DESCRIPTION OF THE RAINFALL-RUNOFF MODEL FRIER

OPIS ZRÁŽKOVO-ODTOKOVÉHO MODELU FRIER

Oliver Horvát

ABSTRACT

The main aim of the study is to describe one physically based rainfall-runoff model with distributed parameters. The model runs at any space and time resolution. The filling in missing data is possible but unnecessary. Many classifications of soil parameters, parameterization of land use types and many determination methods of e.g. evapotranspiration allow reach the more exact results. The determination of net radiation balance and the whole energy balance include the influences of cloudiness, slope orientation and hill shading. Transformation of rainfall excess to runoff is solved by approximation of diffuse wave. Calibration and efficiency are composed in the model. The FRIER model can serve as a complex tool for solution of hydrological and other problems, e.g. water balance calculation, discharge simulation, flood prediction, impact of change in land use and climate and others.

KEY WORDS

rainfall-runoff model, GIS interface, hydrological balance, evapotranspiration, net radiation balance, surface energy balance

KĽÚČOVÉ SLOVÁ

zrážkovo-odtokový model, prostredie GIS, hydrologická bilancia, evapotranspirácia, bilancia slnečného žiarenia, energetická bilancia povrchu

INTRODUCTION

The development and use of rainfall-runoff models is in forefront of hydrologic research for some decades now. Since it is not possible to measure all hydrologic parameters in all points of space and at any time, and also the measured data must be extrapolated into space and time, a model is an instrument that is able to decrease those deficits. The purpose of their development is ambiguous. On the one hand they improve the level of knowledge and the conception of rainfall-runoff processes and on the other hand they are helping with the practical solutions of many problems concerning the environment and water management (changes in the land use, climate changes, more intensive water resources and soil use and other impacts of the human activities on the hydrologic regime).

The new created model FRIER – Water Distribution (Flow, Routing, IUH) Model with Accent to Evapotranspiration and Radiation Methods) is a rainfall-runoff model with distributed parameters. One part of the model is running in GIS interface, in the second part the missing input data can be filled in. The third part serves for determining the instantaneous unit hydrograph (IUH), the water balance, runoff simulation and model efficiency. It can also be used for runoff forecasting.

INTERPRETATION OF THE FRIER MODEL

Inputs

The input files are time series of discharge in the basin outlet, rainfall and climatic data in TXT format and spatial layers of digital elevation model, soil texture and land use of the basin in ASCII format. After that it is necessary to set global parameters and to select relevant methods.

The time series of discharge in the basin outlet, total rainfall and mean air temperature are required for program running. The kind of required climatic data depends on a chosen method. Some of selected methods need sunshine duration value either measured short-wave radiation, real sunshine duration or clouds covering the sky - cloudiness. Others require the knowledge of data on air humidity, input can be either mean relative air humidity or actual water vapour pressure. The mean wind speed is also needed for many methods. The snow cover height can be computed either in the model or the values from measurements can be used and then 3 global parameters do not have to be calibrated.

If a lack of data occurs in the station, no data values equal to -9999 can be written. Missing values can be

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assessed in the subprogram where 3 methods – kriging, lapse rate (vertical gradient) or correlation (Fig. 1) are used for it.

It is not an easy way to estimate hourly rainfall if we have only daily data. The subprogram also solves a lack of gauged values of total rainfall in hourly time step. It computes hourly rainfall on the base of simplified water balance (rainfall = actual evapotranspiration + runoff) where rainfall is an unknown variable. Actual evapotranspiration and partial rainfall ratio could be determined from empirical formulae. If we have discharge data, the average runoff of the basin could be computed by IUH with including runoff late after rainfall event.

In the FRIER model, the conversions of air humidity and sunshine duration data are included. Data from time series are distributed to the space by arithmetic mean, Thiessen polygons, lapse rate (vertical gradient) or kriging (Fig. 2). The spatial data preparation is produced in the GIS interface in the coordinate system S-JTSK used in Slovakia and Czech Republic. The extension FRIER_GIS of program ESRI ArcView GIS 3.3 was created to accelerate GIS operations.

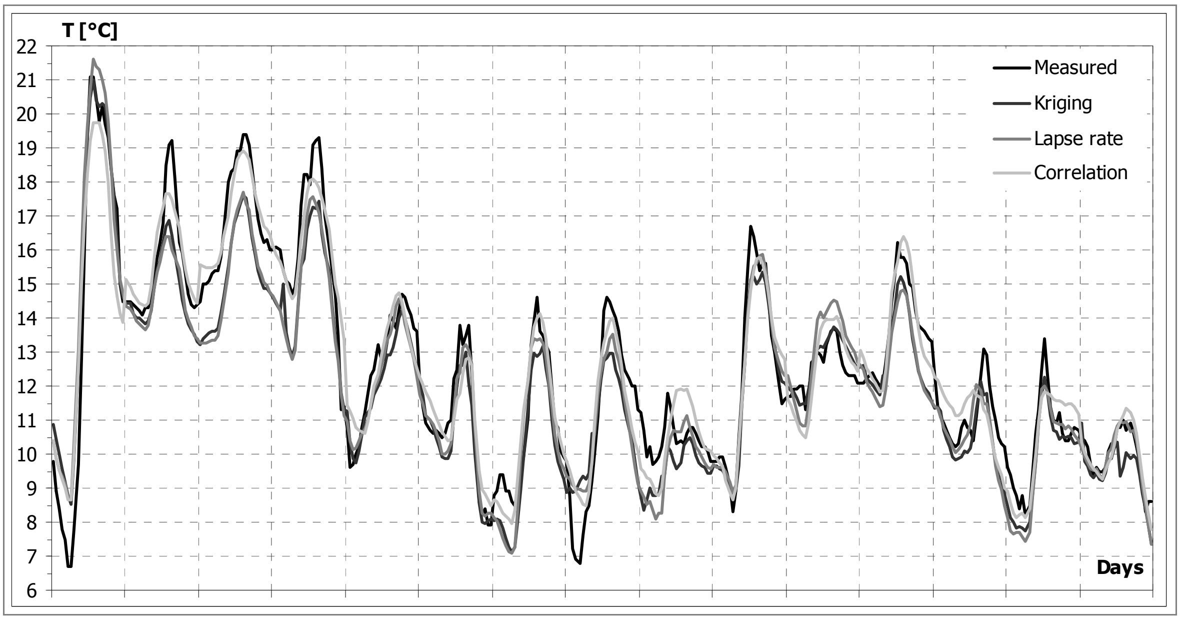

Fig. 1: Data filling by 3 methods – kriging, lapse rate, correlation
Obr. 1: Dopĺňanie chýbajúcich údajov 3 metódami – krigingom, závislosťou od nadmorskej výšky, koreláciou

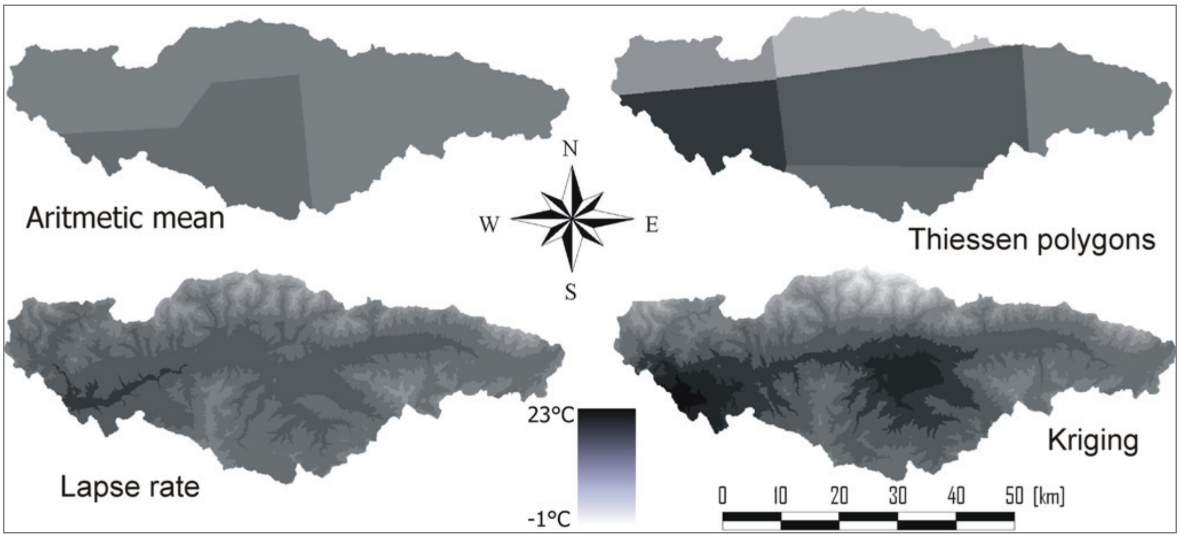

Fig. 2: Choices of possible spatial distribution of input time series in the FRIER model
Obr. 2: Možnosti priestorového rozloženia vstupných časových radov v modeli FRIER

Tab. 1: Land use types
Tab. 1: Druhy využitia krajiny

Land use types	Root depth	Interception	Manning's coefficient	PET coefficient	Emissivity	Albedo	Leaf area index
Units	**mm**	**mm**	**$m^{-1/3}.s^{-1}$**				
01 Water areas	0.5	0.00 – 0.00	0.04	1.20	0.95	0.07 – 0.11	0.0 – 0.0
02 Bogs, marshes, fens	1.0	0.00 – 0.50	0.20	1.15	0.91	0.07 – 0.14	0.5 – 2.0
03 Urban areas	0.0	0.00 – 0.20	0.10	0.70	0.89	0.08 – 0.30	0.0 – 0.0
04 Bare soils	0.5	0.00 – 0.50	0.02	0.85	0.91	0.11 – 0.30	0.5 – 2.0
05 Farmland	1.0	0.00 – 1.00	0.15	1.10	0.89	0.11 – 0.25	0.5 – 6.0
06 Meadows and pastures (short grass)	1.0	0.10 – 1.00	0.20	1.00	0.98	0.16 – 0.27	0.5 – 2.0
07 Natural meadows (tall grass)	1.0	0.15 – 1.50	0.40	1.05	0.97	0.22 – 0.31	1.0 – 6.0
08 Shrubs	1.0	0.15 – 1.50	0.40	1.10	0.98	0.07 – 0.19	5.0 – 6.0
09 Mix between shrubs and forest	1.0	0.05 – 1.50	0.40	1.10	0.98	0.16 – 0.27	1.0 – 6.0
10 Evergreen broad leaf forest	1.5	0.20 – 2.00	0.60	1.15	0.97	0.22 – 0.27	5.0 – 6.0
11 Deciduous broad leaf forest	2.0	0.05 – 2.00	0.80	1.15	0.97	0.16 – 0.27	1.0 – 6.0
12 Mixed forest	2.0	0.15 – 3.00	0.60	1.15	0.98	0.11 – 0.22	3.0 – 6.0
13 Evergreen coniferous forest	1.5	0.30 – 4.00	0.40	1.10	0.98	0.07 – 0.19	5.0 – 6.0
14 Deciduous coniferous forest	1.5	0.15 – 4.00	0.40	1.10	0.98	0.11 – 0.19	1.0 – 6.0

At first, input raster of the digital elevation model is filled. The basin area, flow direction and flow accumulation are generated by standard GIS functions from it. Interception, evapotranspiration, infiltration and other important hydrologic processes are impacted by the land use types. The surface roughness influences flow velocity and flood intensity. 14 land use types are categorized in the FRIER model (Tab. 1) (Heymann, 1994). The parameters for bare soils are dependent on lightness of soil surface and surface moisture, too. The growing period is included in the category of crops. The surface emissivity and the albedo are changed in dependency on snow occurrence and surface moisture.

The stream network is generated from flow accumulation and the setting of threshold of spring beginnings. The less number of threshold the bigger stream network and more river cells. The stream order is generated either by Shreve or by Strahler method. Hydraulic parameters are represented by Manning's roughness coefficient and hydraulic radius. Manning's roughness coefficient is created from a stream order by indirect linear dependency with setting of the highest and lowest order. The hydraulic radius is determined by a power law relationship with an exceeding flood probability (Molnar, Ramirez, 1998), which relates hydraulic radius to the contributing area and it is calculated as a representation of the average behaviour of the cell and the channel geometry. The flow velocity is calculated from the above hydraulic parameters and the slope. The routing of overland flow and channel flow is implemented by the method of a linear diffusive wave approximation. Hence, the flow routing consists of tracking runoff along its topographic determined flow path, and evaluating base flow out of the whole basin.

The total discharge is the sum of the overland flow, interflow and base flow. It is obtained by convolution of the flow response from all grid cells. The advantage of this approach is that it allows a spatially distributed runoff and hydrologic parameters of the terrain can also be used as inputs to the model, and can route runoff from a certain land use area to the basin outlet or any downstream converging point (Liu, de Smedt, 2003). The input vector map of soil texture either with attributes of percentages of sand, silt and clay or with attribute of USDA soil texture classification is needed. The layers of fine-grained elements are used for information about hydrophysical parameters of soil (Tab. 2). It is able to use own maps of these parameters and then a user does not need the input vector map of soil texture. The determination of an initial value of soil moisture is very important. It is expressed by global parameter SM0 and it can be supported by input map which is optional.

In the FRIER model, 11 global parameters are used to simplify some hydrologic processes and to set the most exact initial values, which are necessary to be

Tab. 2: Soil hydrophysical parameters
Tab. 2: Pôdne hydrofyzikálne parametre

Hydrophysical parameters	Rawls-Brakensiek-Saxton + FAO	Carsel-Parrish	Wetspa	Own estmiation		Rawls-Brakensiek-Saxton + FAO	Carsel-Parrish	Wetspa	Own estmiation
Hydraulic conductivity [mm.h^{-1}]					**Residual soil moisture [-]**				
Sand	236.0	297.0	208.8	270.0	Sand	0.020	0.045	0.020	0.020
Silt	5.0	2.5	6.8	91.8	Silt	0.015	0.034	0.015	0.015
Clay	0.6	2.0	0.6	1.8	Clay	0.090	0.068	0.012	0.090
Porosity [-]					**Wilting point [-]**				
Sand	0.440	0.430	0.437	0.395	Sand	0.045	0.045	0.070	0.020
Silt	0.480	0.460	0.482	0.475	Silt	0.170	0.090	0.126	0.170
Clay	0.480	0.380	0.475	0.500	Clay	0.220	0.270	0.250	0.220
Field capacity [-]						**Pore index [-]**		**Lightness [-]**	
Sand	0.120	0.046	0.062	0.070	Sand	3.590		0.0	
Silt	0.320	0.257	0.258	0.280	Silt	3.308		0.5	
Clay	0.360	0.347	0.378	0.360	Clay	3.165		1.0	

calibrated. The instantaneous unit hydrograph of interflow is calibrated by the global parameter I_UH, for base flow by B_UH. 3 global parameters for snow determination do not have to be used in case that the time series of snow cover height will be the input into the model. Otherwise, initial snow cover is assessed by S0, snow accumulation and melt is solved by means of degree-day method with temperature coefficient (kt) and rainfall coefficient (kp). Global parameter Imp informs about covering of urban areas by impervious areas, in that case the same representation of asphalt and concrete, the rest is assumed as a mixture of trees, shrubs and grass. Overland flow is assessed from accumulated rainfall excess, depression losses and real runoff coefficient which are calibrated by Omax. Initial soil moisture is expressed by SM0. It can be supported by input map which is optional. Interflow and percolation depend on slope, hydraulic conductivity, root depth and Imax. The volume of groundwater storage is influenced by percolation, transpiration, base flow and Gmax, its initial volume by G0.

Methodology

The FRIER model is ready to create instantaneous unit hydrograph (IUH) after data preparation. There are generated IUH of overland flow and IUH of interflow for each cell down to basin's outlet cell and IUH of base flow for the whole basin either by non-linear method (flow time dependence) or by linear method (average slope dependence). Global parameter I_UH regulates IUH of interflow and global parameter B_UH regulates IUH of base flow (Fig. 3).

Potential global radiation can be computed with or without cell orientation, slope and shading of neighbouring cells. Net radiation balance is needed for calculation of potential radiation. It consists of short-wave and long-wave radiation balance (Fig. 4). The radiation of outer atmosphere, seasonal correction of solar time, inverse relative distance between the Earth and the Sun, solar declination, noon, east and west of the Sun in the Central European Time, eastern and western potential solar azimuth, eastern and western potential critical solar angle, potential sunshine duration are calculated from date and grid localization. The latent heat of vaporization, atmospheric air pressure, and saturated water vapour pressure are estimated from air temperature. It is possible to assess the cloudiness influence by more approaches either by lapse rate, clearness coefficients, Angström's parameters (by Turc's), Kosťjakovov's coefficient or by our own values. The snow albedo, albedo, actual height, azimuth and angle of the Sun, extraterrestrial radiation, eastern and western real solar azimuth, eastern and western real critical solar angle, optical path of air mass in the altitude, direct and diffuse radiation, clear-sky short-wave radiation are assessed for short-wave radiation balance. Real sunshine duration can be reduced with shading of neighbouring cells. Surface radiation, influence of air humidity by Brunt and clear-sky long-wave radiation are determined for long-wave radiation balance.

For determination of surface specific air humidity it is necessary to know the surface temperature. If data on surface temperature are missing then surface temperature is assessed from surface energy balance.

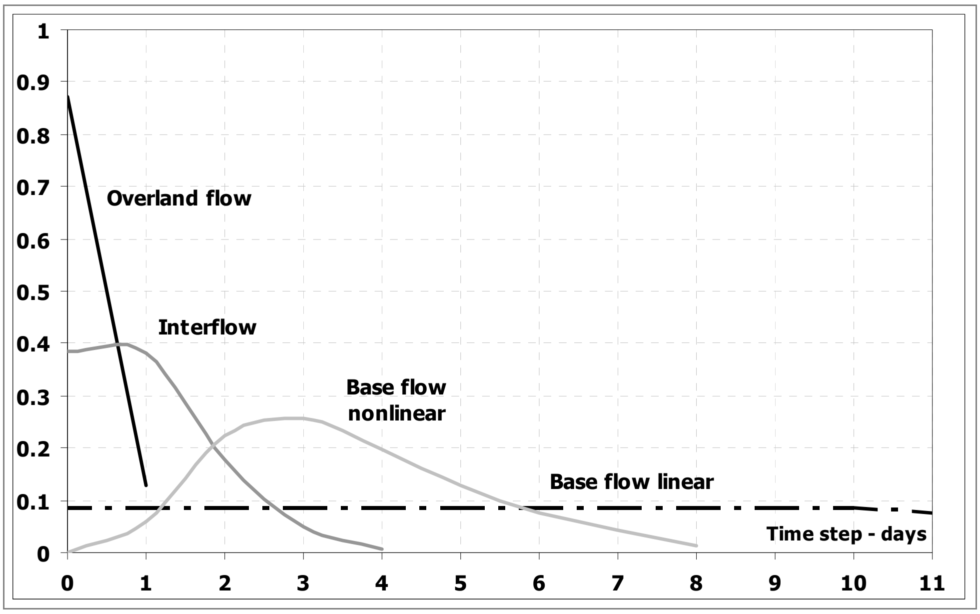

Fig. 3: Mean basin values of individual instantaneous unit hydrographs of the flow components
Obr. 3: Priemerné hodnoty povodia okamžitých jednotkových hydrogramov jednotlivých zložiek odtoku

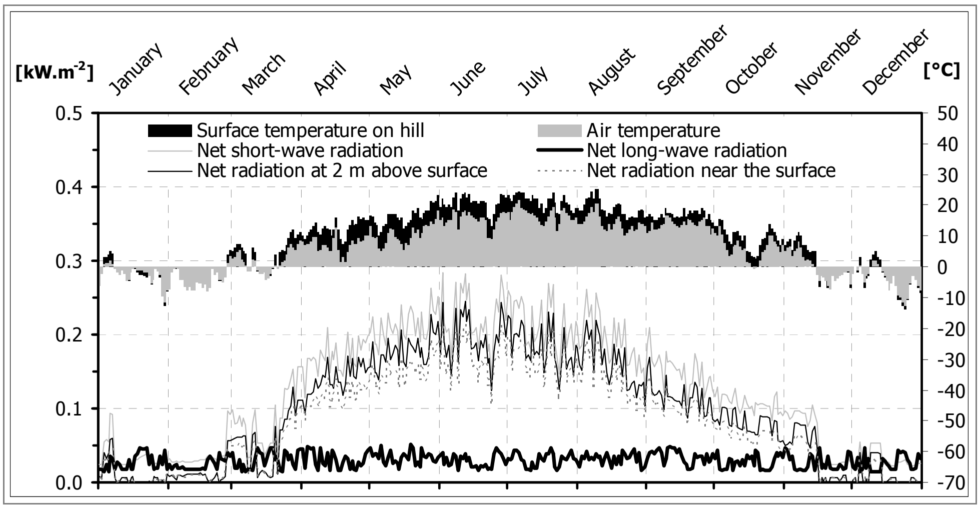

Fig. 4: The whole net radiation balance
Obr. 4: Celková bilancia žiarenia

Basic energy source of physical processes running in atmosphere and on the Earth's surface is the energy, which comes from the Sun. The part of this energy is reflected from the Earth's surface and other part is absorbed by them. The difference between the surface radiation and reflected radiation to the atmosphere is named net radiation balance. Energy balance is expended to soil heat, latent heat and heat of atmosphere (Fig. 5). The equation of surface energy balance has a form (Tomlain, Damborská, 1999):

$$R = \lambda \cdot E + Q_\Lambda + Q_S \text{, where} \qquad (1)$$

R – net surface radiation balance [$kW.m^{-2}$],
λ – latent heat of vaporization [$kJ.kg^{-1}$],
E – evapotranspiration [$kg.m^{-2}.s^{-1}$],
Q_Λ – turbulence heat flux [$kW.m^{-2}$],
Q_S – soil heat flux [$kW.m^{-2}$].

The right side of the Eq. 1 will be considered as positive values if heat fluxes are characterised from surface, R is positive, if heat flux goes to the surface. Other elements of surface energy balance, e. g. heat which is needed for snow and ice melt, heat flux from soil freezing, heat flux from dissipation of mechanical energy of wind, heat flux transfer by rainfall, heat which is needed for photosynthesis etc. are not important for this study in comparison with basic elements, and therefore they are neglected (Tomlain, Damborská, 1999).

Global models allow describe the soil heat flux. It can be compared with the value of net radiation balance, mostly if the surface is covered by vegetation and time step is higher than 1 day, its estimation can be simplified on the assumption that TW = T. It is necessary to notify that these equations give only approximate results and they do not include the crop distance, solar angle, colour, moisture and structure of soil (Allen et al., 1998). But here the more precise solution is used.

Potential evapotranspiration is an essential part of any water balance calculations. The FRIER model has a wide scale of many of its determination methods (Tab. 3).

The water balance is evaluated at 3 levels: surface, soil and underground. The hydrologic processes run simultaneously.

The degree-day method was enforced in snow melt modelling (Martinec et al., 1983). The whole energy balance is substituted by the expression depending on air temperature and total rainfall. The most of energy representing in snow cover comes from atmospheric long-wave radiation, therefore short-wave radiation is neglected due to simplifying. On the other hand, it is taken adding snow melting into account caused by advective heat transfer from rainfall to snow cover. The elements of energy balance participate in the fulfilling mass balance of snow cover. The degree-day coefficient is implicitly representing all these elements for the reason that it is sharply changing in time (Singh et al., 2000) and is reaching different values for different species of vegetation (Kite, Kauwen, 1992). However, the constant value is usually used owing to its simplicity in models. It can be estimated either by local measurements or by calibration.

Interception is the quantity of rainfall which is caught by vegetation (interception loss, change in interception storage) and then evaporated (evaporation from interception storage). The mass balance of interception storage says that if total rainfall is higher than interception storage capacity then rainfall intensity will be decreased by the capacity. In other case, total rainfall is intercepted by vegetation and interception residuum is taken off from total rainfall in the following time step.

Actual evapotranspiration is determined from relation of potential evapotranspiration, rainfall, actual and critical soil moisture or empirically. It is divided on four parts: evaporation from interception storage, evaporation from depression storage, evapotranspiration from soil and transpiration from groundwater storage. It can be calculated by 6 methods (Tab. 3).

Change in depression storage is defined by empiric Linsley's equation (Linsley et al., 1982). The mass balance of depression storage says that water from depressions is either evaporating away (evaporation from depression storage), staying there (depression loss, depression storage) or infiltrating to the soil after rainfall event (infiltration). The depression storage is influenced by relief, slopes, soil surface, land use, actual soil moisture and time (Liu, de Smedt, 2003). Depression storage capacity is approximated by the difference of the filled and real DEM.

Total flow is a sum of overland flow, interflow and base flow. Recall that the rainfall excess is a sum of overland flow and the change of depression storage, the algorithm of the amount of overland flow can be assessed in accordance with depression storage.

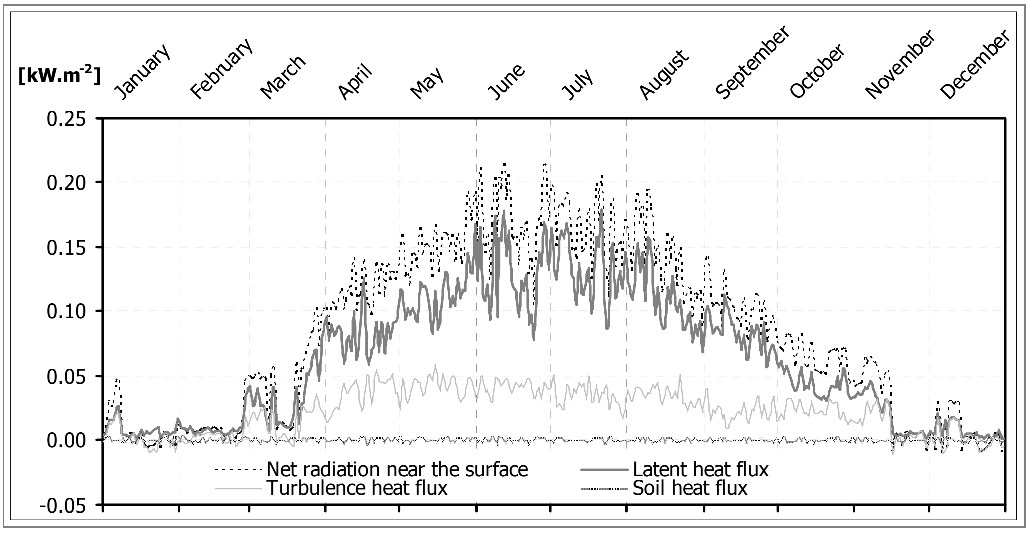

Fig. 5: Sample of surface energy balance
Obr. 5: Príklad energetickej bilancie povrchu

Tab. 3: Methods for potential evapotranspiration determination and necessary inputs for them
Tab. 3: Metódy stanovujúce potenciálnu evapotranspiráciu a potrebné vstupné časové rady do nich

Potential evapotranspiration								Actual evapotranspiration			
Needed meteorological data ►	Air temperature	Relative air humidity	Wind speed	Needed meteorological data ►	Air temperature	Relative air humidity	Wind speed	Needed meteorological data ►	Air temperature	Relative air humidity	Wind speed
Methods▼ Units►	°C	%	$m.s^{-1}$	Methods▼ Units►	°C	%	$m.s^{-1}$	Methods▼ Units►	°C	%	$m.s^{-1}$
Blaney-Criddle	*			Priestley-Taylor	*	*		Water balance	*		
Budyko	*	*	*	Schendel	*	*		Krickij-Menkel-R	*	*	*
Hamon	*			Smith-Stopp	*			Šatský	*	*	
Jensen-Heise	*			Tomlain	*	*		Turc	*		
Mintz-Walker	*			Turc	*	*		Thornthwaite	*		
Penman	*	*	*	Turc-Wendling	*			Zubenokova	*		
Penman-Monteith	*	*	*								

Infiltration adds water into the soil, one part of soil water is evaporating (evapotranspiration from root zone), the second one is staying there (change in soil moisture), the other one horizontally is flowing away as interflow and the last one is flowing down and recharging the groundwater storage (percolation). The infiltration intensity is calculated either as difference of interception loss and rainfall excess with total rainfall, snow melting and depression storage or empirically. It is mainly affected by initial soil moisture, rainfall, surface conditions and soil characteristics under current conditions (Velebný et al., 2000). The real runoff coefficient and rainfall excess can be estimated from dependency among the potential runoff coefficient, land use types and soil texture classes.

The procedure of soil moisture determination is mainly depending on total rainfall and potential evapotranspiration. Soil moisture capacity by various water content in the soil is divided on some limits: maximum saturation capacity, field capacity, crop wilting point and residual soil moisture.

Interflow and percolation depend on hydraulic conductivity and depth of root zone but only interflow depends on slope.

Change in groundwater storage is filled by percolation, one part of groundwater is transpirated up and the other one horizontally flows away as base flow. Transpirated water from groundwater storage has the opposite direction to percolation. It is caused by deep root system or capillary rise in places where groundwater level is near the surface. This phenomenon appears only when actual soil moisture is lower than field capacity, its biggest effect is in summer and causes a quick drop of soil moisture. Groundwater storage capacity is mainly limited by thickness and extent of collector, porosity, meanwhile base flow depends on hydraulic gradient and hydraulic conductivity by Darcy's law (Liu, de Smedt, 2003).

Outputs

The outputs from the FRIER model are in the form of time series and spatial maps. The output time series contains the simulated discharge and its 3 components (overland flow, interflow and base flow) in $m^3.s^{-1}$ and hydrologic processes from water balance for any integer time step in milimeters. Individual mean quantities for the whole basin are calculated for each time step: air temperature, potential evapotranspiration, actual evapotranspiration, rainfall, snow melt, interception, evaporation from interception and depression storages, infiltration, overland flow, depression loss, evapotranspiration from root zone, percolation, interflow, soil moisture change, evapotranspiration from groundwater storage, base flow, water value of snow cover, changes in interception and depression storages, soil moisture and groundwater storage. The output maps can be layers of the total overland flow, interflow, base flow, real and potential evapotranspiration, in milimeters whether mean relative soil moisture or snow cover for any time interval.

Model Calibration and Efficiency

In the FRIER model, there are 2 methods of calibration, random and step by step. A number of iterations are necessary to set for random calibration and set the minimal and maximal values of global parameters. The number of iterations is computed for the step by step calibration according to the number of possible combinations. The bottom and upper values with the step are also needed to be set.

The simulated discharge is compared with measured discharge, for quantity comparison the BIAS model (the best value is equal to 0) is used, for comparison of the hydrographs the Nash-Sutcliffe coefficient (the best value is equal to 1) is used, especially maximal and minimal values of discharges are monitored. There is a possibility to choose the number of including extreme values into the monitoring. The average deviation of absolute differences between simulated and measured discharges is also computing (the best value is equal to 0).

DISCUSSION

The main aim of the study is to describe the FRIER model (Water Distribution (Flow, Routing, IUH) Model with Accent to Evapotranspiration and Radiation Methods), physically based rainfall-runoff model with distributed parameters. Used methodology was explained after description of inputs. Then possible outputs were mentioned. Input files consist of the time series of discharge in basin's outlet, total rainfall, climatic data and the spatial layers of the digital elevation model, soil texture and land use of a basin.

Hourly total rainfall can be assessed from daily total rainfall and hourly mean data of discharge and air temperature. The model runs at any space and time resolution. The filling in missing data is possible but unnecessary. Missing data in time series can be either written in the appropriate code or calculated in the model where 3 methods exist for their filling (Fig. 1). Data from time series can be distributed to space by arithmetic mean of 4 closest measurements, nearest neighbours (Thiessen polygons), lapse rate, or kriging (Fig. 2). Routing parameters are generated in the new developed extension of the ESRI ArcView GIS program in GIS interface.

Other benefits are parameterizations of land use types (Tab. 1) (Heymann, 1994), hydrophysical soil parameters (Tab. 2) and global parameters. User's values of the parameters can be used in combination with model values. Eleven global parameters serve for simplifying of some processes and for the best setting of initial values.

Transformation of rainfall excess to runoff is solved by approximation of diffuse wave (Fig. 3). Potential global radiation can be computed with or without slope orientation of each cell and shading of its neighbouring cells. The difference between short-wave and long-wave solar radiation is expressed by net radiation balance (Fig. 4). Together with the whole surface energy balance (Eq. 1., Fig. 5) they are required for determination of potential evapotranspiration. It is able to choose among many determination methods of evapotranspiration which were selected on the base of the detailed study (Tab. 3) (Horvát, 2004). Calibration of global parameters and also model efficiency are composed in the model.

The outputs from the FRIER model are in the form of time series and spatial maps. The output time series contains the simulated discharge and its 3 components (overland flow, interflow and base flow) in $m^3.s^{-1}$ and hydrologic processes from water balance for any integer time step in milimeters. Individual mean quantities for the whole basin are calculated for each time step: air temperature, potential evapotranspiration, actual evapotranspiration, rainfall, snow melt, interception, evaporation from interception and depression storages, infiltration, overland flow, depression loss, evapotranspiration from root zone, percolation, interflow, soil moisture change, evapotranspiration from groundwater storage, base flow, water value of snow cover, changes in interception and depression storages, soil moisture and groundwater storage. The output maps can be layers of the total overland flow, interflow, base flow, real and potential evapotranspiration, in milimeters whether mean relative soil moisture or snow cover for any time interval.

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BIBLIOGRAPHY

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. 1998: Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56, FAO, ISBN 92-5-104219-5, www.fao.org/docrep.

Heymann, Y., Steenmans, Ch., Croissille, G., Bossard, M. 1994: Corine Land Cover – Technical Guide. Office for Official Publications of the European Communities, Luxemburg, Luxembursko.

Horvát, O. 2004: Porovnanie metód stanovujúcich potenciálnu evapotranspiráciu na povodí horného Hrona. XVI. konferencia mladých hydrológov, SHMÚ Bratislava.

Kite, G.W., Kauwen, N. 1992: Watershed Modelling Using Land Classification. Water Resour. Res., 28. 3193-3200.

Liu, Y., De Smedt, F. 2003: WetSpa Extension, A GIS-based Hydrological Model for Flood Prediction and Watershed Management. Documentation and user manual, Vrije Universiteit Brusel, Belgium. 118 p.

Lull, H.W. 1964: Ecological and Silvicultural Aspects, Handbook of Applied Hydrology. Ed. Ven te Chow, 6.1 - 6.30, McGraw-Hill, New York.

Martinec, J., Rango, A., Major, E. 1983: The Snowmelt-Runoff Model (SRM) User's Manual. NASA Reference Publ. 1100, Washington, D.C., USA.
Molnar, P., Ramirez, J.A. 1998: Energy Dissipation Theories and Optimal Channel Characteristics of River Networks. Water Resour. Res., 34. 1809-1818.
Rowe, L.K. 1983: Rainfall interception by an evergreen beech forest. J. Hydrol, 66, 143-158.
Singh, P., Kumar, N., Arora, M. 2000: Degree-day Factors for Snow and Ice for the Dokriani Glacier, Garhwal Himalayas. J. Hydrol., 235. 1-11.
Tomlain, J., Damborská, I. 1999: Fyzika hraničnej vrstvy atmosféry. Academic textbook, Faculty of Math, Physics and Informatics in Comenian University, Bratislava, Slovakia, ISBN 80-223-1328-9. 132 p.
Velebný, V., Novák, V., Skalová, J., Štekauerová, V., Majerčák, J. 2000: Vodný režim pôdy. Slovak University of Technology, Bratislava, Slovakia, ISBN 85-244-2000. 208 p.
Zinke, P.J. 1967: Forest Interception Studies in the United States. International Symposium on Forest Hydrology, W.E. SOPPER and H.W. HULL (eds.), Pergamon Press, Oxford. 137-161.

USED PROGRAM

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ZHRNUTIE

Práca sa zaoberá opisom nového fyzikálne založeného zrážkovo-odtokového modelu s rozčlenenými parametrami. Od spomenutia potrebných vstupov bola objasnená použitá metodika, a napokon možné výstupy z modelu. Vstupnými súbormi sú časové rady prietoku v odtoku z povodia, úhrn zrážok, klimatické údaje a priestorové vrstvy digitálneho modelu terénu, pôdneho zloženia a využitia krajiny povodia.
Model pracuje v ľubovoľnom priestorovom i časovom rozlíšení, ponúka doplnenie výpadkov meraní v staniciach, hoci beží i bez neho. Chýbajúce údaje v časových radoch sa môžu vyskytovať v príslušnom kóde, ale môžu byť i dopočítané v podprograme, v ktorom sú k dispozícii 3 rôzne metódy ich doplnenia (obr. 1). Jednoduchou bilanciou sa dajú odhadnúť z denných úhrnov zrážok a hodinových priemerných údajoch o prietoku a teplote vzduchu hodinové zrážkové úhrny. Pre vytvorenie routingových parametrov odtoku bola vyvinutá nadstavba programu ESRI ArcView GIS 3.3 v GIS prostredí. Údaje z časových radov môžu byť rozložené do priestoru aritmetickým priemerov 4 najbližších staníc, Thiessenovými polygónmi, závislosťou od nadmorskej výšky alebo krigingom (obr. 2).
Ďalším prínosom je parametrizácia druhov využitia krajiny (tab. 1) (Heymann, 1994), hydrofyzikálnych vlastností pôdy (tab. 2) a globálnych parametrov. Vlastné hodnoty daných parametrov môžu byť použité v kombinácii so zabudovanými hodnotami podľa rôznych klasifikácií. Globálne parametre slúžia na zjednodušenie niektorých procesov a na čo najpresnejšie nastavenie začiatočných hodnôt, v programe ich je 11.
Transformácia efektívnych zrážok na odtok je riešená metódou okamžitého jednotkového hydrogramu pre všetky zložky odtoku (obr. 3). Potenciálne globálne žiarenie môže byť vypočítané bez alebo s orientáciou buniek, sklonu a tienenia susedných buniek. Rozdiel medzi krátkovlnným a dlhovlnným žiarením vyjadruje celkovú bilanciu žiarenia (obr. 4), ktorá je spolu s celkovou energetickou bilanciou povrchu (Vz. 1., obr. 5) potrebná k stanoveniu potenciálnej evapotranspirácie. Dá sa vybrať z množstva metód stanovenia potenciálnej a i aktuálnej evapotranspirácie, ktoré boli vybrané na základe podrobnej štúdie ich presnosti (tab. 3) (Horvát, 2004). V modeli sú zabudované kalibrácia i vyhodnotenie simulácií.
Výstupom z modelu sú časové rady simulovaného prietoku a jeho 3 zložiek (povrchový, hypodermický a podzemný odtok) a hydrologické procesy z hydrologickej bilancie v každom časovom kroku. Výstupné mapy môžu byť vrstvy celkového povrchového, hypodermického a podzemného odtoku, potenciálnej i skutočnej evapotranspirácie za ľubovoľný časový interval alebo priemerná relatívna pôdna vlhkosť, či výška snehovej pokrývky.