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Understanding the Notion between Resiliency and Recovery through a Spatial-Temporal Analysis of Section 404 Wetland Alteration Permits before and after Hurricane Ike

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Abstract**—**Historically, wetlands in the United States have been lost due to agriculture, anthropogenic activities, and rapid urbanization along the coast. Such losses of wetlands have resulted in high flooding risk for coastal communities over the period of time. In addition, alteration of wetlands via the Section 404 Clean Water Act permits can increase the flooding risk to future hurricane events, as the cumulative impact of this program is poorly understood and under-accounted. Further, recovery after hurricane events is acting as an encouragement for new development and reconstruction activities by converting wetlands under the wetland alteration permitting program. This study investigates the degree to which hurricane recovery activities in coastal communities are undermining the ability of these places to absorb the impacts of future storm events. Specifically, this work explores how and to what extent wetlands are being affected by the federal permitting program post-Hurricane Ike in 2008. Wetland alteration patterns are examined across three counties (Harris, Galveston, and Chambers County) along the Texas Gulf Coast over a 10-year time period, from 2004-2013 (five years before and after Hurricane Ike) by conducting descriptive spatial analyses. Results indicate that after Hurricane Ike, the number of permits substantially increased in Harris and Chambers County. The vast majority of individual and nationwide type permits were issued within the 100-year floodplain, storm surge zones, and areas damaged by Ike flooding, suggesting that recovery after the hurricane is compromising the ecological resiliency on which coastal communities depend. The authors expect that the findings of this study can increase awareness to policy makers and hazard mitigation planners regarding how to manage wetlands during a long-term recovery process to maintain their natural functions for future flood mitigation.

Keywords**—**Ecological resiliency, Hurricane Ike, recovery, Section 404 permitting, wetland alteration.

I. Introduction

POST-DISTURBANCE period of renewal and recovery after a disturbance can encourage new developments and reconstruction in an affected community [12]. Such urban development makes significant contributions to wetland loss, as research concerning wetland declination in the coastal margin suggests that urban development is the central cause of wetland losses [9], [21]. Eventually, by losing naturally occurring wetlands during the post-disturbance phase of recovery, coastal communities are more prone to flood risk to future hurricane events [19]. This research is an important starting point for investigating the notion that post-disturbance of renewal and recovery after a hurricane can accelerate the alteration of wetlands via permitting, which can erode the flood resilience of coastal communities. In other words, the very act of restoring human communities may increase their vulnerability to future flood impacts.

Wetland losses pose high risks and future threats to coastal communities. The U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (EPA) established Section 404 of the Clean Water Act (CWA) in the late 1970’s to protect and regulate wetlands in the United States. However, several past studies showed that the implementation of a wetland alteration permitting program in the U.S. can hinder a net gain in wetlands, as net loss is higher than gain in many cases [3], [13], [16], [18]. Such wetland losses disrupt ecological resiliency by reducing essential ecosystem services and landscape functions of wetlands such as flood attenuation, storm surge buffers, erosion control, water quality improvements, and wildlife habitat [3], [15], [22]. According to the Millennium Ecosystem Assessment, such ecosystem services that support human life are possibly worth US$33 trillion per year [1]. The importance of wetlands and their impacts along the coast, however, has been neglected [3]. As a result, by losing wetlands at an increasing rate coastal communities are becoming less resilient [7]. Thus, from an ecological resiliency perspective, it is important to understand the impact of the USACE wetland alteration permitting program, especially since a relatively small amount of empirical research has been conducted on this issue.

Based on the historical evidence, coastal cities in the U.S. have always faced risks from climate-related events such as storms and coastal flooding. Hurricane Ike was one of the biggest disturbances among them. In 2008, this event gave a striking reminder of its existence. It is well known that hurricanes have destructive effects on human communities and infrastructure. Coastal communities affected by hurricane events undergo a long-term recovery and renewal processes.

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During the recovery of destructive hurricane events, structural mitigations (levees, dam constructions, etc.) [5], urban development, and reconstruction along the coastal cities have caused significant changes and increased the risk. Some of the key findings from previous research are highlighted here, 1) by developing new levees and dams after disaster, the community increases risk, 2) non-structural measures are consistently more effective than structural measures in preventing flood damage [1], [2], [5], and 3) none of the structural approaches significantly reduced insured residential property damage from floods [5]. Moreover, conflict arises among decision makers in disaster-affected areas when they are seeking to reconstruct [12]. As a result, holistic recovery and renewal goals may not have been achieved due to unequal attention towards resources and values. Thus, the effects of developments, during post-disturbance period of renewal and recovery processes, on the broad geographic patterns of wetlands need to be investigated. Since development has caused significant changes on urban landscapes, such as continuous production of impervious surfaces [1], [2], and wetland alteration [5], the impact on wetlands during post-disturbance recovery process is worth exploring.

The purpose of this research is to examine how wetlands are impacted by federal permitting during the post-disturbance renewal and recovery processes. We choose Hurricane Ike as the disturbance event, and investigate post-Ike wetland developments in three Ike-affected counties in coastal Texas via wetland alteration permitting. We 1) conduct a comparative analysis of pre-post- Ike permits categorized by four permit types (see [1] for more information) based on the numbers, 2) examine what types of wetlands (palustrine and estuarine) are impacted by the USACE permitting program and conduct a percentage change analysis based on pre-post-Ike scenario, 3) analyze the locations of wetland alteration permits in relation to 100-year floodplain areas and different storm surge zones, and compare pre-post- Ike percentage, and 4) finally, investigate the relationship between the number of permits and insured losses after the Hurricane Ike event.

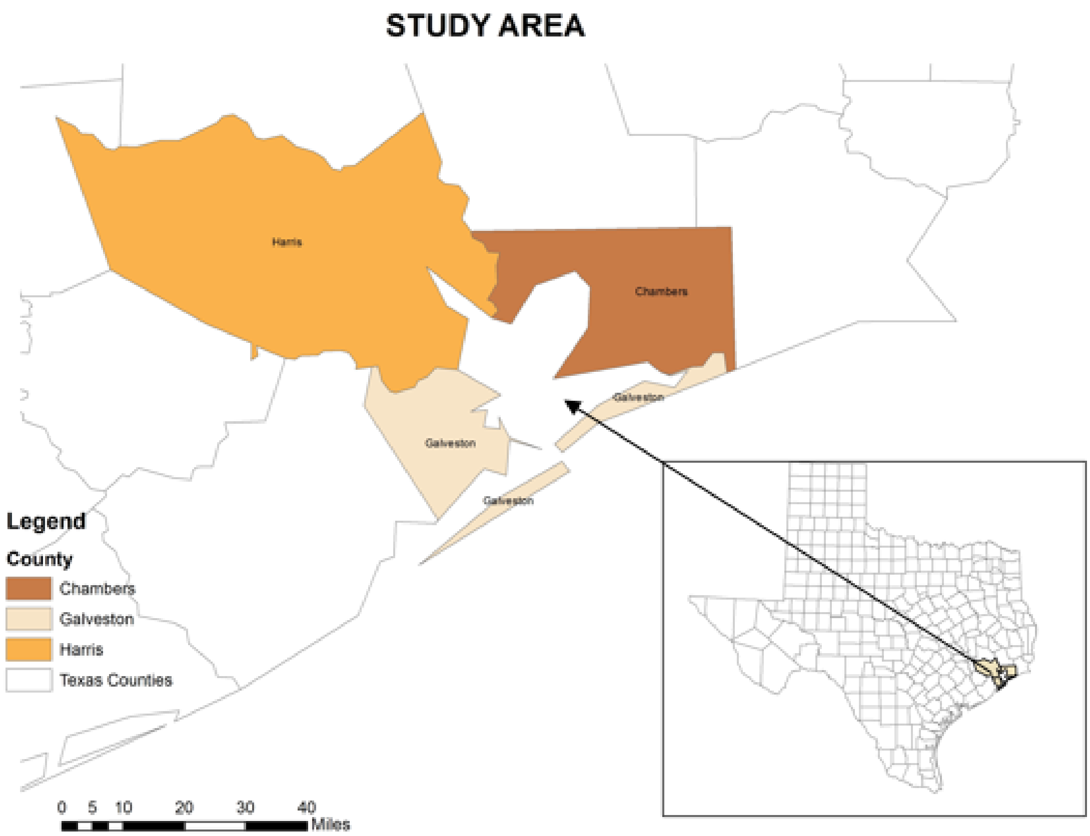

Fig. 1 Map of Texas State with study areas highlighted. Enlarged map shows the Harris, Galveston, and Chambers County

II. Methods

Harris, Galveston, and Chambers Counties in the Texas coastal belt were selected as the study area to investigate the impacts of the USACE wetland alteration permitting program in the post-Hurricane Ike recovery processes (Fig. 1). Selecting these three counties as the study area are ideal for this analysis since all of these counties experienced a devastating impact from Hurricane Ike, followed by a post-Ike period of recovery and renewal processes (Hurricane Ike Impact Report- December 2008). Moreover, a study concerning Houston-area fresh water wetland losses over the past two decades found that the greater Houston metropolitan area has already lost approximately 24,600 of the 447,949 acres of natural fresh wetlands [11]. Their study highlighted that Harris County has already lost 15,853 of the 54,479 acres (almost 30%) of fresh and tidal wetlands, which is highest among all eight counties in this region [11], whereas in Galveston, the loss is 1,066 of the total 14,316 acres of wetlands, and ranked third highest among them. In Chambers County, the loss is only 255 of the 58,041 acres of wetlands, low when compared with Harris and Galveston counties. Their report also highlighted that 62% of total wetland losses in Greater Houston were due to residential and commercial or industrial development projects [11]. Thus, it can be interpreted that high wetland losses occur in those areas (particularly in Harris County) where population concentration and urbanization is increasing. In addition, more developments on wetlands are leading towards more concrete pouring, which is increasing impervious surface area. As a result, the storage capacity for storm water runoff is being reduced, which in turn leads to increased flood risk [1], [2].

We selected the wetland alteration permit data that was obtained from the USACE database as a unit of analysis. We analyzed federal permits issued under Section 404 of the Clean Water Act from 2004-2013 within the three counties. [1]-[3], [8]-[10], [13] and [14] were among the few researchers who used permit records to identify the wetland losses, flood damages, hotspots of development, and peak streamflow in relation with wetland alteration. Permit data for this time period was extracted from a more extensive record of alteration ranging from 1991-2014 (Fig. 2). All of the permits in the database have geographic coordinates (latitude and longitude). These coordinates were used to plot them as a vector point layer in ArcGIS 10.2.1 (Geographic Information System software) to describe the permitting pattern graphically and statistically. Using ArcGIS, these points were analyzed based on the categories of permit types (as discussed in the literature review) and pre-post Ike period.

We categorized a group of variables to descriptively analyze the pattern of wetland alteration over the study period.

TABLE I
CONCEPT MEASUREMENT

Variables	Description	Measurement	Data Source	Range	Mean	Standard deviation
GP	Geocoded general permit types	Number of permits from 2004-2013	USACE	7-53	39.67	23.22
IP	Geocoded individual permit types	Number of permits from 2004-2013	USACE	45-245	140.33	81.92
LOP	Geocoded letter of permission permit types	Number of permits from 2004-2013	USACE	7-69	41.33	25.74
NWP	Geocoded nationwide permit types	Number of permits from 2004-2013	USACE	67-595	295.33	221.38
Flood Plain	FEMA defined 100-year plain area	% of 100-year floodplain	FEMA Q3 data	20.12-51.21%	39.39%	13.74%
Surge Zone	Category 1 to 5 surge zones	% of surge zones	NOAA	9.03-81.32%	56.73%	33.73%
Palustrine Wetland	Non-tidal forested, scrub/shrub, aquatic, and emergent wetland	% of palustrine wetlands	NOAA, Coastal Change & Analysis Program (2006 & 2010)	7.51-24.93%	14.15%	7.80%
Estuarine Wetland	Tidal forested, scrub/shrub, aquatic, and emergent wetland	% of estuarine wetlands	NOAA, Coastal Change & Analysis Program (2006 & 2010)	0.32-14.69%	7.80%	5.88%
Insured Loss (Hurricane Ike)	Content plus building damages paid per household	Logged NFIP claims for flood losses after Hurricane Ike (2008)	NFIP	3.06--6.09	4.95	0.32
		Absolute NFIP claims for flood losses after Hurricane Ike (2008) in US dollars	NFIP	$0-- 1,239,244.43	$116,345.15	$95,871.49

Variables of interest included permit type, C-CAP (Coastal Change Analysis Program) land cover data, FEMA (Federal Emergency Management Agency) defined 100-year floodplain, insured losses, and storm surge zones (categories 1-5) to analyze the wetland alteration permits after Hurricane Ike. Land cover data were used to understand the impact on wetland types; 100-year flood plain data were used to identify the percentage of permit location within the flood plain; and 1-5 category surge zone data were used to identify the number of permits within five different zones. It is important to note that all of these analyses have examined for both before-and after-Hurricane Ike scenario to establish a relationship between the number and type of permits across the study area. A concept measurement table based on the study area is showing range, mean, and standard deviation of variables that has been considered for this study area (Table I).

III. DATA ANALYSIS

In this study, we conducted descriptive spatial analyses of federal wetland alteration permits across the study area to identify the percentage change of post-Ike permits compare to pre-Ike permits. This phase enabled us to identify the percentage increase or decrease of permits after Hurricane Ike in the study area based on permit types (general, individual, nationwide and letter of permission types of permits, location of permits such as inside or outside of the floodplain, permits within different storm surge zones, and type of wetland impacted by the alteration permits (palustrine or estuarine).

Finally, we conducted a hot spot analysis using the CrimeStat IV program [23] to investigate the relationship between insured losses after Hurricane Ike and permits issued during the period 2009-2013. Both the claim and permit data analyzed in this research are point data (Figs. 3 and 4), because CrimeStat considers each dataset as point locations with X and Y coordinates. It is important to note that this study only considered the number of claimed losses from September to December 2008.

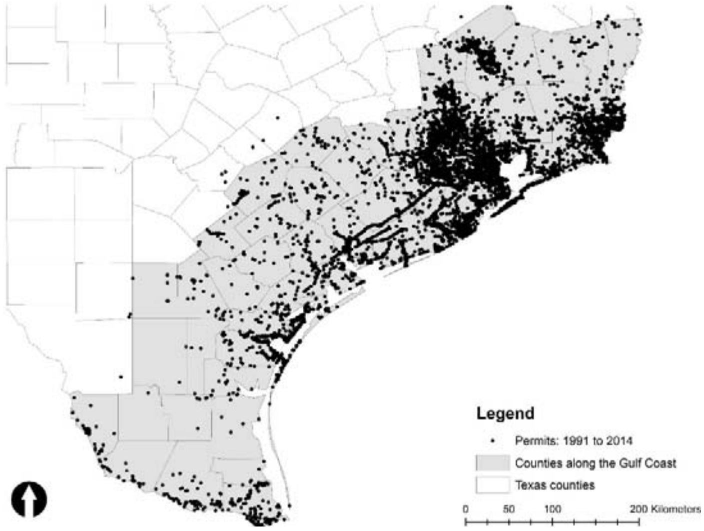

Fig. 2 Map shows the location of Section 404 wetland alteration permits from 1991-2014

IV. Results

By calculating the number of pre-post Ike permits, we measured the percentage change to identify the difference between post-Ike (2004-2008) and pre-Ike (2009-2013) permits (Table II). By comparing the number of permits for the pre-post Ike period, it is evident that permits increased after Ike in the study area. Among the four permit types, there was a 106.56% increase of individual permits and 6.87% increase of national permits in the study area. The increasing trend of individual and nationwide permits after Ike indicating that redevelopment or construction of larger-scale development projects was impacting naturally occurring wetlands. In contrast, for letters of permission and general permits, a large percentage of permits were decreased after Ike in the study area as a whole.

When we analyzed the number change of permits by individual counties, we found that 679 wetland alteration permits were issued within the study area in the pre-Ike period. Among those, 57.58% permits were issued in Harris Chambers County. In contrast, after Hurricane Ike, 704 permits were issued: where 66.45% were in Harris, 23.55% in Galveston and 10% in Chambers County. Comparative analysis between before and after Ike revealed that permitting activities after Hurricane Ike increased in Harris and Chambers County, but decreased in Galveston County. Four types of permit analysis showed that individual permits (IP) were increased after Ike in all three counties compared to the before-Ike scenario. This suggests that larger developments with more than 0.5-acre impacts took place on these wetlands. Conversely, both general and letter of permission types of permits decreased (Table II). From 2009-2013, a significant number of individual permits were increased in Harris (63.12%) and Chambers County (86.04%). However, the number of nationwide permits (NWPs) persisted in the same percentage, only a 10.54% increase in Harris County after Ike.

Next, we analyzed the C-CAP land cover data to investigate how undeveloped land cover is developed by the permitting activity. Based on the C-CAP land cover data, post-Ike wetland permitting activities decreased on the developed land (4.43%) and increased on the developed land (9.07%) in all counties. Further, we categorized the undeveloped land class into two wetland types: palustrine and estuarine, to determine which wetland type is impacted by post-Ike wetland alteration permitting. However, results show that permits issued on palustrine wetlands substantially increased (58.33%) after Hurricane Ike, suggesting that the study area is losing a high amount of flood-water storage capacity and increasing its risk of flooding to future storm events [3]. In contrast, permits issued on estuarine wetlands decreased in study area.

Previous studies showed that naturally occurring wetlands are important flood mitigation devices for those areas where flood vulnerability is high [3], [9]. The results from the location analysis of permits showed that the number of permits significantly increased within the 100-year floodplain after Ike in Chambers County (Fig. 5). In contrast, the number of permits decreased in Galveston County and remained similar in Harris County, compared with before-Ike permitting activity. Permits issued within the floodplain during the post-Ike period were increased by 5.01% in the study area. Findings from the location analysis of permits suggest that after Hurricane Ike, wetland permits in the study area counties were issued more than before Ike in the 100-year floodplain. Future flood impacts can be further exacerbated because of this.

Next, by spatially analyzing the location of permits within five surge zones, we found that post-Ike permits were increased on the category 2 (12.12%) and category 5 (76.19%) zones in the study area. Analysis of permit types based on storm surge zones revealed similar results as in the 100-year floodplain study. Conversely, nationwide permits increased along with individual permits during before-Ike permitting activity.

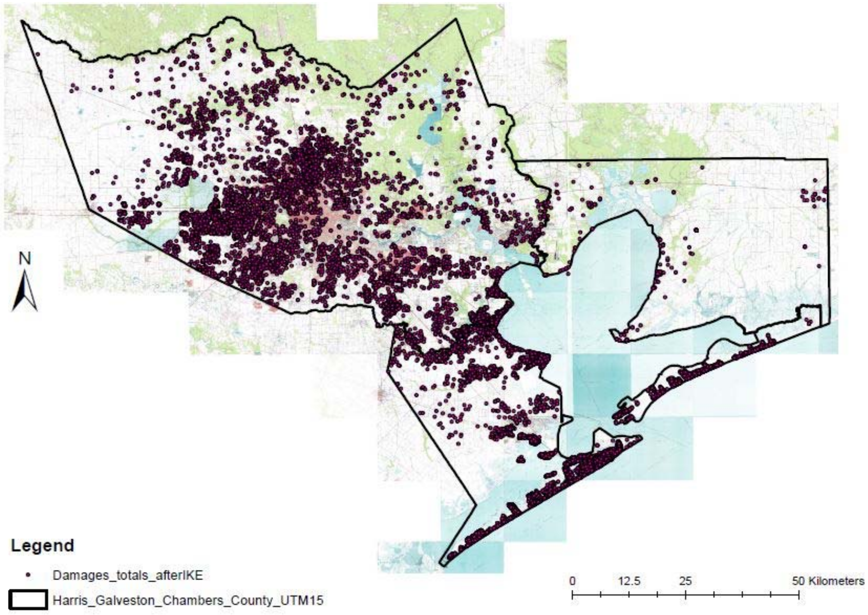

Fig. 3 The point location of claimed losses after Hurricane Ike (September-December 2008)

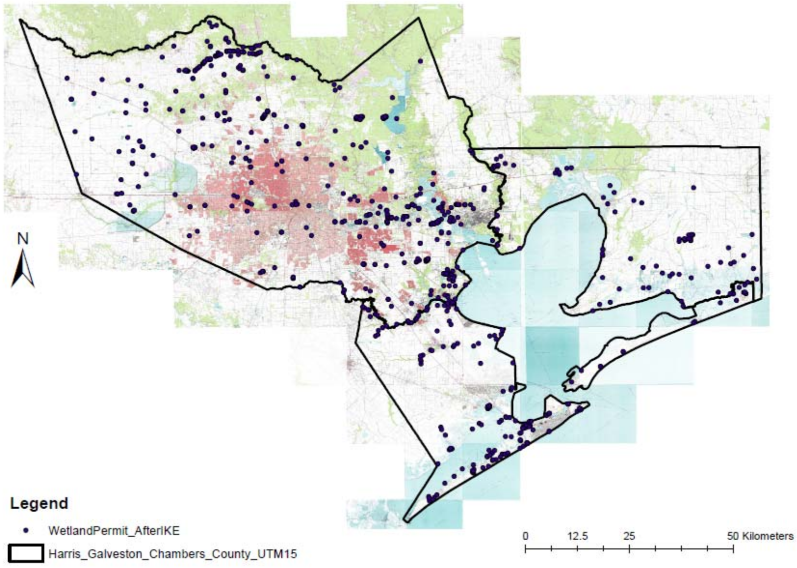

Fig. 4 The point location of permits issued after Hurricane Ike (2009-2013)

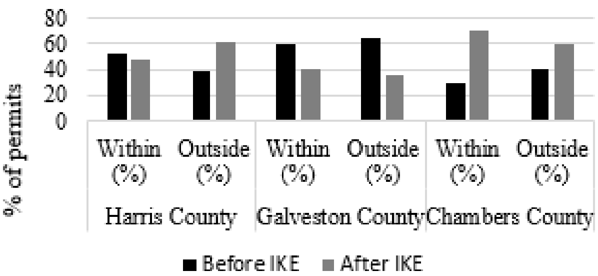

Fig. 5 The percentage of permits within and outside of 100-year floodplain

Finally, we used two hotspot mapping techniques to determine the spatial grouping relationship between the claimed insured losses after Hurricane Ike and permitting activities. After examining both hot spot maps, we identified that one spatial ellipse of alteration permits in Harris County and three in Galveston County established spatial grouping relationships with insured losses. These groupings of hotspots suggest that permitting activities were still being issued where damages occurred after Hurricane Ike. Further analysis on the types of permits within these spatial hot spots showed that 57% and 36% of permits were categorized as IP and NWP, respectively. These results indicate that within the Hurricane-damaged zones, wetlands are impacted by both larger scale and smaller scale developments.

V. Discussion

Recovery, after disaster events, rarely concerns or acknowledges natural systems like wetlands, though they have potential landscape functions for making a resilient coastal community. Therefore, it is essential to protect wetlands instead of encouraging new developments using the wetland alteration permitting program during recovery in hurricane affected areas. In this way, coastal communities can reduce the impact of massive future disaster events. A comparative analysis was therefore necessary to understand how cumulative development activities associated with wetland alteration permitting are impacting wetlands during the recovery process. To do so, this study analyzed the Section 404 alteration permits in before- and after hurricane scenarios. Additionally, analyses of location variables indicate that permitting activities are increasing within the flood-vulnerable zones, which reveals the fact that further losses of wetlands can exacerbate future flood risks even more. Finally, these findings can provide a guideline to planners and policy makers on how to manage wetlands during a long-term recovery process after a disaster event. Thus, these research findings will be helpful for the land-users, land-developers, and policy makers.

First, results show that after Hurricane Ike a large percentage of wetland alteration permits were issued within 100-year floodplain. Particularly in Chambers County, where the numbers are higher than before Ike, while the percentages are almost the same in Harris County. These findings indicate that wetland alteration is still taking place within these flood-vulnerable zones, where coastal communities experienced high flooding damages during hurricanes. These damages need to be taken into account when future permits will be granted within the 100-year floodplain to aid in the recovery process. Wetland alteration permits within the floodplain: 1) Increase impervious surface areas, which eventually decrease flood storage capacity during flooding events [3]; 2) Cause expensive flood damages [9]; and 3) Exacerbate and elongate flooding events, which cause more economic disruption. Therefore, to reduce potential flood risks within the 100-year flood plain, it is necessary to restrict permitting activities, especially with regard to large-scale and cumulative small-scale developments. Conversely, an elaborate review process revealed that permitting activity dealing with low impact developments (restoration and mitigation) can occur within the floodplain without negative impact.

Second, this research reveals that the majority of permits were issued within surge category zone 1 across the study area. It also illustrates that wetland alteration permits increased after Ike, particularly in Harris and Galveston Counties. This result indicates that developments are continuing in onshore areas, which have higher flooding risk during all types of hurricanes. Thus, it is necessary to reduce the wetland loss as well as increase the wetland functions. One important planning policy should be controlling wetland alteration permits by buffering urban growth. This should be an essential consideration for hazard mitigation planners and policy makers.

Third, results indicate that after Ike, the threat of alteration has significantly increased for palustrine wetlands. The primary reason for palustrine wetland alteration is large-scale developments (more than 0.5 acres) in coastal wetlands. On this basis, it can be said that networks of palustrine wetlands are being modified and leading to greater flooding damages because palustrine wetlands can play a major role in regulating disturbances by mitigating the impacts of flooding, storing floodwater and slowly discharging it [4], [6], [20]. Subsequently, all important functions of palustrine wetlands – including regulating, supporting, biological, provisioning, and cultural functions – will continue to be reduced. Thus, it is important to involve multiple agencies (e.g. ecologists and hazard mitigation planners) along with government bodies to review land use decisions that will impact wetlands.

TABLE II
Percentage Change of Wetland Alteration Permits before and after Hurricane Ike

Variables		Pre-Post Ike		% change
		Pre-Ike (no. of permit)	Post-Ike(no. of permit)	
Permit type	GP	80	15	-81.25%
	IP	122	252	**106.56%**
	LOP	84	17	-79.76%
	NP	393	420	**6.87%**
C-CAP land cover data 2006	Developed	271	259	-4.43%
	Undeveloped	408	445	**9.07%**
	Palustrine	72	114	**58.33%**
	Estuarine	52	42	-19.23%
100-yr floodplain	Within	399	419	**5.01%**
	Outside	280	285	**1.79%**
Storm surge zone	Category 1	153	144	-5.88%
	Category 2	33	37	**12.12%**
	Category 3	65	40	-38.46%
	Category 4	42	22	-47.62%
	Category 5	21	37	**76.19%**

Fourth, this study finds that, based on permitting activities, wetlands are being altered in areas where the most flood losses were claimed in response to Hurricane Ike. This finding suggests that the Section 404 wetland alteration permitting program is poorly implemented from a resiliency perspective, and a more detailed review process should be established before issuing permits in a disaster-impacted area.

Fifth, the research findings show that after Hurricane Ike, a greater percentage of individual and nationwide permits were issued. After Ike, mostly larger scale development (0.5 acre or >0.5-acre impact) took place in study area. It also reveals that impervious surfaces (parking lots, roads, rooftops, etc.) increased in all three counties since a large amount of wetlands were altered (see [1]-[3] for more information), which eventually increased the flooding risk even more and decreased the infiltration by reducing the capacity of storing, holding, and discharging flood waters [1], [2], [17]. Since wetland alteration increases impervious surface area, policy makers should consider the adverse impacts when issuing new permits. Additionally, decision makers should carefully review the Individual and Nationwide Permit process and control the total number based on an impact assessment. In regards to Letter of Permission (LOP), the results show that after Ike, LOP permits were decreased significantly compared with the before-Ike scenario. This also suggests that less restoration and mitigation was executed after Hurricane Ike. As a result, the study area is continuously losing flood reduction capacity since Individual and Nationwide Permits have a larger impact on coastal wetlands. In this regard, decision makers can adopt a policy to balance the numbers and types of permits by setting a time frame.

Finally, based on above discussion, it can be said that a storm like Hurricane Ike might be seen as encouragement to develop. Particularly, larger scale developments (with a >0.5-acre impact) were taking place during the recovery process. As recovery is more of a regionally based phenomenon, cumulative impacts on wetlands should not be neglected. Additionally, the spatial pattern of Section 404 wetland alteration permitting program highlights that the impact of this activity is poorly understood and under accounted. Therefore, a comprehensive understanding of wetland alteration permitting activity and its impacts on wetlands should be a priority for issuing authorities and policy makers.

VI. Conclusion

This study should be considered as a starting point to understand the relationship between the Section 404 wetland alteration permitting program and its impacts on wetlands during the post-Ike recovery process. This research investigated how and to what extent wetlands were impacted by the permitting program during the recovery period (2008-2013). Both the numbers and types of permit were analyzed – based on the location variables, land cover data, and insured losses – to calculate the percentage and compare them in a before-and-after scenario. However, further research on this issue is needed in various aspects. First, this study only focuses on a single disaster event: Hurricane Ike. Future investigations need to be carried out on other hurricane events across the region to establish a more complete statement of how wetlands are being impacted by the permitting program during post-disturbance period of recovery and renewal. Second, this study does not consider socioeconomic or political factors that may drive permit issuance. Future research should analyze the wetland alteration permits based on the land use attributes, census data, and the legacy effect, as these might have significant influence on wetland alteration. Third, it only examines three counties of the Texas Gulf Coast. Future work should cover a larger study area to form a more comprehensive understanding of the relationship between the permitting program and its impacts on wetlands during the recovery process. Finally, further research needs to be conducted concerning the impacts of the Section 404 wetland alteration permitting program and its relationship with development activities during the post-disturbance period of renewal and recovery processes. On the whole, this study offers an initial understanding of how coastal communities are becoming less resilient by altering wetlands during the recovery processes. Moreover, this study looked at the issue holistically and examined the research objectives in a systematic way. Such an approach can help permit issuing authorities to analyze the permitting process before issuance.

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