The Rising Costs of Floods

Examining the Impact of Planning and Development Decisions on Property Damage in Florida

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The rising economic cost of floods in the United States cannot be explained solely by monetary inflation or growth in coastal populations. Damaging flood events are also influenced by the way society plans for and physically develops its communities, influencing where structures and impervious surfaces are concentrated and how hydrological systems are altered. We analyze 383 nonhurricane flood events in Florida counties between 1997 and 2001 to isolate how planning decisions and their effects on the built environment affect property damage caused by floods. Our results suggest that alteration of naturally occurring wetlands significantly increases the property damage caused by floods, all else equal. Also, nonstructural methods such as the Federal Emergency Management Agency's Community Rating System, while providing inexpensive means of reducing property damage directly, may also indirectly encourage more development in hazardous areas.

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Among all natural hazards, floods pose the greatest threat to the property, safety, and economic well-being of human communities in the United States. The economic impact from floods is estimated in the billions of dollars annually (Association of State Floodplain Managers [ASFPM], 2000; Pielke, 1996). According to data from the Spatial Hazard Events and Losses Database for the United States (SHELDUS), the average number of floods per year has increased six-fold, from 394 floods per year in the 1960s to 2,444 floods per year in the 1990s. SHELDUS data also show that in the 1960s floods caused $41.69 million dollars of damage a year. By the 1990s, average annual property damage from flooding increased to $378.12 million dollars a year (in 1960 dollars).

It is our proposition that rising flood-related property damage may not be fully explained by inflation or population growth or even by increases in annual mean precipitation. In addition to these factors, increasing costs of floods might also be driven by the manner in which humans plan for and subsequently develop their communities. Individual and community-based decisions pertaining to where buildings and impervious surfaces are distributed, and the degree to which hydrological systems are altered, may be exacerbating losses. Increasing development associated with residential, commercial, and tourism activities, particularly in coastal and low-lying areas, has diminished the capacity of hydrological systems to naturally store surface water runoff. As a result, private property, households, and the economic well-being of coastal communities are increasingly vulnerable to the risks of flooding events. In his book *Disasters by Design*, Mileti (1999) states that disasters do not simply happen, but largely result from how we design and build human communities. We aim to test this central thesis through a quantitative model that will isolate the effects of specific built environment characteristics on flood damage.

Despite its importance, few studies addressing this issue have been conducted longitudinally, over large spatial scales, while controlling for multiple biophysical and socioeconomic variables. We examine 383 individual flood events within coastal counties in Florida between 1997 and 2001 in an effort to better understand how planning decisions and resultant features of the built environment influence flood damage levels over time. These decisions may involve federal, state, or local governments and have varying degrees of public input, but all potentially influence the degree to which local communities become vulnerable to damaging flood events. By analyzing a statistical model that combines both natural and social science data, we isolate the effects of mitigation activities, and the alteration of naturally occurring wetlands on flood damage. In addition, we evaluate the economic costs and benefits of various planning and development decisions with respect to property damage from floods.

We build and improve upon our previous work predicting flooding and flood damage (see Brody, Zahran, Highfield, Grover, & Vedlitz, in press; Highfield & Brody, 2006) in several ways. First, we examine a series of individual floods as opposed to a summation of floods or flood damage over a study period. This research approach provides greater explanatory power than cross-sectional analysis. Second, we include in our models flood damage incurred by neighboring counties. This variable allows us to control for spatial autocorrelation that may bias the results of previous studies, as well as to correct for coding biases in the SHELDUS database. Third, we take a closer look at how various planning decisions may impact community vulnerability to flood events in order to better understand how property damage can be reduced. Fourth, because our unit of observation is the flood event itself, we can more precisely identify the effect of decisions to alter wetlands, the change to the environment which most significantly exacerbates flood damage (Brody, Highfield, Ryu, & Spanel-Weber, 2007). For each flood event, we measure the cumulative total of local wetland permits granted during our study period up to that day. Results from our study will help planners and flood managers understand how planning and development decisions within their jurisdictions may impact the severity of flood outcomes. Such information is needed in light of the continued development of coastal areas vulnerable to flooding.

The following section examines the existing literature on the relationship between planning decisions shaping the built environment and flooding. Next, we describe our sample selection, variable measurement, and data analysis procedures. We then report our results based on multivariate and binary logistic regression analysis of three groups of variables: planning decisions, biophysical, and baseline socioeconomic factors. Next, we interpret our findings and discuss their policy implications for enabling the development of more sustainable and hazard-resilient communities. Finally, we lay out an agenda for future research on the impacts of planning and development decisions on flooding.

The Rising Costs of Floods

As indicated above, flooding is the most ubiquitous and costly natural hazard in the United States. The current average annual damage from floods is $5.2 billion and over 80 deaths per year (National Center for Atmospheric Research, 2001). Using the National Weather Service *Storm Data* publications, Mileti (1999) estimated property losses from floods between 1975 and 1994 were somewhere between $19.6 billion and $196 billion. While damage estimates from floods vary, the economic costs from floods appear to be steadily increasing (Pielke & Downton, 2000). The Federal Emergency Management Agency (FEMA; 1997) estimates that over 9 million households and $390 billion in property have at least a 1% per year probability of flooding.

Due to its low elevation, large coastal population, and frequent storm events, Florida experiences significant annual economic losses from floods. Recent estimates indicate that from 1990 to 2003 the state suffered almost $2.5 billion in losses (in 2003 dollars). Based on a composite risk score accounting for floodplain area and the number and per capita value of housing units, Florida is ranked as the state with the highest risk for flooding, followed by California, Texas, Louisiana, and New Jersey (FEMA, 1997). In general, the combination of rapid population growth and related development, the alteration of hydrological systems through building and channelization, and large amounts of annual precipitation associated with a tropical and subtropical climate have made many local jurisdictions across the state vulnerable to repetitive flooding and flood damage. Flood damage in Florida is driven by both the cumulative effects of many small flood events and of individual large, widespread storms. For example, during a two-day period in early October of 2000, Broward, Collier, Miami-Dade, and Monroe Counties all received over a foot of rain, causing over $450 million dollars of flood damage (National Climatic Data Center, 2005) and prompting over 51,000 individuals to request financial assistance from FEMA (FEMA, 2000).

Planning Decisions and Flood Damage

As mentioned above, the location and intensity of development, and the local policies in place to mitigate the damage caused by flooding events may be important factors contributing to the amount of flood loss experienced at the community scale. Potentially important features of the built environment include the amount of impervious surface within a local jurisdiction, the number and value of housing units, and the degree to which critical components of the hydrological system, such as naturally occurring wetlands, are altered. Flood mitigation can be structural, like dams, levees, and other community works projects; or nonstructural, like land use plans, public information programs, and open space acquisition and preservation. Such community and individual planning decisions may be the most influential determinants of flood damage over time. Some of their most important components are explained in more detail below.

Impervious Surfaces

Impervious surfaces are both a major feature of urbanization and a contributor to flood frequency (Shuster, Bonta, Thurston, Warnemuende, & Smith, 2005). Converting agricultural and forest lands to urban development can diminish a hydrological system's ability to store and slowly release water, resulting in increased flood intensity (Carter, 1961; Tourbier & Westmacott, 1981). As the area of impervious surface coverage increases, there is a corresponding reduction in water infiltrating into the soil, and an increase in surface runoff (Dunne & Leopold, 1978; Paul & Meyer, 2001). According to Arnold and Gibbons (1996), as the percentage of impervious surface within a drainage basin increases to 10–20%, corresponding runoff doubles. More recently, White and Greer (2006) found that as urbanization in the Peñasquitos Creek watershed in southern California increased from 9% to 37%, total runoff increased by an average of 4% per year or 200% over their 1973–2000 study period. Greater surface runoff volume often results in increased frequency and severity of flooding in streams. Finally, Brody, Highfield, et al. (2007) note that an increase in impervious surfaces (measured through remote sensing imagery) correlated with a significant increase in stream flow over a 12-year period across 85 coastal watersheds in Texas and Florida.

Impervious surface has also been associated with increased peak discharges (Brezonik & Stadelman, 2002; Burges, Wigmusta, & Meena, 1998; Leopold, 1994). Under these conditions, floods also peak more rapidly (Hirsch, Walker, Day, & Kallico, 1990) because water reaches streams more quickly when the ability of the hydrological system to store water is compromised (Hey, 2002; Hsu, Chen, & Chang, 2000). For example, Rose and Peters (2001) measured peak discharge increases of approximately 80% in urban catchments that went from 0% to 50% impervious. Flood discharges were at least 250% higher in urban catchments than they were in forested catchments in Texas and New York after similar storms (Espey, Morgan, & Masch, 1965; Paul & Meyer, 2001; Seaburn, 1969). Burns et al. (2005) examined mean peak discharges for 27 storms in the Croton River Basin in New York and observed a 300% increase in a catchment with an impervious area that had increased from zero to only 11.1%. In general, there is ample empirical evidence that urbanization increases not only runoff volume, but also peak discharges and associated flood magnitudes.

Wetland Alteration

The relationship between urban development and flooding depends not only on the amount of impervious surface, but on specifically where in the hydrological landscape that surface is located. Wetlands, a key feature of hydrological landscapes, are believed to provide natural flood mitigation by maintaining a properly functioning water cycle (Lewis, 2001; Mitch & Gosselink, 2000). Overall, research suggests that wetlands may reduce or slow downstream flooding. In a comprehensive literature review, Bullock and Acreman (2003) note 23 of 28 studies on wetlands and flooding report that "floodplain wetlands reduce or delay floods" (p. 366).

Initial research on the role wetlands can play in reducing flooding examined the differences between drained and natural wetlands. These studies generally showed that nondrained peat bogs reduce flood flow from storms of a size likely to occur once in two years, and reduce overall storm flows compared to drained counterparts (Daniel, 1981; Heikuranen, 1976; Verry & Boelter, 1978). Novitski (1979) examined four natural wetland types and found that each had a statistically significant negative effect on flood flows. Similarly, Novitski (1985) discovered that basins with as little as 5% lake and wetland area may have 40% to 60% lower flood peaks than comparable basins without such hydrologic features.

Research utilizing simulation models also suggests that wetlands help reduce flooding. For example, Ammon, Wayne, and Hearney (1981) modeled the effects of wetlands on both water quantity and quality of Chandler Marsh in South Florida. Results indicated that flood peaks are reduced with increasing areas of marsh. The authors concluded that Chandler Slough Marsh increases storm water detention times, changes runoff regimes from surface runoff to increased subsurface infiltration regimes, and is "moderately effective as a water quantity control unit" (p. 326). Ogawa and Male (1986) also used a simulation model to evaluate the protection of wetlands as a flood mitigation strategy. Based on four scenarios in which development encroaches on 25% to 100% of downstream wetlands, the authors found that higher encroachment significantly increased peak flow.

Research based on direct observation also supports the notion that naturally occurring wetlands can reduce flood intensity. For example, based on an experiment that involved constructing wetlands along the Des Plaines River in Illinois, Godschalk, Beatley, Berke, Brower, and Kaiser (1999) found that a marsh of only 5.7 acres could retain the natural runoff of a 410-acre watershed. This study estimated that 3 million acres of wetlands (3% of the upper Mississippi watershed) would have been needed to prevent the catastrophic flood of 1993. Other empirical research indicates that below a critical threshold too much wetland has been lost to attenuate flooding. In a study utilizing the record of stream flow data from stream gauge stations, Johnston, Detenbeck, and Niemi (1990) maintained that even small wetland losses could significantly affect flood outcomes in the same watershed.

While the body of evidence supporting wetlands as a natural flood mitigation device continues to grow, this study, together with others involving the authors of this paper (Brody, Zahran, et al., in press; Brody, Highfield, et al., 2007; and Highfield and Brody, 2006), are the only such empirical studies conducted longitudinally, over large spatial scales, while controlling for multiple biophysical, socioeconomic, and policy variables.

Mitigation: Structural versus Nonstructural Techniques

Community works projects, such as dams, levees, dikes, and channel improvements, have long been used to prevent flooding and reduce flood damage. Such structural approaches to flood mitigation can protect property and lives, particularly for upstream flood events. For example, the U.S. Army Corps of Engineers (ACOE) estimated that U.S. flood damages from 1991 to 2000 were approximately $45 billion dollars, yet their flood control measures may have prevented over $208 billion dollars of additional damage (ACOE, 2002). Brody, Zahran, et al. (in press) found that in coastal Texas counties, each dam resulted in a $27,290 decrease in average property damage per flood. A parallel study (Zahran, Brody, Peacock, Grover, & Vedlitz, in press) noted that an increase in the number of dams decreased the odds of a death or injury from a flood by 21.6%.

While the benefits of structural mitigation devices are clear, so are their disadvantages. Structural flood-control projects can encourage development in vulnerable areas that would have otherwise remained undeveloped (Harding & Parker, 1974; Pielke, 1999; Tobin, 1995). Also, when a flood event exceeds the capacity of a flood control structure, the resulting flood damages can be significantly higher (Burby, French, & Cigler, 1985; Hertzler, 1961; Larson & Plasencia, 200; Stein, Moreno, Conrad, & Ellis, 2000; White, 1945, 1975). Finally, structural measures such as dams are built at a very high price. Since the 1940s, the ACOE has spent over $100 billion dollars (in 1999 dollars) on structural flood protection projects (Stein et al., 2000). While the ACOE speculates that its investment paid dividends by reducing flood damage, this might have been accomplished through less costly means. Studies have also shown that dams disrupt hydrological cycles, sediment budgets, and critical natural habitats (Petts, 1984; Power, Dietrich, & Finlay, 1996).

More recent public-sector flood mitigation initiatives have taken nonstructural approaches. The most widely implemented alternative is the National Flood Insurance Program (NFIP). Established in 1968 as an attempt to internalize flood losses so they would no longer be a burden on the population as a whole, the NFIP has, by many accounts, successfully brought flood insurance and a form of flood mitigation to many communities. However, several scholars have raised concern over NFIP's effect on subsidizing and encouraging floodplain development, the overall equitability of the program, and the high financial costs of repeated losses (Birkland, Burby, Conrad, Cortner, & Mitchner, 2003; Godschalk et al., 1999; Platt, 1999).

FEMA's Community Rating System (CRS), adopted in the early 1990s, encourages communities to go beyond the NFIP's minimum standards for floodplain management by providing discounts of up to 45% on flood insurance premiums for residents of participating communities. Credit points are assigned for 18 measures organized into the following four broad categories of floodplain planning and management activities: public information, mapping and regulation, flood damage reduction, and flood preparedness. Communities with lower CRS scores (on a scale from 9 to 1) have implemented a greater number of the 18 flood mitigation measures and, thus, receive a higher premium discount for insurance coverage. Discounts range from 5% (class 9) to 45% (class 1) depending on the degree to which a community plans for the adverse impacts of floods. As of June, 2006, Florida had over 1.8 million NFIP policies in participating CRS communities. Property owners living within these communities save approximately $98.5 million per year in insurance premiums from involvement in the CRS program (FEMA, 2006).

The CRS program provides a key indicator of planning and development decisions at the local level, since many of the scored activities require implementing spatially targeted land use controls that direct growth away from areas vulnerable to floods. For example, specific activities under the CRS program include preserving floodplains as open spaces to enhance the storage of flood water; zoning floodplains for low densities, to protect their natural functions; and adopting and implementing a comprehensive floodplain management plan. In general, proactive local land use policies effectively reduce flood damage because they focus development in areas least likely to be inundated in a storm. An argument could be made that CRS activities are an even better indicator of local planning decisions than other complementary efforts, such as general comprehensive plans. This is because to receive a score, the CRS program requires activities be implemented, whereas not all adopted comprehensive plan policies are implemented (see Brody & Highfield, 2005).

Research Methods

Sample Selection

We selected for analysis 383 flood events across 54 coastal counties (as defined by the U.S. Environmental Protection Agency) in Florida from 1997 to 2001. Florida presents an ideal study area for examining the impact of planning decisions on inland flooding due to precipitation (we excluded tidal or surge-based flooding, which are entirely different) for the following reasons: (1) as mentioned above, Florida has the highest risk for damaging floods of any state in the country and suffers significant property damage from floods each year; (2) these floods tend to occur in the same locations over time; (3) Florida (particularly the southern coastal portions) has experienced large increases in impervious surface and extensive alteration of wetlands associated with rapid coastal development; and (4) development patterns vary spatially across counties, allowing us to explore our central hypotheses.

Concept Measurement

Dependent Variable. The dependent variable, flood damage, is measured as the total dollar loss (in 1997 dollars) from a flood event (see Table 1). This variable was skewed, as most dollar-based variables are, so we log-transformed it to approximate a Gaussian distribution. We collected data on flood property damage from the SHELDUS database at the Hazard Research Lab at the University of South Carolina, Columbia (Hazards Research Lab, 2006). This database consists of a county-level inventory of 18 natural hazard types, including hurricanes, floods, wildfires, and drought. Each record includes a start and end date for the hazard event, estimated property loss, as well as the number of human injuries and deaths. Our property damage variable ranges from $1,000 to $200 million. It is important to note that dollar estimates of property loss from flooding are often obtained through windshield observation or secondary reports from the National Weather Service that may under- or overestimate the true loss experienced by a property owner. While this is the best available information, it should be interpreted with some caution (Pielke, Downton, & Barnard Miller, 2002). Also, our property loss variable does not include indirect financial loss (e.g., loss of wages), or long-term effects from flooding (e.g., population loss and consequent decreases in local revenue), which may be significant.

Biophysical Variables. To estimate the effect of planning and development decisions on flood-related property damage, we measure and control for several biophysical predictors of flood damage: precipitation, flood duration, stream density, and the county land area in the 100-year floodplain.

Precipitation was measured as the average surface precipitation (in hundredths of inches) recorded by county weather stations on the day of and the day before the flood event. The number of weather stations with available data varied across counties and longitudinally within individual counties. During our study period, Florida had from 76 to 86 weather stations at any one time. Broward County had the highest number of weather stations with 6. We collected daily surface precipitation data from the National Oceanic and Atmospheric Administration's National Data Center Climate Data Online search engine. Search results include latitude, longitude, and altitude coordinates for weather stations, name and county location, and "quality controlled" data on daily (24-hour observation period) surface precipitation. We calculated precipitation the day of and day prior to each flood event because of the lag time between rainfall and peak discharge. While this lag time is shorter in urban environments, it is often the case that a rainfall event on a given day can lead to flooding several days later (for more information, see Brody, Zahran, et al., in press). The highest two-day precipitation total recorded for a flood event in our study was 23 inches in Martin County in August of 2001.

We measured flood duration as the number of days for each flood event based on SHELDUS records of the start and end dates of a hazard event. We measured stream density by using GIS and the National Hydrography Dataset (NHD) to calculate the ratio of total stream length to the area of the county. An area with high stream density is highly dissected by streams, and will typically have a rapid response to rainfall events (Horton, 1932). We also used a GIS to calculate the share of each county's area within FEMA-defined 100-year floodplains (delineated areas that have a 1% chance of flooding in any one year,

Table 1. Model variables, their expected effects on flood-caused property damage, and data sources and years.

Variable	Operational definition	Expected effects	Source and years of data
Baseline socioeconomic variables			
Adjacent damage	Total property damage in all adjacent counties where flooding from the event occurred, as inventoried in the SHELDUS database. This variable is log transformed to compensate for its nonnormality.	+	Spatial Hazard Events and Losses Database for the United States (SHELDUS), 2004
Housing value density	Aggregate county housing value divided by the total county area less the acreages in conservation uses. Annual values assume even intervals of change between the 1990 and 2000 Censuses.	+	U.S. Census of Population and Housing, 1990 and 2000
Natural environment variables			
Precipitation	Average surface precipitation (hundredths of an inch) recorded by NESDIS weather stations in the county on the day of the flood event plus the day before the flood event.	+	National Climate Data Center, 1997–2001
Floodplain area	Area (in square meters) of 100-year floodplain within the county.	+	FEMA Digital Q3 flood data
Stream density	Total length of all orders of streams divided by county area.	+	National Hydrography Dataset
Flood duration	The length of a flood event in days.	+	Spatial Hazard Events and Losses Database for the United States, 2004
Planning variables			
Impervious surface	Square meters of impervious surface in a county, operationalized as the sum of four categories from a statewide land cover GIS layer created from Landsat Thematic Mapper satellite imagery: pavement/roadside, urban, urban residential, and urban open/others.	+	Florida Fish and Wildlife Conservation Commission, 2000.
Dams	Total number of dams in a county.	−	U.S. Army Corps of Engineers, 2004
Wetland alteration	Total federal wetland permits issued in a county from 1990 to the day of the flood event; including general permits, nationwide permits, letters of permission, and individual permits.	+	U.S. Army Corps of Engineers, 2004
FEMA CRS rating System, 2005	FEMA Community Rating System score for a county.	−	FEMA Community Rating
Dependent variables			
Property damage	Total property damage in a county caused by flood events inventoried in the SHELDUS database, in 1997 dollars. This variable is log transformed to compensate for its nonnormality.		Spatial Hazard Events and Losses Database for the United States (SHELDUS), 2004
High flood-damage event (1,0)	1 = flood event caused the county property damage greater than or equal to $50,000 (median damage) 0 = county property damage for flood event was below $50,000.		Spatial Hazard Events and Losses Database for the United States (SHELDUS), 2004

derived from the most recent FEMA Digital Q3 flood data). Franklin County had the highest floodplain overlap in our sample, with approximately 87% of its land area within the 100-year floodplain.

Planning Decision Variables. We measured and analyzed four planning decision and development variables shown to affect the degree of community-wide flood damage: impervious surface, wetland alteration, dam construction, and flood mitigation. We calculated impervious surface using a land cover GIS layer derived from the classification of Landsat Thematic Mapper satellite imagery published in 2000 by the Florida Fish and Wildlife Conservation Commission. The image was classified at a 30-meter spatial resolution. Our impervious surface variable was based on a summation of the following four land cover types: pavement/roadside, urban, urban/residential, and urban open/others. While this is a longitudinal study, there was no way to reliably measure the change in impervious surface month to month or even over years across the entire study area. We, therefore, selected the best available dataset compiled roughly in the middle of the study period as a marker for the level of impervious surface in general. We recognize that the lack of time-sensitive landuse/landcover data is a drawback, and hope to overcome it in future studies as new data are released.

We measured wetland alteration as the cumulative number of wetland permits issued during our study period, but before the day of a flood event, by county. Wetland permits, required under Section 404 of the Clean Water Act, enable an applicant to alter a naturally occurring wetland for a construction project. We obtained permit data from the ACOE Jacksonville District through a Freedom of Information Act request. Permit records include permit type,[1] the date the permit was issued, and the latitude and longitude of the permitted development, which we geocoded into a GIS so we could locate the county where each permitted wetland alteration occurred. Of the 13,282 permits we received, data entry errors or missing data left only 11,899 with sufficient geographic information.

We also counted the number of dams in each county, obtaining their locations from the ACOE. Polk County had the highest number of dams in our sample with 156.

Finally, we measured nonstructural mitigation initiatives using the scores given to counties under the FEMA CRS. As mentioned above, the CRS program promotes mitigation of flood damage through insurance premium discounts and other financial incentives. To qualify for a FEMA discount, communities must enact measures that mitigate flood loss. We measured the CRS rating for each of the 41 Florida counties participating in the program on a scale of 9 (the lowest level of involvement, earning a 5% discount) to 1 (the highest level of involvement, earning a 45% discount). The highest-rated counties in our sample are Charlotte and Miami-Dade, each having ratings of 5, corresponding to a 25% discount.

Baseline Socioeconomic Variables. We used two socioeconomic control variables to help establish a baseline for our statistical models. First, we used an adjacent property damage variable, calculated as the total flood damage in all adjacent counties for a given flood event, to control for spatial autocorrelation in the dependent variable. Storms are regional events that tend to impact several local jurisdictions at the same time. In a statistical model, this adjacency effect may bias parameter estimates. This effect is compounded when flood events affect numerous counties because the National Weather Service distributes the estimated property damage evenly across all afflicted counties. This overlooks real differences in county populations and real estate prices. Our damage estimates are in 1997 dollars, and are log-transformed to approximate a Gaussian distribution. Second, we included in our model a housing value density variable to control for the propertied wealth in each county, since counties with high value per square meter have more at risk from floods. We calculated this measure for each county as aggregate housing value from the 2000 census, divided by buildable area (measured in a GIS as total county area minus the area held in conservation status[2]).

Data Analysis

We analyze the data in three phases. First, we report descriptive statistics related to the spatial and temporal pattern of flood damage over the 5-year study period. Second, we use multiple regression analyses to estimate the effect of planning and development decision variables on reported flood damage in Florida coastal counties. Third, we analyze a binary logistic regression model using the same independent variables to better understand how planning and development variables affect the most serious floods. This logistic regression also allows us to calculate the effect a unit increase in these independent variables will have on the probability of a costly flood occurring in Florida.

Tests to estimate reliability, including specification, multicollinearity, and autocorrelation, exhibited no significant violation of regression assumptions. Based on statistical diagnostics, we did detect heteroskedasticity in the data, leading us to analyze regression equations with robust standard errors.

Results

Over the 5-year study period, 383 recorded flood events resulted in an estimated $979 million in reported property damage among coastal counties in Florida (see Table 2). The average cost per flood was $2,638,712. As shown in Figure 1, heavily urbanized Broward and Miami-Dade counties in the southeast part of the State experienced the most flood damage in the sample, with approximately $246 and $200 million respectively. Interestingly, this flood loss occurred over relatively few events compared to other jurisdictions in the study area. For example, Hillsborough County, which contains the city of Tampa Bay, experienced 36 flood events but reported a comparatively low $13.8 million in damage during the study period. This result indicates the degree of flood damage is driven in part by something other than the frequency of storms. The lowest amount of property damage from floods occurred in less developed inland counties north of Lake Okeechobee. For example, adjacent Seminole, Sumter, and Lake Counties in the central interior portion of the state incurred the least amount of damage among all counties sampled.

Multivariate regression analysis with robust standard errors indicates which factors significantly influence the extent of flood damage in coastal Florida (see Table 3). We sequentially added the following three suites of variables to the model to test their effects both individually and in groups: baseline socioeconomic controls, biophysical, and planning decisions. As a whole, the socioeconomic baseline variables explain 17% of the variance in flood damage across Florida. Particularly strong is the effect of property damage in counties adjacent to a flood event ($p < .001$). This result indicates that floods often extend beyond a single county, and that these adjacency effects must be considered when examining hazard-related phenomena at a county scale. As expected, an increase in housing value density also leads to a significant increase ($p < .1$) in property damage associated with flooding.

Once biophysical variables are added to the model the comparative effect of adjacent property damage is notably reduced, but housing value density has an even stronger positive relationship ($p < .01$) to flood damage. Among the environmental controls, the amount of precipitation the day of and day prior to the flood event is the most powerful predictor of property damage ($p < .001$). In addition to rainfall intensity, the results indicate that, as expected, longer lasting storms significantly increase flood damage to property ($p < .05$).

After planning decision variables are also added, the fully specified model explains over 28% of variation in flood-related property damage. While the amount of impervious surface in a jurisdiction is of no statistical consequence (the confidence interval ranges from −.000000000801 to .000000000631), the alteration of naturally occurring wetlands contributes to a marked increase ($p < .01$) in property damage from floods. The standardized effect of the wetland alteration variable (Beta = .1507) is the third most powerful variable in the full model, following only precipitation (Beta = .2326) and adjacent damage (Beta = .3100). In terms of mitigation measures, our results show that nonstructural activities measured by the CRS rating (Beta = −.1510) are more than twice as effective as dams (Beta = −.0712) in reducing flood damage. This finding is consistent with our study in coastal Texas, which found a significant correlation between CRS rating and reduced flood damage (Brody, Zahran, et al., in press). In fact, the existence of dams is not a statistically significant predictor of flood damage at the .1 level.

Another noteworthy result from the full model is the increased effect of our floodplain variable, which is statistically significant at the .05 level. This result implies that when development and mitigation activities are properly controlled for, floodplain area is a meaningful predictor of property damage. If there were no development in those floodplains this would not be so, but mitigation activities encourage such development. CRS programs make it less expensive for residents to live in the 100-year floodplain; likewise, dams create a perception that areas once vulnerable to flooding are now safer. Thus, the positive coefficient on floodplain area indicates that while the direct effect of mitigation is to reduce flood damage, it may be increasing damage indirectly by encouraging residents to locate in vulnerable locations like floodplains.

To better understand how planning decision and development variables impact the odds of high-damage floods of most concern to planners and communities, we analyzed the model in Table 3 using binary logistic regression. This model predicts the probability of a flood producing property damage above the median value for our sample ($50,000).[3] As shown in Table 4, the fully specified model correctly classifies 71.12% of these flood events by whether they cause more or less than the median amount of property damage. As with the OLS regression model, precipitation, adjacent property damage, and wetland alteration are the most statistically significant predictors of flood damage. Neither flood duration nor CRS rating are significant predictors of high-damage floods in the binary logistic model, while the presence of dams becomes significant at the .1 level.

Based on the odds ratios, a one-inch increase in precipitation increases the odds of experiencing a high damage flood event by 19.4%. A one standard deviation increase in

Table 2. Floods, property damage, and property damage per flood by Florida county, 1997–2001.

Rank	County	Number of floods	Total property damage (thousands of 1997 dollars)	Mean damage per flood (thousands of 1997 dollars)
1	Broward	5	246,000	49,200
2	Dade	4	200,000	50,000
3	Palm Beach	4	62,300	15,600
4	Leon	11	45,200	4,106
5	Bay	4	25,700	6,436
6	Holmes	2	22,900	11,400
7	Wakulla	4	22,900	5,728
8	Washington	3	22,400	7,453
9	Walton	2	22,100	11,000
10	Franklin	2	21,800	10,900
11	Gulf	2	21,700	10,800
12	Jefferson	3	21,700	7,238
13	Madison	2	21,700	10,800
14	Calhoun	1	21,600	21,600
15	Dixie	1	21,600	21,600
16	Gadsden	1	21,600	21,600
17	Jackson	2	21,600	10,800
18	Lafayette	1	21,600	21,600
19	Liberty	2	21,600	10,800
20	Taylor	1	21,600	21,600
21	Hillsborough	36	13,800	382
22	Pasco	37	11,700	316
23	Manatee	24	10,200	425
24	De Soto	25	8,001	320
25	Sarasota	20	4,984	249
26	Citrus	16	3,736	234
27	Flagler	7	3,631	519
28	St. Johns	5	2,655	531
29	Pinellas	21	2,520	120
30	Marion	9	2,386	265
31	Lee	15	1,967	131
32	Duval	6	1,905	318
33	Hernando	16	1,846	115
34	Suwannee	5	1,762	352
35	Nassau	4	1,735	434
36	Putnam	4	1,713	428
37	Clay	2	1,705	853
38	Baker	2	1,703	851
39	Gilchrist	1	1,700	1,700
40	Escambia	5	1,579	316
41	Hardee	11	1,524	139
42	Martin	1	1,500	1,500
43	Polk	14	1,207	86
44	Okaloosa	5	1,045	209
45	Volusia	3	760	253
46	Charlotte	10	727	73
47	Osceola	3	560	187
48	Santa Rosa	3	534	178
49	Collier	2	350	175
50	Brevard	4	140	35
51	Levy	3	111	37
52	Lake	1	85	85
53	Sumter	4	50	13
54	Seminole	2	15	8
	Total	**383**	**997,000**	**2,639**

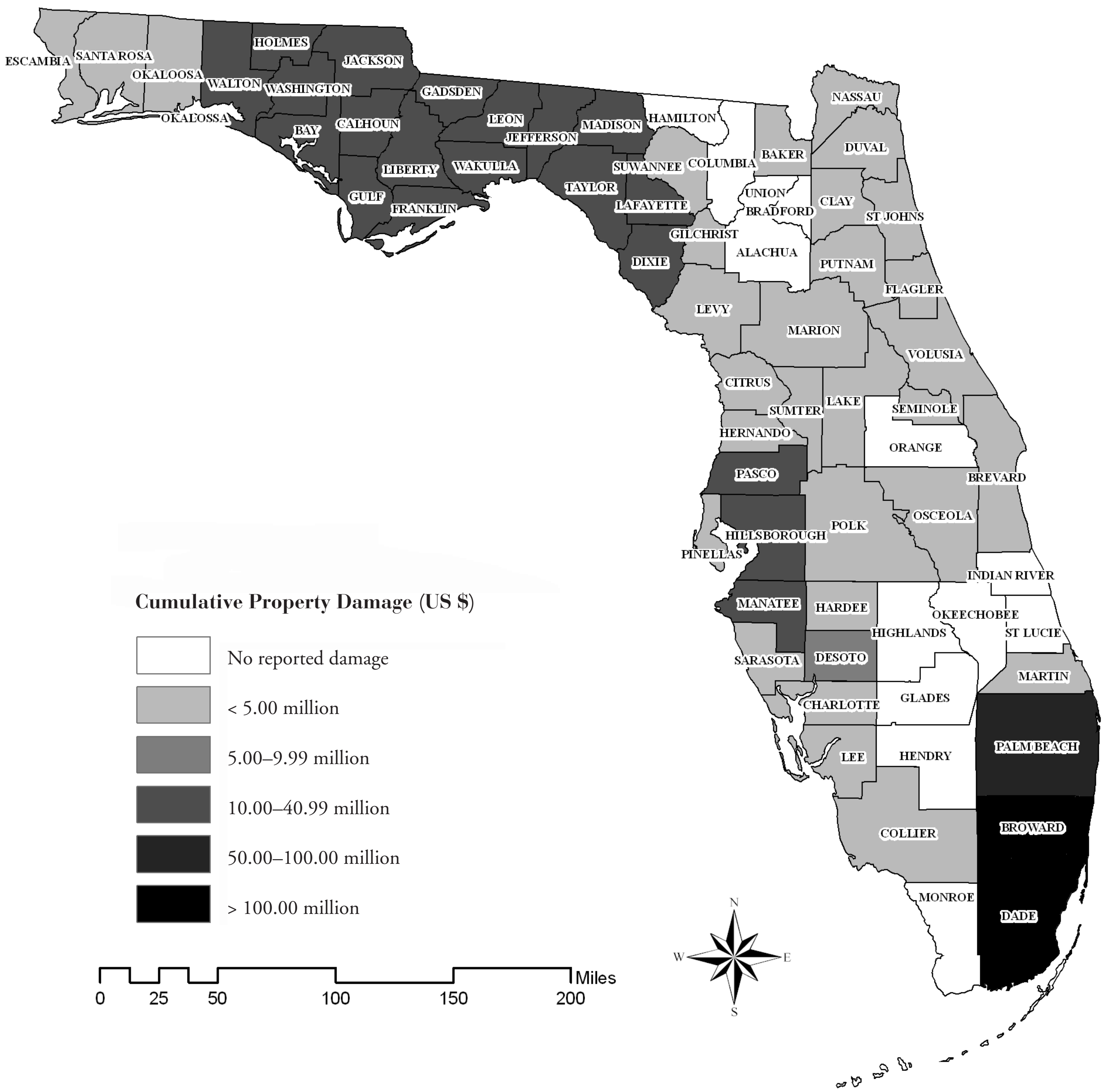

Figure 1. Cumulative property damage in Florida counties, 1997–2001.

precipitation (4.2 inches) increases the odds of a costly flood by 111%. A single wetland alteration permit in Florida has a negligible impact on high damage floods (only increasing the chances by .1%). However, a change in permits of one standard deviation (only 488 permits) increases the odds of a high-damage flood by 42%. Finally, the construction of a dam decreases the odds of a high-damage flood only very modestly, by less than 1%.

Planning Implications

The results of our study indicate that planning decisions made at the federal and local levels for Florida counties are important influences on flood damage, even after controlling for multiple biophysical and socioeconomic factors. Clearly, the strategic choices we make to develop and physically alter natural landscapes directly influence the

Table 3. OLS regression models predicting property damage from floods in Florida, 1997–2001.

	Model 1		Model 2		Model 3	
	B	Beta	*B*	Beta	*B*	Beta
Baseline socioeconomic variables						
Adjacent damage	.17008** (.02155)	.40743	.11926** (.02164)	.28890	.12800** (.02155)	.31007
Housing value density	.02152$^{\Psi}$ (.01159)	.08798	.02845** (.00989)	.12043	.02517* (.01216)	.10654
Biophysical variables						
Precipitation			.05873** (.01651)	.21505	.06353** (.01628)	.23260
Floodplain area			1.88×10^{-10} (1.28×10^{-10})	.07063	3.65×10^{-10} (1.60×10^{-10})	.13744
Flood duration			.02568* (.01107)	.16187	.02336* (.01105)	.14728
Stream density			.07012 (.14002)	.02786	.12890 (.14516)	.05122
Planning variables						
Impervious surface					-8.52×10^{-11} (3.64×10^{-10})	−.01792
Wetland alteration					.00038** (.00011)	.15071
Dams					−.00273 (.00172)	−.07122
FEMA CRS rating					−.02331** (.00910)	−.15105
Constant	4.14526** (.09716)		3.74184** (.19099)		3.74624** (.19632)	
N	383		367		367	
Probability > *F*	0.0000		0.0000		0.000	
R^2	0.1711		0.2495		.2812	
Root Mean Squared Error	1.0754		1.0081		.99208	

Notes:
Robust standard errors are in parentheses. The smaller sample size in models 2 and 3 is due to missing values in the precipitation variable.

$^{\Psi}p < .10$ $\quad$ $^{*}p < .05$ $\quad$ $^{**}p < .01$

degree to which communities are susceptible to damaging flood events. These findings may help Florida planners and flood managers reduce floods' costly impacts.

First, our results show that naturally occurring wetlands act effectively to attenuate floods. Although the total amount of impervious surface in an area is often cited as the culprit for increased flooding and associated property damage, these may result more from exactly where these surfaces are, and how they affect the natural environment. This result runs contrary to many studies cited above that

Table 4. Binary logistic regression models predicting high-damage flood events in Florida, 1997–2001.

		% change in odds if x changes by one			% change in odds if x changes by one			% change in odds if x changes by one	
	b	unit	*SD*	*b*	unit	*SD*	*b*	unit	*SD*
Baseline socioeconomic variables									
Adjacent damage	.2288** (.0379)	25.7	90.7	.1508** (.0459)	16.3	52.4	.1812** (.0479)	19.9	66.0
Housing value density	.0664* (.0275)	6.9	37.7	.0768** (.0273)	8.0	45.5	.0547$^{\Psi}$ (.0306)	5.6	30.6
Biophysical variables									
Precipitation				.1813** (.0451)	19.9	115.1	.1772** (.0441)	19.4	111.4
Floodplain areas				1.62×10^{-10} (2.90×10^{-10})	0.0	7.3	4.34×10^{-10} (3.77×10^{-10})	0.0	20.8
Flood duration				.0138 (.0200)	1.4	10.6	.0176 (.0211)	1.8	13.6
Stream density				.4331$^{\Psi}$ (.2576)	54.2	22.0	.4226 (.2723)	52.6	21.4
Planning variables									
Impervious surface							1.78×10^{-10} (8.03×10^{-10})	0.0	4.4
Wetland alteration							.0008* (.0003)	0.1	42.0
Dams							−.0085$^{\Psi}$ (.0047)	−0.8	−22.6
FEMA CRS rating							−.0102 (.0195)	−1.0	−7.3
Constant		−.8758** (.2076)			−1.8705** (.4161)			−2.1816** (.4591)	
N		383			367			367	
Log-likelihood full model		−243.709			−216.075			−210.385	
Likelihood ratio		41.628			75.417			86.798	
Prob. > likelihood ratio		0.000			0.000			0.000	
Cragg and Uhler's R^2		0.138			0.248			0.281	
% Correctly classified		60.05			69.75			71.12	

Note:
Robust standard errors are in parentheses.

$^{\Psi}p < .10$ $^{*}p < .05$ $^{**}p < .01$.

identify impervious surface as the development-based driver of floods, and matches Moglen and Kim's (2007) recommendation that planners locate development strategically in watersheds rather than relying too heavily on measures of imperviousness. However, by separating the variable measuring wetland development from the variable measuring impervious surface, we eliminate from the latter what may be its most important adverse hydrological impact: loss of wetlands. We noticed the same trends in related studies of floods at both the local jurisdiction scale and the watershed scale (Brody, Highfield, et al., 2007; Brody, Zahran, et al., in press). In both these cases, impervious surface had an only marginally significant effect on flood damage when a wetland alteration variable was also included in the model. In none of our analyses was the pair-wise correlation between wetland alteration and impervious surface variables high enough to pose a multicollinearity problem.

Altering or removing a wetland in order to construct a parking lot, road, or building reduces the local wetland capacity to capture, store, and slowly release water runoff, exacerbating local flooding. Our study estimates that one wetland permit increased the average cost of each flood in Florida by $989.62. Since each county had issued 407 such permits on average, they had on average increased the property damage each later flood would cause by $402,465.29. This wetland permit effect equates to, on average, $563,451 of flood damage per county per year, and an average of $30,426,354 per year for all of Florida. Interestingly, wetlands appear to reduce property loss even for high damage flood events, more so than dams and CRS activities.

These findings could have several important implications for decision makers. First, the concept that wetlands serve as a natural flood mitigation device and an economic asset should be more carefully considered in local land use plans and zoning ordinances before growth occurs. The planning goal in this case should be to allow development to proceed without compromising the hydrological function and value of wetland systems. Achieving this goal will involve identifying the locations of naturally occurring wetlands and then protecting these critical areas through local land use policies, such as zoning restrictions, overlay zones, land acquisition programs, clustered development, density bonuses, transfer of development rights, and so on. (For a more thorough discussion, see Brody & Highfield, 2005; Brody, Highfield, & Thornton, 2006). Proactive planning approaches may yield net economic benefits for localities by reducing costs associated with the repair of flood-damaged structures and the need for engineering alternatives (e.g., culverts, retention ponds, storm drains, etc.) to mitigate flooding when the natural systems are compromised.

Second, the economic burden resulting from altering a naturally occurring wetland should be borne by the individual permit applicant rather than the community at large. To fully internalize what is currently an externality, planning organizations ought to consider setting the acquisition costs of a wetland permit at an appropriate level (in our case at $989.62). Increasing the cost of acquiring a permit, and perhaps charging to maintain it, will reduce the attractiveness of altering wetlands in the first place. The majority of permits issued by the ACOE, including letters of permission, nationwide, and general permits, have no fee. Individual permits cost only $10 for individuals and $100 for commercial projects (for a more detailed explanation of permit types, see Highfield & Brody, 2006). Only 14.7% of the federal permits we included in our study are individual permits. Florida, however, imposes its own requirements before permitting wetland alterations, charging a separate set of fees, which are generally much higher. Local jurisdictions generally also have more regulatory control over natural resource issues in Florida than in other states, and, with appropriate information, could use local codes to set fees that effectively offset external costs to the community.

Our empirical findings also highlight the effectiveness of the FEMA CRS program in reducing property damage resulting from floods. Every time the CRS rating increases by one unit, reducing insurance premiums by 5%, the average amount of flood damage decreases $303,525. This result indicates that nonstructural mitigation techniques and implementing local land use policies (like lowering permitted densities in floodplains and acquiring floodplain land to retain as public open space) do reduce property damage from floods, principally because they direct growth away from vulnerable areas. In fact, one unit increase in the CRS rating buys a locality a buffer against approximately two additional inches of rain.

However, the CRS program offers a perverse incentive to reside in higher-risk areas. Discounting insurance premiums based on community-wide mitigation activities makes it less expensive for people to live in 100-year floodplains in those communities. Thus, the CRS system may actually facilitate development in the areas most vulnerable to flooding, even though residents of these areas are better insured against flood damage. This phenomenon helps explain why CRS ratings are ineffective in reducing high-damage floods. In fact, 56% of all wetland alteration permits in our sample were located in 100-year floodplains. Additionally, occasional extreme storm events can also cause flooding beyond the 100-year floodplain, where the

CRS program does not require mitigation. Local planners should direct growth away from vulnerable areas, such as floodplains, to make communities resilient in the long term. This is consistent with results from previous studies that have shown that land use planning can significantly reduce property loss from floods (Burby, 2005; Burby et al., 1988).

Our study also showed that dams do not significantly reduce flood damage in Florida if we control for influential biophysical, socioeconomic, and planning decision variables. Constructing community works projects may not be an optimal planning technique given their expense compared to nonstructural activities under the CRS program. For example, it would take 29 dams to decrease the odds of a high damage flood by only 22.6%. Increasing a community's CRS rating class by two would reduce flood damage by a similar amount at a lesser expense and without the risk of dam failure. The statistically insignificant effect we found dams to have on flood damage may result from their creating a false sense of security, encouraging development in vulnerable areas (Harding, 1974; Pielke, 1999; Tobin, 1995).

Finally, our results indicate that planners should consider multiple jurisdictions when devising flood mitigation strategies, as evidenced by the adjacent property damage variable, the most powerful predictor in our statistical model. Storms usually affect more than one jurisdiction, and the incidence of flooding is determined primarily by hydrological rather than institutional boundaries. Although most decision makers still plan for political jurisdictions, planning at the scale of the watershed or ecosystem will better protect critical natural resources and effectively mitigate the adverse impacts of floods, as the state of Florida already recognizes.

(For a detailed discussion of multi-jurisdictional ecosystem approaches to management in Florida, see Brody, Carassco, & Highfield, 2003; Brody, Highfield, & Carrasco, 2004).

Conclusion

Our study provides evidence that flood damage in Florida may not be solely a function of the amount and duration of precipitation, but also be driven by planning decisions affecting the natural landscape. Precisely where we choose to develop and how we protect communities from natural hazards influences how much property damage floods produce. Carefully weighing the costs and benefits of these decisions thus becomes critical to building sustainable, resilient communities for future generations.

This study is only a starting point in a longer research agenda. We attempted to analyze a very complicated socioeconomic and biophysical system, and as is often the case for studies of this type, we left most of the variation in the dependent variable unexplained. Further research is needed on several fronts. First, because of the scale at which others collect data on variables like property damage, our study was limited to the county as the unit of analysis. As suggested above, this unit may be inappropriate because flooding usually conforms to hydrological units rather than arbitrarily defined jurisdictional boundaries. Future research should focus on the watershed level to better account for upstream and basin-wide flooding effects. Second, our study covered only a 5-year time span and, thus, may not be representative of longer periods. Future research should consider a longer timeframe, even if this limits analyses to fewer variables and a smaller sample size. Third, our study examines only a few indicators of planning decisions. Future research should attempt to separate out the effects of specific CRS activities, and should consider building permits, infrastructure projects, and where wetland alterations are located within watersheds to better understand the impact of physical development on flood outcomes. Fourth, though we used the best data available at the time, future research may be able to take advantage of more recent and reliable datasets.

We suggest that external flood-related costs, which our work shows rise with permitted alterations to local wetlands, be born by those altering the wetlands. Setting appropriate fees should be possible, given the existing permitting mechanisms and associated charges in Florida and other states. This important topic deserves further investigation.

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Notes

1. Permit types (individual permits, letters of permission, general permits, and nationwide permits) differentiate among different types and intensities of human activities resulting in the alteration of naturally occurring wetlands. Individual permits involve the most extensive alteration of wetlands of over .5 acres. For a more detailed discussion of wetland permit types, see Highfield and Brody (2006).

2. Any area that the Florida Natural Areas Inventory has identified as having natural resource value and being managed at least partially for conservation is classified as a conservation area. National parks, state forests, wildlife management areas, and local and private preserves are included.

3. We chose the median instead of the mean because it was less likely to be upwardly skewed by extreme flood events.

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