Review scientific paper

Received: July 27, 2016
Accepted: September 30, 2016
DOI: 10.1515/rmzmag-2016-0020

A review of the bioretention system for sustainable storm water management in urban areas

Kritični pregled biološko zadrževalnega sistema za trajnostno ravnanje z nevihtno vodo v urbanih območjih

Muhammad Shafique*
University of Science and Technology, Department of Construction Environment Engineering,
283, Goyangdae-Ro, Ilsanseo-Gu, Goyang-Si, Gyeonggi-Do, 10223, Republic of Korea
*shafique@ust.ac.kr

Abstract
Bioretention basins/rain garden is a very suitable low-impact development (LID) practice for storm water management around the globe. By using this practice in urban areas, flash flooding problems can be decreased and the environment of an area can be improved. The concept of bioretention was introduced a few decades ago and has been proven to be the best management practice (BMP) for storm water in urban areas. Due to urbanisation, natural surface areas are converted into hard surfaces such as roads, through which water cannot infiltrate into the ground. Due to this, infiltration decreases and surface run-off increases, which causes depletion of ground water continuously. In this study, we mainly explain the bioretention concept and its function as derived from different studies. This review includes different scientists' results for the performance of the bioretention system at different locations. A summary of the research findings by different scientists on the performance of bioretention systems is also provided, including the hydrologic and water quality performances. Finally, future work necessary to enhance the performance and widespread use of bioretention systems is also explained.

Key words: bioretention, storm water management, best management practices (BMPs), low-impact development (LID), urban area, rainfall run-off, flooding

Izvleček
Biološki, deževno vodo zadrževalni vrt predstavlja zgled ustrezne nizkoimpaktno razvojne (Low Impact Development, LID) metode ravnanja z nevihtno vodo v svetu. S to metodo je mogoče težave, ki jih povzroča nevihtna voda v mestnih območjih, učinkovito ublažiti in tako zboljšati mestno okolje. Načelo biološkega zadrževanja so vpeljali že pred desetletji in v tem času se je uveljavilo kot najboljši postopek ravnanja (Best management Practice, BMP) z nevihtnimi vodami na mestnih območjih. V procesu urbanizacije se spreminjajo naravne površine v trda tla, kot so denimo ceste, v katere se voda komaj more infiltrirati. Posledica zelo zmanjšane infiltracije in povečanega površinskega odtoka so občutno zmanjšane zaloge podtalnice. V pričujočem članku obravnavamo načelo in delovanje biološkega zadrževanja predvsem na osnovi vrste študij. Prikazani so rezultati različnih raziskav biološko zadrževalnega sistema v raznih mestih. Sledi povzetek rezultatov o delovanju sistemov in njihovih hidroloških in vodno-kakovostnih vidikov. Na koncu so naštete naloge, ki jih bo še potrebno opraviti, da bi zboljšali učinkovitost in široko uporabnost biološko zadrževalnega sistema.

Ključne besede: biološko zadrževanje, ravnanje z nevihtno vodo, najboljši postopki ravnanja (Best Management Practices, BMPs), nizkoimpaktni razvoj (Low Impact Development, LID), mestno okolje, odtekanje deževnice, poplavljanje

Introduction

The urban population is increasing continuously around the globe. It is estimated that the urban population of developing countries will be 85.9% by 2050 [1]. The rural population is always trying to move to urban cities due to the availability of many facilities; as a result, greater development is found in urban areas [2]. This is an alarming situation in developing countries because this situation causes many problems for the existing infrastructures. Pervious surfaces of natural land converted into impervious land (i.e. roads, buildings, roofs, etc.) alter the overall hydrology of an area. As a result, runoff increases and infiltration of water into the ground decreases, which causes flash flooding and lowering of the ground water level [3]. Due to all these issues, study of the storm water quality was properly recognised by the United States Environmental Protection Agency (USEPA) in 1990 through the announcement of the National Pollutant Discharge Elimination Systems (NPDES) Stormwater Program [4]. This programme promotes the development and adoption of new innovative storm water best management practices (BMPs) to treat storm flows from urban areas. After this initiative, increasing research has been conducted to find ways to make cities more sustainable and resilient to climate change and o understand the effect of urbanisation on the hydrology and water quality of an area.

Storm water impacts in urban areas

In urban regions, most of the areas are hard compacted surfaces, including buildings, roofs and roads. As the natural vegetation is removed and new hard surfaces created, greater surface run-off and less ground water recharge are seen. As a result, flooding occurs and ground water level decreases gradually in urban areas [3]. This also changes the natural hydrologic conditions of an area [5], including the decline of the water quality [6] and stream erosion [7]. To overcome all these adverse effects, new innovative storm water management practices that can solve all these problems, in addition to making the regions resilient to climate change, need to be developed. Figure 1 shows the impact of hydrologic patterns before and after the development of an area.The figure shows the impact of development on an area. A huge change in the infiltration pattern in an area can be seen. The surface run-off is only 10% in the case of a natural area, whereas run-off is 55% in the case of developed areas. Because of this, many storm water problems occur, including flooding, occurrence of heat island phenomenon and decline in ground water level. To make cities more sustainable and resilient to climate change, there is a need to develop more effective and efficient storm water management practices. A few years ago, low-impact development (LID) was introduced and it shows tremendous results in maintaining the natural hydrology of an area. The main

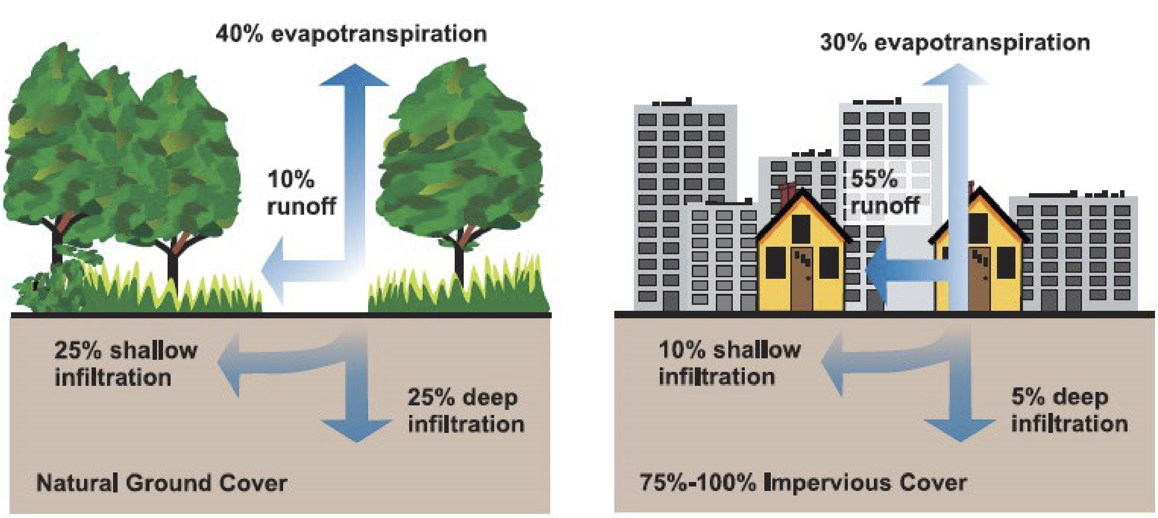

Figure 1: *The hydrologic characteristics of an area before and after development [8].*

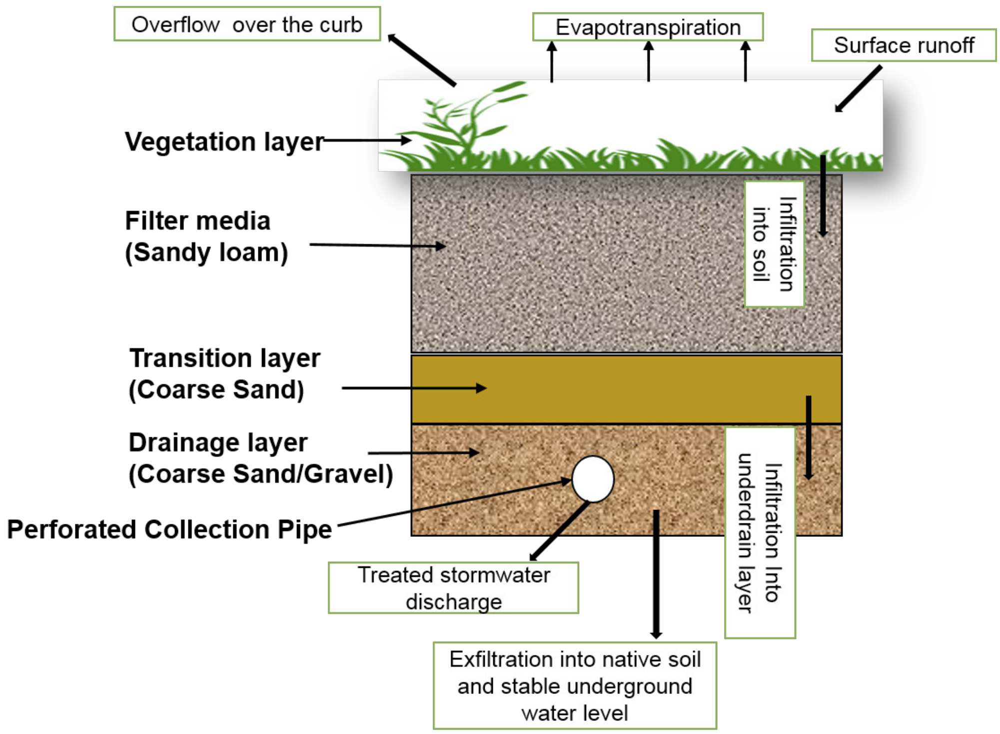

Figure 2: *Bioretention layers and hydrologic function of bioretention system.*

goal of LID is the maintenance of the pre-development state of hydrologic conditions by increased infiltration and evapotranspiration, to reduce run-off and to help in adequate ground water recharge [9]. LID practices include construction of permeable pavements, green roofs and blue roofs, as well as use of rain garden/bioretention basins, grass swales etc. These practices have many advantages for storm water management in an area. Bioretention is the most famous LID practice for storm water management and maintenance of the pre-development conditions of an area.

Bioretention basin/rain garden

Definition and work mechanism

Bioretention system

Bioretention basin/rain garden is the landscaped depression that receives run-off from the nearby impervious surfaces, treats the storm water at the site and reduces the peak flow [10]. A bioretention system consists of different layers, such as filter media, vegetation, an overflow weir and an optional underdrain (Figure 2). Bioretention systems consist of typically small areas, usually less than 2 ha [11]. Bioretention basin/rain garden systems mimic the natural hydrologic conditions by retaining the rainfall run-off and also enhancing the infiltration in an area [12]. This system reduces the run-off, improves the aesthetic value, enhances the habitat and reduces the soil erosion in an area [13]. Figure 2 shows the different layers of the bioretention system. These layers have different functions in storm water management in an urban area. In this system, the precipitation goes into air through evapotranspiration and infiltration occurs through the sandy layer, which reduces the chances of flooding in an area. This practice has many benefits and is very useful for storm water management in urban areas.Research has shown the many benefits of bioretention, including hydrologic restoration, removal of different pollutants, enhancement of biodiversity and reduction in temperature. More details are as follows. Control of rainfall run-off in urban areas by using bioretention depends on the infiltration capacity, which in turn depends on many factors, including the extension and detention depths of the bioretention system, filter media, hydraulic conductivity of

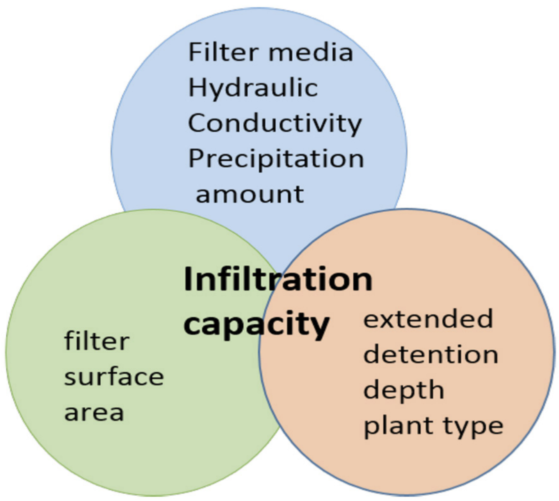

Figure 3: *Factors that influence the infiltration capacity of the bioretention system.*

the soil used in the bioretention system, storm event that occurs and filter surface area.

There are numerous benefits of the bioretention system in urban areas. By using the bioretention system, rainfall run-off can be decreased, the filtration of water increased, the pre-development hydrologic condition can be achieved and quality of water of an area can be enhanced. These advantages are explained in detail as follows.

Advantages of the bioretention system

Hydrologic performance of bioretention system

A review of different articles shows that bioretention systems are very helpful in restoring the hydrology of an area. One of the main features of bioretention is its ability to restore the natural hydrologic conditions and its role in the maintenance of the natural water cycle in an area. A field study was conducted at North Carolina, USA, which compared the underdrain flow from four bioretention cells of almost same characteristics as well as that from undeveloped watersheds. The results showed no significant difference between the outflow rates from the bioretention cells and the undeveloped watersheds over a period of 2 days [14]. This study proved that bioretention outflow is almost the same as the outflow from the undeveloped area and thus it helps to restore the natural hydrologic conditions of an area. A bioretention system also increases the time of concentration. Experimental results indicated that by using bioretention facility near parking lots, the time of concentration can be increased from an initial 5–10 min to a quarter hour to several hours for a parking lot that is 0.2–0.4 ha in size [15].

Some concern has been raised that bioretention performance is affected by clogging, caused due to the presence of small-sized silt and fine particles in the run-off. When these small particles land on the filter media of the bioretention system, they significantly reduce the bioretention performance [16]. A field study on particle capture in urban bioretention media indicated that clay-sized components of incoming total suspended solids (TSS) clogged the media and affected its function [17]. Another concern that demands attention is the exfiltration of water to the surrounding soil. The water migrates into the underground layers and increases the underground water level in some areas. This demands more attention and also suggests the design of buffer areas around the building foundation to avoid any adverse effect.

Performance in run-off reduction

Bioretention basin/rain garden system is a suitable LID practice to control the run-off in an area. It includes plants and soil, which can control and treat the storm water run-off. Numerous studies have indicated that this practice is very useful to control rainfall run-off in urban areas that do not experience flooding or other water-related problems. Many studies by the USEPA have shown that this system can treat the rainfall run-off and can reduce the peak flow [18]. Results of field experiments by other scientists have also proven that rain gardens are suitable for controlling rainfall run-off in an area. Chapman and Horner [19] studied bioretention systems and their experimental results indicated that these systems increase infiltration and evaporation, and only 48–74% of run-off is shown by bioretention systems. DeBusk and Wynn [20] retrofitted a bioretention system at different parking lots and the results were shown to reduce flow volumes and rates by 97% and 99%, respectively, in different storm events. From the different experimental results, it is shown that the reduction in run-off volume and rate is mainly dependent on the storm events. This LID practice performs very well in the case of small storm events [15]. Thus, it is proven from different experimental results that bioretention systems have the ability to control rainfall run-off and can be used as a sustainable storm water management practice in urban areas.

Pollutant removal performance of bioretention systems

Phosphorus, nitrogen and other heavy metals in rainfall can be removed by using bioretention systems in urban areas. Different field studies have proved that bioretention systems can easily remove many sediments and nutrients from the rainfall, so these are the BMPs in urban areas [21]. Davis et al. [21]performed many experiments to investigate the nutrient removal by bioretention systems. From the experimental results, he proved that total phosphorus ranges from 70 to 85% and removal of the total Kjeldahl nitrogen (TKN) by 55–65% were achieved by using the bioretention system in urban areas [22]. A series of experiments performed under different run-off inflow characteristics showed the variation in nutrient removal under different flow conditions [22].

Hunt et al. [23] applied three bioretention cells in North Carolina, USA, to measure the nitrogen removal. Different media types and drainage configurations were used in the cells. The field experiments showed high rates of annual total nitrogen mass removal at two traditional bioretention cells, with 40% reduction each. Nitrogen mass removal rates in these bioretention cells varied between 75 and 13%. This high level of mass removal of the pollutants is due to the substantial decrease in outflow volume from these bioretention cells. In all these bioretention cells, soil media with low phosphorus index (P-index) was used [23]. Soils that have high concentration of phosphorus have low capacities to absorb the phosphorus within the cells. The selection of the soil for the bioretention system is a very important step and should be considered carefully.

Henderson et al. [24] conducted experiments on nutrient removal (nitrogen, phosphorus and carbon) in bio-filtration mesocosms by using synthetic run-off. They used different types of media (gravel, sand and sandy loam) in vegetated and non-vegetated bioretention columns. The results indicated that vegetation has a great influence on the removal of carbon and other nutrients. Their study also indicated that sand vegetation and sandy loam vegetation improved nutrient removal from the bioretention column. Vegetated bioretention was very effective in removing phosphorus (85–94% removal), nitrogen (63–77% removal) and synthetic storm water, in addition to removing more nutrients as compared to the non-vegetated bioretention. The experimental results also showed that, on average, carbon removal from all treatments was 28–66%. In the case of sandy and loam soil media, the carbon mass removal was 58% on average, as compared to gravel media, which is greater than all other media. Plant growth was strong in the sandy and loam soil media, indicating that these are good growth media and greatly improve the removal efficiency of nitrogen and phosphorus [24]. The authors investigated phosphorus removal from synthetic urban storm water run-off by soil media using batch and column adsorption experiments as well as a pilot-scale layered bioretention column in the laboratory. From the results, it was found that with a higher short-term dissolved phosphorus sorption capacity, the column bioretention system retained more dissolved phosphorus from the infiltrating run-off after 3 mg/L phosphorus loading. Mulch with large pore sizes was effective in preventing media from clogging from TSS input. The authors used a specially designed column, RP2 (a high-hydraulic-conductivity media overlaying one with low hydraulic conductivity), resulting in a high run-off infiltration rate. Placing a media with a higher hydraulic conductivity in the upper filtration layer prevents the formation of a capillary barrier that restricts infiltration of run-off. By using the less permeable bottom soil layer, one can increase the contact time between dissolved phosphorus and media. The study proved that this new RP2 media was more efficient in total phosphorus removal than RP1, which used a more traditional media design. It also recommended incorporating a bottom fine sand layer (5 cm) to prevent soil particles from leaching and clogging. By using this modification, optimum phosphorus removals ranged from 67 to 98%. Media extractions suggest that most of the phosphorus retained in the media layers is available for vegetative uptake and that this does not exceed environmental thresholds [25]. Zhang et al. [26] used different materials in the soil media of bioretention systems to improve phosphorus removal. Experiments using fly ash showed significant potential for phosphorus sorption. As the fly ash helps to adsorb the phosphorus, this resulted in improvement of the phosphorus removal. Desorption tests showed negligible amounts of phosphorus leaching from the mixture under low-concentration influents, while 42% of previously sorbed phosphorus leached from a non-amended sand sample [26].

Metals are also of particular concern due to their adverse effects on water systems. These should also be treated in the rain water for safe and sustainable usage. Some experiments have been conducted on metal level reduction by using bioretention systems in specific areas. By using bioretention cells in the District of Columbia, USA, Pb, Zn and Cu with total metal concentrations of 660, 532, and 75 mg/kg, respectively, were collected [27]. TSS can be effectively removed through bioretention layers, with filtration and soil media. A bioretention system in North Carolina, USA, was studied under 23 rainfall events. The experimental results showed a removal ratio of 0.60 for TSS [28]. Another field study in Maryland, USA, by using two cells, has documented 54% and 59% mass removals of TSS [29].

Temperature reduction by using bioretention system

Plants and trees greatly affect the surrounding temperature and environment, in addition to enhancing the evapotranspiration and evaporation of an area, thus cooling the temperature. The hot impervious surfaces account for the temperature rise in the summer season in urban areas. Roseen et al. [30] conducted 4-year experiments, which explained the thermal impacts from a retention pond and a gravel wetland. From the results, the authors found that the retention pond was more vulnerable to thermal variability, while on the other hand, the gravel wetland showed greater capacity for thermal buffering of discharges. Bioretention systems have been found to also provide thermal buffering by both run-off reduction and retention in an area [31]. The different studies also indicate that small-sized bioretention cells are more effective at reducing the surrounding temperature.

Bioretention system implementation issue

Bioretention has many concerns that should be considered from the construction phase to the management phase. Poor construction of the bioretention system can cause many problems. If the construction of the bioretention system is not done according to design guidelines, then it cannot function well. Most of the contractors are not familiar with bioretention system construction, which has led to improper selection of soil, filter media and vegetation [32, 33]. Poor selection of soil media can affect the infiltration capacity, and the system cannot perform well, which leads to huge loss in terms of construction cost. Implementation of the bioretention system is easy while developing a new town, city etc., but in cases of retrofitting, it is not an easy task because so many other factors have to be considered before construction. Morzaria-Luna et al. [34] indicated another important issue, namely, the system ownership. The traditional storm water management system can be easily maintained and monitored and does not require any important management practices or guidelines. On the other hand, the bioretention system requires a proper maintenance and management plan, but the stakeholders and landowners do not have enough knowledge. Therefore, they cannot maintain the bioretention system and it loses its function after some period of time. In North Carolina, a rain garden implementation and public education project [34] found that most landowners did not have good understanding of the installation and maintenance requirements associated with rain gardens. Moreover, the authors surveyed 73 rain gardens just after 2 years of installation. From the survey, it was found that 23% of the gardens had been dissipated or were not functioning, while 44% required maintenance at that time [34]. It was also noted that the public thought that the use of bioretention may cause mosquito production due to ponding condition in an area and may cause many diseases.

Space gaps and time gaps

Extensive research has been conducted on the performance of the bioretention system on both small as well as large scales. Bioretention systems showed numerous benefits in terms of run-off control as well as enhancement of the water quality. But some of the concerns that require more attention are space gaps and time gaps. To apply bioretention in existing cities, the most important thing is to find suitable space. In new constructions, it is very easy to apply this, but in cases of retrofitting, when we have an already laid infrastructure, then we have to consider many factors. To find suitable space while retrofitting is the key aspect because a bioretention system mainly depends on the soil media. We should consider time gaps from construction to the management of the bioretention system. Implementation of bioretention for storm water management needs a special design, special construction and management time. This LID practice shows numerous benefits in urban areas, but the selection of space and time are the main important factors in installing this facility in an area.

Summary and future research needs

Bioretention is a very suitable and innovative LID practice to maintain the natural hydrologic conditions and to improve the water quality in urban areas. Numerous studies by different scientists all around the world indicate the benefits of the bioretention system, including the hydrologic performance of an area, nutrient removal efficiency, control of heat island phenomena, aesthetic values, etc.

— Direct experimental monitoring of field and laboratory bioretention systems indicated the performance of LIDs in terms of run-off control and water quality improvement under some certain climatic conditions. Most of the research on bioretention has been conducted in cold regions (the USA, Germany, Canada, Australia, etc.), but we also need to apply the bioretention systems in hot regions, apart from providing proper guidelines that can guide a new user in all regions.
— Bioretention systems can control the run-off by water infiltration into the ground. Many studies show its performance in enhancing the infiltration capacity, but in some cases, it may not be suitable as it can cause deterioration in the quality of underground water. Therefore, more research should be conducted to investigate the quality of the underground water and to evaluate the biodiversity of a bioretention system. The area of the bioretention system should be compared with urban areas. To get more benefits and to improve the performance of the bioretention system, we should select more good plants that can perform better.
— Sometimes, clogging occurs at the filter media of the bioretention system and it may not perform well. To avoid this clogging problem, there is a need to select suitable filter media.
— A variety of computational models are used to estimate the hydrologic performance and nutrient removal of bioretention systems. But every model has some deficiency and no model is appropriate. Therefore, more research is needed to develop computational models that can perform better at different locations.
— In bioretention, filter media and soil media have great influence on the water quality. Sometimes, the nutrient removal efficiency of the bioretention system is decreased after a period of time. More research is needed to select more appropriate soil and filter media that can perform better after a long time.
— Bioretention systems are very expensive and the cost varies according to location. Currently, there is a need to develop a more cost-effective and efficient bioretention system for storm water management in urban areas. There is also the need to combine this

with other LID practices in such a suitable way that it can perform more efficiently and effectively.

— More research is needed on bioretention systems to find suitable plants that can withstand extreme weather conditions (high and low temperatures).

Bioretention systems are small but very complex. Many physical and biological processes that occur within the bioretention system mimic the natural hydrology of an area and are similar to those occurring in nature. This LID practice is the best effort to restore the pre-development conditions and to improve the quality of water in an area. The most important thing is to develop the most cost-effective bioretention system so that it can also make cities' drainage systems more sustainable and resilient to climate change.

References

[1] The Economist Open-air Computers: Cities are Turning into Vast Data Factories. Available online: http://www.economist.com/news/special-report/21564998-cities-are-turning-vast-datafactories-open-air-computers (accessed on 13 April 2014).

[2] UN News Center Half of Global Population Will Live in Cities by End of This Year, Predicts UN. Available online: http://www.un.org/apps/news/story.asp?NewsID=25762 (accessed on 13 April 2014).

[3] Fletcher, T.D., Andrieu, H., Hamel, P. (2013): Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. *Adv. Water Resour; 51*, 261–279.

[4] National Research Council. 2009. *Urban storm water management in the United States*, The National Academies, Washington, D.C.

[5] Kaushal, S.S., Belt, K.T. (2012): The urban watershed continuum: Evolving spatial and temporal dimensions. *Urban Ecosyst; 15*, 409–435.

[6] Nelson, E.J., Booth, D.B. (2002): Sediment sources in an urbanizing, mixed land-use watershed. *J. Hydrol; 264*, 51–68.

[7] Carey, R.O., Hochmuth, G.J., Martinez, C.J., Boyer, T. H., Dukes, M.D., Toor, G.S., Cisar, J.L. (2013): Evaluating nutrient impacts in urban watersheds: Challenges and research opportunities. *Environ. Pollut; 173*, 138–149.

[8] U.S. Enviornmental Protection Agency, Washington, D.C. (2003): "Protenting Water quality from Urban Runoff." Document No. EPA 841-F-03-003. https://upload.wikimedia.org/wikipedia/commons/4/46/Natural_%26_impervious_cover_diagrams_EPA.jpg. (accessed on 13 July 2016).

[9] Prince George's County. *Low-Impact Development Design Strategies, An Integrated Design Approach*; Department of Environmental Resources, Programs and Planning Division: Largo, MD, USA, 2000.

[10] PGC (Prince George's County, Maryland). Bioretention manual. Maryland: Department of Environmental Resources, Prince George's County, 2007. http://www.aacounty.org/DPW/Highways/Resources/Raingarden/RG_Bioretention_PG%20CO.pdf.

[11] Hunt, W., Smith, J., Jadlocki, S., Hathaway, J., Eubanks, P. (2008): Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, N.C., *J. Environ. Eng; 134*, 403–408.

[12] Dietz, M. (2007): Low impact development practices: A review of current research and recommendations for future directions *Water Air Soil Pollut.; 186*, 351–363.

[13] US Environmental Protection Agency (2012): *Benefits of Low Impact Development: How LID can Protect Your Community's Resources*; Office of Wetlands, Oceans, and Watersheds: Washington, DC, USA.

[14] DeBusk, K., Hunt, W., Line, D. (2011): Bioretention outflow: Does it mimic nonurban watershed shallow interflow? *J. Hydrol. Eng.; 16*, 274–279.

[15] Davis, A.P. (2008): Field performance of bioretention: Hydrology impacts. *J. Hydrol. Eng; 13*, 90–95.

[16] Brown, R.A., Hunt, W.F. (2012): Improving bioretention/biofiltration performance with restorative maintenance. *Water Sci. Technol; 65*, 361–367.

[17] Li, H., Davis, A.P. (2008): Urban particle capture in bioretention media. I: Laboratory and field studies. *J. Environ. Eng.; 134*, 409–418.

[18] USEPA (US Environmental Protection Agency). Stormwater technology fact sheet. Bioretention. Washington, D.C: Office of Water; 1999. EPA 832-F-99-012.

[19] Chapman C, Horner R.R. (2010): Performance assessment of a street-drainage bioretention system. Water Environ Res.; 82(2):109–119. DOI: 10.2175/106143009´426112.

[20] DeBusk, K.M., Wynn, T.M. (2011): Storm-water bioretention for runoff quality and quantity mitigation. J Environ Eng.; 137(9): 800–808. DOI: 10.1061/(ASCE)EE.1943-7870.0000388.

[21] Davis, A.P., Hunt, W., Traver, R., Clar, M. (2009): Bioretention technology: Overview of current practice and future needs. *J. Environ. Eng.; 135*, 109–117.

[22] Davis, A.P., Shokouhian, M., Sharma, H. and Minami, C. (2006): Water quality improvement through bioretention media: Nitrogen and phosphorus removal. *Water Environ. Res.*; 78(3), 284–293.

[23] Hunt, W.F., Jarrett, A.R., Smith, J.T. and Sharkey, L.J. (2006): Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *J. Irrig. Drain. Eng.*; 132(6), 600–608.

[24] Henderson, C., Greenway, M. and Phillips, I. (2007): Removal of dissolved nitrogen, phosphorus and carbon rom storm water by biofiltration mesocosms. *Water Sci. Technol.*; 55(4), 183–191.

[25] Hsieh, C., Davis, A.P. and Needelman, B.A. (2007b): Bioretention column studies of phosphorus removal from urban storm water runoff. *Water Environ. Res.*; 79(2), 177–184.

[26] Zhang, W., Brown, G.O., Storm, D.E. and Zhang, H. (2008):. Fly-ashamended sand as filter media in bioretention cells to improve phosphorus removal. *Water Environ. Res.*; 80(6), 507–516.

[27] Davis, A.P. (2007): Field performance of bioretention: Water quality. *Environ. Eng. Sci.; 24*, 1048–1064.

[28] Hunt, W., Jarrett, A., Smith, J., Sharkey, L. (2006): Evaluating Bioretention hydrology and nutrient removal at three field sites in North Carolina. *J. Irrig. Drain. Eng.; 132*, 600–608.

[29] Kumar, R., Martell, S.J., Pitcher, T.J., Varkey, D.A. (2013): Temperature-driven decline of a cisco population in Mille Lacs Lake, Minnesota. *North Am. J. Fish. Manag; 33*, 669–681.

[30] Roseen, R., Ballestero, T., Houle, J., Avellaneda, P., Briggs, J., Fowler, G., Wildey, R. (2009):Seasonal performance variations for storm-water management systems in cold climate conditions. *J. Environ. Eng; 135*, 128–137.

[31] Long, D.L., Dymond, R.L. (2013): Thermal pollution mitigation in cold water stream watersheds using Bioretention. *J. Am. Water Resour. Assoc*, doi:10.1111/jawr.12152.

[32] Cosgrove, J.F.J. and Bergstrom, J.D. (2004): Design and construction of biofiltration basins: Lessons learned. *Proc., 2003 World Water and Environmental Resources Congress*, ASCE, Reston, Va., 323.

[33] Toronto and Region Conservation Authority (2008): *Performance evaluation of permeable pavement and a bioretention swale—Seneca College, King City, Ontario*, Toronto and Region Conservation Authority, Toronto.

[34] Morzaria-Luna, H.N., Schaepe, K.S., Cutforth, L.B. and Veltman, R.L. (2004): Implementation of bioretention systems: A Wisconsin case study. *J. Am. Water Resour. Assoc.*; 40(4), 1053–1061.