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Hurricane and seasonal effects on hydrology and water quality of a subtropical urban stormwater wetland

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ABSTRACT

Understanding the hydrology of a created or restored wetland is a critical component in understanding the overall functioning of its design, and in determining if the original goals of the wetland are being met. Freedom Park, a 20-ha park constructed in Naples, Florida in 2009, includes a 4.6-ha subtropical stormwater wetland treatment system for improving the water quality of the downstream impaired Gordon River and estuaries that flow into the Gulf of Mexico. Subtropical wetlands often present significant issues of sustaining viable wetland vegetation communities because of long wet and then long dry patterns in the wetlands' hydroperiods. The treatment wetland's watershed includes 1766 ha of an urbanized Naples metro area. The goals of the stormwater wetlands are to improve the water quality, reduce peak flows discharging into Gordon River and further to Naples Bay, and provide an aesthetic water park for the public. A monthly hydrologic budget for the period August 1, 2016 to January 31, 2018 showed the following averages: pumped surface water inflow of 50.1 cm $week^{-1}$; average surface outflow of 38.8 cm $week^{-1}$; precipitation of 3.76 cm $week^{-1}$, potential evapotranspiration (PET) of 5.34 cm $week^{-1}$; and estimated seepage of 14.8 cm $week^{-1}$. During the wet season, water pathways are largely influenced by pumped surface inflow and surface outflow, balanced to not produce significant changes in water level from month to month. Groundwater seepage and evapotranspiration are the most important outflows during the dry season. A stormwater pulsing study during Hurricane Irma (September 10, 2017) showed that after an initial inflow flush due primarily to rainfall, total phosphorus and total nitrogen concentrations were higher at the outflow than at the inflow for several days during and immediately after the hurricane. Similarly, the mass of nutrients leaving the system was 130% and 37% higher for TN and TP, respectively, than the mass entering the system during this 6-day period during and immediately after the hurricane. Ironically, the design of the pump-only inflow did not allow for major urban runoff during the hurricane to enter the wetlands. Samples taken at the inflow and outflow of the system for four other storm events throughout the 2017 wet season (July through October) were also analyzed for their effects on water quality. While total phosphorus removal during and after storm events is comparable to normal conditions at the Freedom Park wetlands and other stormwater treatment wetlands in the world, total nitrogen removal decreased during and after storm events.

1. Introduction

As human populations continue to grow and develop their landscapes, urban stormwater has progressively become a large source of pollution to surrounding bodies of water, while simultaneously increasing the risk of large flood events (Merriman et al., 2016). While there are many Best Management Practices (BMPs) for flood control structures, urban wetlands are one of the few that mitigate both pollution and flooding (Lim and Lu, 2016). Stormwater treatment wetlands can provide many benefits including pollution control, habitat protection, and flood protection (Jenkins et al., 2012). Constructed wetlands are shown to be more effective at nitrogen removal than conventional stormwater control methods (Collins et al., 2010). The hydrology of a wetland has a direct impact on how efficient it is at storing and treating stormwater (Pennino et al., 2016). Many studies have shown that the hydrologic regime is critical to overall wetland function (Mitsch et al., 2005, 2008, 2012; Richardson et al., 2011). Hydrology has a significant influence on the cycling of nutrients, potential primary productivity and species richness, accumulation of organic matter, and overall ecosystem functioning (Mitsch and Gosselink, 2015; Luo et al., 2016).

Constructed wetlands themselves are not new technology; they have most commonly been utilized for tertiary treatment of domestic

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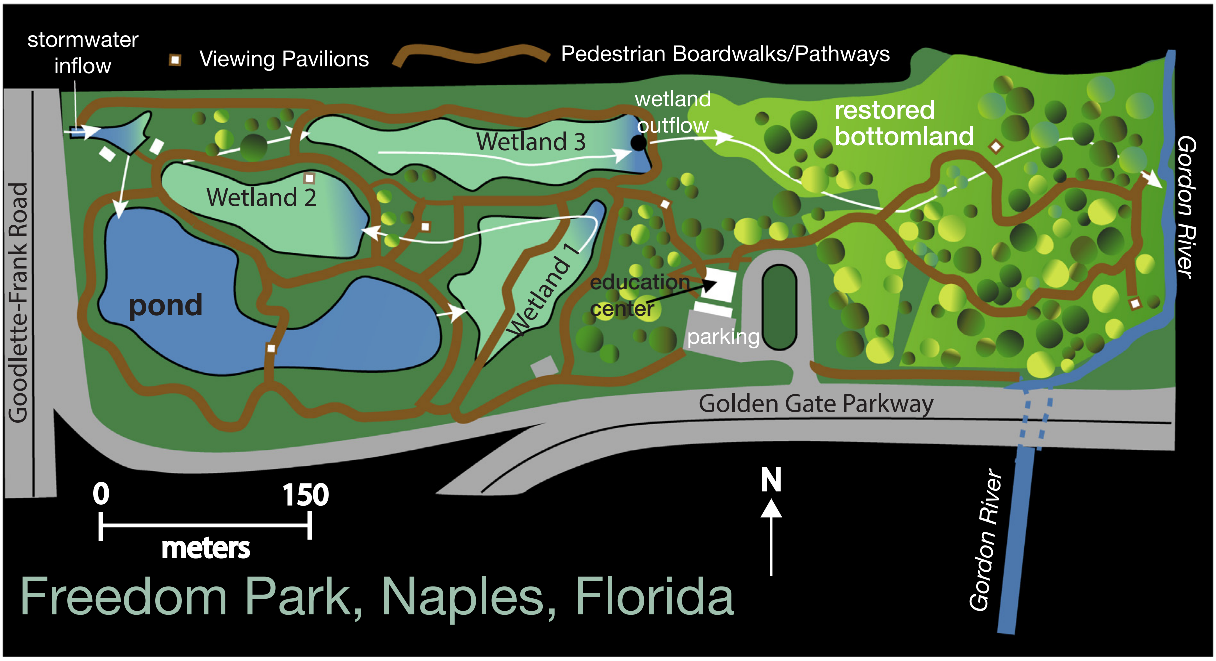

Fig. 1. Map of Freedom Park indicating pathway of water flow through the three constructed wetlands in the western (left) half of the park and finally to the Gordon River on the right (From Mitsch and Gosselink, 2015).

wastewater and treating agricultural waste for decades (Jenkins et al., 2012). However, stormwater treatment wetlands are relatively new, leaving them understudied compared to domestic wastewater wetlands (Moore and Hunt, 2012). Similarly, their effectiveness on a regional and watershed-size scale has not been evaluated (Pennino et al., 2016). Along with urban expansion, a changing climate could result in stormwater treatment wetlands becoming even more necessary in highly populated areas. The southeast region of the United States in particular is predicted to experience yearly and decadal increases in temperature, which will significantly increase the number of hot days (greater than 35 °C) per year (Carter et al., 2014). Coastal regions are likely to experience at least a 0.5–1 °C increase in temperatures (Carter et al., 2014). Precipitation patterns are less certain; however, the frequency and intensity of extreme events is likely to increase, making the occurrences of flood and drought more extreme (Carter et al., 2014). Similarly, some predictions suggest that precipitation will likely exceed evapotranspiration during the wet season, resulting in larger runoff events and peak hydrographs; conversely, baseflows will likely be lower in the winter months due to increased evapotranspiration (Mulholland et al. 1997). Green infrastructure will be critical to stormwater management in these regions to reduce peak flows and mitigate for the changes in hydrographs (Pennino et al. 2016).

Because urban constructed wetlands are designed to protect and restore the water quality of downstream water bodies by attenuating nutrients from stormwater runoff (Adyel et al., 2017), it is imperative to understand how these systems operate during storm events. Previous studies have found that higher nutrient loads occurred after large rainfall events, especially after longer preceding dry conditions (Adyel et al., 2017). Higher hydraulic retention rates have also been found to promote higher nutrient attenuation (Adyel et al., 2017). Such studies have also not been completed during hurricane events at treatment wetlands. A meta-analysis looking at the nutrient removal efficiency of created and restored wetlands found that most studies lacked comprehensive hydrologic data, further indicating its importance in complete understanding of wetland performance factors (Land et al. 2016).

2. Research goal and objectives

The Freedom Park wetland system investigated in this study was designed to store and treat urban stormwater runoff. The goal of this study was to evaluate the hydrologic functioning of the system to provide crucial insights into how nutrients and hydrology are interlinked in different seasons and during storm events (including hurricanes). The specific research objectives were to:

1. Create an annual water budget and identify seasonal trends for the Freedom Park treatment wetlands;
2. Evaluate nutrient loading and retention patterns during seasonal storm events;
3. Understand treatment wetland functioning during extreme storm events, such as hurricanes.

2.1. Hypotheses

The following hypotheses were tested by this study:

1. Surface water inflow and outflow will dominate water pathways in the wet season, while evapotranspiration and/or subsurface drainage will be the major sources of transport during the dry season.
2. Larger storm events will lead to increases in both hydraulic and nutrient loading correlated to the size of the storm.
3. Extreme events, such as hurricanes, will flush water and nutrients out of this specific engineered wetland system with clean rainwater, causing the wetlands to become a source rather than a sink of nutrients during hurricane events.

3. Materials and methods

3.1. Study site

The study site is located at Freedom Park, which is at the intersection of Golden Gate Parkway and Goodlette-Frank Road in Naples, Florida, USA (26°10′28″N, 81°47′22″W). This study took place in the constructed wetlands, which are in the western half of Freedom Park