ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ СОФИЯ

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SENSITIVE PLANNING AND DESIGN OF STORMWATER MANAGEMENT IN URBAN WATERSHEDS

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ABSTRACT

The traditional way of planning and designing stormwater drainage from the urban watershed, based on the collection of all stormwater by the combined sewer system, and its drainage into the nearest recipient, has proved to be unsuccessful. In order to help urbanists and engineers to choose the best practices in sustainable management of stormwater, this paper presents the methodology of planning and design, based on the study of the morphology for an urban watershed. As a case study, the city of Pirot (Serbia) is chosen. The results show that the proposed methodology can be applied to any urban watershed.

1. Introduction

The influence of urbanization is becoming more pronounced on the environment, especially since, according to some estimates, 75% of the global population will live in the cities by the first half of the 21st century [1]. In many urban areas, in spite of brining significant benefits, urbanization caused a number of negative effects, such as the reduction of biodiversity and soil degradation. An increase in the number of the population causes an

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increase in the amount of wastewater, while urbanization, at the same time, significantly reduces the areas with natural ground that can absorb stormwater. Building objects (buildings, roads, parking areas) form a waterproof surface that prevents the infiltration of atmospheric water into the ground. It increases and accelerates the surface runoff and thus increases the amount of wastewater. Fig. 1 shows the influence of urbanization on the change of atmospheric water flows in relation to the natural environment, i.e. surface runoff dramatically increases, while infiltration and evapotranspiration decrease [2].

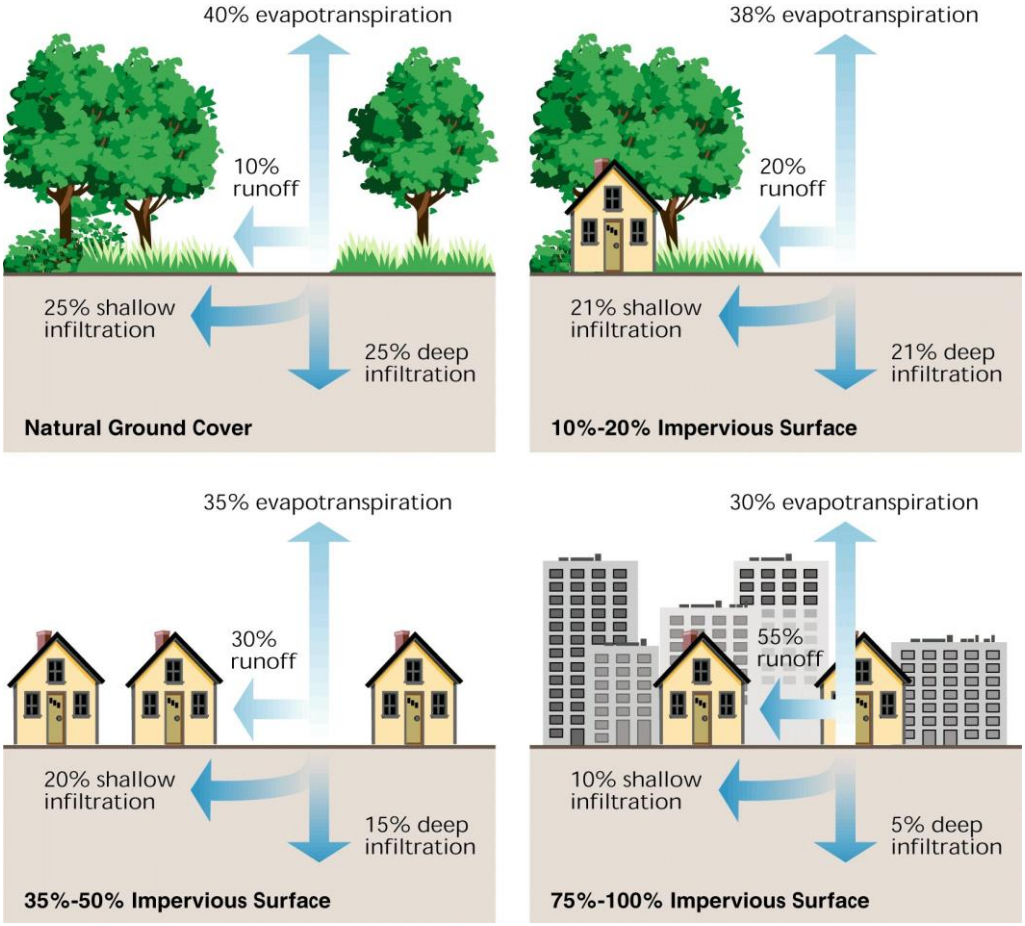

Figure 1. The influence of urbanization on the change of atmospheric water flows [2]

A traditional approach in the planning and design of stormwater flows entailed that all stormwater from urban areas should be collected by the sewage system and taken to the recipient using the fastest path. However, possible improvements of the flow quality before discharging water into the recipient were not taken into account. As a consequence of such an approach, which is not accompanied by the rapid development of the cities, there is frequent flooding during intense rains. With the development of the cities, sewage has become an expensive structure. Also, the risk of flooding has not significantly decreased, and the risk has often increased due to the insufficient sewage system. All these have led to a need for the development of a system that would control and reduce the runoff and that would improve the

water quality with minimal environmental damage. In developed societies, urban drainage has been considered a vital resource, a convenient cleaning mechanism for efficient wastewater transport, and a means for solving flood problems [3].

This paper gives an overview of the methodology for the sensitive planning and design of stormwater management in urban areas, and the city of Pirot is analyzed as a case study (with its problems in water drainage and stormwater management capabilities).

2. Integrated Management of Stormwater

The main aim of conventional stormwater drainage systems is quantitative collection of all stormwater. This drainage method has caused great problems in its functioning, i.e. primarily in the form of frequent floods (an increased risk of flooding). In addition, the pollution of rain runoff is a specific problem, because it can cause the pollution of the recipient and endanger the environment. In order to overcome these problems, the new integrated approach of stormwater management in urban areas is introduced. The main aim of integral management is a sustainable drainage system with the control and reduction of stormwater, which would minimize the damage to the natural hydrological regime and to the state of the watershed, with the constant improvement of runoff quality. Fig. 2 shows a three-way concept, the ratio of the quantity and quality of surface water drainage and an amenity solution for the environment in the case of a conventional and integral approach of stromwater drainage (the three-way concept) [4].

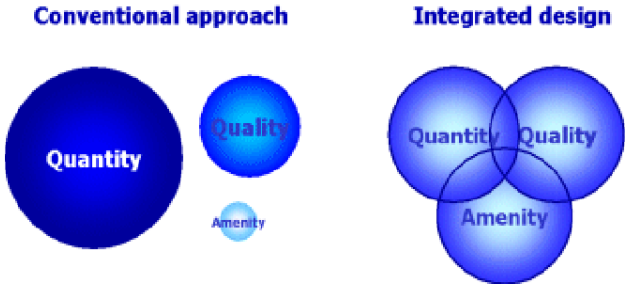

Figure 2. Differences between the conventional and integrated approach in the drainage of stormwater [4]

Integral planning represents a sustainable strormwater management system, where stormwater can be reused in the downstream flow after its drainage into the recipient and after partial self-treatment [5]. The basic tendency is that the new system should represent the natural processes at watershed with decentralized micro drainage systems as much as possible. In order to solve a problem at the watershed using the comprehensive approach, proposed planning involves an interdisciplinary approach in solving problems, including different scientific disciplines. It is necessary to solve the problem of stormwater at the watershed level, because only this would enable the complete application of stormwater integrated planning and management [6]. According to [7], there are four levels of planning by using the integral approach: the plan of the main water course shed, plain of drainage on the shed/subshed level, drainage master plan and implementation plan at a specific location.

In the paper [8], it is recommended to use several hierarchical techniques called the "management train" in order to represent the natural watershed with a newly designed system:

- Prevention – the aim is to prevent the occurrence of stormwater runoff, stormwater is used for technical purposes;
- Source control – control of runoff near its source, quantities and quality runoff control at the most upstream part of the watershed, mostly used objects are soakaways, green roofs, etc.;
- Site control – control of a smaller urban watershed with a larger soakaway or retention;
- Regional control – collection of runoff from several smaller urban watersheds.

Fig. 3 shows management train techniques and their interactions.

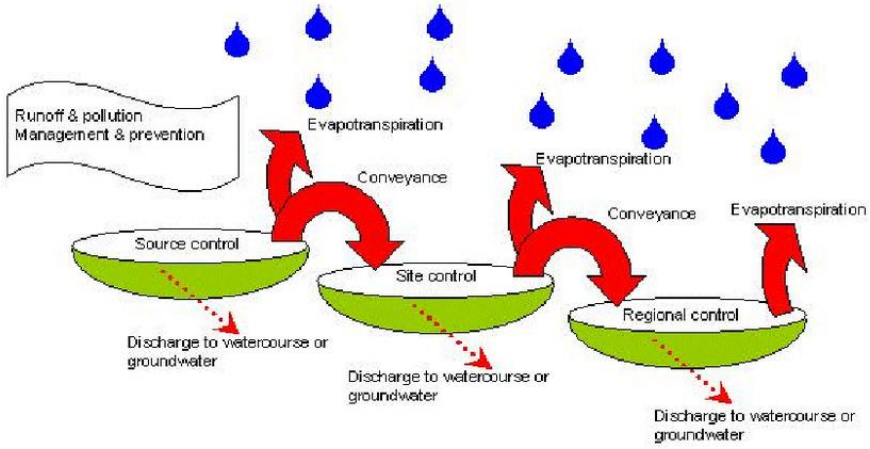

Figure 3. Management train [8]

All of the proposed techniques have the primary aim to control the runoff at the place of its occurrence (first two techniques) using the principle that stormwater should be conveyed elsewhere only if it cannot be dealt with on site. Runoff control can be achieved by placing a large number of smaller objects upstream of the watershed (primarily on parking lots, larger roofs, or roads).

3. Sensitive Planning and Design of Stormwater Management

The watershed concept indicates a specific link between the natural geographic area, water, urban environment and population. Therefore, watershed morphology and human activities on the watershed have a great impact on stormwater runoff at urban watersheds. All this indicates that the analysis and study of watershed morphology is one of the most important elements in the sustainable management of stormwater, resulting in the reduction in the floods risk caused by stormwater in urban watersheds. Recently, the principle of decentralized management, i.e. sensitive design methodology, which is particularly important in urban areas, has been recognized as a form of stormwater management. According to [9], the main aim of sensitive planning and design is to preserve public health, to protect water resources from pollution and to preserve biodiversity, i.e. to reduce the degradation of the environment and to enable the achievement of harmony between water and the urban environment.

In order to achieve the most efficient use of sensitive design, Romnée et al. defined the basic components of the urban watershed: the landscape, the urban fabric and the territorial development agreements (conventions) [10]. What is more, the authors gave an overview of the most common territorial role of the watershed: preservation and increase of biodiversity, promoting a collective management of stormwater, promoting free surface runoff and integrating the levels of the built environment.

Sensitive design methodology of drainage stormawater in urban areas consists of five steps, which are grouped so that steps I, II, III serve as the morphological analysis of urban watershed in terms of sustainable stormwater management, steps IV and V refer to the development of the watershed using the existing and future potentials [10]:

- step I – analyses urban watershed components;
- step II – identifies the territorial roles and strategies for decentralized stormwater management;
- step III – defines spatial typology connected with the road network and urban fabric (block/lots/buildings);
- step IV – defines numerous scenarios of stormwater management;
- step V – designs decentralized stormwater management systems by integrating best management practices in every spatial typology.

The aim of the last step, i.e. this typology, is to evaluate and to find available and sufficient space/land for the implementation of the best management practice for the specific spatial typology (streets or city blocks/lots/buildings) for the solution of the stormwater problem.

The proposed methodology can be applied to a specific project (lot, street, urban block, etc.) as well as to the entire watershed. The method defines how to choose a project scenario and project management at a specific project. For the watershed, the method is based on the design of decentralized stormwater management using the standard elements for every spatial typology identified on the shed. It is especially important to highlight that the proposed methodology does not recognize the standard solution. Therefore, some chosen objects can have more pronounced aesthetic and recreational content in the environments they are in, while some of them place a greater accent on the useful use of stormwater. In addition, objects whose main purpose is not drainage, like parking lots, public parks and roofs can be used as components of a system within the general plan of stormwater drainage control.

4. Case Study – City of Pirot

The city of Pirot is an administrative centre in the Pirot district of Southeast Serbia. Wastewater is collected in a central sewage system which is a combined type in Pirot and in the surrounding settlements. Wastewater and stormwater are discharged through the same pipeline into the Nišava River without previous treatment. There are serious problems during the exploitation of the sewage network in the periods with intensive precipitation [11]. Some parts of the sewage do not have sufficient hydraulic capacity and they do not provide adequate evacuation of the water, so some parts of the city can easily be flooded. The main problems during the exploitation of the sewer are primarily caused with geomorphological characteristics of the city area, which are unfavourable from the aspect of stormwater protection. Also, there are problems that accompany the expansion of the city and accelerated urbanization. Namely,

the sewage was made several decades ago, and the system could not follow the accelerated development of the city, the increase of the population and the multiple increase of the runoff from the urban areas. Regardless of the problems, city administration has plans for an additional extension of the sewage network, by constructing lower order sewage [6]. What is more, the impervious surfaces are further enlarged and runoff coefficient also inceases, which adversely affects the hydrological regime.

For an effective solution of the problem for the stormwater drainage in the city, it is necessary to apply a new approach in the planning and stormwater management that is based on the use of decentralized local systems for the on-site retention, infiltration and reuse of rainwater. The great advantage of the new planning approach is that it can be applied to newly planned areas and to existing urban areas.

In the new urban areas, it is possible to implement a full set of measures for runoff control, but it is also necessary to prescribe the application of decentralized local systems for the management of stormwater, which includes the measures for water retention on the watershed (green roofs, porous pavements – lawn grates, tree planting) and reuse of rainwater (vegetation ditches, rain gardens, tree-box filters, infiltration trenches, gutter routing, water butt).

It is necessary to adapt the solutions to concrete conditions in existing urban areas. What is more, the possibilities for the implementation of measures for runoff control are limited by the existing urbanization and by infrastructure, but the application of simple techniques for water retention and for runoff reduction on the residential plots should be insisted on. Especially, it is possible to intervene during the reconstruction or renovation of city parts or during the building of new facilities, roads, parking lots and other areas (green roofs, infiltration trenches, lawn grates).

For the hydraulic analysis of stormwater management in the city of Pirot, an initial model of sewage network was created. The model has 227 sections of the large-diameter main collection pipeline, for which there are reliable data on network geometry, hydraulic characteristics and load (Fig. 4). The model was developed using the EPA SWMM software package.

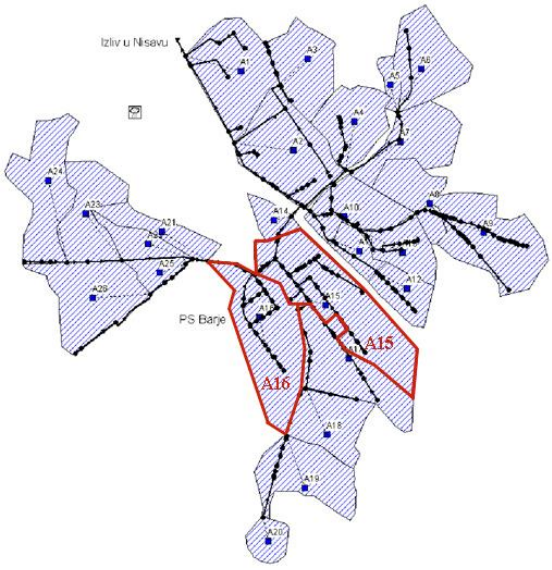

Figure 4. Hydraulic model of Pirot sewage

Sensitive planning effects on stormwater runoff management in Pirot were analysed on the model, using the decentralized systems (water butt, infiltration trenches, lawn grates) on the A15 (91,1 ha) and A16 (76,8 ha) watersheds. The analyses for the most unfavourable rain season from 1973 were conducted and the data were obtained by analysing the precipitation data for the Dimitrovgrad station in the period 1959 – 2008. The obtained results show that even with the application of decentralized systems on 0,25% of the total watershed, where 50% of impervious surfaces will be treated, there will be a significant decrease of runoff from the subcatchment area (by 50% at the peak runoff). Also, there will be a volume reduction of runoff water on the upstream line of the runoff hydrograph, for the section 81 (Fig. 5). When applying the decentralized systems on the areas of approximately 5% of the total watershed area, where 80% of impervious surfaces will be treated, there will be a remarkable reduction of runoff from the subcatchment area (by approximately 80% at the peak runoff), and there will be a decrease not only of the volume but also of the peak runoff through section 81 (Fig. 5).

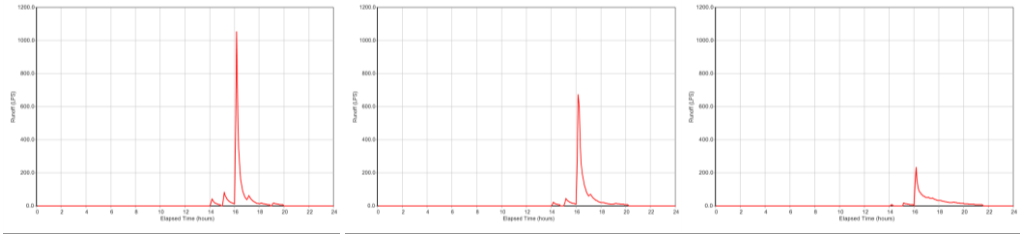

Figure 5. Runoff from subcatchment A15 without (left) and with the application of sensitive technologies on the area of 0,25% (middle) and 5% (right) of the total subcatchment area

The results have shown that, with the application of these systems to all the watersheds, the problems which occur in the periods of intensive precipitation can be minimised or totally resolved by investing relatively small funds when compared to the classical approach. The other results of the sensitive method analysis of stormwater management in Pirot are cited in the paper [11].

One of the most significant advantages of decentralized systems is the possibility of construction in stages. The construction of systems, even of small surfaces, which do not require a significant amount of work and assets (water butts, tree planting, tree box filters) has positive effects on the whole drainage system, immediately after its release for use. On the basis of the analyses and results of the effects of the implementation of decentralized systems performed to date, as well as the positive experiences from the developed countries of the world, the Water Supply and Sewage Public Company in Pirot has opted for the application of the methodology for the sensitive planning and design of stormwater.

5. Conclusion

The paper presents the methodology for sensitive planning and design of the system for stormwater drainage in the urban watershed. The proposed methodology consists of five steps, grouped into two groups. The methodology provides advice for the design of a decentralized approach in stormwater management at the observed location, taking into consideration global and territorial roles on the entire watershed. Also, the paper gives an example of stormwater drainage in Pirot, where the weaknesses of a non-integral and monodisciplinary approach in the planning and management of a stormwater drainage system are clearly highlighted, as well as some proposals for a decentralized management of stormwater. The paper clearly indicates that

the drainage of stormwater must be solved using integral principles, i.e. using the decentralized local systems, and that these principles can be applied to the existing and newly urban environment. The application of a new approach in stormwater management on the urban areas in Pirot enables finding the optimal solutions of stormwater drainage and protection, with undeniable advantages over the classical approaches.

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