Price of Permits: Measuring the Economic Impacts of Wetland Development on Flood Damages in Florida

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Abstract: Floods continue to pose a significant threat to the property and safety of human populations in the United States. The economic impact from floods is estimated in the billions of dollars annually, and these losses are exacerbated by increasing development. This article examines the impact of wetland alteration on flood damage among local jurisdictions in Florida over a 7-year period. Specifically, we measure wetland loss through the record of permits granted under Section 404 of the Clean Water Act. Results show that, after controlling for environmental and socioeconomic variables, the number, type, and location of wetland permits are a significant predictor of flood damages.

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Introduction

Floods continue to pose a significant threat to the property and safety of human populations in the United States, despite ongoing efforts to mitigate their adverse impacts. The economic impact from floods is estimated in the billions of dollars annually [Association of State Floodplan Managers (ASFPM) 2000]. These losses are exacerbated by increasing development for residential, commercial, and tourism uses, particularly in the coastal margin. Rising population density in coastal areas is associated with greater amounts of impervious surfaces, the alteration of hydrological systems (i.e., watersheds), and an overall diminished capacity for these systems to naturally hold and store surface water runoff. As a result, communities, households, and private property are becoming more vulnerable to damage from flooding (Mileti 1999). The development or alteration of wetlands is considered central to the loss of natural water retention within watershed units and increases in flood hazards for local communities. While the importance of wetlands for mitigating flood intensity and duration is understood, the degree to which cumulative wetland development affects the level of damage sustained by a community and the resulting economic impact has never been thoroughly investigated.

This study examines the impact of wetland alteration on flood damage among local jurisdictions in Florida over a 7-year period. We address the research question: *How much is it costing communities to alter or develop naturally occurring wetlands?* Specifically, we map and measure individual wetland alteration permits required under the U.S. Clean Water Act and correlate the number of granted permits with the amount of reported flood damage at the county level while controlling for socioeconomic, demographic, and environmental factors. Results indicate that individual permits issued within the FEMA special flood hazard areas (SFHAs) have a significant effect on increasing economic losses resulting from flood damage.

The following section reviews the literature on the role of wetlands in supporting hydrological systems, flood damage, and the link between naturally occurring wetlands and flood mitigation. Next, we describe the sample selection, measurement of variables, and data analysis procedures. The results are presented in two phases. First, we conduct correlation analysis between different permit types and reported flood damage. Second, we use ordinary least squares (OLS) multiple regression analysis to identify the most important factors explaining county-level flood damage across the state. Finally, we discuss how the results can provide direction for planners, hazard managers, and policy makers to reduce the amount of damage incurred by communities from flooding events.

Reducing the Costs of Flooding: Structural versus Nonstructural Techniques

Flooding is the most pervasive and costly natural hazard worldwide (Mileti 1999). Although loss estimates from flooding are variable, they all demonstrate the widespread and recurring threat posed by this hazard. For example, the ASFPM estimates flood damage ranging from 5 to 8 billion dollars annually (ASFPM 2000). Using the National Weather Service (NWS) *Storm Data* publications, Mileti (1999) estimated that property losses from floods were $19.6 to $196 billion from 1975 to 1994. Although damage estimates vary annually, standardized estimates point to rising financial losses during the last century (Pielke and Downton 2000). For example, Birkland et al. (2003) showed

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flood damages from 1900 to 1920 totaled $1.76 billion, as compared to $4.4 billion from 1980 to 2000.

The state of Florida alone incurred flood damages of approximately 1.1 billion dollars between 1997 and 2002 [National Climactic Data Center (NCDC) 2005]. Damages during this time period were driven by both the cumulative effects of hundreds of small flood events and large, spatially broad events. For example, in a 2-day period in early October 2000, Broward, Collier, Miami-Dade, and Monroe Counties received over a foot of rain, causing over $450 million of flood damage (NCDC 2005) and prompting over 51,000 individuals to request financial assistance from FEMA (2000).

Flooding and associated flood damage have been traditionally addressed through structural measures such as dams, levees, dikes, and channel improvements. Structural approaches to flood mitigation have certainly reduced or prevented flood damages in numerous areas for an abundance of flood events. According to the U.S. Army Corps of Engineers (USACE), flood damages from 1991 to 2000 were approximately $45 billion, yet flood control measures prevented over $208 billion of additional damage (USACE 2002).

However, beginning as early as the 1950s, researchers began to discover the limitations of structural approaches to flood mitigation. This well-documented research indicates that structural flood control projects can generate development in vulnerable areas that would otherwise have been undeveloped. When flood events exceed the capacity of a flood control structure, the resulting flood damages are significantly higher than if the area had been unprotected and thus less developed (White 1945, 1975; Hertzler 1961; Burby et al. 1985; Stein et al. 2000; Larson and Plasencia 2001). Furthermore, structural measures are not conceived without high financial and environmental costs. Since the 1940s, the USACE has spent over $(1999)100 billion on structural flood protection projects nationwide (Stein et al. 2000). These structures have adversely affected native fauna, water quality, and the function of hydrological systems (Birkland et al. 2003).

More recent thinking on flood mitigation has taken a nonstructural approach. The most widely implemented form of nonstructural flood mitigation comes in the form of the National Flood Insurance Program (NFIP), which was established in 1968 as an attempt to combat rising flood losses. The NFIP has, by many accounts, successfully brought flood insurance and a form of flood mitigation to the forefront of many communities, but it is not without its shortcomings. Several questions have been raised concerning the NFIP's effect on subsidizing and thus encouraging floodplain development, the overall equitability of the program, and the high financial costs of repetitive losses (Godschalk et al. 1999; Platt 1999; Birkland et al. 2003). In addition, the NFIP also allows for floodplain and wetland alteration in order to raise the floor elevations of structures in the 100 year floodplain (Birkland et al. 2003). Although this may serve as a protective step for residential and commercial developments in areas vulnerable to flooding, it may also again lead to adverse environmental impacts.

Perhaps the most sustainable and efficient form of nonstructural flood mitigation can be achieved through spatially targeted land use controls. Land use policies and regulations such as development restrictions, clustering, conservation overlay zones, transfer of development rights, etc., can help avoid costly flood events by directing growth away from vulnerable areas. For example, in Portland, Oregon, over 162 acres of flooded properties have been purchased since 1997 (ASFPM 2004). These purchases are complemented by stringent land use controls including restrictions on all residential development in flood hazard areas and the use of "environmental overlay zones" to protect natural features such as wetlands and riparian areas that help reduce flood events as well as flood damages (ASFPM 2004). Proactive planning measures that focus development either outside of the floodplain or in least vulnerable areas within the floodplain cannot only reduce floods, but also protect critical natural habitats and water quality and maintain the structure of key hydrological systems (Whipple 1998).

While land use policies can be effective in reducing the intensity and cost of floods, this approach is not without its own set of barriers. For one, local governments may shy away from implementing strict land use codes in floodplains for fear of legal repercussions and their constituents' stance on property rights (Platt 1999). Second, the administrative and jurisdictional nature of land use policies typically falls under the control of local governments. This "patchy" configuration of land ownership and local land use control does not lend itself to practical management of issues that occur at watershed, ecosystem, or regional scales (Szaro et al. 1998; Birkland et al. 2003). Finally, land use planning should be proactive and does not perform well when existing situations are in need of immediate correction. For example, Burby and French (1981) discovered a policy response they termed a "land use management paradox." In their study, communities often enacted strong hazard management policies only after floodplain development had occurred. Reactive land use policies are far less effective in accomplishing successful flood mitigation; once a hazard prone area is built out, remedial actions can be both financially and politically costly (Platt 1998).

Wetlands Effects on Flooding

As mentioned earlier, using land use policies to protect critical natural areas such as wetlands can be an important component of a successful flood mitigation program. Wetlands are considered to be one of the most valuable, yet seriously threatened, natural resources worldwide (Maltby 1991). For example, the United States has lost an estimated 53% of its total wetlands from anthropocentric activities, with the state of Florida incurring some of the country's greatest losses (Mitch and Gosselink 2000). The loss of wetlands was initially considered a result of agricultural practices converting wetland into pastures and croplands in upland areas (Zedler 2003). More recent research on coastal wetlands attributes their continued decline to urban development within coastal margins (USGS 1996).

Wetlands are considered important for maintaining a properly functioning water cycle (Mitch and Gosselink 2000; Lewis 2001). Early research on wetlands and flooding often looked at the differences between drained and natural wetlands as a basis for assessment. The results from these studies indicated that undrained peat bogs reduce low-return period flood flow and overall storm flows when compared to their drained counterparts (Boelter and Verry 1977; Heikuranen 1976; Verry and Boelter 1978; Daniel 1981). Later work using mostly linear regression analysis yielded similar results. For example, Conger (1971) showed that the ability of wetlands to store water significantly reduced peak flows for recurrence intervals of 100 years and below. Novitski (1979) studied four different types of wetlands and found that each had a negative effect on flood flows. He also showed that flows are only 20% as large in watersheds with 40% lake and wetland areas as compared to like watersheds without lake and wetland areas. Additional work by Novitski (1985) concluded that basins with as little as 5% lake and wetland areas may lead to 40–60% lower flood peaks.

Additional research utilizing simulation models also illustrates the flood-reducing role of wetlands. Ammon et al. (1981) modeled the effects of wetlands on both water quantity and quality of Chandler Marsh in south Florida. The results showed that maximum flood peak attenuation is higher with increasing areas of marsh. The authors concluded that Chandler Slough Marsh increases storm water detention times, changes runoff regimes from surface to increased subsurface regimes, and is "moderately effective as a water quantity control unit" (p. 326). Ogawa and Male (1986) also developed a simulation model to explore the potential of wetlands as a flood mitigation strategy. Using four scenarios of downstream wetland encroachment ranging from 25 to 100% loss, the authors found that increased encroachment resulted in significant increases in peak flow. While small degrees of wetland encroachment did not have significant effects on peak flows, wetland encroachment on upstream tributaries altered peak flows for several miles downstream. However, not all research concludes that wetlands have a significant effect on flooding. Padmanabhan and Bengston (2001) concluded from model simulations that wetland restoration in the Maple River watershed would not have significant effects on high-return period flood events.

Research based on observation also supports the notion that wetlands play an important role in reducing the degree of flooding. For example, recent findings demonstrate that wetlands are able to absorb and hold greater amounts of floodwater than previously thought. Based on an experiment that involved constructing wetlands along the Des Plaines River in Illinois, it was found that a marsh of only 5.7 acre could retain the natural runoff of a 410 acre watershed. This study estimated that only 13 million acres of wetlands (3% of the upper Mississippi watershed) would have been needed to prevent the catastrophic flood of 1993 (Godschalk et al. 1999). Other observational research concludes that there is a critical threshold for the effects of wetland loss on flood storage. In a study that utilized the record of streamflow data from stream gauge stations, Johnston et al. (1990) found that small wetland losses in watersheds with less than 10% of wetlands could have a significant effect on increased flood flows.

Research examining the effects of wetlands on flooding is varied, but overall it appears that the presence of wetlands in a watershed will reduce or slow downstream flooding to some extent. In fact, a comprehensive review of the literature conducted by Bullock and Acreman (2003) showed that wetlands play a significant role in modifying the hydrological cycle. The authors found that, for 23 of the 28 studies on wetlands and flooding, "floodplain wetlands reduce or delay floods" (p. 366).

Methods and Data Analysis

We selected Florida as the study area to examine the relationship between wetland loss and flood damage for several reasons. First, Florida has experienced one of the largest percentages of wetland loss of any state in the country (Mitch and Gosselink 2000). Since the 1700s, drainage for agriculture, channelization for human water supply, and most recently urban and suburban development have contributed to the conversion of more than half of the original wetland acreage. Second, rapid population growth and associated development over the last decade have resulted in a concentrated pattern of wetland alteration in the fringe or outside of urban areas (Brody and Highfield 2005). During the 1990s, Florida's population has increased 24% requiring the approval of thousands of state and federal permits to fill in wetlands. Third, due to its tropical and subtropical climate, Florida receives an abundance of precipitation annually (50–65 in.), oftentimes as sudden flooding events. As a result of these combined geographic and socioeconomic factors, many local jurisdictions across the state must constantly deal with chronic, repetitive flooding that causes significant damage and economic loss.

Concept Measurement

We measured the dependent variable, flood damage estimates, based on data obtained from the Spatial Hazard Events and Losses Database for the United States (Hazards Research Laboratory 2005). The Spatial Hazard Events and Losses Database for the United States (SHELDUS) is a county-level dataset for the United States detailing the characteristics of various natural hazards. Flood damage estimates by each county (the unit of analysis for this research) between 1997 and 2002 were downloaded from the online database. Previous to 1997, the National Climatic Data Center (NCDC) only reported estimated losses on a logarithmic scale. From 1997 onward, estimated damage was reported as raw estimates; hence, the selection of this 6 year time period. It is also important to note that the damage estimates deal only with floods. Damage resulting from hurricane impacts is not included in this analysis. All dollar figures were adjusted for inflation by consumer price index (CPI) correction factors to 2000 dollars and transformed (square root) to best approximate a normal distribution. Based on these calculations, we were able to measure normally distributed and standardized statewide flood damage estimates by county from 1997 to 2002 (Table 1).

We measured wetland alteration using a spatially-defined record of wetland permits as required by U.S. Army Corps of Engineers. Wetland loss has been measured in the past using remote sensing techniques (Kingsford and Thomas 2002) as well as statistical analysis on historical records tied to probable causes of loss such as canal dredging (Turner 1997; Day et al. 2000). However, one underutilized method of quantifying wetland loss is the record of permits issued by the U.S. Army Corps of Engineers under Section 404 of the Clean Water Act. Kentula et al. (1992) and Kelly (2001) were among the few researchers to use the permit record to estimate wetland losses. Stein and Ambrose (1998) also relied on similar data to assess prepermit and postpermit conditions of areas along the Santa Margarita River in California. They concluded that the permit process had failed at minimizing overall cumulative impacts to wetlands associated with the riparian system. Most recently, Brody and Highfield (2005) and Brody et al. (2006) also used the permit record to identify hot spots of development and explain the degree of local-level implementation of environmental policies in South Florida.

We obtained wetland permits issued under Section 404 of the *Clean Water Act* from the U.S. Army Corps of Engineers (USACE), Jacksonville District, through a Freedom of Information Act request. The permit record included the type of permit, the date issued, and the latitude/longitude of the permit. The permit types issued by USACE and analyzed in this study fall into the following four categories:

1. *Individual permits*: Necessary for projects that may result in significant impacts, these permits are required for wetland alterations exceeding 0.5 acre. Public notices, comment periods, and Section 401 water quality certifications are required under this permit type.
2. *Letters of permission*: These permits are required for smaller projects including mosquito control, erosion control, and

Table 1. Concept Measurement

Variable	Source	Description	Mean	Standard deviation
Estimated flood damage (transformed)	SHELDUS	Damage estimates by county corrected for 2000 dollars	13,463,148.45 (2,630.11)	35,518,863.93 (3,172.14)
Total annual average precipitation (in.)	Interpolated from National Climatic Data Center weather station data and locations	Surface of total precipitation at each location summarized by county	821.81	61.94
Individual permits in FEMA SFHA areas	U.S. Army Corps of Engineers, Jacksonville District	Geocoded individual permit types in SFHA areas	12.67	23.81
General permits in FEMA SFHA areas	U.S. Army Corps of Engineers, Jacksonville District	Geocoded general permit types in SFHA areas	15.15	59.41
Letters of permission in FEMA SFHA areas	U.S. Army Corps of Engineers, Jacksonville District	Geocoded letters of permit types in SFHA areas	11.37	45.26
Nationwide permits in FEMA SFHA areas	U.S. Army Corps of Engineers, Jacksonville District	Geocoded nationwide permit types in SFHA areas	41.82	48.29
Individual permits out of FEMA SFHA areas	U.S. Army Corps of Engineers, Jacksonville District	Geocoded individual permit types out of SFHA areas	13.58	19.37
General permits out of FEMA SFHA areas	U.S. Army Corps of Engineers, Jacksonville District	Geocoded individual permit types out of SFHA areas	8.04	16.95
Letters of permission out of SFHA areas	U.S. Army Corps of Engineers, Jacksonville District	Geocoded letters of permit types out of SFHA areas	4.58	8.69
Nationwide permits out of SFHA areas	U.S. Army Corps of Engineers, Jacksonville District	Geocoded nationwide permit types out of SFHA areas	70.37	88.09
Median improvement value	Florida Department of Environmental Protection	Median improvement value of all county parcels; taxable value less land value	1,443,380	1,626,082
Population density	2000 U.S. Census, GIS analysis	2000 U.S. Census population per square mile	196.05	276.83

residential development in freshwater wetlands not exceeding 0.2 ac of fill material, minor modifications to previously issued individual permits, backfill to eliminate boat basins or ramps, and wetland restoration efforts (USACE 1996a,b, 1997).

3. *General permits*: These permits are issued for specific types of activities on a nationwide or regional basis. General permits are issued when "activities are substantially similar in nature and cause only minimal individual and cumulative impacts" (USACE 2005). General permits are reviewed every five years and an "assessment of the cumulative impacts of work authorized under the general permit is performed at that time if it is in the public interest to do so" (USACE 2001). Examples of activities falling under general permit status in the Jacksonville District include residential development/fill, after-the-fact filling, road and bridge repair and construction, and utility work (USACE 2005).
4. *Nationwide permits*: By far the most issued permit type, nationwide permits are issued for specific activities that are deemed to have "no more than minimal adverse effects on the aquatic environment, both individually and cumulatively" ("Issuance of nationwide permits: Notice" 2002, p. 2023). Some categories of nationwide permits allow up to 0.5 ac of wetland to be filled. Public notices are not required, and 401 water quality certification may be required for a nationwide permit.

The permit database was geocoded in a geographical information system (GIS) and further subdivided by year and permit type. Of the 13,282 permits received from the USACE, only 11,899 had sufficient geographic information due to data entry errors or lack of geographic information altogether. Permits were then placed over FEMA coverages of digital flood insurance rate maps (DFIRMS) in GIS and further subdivided based on their locations in or out of special flood hazard areas (SFHA).

Several control variables were also measured and included in a model explaining flood loss estimates. First, precipitation was gathered from the National Climatic Data Center as total annual rainfall at each weather station. The number of stations with available data ranged from a minimum of 76 to a maximum of 86 statewide over the study period. For each year a raster surface was interpolated using an inverse-distance weighted procedure. Surfaces of total rainfall by year were averaged by county and summed across years. Elevation can play an important role in rainfall interpolation (Running and Thornton 1996). However, correlations between rainfall estimates and elevation were extremely weak and insignificant as expected, because Florida's terrain is relatively flat. Second, population density was calculated by dividing total population figures obtained from the U.S. Census Bureau by county land area. Finally, property tax data was downloaded by county from the Florida Department of Environmental Protection. To control for structure values, median county improvement values were calculated by subtracting land values from total property tax values.

Data Analysis

Data were analyzed in two phases. First, we calculated Pearson product-moment correlations between flood damages by county during the 7-year study period and the four types of issued wetland permits (both in and out of the floodplain, for a total of eight variables). This phase enabled us to identify which permit types and their locations are most closely related to flood damages and to select the most significant variables for inclusion in an explanatory model. Because our sample is relatively small, the correlation analysis served as a data reduction technique with which to select variables to include in an explanatory model. Second, we analyzed an ordinary least squares (OLS) multiple regression equation for the most significantly correlated permit variables, while

Table 2. Correlation Analysis of Flood Damages and Wetland Permitting Activity, 1997–2002

Variable	Damage	Total permits
Individual permits in FEMA SFHA	0.572[a]	849
General permits in FEMA SFHA	−0.052	1015
Letters of permission in FEMA SFHA	−0.046	762
Nationwide permits in FEMA SFHA	0.236[b]	2,802
Individual permits out of FEMA SFHA	−0.014	910
General permits out of FEMA SFHA	−0.049	539
Letters of permission out of FEMA SFHA	0.121	307
Nationwide permits out of FEMA SFHA	−0.071	4,715

[a]$\rho < 0.01$.

[b]$\rho < 0.05$.

controlling for socioeconomic, demographic, and climate-based factors. Tests for estimate reliability including specification, heteroskedasticity, multicollinearity, and spatial and serial autocorrelation exhibited no significant violation of OLS regression assumptions.

Results

As shown in Table 2, the relationship between wetland permits and flood damages varies according to permit type and whether a permit is located in or out of the floodplain. Of the eight separate permit variables analyzed, only two are significantly correlated ($\rho < 0.05$) with flood damages between 1997 and 2002. Individual permits located in special flood hazard areas (i.e., the 100-year floodplain) have a strong positive and significant ($\rho < 0.01$) association with flood damages. The correlation for nationwide permits located in the floodplain is also positive and significant ($\rho < 0.05$), although the effect is not as strong as for individual permit types. In contrast, neither general permits nor letters of permission are significantly correlated with flood damages. In addition, none of the four permit types located outside of the floodplain are significantly correlated with flood damages. In fact, except for letters of permission, each permit type has a negative relationship with flood damages.

Based on the results of the correlation analysis, we selected the two statistically significant permit variables (individual and nationwide within the floodplain) to analyze in a regression model. We also combined all permit variables outside of the floodplain into a single control variable analyzed along with environmental, demographic, and socioeconomic variables. As mentioned previously, this data reduction technique was necessary given the small sample size and the comparatively large number of potential independent variables. Based on the regression analysis (Table 3), individual permits issued within the floodplain were found to have a significant ($\rho < 0.001$) positive effect on the amount of reported flood damage while controlling for other factors. Nationwide permits, on the other hand, no longer had a statistically significant impact on flood damages when entered into the regression model.

While several permit types issued within the floodplain significantly increase the amount of flood damages incurred by a county, permits outside of the floodplain have a significant ($\rho < 0.05$) negative effect on the dependent variable. That is, compared to the mean damage estimate, permits to alter a wetland outside of flood hazard zones have a substantially lower degree of economic loss associated with flooding. Other control variables in the model also play important roles in explaining flood damage estimates. As expected, increasing amounts of precipitation result in significantly higher flood losses ($\rho < 0.001$). The median improvement value of structures and the population density also have a significant positive effect ($\rho < 0.01$) on flood damages from 1997 to 2002 at the county level.

On a final note, due to differences in measurement units, regression coefficients cannot be directly compared to assess their relative importance. The use of standardized regression coefficients does, however, allow such comparisons and reveals some interesting results. Individual permits issued in the floodplain have a greater relative effect on flood damage than the amount of precipitation. On average, one standard deviation change in the number of individual permits within the SFHA yields a 0.487 change in the standard deviation in flood damage, as compared to 0.406 for precipitation, which is a difference of 17%.

Discussion

Analysis of the data indicates that the dollar amount of flood damage sustained by local jurisdictions depends in part on the type and location of wetland permits issued. Wetland alteration projects within designated special flood hazard areas result in significantly more damage than similar projects outside of the floodplain. This finding can be explained by two interrelated occurrences, each with its own policy implications for reducing adverse economic impacts within local jurisdictions. First, building in areas most vulnerable to flooding will increase the amount and cost of damages over time. Land use planners and hazard mitigation managers should adopt policies to direct public and private development outside of the floodplain whenever possible. While local jurisdictions in Florida must address flooding issues in their comprehensive plans, over 40% of all permits to alter or fill in a wetland were issued within the 100-year floodplain. Special overlay zones, growth boundaries, tax incentives, and capital improve-

Table 3. Regression Analysis of Permitting Activity and Controls on Flood Damages from 1997 to 2002

Variable	Coefficient	Standardized coefficient	Standard error	*t*-value	Significance
Individual permits in FEMA SFHA	64.9480	0.4873	13.2440	4.90	0.000
Nationwide permits in FEMA SFHA	8.8872	0.1352	8.7545	1.02	0.314
All permits out of FEMA SFHA	−8.2833	−0.3105	3.1399	−2.64	0.011
Precipitation	52.8841	0.4065	11.5987	4.56	0.000
Median improvement value	1,504,693	0.3704	437,996.1	3.44	0.001
Population density	3.2913	0.2872	1.1638	2.83	0.006
Constant	−17,555.31		3,583.898	−4.90	0.000

Note: n=67; F-statistic=18.64; significance=0.00; R^2=0.650; adjusted R^2=0.616; Durbin-Watson=2.22.

ments programming are just a few of the land use policies available to local decision makers that could help guide development away from areas vulnerable to flooding (Burby 1998; Godschalk et al. 1999; Birkland et al. 2003).

Second, wetland alteration within floodplains increases impervious surface area and reduces or eliminates a wetland's ability to capture, hold, and store water runoff. Disrupting the natural hydrological system can exacerbate flooding or create flood problems in areas not originally considered vulnerable to this hazard. Thus, developments initially considered safe from flood threats become an unexpected target of expensive flood damage over time. Assuming some development will occur within SFHAs, it should not be allowed to adversely impact or eliminate wetlands of high hydrological value. These wetland areas can be identified before regional development takes place and protected through local land use and zoning ordinances. The planning goal in this case is to allow development to proceed without compromising the hydrological function and value wetland systems. Such a proactive approach may reduce costs related to both repair of damaged structures and engineering solutions (e.g., levees, culverts, retention ponds, etc.) used to mitigate floods when the natural system is no longer capable of doing so.

In addition to the general location of wetland alteration, the type and scale of the project also has a major impact on the degree of economic loss incurred from flood damages. Large development projects that involve altering wetlands greater than 0.5 ac in the floodplain translate into significantly higher damage estimates than smaller disturbances. Large developments often entail greater areas of impervious surface that increase water runoff and exacerbate flooding. When these projects accumulate over time in a concentrated area, a normal rainfall event can trigger unexpected levels of flood damage. Local planners and decision makers must better respect the dynamic boundaries of the floodplain and position larger projects in areas less vulnerable to flooding. That is not to say that the cumulative effects of altering small areas of wetlands will not translate into costly flooding problems over time. Our study examined only a 7 year period, which may not be long enough to capture the impacts of projects considered to have minimal adverse effects on wetlands and aquatic environments. However, based on the results of this study, the scale of wetland permits, not their sheer numbers, make the greatest contribution to flood damage.

Issuing permits to develop large amounts of wetlands in areas known to be vulnerable to flooding can contribute to significant economic losses over time, particularly since these losses accumulate from one year to the next. Because the developer rarely absorbs the costs associated with flood damage, the true price of permits is paid by government and the local community. Making decisions to reduce flood damage and facilitate sustainable physical and economic development over the long term depends on incorporating critical data into the planning process. Using the wetland permit record to monitor cumulative development patterns and make proactive land use decisions before damage occurs is one approach that can help local communities more effectively avoid flood hazards and their costs. Providing communities access to these types of data through information sharing, joint database production, and technical assistance programs is thus critical to successful land use planning and hazard mitigation.

Conclusion

This study is an initial attempt to estimate the economic costs of wetland alteration at a relatively large spatial and temporal scale. Results provide valuable information to planners and hazard mitigation specialists on how the type and location of permits to develop a wetland can exacerbate flood damage over time. Understanding that there is a price to pay for permanently altering the hydrology of certain wetlands may foster the development of more hazard resilient and economically sustainable communities in the future.

No study is without its limitations, and this one is no exception. While our results generate some useful insights into the potential costs associated with wetland alteration, they should only be considered a starting point for understanding the relationship between wetland development and flood damage. The results reported here must be placed in the context of the data and measurement constraints. Additional research is needed on several fronts before any conclusions can be made on the relationship between wetland alteration, flooding, and flood damages.

First, a sample of 67 jurisdictions lacks statistical power and restricted the number of independent variables we could include in the model. Larger sample sizes covering more diverse regions and multiple states would allow for a more fully specified model and increased confidence in interpreting the results. Second, while we relied on the best available data to measure flood damage, more detailed information collected at a finer spatial resolution would improve the usefulness of our results. Previous research has called for an improved and systematic data collection procedure for recording damage estimates of hazards [Mileti 1999; National Research Council (NRC) 1999; Downton et al. 2005]. Although the *Storm Events Database* and the database located at ⟨sheldus.org⟩ is an invaluable resource, they are limited to observation-based estimates compiled at the county level. An analysis of this type would greatly benefit by more refined methods of damage estimation at the site level, where we already have permit locations.

Third, a study period of 7 years may not be long enough to capture the more subtle effects of wetland alteration on flood damage. Future research should not only examine multiple states and different geographic regions, but also consider the historical record of flooding. Again, our study was limited by the available data. Fourth, a cross-sectional analysis of the data eliminates the ability to detect temporal lag effects between independent and dependent variables. A larger sample size may allow for more sophisticated statistical analyses (e.g., panel data, autoregressive models, etc.) that incorporate the impacts of wetland alteration at time 0 on flood damages at time 1. Fifth, more data needs to be collected to measure control variables (e.g., more accurate measurement of undamaged property values) when testing the effects of wetland alteration on flood damage. These data include land use and land cover change, policy responses to repetitive damage over time, major drainage projects or engineering solutions to flood mitigation, etc. Finally, case study analysis of specific local jurisdictions would complement statistical analyses and provide a more detailed contextual picture of how wetland alteration may contribute to flooding and what communities are doing to respond to chronic flooding events.

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