is accumulated as snow and in the second case (26) it is generated as rain. The SWAT model uses SCS CN model for the calculation of the potential surface runoff. There are two potential cases here:

$$Q_{surf}^i = \frac{(R^i + SNO_{melt}^i)^2}{R^i + SNO_{melt}^i + S}, \quad \text{if } SW_{i-1} \geq 0.2 \cdot S = I_a \quad (27)$$

$$Q_{surf}^i = \frac{(R^i + SNO_{melt}^i - I_a)^2}{R^i + SNO_{melt}^i + S - I_a}, \quad \text{if } SW_{i-1} < I_a \text{ i } R_i > I_a \quad (28)$$

where  $I_a$  is the initial condition for surface runoff, R the value of rainfall reaching the soil and S is the retention parameter calculated from the Equation (29).

$$S = 25.4 \cdot \left( \frac{1000}{CN} - 10 \right) \quad (29)$$

where  $CN = f(ITZ, ITV)$ , ITZ the soil type index (generated for each GIS layer) and ITV is the index of the vegetation type (generated for each GIS layer).

#### 4.5. Calculation of potential evapotranspiration ( $E_o$ )

Hargreaves method is used for calculation of potential evapotranspiration (this method requires only the mean, minimum and maximum air temperatures):

$$\lambda \cdot E_o = 0.0023 \cdot H_o \cdot (T_{max} - T_{min})^{0.5} \cdot (\overline{T} + 17,8) \quad (30)$$

where  $\lambda$  is the latent evaporation heat. Calculation is performed according to the following equation:

$$\lambda = 2,501 - 2,361 \times 10^{-3} \cdot \overline{T} \quad (31)$$

In Equation (30)  $T_{min}$  is the minimum daily temperature ( $^{\circ}C$ ),  $T_{max}$  is the maximum daily temperature ( $^{\circ}C$ ),  $\overline{T}$  is the reference temperature in HRU ( $^{\circ}C$ ) and  $H_o$  is the radiation at the atmosphere boundary ( $MJ/m^2/day$ ).

#### 4.6. Calculation of rainfall reaching soil

The rainfall recorded on rainfall stations ( $R'$ ) does not completely reach the soil if the vegetation is present that is, one part of rainfall stays on leaves and tree trunks. One part of the rainfall evaporates, while the other part is used by plants. The value of canopy storage is computed using the following two formulas:

$$R_{int}^i = R_{int}^{i-1} + R' - E_a^{i-1} \quad \text{and} \quad R = 0 \quad \text{if: } R' \leq \text{can}_{day}^i - R_{int}^{i-1} \quad (32)$$

$$R_{int}^i = \text{can}_{day}^i \quad \text{and} \quad R = R' - (\text{can}_{day}^i - R_{int}^{i-1}) - E_a^{i-1} \quad \text{if: } R' > \text{can}_{day}^i - R_{int}^{i-1} \quad (33)$$

where  $R'$  is rainfall before the plant leaves capture the water,  $R$  the rainfall after the plant leaves capture the water (the rainfall reaching soil (mm)) and  $E_a$  is real evapotranspiration (mm). The following condition is to be met:

$$R_{int} \leq \text{can}_{day} \quad (34)$$

Present condition ensures that canopy storage volume is not greater than the maximum water volume which plants can capture on a given day.

The evapotranspiration process includes canopy storage, in fact the part of canopy storage which can have major impact on infiltration, surface runoff and evapotranspiration.

Canopy storage ( $\text{can}_{day}$ ) varies on daily basis and it is the function of plant leaf size. During the rainfall time, the first condition to meet is the formation of the canopy storage ( $\text{can}_{day}$ ) and after that the water can reach soil:

$$\text{can}_{day} = \text{can}_{max} \cdot \frac{\text{LAI}}{\text{LAI}_{max}} \quad (35)$$

where  $\text{can}_{day}$  is the maximum water volume that can stay on plants on a given day,  $\text{can}_{max}$  the maximum water volume that can stay on full-grown plants and LAI (*leaf area index*) is the total area of green leaves per ground area on a given day ( $\text{m}^2/\text{m}^2$ ). The following functional dependency has been created:

$$\text{LAI} = f(\text{LAI}_{max}, \text{LAI}_{min}, \text{LAI}_1, \text{LAI}_2, \text{LAI}_3, \text{LAI}_4) \quad (36)$$

where  $\text{LAI}_{max}$  is the maximum leaf area index per ground area ( $\text{m}^2/\text{m}^2$ ),  $\text{LAI}_{min}$  the minimum leaf area index per ground area ( $\text{m}^2/\text{m}^2$ ),  $\text{LAI}_1$  the start of the spring vegetation period (day of the year, for example March 21<sup>st</sup>),  $\text{LAI}_2$  the start of summer vegetation period (day of the year, for example June 1<sup>st</sup>),  $\text{LAI}_3$  the end of summer vegetation period (day of the year, for example September 1<sup>st</sup>) and  $\text{LAI}_4$  is the end of the fall vegetation period (day of the year, for example November 15<sup>th</sup>). LAI and  $\text{LAI}_{max}$  are presented in table form in the database (GIS) for each vegetation class separately.

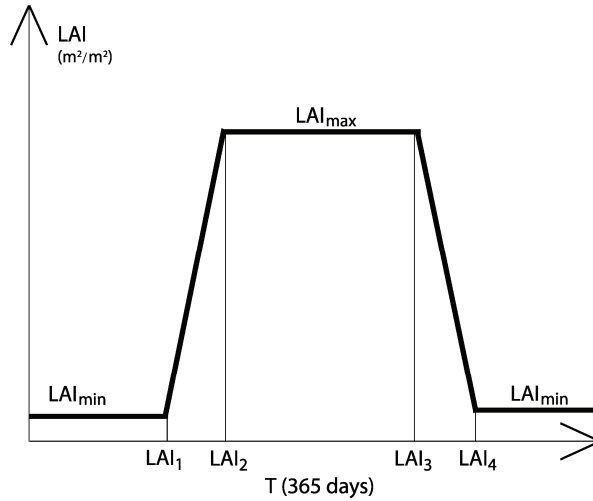
#### 4.7. Calculation of real evapotranspiration

After the calculation of potential evapotranspiration and canopy storage water, real (actual) evapotranspiration can be calculated by:

$$\text{if } E_0 < R_{int} \quad \text{than} \quad E_a = E_0 \quad (37)$$

$$\text{if } R_{INT} = 0 \quad \text{than} \quad E_a = E_0 \quad (38)$$

$$\text{if } E_0 > R_{int} \quad \text{than} \quad E_a = E_{int} \quad (39)$$



**Fig. 5.** Leaf area index per ground area on a given day ( $\text{m}^2/\text{m}^2$ )

#### 4.8. Water penetration into deeper soil layers (percolation)

A part of HRU waters penetrates into the deeper soil layers. The speed of water penetration into deeper soil layers is dependent upon the soil pore size, soil structure, soil fraction density, soil humidity and other parameters.

Water penetration into deeper layers (percolation) is calculated as follows:

$$w_{\text{seep}} = SW_{\text{excess}} \left\{ 1 - \exp \left[ \frac{-\Delta t}{TT_{\text{perc}}} \right] \right\} \quad (40)$$

where  $SW_{\text{excess}}$  is the potential water capacity in soil drained to deeper layers. This is the excess water capacity in soil which is not used by the vegetation blanket. This quantity of water penetrates into deeper layers,  $TT_{\text{perc}}$  is the percolation travel time. Value of  $SW_{\text{excess}}$  is calculated as follows:

$$SW_{\text{excess}} = SW - FC \quad \text{if } SW > FC \quad (41)$$

$$SW_{\text{excess}} = 0 \quad \text{if } SW < FC \quad (42)$$

where FC is the field capacity (mm) and SW is the water content in the soil profile (mm). FC is the required soil humidity used by the plant cover during its normal growth:

$$FC = WP + AWC \quad (43)$$

where WP is water content in soil at the wilting point (mm). This value is dependent upon the type of the vegetation cover and it is constant for a certain type of vegetation cover:

$$WP = 0.4 \cdot \frac{m_c \cdot \rho_b}{100} \quad (44)$$

where  $\rho_b$  is the specific weight of the soil ( $\text{kg}/\text{m}^3$ ),  $m_c$  the clay percentage in soil and AWC is the required soil capacity. This variable is the function of the vegetation cover and it represents the required water quantity in soil during 365 (366) days of the year, necessary for the regular growth and development of the vegetation cover. It is calculated as follows:

$$AWC = AWC_{\max} \frac{LAI}{LAI_{\max}} \quad (45)$$

$TT_{\text{perc}}$  is calculated using one of the two following methods, depending on whether hourly or daily discretization is computed:

$$TT_{\text{perc}} = \frac{SAT - FC}{k_{\text{sat}}} \quad (\text{hourly discretization}) \quad (46)$$

$$TT_{\text{perc}} = \frac{SAT - FC}{24 \cdot k_{\text{sat}}} \quad (\text{daily discretization}) \quad (47)$$

where SAT is the water content in completely saturated soil (mm),  $k_{\text{sat}}$  the hydraulic permeability of saturated soil (mm/h) and  $\Delta t$  is the time step (hour, day).

#### 4.9. Calculation of underground and surface runoff

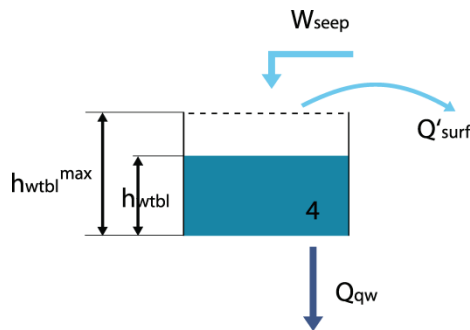
Underground runoff is the part of complex runoff in the basin which is less dependent upon rainfall and snowmelt than the surface runoff. The maximum level of underground waters is determined according to the hydrologic layers as the maximum thickness of the water-bearing layer, while the current height of the underground aquifer in the underground reservoir is calculated as follows:

$$h_{\text{wtbl}}^i = \min(\max(h_{\text{wtbl}}^{i-1} + w_{\text{seep}}^i - Q_{\text{qw}}^{i-1}, 0) h_{\text{wtbl}}^{\max}) \quad (\text{mm}) \quad (48)$$

The following condition is to be met:

$$h_{\text{wtbl}}^i \geq 0 \quad (49)$$

The illustration of the underground reservoir is shown in Figure 6.



**Fig. 6.** Underground reservoir (4)

The underground runoff is calculated by the following equations:

$$Q_{\text{qw}}^i = \frac{h_{\text{wtbl}}^i}{\text{porosity}} \left( 1 - e^{\frac{-g w_{\text{lag}}}{t_{\text{cgw}}^i}} \right) \quad (\text{mm}) \quad (50)$$

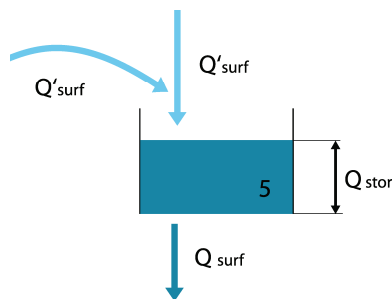
$$t_{\text{cqw}}^i = \frac{(L_{\text{slp}} + 10^{-2} \cdot L_{\text{veg}})}{k_{\text{sathor}} \cdot \frac{h_{\text{wtbl}}^i}{\text{porosity}}} \cdot 10^{-4} \text{ (day)} \quad (51)$$

where  $k_{\text{sathor}}$  is the horizontal component of hydraulic permeability (m/day),  $L_{\text{slp}}$  the travel distance of underground water up to the exit profile (m),  $L_{\text{str}}=L$  the travel distance of underground water up to the exit profile by water courses,  $L_{\text{rast}}$  the distance between the HRU and the exit profile (m) and  $gw_{\text{lag}}$  is the lag coefficient for underground runoff.

When reservoir 4 is full, than one part of water runs to reservoir 5 according to the following equation:

$$Q_{\text{surf}}^i = (Q_{\text{surf}}^i + Q_{\text{stor}}^{i-1}) \left(1 - \exp\left(\frac{-\text{sur}_{\text{lag}}}{t_{\text{conc}}}\right)\right) \quad (52)$$

where  $Q'_{\text{surf}1}$  is the excess water from reservoir 4 which runs to reservoir 5 (mm).



**Fig. 7.** Reservoir of surface runoff (5)

The following equation is used to calculate the surface runoff of HRU:

$$Q_{\text{surf}}^i = (Q_{\text{surf}}^i + Q_{\text{stor}}^{i-1}) \left(1 - \exp\left(\frac{-\text{sur}_{\text{lag}}}{t_{\text{conc}}}\right)\right) \text{ (mm)} \quad (53)$$

where  $Q'_{\text{surf}}$  is the potential surface runoff (mm),  $\text{sur}_{\text{lag}}$  the surface runoff lag coefficient (mm) and  $Q_{\text{stor}}^{i-1}$  is the part of potential surface runoff which is retained (accumulated) (mm). This component of surface runoff is transferred to the next step  $\Delta t$  and calculated as follows:

$$Q_{\text{stor}}^i = (Q_{\text{surf}}^i + Q_{\text{stor}}^{i-1}) - Q_{\text{surf}}^i \quad (54)$$

The following initial condition is introduced:

$$Q_{\text{stor}}^0 = 0 \quad (55)$$

#### 4.10. Calculation of the time of runoff concentration from the basin to exit profile

Surface runoff  $Q_{\text{surf}}$  travels for a certain time before it reaches the exit profile. This is the consequence of the flow along the surface of the catchment area and channel flow. Surface runoffs from all HRUs are superimposed at the exit profile. The time needed for the runoff from

the HRU to reach exit profile is called the inflow time (travel time). Each HRU has its own inflow time:

$$t_{\text{conc}} = t_{\text{ov}} + t_{\text{ch}} \quad (56)$$

where  $t_{\text{ov}}$  is the travel time of surface runoff and  $t_{\text{ch}}$  is the travel time of surface runoff through the water course:

$$t_{\text{ov}} = \frac{L_{\text{slp}}^{0.6} \cdot n^{0.6}}{18 \cdot \text{slp}^{0.3}} \quad (57)$$

where  $L_{\text{slp}}$  is the water travel distance in the basin (m),  $n$  the Manning's coefficient of flow down the basin slopes and  $\text{slp}$  is the average basin slope (m/m):

$$t_{\text{ch}} = \frac{0.62 \cdot L \cdot n^{0.75}}{\text{Area}^{0.125} \cdot \text{slp}_{\text{ch}}^{0.375}} \quad (58)$$

where  $L$  is the length of water flow down the watercourse (km),  $n_{\text{ch}}$  the Manning's coefficient of flow down the watercourse,  $\text{Area}$  the sub-catchment total area ( $\text{km}^2$ ) and  $\text{slp}_{\text{ch}}$  is the watercourse slope (m/m).

#### 4.11. Total basin runoff

SWAT model has two components:  $Q_{\text{surf}}$  and  $Q_{\text{gw}}$ . Provided that the initial condition is that a basin has  $k$  HRUs, the exit basin runoff is the sum of surface and base (underground) runoffs in all HRUs during the observed time step  $j$ :

$$\text{For } t=1 \text{ day} \quad Q_j^{\text{day}} = \frac{1}{86.4} \sum_{i=1}^k (Q_{\text{surf}}^i + Q_{\text{gw}}^i) \cdot A^i_{\text{HRU}} \quad (\text{m}^3/\text{s}) \quad (59)$$

$$\text{For } t=1 \text{ hour} \quad Q_j^{\text{hour}} = f(Q_{j-1}^{\text{day}}, Q_j^{\text{day}}, Q_{j+1}^{\text{day}}) \quad (\text{m}^3/\text{s}) \quad (60)$$

$$Q_k^{\text{hour}} = k \cdot \left( \frac{Q_j^{\text{day}} - Q_{j-1}^{\text{day}}}{24} \right) + \frac{Q_j^{\text{day}} + Q_{j-1}^{\text{day}}}{2} \quad k=0,1,2,3,\dots,11 \quad (61)$$

$$Q_k^{\text{hour}} = (k-12) \cdot \left( \frac{Q_{j+1}^{\text{day}} - Q_j^{\text{day}}}{24} \right) + Q_j^{\text{day}} \quad k=12,13,14,\dots,23 \quad (62)$$

## 5. New SWAT model in HIS applications library

As already mentioned, a hydrodynamic physically-based model was adopted, the operation of which requires numerous input data: meteorological, topographic, pedologic, plant cover data etc. In order to introduce the model into operational use in complex HIS environment, it was necessary to develop a library of classes that describe the model structure and its implementation, as well as the part of user interface to handle relevant GIS data, time series and model performances. The method of development of library of classes and its implementation in .NET environment, as well as its integration with HIS applications are described in Milivojević et al. (2009). The specific classes developed for purposes of model implementation, as well as the part of the graphically oriented interface, which is the extension of the HIS interface for the purpose of model application, will be analyzed below.

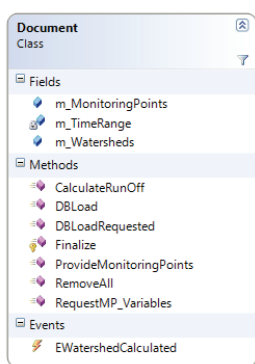


### 5.1. Model classes

In order to implement the presented model in the form of a functional library, a certain number of classes describing model configuration, individual sub-catchments and, finally, each hydrologic response unit, were developed. In order to define the calculation procedures, firstly present the most important classes, as well as their mutual links, will be presented.

### 5.2. Class for configuration of complex basins

The central class of the document is the one that contains the configurations of complex basins formed for simulation purposes. The task of the presented class of the hydrologic document is to extract all required data on simulated basins, their linking based on the hydrologic network of flows and runoff propagation in complex situations, when a larger number of basins shall be simulated simultaneously. The document in the collection *mWatersheds* stores the objects of all basins that are simulated.



**Fig. 8.** Class for configuration of complex basins

The function *DBLoad* is used for formation of the document based on the configuration and the parameters in the database. This function initiates the chain process of creation and reading of sub-catchment objects, then the creation and reading of objects of each HRU and, finally, all available data on input time series (rainfall, temperature etc.). After the successful document formation, the call of the *CalculateRunOff* method is used to perform sequential calculation of runoff per basins that is, per individual hydrologic response units.

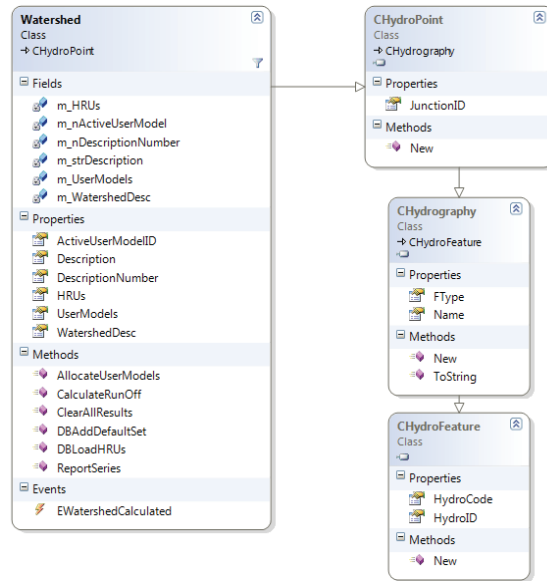
In calculation of the runoff, HIS applications communicate with the model predominantly by the means of these two functions.

### 5.3. Class of basin model

Class of the basin model has been formed around the collection *m\_HRUs* representing the physical network of hydrologic response units. In addition to the functions related to database communication, it contains the *CalculateRunoff* function which performs the simulation of individual elements and summarizes the data at the basin level.

Figure 9 shows that the basin class has been derived from the *CHydropoint* class which is the structure inherited from the implemented *ArcHydro* database model.

Function *DBLoadHRUs* is used for the process of creation and reading of objects for each HRU. After the successful document formation, the call of *CalculateRunOff* method is used to perform the sequential calculation of runoff per individual hydrologic response units.



**Fig. 9.** Class of the mathematical model of the basin

#### 5.4. Class of hydrologic response unit

Hydrologic response units are mainly of square shape, except on the boundaries of multiple basins where they form an irregular shape. It is assumed that all input values of the model at the unit level are homogenous, i.e. quasi-homogenous.

In addition to many variables, the class contains a certain number of functions, the most important of which is the function *Calculate* that initiates the simulation procedure. The result of the call of this function is the new state of the hydrologic unit with generation series that represent the states of surface runoffs, underground waters, snow, soil humidity and similar. Only the total runoff series represents the input data, while other series are used for visualization of dynamics of the associated phenomena that are the cause or the consequence of runoff.

#### 5.5. Extension of HIS user interface

In order to make possible the efficient use of the model, HIS user interface has been extended by a certain number of dialog boxes for interaction with the model (Figure 10). This interaction is reflected both in definition of the configuration, and in modification of model parameters, input series, as well as the capability of review of the results.

The basic dialog box for the access to the basin model has been developed. This provided for the following data to be presented: input time series (rainfall, temperature), sub-catchment parameters, CN parameter, vegetation parameters, soil parameters and river section types.

Since the input time series include rainfall, mean temperatures, maximum temperatures and minimum temperatures, their visualization, as well as their modification, has been made possible (Figure 11).

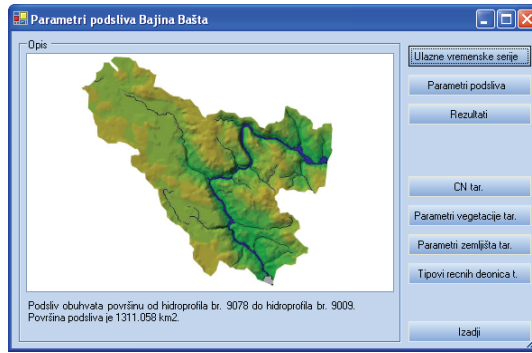


Fig. 10. Basic dialog box for interaction with basin model

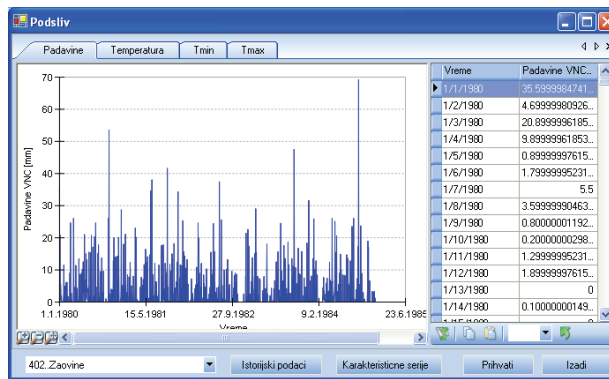


Fig. 11. Dialog box with input time series

Sub-catchment parameters include the presented data typical for each sub-catchment. This data is important for the rainfall-runoff calculation based on the proposed model. Some of relevant data is presented in Figure 12.

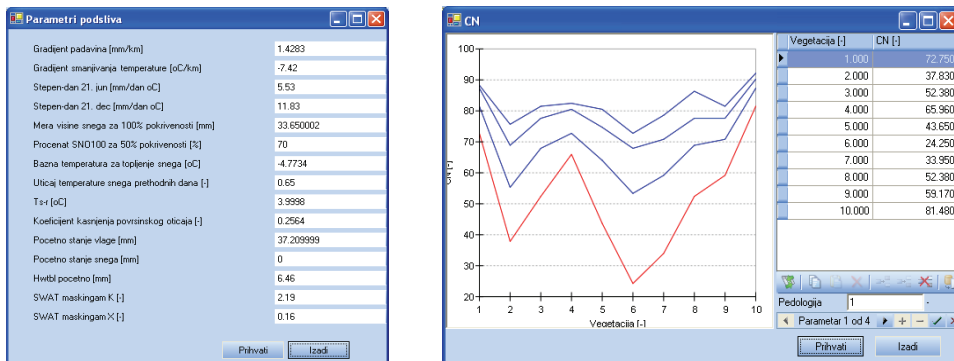


Fig. 12. Dialog boxes with parameters of the basin model

Hydrologic response units are mainly of square shape, except on boundaries of multiple basins where they form an irregular shape. It is assumed that all input values of the model at the unit level are homogenous, i.e. quasi-homogenous. Dialog boxes show the GIS layers (relief,

pedology, vegetation and hydrology), as well as the HRU network of the selected sub-catchment and the access to each individual HRU. Dialog boxes show their characteristics: vegetation (coverage in percentages), pedology (coverage in percentages), river section type, rainfall stations, temperature stations, total area, median elevation, length of basin flow, flow slope in the basin, length of flow down the watercourse and flow slope of the watercourse.

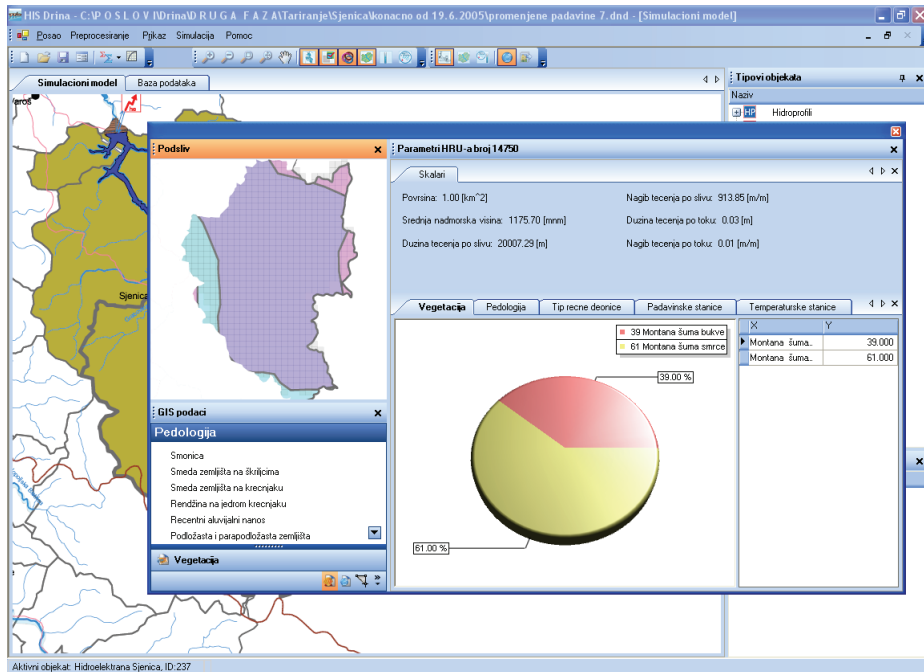


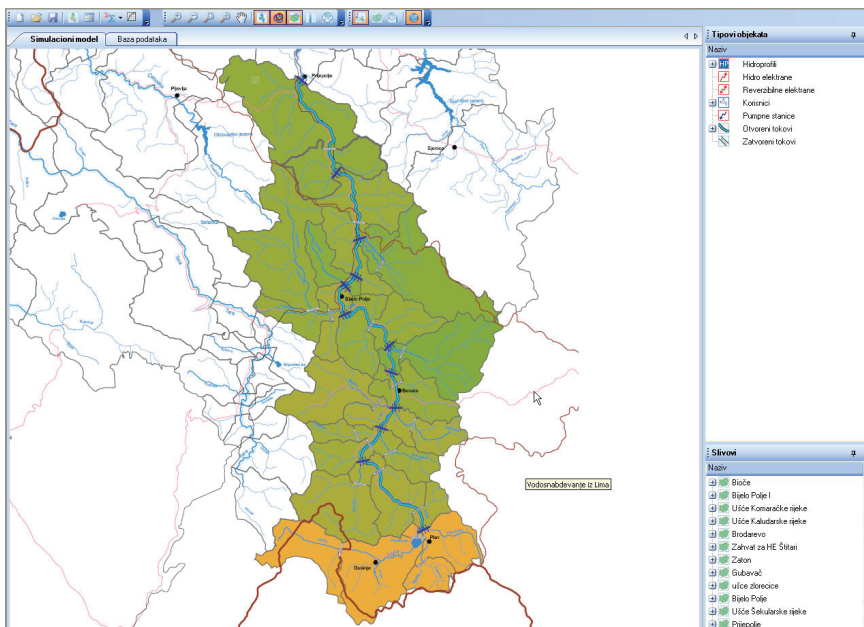
Fig. 13. HRU data obtained from GIS layers

## 6. Example of application of new model

Further below we present the example of SWAT model for the River Drina basin, with the total area of 19232 km<sup>2</sup>. Figure 14 shows only one small sub-catchment of this catchment, from the River Lim up to the "Prijepolje" profile (sub-catchment area covers 14.7% of the total River Drina basin).

In order to present the Drina basin faithfully, the hydrologic model has used the following data in the digital form, organized in layers: digital terrain model, river network, network of meteorological stations, pedology, vegetation, hydrogeology and the layer describing transfer of underground water to the basin and from it.

**Digital Terrain Model.** Digital terrain model (DEM) was created based on 1:300000 scale maps that is, based on the digital terrain model (DTM) in raster form, with the pixel size of 100x100 meters. A high-quality DEM is the base for formation of physically-based hydrologic models. The analyses and the use of DEM layer are used for determination of the potential surface flows, basin boundaries, calculation of terrain slope and determination of the effect of meteorological stations.



**Fig. 14.** Configuration of Lim River to the “Prijepolje” profile

**River network.** Available river network data were: rivers as lines in the vector form as 2D polygonal lines, rivers as polygons (large rivers were defined in this manner) and lakes in vector form as 2D enclosed polygons. The role of river network defined in the vector form in the hydrologic model is related to the DEM creation. For all subsequent hydrologic analyses, river network is automatically generated from DEM according to the predefined requirements regarding the upstream associated area, length, river order or similar.

**Network of meteorological stations.** Meteorological data (rainfall, temperature, air humidity) are given only in the form of position of meteorological stations in the basin, with their identifications and data on what is measured on the subject station (rainfall, temperature, air humidity and other).

**Pedology.** For the purpose of formation of the distributed hydrologic model a layer presenting the spatial distribution of soil types, i.e. pedology, is required. This layer was formed by digitalization of the pedologic atlas of 1:1000000 scale, together with classification of soil in 9 classes and mapping of these classes into 4 CN classes.

**Vegetation.** Vegetation in the hydrologic model has a twofold role: in the energy balance, it consumes the part of solar energy and in the hydrologic balance the water evaporates off the vegetation, i.e. it is consumed for plant growth and development. The importance of vegetation in the model is great, because the major part of water exchange takes place there. The model has a vegetation layer based on the reclassification of satellite images according to the EU recommendations set in the CORINA program.

**Hydrogeology.** Hydrogeologic layer is obtained by digitalization of paper layers in the 1:300000 scale, whereby the attention was paid to the separation of layers by age, water permeability and thickness. Then, all layers were classified in 9 categories.

**Data time series in the model.** “Drina” HIS database contains historic data on mean daily values of water level and discharge on 54 water measurement stations in the River Drina basin,

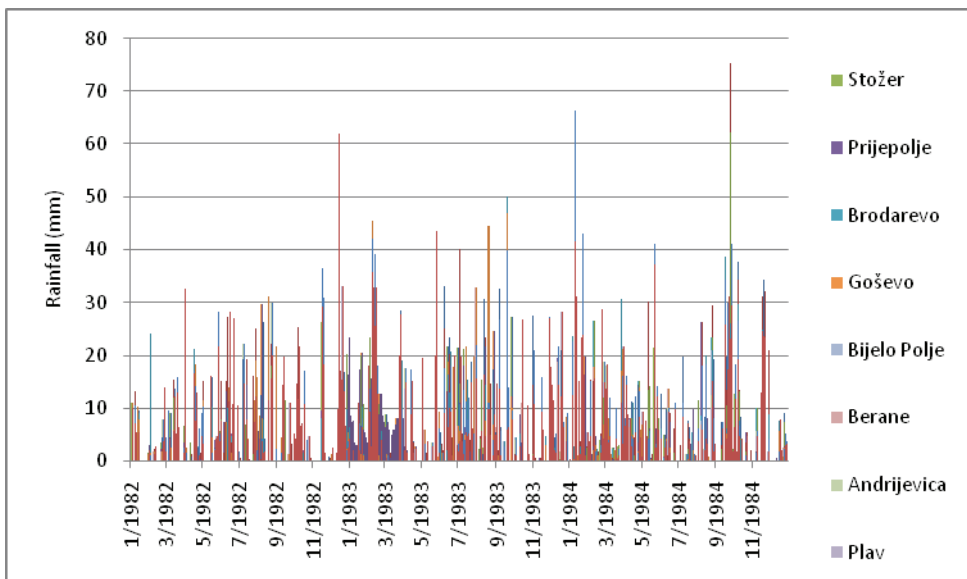
what makes a data fund of 716,132 daily values related to these phenomena. Some 41.36% of this data is related to water levels and 59.64% to discharges. Data sources were the annual reports of the Federal and Republic Hydro-Meteorological Services. The database holds daily value of the following meteorological phenomena: daily rainfall sums on 96 rainfall or meteorological stations, daily air temperatures on 31 meteorological stations, daily values of vapor pressure on 24 meteorological stations, daily values of air humidity on 26 meteorological stations, daily sums of evaporation off the water table and vessels on 2 meteorological stations and daily snow pack height on 27 meteorological stations.

### 6.1. Example of simulation of runoff from basin upstream from “Prijepolje” hydrologic station

The hydrologic station “Prijepolje” covers the catchment with the total area of 2827.2 km<sup>2</sup>, which is 14.7% of the total River Drina basin. Period chosen for simulation was from October 1<sup>st</sup>, 1982 to October 1<sup>st</sup>, 1984.

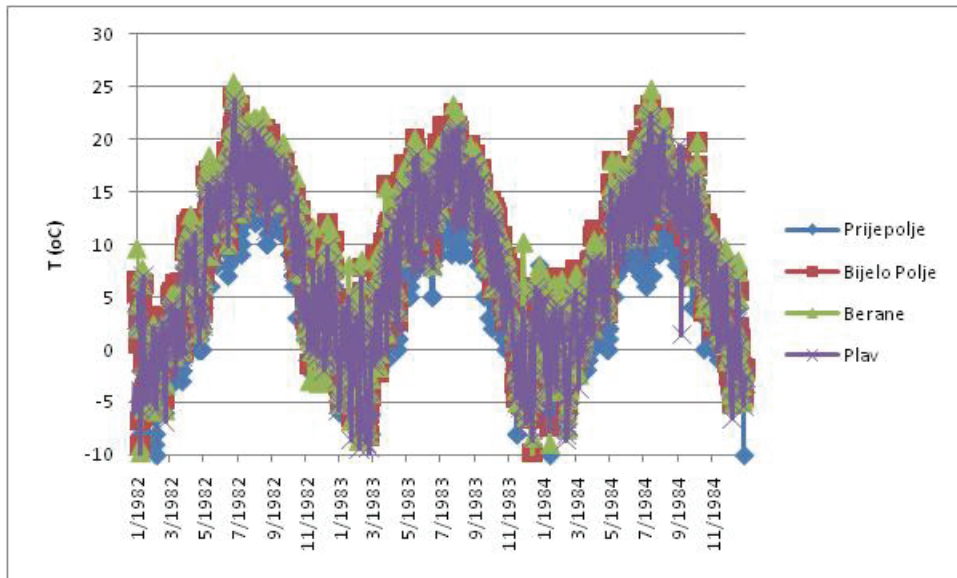
The rainfall in the subject part of the basin is observed by 8 rainfall stations, as shown in Figure 15. The average annual rainfall was 755 mm.

Air temperatures in the subject part of the basin are observed on 4 meteorological stations, as shown in Figure 16. The average annual temperature was 7.8°C.

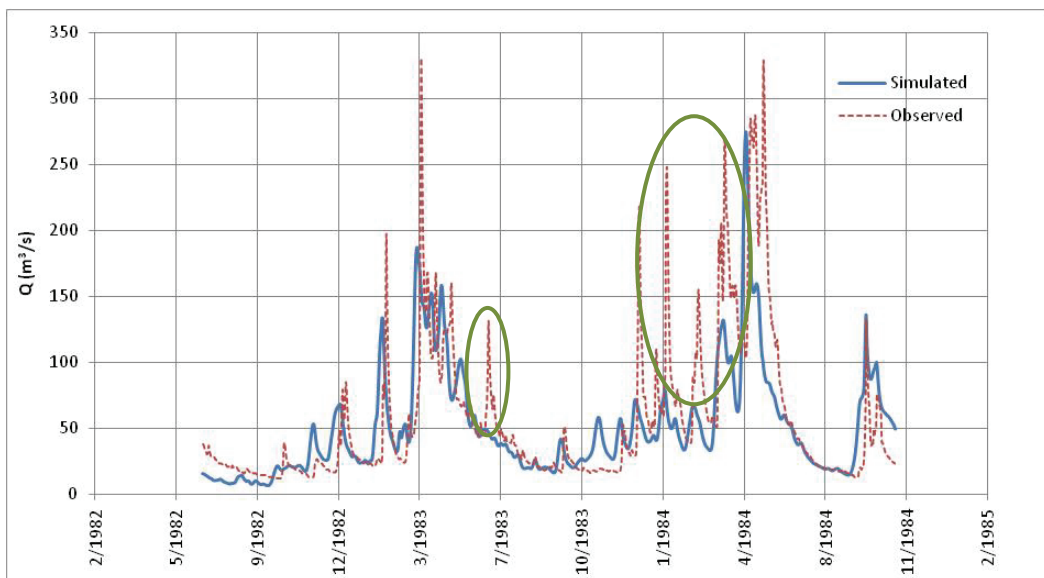


**Fig. 15.** Rainfall on the stations of the Lim River basin up to the “Prijepolje” profile during the subject period

The comparison of observed and simulated values shows mainly satisfactory matching between the measured and the simulated hydrographs. Typical phenomena such as snowmelt and base runoff during the period without rainfall were successfully simulated. The peak values resulting from rainfall show good matching, except during June 1983 and during the period from December 1983 to April 1984. This indicates that the rainfall recorded on some of the referent stations were of local nature, or that the error in measurement or data entry was made. Also, the preset initial conditions provide relevant runoff in the transition period, too.



**Fig. 16.** Temperatures on the stations of the River Lim basin up to the “Prijepolje” profile during the subject period



**Fig. 17.** Comparison of observed and simulated hydrographs on the “Prijepolje” profile

## 7. Conclusions

Present paper presents the Soil and Water Assessment Tool model developed by USDA Agricultural Research Service (ARS). In it is demonstrated that SWAT model has been developing for almost 30 years now and that it has undergone numerous modifications and adaptations. The reasons for model adaptation to potential application in the wider region of

Serbia are also explained. The adapted (new) model has a detailed theoretical background and its software implementation has been performed. This paper also makes a review of the role of the SWAT model in the HIS application library (model classes and extension of the user interface) and presents an example of the model use in the River Drina basin.

This example shows that the model reacts properly during the dry and rain seasons and that it can be used successfully for annual and multiannual of simulations rainfall-runoff transformation. The example also indicates that the quality of simulation results during rain seasons is directly related to input data (rainfall, temperature and other). This is the reason why in the region of Serbia it is necessary to invest more efforts into the creation of an information environment with input data as precise possible, collected from the required number of measurement stations in the analyzed catchment.

The developed SWAT model is applicable in hydro-information systems in Serbia, as well as in the catchments and hydro-information systems in other surrounding regions (B&H, Montenegro and others). This model has been already applied in the "Drina" HIS, "Vlasina" HIS and "Vrbas" HIS. In addition to further model application, further efforts should be invested in its development and improvement. SWAT model development should be focused on the use of hourly discretization data and its application in specific hydrologic situations (such as the occurrence of flood waves and improvement of the base runoff component).

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