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Retrofitting impervious urban infrastructure with green technology for rainfall-runoff restoration, indirect reuse and pollution load reduction

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A B S T R A C T

The built environs alter hydrology and water resource chemistry. Florida is subject to nutrient criteria and is promulgating “no-net-load-increase” criteria for runoff and constituents (nutrients and particulate matter, PM). With such criteria, green infrastructure, hydrologic restoration, indirect reuse and source control are potential design solutions. The study simulates runoff and constituent load control through urban source area re-design to provide long-term “no-net-load-increases”. A long-term continuous simulation of pre- and post-development response for an existing surface parking facility is quantified. Retrofits include a biofiltration area reactor (BAR) for hydrologic and denitrification control. A linear infiltration reactor (LIR) of cementitious permeable pavement (CPP) provides infiltration, adsorption and filtration. Pavement cleaning provided source control. Simulation of climate and source area data indicates re-design achieves “no-net-load-increases” at lower costs compared to standard construction. The retrofit system yields lower cost per nutrient load treated compared to Best Management Practices (BMPs).

1. Introduction

Over the last century, Florida has experienced rapid population growth. From 1960 to 1997, the population increase in the United States averaged 1.1 percent each year while the State of Florida experienced a growth rate of 2.95 percent each year during the same time period (Reynolds, 2001). With this growth, Florida has experienced increased urbanization. In 1965, 1.2 million acres of land in the state were urbanized. By 1997, more than 5 million acres in the State of Florida had been converted for urban land uses. Between 2000 and 2020, nearly 2.6 million more acres of land are expected to be converted for urban land uses. For example, Orange County alone will convert 125,000 acres to urban land uses during this period (Bergstrom, 2001). Commensurate with this growth are increases in wastewater and stormwater reuse in Florida, in part for irrigation. By 2010 Florida will reclaim approximately 4 billion liters per day; primarily wastewater for non-potable uses.

As a second example, the location of this study is in Gainesville, Florida (FL), a MS4 (municipal separate storm sewer system) of approximately 200,000 residents and encompasses the source area of this study. Gainesville has followed population and urban growth trends in Florida. The mean impervious area of the City of Gainesville is 37%, classifying the city as ultra-urban. This imperviousness coupled with the average annual rainfall for Gainesville from 1999 to 2007 (1240 mm) illustrates the challenge of stormwater management. The mean annual stormwater flows for Gainesville from only impervious areas is 50 $\times$ 10^6 m^3, illustrating the challenge if stormwater controls are not adequately designed and maintained. Treatment and reuse of stormwater in Gainesville as well as other areas in the USA is just as important as treatment and reuse of wastewater for the sustainability of water resources; albeit more difficult due to episodic arrivals of large runoff volumes.

1.1. *Source area and rainfall-runoff loading information*

The source area is located west of Center drive, directly south of Museum drive in Gainesville. During the work week from the hours of 7:30 AM until 5:30 PM, the paved surface parking area provides ingress/egress and vehicular parking. Outside these hours, the rectangular surface parking area is open for public use. The road and parking surfaces are impervious asphalt, while the sidewalks are constructed of impervious concrete. The imperviously-paved

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area of the 1.4 ha source area is 76% with the other 24% as raised vegetated islands that drain to the pavement. This subject site is located in the 450 ha Lake Alice watershed in Gainesville.

Historical rainfall time series data were utilized to characterize precipitation loadings for analysis. 1999–2009 hourly data from the Gainesville Regional Airport (GNV) station, the nearest (10 km) rain gage with continuous recording data, was utilized (NCDC, 2009). These data were validated with event-based on-site rain gage data. These data illustrate a “wet season” and “dry season” for Gainesville as shown in Fig. 1a. The dry season occurs between October and May and the wet season between June and September. The mean number of events on an annual basis for Gainesville is 148 events.

The simulations required representative hydrologic and pollutant load characterization. Rainfall-runoff data from the site were collected and analyzed for 15 storms. Of the 15 storms examined, both mass limited (first-order washoff) events and flow limited events (zero-order washoff) were observed. Mass limited events exhibit a first flush of mass, while in flow limited events runoff load is directly related to runoff volume at any given time. Different pollutants and pollutant phases generate different washoff behavior; with particulate matter (PM) exhibiting mass limited transport (first flush) while dissolved tends to exhibit flow limited transport. For example, Fig. 1b illustrates event mean concentrations (EMC) for TP, phosphate, TN, nitrate, ammonia, and PM fractions (sediment, >75 μm, settleable and suspended, < ~25 μm) monitored and analyzed for the 15 storms.

Phosphorus (P) transported by runoff can originate from lawn and garden chemicals, animal excrements, pavement materials, and anthropogenic sources (Whipple et al., 1983). Though many sources can be identified, there is variability between land uses and cover

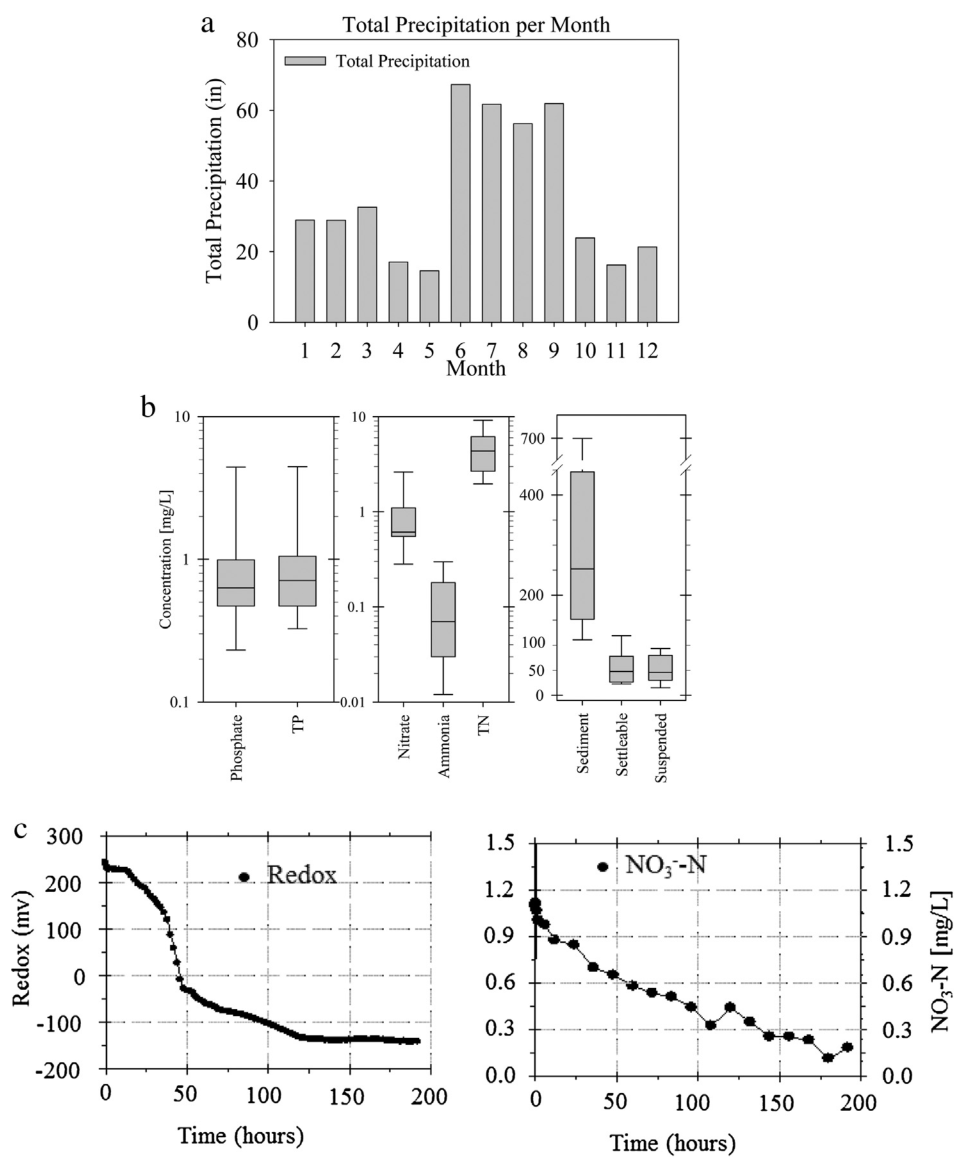

Fig. 1. (a). Monthly precipitation from August 1998 and July 2008 in Gainesville, (b) Stormwater event mean concentrations (EMCs) for phosphorus, nitrogen, and particulate matter (PM) fractions of 15 storms monitored at source area. Suspended sediment concentration, SSC = Sum of suspended (< ~ 25 μm) + settleable + sediment (>75 μm) PM. TP: Total phosphorus, TN: Total nitrogen, (c) Subsurface BAR redox and nitrate trends with time.