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Procedia Environmental Sciences 9 (2011) 83 – 89

Procedia
Environmental Sciences

Ecological engineering: from concepts to applications

Management practices for the amelioration of urban stormwater

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Abstract

Urban runoff has been identified as a non-point source (NPS) contributor. The most effective mechanism for controlling urban NPS pollution is to reduce the amount of runoff through infiltration and storage on the landscape. Traditional infiltration best management practices (BMPs) have lacked long-term effectiveness because of clogging. The addition of vegetation to the system enhances the longevity of infiltration BMPs by enhancing soil structure. In order to better understand the design and function of vegetated, infiltration-based BMPs, Kansas State University is monitoring several sites in Kansas. Results indicate that vegetation enhances the ability of stormwater systems to store water and reduce down channel erosion and flooding.

Selection and/or peer-review under responsibility of Laboratory “Biochemistry and ecology of continental environments

Keywords: eutrophication; man-made lake; pollution; restoration; solid waste; urban agriculture; wastewater

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1. Introduction

The 2005 Millennium Ecosystem Assessment reports that, due to severe pollution from anthropogenic sources, the supply of fresh water continues to be reduced in many parts of the world [1]. As of 2008, in the United States more than 744,690 km of rivers and streams, 46,950 km2 of lakes, reservoirs, and ponds, and 30,400 km2 of bays and estuaries failed to meet the designated water use, with urban related runoff and stormwater being one of the major probable sources of impairment [2]. As the development of rural lands continues, the pressure urban runoff places on local waterways becomes of greater concern. Loadings of heavy metals, sediments, and excess nutrients have been identified in urban runoff [3,4,5]. Impervious surfaces in urban areas intensify the problem by increasing the volume and flow rate of runoff and providing an area for contaminants to accumulate before wash off [6].

Traditional urban stormwater removal systems, or storm sewers, quickly convey stormwater runoff away from buildings and people to reduce flood potential and the risk of water damage. Prior to being collected in the storm sewer pipes and transported to the nearest surface water body, the stormwater runoff travels over buildings, lawns, roadways, and parking lots washing away atmospheric pollution, lawn chemicals, petroleum products, and pet

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Selection and/or peer-review under responsibility of Laboratory “Biochemistry and ecology of continental environments
doi:10.1016/j.proenv.2011.11.014

waste. The water temperature increases as it travels across the heated surfaces of buildings and roadways resulting in thermal pollution of the receiving waters. Additionally, because water travels quickly across impervious surfaces into the receiving water body, the natural hydrology and hydraulics of the water system are modified resulting in reduced groundwater recharge and greater stormwater runoff volumes and velocities, which cause stream channel degradation. In an effort to control the effects of urban stormwater, many communities are turning to more ecological-based treatment systems.

The most effective mechanism for controlling urban NPS pollution is to reduce the amount of runoff through infiltration and storage on the landscape. Reductions in runoff decrease the pollutant carrying capacity of the runoff and reduce erosive in-channel flows. Traditional infiltration best management practices (BMPs) have lacked longterm effectiveness because of clogging with sediment and debris. The addition of vegetation to the system enhances the longevity of infiltration BMPs by enhancing soil structure in addition to increased macropore development from the root network for transport of water. In order to effectively design urban stormwater vegetation based BMPs, it is necessary to understand the local climate, soils, and native vegetation such that natural infiltration and storage processes can be optimized with ecologically engineered systems.

1.1. Climate

When designing stormwater treatment systems, it is necessary to have a good understanding of the local climate. Rainfall distribution patterns and intensities have a large impact on the ability of vegetated systems to infiltrate, or absorb, the runoff. If rainfall occurs within short time intervals, there may not be adequate time for the soil profile to dry out before the next rainfall event, which greatly reduces the system's ability to absorb and store subsequent rainfall events. When the interval between rainfall events is too long, the system may not be able to store enough water to survive the drought period, particularly during extreme heat. Additionally, if the rainfall intensity is too great, the vegetated stormwater system's infiltration rate may not be adequate to slow the runoff.

1.2. Soils

Selection of the growing media used in stormwater BMPs is critical, including whether or not to use native soils or an engineered growing media. Soils with a loose, sandy texture provide superior infiltration and are capable infiltrating and filtering frequent rainfall events. However, these soils have minimal water storage and holding capacity, which results in an inability to sustain plant growth during drought periods. Soils with a tighter texture (e.g. higher silt and clay contents) have greater water storage and holding capacities. Storing water in the system helps to reduce the volume of runoff and delays or reduces the peak runoff rate. Additionally, stored water helps vegetation survive between rainfall events. However, soils with higher silt and clay content have slower infiltration rates and are not as effective at handling frequently storms with higher intensities.

1.3. Vegetation

Both climate and soils must be considered when selecting vegetation for an eco-based stormwater management system. If the system is located in an area that receives frequent rainfall events throughout the year, plants are not likely to experience severe drought conditions. However, they may be under flooded conditions and need to survive several days of inundation. Conversely, if the system is located in a region that receives infrequent rainfall, it is likely that the vegetation will experience drought conditions during the summer period. In this case, the vegetation must be able to survive these drought periods while also handling flood conditions and inundation during heavy rainfall periods, as is the case in the central United States. In either case, it is best to look to vegetation native to the area as this vegetation has adapted over to time survive the local climate variability.

2. Case Studies from a Mid-Continental Climate

Kansas is located in the center of the United States on the western edge original tallgrass prairie. The predominant native grass species include tall-grasses big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*), and mid-grasses little bluestem (*Schizachyrium* *scoparium*) and sideoats grama (*Bouteloua curtipendula*). The region has a temperate continental climate characterized by hot summers, cold, dry winters, moderate winds, and a pronounced peak in rainfall late in the spring and the first half of the summer. Specific climate data for each case study location are shown in Fig. 1.

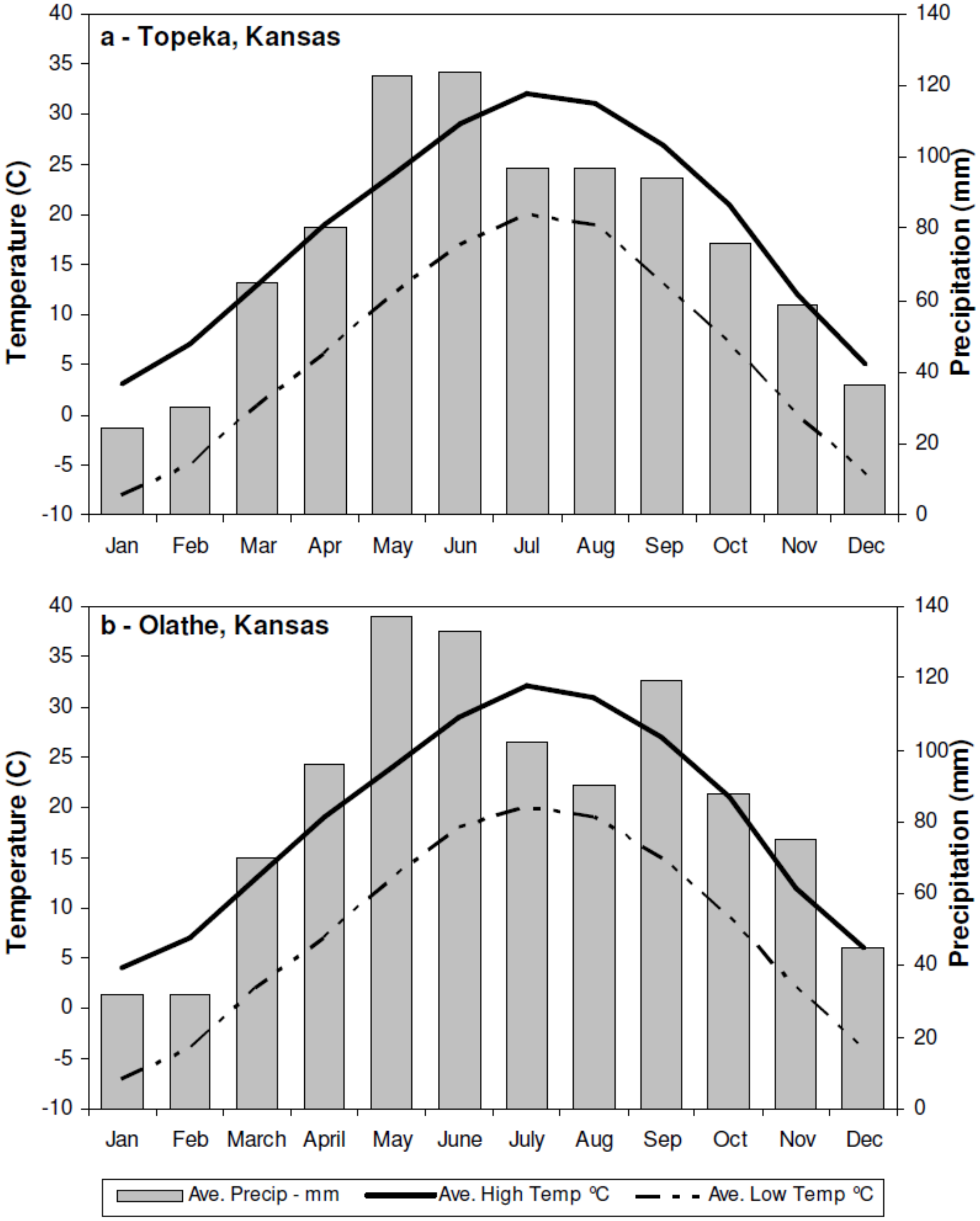

Fig. 1. Average temperature and precipitation data for case studies (a) Topeka, KS and (b) Olathe, Kansas (www.usclimatedata.com)

2.1. Quinton Heights Vegetated Detention System – Topeka, Kansas, United States

Established in 1895, Quinton Heights is one of the oldest neighborhoods in Topeka, Kansas. This area is noted for its steep streets and alleyways that are not connected to an underground storm sewer system. Instead, a surface stormwater drainage system (small surface drainage channels with 25.4 to 38.1 cm culverts under driveways and cross roads) established at the time of development struggles to transport stormwater runoff away from the residences. As the surrounding area developed, the capacity of the stormwater system was surpassed resulting in substantial flooding of houses and driveways with rainfall events as small as 25 mm.

The Quinton Heights-Steele Neighborhood Improvement Association (NIA) requested the City of Topeka develop a solution to the frequent flooding problem. Working together, a plan was developed to address the stormwater issues that would reduce flooding, improve water quality and provide green space in the neighborhood. The planned improvements for the project included the addition of two detention areas, two bioretention swales, the reforming of some street ditches, and the installation of some new storm sewers.

Construction on the stormwater project began in 2004 with planting of the site completed in the spring of 2005. The 1,550-mbasin was designed to receive runoff from a 6,000-marea, the majority of which flows down a street and into the basin through a grated opening placed in the middle of the street [7]. After excavation, the basin was replanted with grasses and forbs native to the tallgrass prairie, including big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), prairie cord grass (*Spartina pectinata*), and sideoats grama (*Bouteloua curtipendula*).

Fig. 2. Quinton Heights site after planting in July 2005 and at the beginning of the third growing season in May 2007. Note the grassed waterway through the bottom of the cell was planted with prairie cord grass plugs while the rest of the site was drilled with seed

Since installation of the new eco-based stormwater management system in Quinton Heights, there have been no flooding events. Monitoring data showed a significant reduction in peak discharge rate (Fig. 3). Discharge volumes continued to decline as the vegetation matured, enhancing soil structure and macropore flow. Monitoring was discontinued at the end of the 2007 growing season due to budget constraints.

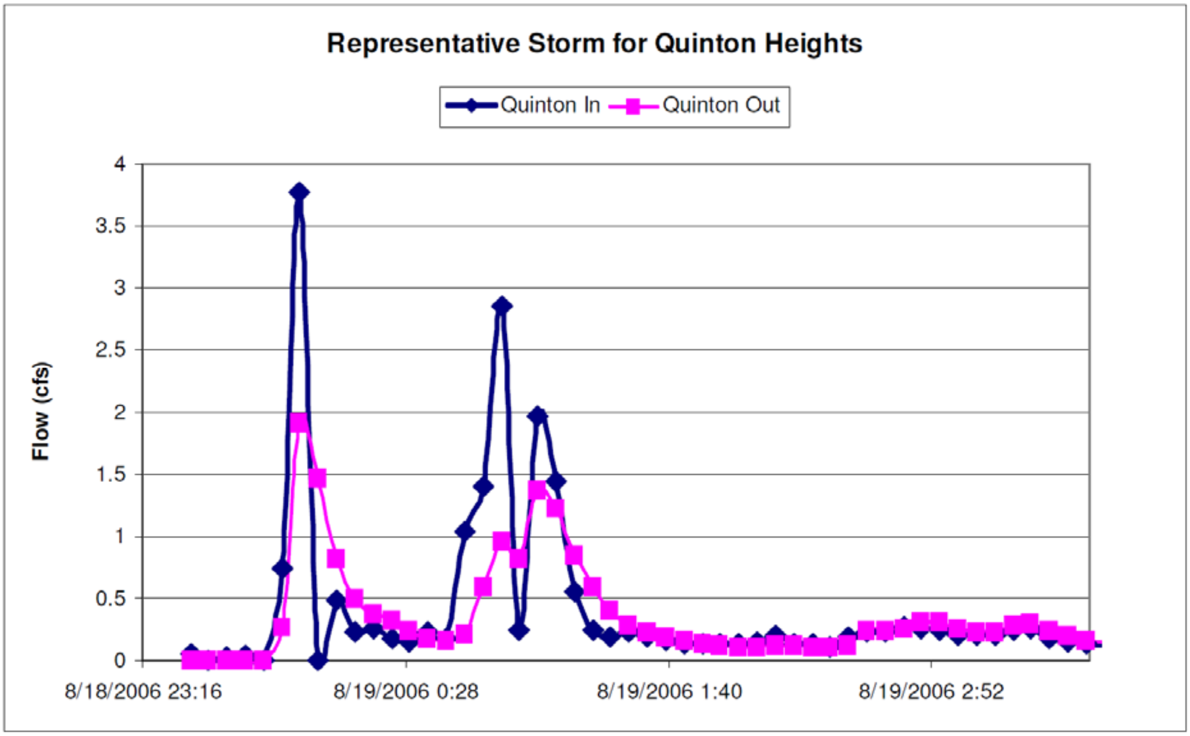

Fig. 3. Inflow and outflow from the Quinton Heights eco-based stormwater system for a representative storm in August 2006. Note the reduction of peak flow rates, which results in less erosion of the downstream receiving water body

2.2. Johnson County Transit Center – Olathe, Kansas, United States

A prairie restoration project was established at the Johnson Country Transit Center located in Olathe, Kansas, United States to assess the impact of native vegetation on stormwater quantity, ability of plants to enhance infiltration and reduce runoff, and ability of vegetation to remove pollutants from water through filtration and pollutant transformation/ degradation. The project was established in June 2007 (Fig. 4) when the traditional fescue turfgrass lawn was converted to a mix of native prairie grasses and forbs (Table 1).

Fig. 4. Johnson County Transit Center prairie restoration site immediately after seeding in June 2007 and after the growing season in September 2007

Table 1. Native plant mix used for prairie restoration project at the Johnson County Transit Center, Olathe, Kansas, United States

GRASSES/FORBS - SEED	SCIENTIFIC NAME	COMMON NAME
DRY PRAIRIE MIX		
	Amorpha canescens	Lead Plant
	Asclepias tuberose	Butterfly Milkweed
	Bouteloua curtipendula	Side oats grama
	Liatris punctata	Dotted Grayfeather
	Rosa arkansas	Arkansas Rose
	Rudbeckia hirta	Black-eyed Susan
	Schizachyrium scoparium	Little Bluestem
	Solidago rigida	Stiff Goldenrod
MAINTAINED EDGE / FIREBREAK MIX		
	Buchloe dactyloides	Buffalo Grass
	Bouteloua gracilis	Blue Grama
MESIC PRAIRIE MIX		
	Panicum virgatum	Switch Grass
	Symphytrichum novae-angliae	New England Aster
	Tradescantia bractea	Bracted Spiderwort
SHADE TOLERANT GRASS		
	Chasmanthium latifolium	Wild Oats
	Elymus canadensis	Canadan Wild Rye
	Tripsacum dactyloides	Eastern Gama Grass

Preliminary results indicate that the prairie grasses are improving the infiltration of stormwater runoff. Changes in the NRSC Curve Number [8] show a reduction in infiltration after planting with continued improvement during site establishment (Fig. 5). Curve numbers greater than 100 were attributed to rerouting of roof runoff onto the project site in the fall of 2007. There were no runoff producing storm events during the 2009 monitoring season.

The site was burned on April 9, 2010 to enhance native grass growth and root development. Monitoring of runoff is scheduled to continue through 2011.

3. Conclusions

Developing sustainable urban stormwater management systems is critical to protecting our water resources. By understanding the impact of local climate, soils, and vegetation, it is possible to develop ecologically based systems capable of reducing runoff peak flow rate and volume as well as filtering and degrading pollutants. Because of the inherent variability of weather and natural system function, long-term monitoring is required to optimize system design and function.

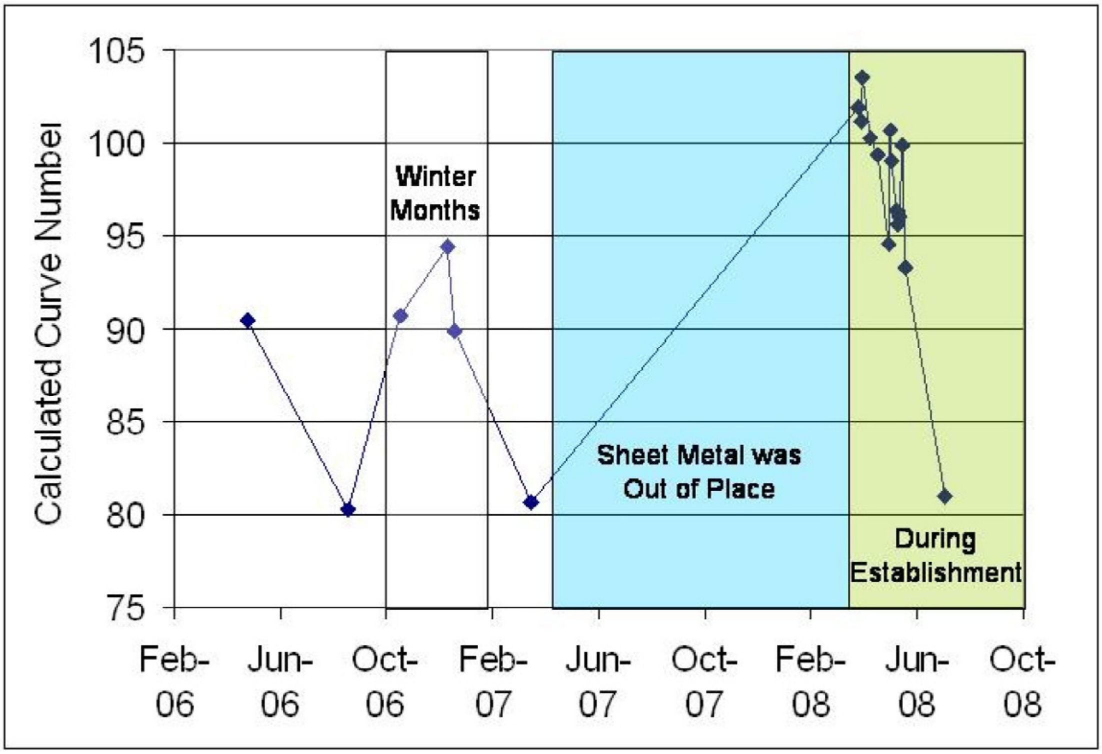

Fig. 5. NRCS curve number for the Johnson County Transit Center prairie restoration site from pre-planting (fescue turf) in 2006 through the 2009 growing season. No runoff producing events occurred in 2009 so the last data points occurred in 2008. Additional roof runoff was rerouted to the site in fall 2007, resulting in curve numbers greater than 100

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