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Research paper

Water quality before and after watershed-scale implementation of stormwater wet ponds in the coastal plain

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ABSTRACT

Wet ponds have been used extensively for stormwater control throughout the US, including coastal areas. Despite the widespread application of these water control structures, few studies have investigated how watershed-scale implementation of wet ponds affects downstream water quality or how the pollutant removal efficacy of wet ponds changes over time in a coastal setting. This study utilizes a seven year data set of nutrient, total suspended solid, and chlorophyll-*a* concentration data collected during baseflow and stormflow from two coastal headwater streams draining a developed (28% impervious) and an undeveloped (1.2% impervious) watershed. The seven year record encompasses before, during, and after a large construction project and concurrent implementation of wet ponds in the developed watershed that drain 97% of the watershed area. Additional nutrient, total suspended solid, and chlorophyll-*a* concentration data were collected from within a wet pond in the developed watershed during baseflow over a single spring and summer. A comparison of stream water quality before and after the construction project and wet pond implementation in the developed watershed showed that mean chlorophyll-*a*, nitrate-nitrite (NO_x^-), organic nitrogen, and total suspended solid concentrations significantly increased, the mean orthophosphate (PO_4^{3-}) concentration significantly decreased, and the mean ammonium (NH_4^+) concentration did not change. Over a three year time period after construction and pond implementation, developed stream chlorophyll-*a*, ammonium, and organic nitrogen concentrations decreased, and nitrate-nitrite, orthophosphate, and total suspended solid concentrations increased compared to the reference stream during the same period, indicating changes in pollutant removal capacity. A comparison of baseflow and stormflow samples during the Post period and samples from a wet pond in the developed watershed indicated that ponds were functioning as sources of chlorophyll-*a* and total suspended solids to the stream and sinks for nitrate-nitrite. Overall, watershed-scale implementation of wet ponds in the developed watershed failed to mitigate many negative water quality impacts caused by increased development. This study suggests that centralized stormwater management may not be optimal for maintaining water quality in coastal environments, and that pond retrofits combined with frequent excavation could improve pollutant removal by wet ponds. Further research on the effects of nutrient cycling in coastal wet ponds and wet pond maintenance is needed.

1. Introduction

Nearly 80% of the US population lives in urban areas, and this percentage is increasing (U.S. Census and Bureau, 2010). Concomitantly, the amount of impervious area is increasing due to the expansion of urban and sub-urban areas (Terando et al., 2014). Specifically, the coastal plain of the southeastern US is predicted to experience urban expansion over the next 50 years (Terando et al., 2014). Despite known negative impacts of stormwater runoff from urban areas on coastal stream hydrology and water quality, research on stormwater mitigation techniques in coastal regions is very limited when compared to extensive research in non-coastal regions (Ex. DeLorenzo et al., 2012; EPA National Estuary Program, 2014; Lewitus et al., 2008; Merriman et al., 2016; Serrano and DeLorenzo, 2008). Coastal stormwater managers apply similar stormwater control measures (SCMs) as managers in non-coastal areas and have the same priorities for water quantity and quality (Collins et al., 2010). To test the assumption that stormwater management in coastal systems and non-coastal systems can be approached the same way, it is necessary to determine the effects

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of prevalent types of SCMs, particularly wet ponds, on the water quality of coastal watersheds.

The effects of increased watershed impervious area on streams are well-studied and predictable in most geographic regions of the US, including coastal systems (Ex. O'Driscoll et al., 2009; O'Driscoll et al., 2010). As watershed impervious area increases, more runoff is generated from storm events, and evaporation and infiltration within the watershed decreases. Typically, the total volume of water leaving a watershed increases due to an increase in stormflow and a decrease in baseflow (Booth and Jackson, 1997; O'Driscoll et al., 2010; Paul and Meyer, 2001; Walsh et al., 2005), although the effect of increased impervious area on baseflow dynamics can vary (Price, 2011). Changes in catchment hydrology due to development generally leads to lower stream biota diversity, increased loading of nutrients and other pollutants, and channel incision or enlargement (Goetz and Fiske, 2008; Paul and Meyer, 2001; Walsh et al., 2005). Similar effects have been observed in urban areas within the southeastern coastal plain of the US (O'Driscoll et al., 2009; O'Driscoll et al., 2010; Sanger et al., 2013).

Conventional stormwater management has focused on the objectives of flood mitigation and pollutant removal (Burns et al., 2012; Walsh et al., 2016), and most SCMs have focused on detaining stormwater and slowly releasing it to lower peak flows (Collins et al., 2010). The most prevalent kind of SCM is a wet pond, which is designed to hold a large volume of runoff and retain a permanent pool of water (Collins et al., 2010). Wet ponds are primarily intended to mitigate increased surface runoff from impervious surfaces during storms by lowering peak stormflows and extending the hydrograph (Hancock et al., 2010), but the effects of these ponds on downstream water quality are not well constrained. In some cases wet ponds have been shown to offer valuable ecosystem services, such as increased biodiversity (Hassall and Anderson, 2014; Moore and Hunt, 2012), carbon sequestration (Moore and Hunt, 2012), and nutrient and suspended sediment retention (Bettez and Groffman, 2012; McPhillips and Walter, 2015; Rosenzweig et al., 2011). Conversely, some studies have shown that wet ponds failed to meet regulatory goals for stream channel protection (Hancock et al., 2010), increased nutrient loading at times (Duan et al., 2016; Rosenzweig et al., 2011), created longer periods of erosive stormflow (Tillinghast et al., 2011), increased heavy metal concentrations (Stephansen et al., 2014; Wium-Andersen et al., 2011), and grew harmful algae and bacteria (DeLorenzo et al., 2012; Lewitus et al., 2008).

The implementation of wet ponds may have distinctive effects on water quality in coastal watersheds in the southeastern US due to the landscape's high water table, low relief, soil type, and biogeochemistry. Many coastal watersheds in the southeastern coastal plain have soils and natural hydrologic and biogeochemical processes that produce blackwater streams – streams characterized by large amounts of dissolved organic matter and low concentrations of chlorophyll-*a* and suspended sediments (Meyer, 1990). The optical properties, nutrient concentrations, and suspended sediment concentrations of the blackwater naturally found in coastal streams is significantly different than the water funneled into wet ponds from impervious surfaces (Piehler et al., in prep). Few studies have investigated the effects of watershed-scale implementation of wet ponds on coastal stream water quality, but many of the SCMs in coastal NC counties are wet ponds or dry ponds (NCDEQ, 2017). Previous research on coastal stormwater management has focused on water quality in tidal and brackish water or on single SCMs (Ex. DeLorenzo et al., 2012; Lewitus, 2008; Merriman et al., 2016; Serrano and DeLorenzo, 2008). Improving and broadening the understanding of watershed-scale stormwater management in coastal areas will have clear implications for coastal water quality, public health, and estuarine ecology.

Another unresolved issue is how pollutant removal functions of coastal wet ponds may change over time. Wet ponds fill in with vegetation and sediment over time, but the establishment of vegetation in deeper parts of the ponds is discouraged (Mitsch and Jørgensen, 2004). The excavation of in-filled areas every few years in wet ponds and wetlands is required to maintain water storage capacity and sediment and phosphorus removal (Hunt and Lord, 2006; Merriman and Hunt, 2014). This wet pond maintenance, like most SCM maintenance, is often overlooked but recommended (Blecken et al., 2015). Understanding how stream water quality from a coastal watershed outfitted with stormwater wet ponds changes over time will inform plans for excavation to maximize nutrient and suspended sediment removal and demonstrate the need for maintenance in coastal wet ponds. Few studies have investigated how the pollutant removal function of SCMs changes over extended periods of time (ex. Merriman and Hunt, 2014; Merriman et al., 2016), and none have been conducted on wet ponds in a coastal watershed.

Here we examined the effects of watershed-scale wet pond implementation and increased development on coastal stream water quality by analyzing a time series of nutrient, total suspended solids, and chlorophyll-*a* concentration data. Assessing the efficacy of coastal wet ponds through analysis of data before and after wet pond implementation offers a unique opportunity to understand the role these structures play in shaping coastal water quality and mitigating the negative effects of increased development. Our data span seven years, encompassing before, during, and after increased development and concurrent implementation of wet ponds in a developed coastal watershed and parallel sampling in a minimally developed reference coastal watershed aboard US Marine Corps Base Camp Lejeune in coastal North Carolina.

The goals of this study were to:

1 Quantify the changes in stream chemistry that occurred due to increased development and the watershed-scale implementation of wet ponds.
2 Identify trends in stream nutrient and suspended sediment concentrations after development and the implementation of wet ponds.
3 Determine if wet ponds were functioning as sources or sinks for nitrogen and phosphorus, suspended sediments, and chlorophyll-*a*.
4 Assess implications for future coastal stormwater management and wet pond management along the US Southeastern coast and other similar systems.

2. Site description

Study watersheds sampled were located aboard US Marine Corps Base Camp Lejeune in Jacksonville, NC in the coastal plain of North Carolina (Fig. 1). Camp Lejeune is the largest US Marine base in the world, employing 170,000 people and covering an area of 640 km^2 (http://www.lejeune.marines.mil/About.aspx). Camp Lejeune surrounds the New River Estuary, and has installed over 200 wet ponds to mitigate negative hydrologic impacts of increased impervious area on coastal streams. The New River Estuary, like many other estuaries in NC, has experienced intense eutrophication in the past due to high levels of nutrient loading (Mallin et al., 2005), so understanding the effects of stormwater management on nutrient dynamics is imperative. The two study streams drain into the New River Estuary but did not experience significant tidal fluctuations or any salinity during the study period.

The developed watershed (70 ha, 28% mean imperviousness (Xian et al., 2011)) for this study is located in a residential neighborhood called Tarawa Terrace on the northern boundary of the