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Urban Water Retention Measures

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Abstract

Many cities and urban areas are located in flood plains because land is fertile and flat which is suitable for agriculture and urban development. Rivers provide water supply for domestic, industrial and irrigation uses; they also provide convenient means for navigation, transportation and communication. Cities have large percentage of impervious areas that prevent effective infiltration of rainfall into soil. To have successful flood control and flood risk management, we should consider not only hydraulic and engineering aspects but also socio-economic and environment aspects. Flood management should have involvement of various stakeholders including concerned authorities such as urban planners, civil and water resources engineers, civil disaster defence authorities, health and social services, etc. The best flood mitigation measures from all main points of view – social, economic and environmental are natural water retention measures. Natural water retention measures cover a diversity of measures that are implemented by different sectors or considered in different planning processes dealing with water, food risk management, biodiversity protection, climate change adaptation or urban planning. Some of these measures aim to directly modify the ecosystem, while others focus on changes of practice of economic operators. The paper presents natural water retention measures suitable for application in urban areas.

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Keywords: flash flood; urban development; water retention; mitigation measures.

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1. Introduction

From the 1980s to the last decade, the annual economic losses caused by natural disasters have increased from \$50 billion to \$180 billion and of these losses, 75% are linked to extreme weather events. The trend suggests that losses will continue to increase in future years due to economic development, population growth, rapid urbanization and climate change. In order to mitigate the significant damages associated with natural disasters and extreme hydro-meteorological events in particular, it is recommended to integrate disaster risk management which include mitigation measures into various planning, design and operational policies and regulations [1,2]. There are practical links between disaster risk management and sustainable development leading to the reduction of disaster risk and re-enforcing resilience as a new development paradigm. There has been a noticeable change in disaster management approaches, moving from disaster vulnerability to disaster resilience; the latter viewed as a more proactive and positive approach [3,4]. Floods have the greatest damage potential of all natural disasters worldwide and affect the greatest number of people. Causes of floods are due to natural factors such as heavy rainfall, high floods and high tides, deforestation, etc., and human factors such as blocking of channels or aggravation of drainage channels, improper land use, deforestation in headwater regions, etc. [5,6] Floods result in losses of life and damage properties. Population increase results in more urbanization, more impervious area and less infiltration and greater flood peak and runoff. Problems become more critical due to more severe and frequent flooding likely caused by climate change, socio-economic damage, population affected, public outcry and limited funds [7]. Recognizing that traditional flood management interventions focus on defence, attempting to eliminate contingencies in the urban relationship with rivers, an emergent perspective, spearheaded by spatial design, seeks to deal with floods through a more holistic framework. In contrast to the prevalent ‘design against floods’ approach that targets either the hazard or the exposure components of flood risk, ‘design with floods’ focuses as well on the assets at stake (including the built envelopes of exposed people and activities, usually covered under the term vulnerability), duly acknowledging the intertwining of natural and human processes [8]. Analyses of Hobeica and Santos [8] have so far suggested that ‘design with floods’ requires a positive stance through which problem-solving and sense-making approaches are merged to provide both safety and urbanity (enriched urban realm and experience), without eliminating floods per se, accepted as a complex hybrid process. According to Water Framework Directive [9] in making operational the programmes of measures specified in the river basin management plan for surface water Member States shall implement the necessary measures to prevent deterioration of the status of all bodies of surface water with the prioritization of environmental measures. The paper presents natural water retention measures as a flood protection measures for urban areas with aim to achieve goals of Water Framework Directive.

2. Methodology

Under the 2013-2015 Work Programme of the Common Implementation Strategy for the Water Framework Directive, and in response to the 2012 Blueprint to Safeguard Europe's Water Resources proposals, the Working Group Programme of Measures is asked to develop a guidance or other tool for supporting the implementation of Natural Water Retention Measures (NWRM) in Europe [10]. A guide to support the selection, design and implementation of Natural Water Retention Measures in Europe - capturing the multiple benefits of nature-based solutions, has been developed as part of the NWRM project. It places the emphasis on the multiple-benefits NWRM can deliver and on the required policy coordination and coherence that is required to make best use of NWRM. It aims to support the selection, design and implementation of NWRM in Europe. It targets managers, decision makers, experts and stakeholders involved in the selection, design and implementation of NWRM as part of plans and programmes addressing water, floods, biodiversity, climate change adaptation, forestry, agriculture or urban issues [11].

Natural Water Retention Measures are multifunctional measures that aim to protect and manage water resources using natural means and processes, therefore building up Green Infrastructure, for example, by restoring ecosystems and changing land use [10,11]. NWRM have the potential to provide multiple benefits, including flood risk reduction, water quality improvement, groundwater recharge and habitat improvement. As such, they can help achieve the goals of key EU policies such as the Water Framework Directive [9], the Floods Directive [12] and Habitats and Birds Directive. Figure 1 illustrates selected EU policy initiatives recognized in the potential role of NWRM in contributing to the achievement of their objectives.

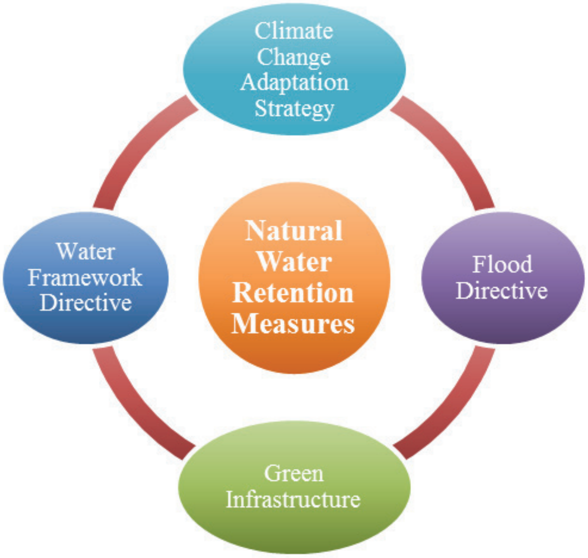

Fig. 1. Natural water retention measures and selected EU policy initiatives.

NWRM can contribute to both Water Framework and Flood Directives goals and can enhance synergies between the implementation of both directives and support the coordination between the River Basin Management Plans and Flood Risk Management Plans. The uptake of NWRM in management plans is triggered through the potential to improve or preserve hydro-morphological conditions, as well as the water quantity and quality.

The next chapter introduces selected natural water retention measures applicable in urban areas.

3. Results

NWRM are not new, and are already being applied in practice by water managers, nature protection organizations, farmers, urban planners and many others. Implementation may be as part of catchment management, rural and urban planning processes, or sector-oriented strategies (e.g. for the agriculture or the forestry sectors). It is possible to discover practical experiences of NWRM applications under many different climate, ecological, socio-economic and institutional contexts. In the following the NWRM applicable in urban areas are presented [11].

3.1. Green roofs

Green roofs (Figure 2) are designed to intercept rainfall, which is slowed as it flows through the vegetation and a drainage layer, mimicking the predevelopment state of the building footprint. Some of the rainwater is stored in the drainage layer and taken up by the vegetation, with the remainder discharged from the roof in the normal way (via gutters and downpipes). Flow rates from the green roof are reduced and attenuated compared to a normal roof, and the total volumes discharged from the roof are also reduced. Green roofs therefore intercept rainfall at source and provide the first component of a sustainable drainage systems management [11]. Connected to this type of system, especially for buildings with generous technical spaces, it can be developed a mechanism for storing water collected from the green roof and use it later for different purposes (watering the green spaces, water for toilets, etc).

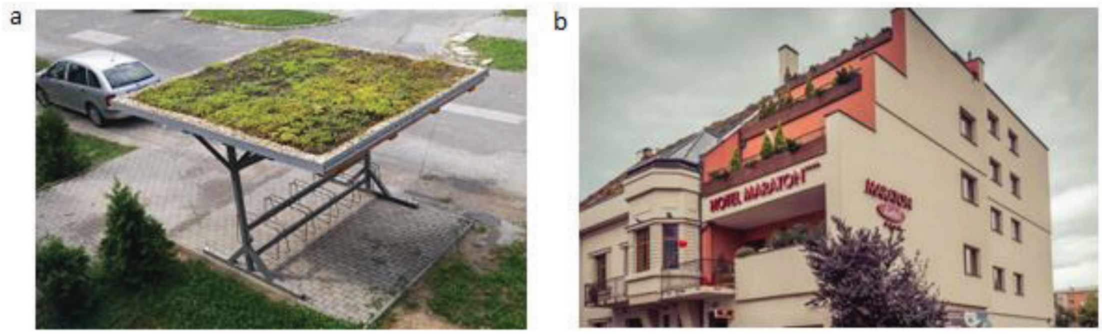

Fig. 2. (a) Green shelter in university campus in Košice; (b) Hotel with green roof in Košice.

3.2. Permeable surfaces

Permeable paving (Figure 3 (a)) is designed to allow rainwater to infiltrate through the surface, either into underlying layers (soils and aquifers), or be stored below ground and released at a controlled rate to surface water [13]. It is most commonly used on roads and car parks, but the measure can also apply to broader use of permeable areas to promote greater infiltration [11]. The negative aspect of this solution is that aquifers or the surface of soil can be polluted with oil or other materials generated by road transport.

As a type of permeable surface the porous concrete can be used (Figure 3 (b)).

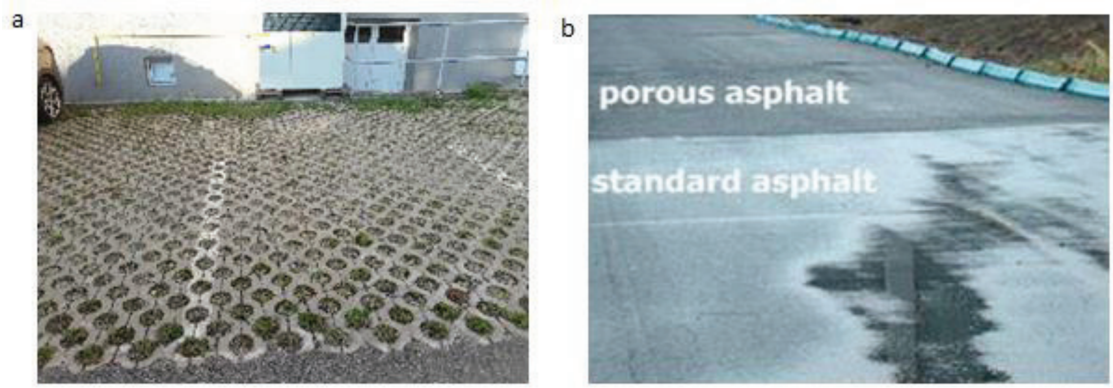

Fig. 3. (a) Parking area in university campus in Košice; (b) Example of porous asphalt.

3.3. Swales, channels, rills, filter rips and infiltration trenches

Swales (Figure 4 (a)) as well as green areas (Figure 4 (b)) are applicable to a wide range of situations. Swalles are typically located next to roads, where they replace conventional gullies and drainage pipe systems, but examples can also be seen of swales being located in landscaped areas, adjacent to car parks, alongside fields, and in other open spaces. They are ideal for use as drainage systems on industrial sites because any pollution that occurs is visible and can be dealt with before it causes damage to the receiving watercourse [11].

The main role of channels (Figure 4 (c)) and rills are to capture runoff at the start of a sustainable drainage systems train, allow deposition of sediment and convey the runoff to downstream sustainable drainage system features. They can also be used in between sustainable drainage systems features as connectors. They collect water, slow it down and provide storage for silt and oil that is captured. The outlets are designed to act as a mini oil separator, making them effective at treating pollution and reducing treatment requirements downstream. Clearly channels can be included in many situations and settings, but would not always considered to be NWRMs unless specifically designed to perform these functions and used in conjunction with other measures.

Infiltration trenches reduce runoff rates and volumes and can help replenish groundwater and preserve base flow in rivers. They treat runoff by filtration through the substrate in the trench and subsequently through soil. They are effective at removing pollutants and sediment through physical filtration, adsorption onto the material in the trench, or biochemical reactions in the fill or soil. However they are not intended to function as sediment traps and must always be designed with an effective pre-treatment system where sediment loading is high (e.g. filter strip) [11].

Fig. 4. (a, b) Swale; (c) Channel; (d) Infiltration trenches with stones.

3.4. Soakaways and rainwater harvesting

Soakaways provide storm water attenuation, and storm water treatment. They also increase soil moisture content and help to recharge groundwater, thereby offering the potential to mitigate problems of low river flows. They store rapid runoff from a single house or from a development and allow its efficient infiltration into the surrounding soil. They can also be used to manage overflows from water butts and other rainwater collection systems, or can be linked together to drain larger areas including highways.

Rainwater harvesting involves collecting and storing rainwater at source for subsequent use, for example, using water butts or larger storage tanks. Water butts are the most widely applied and simple rainwater harvesting technique, collecting rainwater runoff from roofs via a connection to the roof down-pipe. They are primarily designed for small scale use such as in household gardens, although a range of non-potable uses is possible. A limitation of rainwater harvesting as an NWRM is that during wet periods, water butts are often full and water use may be low, resulting in little or no attenuation or reduction in outflow rates or volumes. As a result, there are differing opinions about the role of rainwater harvesting in providing a water retention function. Tanks can be specifically designed and managed to accommodate storm water volumes, which is likely to be more effective when applied at a larger scale than individual properties. In general, however, rainwater harvesting should be considered only as a source-control component in a sustainable drainage system ‘train’ where, in combination with other measures, they will contribute to effective and sustainable water management [11].

3.5. Rain gardens

Rain gardens (Figure 5) are typically applied at a property level and close to buildings, for example to capture and infiltrate roof drainage. They use a range of components, typically incorporated into the garden landscape design as appropriate. These components may include [11]:

- Grass filter strips to reduce incoming runoff flow velocities and to filter particulates. For example, these may be used at the base of roof drainage downspouts to slow and filter roof runoff as it enters the rain garden.
- Ponding areas for temporary storage of surface water prior to evaporation, infiltration or plant uptake. These areas will also promote additional settling of particulates.
- Organic/mulch areas for filtration and to create an environment conducive to the growth of micro-organisms that degrade hydrocarbons and organic matter. These may be particularly effective where rain gardens are used to treat excess highway runoff.
- Planting soil, for filtration and as a planting medium. The clay component of the soil can provide good adsorption for hydrocarbons, heavy metals and nutrients.
- Woody and herbaceous plants to intercept rainfall and encourage evaporation. Planting will also protect the mulch layer from erosion and provide vegetative uptake of pollutants.
- Sand beds to provide good drainage and aerobic conditions for the planting soil. Infiltration through the sand bed also provides a final treatment to runoff.

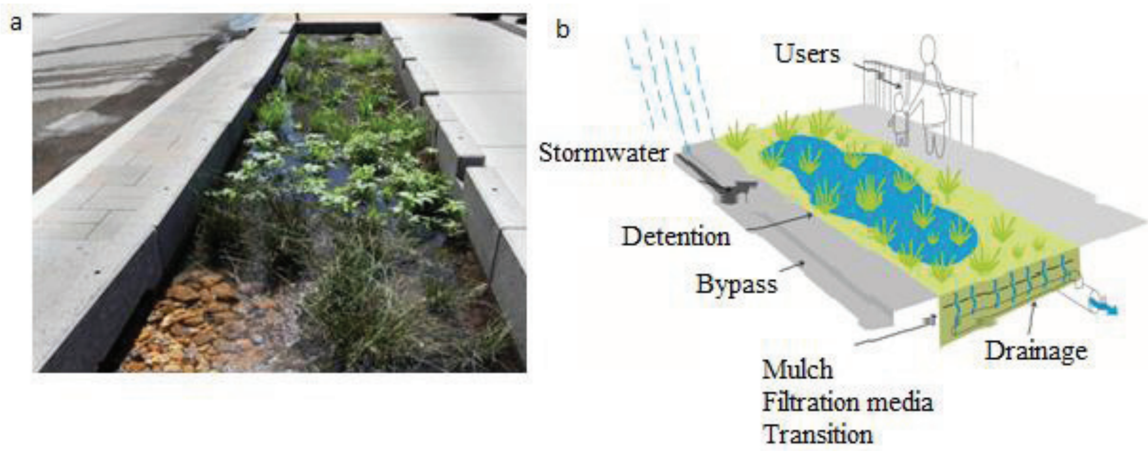

Fig. 5. (a) Rainwatergarden; (b) Critical elements in rainwatergarden design [14].

The filtered runoff is then either collected and returned to the conveyance system (using an underdrain) or, if site conditions allow, infiltrated into the surrounding ground. They aim to capture and treat storm water runoff from frequent rainfall events, while excess runoff from extreme events is passed on to other drainage features as part of a sustainable drainage systems 'train'. Rain gardens should be planted up with native vegetation that is happy with occasional inundations. Rain gardens are applicable to most types of development, and can be used in both residential and non-residential areas. They can have a flexible layout and should be planned as landscaping features, enhancing the amenity value.

3.6. Detention basins, retention ponds and infiltration facilities

Detention basins are landscaped areas that are dry except in periods of heavy rainfall, and may serve other functions (e.g. recreation), hence have the potential to provide ancillary amenity benefits. They are ideal for use as playing fields, recreational areas or public open space. They can be planted with trees, shrubs and other plants, improving their visual appearance and providing habitats for wildlife.

Retention ponds can provide both storm water attenuation and water quality treatment by providing additional storage capacity to retain runoff and release this at a controlled rate. Ponds can be designed to control runoff from all storms by storing surface drainage and releasing it slowly once the risk of flooding has passed. Runoff from each rain event is detained and treated in the pond. The retention time and still water promotes pollutant removal through sedimentation, while aquatic vegetation and biological uptake mechanisms offer additional treatment. Retention ponds have good capacity to remove urban pollutants and improve the quality of surface runoff [11].

Infiltration facilities may also act as “bioretention areas” of shallow landscaped depressions, typically under-drained and relying on engineered soils, vegetation and filtration to reduce runoff and remove pollution. They provide water quality benefits through physical filtration to remove solids/trap sediment, adsorption to the surrounding soil or biochemical degradation of pollutants. Water quality is, however, a key consideration with respect to infiltration basins as the potential for the infiltration to act as a vector for poor quality water to enter groundwater may be high. Pre-treatment may be required in certain areas before infiltration techniques are appropriate for use, for example swales or detention basins to reduce sediment loading and retain heavy metals and oils [11]. Infiltration percolation is linear shaped underground precipitation of precipitation runoffs into a pipe bedded in a dynamic storage material with underground feed pipe [15]. Percolation and infiltration shafts (Figure 6) are an effective way of rainwater harvesting in a new built areas where the permeable underground exist [16, 17].

Fig. 6. Infiltration shafts in uUniversity campus in Košice.

3.7. Rainwater management

Rainwater harvesting involves collecting and storing rainwater at source for subsequent use, for example, using water butts or larger storage tanks. Tanks can be specifically designed and managed to accommodate storm water volumes, which is likely to be more effective when applied at a larger scale than individual properties. In general, however, rainwater harvesting should be considered only as a source-control component in a sustainable drainage system ‘train’ where, in combination with other measures, they will contribute to effective and sustainable water management.

If collecting systems and rainwater infiltration, cannot cope with high rainfall intensity, this can be done by municipalities or by the services of water supply and sanitation, storage pools volumes of water. These volumes are stored for a short time after being pumped into sewers or drainage. These tanks can be positioned in park areas, parking areas, shops, etc.

Existing experiences can be sources of inspiration for your own organization, planning process and geographic area.

4. Conclusion

Natural Water Retention Measures (NWRM) are multi-functional measures that aim to protect water resources using natural means and processes. NWRM can contribute to reducing the risk of floods and water scarcity and drought while also improving the status of surface and ground water bodies. NWRM can support the achievement of the goals of a range of EU policies, including those for surface water, groundwater and coastal management, nature conservation, agriculture, forestry, urban, green growth and climate change mitigation and adaptation.

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References

[1] World Bank, Disaster Risk Management, available at http://www.worldbank.org/, 2015.

[2] IPCC, Summary for policymakers. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, eds. C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor & P.M. Midgley, Cambridge University Press: Cambridge, pp. 1–19, 2012. http://dx.doi.org/10.1017/CBO9781139177245

[3] S.P. Simonovic, Systems Approach to Management of Natural Disasters: Methods and Applications, Wiley: Hoboken, 2012.

[4] S.P. Simonovic, From Risk Management To Quantitative Disaster Resilience. Int. J. of Safety and Security Eng. 6:2 (2016) 85–95.

[5] R. Pravalie, I. Sirodoev, D. Peptenatu, Detecting climate change effects on forest ecosystems in Southwestern Romania using Landsat TM NDVI data, Journal of Geographical Sciences, 24:5 (2014) 815-832.

[6] R.D. Pintilii, I.C. Andronache, A.G. Simion, C.C. Draghici, D. Peptenatu, A.M. Ciobotaru, R.C. Dobrea, R.M. Papuc, Determining forest fund evolution by fractal analysis (Suceava-Romania), Urbanism. Architecture. Constructuins, 7:1 (2016) 31-42.

[7] T. Tingsanchali, Urban flood disaster management, Procedia Engineering 32 (2012) 25–37

[8] L. Hobeica, P. Santos, Design With Floods: From Defence Against A 'Natural' Threat To Adaptation To A Human-Natural Process, Int. J. of Safety and Security Eng. 6:3 (2016) 616–26.

[9] European Union, Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities L 327/1.

[10] European Union, EU policy document on Natural Water Retention Measures By the drafing team of the WFD CIS Working Group Programme of Measures (WG PoM), Luxembourg: Ofce for Ofcial Publications of the European Communities, 2014.

[11] NWRM project "Concept Note: Natural Water Retention Measures (NWRM) and the WFD and other daughter Directives", http://www.nwrm.eu, January 2014.

[12] European Union, Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. Official Journal of the European Communities L 327/1.

[13] P. Hlavínek, et al., Rainwater management in urban areas, Brno, Ardec s. r. o., 2007.

[14] K. Archdeacon, Streetscape Raingarden Design Principles: Guide, 2012, http://www.sustainablemelbourne.com/visions/streetscape-raingarden-design-principles-guide/

[15] Standard DWA-A 138E, Planning, Construction and Operation of Facilities for the Percolation of Precipitation Water, 2005.

[16] M. Zeleňáková, G. Hudáková, The Concept of Rainwater Management in Area of Košice Region Procedia Engineering: 16th Conference on Water Distribution System Analysis, WDSA2014 - Urban Water Hydroinformatics and Strategic Planning: Bari, Italy, 89 (2014), 1529–1536.

[17] G. Markovič, M. Zeleňáková, D. Káposztásová, G. Hudáková, Rainwater infiltration in the urban areas, Environmental Impact 2. Southampton: WITT press, 181 (2014), 313–320.