Bioswales as elements of green infrastructure – foreign practice and possibilities of use in the district of the City of Nis, Serbia

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BIOSWALES AS ELEMENTS OF GREEN INFRASTRUCTURE – FOREIGN PRACTICE AND POSSIBILITIES OF USE IN THE DISTRICT OF THE CITY OF NIŠ, SERBIA

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ABSTRACT

The experience in stromwater management shows that traditional stormwater systems are often unable to absorb and process all of the excess water runoff, resulting in frequent flash flooding in urban areas. Contemporary approaches suggest the implementation of vegetated swales as green infrastructure that is an alternative or a supplement to traditional storm sewers. Bioswales are cost-effective and attractive, and in addition to improving the treatment of stormwater runoff, they restore the ecosystem, improve visual identity and environmental quality and provide long-term sustainability. The goal of this paper is to exlore the concept of bioswales and to suggest potential locales for their implementation in the case of a residential district of the City of Niš. Therefore, the experiences of three typical foreign best practice examples are presented. The use of vegetated swales in the case of Niš is recommended in various types of urban fabic: residential streets, vast surface parking lots and unorganized green areas in waterfront zones. This is especially important for post-socialist cities that underwent significant urban densification and cannot afford more loss of public open space nor green areas. The results of this research should help in promoting the implementation of bioswales in both urban planning theory and practice.

Keywords: stormwater management; vegetated swales; residential streets; parking lots; waterfront zones; urban denisification

1. INTRODUCTION

Increasing urbanisation and especially urban densification have resulted in the increase of paved surfaces in urban areas, which are ususally impervious. Impervious land cover alters the quantity and quality of surface runoff water (Xiao and McPherson, 2011). Large volumes of excess stormwater runoff in a short amount of time can not only cause flash flooding, but also result in water pollution and destroyed habitat in urbanized areas (USEPA, 2005). Certain strategies and Best Management Practices (BMP) have been developed in the world in the last couple of decades in order to mitigate the impact of stormwater runoff and pollutant loading. Bioswales or vegetated swales are one of those BMPs and represent elements of green infrastructure that are used for stormwater management.

This research investigates the concept of bioswales and explores their potential use in the case of the City of Niš. With a population of approximately 260.000 inhabitants (2011 Census), the City of Niš is the third largest city in Serbia and a typical post-socialist city of medium-size. Post-socialist development period had significant implications upon the urban landscape of Niš, with the urban densification and loss of public open space/green areas being one of the most remarkable features of transition (Dinić Branković et al., 2018a). Urban densification and increase of paved surfaces had significant environmental impacts in Niš, including flash flooding, waterway pollution and degradation of the ecosystem. Traditional stormwater system is often unable to absorb and process all of the excess water runoff, resulting in flooding of various parts of urban area. However, modern stormwater management approaches have, to date, not been implemented. It is the standpoint of this research that the use of bioswales as elements of green infrastructure could significantly improve stormwater management in Niš. Therefore, this paper discusses the main urban design principles of bioswales, investigates typical urban environments that use these elements of green infrastructure, and examines the possibilities of their implementation in the case of a residential district in the City of Niš.

2. BIOSWALES: CONCEPT, DESIGN, BENEFITS AND BEST PRACTICE EXAMPLES

Bioswale or vegetated swale is a linear form of bioretention used to partially treat water quality, attenuate flooding potential and convey stormwater away from critical infrastructure (University of Florida, 2008). Bioswales are designed as gently sloping depressions planted with dense vegetation or grass and they treat stormwater runoff from rooftops, streets and parking lots (ES-CPO, 2004). The slope enables the water to flow efficiently through the system. Bioswales absorb low flows or carry runoff from heavy rains to storm sewer inlets or directly to surface waters (NRCS, 2005). As conveyance systems, bioswales can represent an alternative or a supplement to traditional storm sewers. According to the NRCS (2005), bioswales should be sized to convey at least 11 cm in 24 hours.

The vegetation of the swale slows the runoff water, filters it and then allows it to infiltrate into the ground or into a storm drain, thereby improving water quality. Most water runoff nowadays contains hard metals from roads, roofs and hard surfaces, as well as lawn chemicals from fertilization. Filtering these hard materials before they enter our drinking water system is of crucial importance for the sustainability of rivers and streams. The way of functioning of a bioswale is illustrated in Figure 1.

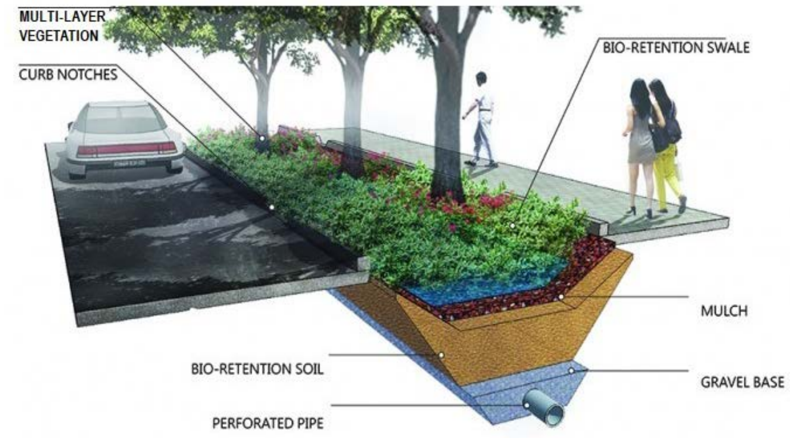

Figure 1. Bioswale concept diagram: (1) Dirty and polluted water from rooftops, roads and parking lots enters the bioswale; (2) Water is slowed down by various plants and rocks, pollutants settle out, clean water infiltrates the soil; (3) Water enters the perforated pipe and is slowly absorbed into the ground; (4) Excess stormwater exits the bioswale and flows through the pipe into the recipient, cleaner then when it entered and in the amount significantely reduced. Source: http://www.cranejapan.co/grass-bioswale-diagram.html

Bioswales are engineered with gravelly soil, so stormwater is absorbed quickly and deeply. An underdrain pipe is not necessary in naturaly well drained soils (Univeristy of Florida, 2018). In cases where soils do not drain well, bioswales are typically lined and convey runoff to a dry well or soakage trench (ES-CPO, 2004). The site where bioswales are applied should be designed so that runoff water is directed or drained into the swale. In bioswales in the streets or parking lots, this can be acheived by using curb cuts in planting areas (Figure 2C). Swales should be used to serve areas less than 4 hectares with slopes no greater than 5%, while total surface area of the swale should be 1% of the area from which it is receiving stormwater (University of Florida, 2008). For slopes greater than 5% swales can include check dams to help slow and detain the flow and extend time for infiltration (Figure 2D).

Bioswales can be planted with a variety of vegetation, including trees, shrubs, wildflowers and grass. Thicker and heavier grass in the bioswale can filter out contaminants better, while deep-rooted native plants are preferred for infiltration and reduced maintenance (NRCS, 2005). It is also very important that a bioswale can be designed as a decorative greening element, which greatly enhances its landscaping potential. Regarding the maintenance, biowswales should be inspected periodically, especially after major storm events. Irrigation may be required in dry summer months. However, with proper construction and maintenance, bioswales can last indefinitely.

Besides reducing the total volume of stormwater runoff, the main value of bioswales lies in the fact that they infiltrate and filter nearly all of the water that comes from frequent, small rain events (NRCS, 2005). In this way, bioswales reduce the strain on city's municipal sewer system, which ultimately leads to cleaner rivers and waterways. Bioswale conveyance systems can treat and dispose of stormwater runoff from an entire site, thus reducing the number and cost of traditional storm drains and piping (ES-CPO, 2004). They are less expensive than traditional curb and gutter treatment or unederground strormwater systems (University of Florida, 2008). Bioswales also increase infiltration and groundwater recharge (University of Florida, 2008). Bioswales keep the water from flooding nearby structures and infrastructure, where it can create puddles and swamps. Another benefit of bioswales is that they also represent a favorable habitat for wildlife and may very well enhance biodiversity. Importantly, even though construction costs may vary, bioswales typically cost less than a standard piped, drainage system (ES-CPO, 2004). Last but not least, bioswales as greening elements can help improve the visual identity and aesthetics of space.

Bioswales are usually applied in parking lots, along residential roads and highways, in landscape buffer zones, in waterfront areas, in residential parks or other public spaces and in residential plots. Some best practice examples on the use of bioswales are presented in the following sections.

2.1. NE Siskiyou Green Street, Portland, Oregon, USA

The NE Siskiyou Green Street is one of Portland's best green street stormwater retrofit examples and the first of its kind anywhere (ASLA, 2007). Built in 2003, this simple, cost effective and innovative project promotes the principles of sustainable stormwater management. The 80 year-old residential street was remodeled by carving out a portion of the street's parking zone and converting it into two landscaped curb extensions that capture, slow, cleanse and infiltrate street runoff. The project disconnects the street's rainwater runoff from the City's combined storm/sewer pipe system and manages it on-site using a landscape approach.

According to project description of American Society of Landscape Architects (2007), stormwater runoff from 930 m2 of NE Siskiyou Street and neighboring driveways (Figure 2A) flows downhill along the existing curb until it reaches curb extensions (size 2,1 m x 15,2 m each) (Figure 2B). Water enters each curb extension through a 46 cm wide curb cut (Figure 2C), where it is retained to a depth of 18 cm by a series of checkdams (Figure 2D). Depending on the intensity of a rain event, water will cascade from one "cell" to another until plants and soil absorb the runoff or until the curb extensions reach their storage capacity. The bioswale system infiltrates water at a rate of 7,6 cm per hour. If a storm is intense enough, water will exit the landscape area through another curb cut at the end of each curb extension and will flow into the existing street inlets. In this way nearly all of NE Siskiyou's annual street runoff (estimated at 10,000 hectolitres) is managed by its landscape system. Simulated flow tests have shown that the curb extensions at NE Siskiyou Street have the ability to reduce the runoff intensity of a typical 25-year storm event by 85 percent.

Figure 2. NE Siskiyou Green Street project: (A) Stormwater curb extensions plan; (B) Stormwater curb extensions flow diagram; (C) Curb cut in a bisowale for stormwater runoff; (D) Series of checkdams made from packed earth and river rock. Source: https://www.asla.org/awards/2007/07winners/506_nna.html

The author of the project is a landscape architect Kevin Robert Perry, who worked together with city officials and local community members. The City and neighborhood residents have agreed to share responsibilities in maintaining the landscaped stormwater curb extensions. The NE Siskiyou Green Street project has achieved three primary goals (ASLA, 2007): (1) *Low-cost design and execution* - the project was relatively simple to construct, maintenance friendly and cost effective since it was built for less than 20.000 dollars; (2) *Benefits the environment and embodies community livability* - aside from being aesthetically pleasing, this landscaped stormwater solution brings natural hydrologic functions back into the city; and (3) *Provides a model for other national and local stormwater regulations* - the creative and positive partnership of various stakeholders resulted in a widespread community acceptance of the project, and inspired similar landscaped stormwater facilities in other residential streets.

2.2. Edwards Gardens Parking Lot Retrofit, Toronto, Ontario, Canada

The largest parking lot in the City of Toronto's park system, with a total area of 15.045 m2, is located at the botanical garden Edwards Gardens, and also serves Wilket Creek Park and Toronto Botanical Garden. Before the retrofit, deteriorated asphalt parking lot was a major source of urban runoff to Wilket Creek during storm events, contributing to erosion, elevating flooding risk, and degrading downstream water quality and aquatic habitat (STEP, 2016). Wilket Creek Valley was also affected, resulting in damage to bridges, trails and park amenities and impacts to the valleyland ecosystem (STEP, 2016). The prime objective of the retrofit project was to mitigate stormwater impacts on Wilket Creek, while improving pedestrian access, safety and circulation, conserveing water and energy, and promoting alternate forms of transportation (CSLA, 2013).

Retrofit project was designed by landscape designers Schollen&Company Inc and implemented in 2012 (Figure 3A). General retrofit idea was to capture stormwater runoff and convey it through stormwater biofilters - combined bioretention and infiltration trenches with native plantings (Figure 3B). A bioswale lined with loose stone was constructed to convey flows from the parking lot to an existing stormwater outet that discharges to Wilket Creek. A network of stormwater biofilters totaling 880 m2 area, that are situated in traffic islands, capture, infiltrate and convey runoff (STEP, 2016). Water enters the biofilters through gravel inlets (Figure 3C), while excess water is directed to an outfall via perforated exfiltration pipe. Bioswales are landscaped using a diverse selection of native trees, shrubs, and grasses that are drought tolerant (Figure 3D). The plantings increase evapotranspiration, reduce of the urban heat island effect of the parking lot, enhance biodiversity and improve the overall impression of the area (STEP, 2016). Tall plant material helps to further absorb pollutants while providing shade (Schollen&Company, 2018). Permeable pavement was also implemented in parking areas and pedestrian paths. The project enhances infiltration, reduces runoff rates, limits the amount of pollutants that are contained within stormwater runoff and increases groundwater recharge.

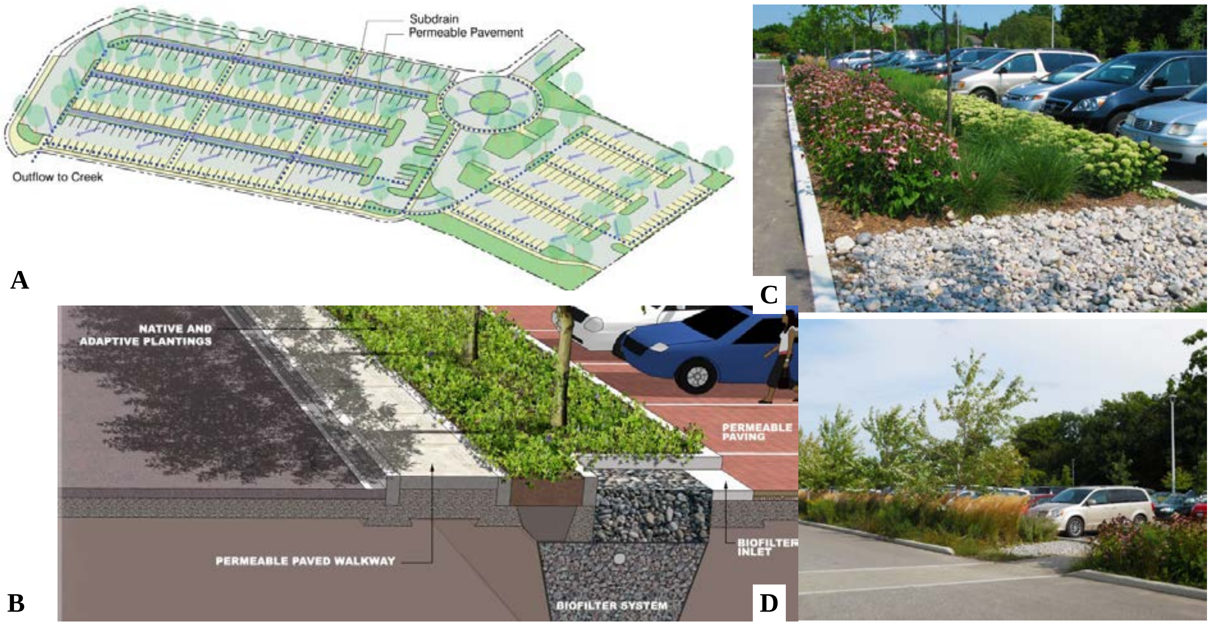

Figure 3. Edwards Gardens Parking Lot Retrofit: (A) Stormwater flow plan; (B) Bioswale concept diagram; (C) Bioswale stormwater inlet with loose stone; (D) Native plantings in the bioswale. Source: http://schollenandcompany.com/projects/edwards-gardens-parking-lot/

The total cost of the new green parking lot was 1.8 million dollars. Even though this investement was initially higher than standard asphalt surfacing, in the long run it is considered cheaper than total costs associated with repair of erosion and flood damages (STEP, 2016). The retrofitted parking lot has received positive feedback from all partners and the public. The use of bioswales within the project was successful in fulfilling three main objectives: (1) *Transformation a deteriorated parking lot into an inovative sustainable design while maintaining the original parking capacity*, (2) *Significant reduction in the amount of stormwater run-off being released to the Wilket Creek subwatershed* and (3) *Enhancement of urban biodiversity and tree canopy through native tree, shrub and grass plantings*.

2.3. Harold Simmons Park along Trinity River, Dallas, Texas, USA

After the great flood of 1908, Trinity River was moved away from downtown Dallas to the west, and levees were built to protect the city from future flooding. This left Trinity River disconnected from the public by long stretches of undeveloped land and a general lack of access (MVVA, 2016). In an effort to connect the river with the city, Dallas is nowadays creating an 115ha-park named after Harold Simmons, as a part of the Trinity River Corridor Project[1] (Figure 4A). The Harold Simmons Park project is set to be completed by 2021.

The designer, Michael Van Valkenburgh Associates (MVVA), envisions the space of the Harold Simmons Park as a network of trails, meadows and lakes along Trinity River. The concept of the park is based on two main elements: civic spaces and naturalistic landscapes. Civic spaces, such as playgrounds, fountains, plazas and lawns, are located in 5 access parks at the upper level of the river's levees, connecting the urban fabric to the floodplain. These amenities are therefore protected from flooding. Naturalistic landscapes along the river are supposed to restore the ecological function and natural beauty of the channel. The design enables rich river habitat with thriving wildlife and diverse landscapes from prairie to wetlands. However, the main purpose of the park is to provide protection from major flood events. The park is accessible even during 10-year storms,

[1] Large nature district Trinity River Corridor Project began in the early 2000s. This 4046ha-nature area includes trails, a predestrian bridge, a horse park, a golf course and a community center, with plans to build shops, restaurants, housing and offices in the near future. The City plans for the park to become a catalyst for urban growth and economic development.

ensuring the adaptability of the space even under extreme circumstances (MVVA, 2016). During the Trinity River's wet season, low-lying parts of Harold Simmons Park will receive flood waters from the Trinity River, redirect and absorb them into storage areas using sloped bioswales (Figures 4B, 4D) (Water Environment Federation, 2017). During the more arid months, the river bottom and plants will be exposed, allowing views and access to Trinity River habitat (Figures 4B, 4C). In this way, the park will naturally flood only in controlled areas, while the overflow water will drain into bioswales.

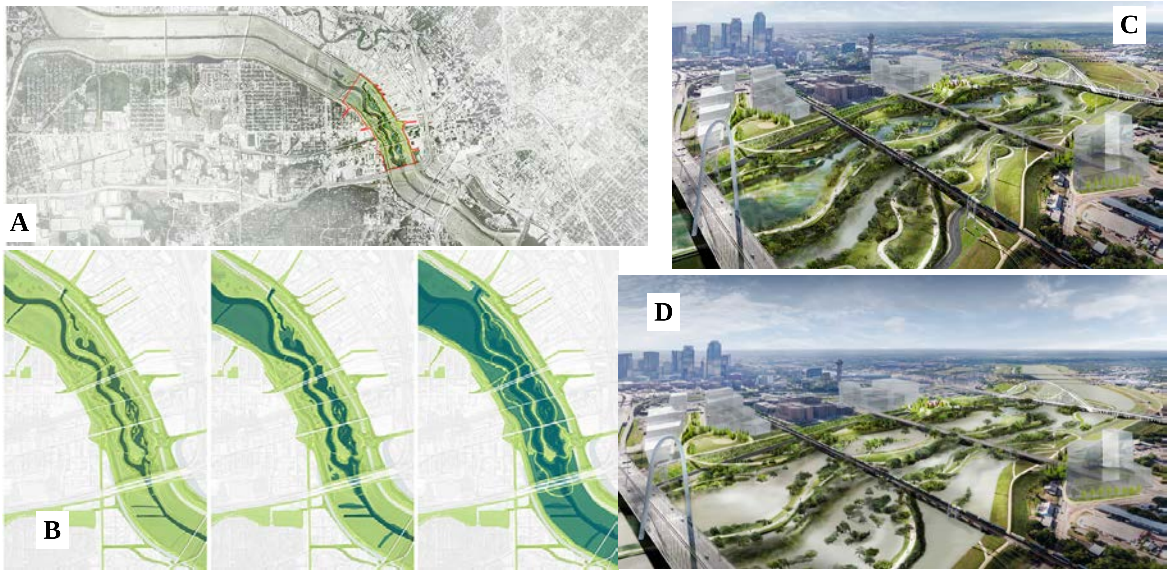

Figure 5. Harold Simmons Park project: (A) Location of the park. Source: https://network.thehighline.org/projects/trinity-river-park/; (B) Floodplane in a normal flow channel, 1-year flood event and 3-year flood event; (C) Park design. Source: http://www.mvvainc.com/project.php?id=114; (D) Park during a 3-year flood event. Source: https://www.businessinsider.com/dallas-trinity-river-park-project-2016-12#before-the-harold-simmons-park-breaks-ground-the-us-army-corps-of-engineers-will-need-to-approve-the-plans-since-its-in-a-flood-zone-4

This project for Trinity River Park achieves three main goals. By using region-specific native flora and natural features, as well as bioswales as elements of green infrastructure, Harold Simmons Park will: (1) *Provide recreational opportunities for people*, (2) *Restore the ecosystem* and at the same time (3) *Preserve the floodplain's resilience against river overflow to surrounding structures*. The true impacts of this waterfront revitalization will be determined once the project is completed.

3. POSSIBILITIES OF USE OF BIOSWALES IN DUVANIŠTE DISTRICT, CITY OF NIŠ, SERBIA

Duvanište district is located in the Municipality of Medijana, at the periphery of Niš urban area. It was developed in the 60's as a planned settlement, equipped with modern communal and infrastructure facilities. Original construction involved mostly housing on individual plots, and was intensified in the 80's when multi-storey residential development became dominant. Duvanište district was planned and designed with high ecological standards and significant housing value. During socialism, planning regulations favoured public interest and the area was well-planned for all necessary urban functions.

After the fall of the socialist regime, due to changed market conditions, as many as three revisions of the Master Plan (MP) of Niš 1995–2010 occurred, affecting directly the area of Duvanište and causing intensive transformations in the late 90's (Dinić Branković et al., 2018b):

(1) *The waterfront area of Nišava River became eroded with postsocialist commercial development, while the sports-recreational use was significantly reduced*. The First revision (2001) of the MP of Niš 1995–2010 provided for a commercial strip in the part of green area east of Proleterska Street, changing the recreational land use to a 'settlement center'. Then, the Third revision (2007) of this MP added the use 'settlement center' to the vast green area west of Proleterska Street, while further elaboration of this area within the urban project provided for a shopping center. Formely planned extensive sports and recreational facilities have not been provided until today. The current MP of Niš 2010–2025 and the Plan of General Regulation of the Municipality

of Medijana enabled further loss of recreational use, and a new megamarket and a church were built in the waterfront area.

(2) *Decentralization of retail resulted in changes in land use and new construction of big-box retail fomats, auto-oriented and surrounded by vast surface parking lots, thus reducing open and green space.* The Second revision (2004) of the MP of Niš 1995–2010 changed the land use from a former school complex in Duvanište to an 'urban residential zone with business'. This enabled the construction of a megamarket and large-scale shops that occupy large surface area for both structures and parking. In 2009 another big-box store was constructed in the northeast part of Duvanište district, in the former storage/services zone, with a huge building setback and a parking lot facing the street. One more new suburban form, a retail park, opened in 2016 in the location of the former tourist complex Medijana (Dinić Branković et al., 2016). Retail area encompasses a megamarket and variuos shops surrounding a vast surface parking lot.

Post-socialist trandsformations in Duvanište district resulted in significant urban densification and loss of public open space and green areas. At that point in time, none of these new developments considered the increase of paved surfaces and its implications upon stormwater treatment. However, due to numerous transformations of urban structure and several flash flooding events in the past couple of decades, the impression is that modern approaches could help significantly in improving the current treatment of stormwater runoff. From the standpoint of this research, several urban forms and various sites are identified and suggested as potential locales for the implementation of bioswales (Figure 5):

(1) *Street grid*. Streets that could accomodate bioswales as elements of green infrastructure were chosen based on the following selection criteria: the rank of residential streets only (low traffic flow), minimum 10 m of total regulation width of the street (1x5,0 m driveway, 2x1,5 m sidewalk and 1x2,0 m bioswale) and slope of terrain no greater than 5%. In these residential streets, aside from stormwater treatment, bioswales would also bring the benefits of traffic calmming (intermittent or opposite layout of bioswales depending on street width) and improvement of pedestrian safety (position of bioswales between the driveway and the sidewalk).

(2) *Parking lots.* There are six parking lots[2] with paved area ranging from 4.500 to 15.000 m2 that could benefit from bioswale application. Only one of them is a socialist legacy and is associated with residential use (F), while all the others were designed in the post-socialist period. The use of bioswales would also contrubte to a reduction in air temperature and to minimizing of heat island effects of the parking lot, as well as to the improvement of overall aesthetics of space. The use of bioswales is recommended but not limited to large parking lots, and smaller parking areas in residential zones are also potential implementation sites.

(3) *Waterfront.* The riverside open green area of Nišava River was significantly reduced in the transition period due to new developments. However, the remaining undeveloped area in the waterfront zone has significant potential for the use of bioswales. The main purpose of bioswales would be flooding control, but they could also help restore the ecosystem and improve the visual identity of the area.

[2] Number of parking space (p.s.) and paved surface area (m2) of selected parking lots are as follows: A – 210 p.s., 15.000 m2; B – 120 p.s., 4.500 m2; C – 180 p.s., 7.500 m2; D – 290 p.s., 5.800 m2; E – 300 p.s., 10.800 m2; F – 300 p.s., 8.200 m2;.

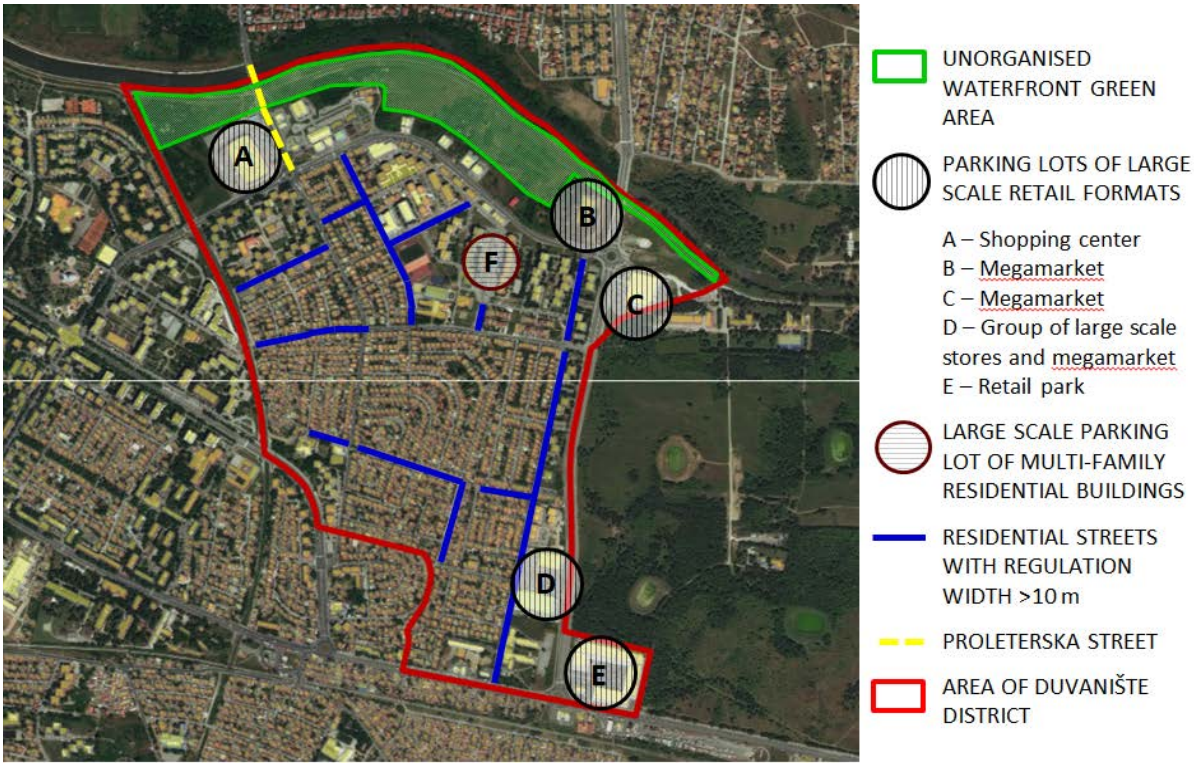

Figure 5. Potential locales for the implementation of bioswales in Duvanište residential district, City of Niš. Source: https://www.google.rs/maps, drawing by Milena Dinić Branković

4. CONCLUSIONS

It can be concluded that bioswales are a very topical issue in modern stromwater management. Analyzed examples confirm that the implementation of bioswales as elements of green infrastructure can significantly improve stormwater treatment as well as the design of various urban forms, resuting in more favourable environmental impacts. The NE Siskiyou Green Street retrofit project demonstrates how both new and existing streets can be designed to provide direct environmental benefits and be aesthetically integrated into the neighborhood streetscape. Sustainable green design of the parking lot in Edwards Gardens not only improves stream stability and water quality through inovative stormwater management strategy, but also promotes green initiatives and serves as a prototypical demonstration project for other similar developments. An ambitious project of the Harold Simmons Park along Trinnity River uses naturalized river landscape and public open spaces to create a new urban hub in a natural environment, preserving at the same time the role of protecting the city in case of flooding.

This paper suggested some potential locales where bioswales could be applied as green infrastructure for the treatment of stromwater runoff in the case of a residential district of the City of Niš. A more detailed examination is necessary to determine the exact locations, size and design of bioswales and to investigate the benefits of their use. The options of bioswale use in residential plots of single-family housing and public open space of multifamily housing should also be explored. Further studies are suggested to investigate the potential use of bioswales not only in Duvanište district, but in other parts of urban territory. However, it is the conclusion of this research that bioswales require more attention in both planning documents and in plannning practice of the City of Niš, since their implementation brings multiple benefits to the urban environment.

Vegetated swales are cost-effective, attractive and can provide wildlife habitat and visual enhancements. By introducing bioswales into retrofit projects and new developments urban areas achieve long-term sustainability. This is especially important for post-socialist cities that underwent significant urban densification and cannot afford more loss of public open space, green areas nor deterioration of environmental quality.

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