



## Research Paper

## Evaluating the effects of open space configurations in reducing flood damage along the Gulf of Mexico coast

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## ABSTRACT

Economic losses from floods along the Gulf of Mexico have triggered much debate on different strategies to reduce risk and future adverse impacts from storm events. While much of the discussion has focused on structural engineering approaches to flood mitigation, increasing emphasis is being placed on avoidance strategies, such as the protection of undeveloped open spaces. This study leverages previous work to examine undeveloped lands across approximately 2600 watersheds along the Gulf of Mexico.

Different types and spatial configurations of naturally-occurring open spaces are statistically evaluated across landscapes for their effects on reducing observed flood losses (economic damage to building and/or contents) under the National Flood Insurance Program (NFIP) occurring from 2008 through 2014. Statistical models isolate the influence of natural open spaces, while controlling for multiple socioeconomic, environmental, and development-based local conditions. Results estimate the dollar-savings in flood losses by maintaining open spaces over time. This study provides quantitative guidance on which types and spatial characteristics of open spaces are most effective in reducing the adverse impacts from floods. Findings indicate that large, expansive, and continuous patches of naturally-occurring open spaces most effectively reduce losses from flood events.

## 1. Introduction

Increasing physical risk combined with rapid land use change and development in flood-prone areas has amplified the adverse impacts of flooding in the United States (U.S.) (Pilkey et al., 2008). Losses from both acute and chronic flood events are especially problematic in low-lying coastal areas, where development has accelerated in recent decades (Hellegatte et al., 2013). From 2003 to 2013 alone, property owners in the U.S. claimed over \$3.5 billion per year in insured flood losses (calculated by authors using federal insured flood loss data). The vast majority of these losses have occurred along the Gulf of Mexico coast, where increasing development in flood-prone areas has exacerbated the vulnerability of local communities (Michel-Kerjan, Lemoyne de Forges, & Kunreuther, 2012).

Large amounts of property damage from inundation of structures in coastal communities raises the issue of whether non-structural and avoidance strategies may be an effective way to mitigate future adverse impacts. Open space protection has long been used to maintain ecological functions and provide recreational amenities, but only fairly recently this land use strategy being considered for flood mitigation

(Beatley, 2009). Despite the promise of using open space to accept, retain, and slowly release flood waters, relatively little observational study has been done on the effectiveness of this technique specifically for reducing the economic impacts of floods.

This study builds on previous work to better understand the flood mitigation value of naturally-occurring open space protection by examining undeveloped lands across 2651 watersheds along the Gulf of Mexico (GOM). Multiple types and spatial configurations of open spaces are statistically evaluated for their effects on reducing observed flood losses under the National Flood Insurance Program (NFIP) occurring from 2008 through 2014. Statistical models isolate the influence of natural open space, while controlling for multiple socioeconomic, environmental, and policy-related variables. Results calculate the dollar-savings in insured flood loss that communities experience by maintaining open spaces. Study findings provide insights to decision makers on which types and spatial characteristics of open spaces may be most effective in reducing flood losses.

The following section examines protecting open space as an alternative to structural engineering approaches for flood mitigation. Special attention is paid to protecting critical natural areas, such as

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wetlands for their ability to absorb and hold storm waters. Next, we describe the research methods employed in the study, including study area, sample selection, concept measurement, and data analysis. Results are then presented focusing on the effects of nine open space spatial metrics on flood loss using maximum likelihood spatial error regression models. The results are put into context for planners interested in reducing the economic impacts of flooding along the Gulf of Mexico coast. Finally, we discuss the ramifications of the study and point the way for future research on this topic.

## 2. Open space protection as a flood mitigation tool

Protecting undeveloped land as open space has been used for multiple purposes throughout history. These include creating public parks and recreation areas, separating conflicting land uses, protecting biodiversity, water quality, and maintaining critical ecological functions (Bengston, Fletcher, & Nelson, 2004; Gaston, Jackson, Cantú-Salazar, & Cruz-Piñón, 2008; Randolph, 2004). The implementation of open space protection programs is ubiquitous across the U.S. (Maruani & Amit-Cohen, 2007). In 2002, for example, Geoghegan (2002) showed that 46 of the 50 states had some form of open space designation. These protected areas can be established through various techniques, including zoning provisions, fee simple purchase, conservation easements, setbacks, the transfer of development rights, and conservation overlay zones (Berke and Kaiser, 2006).

More recently, planners and floodplain managers have begun to consider protecting undeveloped lands for their role in reducing the adverse impacts of floods (Kousky & Walls, 2014; Randolph, 2004). In particular, keeping floodplains, riparian areas, and other key locations free of development can help maintain the natural storage capacity of hydrological systems (Freitag, Bolton, Westerlund, & Clark, 2009; Opperman et al., 2009) and also prevent structures from being placed in areas most likely to be inundated (Calil et al., 2015). Greenway systems that buffer development along waterways and wetlands are especially useful for creating areas that collect storm-water runoff while promoting public access (Kusler & Larson, 1993; Tate, Strong, Kraus, & Xiong, 2016). For example, after Tropical Storm Allison flooded multiple homes in Friendswood, TX in 2001, the city acquired floodplain areas around Clear Creek as a greenway to provide natural drainage for future flood waters, rather than force runoff into a restricted channel and possibly residents' home. In this case, allowing undeveloped lands to collect and store runoff provides natural retention that can compensate for lost storage from development in surrounding areas.

Protecting open space, particularly in and adjacent to the 100-year floodplain, can be considered part of an "avoidance" strategy for mitigating flood impacts (Beatley, 2009). If properly located, open space designations prevent or steer development away from the most flood-prone areas, helping to reduce property loss and human casualties. Buffers along flood-prone areas can serve as the horizontal equivalent of elevating structures above the 100-year level of inundation delineated by FEMA (Medlock, 2008).

Preventing development of riverine systems can also protect naturally-occurring wetlands that support natural absorption and storage of flood waters, and prevent inundation of a larger surrounding area. The ability of wetlands to reduce the adverse effects of flooding is well-studied (Bullock & Acreman, 2003; Fausol and Lillieholm, 1996; Godschalk, Norton, Richardson, & Salvesen, 2000; Lewis, 2001; Mitch & Gosselink, 2000, among others). An observational analysis of land cover within watersheds adjacent to the Gulf of Mexico from 1999 to 2009 found that a one-percent increase in area of palustrine wetlands was the equivalent to, on average, a \$7580 reduction in insured flood losses per year. In the final year of the study period, these wetlands were responsible for, on average, approximately \$188,000 in avoided losses for each watershed within the study area (Brody, Highfield, & Blessing, 2015).

When naturally occurring wetlands are replaced by impervious surfaces, runoff enters stream channels more quickly, often resulting in more extensive losses during a heavy precipitation event. For example, Brody et al. (2012) calculated that conversion of wetland land cover increased insured claims paid from flood damage by approximately \$1.5 million per year across Gulf of Mexico communities from 2001 to 2005. Also, an analysis of permits under Section 404 of the *Clean Water Act* in coastal Texas counties showed that wetland alteration or removal added over \$38,000 in property damage per flood (Brody, Zahran, Highfield, Grover, & Vedlitz, 2008).

Other undeveloped land cover types have also been shown to reduce flood impacts within and adjacent to exposed areas. For example, lands made up of woody vegetation have higher capacities for flood regulation based on their ability to catch or slow surface runoff (Nedkov & Burkhard, 2012). Forest land cover with trees and dense undergrowth can help trap and slow storm-water runoff, reducing observed flood peaks (McCulloch & Robinson, 1993). In contrast, grasslands have mixed results in terms of reducing adverse impacts of floods in adjacent residential properties. While this type of undeveloped land still absorbs runoff, it lacks the same degree of infiltration and trapping properties compared to wetlands or forests. Nedkov and Burkhard (2012), for example, showed that the flood attenuation effects of grasslands depend on the type of watershed being studied.

Another type of land use/land cover type that can help reduce watershed-based flood damage is developed open space, such as parks, recreational facilities, and local preserves. While these areas can include some impervious surfaces usually associated with sporting facilities, they are compensated by far larger percentages of natural land cover and well-designed drainage infrastructure to capture storm-water runoff (Dempsey, Smith, & Burton, 2014). A national study of points accrued for open space protection under the FEMA Community Rating System (CRS) found that nationwide, participating communities avoided, on average, approximately \$200,000 per year in insured flood loss (Brody & Highfield, 2013).

While there is increasing observational evidence that undeveloped land and open spaces in general have the potential to attenuate flood impacts, seldom have the specific composition and configuration of these land types been considered. Landscape metrics provide a useful tool for examining the relationship between open spaces and flood loss because they quantify specific spatial characteristics of individual land patches and the spatial relationship among multiple patches (Gustafson, 1998; Uemaa et al., 2013). These metrics are increasingly being used to form a better understanding of the relationships among and changes in physical landscapes (Brody, Kim, & Gunn, 2013; Hepcan, 2013).

## 3. Research methods

### 3.1. Study area and sample selection

The Gulf of Mexico coastal margin provides an ideal region in which to study the relationship between undeveloped open spaces and flood loss for a variety of reasons. First, this low-lying landscape is composed of large percentages of 100-year floodplain (on average, approximately 32% of the study area), making it extremely vulnerable to flooding from both rainfall and surge. For example, localities within the study area experience the largest amount of insured property damage from floods in the U.S. (Brody, Gunn, Highfield, & Peacock, 2011). Second, while the Gulf coast region is experiencing rapid population growth and associated development of various types, there remain large tracts of undeveloped lands that if protected could help prevent future flood losses during extreme events.

We examined 2651 12th order watersheds (based on the USGS Hydrological Unit Code (HUC)) along the Gulf of Mexico coast (Fig. 1). This area stretches from the Florida Keys to the Southern tip of Texas, including watersheds encompassing 144 counties and parishes in six states.

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