"Blue-green" corridors as a tool for erosion and stream control in highly urbanized areas – case study of Belgrade city

RATKO RISTIĆ[1], BORIS RADIĆ[1], GORAN TRIVAN[2] & IVAN MALUŠEVIĆ[1]
1 University of Belgrade Faculty of Forestry, Kneza Višeslava 1, Belgrade, Serbia
ratko.risticc@gmail.com
2 Secretariat for Environmental Protection of the City of Belgrade, 27.marta 43-45, Belgrade, Serbia

Abstract Highly urbanized areas constantly need new surfaces for building of commercial, residential or infrastructure objects. Belgrade, the capital of Serbia, is a large regional centre with a population of 2 000 000 dwellers, covering a territory of 3500 km^2. The territory of Belgrade is intersected by 187 streams, with watersheds mostly rural in higher parts, urbanized and highly urbanized in lower parts. Torrential floods that once occurred rarely during pre-development period have now become more frequent and destructive due to the transformation of the watershed from rural to urban land uses. Authorities of Belgrade defined a strategy for erosion control and protection from torrential floods, based on the restoration of "blue-green" corridors (residuals of open streams and fragments of forest vegetation). The restoration of "blue-green" corridors helps the establishment of new recreational areas, the preservation of biodiversity and the mitigation of effects of climate change.

Key words "blue-green" corridors; erosion control; torrential floods; highly urbanized areas

INTRODUCTION

Floods, in all their various forms, are the most frequent natural catastrophic events that occur throughout the world (Berz *et al*., 2001; Barredo, 2007). Among natural hazards with serious risks for people and their activities, the torrential floods represent the most common hazard in Serbia (Ristić & Nikić, 2007), being the prime cause of losses, causing much damage and loss of human lives, both in urban and rural areas. Land-use changes (deforestation and topsoil removal; inadequate agricultural measures; increase of impervious surfaces) dramatically alter hydrological conditions by reducing the interception and infiltration–retention capacity of the soil (Ristić & Macan, 2002), exposing the soil to the impact of rain, which accelerates erosion and surface runoff. Torrential floods that once occurred rarely during the pre-development period have now become more frequent and destructive due to the transformation of the watershed from rural to urban land uses (Ananda & Herath, 2003; Ristić *et al*. 2012). Belgrade, the capital of Serbia and a big regional centre with a population of 2 000 000, covers a territory of 3500 km^2. The territory of Belgrade has 187 streams with watersheds that are mostly rural in the higher parts and urbanized or highly urbanized in the lower parts (Faculty of Forestry & Institute for Water Resources Management "Jaroslav Černi", 2005). The authorities of Belgrade defined a strategy for erosion and torrent control based on the restoration of "blue-green" corridors (residuals of open streams and fragments of forest vegetation). The restoration of "blue-green" corridors helps the establishment of new recreational areas, preservation of biodiversity (Saumel & Kowarik, 2010; Ramirez & Zuria, 2011) and urban adaptation to climate change (Kazmierczak & Carter, 2010).

MATERIAL AND METHODS

The concept of restoration of the "blue-green" corridors is presented at two experimental watersheds of the Kaljavi and Jelezovac streams, just a few kilometres from the centre of Belgrade (Fig. 1). The main hydrographic characteristics of the experimental watersheds are presented in Table 1. The experimental watersheds experienced torrential floods (in 1965, 1994, 2002), which endangered buildings, land and roads, when the water levels increased from 0.10–0.15 m to 1.6 m (the Kaljavi stream) and 1.7 m (the Jelezovac stream), as a consequence of severe thunderstorms, with the intensity of precipitation of up to 6 mm min^{-1}.

The consequences of land-use changes have been analysed on the basis of field investigations, the use of aerial and satellite photo images, topographic, geological and soil maps. The land use classification was made on the basis of CORINE methodology (EEA, 1994). The area sediment

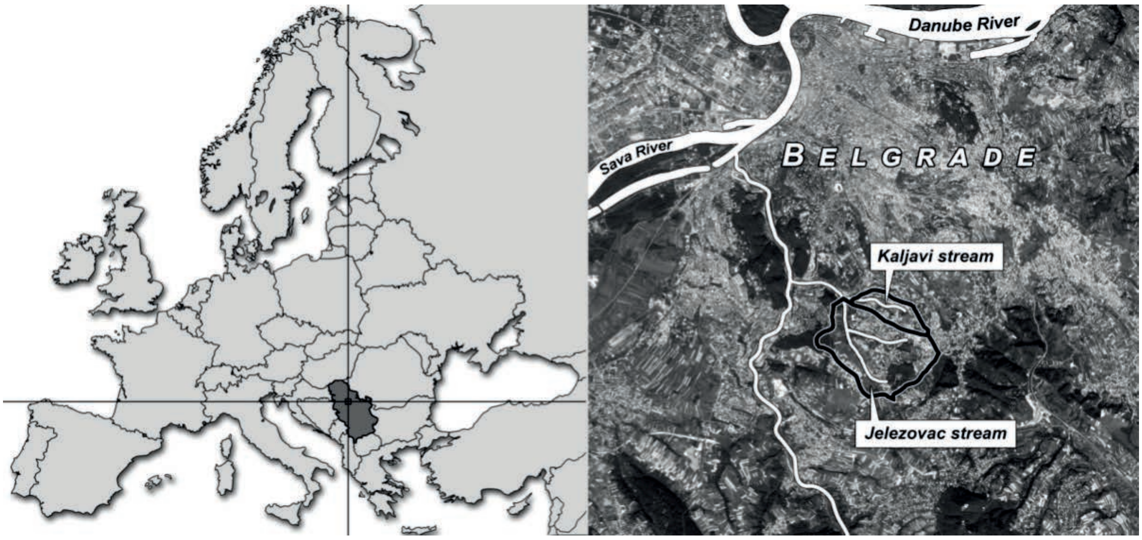

Fig. 1 Location of the experimental watersheds of Kaljavi and Jelezovac streams.

Table 1 Main hydrographic characteristics of the experimental watersheds.

Parameter	Mark	Unit	Kaljavi s.	Jelezovac s.
Magnitude	*A*	km^2	1.4	6.22
Perimeter	*P*	km	5.76	10.54
Peak point	*Pp*	m.a.s.l.	249	308
Confluence point	*Cp*	m.a.s.l.	115	112
Mean altitude	*Am*	m.a.s.l.	191.6	184.2
Length of the main stream	*L*	km	2.45	4.12
Absolute slope of stream bed	*Sa*	%	5.47	4.76
Mean slope of stream bed	*Sm*	%	4.74	2.91
Mean slope of terrain	*Smt*	%	7.44	10.64

yields and the intensity of erosion processes have been estimated on the basis of the "Erosion Potential Method" (EPM). This method was created, developed and calibrated in Serbia and it is still in use in all the countries originating from former Yugoslavia (Kostadinov, 2008).

The changes of hydrological conditions were estimated by the comparison of the maximal discharges under current conditions (2013) and after the complete restoration of the "blue-green" corridors (2020). The computations of maximal discharges (Q_{max}) have been performed using the synthetic unit hydrograph theory and the SCS methodology (SCS, 1979; Chang, 2003), enriched by a regional analysis of lag time, the internal daily distribution of precipitation and the determination of soil hydrologic classes (Ristić *et al*., 2012). The data concerning maximal daily precipitation have been obtained from the observation system of the Republic Hydrometeorological Office of Serbia (RHOS, 1945–2012). The computation has been performed for AMC III (Antecedent Moisture Conditions III, high content of water in the soil and significantly reduced infiltration capacity). The synthetic triangular unit hydrographs have been transformed to synthetic (computed) curvilinear hydrographs of total discharge, using the computer model "Wave" (Malošević, 2003).

The aim of this investigation was to show how the planned restoration of the "blue-green" corridors, as well as adequate land-use changes, can help the improvement of hydrological conditions in the endangered watersheds, the provision of effective erosion and torrent control, and environmental and social goals.

RESULTS OF INVESTIGATION

Land use changes

The land-use changes in the experimental watersheds are presented in Figs 2 and 3, under current (2013) and future conditions (2020). The current area of forest surfaces will be increased from 0.21 km^2 (15.0%) to 0.48 km^2 (34.3%) in the Kaljavi stream watershed, and from 1.27 km^2 (20.4%) to 2.38 km^2 (38.3%) in the Jelezovac stream watershed.

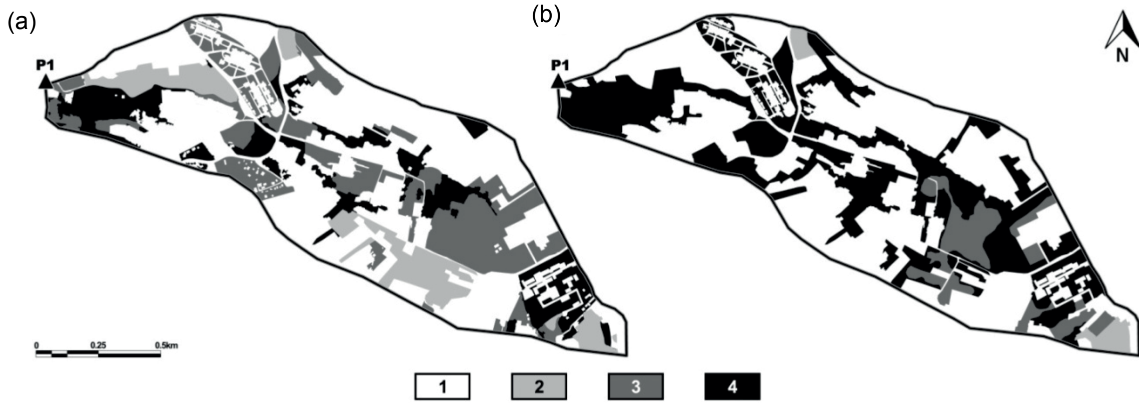

Fig. 2 Land use in the watershed of the Kaljavi stream; (a) (2013; 1 Discontinuous and continuous urban fabric, 0.74 km^2; 2 Complex cultivation patterns: arable land, orchards, gardens, 0.14km^2; 3 Grasslands, 0.31 km^2; 4 Mixed forests and forest belts, 0.21 km^2); (b) (2020; 1 Discontinuous and continuous urban fabric, 0.79 km^2; 2 Complex cultivation patterns: orchards, gardens, 0.03 km^2; 3 Grasslands, 0.10 km^2; 4 Mixed forests and forest belts, 0.48 km^2

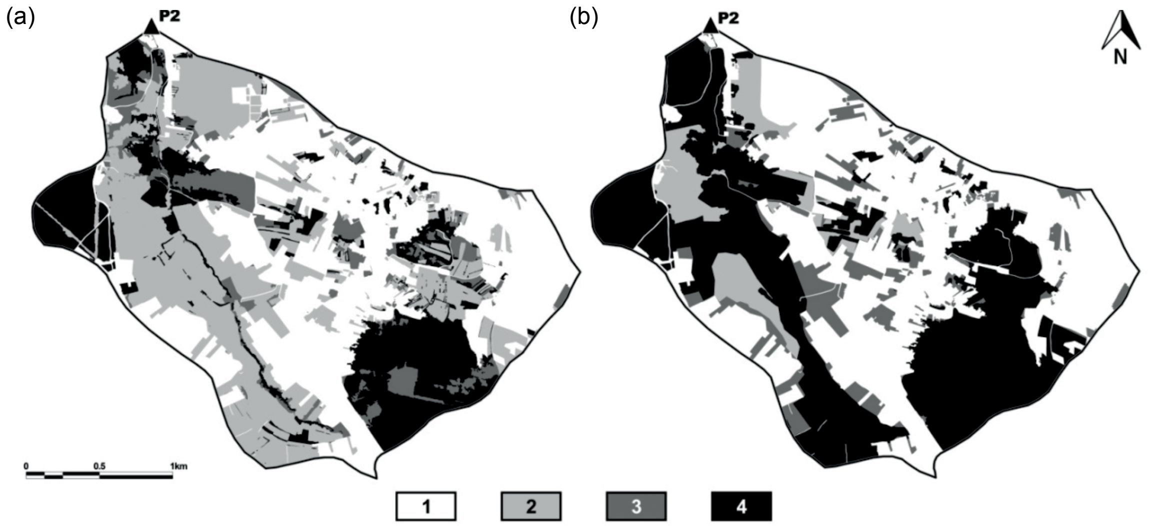

Fig. 3 Land use in the watershed of the Jelezovac stream; (a) (2013; 1 Discontinuous and continuous urban fabric, 2.49 km^2; 2 Complex cultivation patterns: arable land, orchards, gardens, 1.90 km^2; 3 Grasslands, 0.56 km^2; 4 Mixed forests and forest belts, 1.27 km^2); (b) (2020; 1 Discontinuous and continuous urban fabric, 2.73 km^2; 2 Complex cultivation patterns: orchards, gardens, 0.48 km^2; 3 Grasslands, 0.63 km^2; 4 Mixed forests and forest belts, 2.38 km^2.

The traditional agricultural production will be transformed into organic food production, with a significant reduction of agricultural surfaces from 0.14 km^2 (10.0%) to 0.03 km^2 (2.1%) in the Kaljavi stream watershed, and from 1.9 km^2 (30.6%) to 0.48 km^2 (7.7%) in the Jelezovac stream watershed.

Restoration works will be performed in the 2014–2020 period, on the basis of erosion and stream control demands, as well as environmental and social requests. The following biological and soil-bioengineering activities are planned: the afforestation of degraded arable land on steep slopes (1.15 km^2; 1500–2000 seedlings per ha, 2- to 3-years old) with planting along the contours on the previously prepared bench terraces; re-grassing of the degraded meadows, 0.73 km^2; the establishment of orchards on terraces, with grassing between terraces (mostly apple, plum trees and currant; 0.2 km^2) and gardens (cherry tomato, red peppers, basil; 0.31 km^2) for organic food production, instead of abandoned plough land; the establishment of protective forest belts along the stream beds; and walking and cycling paths (0.23 km^2). Also, some administrative measures (bans) are planned, including clear cuttings, cuttings on steep slopes, straight row farming down the slope and uncontrolled urbanization. Land owners have (with financial support from the authorities) the duty to apply contour farming and terracing of agricultural land (orchards and gardens) as effective measures of erosion control. In addition, 10 km of sealed walking and cycling paths, 1.7 km of unsealed forest paths, six open gyms and seven rest areas are planned.

Erosion and sediment transport

Some characteristic outputs of the computations of sediment yields and transport are presented in Table 2, along with the representative values of the coefficient of erosion Z, in current conditions (2013) and after the complete restoration of the "blue-green" corridors (2020), in the experimental watersheds (W_a, annual yields of erosive material; W_{asp}, specific annual yields of erosive material; W_{at}, annual transport of sediment through hydrographic network; W_{atsp}, specific annual transport of sediment through hydrographic network; W_{abls}, annual amount of bed-load sediment; W_{ass}, annual amount of suspended sediment).

Table 2 Characteristic outputs of computations of sediment yields and transport under current conditions (2013) and after restoration (2020).

Parameter	Current conditions (2013)		After restoration (2020)	
	Kaljavi s.	Jelezovac s.	Kaljavi s.	Jelezovac s.
W_a (m^3)	336.9	1730.3	187.9	1084.1
W_{asp} ($m^3km^{-2}year^{-1}$)	240.6	278.2	134.2	174.3
W_{at} (m^3)	71.8	427.4	40.0	267.8
W_{atsp} ($m^3km^{-2}year^{-1}$)	51.3	68.7	28.6	43.1
W_{abls} (m^3year^{-1})	7.0	32.6	1.9	14.9
W_{ass} (m^3year^{-1})	64.8	394.8	38.1	252.9
Z	0.217	0.239	0.147	0.175

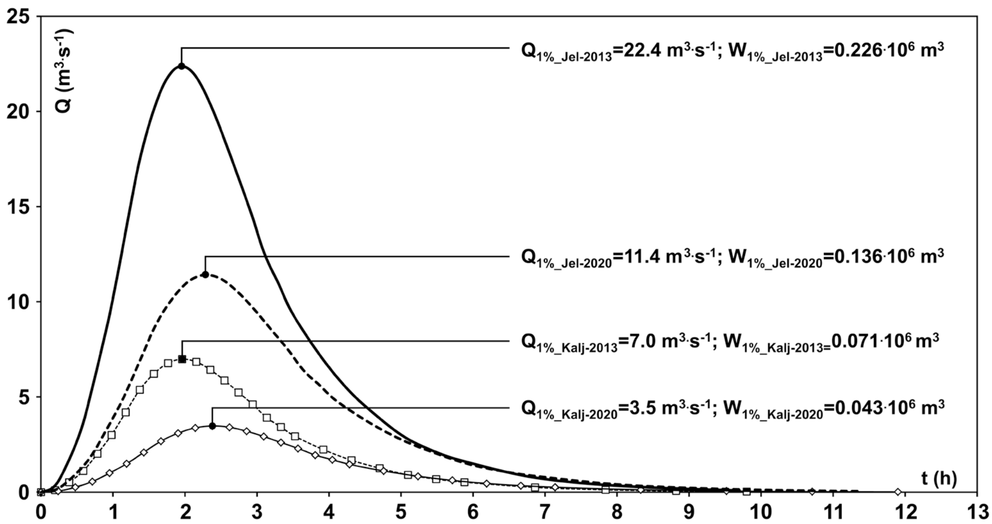

Fig. 4 Computed hydrographs of maximal discharges into the Kaljavi and Jelezovac streams (under conditions before and after restoration of the "blue-green" corridors).

Changes in hydrological conditions

The effects of hydrological changes were estimated by determining the maximal discharges in current conditions (2013) and after the complete restoration of the "blue-green" corridors (2020). The computed values of maximal discharges (for the control profiles P1 and P2, at the Kaljavi and the Jelezovac streams, Figs 2, 3) are presented in Fig. 4, as hydrographs for probability p = 1%.

The values of computed maximal discharges under current conditions ($Q_{1\%\_Jel\text{-}2013}$ = 22.4 $m^3 s^{-1}$; $Q_{1\%\_Kalj\text{-}2013}$ = 7.0 $m^3 s^{-1}$) and after the planned restoration works ($Q_{1\%\_Jel\text{-}2020}$ = 11.4 $m^3 s^{-1}$; $Q_{1\%\_Kalj\text{-}2020}$ = 3.5 $m^3 s^{-1}$), will be significantly reduced, as well as the volumes of a direct runoff ($W_{1\%\_Jel\text{-}2013} = 0.226 \times 10^6$ m^3; $W_{1\%\_Kalj\text{-}2013} = 0.071 \times 10^6$ m^3; $W_{1\%\_Jel\text{-}2020} = 0.136 \times 10^6$ m^3; $W_{1\%\_Kalj\text{-}2020} = 0.043.\times 10^6$ m^3). In addition, planned land use changes will cause a decrease in the values of runoff curve numbers CN, under the conditions before ($CN_{Jel\text{-}2013}$ = 70; $CN_{Kalj\text{-}2013}$ = 70) and after the restoration of the "blue-green" corridors ($CN_{Jel\text{-}2020}$ = 55; $CN_{Kalj\text{-}2020}$ = 57).

DISCUSSION

The restoration works were planned to ensure minimal impacts of the surrounding environment built on the restoration areas (Hostetler *et al*., 2011), maximize connectivity between "blue-green" areas and minimize development at the watershed scale (Ives *et al*., 2011), taking into account ecological, recreational, natural and cultural characteristics of the local areas (Asakawa *et al*., 2004; Briffett *et al*., 2004). Biological and soil-bioengineering works, as well as the application of administrative measures, will alter and improve the hydrological conditions by increasing the interception and infiltration-retention capacity of the soil, protecting the soil from the impact of rain, decreasing erosion and surface runoff. In this way, the experimental watersheds of the Kaljavi and Jelezovac streams will become less responsive to extreme events such as with high rainfall intensities.

The restoration of "blue-green" corridors in the experimental watersheds of the Kaljavi and Jelezovac streams will decrease the values of maximal discharges (p = 1%) by about 50%, and the volumes of direct runoff by about 40%. Erosive material production and transport will be

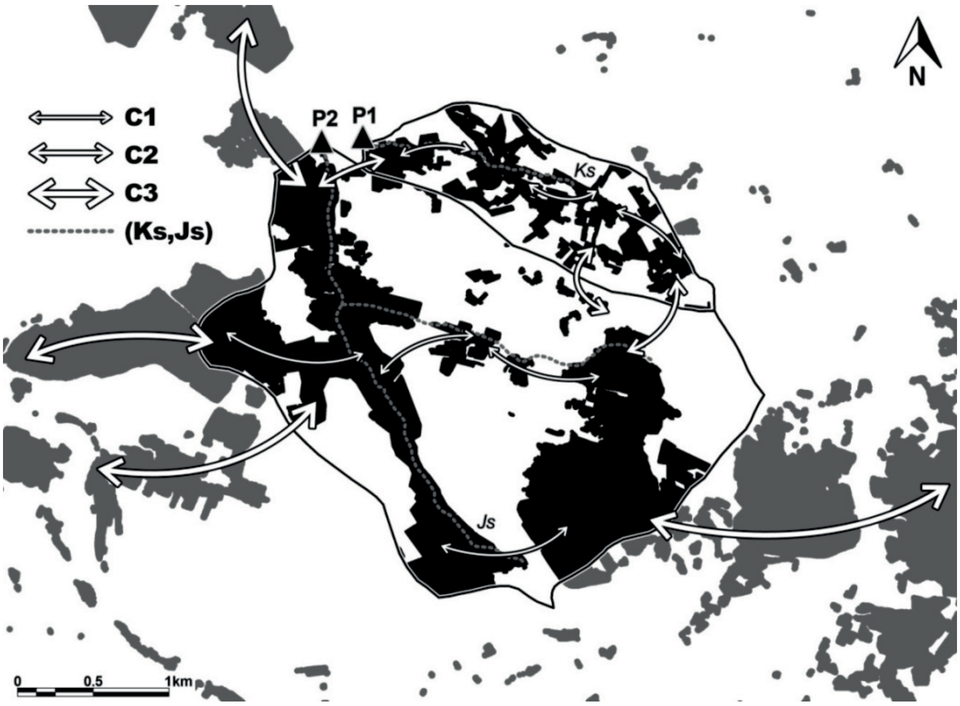

Fig. 5 C1 (Microscale connections; intra-watershed level); C2 (Mesoscale connections; inter-watershed level); C3 (Macroscale connections; trans-watershed level); Ks (Kaljavi stream); Js (Jelezovac stream); P1 (outlet control profile at the Kaljavi stream watershed); P2 (outlet control profile at the Jelezovac stream watershed).

decreased by about 44% in the Kaljavi stream watershed, and 37% in the Jelezovac stream watershed. Ten kilometres of sealed walking and cycling paths, 1.7 km of unsealed forest paths, six open gyms and seven rest areas will enrich the potential of this area for sports and recreation. In addition, the restoration will help the protection and controlled usage of the natural and cultural values in the area, including a very rare object of geodiversity (phonollyte rocks), the section for ornitofauna (40 bird species) observation and a neolite settlement. The restoration of the "blue-green" corridors enables their connection at different spatial levels (Fig. 5), including the following: at the intra watershed level (C1-microscale connections), the inter-watershed level (C2-mesoscale connections) and the trans-watershed level (C3-macroscale connections). The final goal is the creation of a network of "blue-green" corridors in the territory of Belgrade city, which provides effective erosion and stream control, and environmental and social services.

Acknowledgements The Serbian Ministry of Science supported this study within project 43007 (Investigation of climate changes and their influence on the environment: monitoring, adaptation and mitigation; Subproject: Frequency of torrential floods and degradation of soil and water as a consequence of global changes).

REFERENCES

Ananda, J. & Herath, G. (2003) Soil erosion in developing countries: a socio-economic appraisal. *J. Environ. Manage.* 68, 343–353.

Asakawa, S., Yoshida, K. & Yabe, K. (2004) Perceptions of urban stream corridors within the greenway system of Sapporo, Japan, *Landscape and Urban Planning* 68, 167–182.

Barredo, J. I. (2007) Major flood disasters in Europe: 1950–2005. *Natural Hazards (Springer)* 42, 125–148.

Berz, G., Kron, W., Loster, T., Rauch, E., Schimtschek, J., Schmieder, J., Siebert, A., Smolka, A. & Wirtz, A. (2001) World map of natural hazards – a global view of the distribution and intensity of significant exposures. *Natural Hazards* (Kluwer Academic Publishers) 23, 443–465.

Briffett, C., Sodhi, N., Yuen, B. & Kong, L. (2004) Green corridors and the quality of urban life in Singapore. In: *Proceedings 4th International Urban Wildlife Symposium* (ed. by W. W. Shaw, L. K. Harris & L. VanDruff), 56–63.

Carbo-Ramirez, P. & Zuria, I. (2011) The value of small urban green spaces for birds in a Mexican city. *Landscape and Urban Planning* 100, 213–222.

Chang, M. (2003) *Forest Hydrology*. CRC Press, Washington DC.

EEA (European Environmental Agency) (1994).Coordination of information on the Environment.

Faculty of Forestry& Institute for Water Resources Management "Jaroslav Černi" (2005) *Plans for Announcement of Erosive Regions and Plans for Protection from Torrential Floods*. Belgrade, Serbia.

Hostetler, M., Allen, W. & Meurk, C. (2011) Conserving urban biodiversity? Creating green infrastructure is only the first step, *Landscape and Urban Planning* 100, 369–371.

Ives, C. D., Hose, G. C., Nipperess, D. A. & Taylor, M. P. (2011) Environmental and landscape factors influencing ant and plant diversity in suburban riparian corridors. *Landscape and Urban Planning* 103, 372–382.

Kazmierczak, A. & Carter, J. (2010) Adaptation to climate change using green and blue infrastructure; a database of case studies. University of Manchester, UK.

Kostadinov, S. (2008) *Torrential Flows and Erosion*. University of Belgrade, Faculty of Forestry, Serbia.

Malošević D. (2003) *Wave–Computer Model for Rainfall–Runoff Analysis*. Belgrade, Serbia.

RHOS (Republic Hydrometeorological Office of Serbia) Hydrologic annual reports-precipitation, Belgrade, Serbia, annuals from 1945 to 2012.

Ristić, R. & Macan, G. (2002) Investigation of interception in beech-fir stand on mountain Goč, *Journal of Forestry Faculty* 86, 181–188.

Ristić, R. & Nikić, Z. (2007) Sustainability of the System for Water Supply in Serbia from the aspect of Erosion Hazard, Journal for Water Resources Management 225–227, 47–57.

Ristić, R., Kostadinov, S., Abolmasov, B., Dragićević, S., Trivan, G., Radić, B., Trifunović, M. & Radosavljević, Z. (2012) Torrential floods and town and country planning in Serbia, *Natural Hazards and Earth System Sciences* (ISSN: 1561-8633) 1(12), 23–35, (doi: 10.5194/nhess-12-23-2012).

Saumel, I. &Kowarik, I. (2010) Urban rivers as dispersal corridors for primarily wind-dispersed invasive tree species, *Landscape and Urban Planning* 94, 244–249.

SCS (Soil Conservation Service) (1979) National Engineering Handbook, Section 4, Hydrology, US Department Agriculture, Washington, DC.