Agent-based study of stormwater reuse system operational capabilities during drought

Dragan Milićević[(1)], Borislava Blagojević[(1*)], Slaviša Trajković[(1)]
(1) University of Niš, Faculty of Civil Engineering and Architecture, Serbia
(*)b.blagojevic@eunet.rs; borislava.blagojevic@gaf.ni.ac.rs

Abstract: The multi-agent methodology presents an innovative approach in software engineering, social, economic, and environmental modeling. The multi-agent system has been created for utilizing stormwater control facilities i.e. water usage from retention/detention ponds at the site of Vlasina Lake, Serbia. The system has been chosen due to its capability to model dynamic processes. The model is developed in the Netlogo multi-agent programmable environment. The physical environment of the Vlasina Lake site model is realistic. The model illustrates the relationship between water availability and demand for secondary water use. There are two groups of agents: water source agents and water use agents. The group of water source agents consists of 17 ponds, while the group of water use agents comprise agricultural, communal, and tourist user. The intended water consumptions for water use agents are: agricultural land and park irrigation, washing roads and parking lots, and artificial snow production for ski trails. The goal of this paper is to assess the portion of water demand that could be satisfied from the stormwater reuse system during drought. We use the Standard Precipitation Index (SPI) to identify drought, and observed climatic data and their products in climatic scenario for model input. Contrary to usual model output as the accumulated inflow of water to the ponds and the accumulated water consumption, we try to take into account that the ponds can run empty and also have a maximum volume. Because the software we use in not capable of simulations of operational capabilities of small size ponds with monthly climatic data, we display a plot of the available water volume for the ponds and the estimated drought severity. We register the ponds that have stormwater volume available for reuse in the studied 51 year period. We also discuss the improvements that should be made in simulations, because the agent-based model could be a useful tool for decision makers to understand both the consequences of changing the sizes of the ponds, and cost effectiveness of system during extreme water stress episodes.

Key words: Agent based model, Drought, Water reuse, Water stress.

1. INTRODUCTION

The understanding of urbanization effects on hydrologic cycle has brought a suite of engineering measures and approaches over the last two decades, primarily aimed at mitigation of negative urbanization effects through innovative stormwater management. These approaches and measures include Stormwater Control Measure (SCM), Best Management Practice (BMP), Integrated Management Practices (IMPs), Low Impact Development (LID), Sustainable Drainage Systems (SuDS), Sustainable Urban Drainage Schemes (SUDS), and Water Sensitive Urban Design (WSUD). Nowadays, key sustainability principles of water consumption, water recycling, waste minimization and environmental protection are integrated in the approaches to stormwater management.

In order to design the stormwater system according to the current requirements, hydraulic engineers face an increased number of steps that should be considered in the planning stage as part of an integrated water resources plan. The multi-agent methodology presents an innovative approach in software engineering, social, economic, and environmental modelling (North and Macal, 2009). Temporal and spatial modelling is achieved through data exchange between geographic information system (GIS) on one side, and an agent-based (ABM) and system dynamic model (SDM) on the other.

This paper presents the continuation of the research on the stormwater system capabilities for water reuse (Blagojević et al., 2013) by ABM. The focus of the paper is water management in the drought conditions in the system designed according to the LID principles.

In the Methodology section we briefly explain the study area and input data, as well as the scenarios we use to improve the published study and input data. The third section Results, shows critical periods for the considered scenarios, and plots of the available water volumes for selected ponds in the system. In the fourth section we reveal the software improvements needed for simulations of the system operational capabilities in the situation when monthly input data is available. At the end we discuss our findings regarding system potential for water reuse, potential measures that could be taken into consideration in order to improve system efficiency in the light of water reuse for the purposes considered.

2. METHODOLOGY

2.1 Study area

The paper deals with the completed stormwater management system design for the area of the distinct characteristics 'Vlasina' situated in the South-East Serba (Fig.1.). Application of the highest environmental protection standards in the Area of Distinct Land Use Master Plan for the Vlasina Lake site, together with adopted stormwater system design solution, allow for using water as a foundation for further planning and design (Blagojević et al., 2013).

2.2 Agent-based model

In this research we partially use the agent-based system (ABS) developed for the study of the stormwater system water reuse potential (Blagojević et al., 2013). We use the same physical environment implemented as regular grid where various agents are placed, e.g. lake as water source, or irrigation as water user. We take over the spatial distribution of the agents obtained from available information in Geographic Information System (GIS) for the Vlasina lake site, while we obtain water reuse capacities of retention basins (RB) for three different scenarios for the water volume in RBs. The water volume in the studied RBs depends on the amount of sediments accumulated in the RBs. We consider the following scenarios: 1) Empty RB (without sediment), 2) Half-full RB, and 3) Full RB. Because operational plan for RB maintenance implies sediment removal in two and three years, each scenario covers event that occurs once in every 24 and 36 months.

We use the same socio-economic scenario (Blagojević et al., 2013) that is projection of water demand in the situation when the area is fully built and all of the accommodation and tourist potential activated. The climatic data we use for this research are different from the previous study. There, we used an average monthly precipitation amounts for the standard normal World Meteorological Organization period 1961-1990, distributed by the software built-in scenarios for low and medium precipitation. Here, we use historic climatologic input data. The software we use is the Netlogo multi-agent programmable environment (Wilensky, 1999), version 4.0.5. ABM is based on the Bali irrigation system model (Lansing, 1991; Lansing and Kremer, 1993).

2.2 Input data

The historic climatologic data we use for this research is 1955-2006. The beginning of the period is the first year we anticipate micro-climate was stabilized after the dam of the Vlasina lake has been constructed and the reservoir filled. The last available data record on climatic parameters for the stormwater system design project was 2006.

The monthly precipitation data is available for three precipitation stations (PS) mapped in the Fig.1. d). PS Vlasina is also a meteorological station. We designate monthly precipitation sums for each RB from PS, according to the closeness of RB to PS, in the same way the Thissen method delineates polygons (Blagojević et al., 2013a). We estimate the potential monthly water volume available for RB as the product of precipitation depth, catchment area and runoff coefficient, using the average runoff coefficient for the area of Vlasina (0.27).

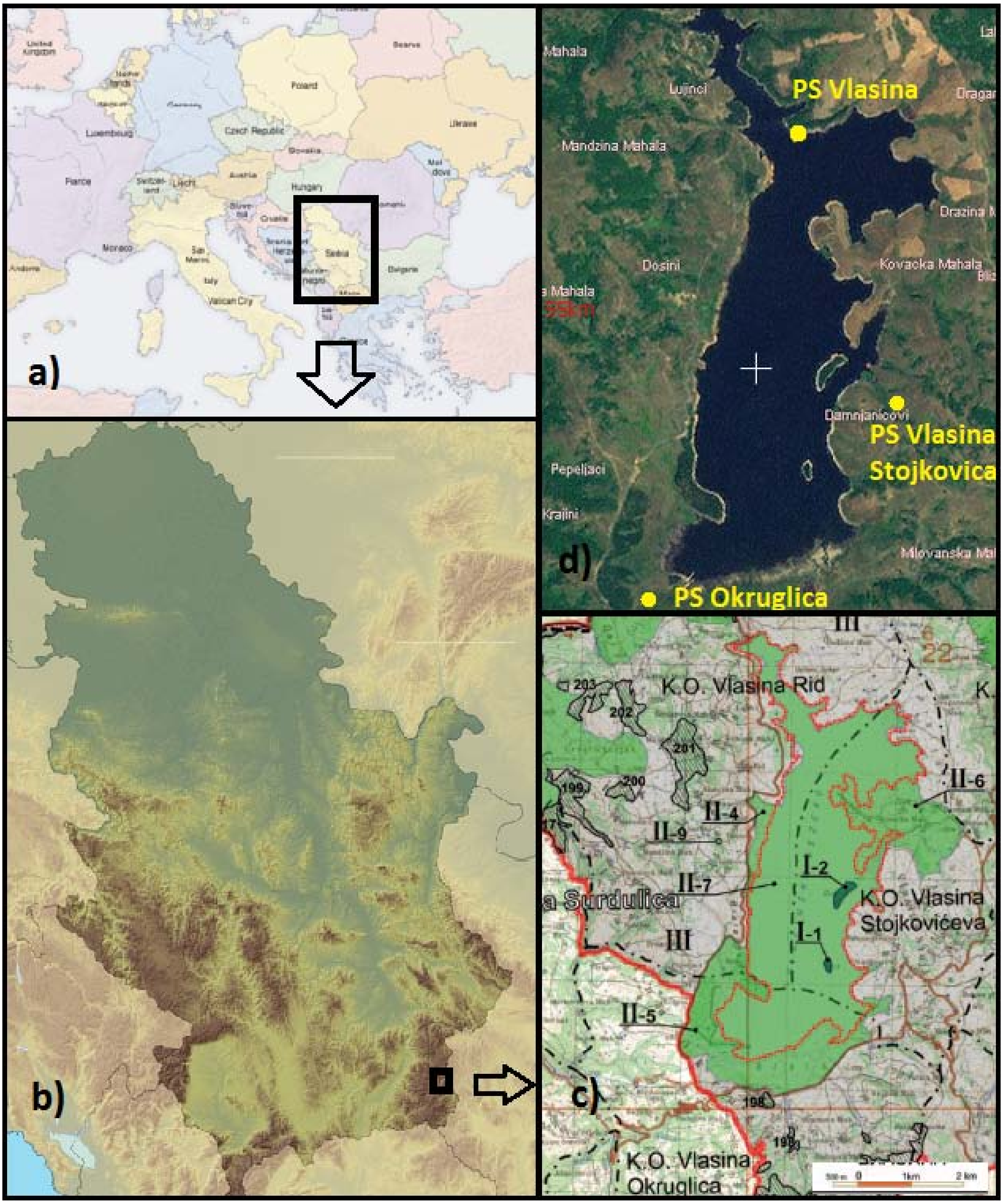

Fig. 1. a) The Republic of Serbia location in Europe. b) Relief of Serbia showing study area in the South-East part of the country- the mountainous area at the Bulgarian border. c) The environmental protection zoning of the Vlasina lake - the area of the distinct characteristics ''Vlasina''. I-the highest protection zone. d) Satellite image of the Vlasina lake with precipitation stations (PS) locations. (The image and maps source a-d: www.wikimediacommomns.org)

We use the following characteristics of RB: *VRB*- RB design volume [m^3], *VSED* - sediment volume (2 or 3 years) [m^3], *ARB* - RB area [m^2].

The amount of water loss due to evaporation *RB (VE)* [m^3], we obtaine as a product of RB area and monthly sum of evaporation from a shallow water (*E*): $RB\ (VE) = ARB \cdot E$. We approximate *E* from the FAO-24 method for evapotranspiration $ET = E \cdot Kp$ [mm/day], where we estimate *ET* using the Hargreaves method with modification of Trajković (Trajković, 2007). For *Kp* -evaporation class A pan coefficient, we use the value of 0.85. The coefficient depends on the following factors: distance to dry soil (no vegetation), average wind speed at 2 m altitude and average relative air humidity. *Kp* values are read from Table A or B, depending on the above factors, for each month. We used Table A, because the pan is surrounded by vegetation. For the entire period wind speeds are less than 2.1m, and the ranges of relative humidity are 40-70 and greater than 70%, that lead to the unique value of *Kp* for the entire period. We use the average monthly data to obtain daily evaporation *E* as described above, and multiply it by number of days in the corresponding month.

Based on the simple monthly water budget equation, we estimate the volume of stormwater available for RB in each month of the period 1955-2006, under the following scenarios: 1) Empty RB (without sediment), *V-0=WRB- ARB · E* [m^3]*;* 2) Half-full RB, *V-0.5=WRB- ARB · E-VSED· 0.5* [m^3]*;* 3) Full RB, *V-1=WRB-ARB · E-VSED* [m^3].

We use the Standardized Precipitation Index (SPI) to assess the drought severity. The SPI is a meteorological index (McKee et al., 1993) that quantifies the degree of meteorological drought using monthly precipitation sums. We calculate SPI for the monthly precipitation data sums and compute it by fitting the two-parameter gamma distribution to the frequency distribution of the precipitation sum to 1 month timescale, due to size of the RBs. For the frequency distribution parameter estimates, we use the entire period 1955-2006. For SPI estimation we use the Web services, a part of Service-Oriented Architecture represented as tools for requesting time series and estimating SPI (Blagojević et al., 2013a). We estimate SPI1 time series for each PS and assign it to RB according to the position of the Tissen polygons.

3. RESULTS

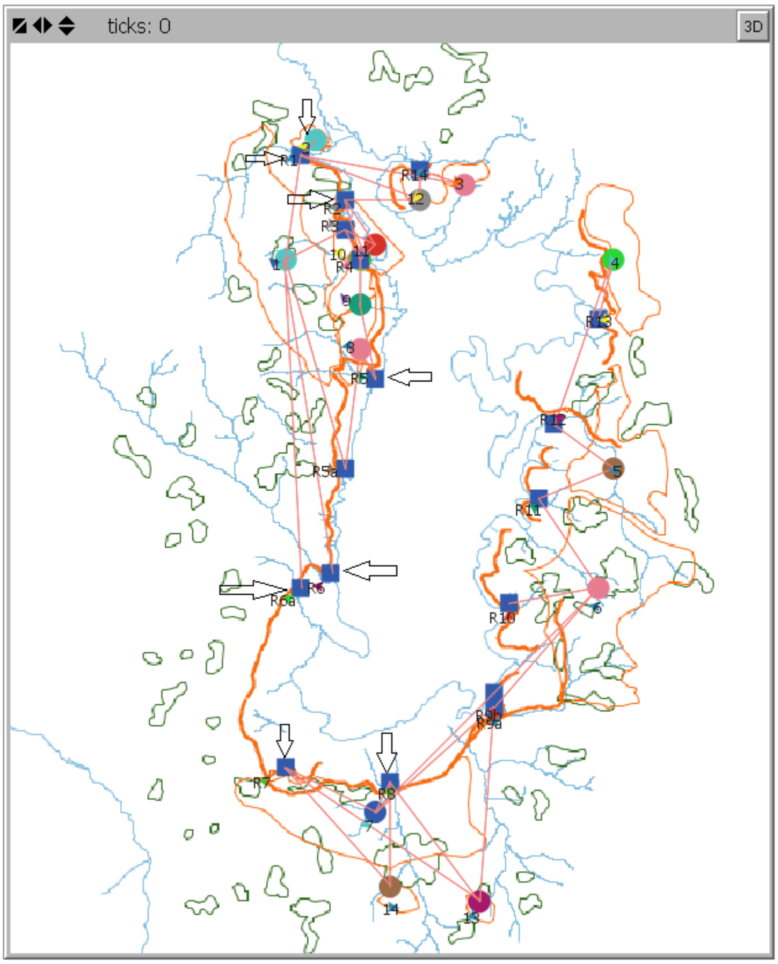

Fig. 2. The Netlogo screenshot of the ABS for the Vlasina lake site. Water source agents are RBs (squares) and water use agents are agricultural, communal and tourist user (circles). Links (lines) between water source and water use agents represent potential water reuse from RBs.

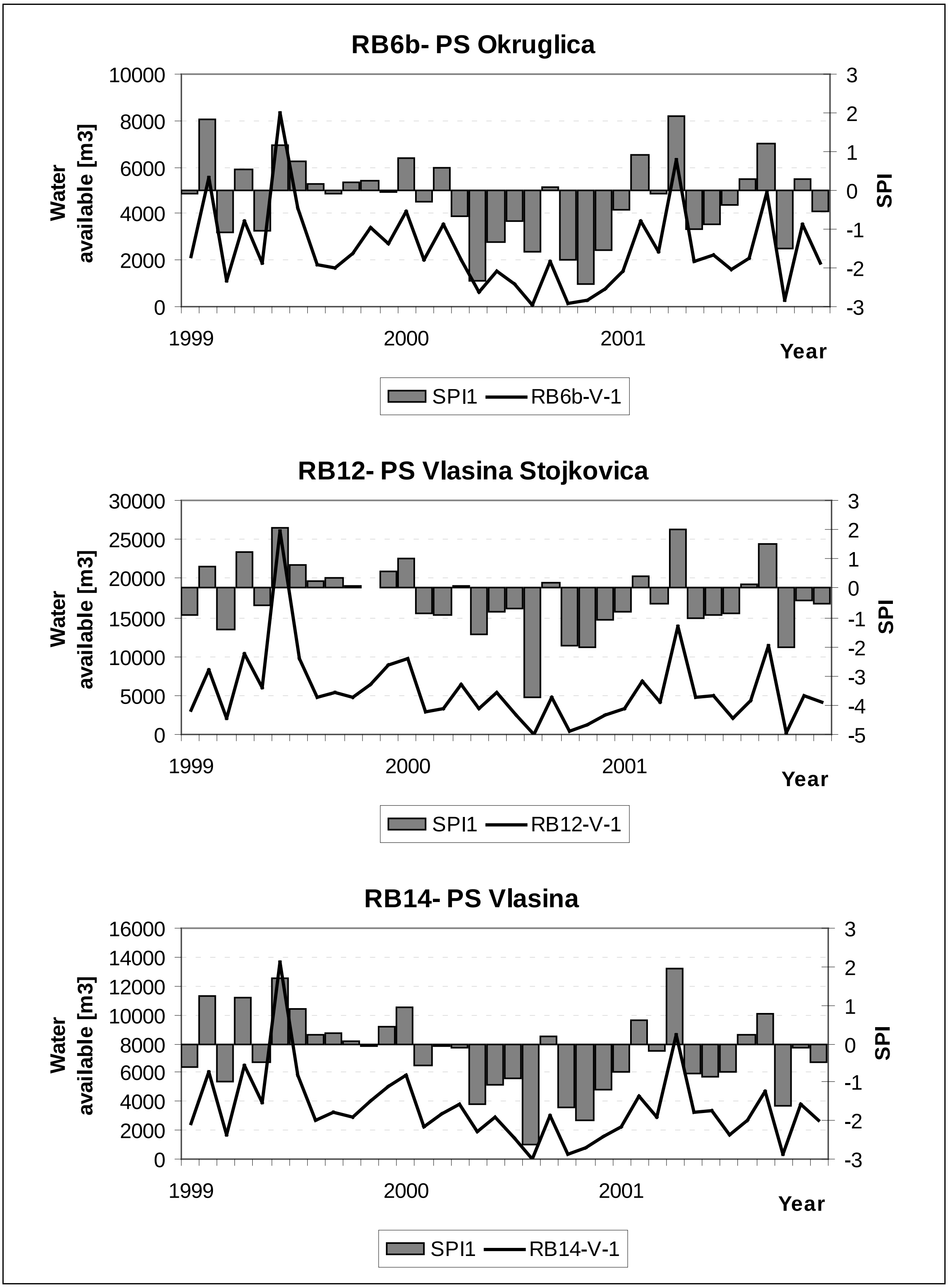

Fig. 3. Available water monthly stormwater volume for three characteristic RBs in the period 1999-2001.

Fig. 2. shows the spatial distribution of water source and water use agents, where each circle colour represents the type of water use agent and its water consumption norm. The arrows show the water sources (RBs) that have stormwater available on monthly timescale under the worst case scenario, when RB is full of sediment and the drought is exceptional (SPI<-2.363) according to the precipitation data in the entire processing period (1955-2006).

Three RBs are selected for illustration of available stormwater volume for RB operation in Fig.3. in the period of exceptional drought recorded in the area.

4. DISCUSSION AND CONCLUDING REMARKS

The results presented in Fig.2. related to RBs that still have stormwater available for reuse on monthly timescale under the worst case scenario is not obtained by ABS. They are obtained from the simple monthly water budget.

The Netlogo software requires daily precipitation data in order to perform simulation of the described scenarios. It does not have the ability to distribute or downscale monthly precipitation data in order to define daily water supply curve, required for RBs of such a small volume as is the case in our system. The uniform distribution of monthly precipitation throughout a month is unrealistic, and it gives the expected results of permanently satisfied water demand. While this could be solved for historic data by feeding the system with daily precipitation data, the problem of the system behaviour in the future, under different climatic scenario is more pronounced. Further studies could include development of the algorithm for downscaling monthly precipitation data to daily precipitation for this purpose.

Nevertheless, the results obtained by the simple water budget estimates, show that there is a ready available potential for water reuse from some of the RB in the system. The future stormwater system manager i.e. the institution, should consider this solution for different stormwater uses. It is possible to either upgrade designed RBs to micro reservoirs or to build cascades of RBs in order to preserve available stormwater potential for water reuse.

ACKNOWLEDGEMENT

The research presented in the paper is funded from the Republic of Serbia Ministry of Education, Science and Technological Development resources within scientific project no. TR37003. We also appreciate our colleagues' support in this research- Prof. dr Olivera Potić for providing data on retention basin characteristics, and Milan Gocić for providing SPI by newly developed Web services.

REFERENCES

Blagojević, B., Milićević, D., Potić, O., 2013. Agent based assessment of stormwater re-use potential of low-impact development control facilities at the site of Vlasina Lake, Serbia. Water Science & Technology, Vol. 68, No. 3, 705-713.

Blagojević, B., Mihailović, V., Gocić, M., Trajković, S., 2013a. Streamflow Drought Index modelling through Standard Precipitation Index assisted by service-oriented paradigm. Conference Proceedings of the 1st CIGR Inter-Regional Conference on Land and Water Challenges – Bari (Italy), 10-14 September, 2013. (In press)

McKee, T.B., Doesken, N.J., Kleist, J., 1993. The relationship of drought frequency and duration to time scales. In: 8th Conference on Applied Climatology, 17–22 January, Anaheim, California, pp. 179–184.

North, M.J., and Macal, C.M., 2009. Agent-based Modeling and Systems Dynamics Model Replication. International Journal of Simulation and Process Modelling, Vol. 5, No. 3/2009, 256-271.

Lansing, S.J., 1991. Priests and Programmers. Princeton University Press: Princeton, N.J., ISBN13: 978-0-691-02863-7, p. 200.

Lansing, J.S., and Kremer, J.N., 1993. Emergent properties of Balinese water temples. American Anthropologist 95 (1), pp. 97–114.

Wilensky, U., 1999. NetLogo. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL, USA; http://ccl.northwestern.edu/netlogo/ (accessed August 2013).

Trajkovic, S., 2007. Hargreaves versus Penman-Monteith under Humid Conditions. Journal of Irrigation and Drainage Engineering, Vol. 133, No. 1.