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Quantifying Riverine and Storm-Surge Flood Risk by Single-Family Residence: Application to Texas

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The development of catastrophe models in recent years allows for assessment of the flood hazard much more effectively than when the federally run National Flood Insurance Program (NFIP) was created in 1968. We propose and then demonstrate a methodological approach to determine pure premiums based on the entire distribution of possible flood events. We apply hazard, exposure, and vulnerability analyses to a sample of 300,000 single-family residences in two counties in Texas (Travis and Galveston) using state-of-the-art flood catastrophe models. Even in zones of similar flood risk classification by FEMA there is substantial variation in exposure between coastal and inland flood risk. For instance, homes in the designated moderate-risk X500/B zones in Galveston are exposed to a flood risk on average 2.5 times greater than residences in X500/B zones in Travis. The results also show very similar average annual loss (corrected for exposure) for a number of residences despite their being in different FEMA flood zones. We also find significant storm-surge exposure outside of the FEMA designated storm-surge risk zones. Taken together these findings highlight the importance of a microanalysis of flood exposure. The process of aggregating risk at a flood zone level—as currently undertaken by FEMA—provides a false sense of uniformity. As our analysis indicates, the technology to delineate the flood risks exists today.

KEY WORDS: Catastrophe modeling; flood risk; National Flood Insurance Program; risk-based flood insurance premiums

1. INTRODUCTION

Floods are among the most significant disasters in the United States, accounting for about two-thirds of all presidential disaster declarations between 1958 and 2011.(1) Coverage for flood damage is explicitly excluded in U.S. homeowners' insurance policies because insurers contended since the severe floods of 1927 and 1928 that the peril was uninsurable by the private sector.(2) At that time, one of the main concerns of the insurance industry was the quite limited level of sophistication in flood hazard assessment and mapping.(3,4) Since 1968, U.S. flood insurance has been available through the federally managed National Flood Insurance Program (NFIP), which today covers more than 5.3 million residences with a total of $1.23 trillion of insured value.

The ability to quantify the likelihood of events and the extent of incurred losses is a condition for private insurance providers to offer coverage against any risk. The difficulty with meeting this key condition in regard to natural hazards such as floods, is the relative infrequency of events and the abundant sources of loss uncertainty, especially for extreme events. Utilizing a catastrophe model that generates a very large number of possible hazard scenarios is the most appropriate way to handle these issues.(5) Notably, significant progress in catastrophe

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modeling, geographic information systems (GIS), and risk map digitalization has improved risk assessments of natural hazards considerably in recent years. Catastrophe models are currently used to determine risk-based pure premiums for hurricanes and earthquakes,(6–9) but their role in the U.S. flood insurance market has been limited. A principal reason for this is the existence of the NFIP.

Recently, there have been discussions about the possibility of moving some NFIP coverage to the private sector. This was proposed by the Federal Emergency Management Agency (FEMA) as one possible reform option, based on three years of consultations with the public and experts. In July 2012, the Flood Insurance Reform and Modernization bill was signed into law by the president calling for risk-based flood premiums that importantly include catastrophic loss years. In order to set such risk-based premiums, FEMA[1] and private insurers would need the capacity to determine at a building level what such premiums should be. This is in contrast to the way FEMA does risk assessment today, mainly through flood zone determination. This can result in significant misalignment between the true risk a homeowner faces, and the price FEMA charges for flood insurance. In this context, this article proposes a methodological framework to demonstrate how risk-based pure premiums (i.e., expected average annual loss [AAL]) for flood losses would be generated by private insurers (or FEMA, should the agency go this route) using recent data and catastrophe modeling capacity developed jointly by CoreLogic, a large data provider, and Swiss Re, a global reinsurer.

We partnered with both organizations to undertake a series of detailed microanalyses of flood risk assessment for approximately 300,000 individual dwellings in two counties in Texas (Travis and Galveston), to assess inland and coastal flood risk. Texas was a natural choice for the study because it has the second largest number of NFIP policies-in-force of all states in the nation today (Florida being the highest) and is exposed not only to significant riverine flooding but also to storm-surge-related flooding from hurricanes and tropical storms.

Our analysis first reveals that, on average, there is substantial variation in flood exposure— and hence pure premiums—between coastal and inland counties within zones of similar FEMA flood risk classification.[2] Second, there is substantial variation of average flood risk within a given county between existing high- to low-risk classifications, and this can differ significantly from one county to another. Third, FEMA characterizes only an average flood risk in a given zone without indicating the variance across properties in that zone. We find this variance to be significant and nearly identical across all high-, moderate-, and minimal-risk zones. Finally, we find a significant amount of storm-surge exposure outside of the FEMA designated storm-surge risk zones. All of these factors contribute to the long-term financial imbalance of the program. These findings highlight the importance of undertaking a microanalysis of the exposure of residents to riverine flood and storm surge, and demonstrate that the technology to do just that exists today.

The article is organized as follows. Section 2 discusses the rationale for choosing Texas for this study, specifically the counties of Travis and Galveston. Section 3 introduces the different components of the CoreLogic and Swiss Re flood catastrophe model and how each component was constructed. Section 4 quantifies the flood risk pure premium for our sample of single-family residences in Travis County, an inland county exposed primarily to riverine flooding. Using the same methodology, Section 5 provides a similar quantification for residences in Galveston County, a coastal county exposed to both riverine and storm-surge flooding. Section 6 discusses the policy implications of our findings.

2. FOCUS ON TEXAS

Texas is frequently affected by hurricanes and tropical storms due to its position along the Gulf of Mexico coastline. Thus, the state is exposed to both storm-surge-related flooding and to riverine flooding. In addition to its geographic location and corresponding flood risk, other factors make Texas a good candidate for our case study. It is the second

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[1] FEMA has conducted its own assessment of the "current state of hazard modeling and the possible applicability of those models to the NFIP."(10)

[2] FEMA flood zones are geographic areas that the U.S. Federal Emergency Management Agency has defined according to varying levels of flood risk. The "A zone" is designated as a high-risk area with a 1% annual chance of flooding (100-year return flood), the "X500/B zone" is an area of moderate flood hazard between the limits of the 100-year and 500-year floods, and the "X/C zone" is an area of minimal flood hazard above the 500-year return flood level. Further, for coastal areas, the "V zone" is designated as a high-risk coastal area with a 1% or greater chance of flooding and an additional hazard associated with storm waves (see the Appendix for all the flood zone definitions used for this article).

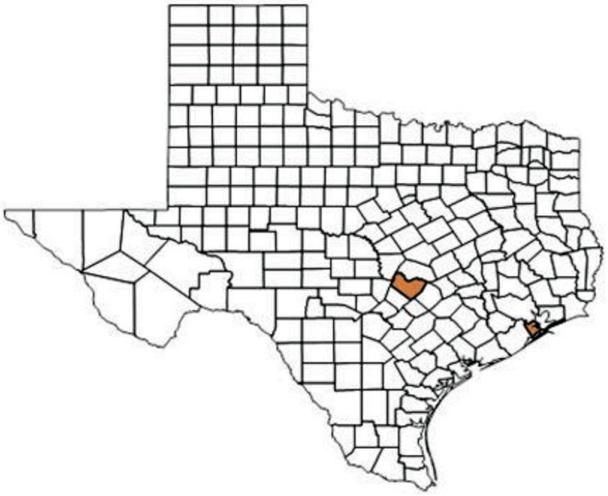

Fig. 1. Focus of the study: Galveston and Travis Counties, TX.

most populous state in the United States with over 24 million residents, one-third residing in coastal counties.(11) Texas has also the second largest number of NFIP policies-in-force after Florida—about 12% of the total national policies-in-force. Our analysis of the NFIP portfolio provided to us by FEMA indicates that total NFIP-insured building and contents exposure net of deductibles for single-family residences in Texas was over \$130 billion in 2008 with 16 counties each having at least \$1 billion of insured exposure. The county average annual flood insurance premium in Texas in 2008 was \$418,[3] and the county average premium per \$1,000 of flood coverage was \$1.85.

We focus our Texas study on two specific counties as highlighted in Fig. 1, Galveston (coastal, along the Gulf of Mexico) and Travis (inland), that have substantial population and single-family residential flood exposure, and have had a history of significant damages from riverine and storm-surge flooding. According to the Texas State Data Center's 2009 population estimates, these two counties combined have over 1.3 million residents and represent 5.2% of the total state population.(13) Galveston has the second highest NFIP exposure of all counties in Texas in 2008, with nearly \$14 billion in NFIP-insured exposure; Travis is ranked 14th in Texas with \$1.2 billion of NFIP-insured exposure. Data on 18 Texas coastal counties from the National Oceanic and Atmospheric Administration (NOAA) based upon 2000 Census data(14) reveal that Galveston has the second highest percentage of the total state population located in a FEMA floodplain (33%).

Table I shows the relative rank of the total number of events and associated property damages (adjusted to 2009 dollars) due to flooding and hurricanes/tropical storms for our two selected Texas counties over the time period of 1960–2009 collected from the SHELDUS[4] database.(15) These two counties rank in the top seven most flooded counties of the total 254 in Texas in this time period, with Galveston being fifth and Travis seventh. Galveston is also the county most frequently hit by hurricanes and tropical storms over this time period. Galveston County has incurred the third most aggregate hurricane damage in the state (including \$1.3 billion of the total \$2.6 billion from Hurricane Ike). Both Travis and Galveston Counties are in at least the 72nd percentile of damages due to flooding. Clearly, Galveston and Travis are two of the most frequently flooded and highly damaged counties in Texas due to either riverine or storm-surge flooding.

3. CATASTROPHE MODELING MODULE OVERVIEW AND TEXAS MODEL ASSUMPTIONS

The four basic components of a catastrophe model are hazard, inventory (exposure), vulnerability, and loss. On the basis of the outputs of a catastrophe model, the insurer can construct an exceedance probability (EP) curve. For a given portfolio of structures at risk, an EP curve is a graphical representation of the probability p that a certain level of loss \$$X$ will be surpassed in a given time period. Special attention is given to the right-hand tail of this curve where the largest losses are situated, that is, catastrophic losses. Utilizing such a catastrophe

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[3] This is slightly lower than the national average of \$506.(12)

[4] SHELDUS is a county-level hazard data set for 18 different hazard events (including flooding and hurricanes) containing property losses that affected each county by designated hazard. As SHELDUS does not explicitly account for storm-surge damage, we collected the database designated as hurricane and coastal damage estimates as a proxy for storm-surge flooding damages. Thus, we are including wind damage from hurricanes, in which case the flood-related losses will be overestimated. Furthermore, as SHELDUS spreads the total damages per hazard event over the number of counties affected by each storm, thereby overweighting damages to some counties whereas underweighting others, we present only a ranking of the total damages from the data collected to give a sense of the aggregate order of magnitude of damages over time.

Table I. Summary of Flooding and Hurricanes Frequency and Damages from 1960–2009 for Galveston and Travis Counties

	Number of Floods	Number of Floods Rank/(Percentile)[a]	Total Flood Property Damage Rank/(Percentile)[a]	Number of Hurricanes/ Tropical Storms	Number of Hurricanes Rank/(Percentile)[a]	Total Hurricane Property Damage Rank/(Percentile)[a]
Galveston	66	5/(98th)	71/(72nd)	33	1/(100th)	3/(99th)
Travis	62	7/(97th)	55/(78th)	6	73/(71st)	80/(69th)

[a] Of 254 Texas counties.

Sources: Calculation by the authors. Data from SHELDUS.

model enables insurers to determine pure premiums[5] that reflect the specific risk of their insureds.(5)

Below we describe in detail the key data and assumptions utilized within the four modules of the CoreLogic and Swiss Re flood catastrophe model used for this study.[6] These models are currently used by numerous global clients to assess and manage the inland and coastal flood risk associated with trillions of dollars of residential and commercial exposure.

3.1. Hazard Modules[7]

Flood hazards within the catastrophe models comprise both riverine flooding and hurricane-related storm-surge flooding for coastal locations, where applicable. Hence, we describe the riverine hazard module and storm-surge hazard module separately below.

3.1.1. Hazard Module: Riverine Flooding

At a given property's latitude and longitude, the resulting riverine flood inundation water depths from a collection of flood events are computed through an empirical relationship determined by the probability of flood occurrence combined with the flood intensity of the events. By specifying the set of water depths across all flooded properties, one can then determine the financial loss impacts of flood events on a targeted geographical area (such as a county). Water depth in the hazard module is defined as flood elevation minus property elevation where flood elevation is the 100-year flood elevation based on intrinsic characteristics of the river system. The 100-year flood elevation is determined from the national 100-year flood elevation database containing 269 million flood elevation surface features. These features are continuously revised through live flood map updates, and therefore the hazard module is also continuously revised with approximately 1,000 modifications per year incorporated into the hazard module.

The flood frequency map quantifies the probability of any given location being flooded and is constructed via three inputs—FEMA national flood risk zone maps, the U.S. Geological Survey (USGS) National Hydro data set, and the USGS National Elevation data set. To establish the flood frequency map, these three inputs are analyzed by a proprietary statistical regression method resulting in a national flood frequency map implemented with a 90 m × 90 m resolution from which 360 million defined cells over the entire United States are assigned the computed probabilities from the statistical regression. Therefore, for any given property's latitude and longitude, the model locates the associated 90 m × 90 m area and retrieves the assigned probability value.

Intensity of flood events, flow velocity over a specified monthly duration, is defined at a ZIP code resolution. The historical flood event intensities are derived from Monte Carlo simulations using a data set sourced from monthly measurements of maximum discharge from more than 4,100 gauging stations in the United States over the past 43 years. To get the best possible historical discharge records, this data set was extended to outlets of each of the nation's 24,000 drainage basins via a methodology that takes into account river networks, drainage area, and precipitation. The simulated probablistic event set has the same spatial and temporal correlations as the original data set, but covers a time span of 10,000 years. The final event set contains 400,000 events. Approximately 2,000 of them impacted Galveston

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[5] These pure premiums do not include the loading factor that insurers would need to add to the generated pure premiums to cover administrative and other costs.

[6] The probabilistic catastrophe models developed by CoreLogic and Swiss Re are proprietary, so we cannot discuss the set of equations established to quantify each one of these modules. Still, we provide as much information as possible as to how the results of each module were generated.

[7] This material is sourced from internal documentation provided by CoreLogic and Swiss Re.

County and approximately 5,000 of them impacted Travis County. These 7,000 probabilistic flood events are used in the loss computation.

3.1.2. Hazard Module: Storm-Surge Flooding

For a given coastal location, the hurricane storm-surge flood inundation water depths are computed through an empirical relationship determined by the storm-surge heights (associated with hurricanes of different intensities) at different landfall locations combined with the stochastic hurricane event set defining storm-surge location, frequency, and intensity. Thus, the resulting storm-surge flood event is defined as the set of varying water depths across all flooded properties within the predetermined coastal geographical area.

The geospatial distribution of storm surge heights was based on modeled probabilities of hurricanes of various intensities making landfall at different points along the coast. The storm-surge module then utilizes maximum storm-surge heights to simulate the resulting surge impact area and corresponding water depths. The probabilistic event set provides simulated data for tropical cyclones over the 10,000 years, based on statistical data for storms in the North Atlantic and Gulf Coast regions over the past 150 years. The stochastic event set is generated by altering paths of the historical cyclones using a process based on a Monte Carlo simulation. Over 100,000 individual storm tracks are represented by their peak wind gust footprint. Given this generated storm-surge intensity from the stochastic event set, the storm-surge height at a specific geographic location is determined as well as the associated probability of occurrence. Table II illustrates the distribution of the various hurricane categories for Galveston County generated in the model.[8] Approximately 1,000 of the simulated hurricane events impacted Galveston County. Nearly 70% of these events will be below major hurricane strength, Category 2 or below.

Table II. Hurricane Event Set; Saffir-Simpson Category Summary for Galveston County

Hurricane Category	Number of Events Generated in Our Probabilistic Approach Greater or Equal to Category Level	Cumulative%
5	108	11.1
4	196	20.2
3	304	31.4
2	470	48.5
1	969	100.0

3.2. Inventory (Exposure) Module

The inventory of properties at risk used for the study is single-family residences representing approximately 62% of the total 160,324 land parcels collected from CoreLogic for Galveston County and 76% of the total 316,479 parcels collected for Travis County. (The next largest group of parcels in each county is vacant property, and therefore would have no buildings exposed to floods). From these single-family residences, we eliminate any properties that have building value of $0, have more than one building on the land, or those that are classified as mobile homes. In cleaning the data that way, in Galveston we eliminated 9,590 of the 98,636 single-family residences collected (9.7%), and in Travis we eliminated 13,301 of the 239,708 single-family residences collected (5.5%). Thus, there are 89,046 single-family residences in Galveston and 226,407 single-family residences in Travis that represent the exposure inputs to the catastrophe model for each county.

Geographically, each single-family residence parcel is defined by its exact latitude and longitude coordinates. The ground elevation (i.e., property elevation) of the centroid of the parcel is based upon USGS digital elevation data determined from these exact coordinates. The total insured value of these single-family residences inputted into the model is the collected building value with an assigned contents assumption of 40% of the building value, which is aligned with Swiss Re client data content percentages. Building value, provided by CoreLogic, is defined as the current market improvement value: the residence's total market value net of the market value of land. All values were provided by the county or local taxing/assessment authority.[9]

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[8] It is important to note that the event set results of the CoreLogic and Swiss Re models are not meant to be interpreted literally as the forecasted events for these counties. If they were to regenerate the event set, the outcome could be different due to the random sampling.

[9] Replacement cost values were not readily available. Also, given that there is a range of deductible values that homeowners can choose as part of their insurance policy, to which the research team has not had comprehensive access, the model does not include deductible values. (Data reveal, however, that the majority of NFIP policyholders have selected a low $500 deductible.(12))

3.3. Vulnerability Module[10]

In the catastrophe model, vulnerability to flood hazards is the mean of the proportion of the property damaged by the specified flood depth over a large number of possible flood scenarios generated in the hazard module that reflect the annual probability that floods of different magnitudes will occur. The resulting output from the model is thus the annual expected loss to the property. The relationship between the proportion of the property damaged and water depth is specified through proprietary vulnerability curves, and multiple sources of vulnerability data are used to generate the vulnerability curves utilized in the model. The main source of vulnerability data is the detailed NFIP loss statistics compiled between 1978 and 2002 by FEMA consisting of approximately 850,000 separate losses. To complete the vulnerability set, engineering methods of damage assessment (proprietary to Swiss Re) were used and complemented with expert opinions. This flood model has been used in other countries outside the United States and has been calibrated for claims there as well. Finally, existing community flood protection measures along streams (levees, dams, etc.) are accounted for in the calibrated flood frequency values utilized in the model.

3.4. Financial Loss Module

Financial losses from the catastrophe model are represented as average annual loss (AAL) values, which are calculated in the following manner. Suppose there is a set of natural disaster events, E_i, which could damage a portfolio of structures. Each event has an annual probability of occurrence, p_i, and an associated loss, L_i. The number of events per year is not limited to one; several events can occur in the given year. If an event E_i does not occur, the loss is zero. The expected loss for a given event, E_i, in a given year, is simply: $E[L] = \mathrm{p_i} \cdot L_i$ The overall expected loss for the entire set of events, denoted as the AAL, is then the sum of the expected losses of each of the individual events for a given year and is given by $\mathrm{AAL} = \Sigma_\mathrm{i}\, p_i \cdot L_i$. Here we focus on losses to the building and contents, thus excluding possible human losses.[11]

We apply this catastrophe modeling methodology to single-family residences in Travis and Galveston counties where the CoreLogic and Swiss Re flood models combine the exposure and associated vulnerability of those single-family residences to determine the AAL for each individual single-family residence. With AAL values of individual residences, it is possible to aggregate such estimates for all single-family residences in a given county or in a given FEMA flood zone for that county.

4. ANALYSIS FOR TRAVIS COUNTY

Data on 226,407 single-family residences are collected and inputted into the CoreLogic and Swiss Re flood catastrophe models for Travis County. Table III indicates the total number of residences per FEMA flood zone and the mean exposure values in each zone. Across all FEMA flood zones there is more than \$54 billion in exposure in Travis County, with 95% of this exposure (number of residences and dollar value) located in the FEMA-designated minimal-risk X/C zone. Although only 5% of total Travis County residences are in the high- and moderate-risk 100-year and 500-year return floodplains (A and X500/B zones, respectively), there is more than \$2.6 billion in exposed value.

The EP curve for our portfolio of 226,407 single-family residences in Travis County is shown in Fig. 2. Focusing on the right-hand tail of the curve in Fig. 2, we find that the 10,000-year return loss is nearly \$890 million—1.6% of the total county \$54 billion in exposure.[12] Other key return period losses for the county are \$14 million for the five-year flood event and nearly \$200 million for the 100-year flood event.

It is also possible to generate EP curves for a subsection of the entire set of 226,407 single-family residences we study here. For instance, Fig. 3 illustrates EP curves for all residences located in a given FEMA-designated flood zone: the high-risk A zone, moderate-risk X500, and the minimal-risk X zone. Focusing on the right-hand tail of the EP curve in Fig. 3, we find that the 10,000-year return

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[10] This material is sourced from internal documentation provided by CoreLogic and Swiss Re.

[11] The event loss values generated by the CoreLogic/Swiss Re model explicitly accounted for uncertainty through a five-point loss scheme. That is, the loss value returned per event is a weighted average calculation of five-point lower and higher loss estimates with various frequencies with higher losses weighted more heavily in the aggregated event loss outcome to reflect aversion to catastrophic losses.

[12] We show later that three-quarters of residences have no flood risk. When these homes are excluded, the 10,000-year loss of nearly \$890 million is approximately 7.4% of the \$12 billion in exposure for only those homes at risk for riverine flooding.

Table III. Travis County Exposure Value Summary by FEMA Flood Zone

FEMA Flood Zone	Number of Single-Family Residences	% of Total Residences	Total Exposure Value[a] ($)	% of Total Exposure Value	Average Exposure Value ($)
A	6,790	3	1,536,512,177	3	226,290
X500/B	5,010	2	1,125,747,322	2	224,700
X/C	214,607	95	51,806,029,170	95	241,400
Total county	226,407	100	54,468,288,669	100	240,577

[a] Exposure value = building value + 40% contents.

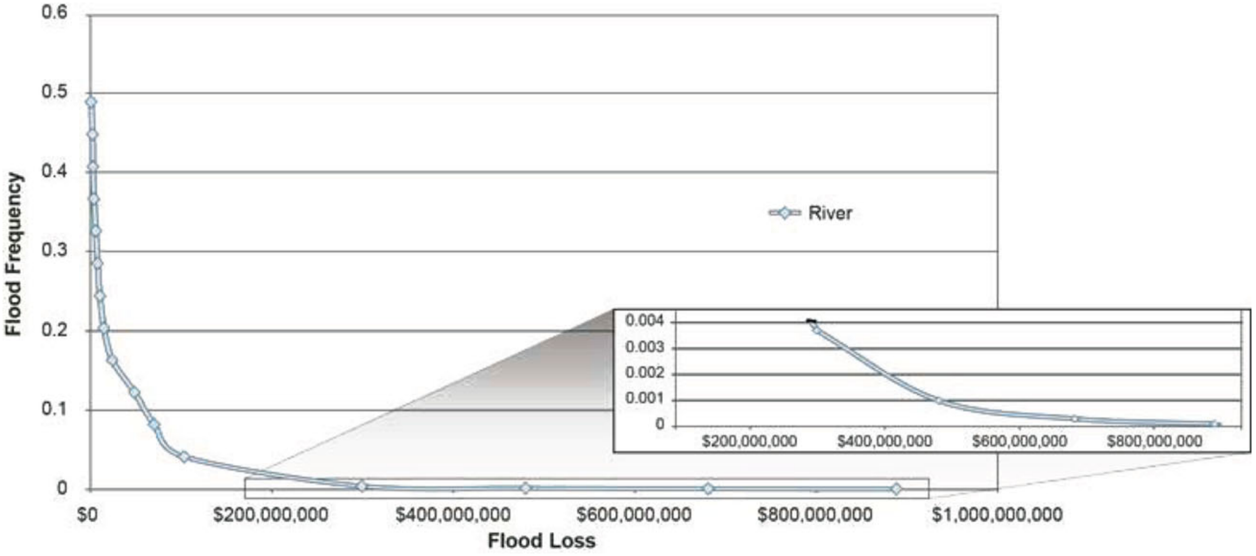

Fig. 2. EP curve for our portfolio of 226,407 single-family residences in Travis County.
Note: Given the scale of the figure, we include a zoom of the flood losses for the tail of the distribution.

loss is largest in the X zone at $600 million (vs. $200 million for all residences in the A zone). This larger maximum loss in a flood zone designated as minimal flood risk by FEMA is likely due to the sheer number of total homes in this zone, some significant portion of which would be impacted by such an extreme flood event.

AAL is used by insurers to determine a risk-based premium. Everything else being equal, the higher the exposure, the higher the AAL. We calculate the ratio of AAL over quantity of exposure per $1,000. House-level AAL results grouped by FEMA flood zone for Travis County are presented in Table IV.[13]

Since Travis County has no exposure to storm surge but only to riverine flooding, we note this by "riverine only" or "none" in the column labeled "peril." "None" refers to the number of residences with no exposure to flood risk as an outcome of the model. As depicted in Table IV, all homes in the A (high-risk) and X500 (moderate-risk) FEMA zones have some level of flood risk loss associated with them. The total AAL for single-family residences in the A and X500 zones is $10.2 and $2.3 million, respectively. However, the model reveals that a large number of residences located in FEMA-designated X zones (low risk) (165,238 of 214,607, or 77% of all residences in these zones) have no exposure to flood risk. Still, there are nearly 50,000 homes in the Travis County X zone having some flood risk with total AAL = $3.9 million from their associated total $9.3 billion in exposure. This provides an example of a relatively significant amount of flood risk associated within a FEMA-designated "minimal" flood risk zone from a catastrophe model perspective.

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[13] As a robustness check on these results, we also ran the analysis for those homes with insured values falling under the NFIP building coverage limit of $250,000 that constitute 83 to 88% of insured home values in any FEMA flood zone in Travis County. The largest difference in mean AAL cost per $1,000 was 8.5% in the Travis County A zone.

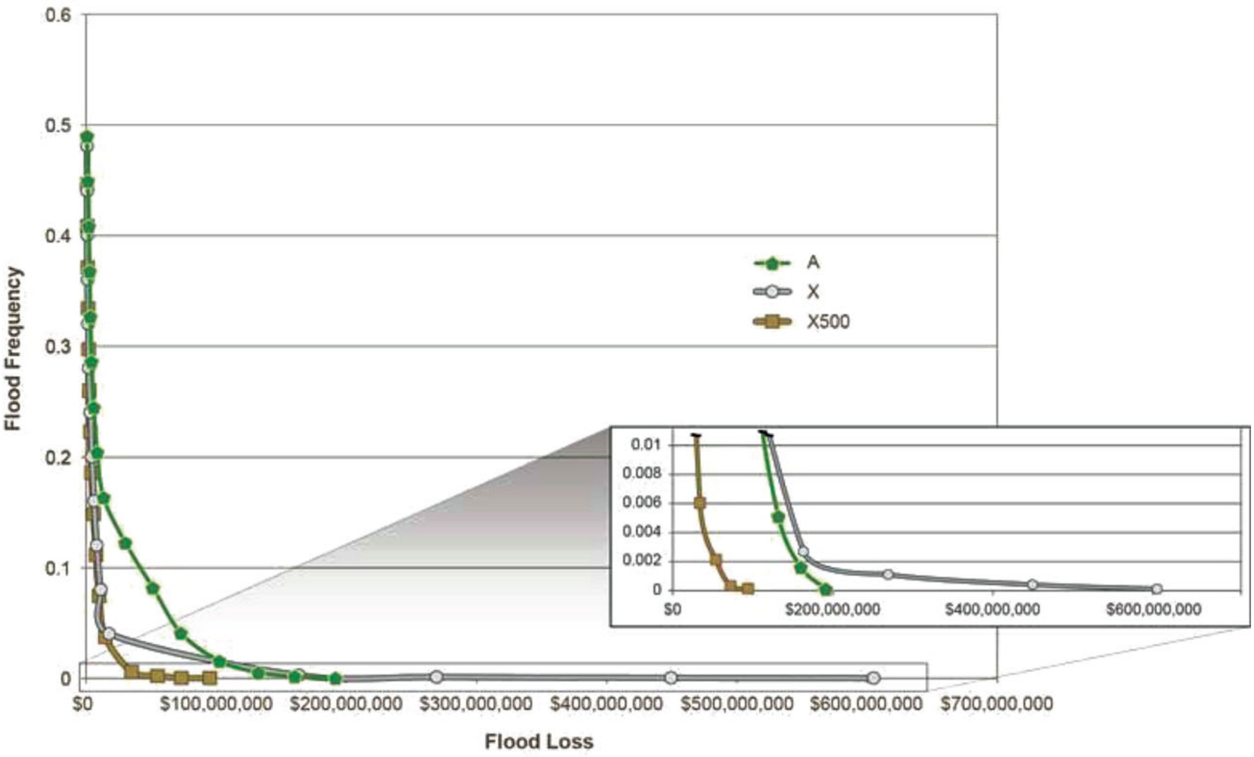

Fig. 3. Travis County EP curves for our portfolio of single-family residences as categorized by FEMA flood zone. *Note*: Given the scale of the figure, we include a zoom of the flood losses for the tail of the distribution.

Table IV. Travis County AAL for Single-Family Residences by FEMA Flood Zone

FEMA Flood Zone	Peril	Number of Single-Family Residences	Total Exposure Value (Building + 40% Contents)	Total AAL = Riverine AAL	Mean Total AAL per Home	Mean AAL Cost per $1,000	Minimum AAL Cost per $1,000	Maximum AAL Cost per $1,000	Standard Deviation AAL Cost per $1,000
A	Riverine only	6,790	$1,536,512,177	$10,241,077	$1,508	$5.51	$0.06	$14.19	$4.63
	None	–	–	–	–	–	–	–	–
	Total	6,790	$1,536,512,177	$10,241,077	$1,508	$5.51	$0.06	$14.19	$4.63
X500/B	Riverine only	5,010	$1,125,747,322	$2,309,197	$461	$1.69	$0.06	$14.07	$3.17
	None	–	–	–	-	–	–	–	–
	Total	5,010	$1,125,747,322	$2,309,197	$461	$1.69	$0.06	$14.07	$3.17
X/C	Riverine only	49,069	$9,346,189,517	$3,955,547	$81	$0.31	$0.01	$14.28	$1.09
	None	165,538	$42,459,839,653	–	–	–	–	–	–
	Total	214,607	$51,806,029,170	$3,955,547	$18	$0.07	–	$14.28	$0.54
County	Total	226,407	$54,468,288,669	$16,505,821	$73	$0.27	–	$14.28	$1.43

On average, total AAL per home is over three times higher in the A zone ($1,508) as compared to the X500 zone ($461), and over 18 times higher than the 49,069 at-risk homes in the X zone ($81). Similarly, when accounting for the exposure value differences across zones, the $5.51 mean AAL cost per $1,000 in the A zone is still approximately 3 and 18 times higher than the $1.69 and $0.31 mean AAL cost per $1,000 for the X500 and X zones, respectively.[14]

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[14] Note that these values are the average across each *individual* home's AAL exposure per $1,000 determined result. Consequently, multiplying the (Total AAL/Total Exposure) by $1,000

This provides a first set of results that allow better appreciating differences in AAL across FEMA-designated flood zones. Indeed, using classifications such as "high," "moderate," and "minimal" to describe the risk might be very misleading to some individuals who might think there is a linear relationship between the risks in these three categories. The catastrophe model is able to provide a specific scale of what the "true" pure premium should be: three times more in high-risk zones than in moderate ones, and six times more in moderate than in minimal zones, on average. This same level of specificity cannot be achieved from the current FEMA risk classifications.

Because the mean AAL can hide important differences across all properties within the same flood zone, we are interested in the distribution of the AALs at the individual residence level. We find that the range of AAL costs per $1,000 across all three flood zones is essentially the same, ranging from $0.06 or less per $1,000 of exposure to approximately $14 per $1,000 of exposure as exhibited in Table IV. This would indicate that some residences that are considered high risk by FEMA (because they are located in an A zone) might actually be low risks because of a specific location within that zone and/or characteristic of the property. And vice versa, some residences located in a FEMA-designated low-risk zone can actually be highly exposed to flooding. In fact, the single highest AAL cost per $1,000 of exposure of our entire portfolio of residences in Travis County is $14.28 for a residence located in the designated minimal-risk X zone (Table IV).

Table V provides a further detailed view of the distribution of AAL costs per $1,000 of exposure across all three flood zones for those homes with AAL higher than $0. Our results show that the distribution of AAL cost per $1,000 is significant within a given FEMA flood zone. In other words, many residences are in the same AAL range despite being in zones labeled as low, medium, and high risk by FEMA. For instance, Table V shows that there are 308 residences with AAL cost per $1,000 in the $4.01 to $5.00 range in high-risk A zone, but also 102 residences in the the moderate X500 zone and 131 in the minimal-risk X zones with similar AAL. Further, in the AAL cost per $1,000 range from $5.01 to $7.50, the low-risk X zone has 55 more residences than the moderate-risk X500 zone.[15]

Table V. Distribution of Travis AAL Cost per $1,000 of Exposure by FEMA Flood Zone

Range of AAL Cost per $1,000 of Exposure	FEMA Flood Zone		
	A	X500/B	X/C
$0.01–$1.00	1,136	3,770	47,323
$1.01–$2.00	1,168	240	505
$2.01–$3.00	817	188	316
$3.01–$4.00	471	116	224
$4.01–$5.00	308	102	131
$5.01–$7.50	529	128	183
$7.51–$10.00	683	191	153
$10.01–$12.50	852	192	147
$12.51–$15.00	826	83	87
Total	6,790	5,010	49,069

This house-level analysis reveals that if one considers only the *average* flood risk in a given FEMA zone, the heterogeneity of risk across properties is not taken into account. So, from a probabilistic perspective, a single-family residence located in a FEMA-designated low- (high-)risk flood zone does not necessarily translate into a low- (high-)flood insurance risk-based pure premium. The key takeaway is thus that risk-based pure premiums have to be based on a probabilistic risk assessment for each property, *not a simple average across flood zones*. However, this is not how flood insurance rates are currently determined by the NFIP.

The NFIP focuses on homes in a specific flood zone across the entire nation (e.g., residences in the 100-year return period) and the risk-based rates are then specified as a function of elevation relative to the base flood elevation. Although the FEMA model calculates rates for a variety of floodplains within the high-risk A and V zones, similar structures with the same elevation relative to the base flood elevation in similar flood zones are charged the same premiums everywhere in the country.(16) In reality, a more granular analysis than the one used by FEMA reveals that the flood return periods vary considerably for those residents in the same zone; some flood events could have a 50-year return and others a 80-year return, etc., while FEMA considers all of them as being in a 100-year return period flood zone. The

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at the county or grouped flood zone levels shown in the table will not provide the same result.

[15] This result may simply be due to the total number of residences in the X zone being nearly 10 times larger than the number in the X500 zone (49,069 vs. 5,010, respectively).

technology employed in the flood model utilized here addresses this granularity not only in the 100-year flood zone but other zones (e.g., X zones), whereas the FEMA "risk-based rates" are derived using averages from national data rather than local flood risk maps.

There are other significant differences between the flood model we employ in our analysis and the inputs utilized by FEMA to determine flood risk and insurance premiums that help to explain the differences in the catastrophe model results and the FEMA flood risk zones in Tables IV and V. It is no secret that FEMA's identified flood zones are not as accurate as they could be in determining flood risk. For example, as of 2008, about half of FEMA's 100,000 flood risk maps were outdated, primarily due to limited resources at its disposal.(10) Moreover, while much of FEMA's flood mapping activities are focused on the high-risk flood areas (i.e., 1% annual chance of flooding), flood risk extends beyond these boundaries. To address these accuracy concerns, FEMA has developed a Flood Map Modernization Plan to update its maps and convert them to a digital format.[16] However, while new technology allows FEMA to more accurately evaluate flood exposure, local political pressure has prevented some elected officials from approving new maps that situate their constituents in a high-risk zone.

The flood catastrophe model utilized here employs the latest technology and should result in better geographical estimates of flood risk than FEMA flood hazard assessments. More specifically, the overall extent of the flood zones is expanded to outside the FEMA 100-year and 500-year flood zone boundaries through a flood elevation variance-based methodology and intrinsic characteristics of the riverine system. In addition, these features are continuously revised through live flood map updates, and therefore the hazard module is also continuously revised with approximately 1,000 modifications per year incorporated into the hazard module.

A catastrophe model probabilistic approach includes 200-year, 500-year, 1,000-year, and greater flood magnitudes, whereas FEMA rates do not include events in the tail of the distribution that have an annual likelihood of less than 1 in 100. In other words, FEMA truncates the tail of the distribution, whereas a catastrophe model integrates the possibility of truly catastrophic losses into the flood assessment (e.g., events with a 500-year, and 1,000-year return period). Significant flood events are not limited to the 100-year floodplain and could affect structures in FEMA-designated minimal flood risk areas. Furthermore, some residences that are considered high risk by FEMA (because they are located in an A zone) might actually be low risks because of a specific location within that zone and/or characteristic of the property. The U.S. Government Accountability Office (GAO) recognized this problem by noting that rates (ultimately derived from these mapped risks) do not reflect local topographical conditions.(10)

5. ANALYSIS FOR GALVESTON COUNTY

Galveston County is exposed to both riverine and storm-surge flooding. Data on 89,046 Galveston County single-family residences were collected and inputted into the CoreLogic and Swiss Re flood catastrophe model. Table VI provides the total number of residences per FEMA flood zone as well as the mean exposure values inputted into the model in each zone. Across all FEMA flood zones in Galveston County, there is a total of over $14 billion dollars of exposure. Approximately 55% of this exposure (measured by the number of residences or the total value) is located in the FEMA-designated minimal-risk X/C zone (vs. 95% in the case of Travis). Although there is not as much exposure (number of residences and total value) in the high- and moderate-risk coastal 100-year, noncoastal 100-year, and 500-year floodplains (V, A, and X500/B zones, respectively), there is still a significant amount of flood exposure located in these zones at over $6 billion.

Fig. 4 geographically illustrates all single-family residences in Galveston County. Although the majority of minimal (X zone) to moderate (X500) flood risk homes are located inland, there are pockets of these homes located very close to coastal waters (examples are circled in Fig. 4) subject to potentially significant amounts of storm surge, yet not

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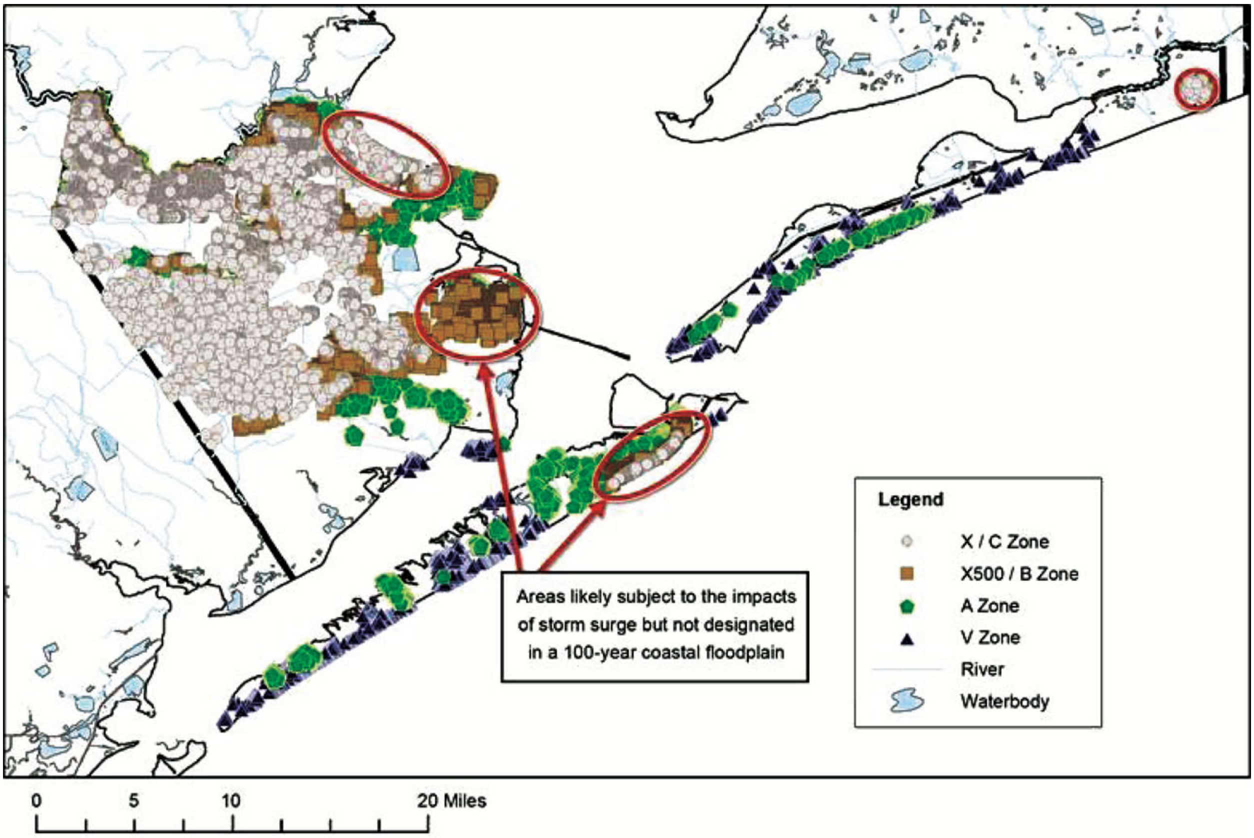
[16] As an example, FEMA is currently in the process of updating all coastal flood risk maps: "Throughout the next several years, the Federal Emergency Management Agency (FEMA) Regional Office in Atlanta, along with regional, state, and local partners throughout the Southeast, will update the effective FIRMs for coastal areas using more recent data and the latest scientific engineering tools." http://www.fema.gov/news-release/2012/10/11/flood-hazard-information-being-updated-southeast-coastal-communities (October 11, 2012).

Table VI. Galveston County Exposure Value Summary by FEMA Flood Zone

FEMA Flood Zone	Number of Single-Family Residences	% of Total Residences	Total Exposure Value[a] ($)	% of Total Exposure Value	Average Exposure Value ($)
V	5,355	6	1,427,884,401	10	266,645
A	17,940	20	2,701,793,277	19	150,602
X500/B	18,922	21	2,346,051,193	16	123,985
X/C	46,829	53	7,857,561,222	55	167,793
Total county	89,046	100	14,333,290,093	100	160,965

[a] Exposure value = building value + 40% contents.



Areas likely subject to the impacts of storm surge but not designated in a 100-year coastal floodplain

Fig. 4. Geographic distribution of Galveston County FEMA flood zone single-family residences.

classified within a FEMA storm-surge designated risk area.

For our portfolio of 89,046 single-family residences in Galveston County, Fig. 5 illustrates the EP curve for the entire county split by flood peril—one for riverine flooding and one for storm-surge flooding. As can been seen in the right-hand tail of the curves in Fig. 5, the 10,000-year storm-surge loss of \$2.3 billion is approximately 17% of the total county's \$14 billion in exposure, whereas the 10,000-year riverine loss of \$825 million is approximately 6% of the total county's \$14 billion in exposure. Other key return period losses for the county range from \$351,000 for the five-year riverine flood event to nearly \$58 million for the 100-year riverine flood event, and \$27 million for the 10-year storm-surge flood event to nearly \$1.3 billion for the 100-year storm-surge flood event.[17] From the 10-year to the 10,000-year return period, expected

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[17] Comparatively, NFIP claims paid from Hurricane Ike in 2008 were \$1.3 billion in Galveston County alone, suggesting a 100-year event from our model storm-surge loss results. Although Ike was a lower return period storm (somewhere in the 20- or

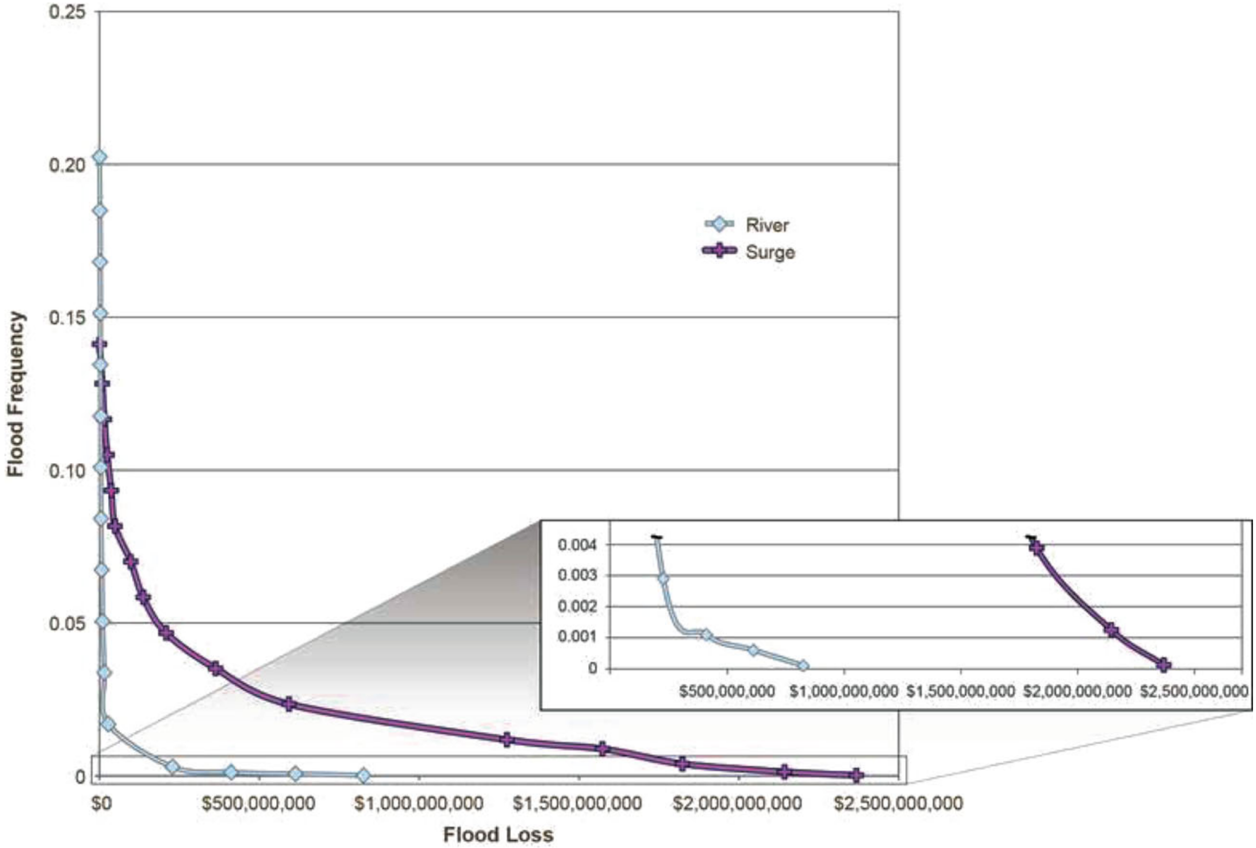

Fig. 5. Riverine and storm-surge EP curves for our portfolio of 89,046 single-family residences in Galveston County.

storm-surge flooding losses always dominate riverine flooding losses in Galveston, being 3 to 30 times higher.

Individual AAL results grouped by flood zone and county are presented in Table VII.[18] Given that Galveston County is subject to both riverine and storm-surge flooding, residences here can incur riverine loss only, storm-surge loss only, both riverine and storm-surge losses, or no losses. From Table VII we see there are only 1,105 residences at no peril across all flood zones, so essentially all homes in Galveston County (98.8% of the total) can potentially be damaged by riverine flooding or storm-surge flooding; in other words, all of Galveston County is exposed to flood risk. In the X/C zone, 98.2% of the residences have some flood risk loss with an AAL equal to $11.7 million based on the $7.7 billion exposure value located in this zone. Furthermore, there is a significant amount of storm surge risk outside of the V and coastal A zones, the only areas subject to storm surge-flood risk according to FEMA flood zone classifications.[19] Focusing on the "surge only" peril identified in Table VII, in zones X500 and X there is $3.1 billion of storm surge exposure with an AAL of

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30-year range), it did produce storm-surge above its landfall intensity.

[18] As a robustness check on these results, we ran the analysis for those homes with insured values falling under the NFIP building coverage limit of $250,000 that constitute 76–97% of insured home values in any FEMA flood zone in Galveston County. The largest difference in mean AAL cost per $1,000 was 10.2% in the Galveston County A zone.

[19] In coastal areas, the A zone can potentially be divided into two separate zones—the coastal A zone and the A zone—with the distinction being that the coastal A zone's principal source of flooding is storm-surge related, although not as severe as the V zone storm-surge flooding.(17) Moreover, while coastal A zone areas exist, they are not explicitly shown on the flood insurance rate maps, and we do not have access to their boundaries in the counties under analysis here. Thus, some unknown portion of the $1.97 billion of "storm-surge only" exposure identified by the model in the Galveston County A zone is very likely outside of the FEMA coastal A zone (see Table VII).

Table VII. Galveston County AAL for Single-Family Residences by FEMA Flood Zone

Flood Zone	Peril	Number of Single-Family Residences	Total Exposure Value	Total AAL Riverine	Total AAL Surge	Total AAL = Riverine + Surge	Mean Total AAL per Home	Mean AAL Cost per $1,000	Minimum AAL Cost per $1,000	Maximum AAL Cost per $1,000	Standard Deviation AAL Cost per $1,000
V	Riverine only	–	–	–	–	–	–	–	–	–	–
	Surge only	5,164	$1,364,032,235	–	$9,469,790	$9,469,790	$1,834	$6.78	$2.42	$15.05	$2.45
	Riverine and surge	37	$5,346,810	$3,252	$37,083	$40,335	$1,090	$7.76	$5.84	$ 2.43	$1.76
	None	154	$58,505,356	–	–	–	–	–	–	–	–
	Total	5,355	$1,427,884,401	$3,252	$9,506,872	$9,510,124	$1,776	$6.60	–	$15.05	$2.67
A	Riverine only	354	$138,337,444	$236,666	–	$236,666	$669	$1.77	$ 0.16	$10.11	$1.87
	Surge only	13,574	$1,968,068,542	–	$13,644,713	$13,644,713	$1,005	$6.52	$1.76	$13.26	$2.28
	Riverine and surge	3,897	$565,693,334	$1,431,961	$2,074,469	$3,506,429	$900	$6.19	$0.60	$21.92	$3.37
	None	115	$29,693,958	–	–	–	–	–	–	–	–
	Total	17,940	$2,701,793,277	$1,668,627	$15,719,182	$17,387,809	$969	$6.31	–	$21.92	$2.68
X500/B	Riverine only	295	$94,706,934	$44,164	–	$44,164	$150	$0.45	$ 0.17	$4.26	$0.44
	Surge only	12,258	$1,244,440,375	–	$5,943,206	$5,943,206	$485	$4.76	$1.68	$10.78	$1.38
	Riverine and surge	6,369	$1,006,903,884	$396,174	$2,797,555	$3,193,729	$501	$3.32	$ 0.44	$13.46	$1.08
	None	–	–	–	–	–	–	–	–	–	–
	Total	18,922	$2,346,051,193	$440,337	$8,740,761	$9,181,099	$485	$4.21	$0.17	$13.46	$1.52
X/C	Riverine only	6,526	$1,450,772,274	$311,832	–	$311,832	$48	$0.20	$0.06	$2.02	$0.13
	Surge only	13,070	$1,915,649,074	–	$3,775,634	$3,775,634	$289	$1.98	$0.24	$14.61	$1.05
	Riverine and surge	26,397	$4,403,229,485	$1,183,185	$6,500,918	$7,684,103	$291	$1.88	$0.33	$7.42	$1.01
	None	836	$87,910,389	–	–	–	–	–	–	–	–
	Total	46,829	$7,857,561,222	$1,495,016	$10,276,552	$11,771,568	$251	$1.64	–	$14.61	$1.14
County	Total	89,046	$14,333,290,093	$3,607,232	$44,243,368	$47,850,600	$537	$3.43	–	$21.92	$2.67
								↓			
							Mean Riverine AAL Cost per $1,000	$0.22			
							Mean Surge AAL Cost per $1,000	$3.20			
								V	A	X500/B	X/C
							Mean Riverine AAL Cost per $1,000	$0.01	$0.49	$0.14	$ 0.18
							Mean Surge AAL Cost per $1,000	$6.59	$5.82	$4.07	$1.46
								$6.60	$6.31	$4.21	$ 1.64

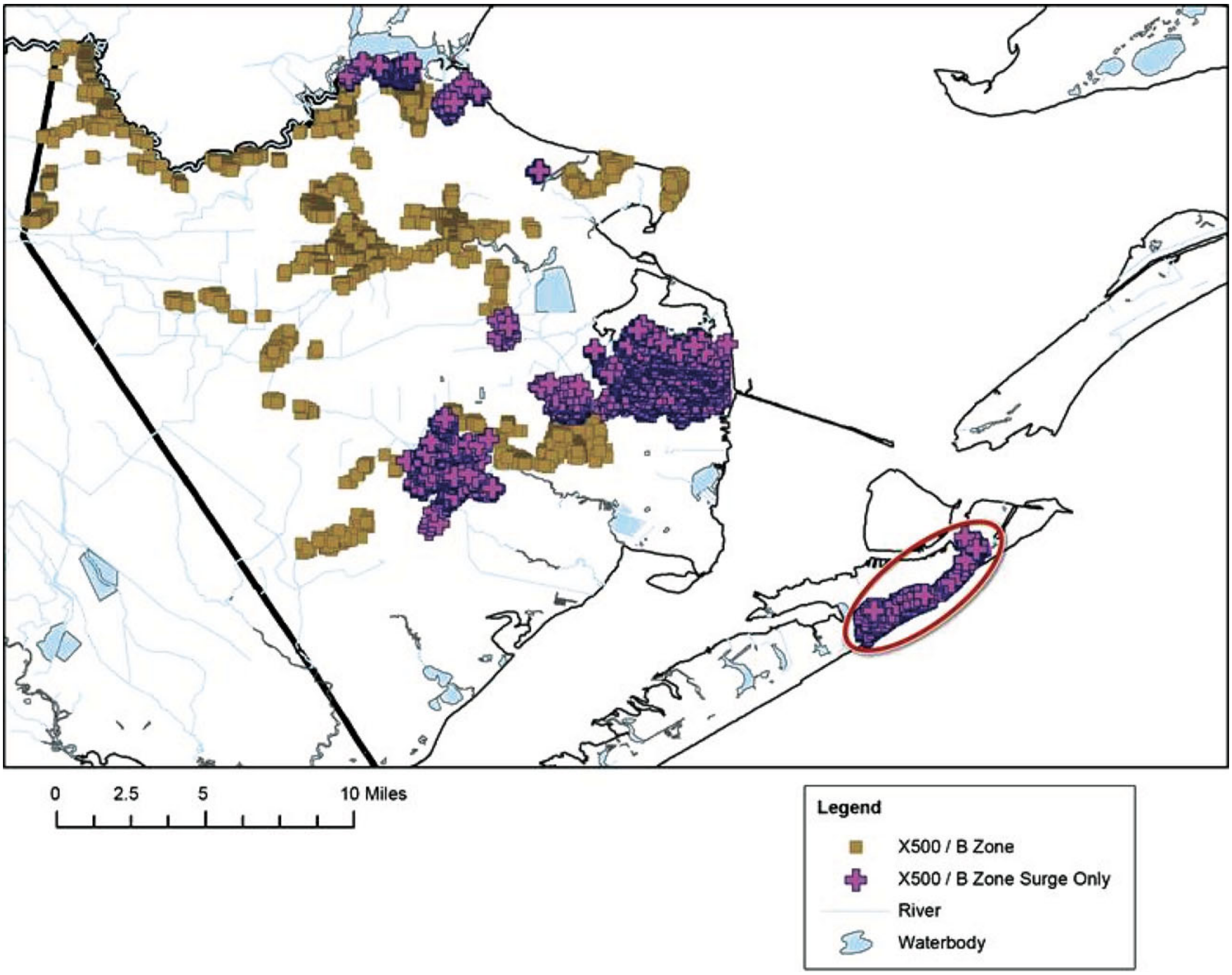

Fig. 6. Galveston County X500 residences subject only to storm-surge risk.

$9.7 million, or 22% of the total storm-surge AAL of the county.

Fig. 6 provides a geographical depiction of the location of the 12,258 homes in X500 zones that are subject to storm surge only (of the 18,922 total homes in Galveston County's X500 zones). Of these storm-surge only homes, 17.5% are located directly on the Gulf of Mexico, as circled in Fig. 6.

In order to calculate the total AAL per home, we additively combine the derived riverine AAL and storm-surge AAL. From a mean total AAL per home basis, V zone flood risk ($1,776) is 1.8 times higher as compared to the A zone ($969), 3.6 times higher as compared to the X500 zone ($485), and more than 7 times higher than the X zone ($251). However, when accounting for the exposure value differences across zones via the mean AAL cost per $1,000 of exposure, the result for residences located in the V zone ($6.60) is approximately the same as for those in the A zone ($6.31) and 1.5 and 4 times higher than the $4.21 and $1.64 AAL cost per $1,000 for the X500 and X zones, respectively.[20] The bottom of Table VII presents a breakdown of these mean AAL costs per $1,000 values by riverine and storm-surge losses. Storm surge is the main driver of the AAL costs in Galveston County, comprising at least 89% of the mean AAL costs per $1,000 values across all flood zones—even for the non-V and noncoastal A zones that are not the areas subject to storm-surge flood risk according to FEMA flood zone classifications.

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[20] Note that these values are the average across each individual home's AAL exposure per $1,000 determined result. Consequently, multiplying the (Total AAL/Total Exposure) by $1,000 at the county or grouped flood zone levels shown in the table will not provide the same result.

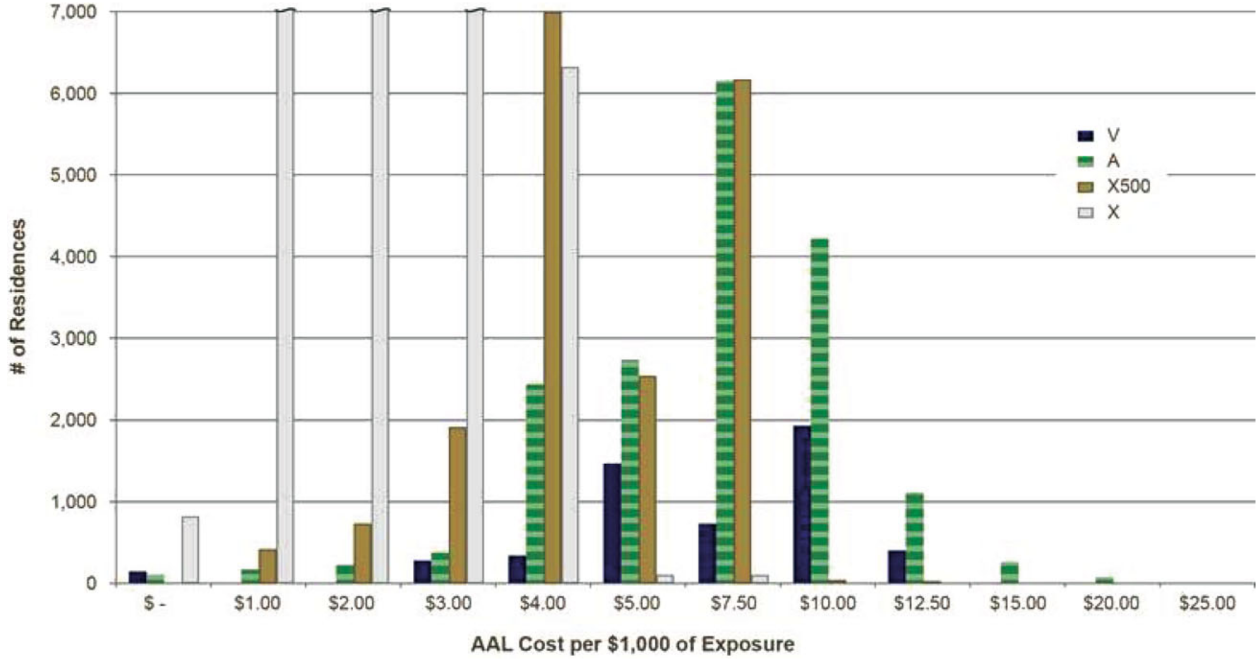

Fig. 7. Distribution of Galveston AAL cost per $1,000 of exposure by FEMA flood zone.

Focusing on the range of AAL costs per $1,000 across all four flood zones, we generally see similar ranges of AAL values. Although the single highest AAL cost per $1,000 of exposure is $21.92, located in the Galveston County A zone, maximum AAL cost per $1,000 of exposure values in the X500 ($13.46) and X ($14.61) zones are comparable to the V zone maximum value of $15.05. Especially for those homes with storm-surge only risk, there is little difference in the maximum AAL cost per $1,000 of exposure values across flood zones ($15.05, $13.26, $10.78, and $14.61 for V, A, X500, and X zones, respectively).

Fig. 7 provides a detailed view of the AAL cost per $1,000 of exposure distribution across all four flood zones. From this figure we see that for some AAL cost per $1,000 ranges, such as the two ranges from $5.01 to $10.00, the X500 zone has a larger number of residences than the V zone and is relatively comparable to the A zone within these loss cost ranges.[21]

This confirms again that the FEMA zone segmentation can be misleading; that is, there are a number of residences in Galveston that have similar AAL according to the results of the probabilistic catastrophe models, but are designated as being located in flood zones associated with very different levels of risk.

6. DISCUSSION OF RESULTS AND POLICY IMPLICATIONS

For Travis County, the study results indicate that the pure premium per $1,000 of exposure is over 12 times lower than in Galveston County, illustrating a significant disparity in flood risks between coastal and inland counties. For Travis, pure premium per $1,000 of exposure for residences in the high-risk A zone is over 3 times higher than for those in the moderate-risk X500/B zones, and nearly 18 times greater than for those in the low-risk X/C zones. However, for Galveston, the pure premium per $1,000 of exposure range across flood zones is not nearly as large: the high-risk A zone pure premium per $1,000 of exposure is 1.5 times greater than residences in the moderate-risk X500/B zones and 4 times greater than those in the low-risk X/C zones. The pure premium for Galveston's high-risk A zone is relatively similar to the one for residences in the coastal high-risk V zones.

According to the FEMA flood zone classifications, V and coastal A zones are the only areas subject to some level of storm-surge flood risk. However,

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[21] This result may simply be due to the total number of residences in the X500 zone being nearly four times larger than the number in the V zone (18,922 vs. 5,355, respectively).

our probabilistic model-based results identify a significant amount of storm-surge exposure and risk for a number of residences located *outside* of these V and coastal A zones in Galveston County. For example, in the Galveston X500 and X flood zones, there is $3.1 billion of property exposure at risk to storm-surge only.

Several conclusions can be drawn from our findings. First, there is substantial variation in flood exposure between coastal and inland locations within zones of similar risk classification by FEMA. For instance, homes in the designated moderate-risk X500/B zones in Galveston are exposed to a flood risk on average 2.5 times greater than residences in X500/B zones in Travis. Second, there is substantial variation of flood risk within a given coastal or inland county: the range of average values between high and low risks are much wider in Travis than in Galveston County as noted. Third, FEMA characterizes only an *average* flood risk in a given zone without indicating the variance across properties, which is clearly exhibited in our results. Finally, the model results indicate a significant amount of storm-surge exposure outside of the V and coastal A zones. In summary, these findings highlight the importance of undertaking a micro-analysis of the exposure of residents to riverine flood and storm surge to determine the pure premium associated with a given house.

As demonstrated here, similarly classified FEMA flood zones in different parts of the country can have significantly different flood exposure; thus, one cannot simply average the risk in a given flood zone. Not doing so will most likely lead the NFIP to charge many insured residents a premium that is "too high" in some areas and premiums that are "too low" in other areas in relation to risk-based premiums. This analysis demonstrates that the technology exists today to incorporate more granular risk assessment within all the flood zones (not just the 100-year flood zone), and the inclusion of flood events at the tail of the event distribution to more accurately price flood insurance.

In future research, it would be worthwhile to compare our catastrophe model results with prices currently being charged by the NFIP to get a sense of where NFIP premiums differ from the true risk-based premium (being higher or lower), and by how much. That will help quantify how much cross-subsidization there is today so as to make the NFIP more financially balanced by charging risk-based premiums. This has also become a requirement for FEMA with the passage of the Flood Insurance Reform and Modernization Act signed into law in July 2012. A critical component for inclusion in this NFIP premium comparison is the cost of capital and marketing/administrative cost for specifying a risk-based premium that would be charged by private insurers to homeowners residing in flood-prone areas should they start selling this coverage.

Several other catastrophe modeling and data mining firms as well as some large insurers and reinsurer are currently developing their own U.S. flood models and are planning to release them in the coming few years. It would be instructive to compare the results of similar analyses using these other catastrophe models to examine their differences and similarities. Having several flood models available on the market should also lower the cost of using these models due to competition, making them more affordable to small insurers and public-sector agencies who use them.[22]

Moving forward, it will be important to undertake similar analyses for a larger number of counties and residences across the nation and compare the results from different probabilistic flood risk models. It will also be important to determine how the true risk-based premium would be reduced if homeowners invested in different measures to reduce their future flood losses (e.g., flood proofing, elevating their property).

As discussed in Section 1, the 2012 Flood Insurance Reform Act also calls for a study on possible strategies to privatize flood insurance in the United States. Technology has radically improved since the inception of the NFIP in 1968 with significant progress made in the fields of catastrophe modeling, GIS, and risk map digitalization. Building on this technological progress, this article has proposed a methodological framework to appraise how private insurers would begin to price flood risk in the United States, benefiting from a unique access to the CoreLogic and Swiss Re flood catastrophe models, which we have applied to nearly 300,000 residences. Thus, this research provides insights that should be of interest to Congress and the Office of Management and

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[22] We thank two anonymous reviewers for pointing out the possible barrier that a high cost of purchasing a catastrophe model would constitute, including the cost of obtaining and maintaining the relevant granular level of data. Catastrophe models for earthquakes and hurricanes are affordable today and used by many organizations; it is likely that flood models would be viewed similarly. There is also a call for more transparency into these models by disclosing to clients the underlying assumptions of the model.

Budget (OMB) at the White House as they examine ways to reform the flood insurance program further. It should be of interest to researchers who are studying natural hazards and catastrophe risk in general, and disaster insurance in particular. It should also enable the insurance industry and other stakeholders to reconsider the role that the private sector can play in reducing America's exposure to future floods.

ACKNOWLEDGMENTS

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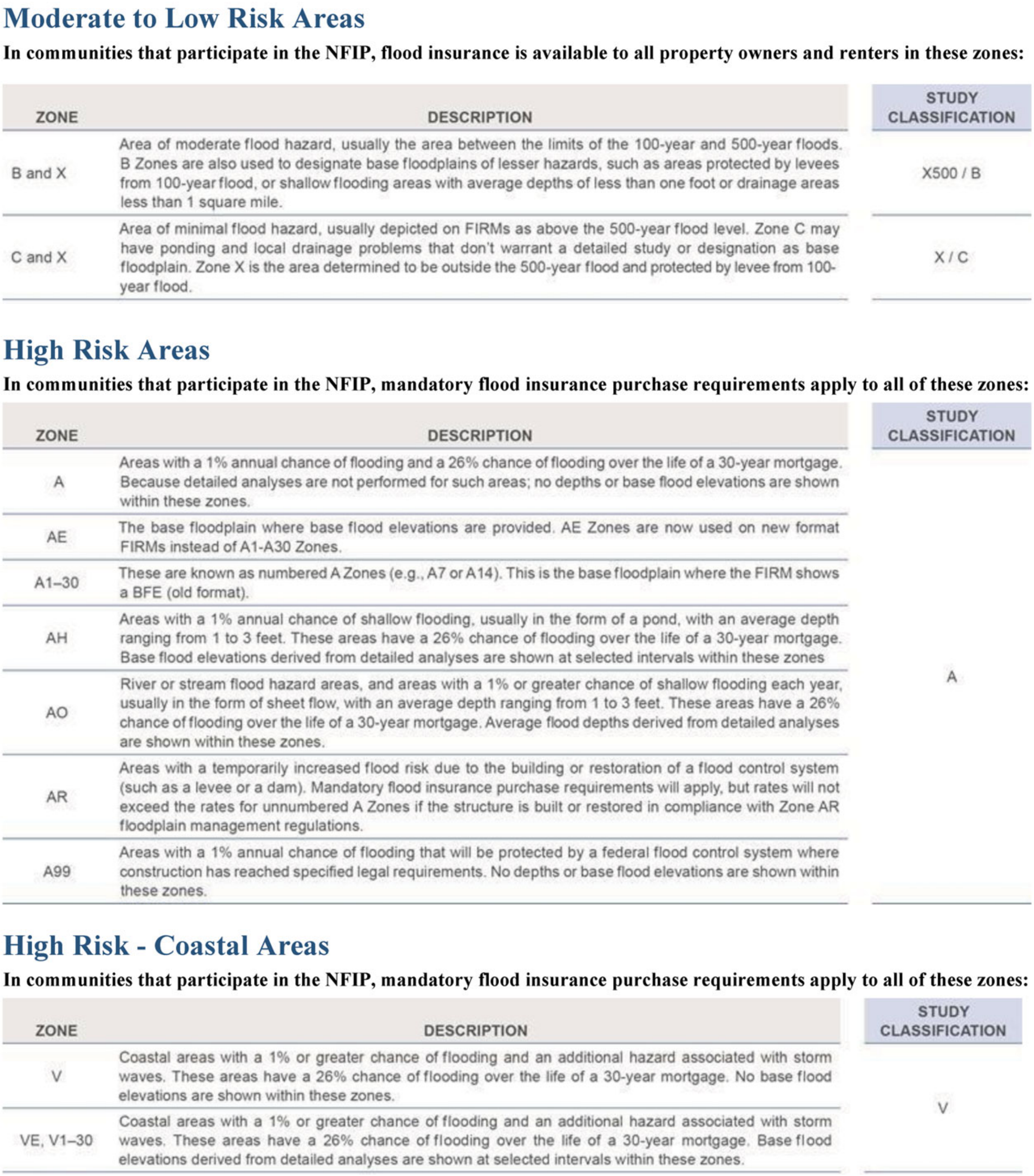
APPENDIX: DEFINITIONS OF FEMA FLOOD ZONE DESIGNATIONS AND STUDY CLASSIFICATION

Flood zones are geographic areas that FEMA has defined according to varying levels of flood risk. These zones are depicted on a community's Flood Insurance Rate Map (FIRM) or Flood Hazard Boundary Map. Each zone reflects the severity or type of flooding in the area.



Moderate to Low Risk Areas

In communities that participate in the NFIP, flood insurance is available to all property owners and renters in these zones:

ZONE	DESCRIPTION	STUDY CLASSIFICATION
B and X	Area of moderate flood hazard, usually the area between the limits of the 100-year and 500-year floods. B Zones are also used to designate base floodplains of lesser hazards, such as areas protected by levees from 100-year flood, or shallow flooding areas with average depths of less than one foot or drainage areas less than 1 square mile.	X500 / B
C and X	Area of minimal flood hazard, usually depicted on FIRMs as above the 500-year flood level. Zone C may have ponding and local drainage problems that don't warrant a detailed study or designation as base floodplain. Zone X is the area determined to be outside the 500-year flood and protected by levee from 100-year flood.	X / C

High Risk Areas

In communities that participate in the NFIP, mandatory flood insurance purchase requirements apply to all of these zones:

ZONE	DESCRIPTION	STUDY CLASSIFICATION
A	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones.	A
AE	The base floodplain where base flood elevations are provided. AE Zones are now used on new format FIRMs instead of A1-A30 Zones.	
A1–30	These are known as numbered A Zones (e.g., A7 or A14). This is the base floodplain where the FIRM shows a BFE (old format).	
AH	Areas with a 1% annual chance of shallow flooding, usually in the form of a pond, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones	
AO	River or stream flood hazard areas, and areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Average flood depths derived from detailed analyses are shown within these zones.	
AR	Areas with a temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam). Mandatory flood insurance purchase requirements will apply, but rates will not exceed the rates for unnumbered A Zones if the structure is built or restored in compliance with Zone AR floodplain management regulations.	
A99	Areas with a 1% annual chance of flooding that will be protected by a federal flood control system where construction has reached specified legal requirements. No depths or base flood elevations are shown within these zones.	

High Risk - Coastal Areas

In communities that participate in the NFIP, mandatory flood insurance purchase requirements apply to all of these zones:

ZONE	DESCRIPTION	STUDY CLASSIFICATION
V	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. No base flood elevations are shown within these zones.	V
VE, V1–30	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.	

Source: Modified from: https://www.msc.fema.gov/webapp/wcs/stores/servlet/info?storeId=10001&catalogId=10001&langId=-1&content=floodZones&title=FEMA%Flood%20Zone%20Designations

REFERENCES

1. Michel-Kerjan E, Kunreuther H. Redesigning flood insurance. Science, 2011; 333(6041):408–409.
2. Kunreuther H, Ginsberg R, Miller L, Sagi P, Slovic P, Borkan B, Katz N. Disaster Insurance Protection: Public Policy Lessons. New York: John Wiley and Sons, 1978.
3. Overman ES. The Flood Peril and the Federal Flood Insurance Act of 1956. Annals of the American Academy of Political and Social Science, 1957; 309:98–106.
4. Anderson DR. The National Flood Insurance Program: Problems and potential. Journal of Risk and Insurance, 1974; 41:579–599.
5. Grossi P, Kunreuther H (eds). Catastrophe Modeling: A New Approach to Managing Risk. New York: Springer, 2005.
6. Vickrey P, Master F, Powell M, Wadhera D. Hurricane hazard modeling: The past, present, and future. Journal of Wind Engineering and Industrial Aerodynamics, 2009; 97:392–405.
7. Cole C, Macpherson D, McCullough K. A comparison of hurricane loss models. Journal of Insurance Issues, 2010; 33: 31–53.
8. Hamid S, Kibria B, Gulati S, Powell M, Bachir A, Cocke S, Pinelli J, Gurley K, Chen S. Predicting losses of residential structures in the state of Florida by the public hurricane loss evaluation model. Statistical Methodology, 2010; 7(5): 552–573.
9. Hamid S, Pinelli J, Chen S, Gurley K. Catastrophe model-based assessment of hurricane risk and estimates of potential insured losses for the state of Florida. Natural Hazards Review, 2011; 12(4):171–176.
10. Government Accountability Office (GAO), Flood Insurance. FEMA's Rate-Setting Process Warrants Attention. GAO-09–12. Washington, DC: U.S. GAO, 2008.
11. U.S. Census Bureau 2011 Statistical Abstract. Available at: http://www.census.gov/compendia/statab/ Accessed October 2011.
12. Michel-Kerjan E, Kousky C. Come rain or shine: Evidence for flood insurance purchases in Florida. Journal of Risk and Insurance, 2010; 77(2):369–398.
13. Texas State Data Center (2011). Available at: http://txsdc.utsa.edu/, Accessed on August 12, 2011.
14. National Oceanic and Atmospheric Administration (NOAA) (2011). Coastal County Snapshots. Available at: http://www.csc.noaa.gov/digitalcoast/tools/snapshots/index.html, Accessed on August 12, 2011.
15. SHELDUS (2011). Available at: http://webra.cas.sc.edu/hvri/products/sheldus.aspxc, Accessed on August 12, 2011.
16. Hayes TL, Spafford DR. Actuarial Rate Review. Washington, DC: Federal Emergency Management Agency, 2008.
17. Federal Emergency Management Agency (FEMA). Design and Construction in Coastal A Zones, January 2009. Available at: http://www.riema.ri.gov/documents/FEMA/FloodRelated/757_apd_2_coastalazones-1.pdf, Accessed on September 30, 2011.