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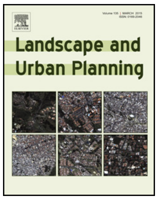

Research paper

Evaluation of three vegetation treatments in bioretention gardens in a semi-arid climate

C. Dasch Houdeshel[a,*], Kevin R. Hultine[b], Nancy Collins Johnson[c], Christine A. Pomeroy[d]

[a] Utah State University, Ecology Center, 5205 Old Main Hill, NR 314, Logan, UT 84322-5205, United States
[b] Desert Botanical Garden, Department of Research, Conservation and Collections, Phoenix, AZ 85008, United States
[c] Northern Arizona University, School of Earth Science and Environmental Sustainability, Flagstaff, AZ, United States
[d] University of Utah, Department of Civil and Environmental Engineering, Salt Lake City, UT, United States

HIGHLIGHTS

- Total nitrogen (TN) and NO_3 retention was greatest in the wetland.
- Both vegetated treatments were observed to be net TN sinks.
- Phosphorus (PO_4) treatment improved with cell age in all treatments.
- TN and P retention in bioretention is likely driven by soil microbes.
- Increased plant density may improve TN & PO_4 retention of upland vegetation.

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ABSTRACT

Bioretention is a well-established tool to reduce nutrient transport from impervious urban landscapes to sensitive riparian habitat in mesic climates. However, the effectiveness of bioretention is less tested in arid and semi-arid climates. Nutrient retention performance was evaluated in three 10 m^2 bioretention cells with different vegetation communities: (1) an irrigated wetland vegetation community, (2) an un-irrigated upland vegetation community, and (3) a no-vegetation control. Synthetic stormwater was added to each cell to simulate the average annual runoff of precipitation from a 220 m^2 impervious surface in Salt Lake City, UT. A significant amount of phosphate (≈50%) was retained by all treatments during the 12-month study. However, total nitrogen (TN) retention was only achieved in the Wetland and Upland treatments (59% and 22%, respectively), and nitrate retention was only achieved in the Wetland treatment (38%). In contrast, the Upland and Control treatments exported 2 and 9 times more nitrate than was added in the simulated rainfall events. Improved nitrogen retention by the Wetland treatment came at the cost of over 12,000 l (3200 gal) of irrigation to sustain the vegetation through the hot, dry summer. We hypothesize that plant uptake and soil microbial communities are driving nutrient retention in bioretention systems, and that increasing net primary production will increase nutrient retention. In water-limited climates, this can be sustainably achieved by either: increasing native upland vegetation densities above naturally expected densities, or, by using gray water instead of municipal water sources to irrigate wetland communities through dry summer periods.

1. Introduction

Riparian ecosystems in arid and semi-arid regions are hotspots for biodiversity in areas that otherwise lack diversity and productivity. Because riparian ecosystems act as sinks for nutrients, pollution, and other materials, they are at an increased risk to changes on the landscape, and especially the expansion of heavy urban land use. Opportunities to restore riparian ecosystems in arid and semi-arid regions after they are degraded are often limited by water availability and other resources, thereby increasing

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* Corresponding author. Tel.: +1 435 797 2555.
E-mail addresses: dasch.houdeshel@aggiemail.usu.edu, daschh@gmail.com, dasch.houdeshel@aggiusu.edu (C.D. Houdeshel), khultine@Dbg.Org (K.R. Hultine), nancy.Johnson@Nau.Edu (N.C. Johnson), christine.Pomeroy@Utah.Edu (C.A. Pomeroy).

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the length of time between degradation and recovery (Gasith & Resh, 1999; Schwinning, Belnap, Bowling, & Ehleringer, 2008; Whisenant, 1999). The fastest growing populations in the United States are in the most arid regions (U.S. Census Bureau, 2005). Urbanization of the arid West is rapidly replacing natural and agricultural lands with impervious surfaces that increase the volume and frequency of urban runoff (Hollis, 1975; Konrad & Booth, 2005; Paul & Meyer, 2001; Walsh et al., 2009). Poor air quality from particulate dust and the burning of fossil fuels in heavily populated basins increases dissolved N levels in precipitation that ultimately accumulate in urban streams (Buchanan & Honey, 1994; Burian, Streit, McPherson, Brown, & Turin, 2001; Galloway et al., 2003; Pataki et al., 2006; Taylor, Fletcher, Wong, Breen, & Duncan, 2005). Fertilizers used on lawns and residues from the burning of fossil fuels found in urban systems can also increase nitrogen (N) and phosphorus (P) levels in streams so that these nutrients are no longer limiting to primary production (Burton & Pitt, 2001; Eriksson, Auffarth, Henze, & Ledin, 2002; Hultine, Jackson, Burtch, Schaeffer, & Ehleringer, 2008; Schade, Marti, Welter, Fisher, & Grimm, 2002). Receiving waters down-stream from rapidly growing population centers are at a serious risk of erosion, eutrophication, and invasion from non-native species; each of these consequences of untreated stormwater runoff further compounds water availability in regions where water demand often exceeds local supply (Hultine et al., 2008; Hultine, Bush, & Ehleringer, 2010a; Hultine et al., 2010b; Konrad & Booth, 2005; Pataki, Bush, Gardner, Solomon, & Ehleringer, 2005; Rickey & Anderson, 2004; Stromberg, Tiller, & Richter, 1996).

Bioretention is a form of low impact development (LID) that collects stormwater runoff from impervious surfaces in a specially designed cell built to maximize ecological treatment of nutrients and other pollutants and to reduce total runoff volume from a site (Davis, Hunt, Traver, & Clar, 2009; U.S. EPA, 2013). Bioretention was first implemented for stormwater control in mesic climates that receive 750 to 2000 mm of annual precipitation, and has been demonstrated to reduce peak flows of stormwater runoff and nutrient loading to receiving waters (BMPDatabase.org, 2012; Bratieres, Fletcher, Deletic, & Zinger, 2008; Chen, Peltier, Sturm, & Young, 2013; Collins et al., 2010; Davis, 2007; Dietz & Clausen, 2005; Hatt, Fletcher, & Deletic, 2009; Hunt, Jarrett, Smith, & Sharkey, 2006; Hunt, Smith, Jadlocki, Hathaway, & Eubanks, 2008; Kim, Seagren, & Davis, 2003; Li & Davis, 2009; Prince George's County, 2002). These systems utilize various designs of media layering and outlet controls to facilitate ecological immobilization of N and P during storm events by vegetation communities (Bratieres et al., 2008; Brown & Hunt, 2011; Davis et al., 2009; Henderson, Greenway, & Phillips, 2006; Hsieh, Davis, & Needelman, 2007a,b; Lucas & Greenway, 2008, 2010). However, in spite of requests from federal agencies and other watershed protection advocates, little research has been conducted to determine whether these systems could significantly improve water quality in arid and semi-arid climates (Davis et al., 2009; Transportation Research Board, 2013; U.S. EPA, 2013).

The most difficult challenge for designing bioretention in drylands is sustaining vegetation through the long hot and dry periods that characterize these regions. The bioretention designs and vegetation communities recommended for mesic climates are not sustainable in arid and semi-arid climates without supplemental irrigation. Water use in large cities in arid and semi-arid climates often exceeds local water supply such that most urban areas in the western United States import large volumes of water through inter-basin transfers (Kjelgren, Rupp, & Kilgren, 2000). Piping and pumping water out of one watershed and into another to irrigate ornamental landscaping dramatically alters natural hydrological processes at the regional scale (Barnett & Pierce, 2009; Carriquiry & Sánchez, 1999; U.S. Bureau of Reclamation, 2007) and therefore, does not meet LID objectives.

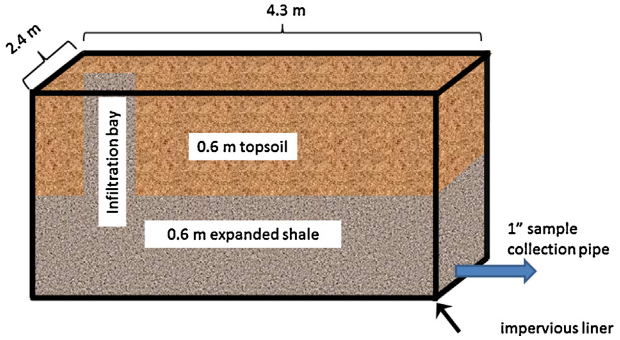

Fig. 1. Cross section of the media design of the tested bioretention cells adapted to xeric climates (adapted from Houdeshel et al., 2012). The control cell and upland cell included the infiltration bay shown in the image, however, the Wetland Cell did not. Flow from the 1" sample collection pipe was controlled to replicate the water level drop from the expanded shale reservoir as measured in an adjacent cell of similar design without an impervious liner (Steffen, 2012).

Houdeshel, Pomeroy, and Hultine (2012) proposed design guidelines for bioretention stormwater treatment facilities in water-limited climates based on biogeochemical processes such as evapotranspiration (ET) and nutrient cycling in water-limited ecosystems. These guidelines include: (1) the use of regionally native upland vegetation adapted to water-limited climates instead of wetland vegetation that has substantially higher water demands, and (2) routing stormwater to a sub-grade gravel storage layer instead of allowing stormwater to pond on the surface of bioretention facilities. Houdeshel et al. (2012) demonstrated the hydrological performance of their suggested design, but the nutrient treatment performance of using upland vegetation in bioretention in concert with a sub-grade storage reservoir has not been tested.

The purpose of this study was to quantify the capture and retention of N and P from urban stormwater runoff by bioretention in a semi-arid climate. We compared the treatment capacity of the bioretention design recommended by Houdeshel et al. (2012) against a wetland vegetation community suggested for use in bioretention in more mesic climates and against a media-only system without vegetation (i.e. bare soil). We predicted that a wetland community would achieve significantly better N and P reduction than an upland shrub/bunchgrass community or a bare soil system because greater plant and microbial biomass will sequester more nutrients and facilitate treatment. However, maintaining wetlands in semiarid and arid environments comes with the substantial cost of supplemental irrigation.

2. Methods

2.1. Site description

Three bioretention cells (2.4 m wide by 4.3 m long by 1.2 m deep) were constructed in 2010 to test the retention capacity of different vegetation communities on N and P in stormwater at the Green Infrastructure Research Facility in Salt Lake City, Utah, USA (40°45′39″N, 111°49′49″W, 1481 m). The site averages less than 400 mm of precipitation annually, characterized by snowy winters, cool and rainy springs, and extended dry periods with little precipitation throughout the hot, dry summer. Each cell was sized based on recommendations for bioretention design in semi-arid climates from Houdeshel et al. (2012) to capture 95% of annual runoff from a 220 m^2 (2400 ft^2) parking lot (Fig. 1). The vegetation treatments tested were: (1) a media treatment without plants, which will be referred to as the "Control" treatment, (2) an upland native community that did not require irrigation in the semi-arid climate at the test site ("Upland" treatment),