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HYDROLOGICAL MODELLING OF SMALL RIVERS FLOW AND ANTHROPOGENIC TRANSFORMATION IN MOLDOVA

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Abstract. *The article briefly discusses the concept and history of hydrological modeling, as well as modern tools for its implementation. The practical application of the SWAT model for simulating a river runoff and assessing the impact of anthropogenic load on its transformation is demonstrated by example one small river of Moldova.*

Key words: *hydrological modeling, hydrological мodel, small river, surface runoff, Moldova*
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Hydrological modeling as a concept

The movement and storage of water at watershed scales is a complex system affected by climatic, geologic, soil, land use, anthropogenic and other factors. A nature of the processes inherent in surface and subsurface hydrology is best investigated by the hydrologic models simulating these processes over different spatial and time intervals, and in different physiographical conditions.

By definition, any hydrologic model is certain simplification of a real-world water system (surface and soil waters, wetland, groundwater, estuary, etc.); such simplification aids in understanding, predicting, and managing water resources. In recent years, a number of conceptual hydrological simulation models have been developed and increasingly used by hydrologists and water resource managers to understand and address the extensive array of water resource problems, including those related to watersheds, streamflow and reservoir management, as well as to human activities that affect water systems. Numerous review studies that provide comparisons either of specific components or complete hydrologic modeling packages, with varying levels of input/output data and their structure complexity, have been done by different authors (e.g., Beven, 2019; Daniel et al., 2011; Refsgaard et al., 2010; Van Liew et al., 2005 and 2007; Zhang et al., 2008).

However, while hydrology as a science has a long history, Singh (2018) attributes the birth of hydrologic modeling to the second half of the 1850s. Then, until the 1960s, many advances took place in modeling the different components of a hydrologic cycle, which were based mainly on mathematical physics, laboratory and field experiments. In the post-1960s decades, due to the computer revolution, the hydrologic modeling made a giant progress, and new branches of hydrology, such as digital or numerical hydrology, statistical or stochastic hydrology were born. Finally, we are witnessing how a computing power is exponentially increasing, promoting the maturing of hydrological modeling, in particular, permitting to process huge quantities of raster and vector data in the Geographical Information Systems (GIS) environment.

Hydrologic models study usually a water flow and water quality, but are also used in decision-making at different scales. These models perform very well in long-term assessments of surface runoff, soil erosion and sediment yield for a wide range of soil types, land uses and climatic conditions (Dutta and Sen, 2018). Watershed, basinwide or other hydrologic modeling is considered as the best because it is economic and less time consuming. Singh (2018) highlighted several major advances and opportunities of hydrological modeling:

- Simulation of the entire hydrology;
- Development of research techniques that form a basis for reservoirs management as well as river basin simulation and hydrologic models calibrating;
- Creation of possibilities for two- and three-dimensional modeling;
- Simulation of liquid flow's different phases that result in simulation of a water flow and sediment/pollutant transport;
- Modeling at large spatial scales, such as a river basin, and at small temporal scales.

Integration of hydrology with allied sciences, for example, with climatology, includes climate change issues in hydrologic analysis.

The selection of a hydrological model depends on the research objectives, the availability of input data to its running and the uncertainty in interpreting the outputs obtained. Moreover, if to date many developed countries have their own hydrologic models, the developing countries are objectively limited in hydrologic modeling capabilities due to such factors as the maintenance, computational costs and technical capacity needed to develop and run up-to-date models. In this situation they are forced to use the well-proven foreign models, with appropriate validation and calibration for their regions. Some of such models, which are used in Moldavian research, are shortly presented below.

The examples of using the hydrological modeling, demonstrated in this article, were aimed at solving three main problems: modeling a catchment runoff, assessing the transfer and accumulation of sediments in water bodies, and assessing the anthropogenic load on a river flow. These tasks were solved in relation to small rivers of the country, which due to anthropogenic transformation (uncontrolled pollution, low farming cultures, illiterate land use, etc.), intensified by climate change, are catastrophically degraded or even disappear as watercourses.

The hydrological models as simulation tools

World experience shows that hydrological modeling for small catchments is most successfully solved, using hydrological models SWAT and WEPP.

The hydrological model SWAT *(Soil and Water Assessment Tool)* represents multiple decades of its individual components development (Gassman et al., 2014). A history of its first version, emerged in the early 1990s, and its following enhancement can be found in Arnold et al. (2012b). In detail the model is described by Arnold et al. (2012a, b), Neitsch et al. (2011) and Winchell et al. (2013). Due to its comprehensive nature, strong methodical support and open access status, the SWAT has proved to be highly flexible in addressing a wide range of water resource problems. A good review of SWAT extensive testing for hydrologic modeling at different spatial scales was provided by Zhan et al. (2008); the widespread use of SWAT in comparison with several other leading hydrologic models was demonstrated by Refsgaard et al. (2010).

As input information, the SWAT uses long-term data on daily minimum and maximum air temperature and precipitation, as well as on soils, land use and slopes in the study area. However, given the sometimes objective difficulties in obtaining daily data, the model provides for the possibility of using the monthly averages. Also, certain weaknesses, encountered in some of the SWAT outputs, clearly show, that expanded testing or validation of this model, initially developed and adapted to specific USA conditions, is needed.

The first experience of SWAT use in Moldova was received in the early 2020s (Corobov et al. 2015, 2016).

The second from the above mentioned models – WEPP *(Water Erosion Prediction Project)* – is the result of erosion research in the USA. In contrast to the empirical model approaches these research have led to the development of this process-based soil erosion model **(**Renschler et al., 2002). WEPP allows simulating a water and sediment balance in river watersheds and on hill slope profiles within watersheds. It simulates and consolidates climate, infiltration, water balance, plant growth and residue decomposition to predict a surface runoff, soil loss, deposition and sediment delivery over a range of time scales. As a soil erosion assessment tool with continuous distributed-parameters, the WEPP can be applied to representative hill slopes and a channel network at small watershed scales (e.g., Amaru and Hotta, 2018; Elliot, 2013).

The new Geo-spatial interface for WEPP *(GeoWEPP)*[1] utilizes readily available digital geo-referenced information from publicly accessible internet sources (DEM, topographical maps, land use data, etc). GeoWEPP enables even non-GIS modeling users to derive and prepare valid model input parameters to assess representative conditions in the area of interest. After establishing the main data input for a particular site, various land use scenarios can be evaluated to assist in a soil and water conservation planning.

At present we are testing this model for the assessment of potential erosion and sediments contribution to small rivers pollution in the framework of the BSB963 Project[2]. The first reliable outputs are expected in early 2022. Therefore, here some examples of hydrological modeling will be demonstrated on the SWAT use. As a case study the Baltata River basin was selected.

The examples of hydrological modeling: Baltata River as a case study

Study area. The Baltata River is a right tributary of the Dniester River – one of main Moldavian rivers, that flows into the Black Sea. This river presents current situation in other analogous small basins of the country. Its catchment area has 153.9 km^2, the length from northwest to southeast – 27.47 km and width – 7.74 km. Its relief is predominantly flat, with absolute elevations from 16 m to 219 m (120 m on average). The slopes vary from sub-horizontal to steep (about 17º). The main types of land use are agriculture, forests, pastures, meadows, perennial plantations and built-up plots. 46.2% of the land is occupied by crops; the perennial plantations and pastures occupy 13.8% and 11.4%, respectively. Only 17.4% of the territory is covered by forests. As a result of intensive farming and its low culture, the soils are degraded above 29%.

Input information. As it was mentioned above, the SWAT simulation can be based on air monthly maximum *(Tmax)* and minimum *(Tmin)* temperatures and their standard deviations *(Sd);* the last statistic is used to transform the monthly averages into daily values in the weather generator (Arnold et al., 2012a). The climatic period (1981-2010) was chosen as the IPCC baseline thirty years for modeling likely change in climate expected in the 21st century (Table 1).

Table 1

Average monthly air temperature and precipitation at Baltata weather station in 1981-2010

Climatic variable	**Months**											
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
Tmax, ºC	1.3	3.0	8.7	16.3	22.7	25.8	28.0	27.8	22.2	15.7	7.9	2.6
Sd	3.1	4.0	3.6	2.2	2.0	1.7	1.9	1.9	2.1	1.4	2.9	2.6
Tmin, ºC	-5.2	-4.6	-0.9	4.5	9.5	13.4	15.2	14.4	9.8	4.9	0.5	-3.7
Sd	3.2	3.2	2.0	1.4	1.2	0.9	1.3	1.1	1.1	1.4	3.0	2.7
Precipitation, mm	28	25	30.0	37	43	71	63	56	45	38	32	32

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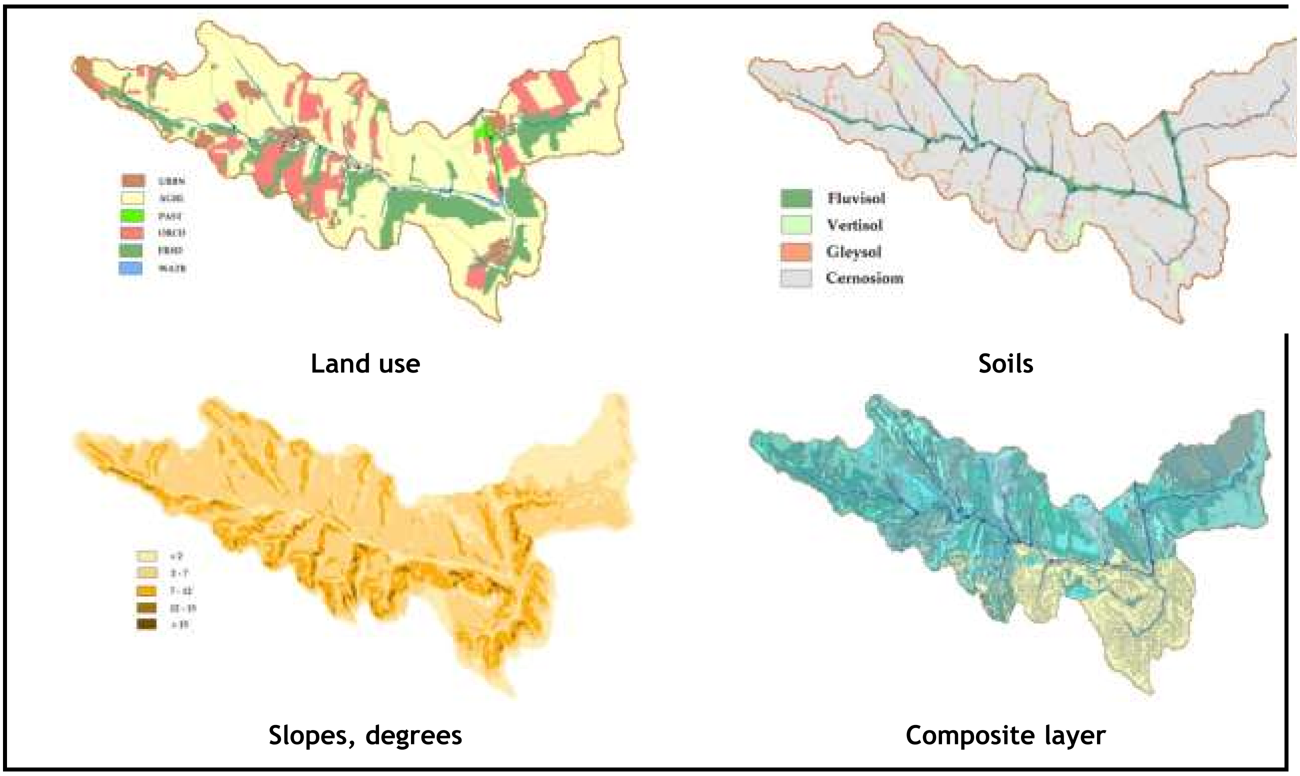
[1] See: *http://geowepp.geog.buffalo.edu/*

[2] See: *http://websites3.teiemt.gr/p4sea/index.php*

Other input information – the SWAT geographic database (land-use, soil and slope maps) – is shown in Fig. 1. Here, these thematic maps are reclassified into SWAT formats (thematic layers), which allowed their overlapping resulting in a new layer (composite one), which was added as a basis for runoff modeling.



Land use

Soils

Slopes, degrees

Composite layer

Fig. 1. Thematic geographical layers of the Baltata basin and the result of their overlap

Runoff modeling. Results of SWAT modeling of the Baltata watershed's annual runoff in 1981-2010 are shown in Fig. 2. The values of simulated surface runoff are the weighted sum of each sub-basin contribution to the river flow. As one can see, the maximum annual runoff (> 324 mm) occurs in the extreme northwestern part of the basin, and the minimum (<315 mm) – in its southwestern part. Basically the runoff is ranges from 318 mm to 324 mm**.**

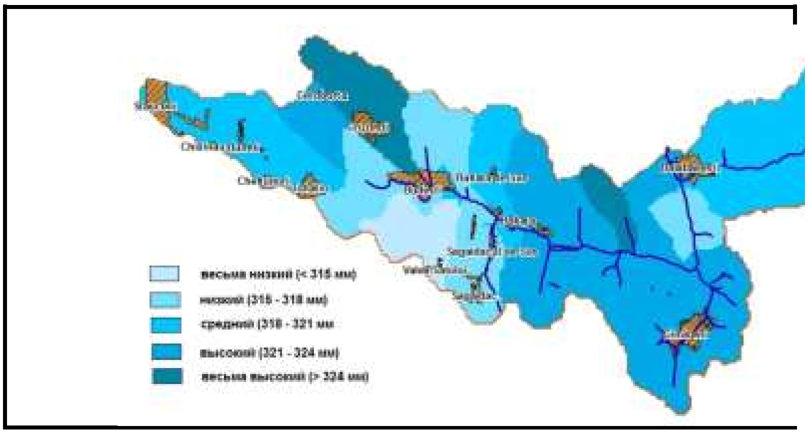


Fig.2 Spatial distribution of annual surface runoff in theBaltata catchment under a baseline climate

However, for the user of river water resources, in addition to the potential surface runoff, it is important to know its distribution along the river channel. In particular, one of the important features of the studied river is the presence of four artificial reservoirs in its bed. Therefore, in addition to modeling the potential total runoff from the entire catchment area, its inflow into each of these reservoirs was modeled (Table 2). The simulated mean annual flow into these reservoirs is currently equals from ~ 0.0004 km^3 near the village Balabanesti to 0.017 km^3 near the village Chimiseni. In total, as one can see from Table 9, more than 0.031 km^3 of water enter the ponds during the year, which amount about 65% of the watershed total runoff (0.048 cubic km).

Table 2

The surface runoff in the Baltata River watershed, simulated by the SWAT model, and its accumulation in the riverbed's reservoirs in 1981-2010

Reservoirs location	**Runoff by months**												**Annual**	
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*mm*	*km^3*
v. Baltata	0.05	2.1	3.7	1.5	0.09	3.6	9.1	9.6	5.8	3.2	6.2	0.0	*44.9*	*0.0043*
v. Baltata	0.09	4.4	7.5	2.1	1.6	6.5	17.8	17.7	11.7	5.7	12.6	0.2	*87.9*	*0.0093*
v. Cimiseni	0.14	6.5	11.2	3.6	2.6	10.1	26.7	27.3	17.5	8.9	18.8	0.2	*133.5*	*0.0172*
v.Balabanesti	0.02	1.4	2.1	0.7	0.06	1.6	5.6	5.1	3.9	2.6	4.1	0.0	*27.2*	*0.0004*
Into ponds	*0.3*	*14.4*	*24.5*	*7.9*	*4.35*	*21.8*	*59.2*	*59.7*	*38.9*	*20.4*	*41.7*	*0.4*	293.6	0.0313
Total runoff	***0.4***	***15.1***	***27.4***	***8.9***	***4.6***	***23.1***	***62.2***	***63.0***	***40.4***	***21.6***	***44.5***	***0.5***	**311.8**	**0.0480**

These results are in good agreement with the estimates obtained during model validation. In the course of this procedure, the simulation results were compared with the results of hydrological observations in 2006-2010. The observed flow in that period was only about 8-9% of its simulated values (Corobov et al., 2016). As has been shown by a carried out analysis, this result was caused not only by certain uncertainties objectively inherent in hydrological models, but also by the anthropogenic transformation and pollution of the Baltata River catchment.

Conclusion

Undoubtedly, hydrological modeling can be considered as one of the tools for assessing the consequences of anthropogenic pressure on the small rivers runoff. At the same time, it should be noted the difficulties of using both SWAT and WEPP in small countries. These models were developed for the specific conditions of the United States and are equipped with all databases, necessary for modeling, and certain tools (e.g., weather generators) for its entire territory. Under these conditions, any use of these models in other countries requires preliminary creation of the corresponding databases and subsequent validation and calibrations, which significantly complicates their widespread practical application. From this point of view, the presented here research in the field of hydrological modeling has primarily a purely exploratory nature.

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ГИДРОЛОГИЧЕСКОЕ МОДЕЛИРОВАНИЕ СТОКА МАЛЫХ РЕК И ИХ АНТРОПОГЕННОЙ ТРАНСФОРМАЦИИ В МОЛДОВЕ

Роман Коробов, Геннадий Сыродоев, Илья Тромбицкий

Аннотация. В статье кратко рассматриваются концепция и история гидрологического моделирования, а также современные инструменты для его реализации. Практическое применение модели SWAT для моделирования речного стока и оценки влияния антропогенной нагрузки на его трансформацию продемонстрировано на примере одной из малых рек Молдовы

Ключевые слова: гидрологическое моделирование, гидрологическая модель, малая река, поверхностный сток, Молдова.