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Review

The role of plants in bioretention systems; does the science underpin current guidance?

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ABSTRACT

Plants are essential components of bioretention systems, with bioretention design-guides around the world providing extensive advice on the role of selection of plants to maximize system performance and sustainability. Four principal hypotheses regarding the role of plants have been identified in bioretention design manuals: (i) Planted systems are more effective than unplanted systems, (ii) Plant species differ in their effectiveness, (iii) Native species are more effective than exotic ones, (iv) Diverse systems are more efficient than monocultures. This paper examines the extent to which these hypotheses are supported by the scientific literature. Comparison of planted and unplanted systems show that increased permeability and hydraulic conductivity, as well as removal of nitrogen, are the main benefits of the presence of plants in bioretention. Knowledge on their positive effect on hydrocarbons remains fragmented, although there is evidence from phytoremediation studies in other plant-based technologies. Choosing the right species makes a difference in hydraulic performance and nitrogen removal, with root traits being identified as important predictors of performance. No scientific results can support the hypothesis that native plants or diversely-planted systems offer better performance than systems planted with fewer species or with exotic species. Questions remain regarding the plant-microbe interaction in the bioretention context, the role of biomacropores in pollutant migration or the differential impact of plant choice on performance.

1. Introduction

Without appropriate mitigation strategies, impervious areas and hydraulically efficient drainage systems created as part of the process of urbanization, pollute and degrade receiving waters, leading to the 'the urban stream syndrome' (see for example Roy et al., 2009; Walsh et al., 2005). Traditionally, stormwater has been managed with a singular focus on flood mitigation (Chocat et al., 2001; Fletcher et al., 2015). However, recent decades have seen the evolution of alternative approaches, aimed at reducing the degradation of receiving waters, by restoring more natural flow regimes, reducing the concentrations and loads of pollutants, and returning a more natural site water balance.

A wide range of stormwater treatment technologies or *stormwater control measures* (SCMs) has been developed to address these objectives. Some of them are highly sophisticated engineered systems, often simultaneously designed to reduce runoff volumes, promote evapotranspiration and infiltration, and to ensure treatment or retention of pollutants (e.g. Van Roon, 2005).

One of the most promising of the SCMs is the suite of technologies commonly called *bioretention* or *biofiltration* systems (Fig. 1) (Bratières et al., 2008b). Often also called 'raingardens', swales or bioswales, they are favored not only for their demonstrated pollutant removal (City of Portland, 2014; Davis, 2007; Davis et al., 2001; Hatt et al., 2009; Hunt et al., 2008; Trowsdale and Simcock, 2011), but also for their flexible incorporation into the urban landscape (Bratières et al., 2008b; Ellis, 2013). Like many of the green infrastructure technologies, they provide a range of co-benefits including enhancement of local biodiversity (Kazemi et al., 2009), mitigation of the urban heat island effect (Coutts et al., 2012; Wadzuk et al., 2015) and benefits for human health and well-being (Church, 2015; Dill et al., 2010).

Given this wide range of benefits, it is perhaps not surprising to see the use of bioretention systems becoming increasingly popular (Bratières et al., 2008b). As in most areas of practice, professionals involved in their implementation rely heavily on local, regional or

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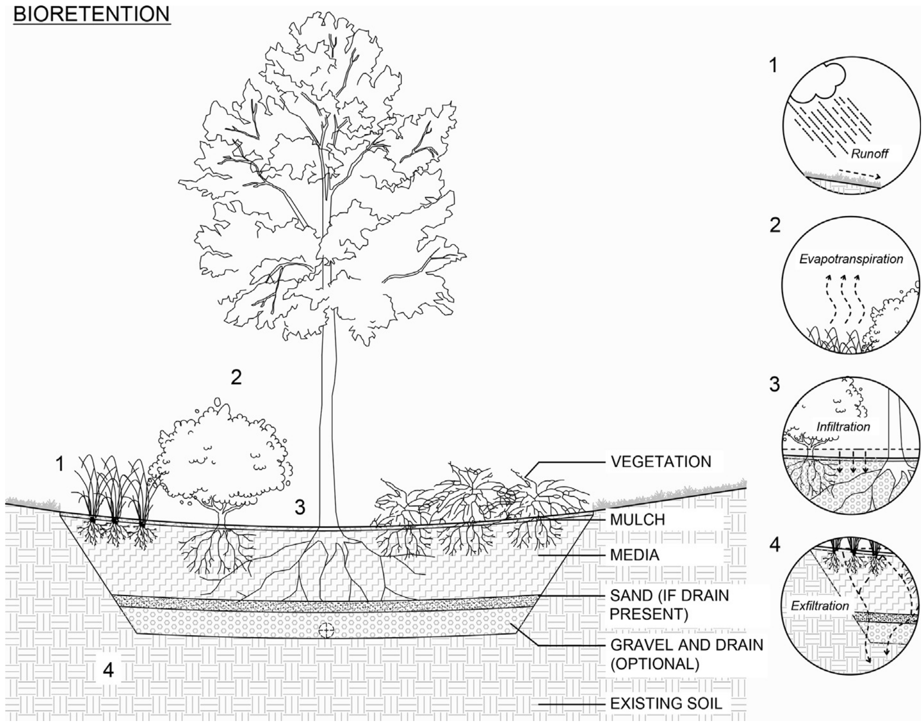

Fig. 1. Schematic representation of the structure and main water fluxes in a bioretention system.

national guidelines on the design, construction and maintenance of bioretention systems. In recent years, many such manuals have been developed (e.g. City of Portland, 2014; Minnesota Pollution Control Agency, 2014b; Philadelphia Water Department, 2014). In some regions, such manuals are even applied as standards (e.g. Hasenin et al., 2011). The recommendations provided in these manuals are thus likely to be quite influential on the design and ultimately the performance of stormwater bioretention systems around the world.

The various bioretention guidelines around the world contain many hypotheses and statements regarding the performance of bioretention systems and specifically on the influence of vegetation on this performance (Table 1). Some even provide information about the effects of the type of vegetation used eg.: "*Plants with fibrous root systems are more effective in bioretention systems than those with tap root systems*" (Water by

Table 1
Statements regarding the role of vegetation in the performance of bioretention and examples of quotations from the manuals.

Categories of frequent statements	Examples of quotations	Explanations
Vegetation is essential for the functioning of bioretentions	"Vegetation is a vital component of the environmental and hydrologic function of LID practices. Plants are effective in slowing and soaking up runoff and treating pollution through various natural processes" (Toronto and Region Conservation Authority & Credit Valley Conservation Authority, 2010, p. 5)	"The beneficial functions plants perform in the landscape are varied and complex, and range from providing habitat for beneficial microbes to physically inhibiting the flow of stormwater. The ability of plants to intercept and hold rainwater and to decrease water flow with stalks, stems, branches and foliage is one of the better recognized functions of vegetation, but there are many others" (Shaw & Schmidt, 2003, p. 1)
Vegetation maintains soil porosity and contributes to the removal of TSS, nutrients, metals and organics, more specifically hydrocarbons	"Plants in bioretention systems have been shown to improve dissolved nutrient removal, improve hydrocarbon removal and aid TSS sequestration", (Minnesota Pollution Control Agency, 2014a) "…the vegetation in bioretention gardens uses the nutrients found in stormwater as it grows. Plants also take up metals, organics and other pollutants to be used by the plant, stored as a by-product in specialised cells, or transformed through enzymatic action by plant cells" (Malcolm & Lewis, 2008, p. 4)	"High plant surface area and soil organics" are associated with the "biological microbial decomposition" of "BOD, COD, petroleum hydrocarbons, synthetic organics, pathogens», «Plant uptake and metabolism» and «high plant activity (and) surface area» are linked to "N, P (and) metals uptake and metabolism" and finally "plant excretions" to the "natural die-off of pathogens" (Auckland Regional Council, 2003, pp. 4–10) "Root growth and decay provides micro-pathways for water infiltration and oxygen movement and limit the potential for the filter media to become clogged" (Water by Design, 2014, p. 87) "The nutrient removal efficiency of biofiltration systems is related to the root structure and density of the plants within the system" (Payne et al., 2015, p. Appendix K) "Denitrification requires organic matter as a carbon source, which is supplied by decaying root matter and mulch" (Minnesota Pollution Control Agency, 2016a)
Phosphorus removal is mainly or exclusively due to the media, not to the vegetation	"Principal mechanisms for phosphorus (P) removal in bioretention are the filtration of particulate-bound P and chemical sorption of dissolved P" (Minnesota Pollution Control Agency, 2016b)	