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Economic impacts of urban flooding in South Florida: Potential consequences of managing groundwater to prevent salt water intrusion

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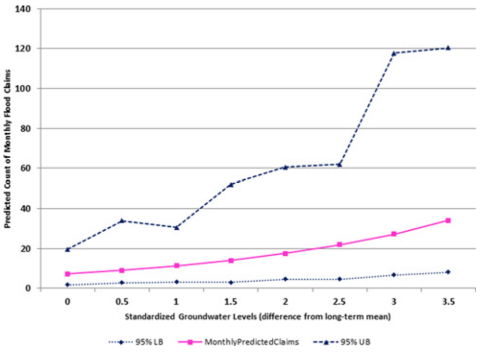
HIGHLIGHTS

- South Florida water levels may have to be increased over time to prevent the increased salt water intrusion.
- Higher canal water levels also lead to an increased risk of inland flooding.
- Model the relationships between flood losses and groundwater levels over time.
- Analysis will help water managers better understand high water level and flood risk trade-off.

GRAPHICAL ABSTRACT



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ABSTRACT

High-value urban zones in coastal South Florida are considered particularly vulnerable to salt water intrusion into the groundwater-based, public water supplies caused by sea level rise (SLR) in combination with the low topography, existing high water table, and permeable karst substrate. Managers in the region closely regulate water depths in the extensive South Florida canal network to control closely coupled groundwater levels and thereby reduce the risk of saltwater intrusion into the karst aquifer. Potential SLR adaptation strategies developed by local managers suggest canal and groundwater levels may have to be increased over time to prevent the increased salt water intrusion risk to groundwater resources. However, higher canal and groundwater levels cause the loss of unsaturated zone storage and lead to an increased risk of inland flooding when the recharge from rainfall exceeds the capacity of the unsaturated zone to absorb it and the water table reaches the surface. Consequently, higher canal and groundwater levels are also associated with increased risk of economic losses, especially during the annual wet seasons. To help water managers and urban planners in this region better understand this trade-off, this study models the relationships between flood insurance claims and groundwater levels in Miami-Dade County. Via regression analyses, we relate the incurred number of monthly flood claims in 16 Miami-Dade County watersheds to monthly groundwater levels over the period from 1996 to 2010. We utilize these estimated statistical relationships to further illustrate various monthly flood loss scenarios that could plausibly result, thereby

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providing an economic quantification of a "too much water" trade-off. Importantly, this understanding is the first of its kind in South Florida and is exceedingly useful for regional-scale hydro-economic optimization models analyzing trade-offs associated with high water levels.

1. Introduction

The counties of the Lower East Coast (LEC) of Florida – Palm Beach, Broward, and Miami Dade – are the three most populous in the state with a population of over 5.6 million people, forecast to rise to over 8.4 million in 2040 (BEBR, 2013). Consequently, the LEC is a significant end-user of publically supplied groundwater withdrawn from Florida aquifers today and into the foreseeable future (USGS, 2010). Moreover, canal water levels in the LEC are managed in part to create a positive hydraulic gradient that continually recharges the Biscayne aquifer with freshwater, thereby lowering the risk of salt water intrusion from the Atlantic Ocean and coastal embayments into groundwater supplies (Carter et al., 2010). However, ensuring there is enough potable groundwater supply to meet the existing and growing needs of the urban areas of the LEC comes at a potential simultaneous and unintended cost to urban users.

Because the urban canal network is also used to receive and discharge excess water during the wet season and extreme rain events, the efforts to prevent salt water intrusion through the manipulation of canal water levels also represent a source of flood risk. And Florida has one of the highest risks of flooding in the United States, ranking 3rd highest in the number of National Flood Insurance Program (NFIP) claims incurred since 1978 U.S., behind Louisiana and Texas (NFIP, 2015). Miami-Dade and Broward are the top two Florida counties to have incurred flood claims in the state (Palm Beach is 6th), with all three LEC Counties representing 36% of the total Florida flood claims incurred (NFIP, 2015).

It is these types of system-wide tradeoffs associated with meeting the water demands while also providing flood control for the already large and growing urban areas in the LEC and the Everglades Agricultural Area (EAA), as well as maintaining the ecological integrity of the natural wetland habitats including the Everglades, that characterize South Florida's water management system (e.g., Watkins et al., 2004). Moreover, as sea level rises, South Florida water managers will increasingly face potentially more severe trade-offs associated with maintaining, on one hand, the high canal and groundwater levels needed to meet the increasing demands of the growing population and to stave off saltwater intrusion; and on the other, the requirements to meet both flood protection goals for urbanized areas and environmental water demands. Extreme rainfall events such as tropical storms or changes in seasonal rainfall patterns associated with climate change may increase the challenges of meeting these potentially conflicting objectives, and quantitative economic analyses are needed to inform water resource management decisions in this region. Given this, the purpose of this study is to provide such a quantitative analysis of the flood risk to better ascertain the associated economic trade-off with maintaining higher groundwater levels.

Specifically we examine the relationship between groundwater levels and the rate of flood insurance claims in urbanized areas of Miami-Dade County, the most populous and most flood-impacted county of the LEC. Significantly, this relationship is not particularly well understood by South Florida residents and water management experts alike (Bolter, 2013), with the typical SLR flood risk focus primarily related to more intense storm surge impacts or direct waterfront coastal areas and rising tides (Lemonick, 2012). Flood losses herein are represented by the number of actual flood claims incurred during the study period of 1996 to 2010. We benefit from access to the entire policy and claim portfolio of the NFIP. We first relate via panel data regression analyses (Dell et al., 2014) the incurred number of flood claims to corresponding monthly groundwater levels for individually managed watersheds in Miami-Dade County. By controlling for relevant flood hazard, land-use, and other exposure variables in the regression analyses, a predictive model of the number of urban residential flood claims per varying groundwater levels is obtained at a given managed watershed location.

This information is expected to be useful in urban planning and water resource forums in South Florida where new strategies for managing the region's water resources are being sought during this period of rapidly changing environmental and land use conditions. The predictive model is particularly relevant to applications of water resources systems analysis, including hydro-economic optimization (HEO, Mirchi et al., 2017 this issue), trade-off analysis, and collaborative modeling (e.g., Brown et al., 2015). In particular, hydro-economic modeling provides a solution-oriented framework for integrated analysis of complex water resources systems and for assessing potential economic impacts of management decisions and resource development options on different system sectors (Heinz et al. 2007; Harou et al. 2009, Mirchi et al. 2010). These models are most frequently applied to assist in water resources management under conditions of water scarcity (Jenkins et al., 2004; Marques et al., 2006; Pulido-Velazquez et al., 2006; Ward et al., 2006; Maneta et al., 2009; Harou et al., 2010; Tilmant et al., 2014). However, they are similarly useful for regions where economic performance is also dependent on managing flood risk (Harou et al. 2009). The economic relationship we are modeling here has not previously been readily available for such uses.

Beyond South Florida, coastal areas around the world are increasingly exposed to flooding due to higher water tables caused by high tides and sea level rise. The National Climate Assessment (Melillo et al., 2014) reports that sea levels may rise between 0.3 and 2 m by 2100. This will cause increases in coastal groundwater levels and the potential for exacerbating sea water intrusion (Werner and Simmons, 2009; Chang et al., 2011). Subsurface storage of stormwater is reduced by higher water tables and the water table can rise above the land surface leading to flooding. The National Climate Assessment (Melillo et al., 2014) points out that erosion and inundation in some portions of Alaska, Louisiana, the Pacific Islands, and other coastal regions, have already forced communities to relocate away from their historical homelands. Miami Beach Florida and Norfolk Virginia (Corum, 2016) are two prime examples of areas experiencing tidally-driven "sunny-day" or "nuisance" flooding while Hawaii and California will likely lose land to sea level rise. Wdowinski et al. (2016) found that tidal and rain-based flooding became more frequent in Miami Beach between 2006 and 2013. Habel et al. (2017) and Rotzoll and Fletcher (2013) investigated groundwater inundation in Hawaii, while Hoover et al. (2016) assess potential groundwater emergence on the California coast. Our work here importantly adds to this literature.

The remainder of the paper is organized as follows. Section 2 provides further detail on the managed South Florida water system and its connection to urban residential flooding from groundwater. Section 3 details the study area, methodology, and data used for the flood claim statistical analyses. Section 4 presents the regression results. Section 5 discusses potential HEO application of these results. Section 6 provides concluding comments.

2. South Florida Water Management System

The South Florida Water Management District (SFWMD) operates and maintains the regional water management system (Fig. 1) known