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„BLUE-GREEN“ CORRIDORS AS A TOOL FOR MITIGATION OF NATURAL HAZARDS AND RESTORATION OF URBANIZED AREAS: A CASE STUDY OF BELGRADE CITY

Ratko Ristić[1], University of Belgrade Faculty of Forestry, Dept. for Ecological Engineering in Protection of Soil and Water Resources, Belgrade, Serbia
Boris Radić, University of Belgrade Faculty of Forestry, Dept. for Ecological Engineering in Protection of Soil and Water Resources, Belgrade, Serbia
Veliša Miljanović, Ministry of Transport, Authority for Determination of the Seaworthiness, Belgrade, Serbia
Goran Trivan, Secretariat for Environmental Protection of Belgrade City, Belgrade, Serbia
Milanko Ljujić, Public Enterprise „17 September“, Gornji Milanovac, Serbia
Ljubomir Letić, University of Belgrade Faculty of Forestry, Dept. for Ecological Engineering in Protection of Soil and Water Resources, Belgrade, Serbia
Radovan Savić, University of Novi Sad, Faculty of Agriculture, Department of Water Management, Novi Sad, Serbia

Urbanized areas constantly need new surfaces for building of commercial, residental or infrastructure facilities. Belgrade, the capital of Serbia and a big regional center, with 2,000,000 inhabitants, covers a teritorry of 3,500 km^2. Decreasing of surfaces under forest vegetation, urbanisation and inadequate agricultural measures have caused intensive erosion and more frequent torrential floods. Belgrade authorities have defined a new strategy for land use and urban planning in order to decrease the risk from destructive erosion processes and torrential floods and help the establishment of new recreational areas, preservation of biodiversity and mitigation of the „heat island“effect. The strategy is based on the restoration of „blue-green“ corridors (residuals of open streams and fragments of forest vegetation). The restoration of „blue-green“ corridors is presented at the experimental watersheds of the Kaljavi and Jelezovac streams. The 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, including biological, soil-bioengineering activities and certain administrative measures. The forest surfaces will be increased by 1.38 km^2 (18.11% of the total area). The restoration of "blue-green" corridors in the experimental watersheds 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 decreased by about 44% in the Kaljavi stream watershed, and 37% in the Jelezovac stream watershed. Ten kilometers of sealed walking and cycling paths, 1.7 km of unsealed forest paths, six open gyms and seven rest areas will strengthen the potential of this area for sports and recreation. The restoration will help the protection and controlled usage of the natural and cultural values in the area, and the connection of „blue-green“ corridors at different spatial levels. The final goal is the creation of a network of "blue-green" corridors in the territory of Belgrade city, which provides both effective erosion and stream control and environmental and social services.

***Key words:** „blue-green“ corridors, natural hazards, watershed restoration, land use, urban planning.*

INTRODUCTION

The development of highly urbanized areas requires the occupation of new spaces that are mainly located in riparian areas or in the remaining fragments of green spaces (Li *et al.*, 2005; Nichols, 2009). Land-use changes such as deforestation and topsoil removal, dramatically alter hydrological conditions by reducing the interception and infiltration–retention capacity of the soil, exposing the soil to the impact of rain, which accelerates erosion and surface runoff (Ristić *et al.*, 2012). The dynamic and uncontrelled urban development of Belgrade have caused the vanishing of great

[1]Kneza Višeslava 1, 11030 Belgrade, Serbia
ratko.risticc@gmail.com

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green complexes and the occupation of spaces in riparian areas, and this is still an ongoing process: construction of the apartment and office block on the edge of the Terazije plateau; a large number of apartment blocks on the left bank of the Sava River, in the area intended for flood protection and recreation; illegal construction on the edge of the park forest Zvezdani Gaj; the disappearance of forest areas near the Lisičji stream. The core of the city area involves a few dozens of watercourses, with fully or partly urnbanized watersheds, which have been introduced into the sewerage system (the Čuburski, Kumodraški, Mokroluški, and Žarkovački streams, etc.). Numerous important city streats were built just above former stream beds (South boulevard, and Nemanjina streat, etc). At the same time, some big cities in the world can show different examples that are in line with the modern urban sensibility and ecologism. These examples are the restoration of the Cheonggyecheon stream in Seoul (Seoul Development Institute, 2003), or the locality Don Valley Brick Works in Toronto (Foster, 2005).

Belgrade, the capital of Serbia and a big regional centre with a population of 2,000,000, covers a territory of 3,500 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). A high concentration of housing, office and infrastructural facilities made Belgrade poor in green areas compared to other cities in Europe. Green areas occupy 14 m^2 per capita at the city level, whereas in some parts of the city, such as Vračar, they cover only 2 m^2 per capita (Urbanistic Institute of Belgrade, 2001).

The authorities of Belgrade defined a strategy for erosion and torrent control based on the restoration of "blue-green" corridors. The restoration of "blue-green" corridors helps the establishment of new recreational areas, preservation of biodiversity (Saumel and Kowarik, 2010; Ramirez and Zuria, 2011) and urban adaptation to climate change (Kazmierczak and Carter, 2010). The restoration of „blue-green" corridors is presented at the experimental watersheds of the streams Kaljavi and Jelezovac.

The „blue-green" corridors concept

Each watershed contains certain elements that can be unconnected (isolated), which gives them a static character, or functionally connected, which gives them a dynamic character (Figure 1). If the residuals of open streams and fragments of vegetation (forests, meadows, shrubs) are connected with the green line structures that comprise paths (walking, cycling), they form „blue-green" corridors, with the following functions: mitigation of the „heat island" effect, terrain drainage, sports and recreation, restoration of autochtonous flora and fauna, aesthetic and visual effects.

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 (Figure 2). 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.

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, using ArcMap10. The land use classification was made on the basis of modified CORINE methodology (EEA, 1994). The visual impact in the studied area was assessed through a view shed analysis using the ArcMap10 software (module Spatial Analyst Tools). Particularly, the scale of the influence of restoration works in accordance with the specific topography and visual exposure of the area has been analyzed (Bell 1994; Selman 2006; Bell and Apostol, 2008).

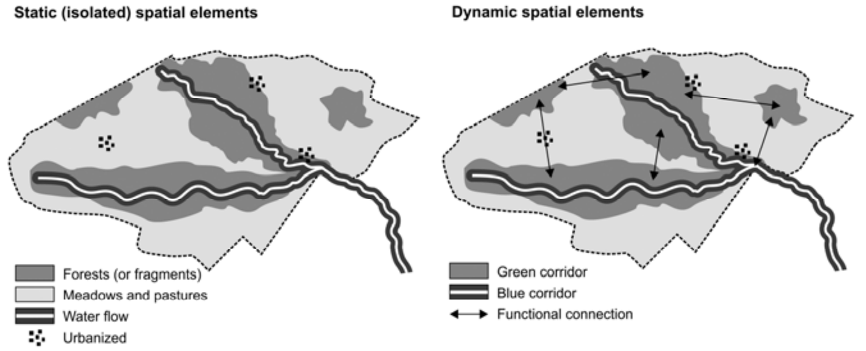

Figure 1. „Blue-green" corridors concept

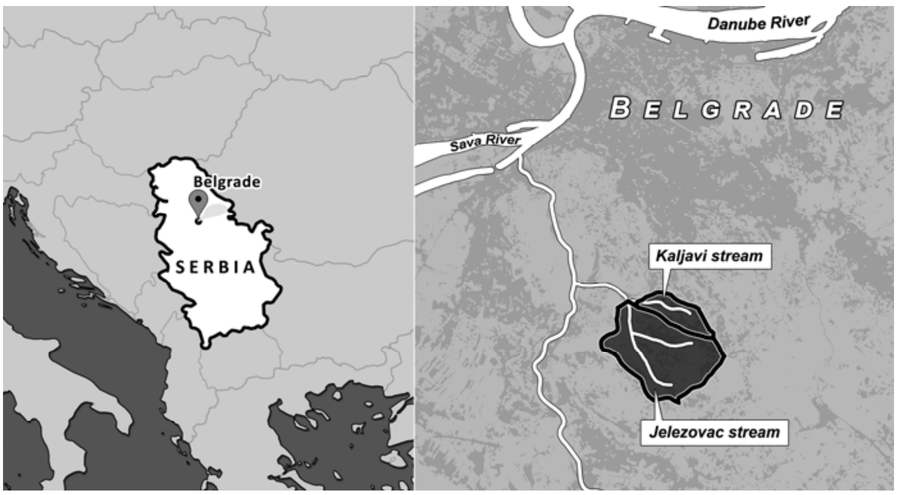

Figure 2. Location of the experimental watersheds of Kaljavi and Jelezovac streams

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

The area sediment yields and the intensity of erosion processes have been estimated on the basis of the “Erosion Potential Method” (EPM) (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), on the basis of computations of maximal discharges (Q_{max}) using the synthetic unit hydrograph theory and the SCS methodology (SCS, 1979; Chang, 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 Figures 3 and 4, 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.

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.

Effects of mitigation of natural hazards

The most significant natural hazards in the investigated area are erosion processes and torrential floods. 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).

The effects of hydrological changes were estimated by determining the maximal discharges in current conditions (2013) and after the complete restoration of the “blue-

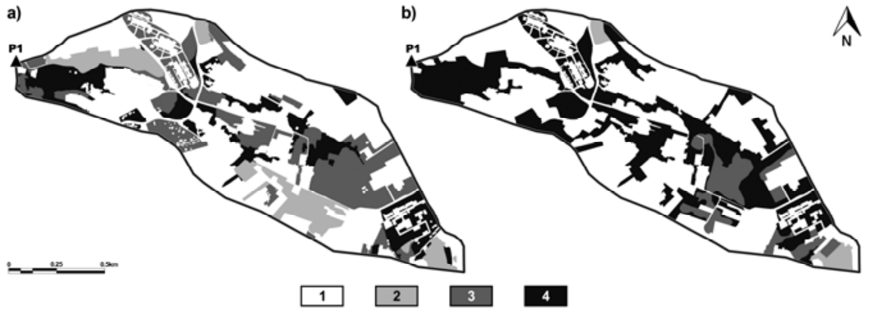

Figure 3. Land use in the watershed of the Kaljavi stream; (a) (2013; 1 Discontinuous and continuous urban fabric, 0.74 km^2; 2 Complex cultivation patterns: arable land, orchards, gardens, 0.14km^2; 3 Grasslands,0.31 km^2; 4 Mixed forests and forest belts, 0.21km^2); (b) (2020; 1 Discontinuous and continuous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

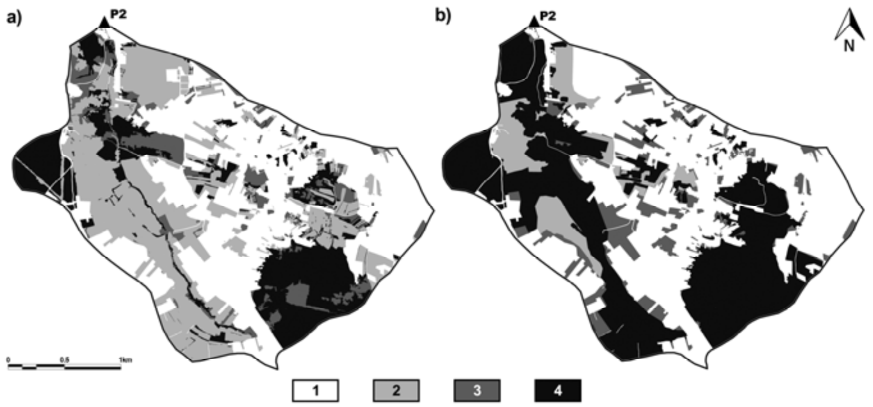

Figure 4. Land use in the watershed of the Jelezovac stream; (a) (2013; 1 Discontinuous and continuous urban fabric, 2.49 km^2; 2 Complex cultivation patterns: arable land, orchards, gardens, 1.90 km^2; 3 Grasslands, 0.56 km^2; 4 Mixed forests and forest belts, 1.27 km^2); (b) (2020; 1 Discontinuous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

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} ($m^3 km^{-2} year^{-1}$)	240.6	278.2	134.2	174.3
W_{at} (m^3)	71.8	427.4	40.0	267.8
W_{atsp} ($m^3 km^{-2} year^{-1}$)	51.3	68.7	28.6	43.1
W_{abls} ($m^3 year^{-1}$)	7.0	32.6	1.9	14.9
W_{ass} ($m^3 year^{-1}$)	64.8	394.8	38.1	252.9
Z	0.217	0.239	0.147	0.175

green" corridors (2020). The computed values of maximal discharges (for the control profiles P1 and P2, at the Kaljavi and the Jelezovac streams, Figures 3 and 4) are presented in Figure 5, as hydrographs for probability p = 1%. The values of computed maximal discharges under current conditions ($Q_{1\%\_Jel\text{-}2013}$=22.4 $m^3 \cdot s^{-1}$; $Q_{1\%\_Kalj\text{-}2013}$=7.0 $m^3 \cdot s^{-1}$) and after the planned restoration works ($Q_{1\%\_Jel\text{-}2020}$= 11.4 $m^3 \cdot s^{-1}$; $Q_{1\%\_Kalj\text{-}2020}$=3.5 $m^3 \cdot s^{-1}$), will be significantly reduced, as well as the volumes of a direct runoff ($W_{1\%\_Jel\text{-}2013}$ = 0.226×10^6 m^3; $W_{1\%\_Kalj\text{-}2013}$ = 0.071×10^6 m^3; $W_{1\%\_Jel\text{-}2020}$=0.136×10^6 m^3; $W_{1\%\_Kalj\text{-}2020}$ = 0.043×10^6 m^3).

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 (Đeković *et al.*, 2013). 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 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 (Figure 6).

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 (Figure 7), including the following: at the intra

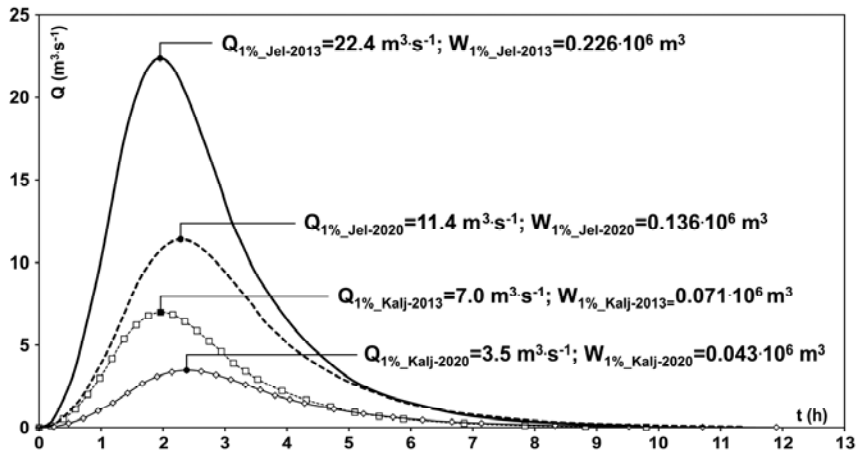

Figure 5. Computed hydrographs of maximal discharges into the Kaljavi and Jelezovac streams (under conditions before and after restoration of the "blue-green" corridors).

Figure 6. Possible image of the Jelezovac stream riparian area

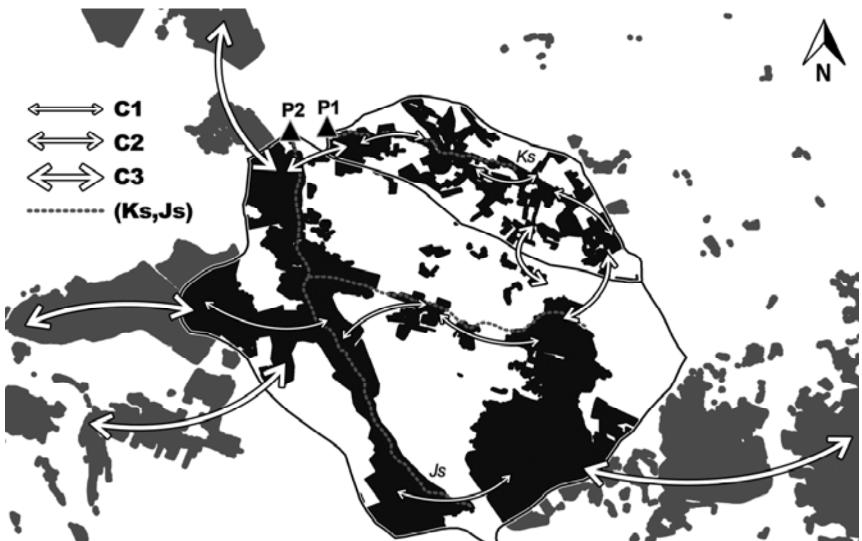

Figure 7. C1 (Microscale connections; intra-watershed level); C2 (Mesoscale connections; inter-watershed level); C3 (Macroscale connections; trans-watershed level); Ks (Kaljavi stream); Js (Jelezovac stream); P1 (outlet control profile at the Kaljavi stream watershed); P2 (outlet control profile at the Jelezovac stream watershed).

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.

CONCLUSIONS

The findings of this research indicate that the restoration of „blue-green" corridors in the city of Belgrade will have significant positive effects on the following:

- The identification and protection of the remaining forest areas, other valuable green areas and watercourses;
- The prevention of natural hazards (torrential floods, destructive erosion processes);
- A necessity to react quickly in order to protect the remaining green areas, open streams and riparian areas;
- The mitigation of the effects of climate change (CO_2 sequestration; O_2 emission; reduced "heat island" effect);
- The conservation and protection of biodiversity;
- The establishment of new sports and recreational areas;
- The rehumanization of the city space.

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