Pricing storm surge risks in Florida: Implications for determining flood insurance premiums and evaluating mitigation measures

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Pricing storm surge risks in Florida: Implications for determining flood insurance premiums and evaluating mitigation measures

Marilyn Montgomery and Howard Kunreuther

Abstract

The National Flood Insurance Program (NFIP) has been criticized for inaccurate flood hazard maps and premiums that are not risk-based. We employ granular storm surge data comprised of five different event probabilities with associated flood elevations to calculate surge risk-based premiums for homes in Pensacola, Florida, that we compare with NFIP premiums which are based on flood risk data with only one event probability (1% annual chance floods). We demonstrate how more granular flood risk data used for calculating risk-based insurance premiums should be part of the NFIP mapping and rate-setting processes. We then examine three different sea level rise scenarios specific to Pensacola from the National Oceanic and Atmospheric Administration (NOAA), and assess surge risk-based premiums out to 2100. We analyze the cost-effectiveness of elevating homes to mitigate surge risks when costs of elevation are one lump upfront sum, and when costs are spread over 30 years via low-interest mitigation loans. Benefits are the avoided future losses from surge risks going out to 2100 with the three different sea level rise scenarios. Findings show that it is cost-effective to elevate high value homes with low first-floor elevations in the most risky surge zones. Spreading costs of elevation with 30-year loans should be directed at low-income households to address affordability concerns. Alternative flood mitigation actions, such as wet floodproofing and elevating electrical and plumbing utilities, should be considered in instances where elevation is not cost-effective.

KEYWORDS: risk-based insurance premiums, National Flood Insurance Program, storm surge, sea level rise, benefit-cost analysis

1. INTRODUCTION

Florida is one of the most flood-prone states in the U.S. because of its low-lying topography, tropical and subtropical climate, and miles of coastline exposed to hurricane and storm surge hazards. According to data published online by the National Flood Insurance Program (NFIP) in May 2017,[1] Florida is ranked fifth among all U.S. states in dollar amounts of flood insurance claims since the inception of the NFIP in 1968. One-sixth of Florida's NFIP claims are from Escambia County, although this county has only 1.5% of Florida's population based on U.S. Census Bureau population estimates from July 2016.[2] Located in the northwestern-most part of the Florida panhandle, the study area for this research is the City of Pensacola, the county seat of Escambia County. This paper focuses on the importance of accurate mapping of flood risks for determining risk-based flood insurance premiums, how risk-based flood insurance premiums could be reduced by elevating residential property, and cases in which home elevation as a mitigation measure would be cost-effective in Pensacola.

The NFIP has been criticized because it does not charge premiums that accurately reflect flood risk,[(1)] as NFIP rates are set according to flood zone characteristics for the entire nation.[(2,3,4)] This broad approach results in policies that may be underpriced or overpriced with respect to the actual risk. Underpricing insurance conveys a false sense of security to policyholders that their flood risk is lower than it may actually be.[(5)] Overpricing could be viewed as unfair by homeowners who may decide not to purchase coverage unless they are required to do so.

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[1] National Flood Insurance Program (NFIP) loss statistics can be found at https://bsa.nfipstat.fema.gov/reports/1040.htm.

[2] County-level population and ranks can be searched in U.S. Census Bureau quick facts at https://www.census.gov/quickfacts/.

NFIP digital flood insurance rate maps (DFIRMs) delineate flood zones with annual probabilities of only 1% and 0.2% (corresponding to 100- and 500-year floods, respectively), because NFIP premiums are based largely on structures' coincidence with either of these two zones. The annual 1% chance flood zones are designated as Special Flood Hazard Areas (SFHAs) in the DFIRMs, and base flood elevations (BFEs) are provided within SFHAs where detailed hydraulic and hydrologic modeling has been done. The BFE is the stillwater (i.e., without waves) elevation that floodwater is expected to reach during an annual 1% chance flood event.[3] NFIP insurance rating for structures in SFHAs is generally classified as either post-FIRM or pre-FIRM, that is, whether the property was built before or after Flood Insurance Rate Maps (FIRMS) were put into effect. Post-FIRM rates depend on a structure's first floor elevation (FFE) in relation to the BFE according to an elevation certificate; pre-FIRM rates do not account for structures' FFE in relation to BFE[4].

Two cross-subsidies of the NFIP premium rates result from methods used to create DFIRMs. The first cross-subsidy applies to structures in the 0.2% annual chance/500-year flood zones (X500 zones). Rating for structures in the 0.2% annual chance zones is not based on the structure's elevation with respect to its flood hazard so there is an implicit subsidy from properties with higher elevations within X500 zones.[(6)] A second cross-subsidy from the DFIRMs occurs in A zones. The A zones include areas at risk to wave action hazards less than three feet; [(7)] rates within A zones are based only on the BFE. As stated above, the BFE represents stillwater flood elevation and thus does not include wave heights. Ignoring wave hazards in A zone rating results in implicit cross-subsidies from policies for structures without any risk to wave hazards to policies covering structures at risk to wave hazards less than three feet.[(6)]

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[3] The definition of the Base Flood Elevation (BFE) can be found at https://www.fema.gov/base-flood-elevation.
[4] We discuss pre- and post-FIRM NFIP rating further in Section 2.4 of this manuscript.

Previous research has established that granular flood risk data are necessary for accurately estimating expected losses for structures and risk-based insurance premiums.[2,8] By *granular*, we mean flood risk data that have more than one flood event probability with associated flood elevation/depth. There are no specific guidelines for the number of flood probabilities that are necessary to accurately model flood risks for all study areas, but FEMA recognizes that annual 1% and 0.2% annual chance flood zones are not sufficiently granular for accurate flood risk assessments and specifying risk-based flood insurance premiums.[9] Messner et al. (2007)[10] recommend flood hazard models with six flood probabilities, while Tate et al. (2016)[11] employed ten flood probabilities.

Because granular flood risk data for Pensacola residences are currently unavailable, we have employed granular *storm surge* data for Escambia County to estimate surge risk-based insurance premiums. The storm surge data include surge elevations for the 10%, 4%, 2%, 1% and 0.2% annual chance events. To estimate surge risk-based premiums, we implement an expected annual average losses (AAL) approach, as others have done.[2,8,10, 11] Furthermore, a choice of a depth-damage function must be made to relate depth of water inside structures to the costs of expected damages from flooding. There are several depth-damage functions used in research on flood losses, thus we utilize two different functions and evaluate the differences in surge risk-based AAL premiums resulting from the different functions.

Our study areas are the City of Pensacola and Sanders Beach. The City of Pensacola is defined as areas within the city limits, and Sanders Beach is defined as the 2010 census tract near downtown Pensacola that mostly encompasses the waterfront Sanders Beach neighborhood. Sanders Beach is singled out because it is more vulnerable than other parts of the city to storm surge and sea-level rise and has modest property values. Figure 1 shows the location of Sanders Beach, and the location of Escambia County in northwest Florida. We used the NFIP manual (October 2016 version)[12] to estimate NFIP premiums. We compare NFIP premiums to surge risk-based premiums for homes at risk to surge in Sanders Beach and Pensacola.

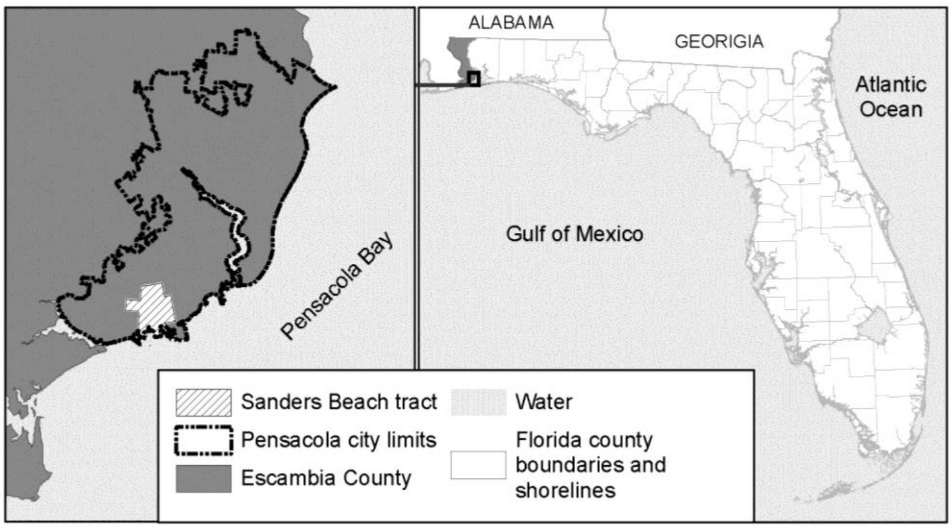

Figure 1. Location map of the Sanders Beach tract within the Pensacola city limits, and Escambia County in northwest Florida.

We then examine how sea level rise for every year from 2017 until 2100 might impact surge risk-based premiums. We examine three different sea level rise scenarios specific to Pensacola from the National Oceanic and Atmospheric Administration (NOAA), and assess surge risk-based premiums out to 2100 because 2100 is the recommended year for planning flood mitigation projects in communities that participate in the NFIP Community Rating System (CRS)[5].[(13)] The CRS is an NFIP program that rewards NFIP communities for implementing stricter floodplain regulations than minimum NFIP regulations.

The cost-effectiveness of home elevation as a flood mitigation strategy in Sanders Beach and Pensacola is assessed by calculating costs to elevate homes[6] by four and eight feet to reduce flood risks and thus reduce surge risk-based insurance premiums going out to 2100 with sea level rise. The savings in risk-based surge premiums after elevating homes are compared with the costs of home elevation as one upfront lump sum and costs spread with low- and zero-interest 30-year mitigation loans. We find that that home elevation is cost-effective for some homes in the most risky surge zones, but is particularly costly for existing structures with slab on-grade foundations, [(14)] and hence is rarely cost-effective for many homes in Sanders Beach and Pensacola when the costs are a single lump sum.

Our analyses are designed to answer the following research questions:

1. How do surge risk-based premiums compare with NFIP premiums for single-family homes in Sanders Beach and Pensacola using more granular storm surge data than the flood zones delineated in FEMA DFIRMs?
2. How do storm surge risk-based premiums vary with different depth-damage functions for the present year and the future using sea level rise estimates?

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[5] The estimated sea level rise data for Pensacola based on NOAA Low, Intermediate High, and High scenarios were obtained from a web-based tool located at http://www.corpsclimate.us/ccaceslcurves.cfm in which users input the initial year and intervals, going out to the maximum year of 2100. This web-based tool, hosted by the U.S. Army Corps of Engineers, is recommended by the most recent version of the Community Rating System (CRS) handbook located at https://www.fema.gov/media-library-data/1493905477815-d794671adeed5beab6a6304d8ba0b207/633300_2017_CRS_Coordinators_Manual_508.pdf.

[6] See Appendix B for figures used to estimate total costs of elevating homes.

3. Is elevation a cost-effective method of surge risk mitigation for homes in Sanders Beach and Pensacola, looking to the year 2100 with sea level rise?

2. DATA AND METHODS

2.1 Data Sources

The data originated from the Escambia County Property Appraiser (ECPA), Escambia County Geographic Information Systems (GIS), the City of Pensacola, the Northwest Florida Water Management District (NWFWMD), Florida Department of Emergency Management, the Federal Emergency Management Agency (FEMA), and Marine Weather & Climate.

2.2 Geospatial Analysis

The geospatial procedures were implemented with ArcGIS version 10.2.2. First, we prepared our residential dataset by joining parcel attributes required to estimate flood risk and exposure from the ECPA's 2015 parcel dataset to the parcel outlines. The parcel attributes relevant to determining flood risk included land use type, improvements values, year of construction, foundation and frame types, number of floors, and heated area in square feet. We obtained building footprints from City of Pensacola GIS personnel. Building footprints are drawn in a GIS by identifying rooftops of homes with high-resolution aerial photography. Although rooftops are technically not the structures' footprint on the ground, it is the most accurate available representation of homes' location, shape, and size. Next, we spatially joined building footprints within the Pensacola city limits to single-family parcels and determined the effective flood zones in which they were located using the 2006 FEMA Digital Flood

Insurance Rate Map (DFIRM) for Escambia County.[7] Homes (i.e., building footprints) in SFHAs of the DFIRM where BFEs were given were attributed with the coincident BFE.

Then we attributed building footprints with first floor elevation (FFE) information, most of which were based on elevation statistics from the LiDAR-derived digital elevation model (DEM) from the NWFWMD (collected in 2006). The average elevation of the DEM within each building footprint was chosen as a basis to estimate FFEs of single-family homes, except for the 15 homes (1% of 1,337 homes at risk to surge) that had a geocoded elevation certificate from the City of Pensacola Building Inspections Department. Because there is not significant variation in elevation within the Pensacola building footprints[8], we chose to use the average of the elevations within building footprints. For the remainder of the building footprints within single-family home parcels that did not have a geocoded elevation certificate, we applied the following assumptions to estimate FFE based on average elevation and foundation type[9] as follows:

[7] The DFIRM for Escambia County is published as an ArcGIS geodatabase that can be downloaded at FEMA Flood Map Service Center (https://msc.fema.gov/portal).

[8] The range of elevation values within the 18,407 Pensacola building footprints in our original dataset has an average of 1.50 feet with a standard deviation of 1.61. Although there are 79 building footprints with an elevation range over 10 feet, this represents only 0.4% of our 18,407 building footprints.

[9] Email communication with an Appraisal Supervisor at ECPA provided the following information on foundation types listed in the ECPA data: a slab above grade foundation is built up by 3 blocks or more, typically for sloped lots; and a wood foundation with a subfloor is an elevated home on pilings or crawlspace. Assumptions 1 and 2 listed on this page are minimum heights based on our understanding of these foundations types from our communications with personnel at the ECPA. Assumptions 3 and 4 are somewhat arbitrary, but piling homes usually have higher foundations than crawlspace homes.
Assumptions of FFEs based on foundation type were also ground-truthed for a sample of homes in Pensacola and Sanders Beach with visual inspections and conversations with homeowners. We conducted sensitivity analyses of FFE assumptions with two alternative sets of assumptions based on foundation types. The results are not presented herein but are available from the authors on request.

1. If foundation type is slab above grade, then add 2 feet to the average elevation of the DEM within the building footprint to estimate FFE. According to the ECPA, slab above grade foundations are elevated at least 3 blocks, and a standard block is 8 inches high.
2. If foundation type is slab on grade, then simply use the average elevation of the DEM within building footprint as FFE.
3. If foundation type is pilings, then add 6 feet to average elevation of the DEM within building footprint to estimate FFE.
4. If foundation type is wood with a subfloor, then add 3 feet to average elevation of the DEM within building footprint to estimate FFE. Wood with subfloors, according to the ECPA data, are elevated homes not on a slab.

Once FFEs were estimated for all single-family homes in Pensacola, the final step of our geospatial analysis was intersecting the building footprints with surge risk data called U-Surge, from Marine Weather & Climate.[10] Based on observations from the National Oceanic and Atmospheric Administration (NOAA), tide gauges and other data sources, storm surge data from 1900 to 2016 for Escambia County were analyzed and used to develop the U-Surge dataset for our study area. The U-Surge dataset was produced from a regression analysis of water level (storm tide height) as the dependent variable and frequency (return period) as the independent variable, and involved conversion of all high water marks to one common vertical datum (the North American Vertical Datum of 1988, or NAVD88) to enable statistical analysis.(15, 16, 17, 18, 19)

U-Surge data for surge risks (water elevations and probabilities) in Pensacola for the year 2017 were utilized for analysis. The U-surge data are more granular than DFIRM data because surge hazards are

[10] https://www.u-surge.net/about.html

disaggregated into annual probabilities of 10%, 4%, 2%, 1%, and 0.2%. Each annual surge probability event has a corresponding surge height, as shown in Table 1 (in feet). The U-Surge data are based on a log-linear regression model that fits surge heights as the dependent variable against return period for events that occurred in Pensacola from 1900 to 2016. The equation for Pensacola is

$$\mathbf{y = 3.9105 \ln(x) - 4.0896}$$ with x = return period and y = storm tide height above NAVD 88.

There are no control variables in this equation for Pensacola, and the $R^2 = 0.95385$. This equation and the surge depths provided in our paper are only valid for Pensacola, which is spatially defined as a 10-mile radius from the City of Pensacola.(18, 19)

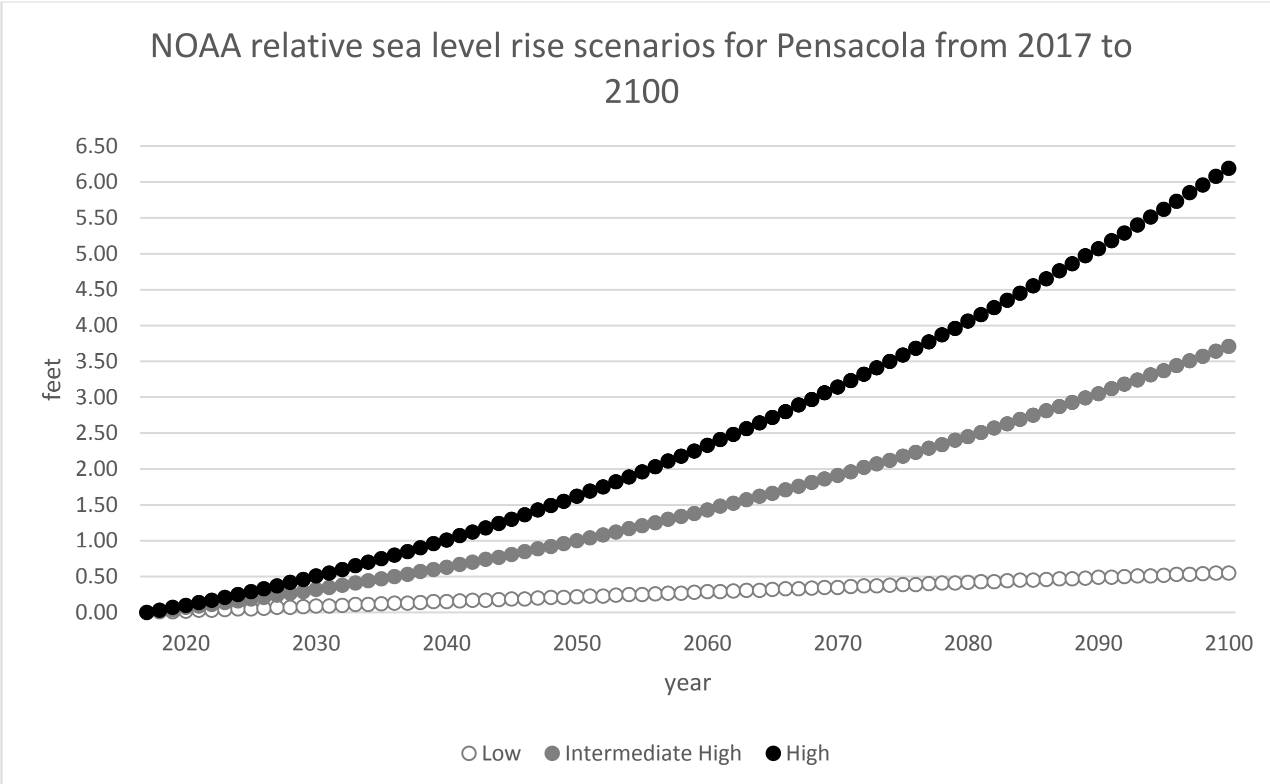
Homes that coincide with surge hazards were attributed with the minimum surge elevation based on the five annual probability events shown in Table 1, and then surge elevations that were higher were also attributed to the homes to calculate the total surge risk for homes. For example, if a home is coincident with the surge elevation corresponding to the 2% annual surge event, then we can assume it is also vulnerable to the 1% and 0.2% annual chance events.

Future conditions of surge hazards with sea level rise were also assessed for every year from 2017 to 2100 by applying three different NOAA sea level rise scenarios: Low, Intermediate-High, and High. The data for each of these three sea level rise scenarios are unique to Pensacola, and were obtained from the web-based tool provided by the U.S. Army Corps of Engineers (USACE), as recommended in the NFIP CRS manual.(13) Figure 2 shows the sea level rise in feet for each NOAA scenario. We estimate future conditions of surge hazards for every year until 2100 by adding the projected sea level rise to current surge water elevations.

Table 1. Stillwater surge elevations in feet for each probability event for Pensacola relative to NAVD88 (North Atlantic Vertical Datum of 1988) for year 2017, according to the U-Surge data. Storm tide return levels based on observed data from 1900-2016 (117 years) for the Pensacola area. (Source: U-Surge. 2017 Marine Weather & Climate https://www.u-surge.net/pensacola.html).

Annual probabilities of surge events	**Stillwater surge elevation (feet)**
10%	4.91
4%	8.50
2%	11.21
1%	13.92
0.2%	20.21

Figure 2. Estimated relative sea level rise scenarios (in feet) for Pensacola for every year from 2017 to 2100 according to National Oceanic and Atmospheric Administration (NOAA) (see http://corpsclimate.us/ccaceslcurves.cfm). Years are labeled on the horizontal axis in yen-year increments starting at 2020.



2.3 Determining Surge Risk-Based Insurance Premiums

To estimate average annual expected losses (AAL) from stillwater surge hazards for homes in Pensacola and corresponding risk-based insurance premiums, we applied two different depth-damage functions from the Hazus[11] software package that estimate percentages of the dollar values of damage to building and contents according to flood elevations (in whole feet) of water inside homes.[12] (20) We used the FIA/FIA modified function[13] since it is the default for the Hazus program, and the U.S. Army Corps of

[11] Hazus is software developed by FEMA that has a nationally applicable standardized methodology for estimating potential losses from earthquakes, floods, and hurricanes (https://www.fema.gov/hazus).

[12] Depth-damage functions are developed for each type of occupancy class (e.g., residential single-family), and vary for foundation types (basement or no basement), and number of stories/floors in the building. The two depth-damage functions we employ in this study are based on occupancy type, presence of a basement, number of floors, and flood zones (A or V zones) for the FIA/FIA modified functions. Depth-damage functions are developed from engineering studies and observed damage and claims data, and more information on depth-damage functions can be found in Chapter 5 of the Hazus Technical Manual (version 2.1).(20)

[13] FIA is the same agency that is now called the Federal Insurance and Mitigation Administration (FIMA).

Engineers (USACE) Institute of Water Resources (IWR) function because it does not involve specifics based on any geographic region of the United States. Damages to homes and contents were estimated using the IBM SPSS Statistics software (version 24) based on these two depth-damage functions. To estimate homes' vulnerability to storm surge hazards, we subtract the homes' FFEs from the surge water elevations to obtain the water depths inside the homes for each flood frequency/probability surge event for every year from 2017 to 2100. We computed AALs for all homes vulnerable to surge risks using the equation n the Hazus Technical Manual (version 2.1, page 14-38):

$$AAL = [(f_{10} - f_{25}) * ((L_{10} + L_{25}) /2)] + [(f_{25} - f_{50}) * ((L_{25} + L_{50}) /2)] + [(f_{50} - f_{100}) * ((L_{50} + L_{100}) /2)] + [(f_{100} - f_{500}) * ((L_{100} + L_{500}) /2)] + (f_{500} * L_{500})$$

where $f_x = 1/x$ (frequency/probability of an x-year flood event) and L_x are the losses attributable to the x-year event (expressed as percentages of building and contents) where x=10, 25, 50,100 and 500.

The AAL equation is based on the annual probability of each flood with the corresponding flood depths inside the home, and the damage to buildings and contents attributed to each depth of water inside homes according to the selected depth-damage function. We used the improvements values from the 2015 ECPA parcel data as building values, and assumed that contents values were half of the building values (after Kunreuther et al., 2018 [(8)]). The results of the AAL computations for homes at risk from surge hazards are the basis for the surge risk-based premiums. Surge risk-based premiums are calculated with $1,000 deductibles for building coverage and $1,000 deductibles for contents coverage to align comparisons with NFIP premiums, as the minimum and default NFIP deductibles for post-FIRM policies are $1,000 for building coverage and $1,000 for contents.

2.4 Estimating NFIP Premiums

To compare NFIP premiums with surge risk-based premiums, we applied the NFIP rate-setting methods using the October 2016 NFIP manual.(12) Building and contents coverages were determined as stated above in section 2.3, and we imposed NFIP limits of $250,000 for building coverage and $100,000 for contents coverage.[14] The flood risk data for each single-family home were from the 2006 Escambia County DFIRM.

For homes within SFHAs, which are all A, AE, AH, and AO zones in the DFIRM, NFIP premiums are rated as either pre-FIRM or post-FIRM. Appendix A lists the flood zones and definitions used in DFIRMs. Pre-FIRM ratings can be used when the date of home construction is prior to when the community entered the NFIP and received its first flood insurance rate map (FIRM); for Pensacola this date was September 15, 1977. Communities typically had no minimum floodplain construction standards prior to entering the NFIP, therefore homes built prior to the first FIRM constructed for their community probably have FFEs that are below the regulatory BFEs. Pre-FIRM premiums are considered subsidized according to FEMA, and are not based on FFE information from elevation certificates. Post-FIRM rates involve homes' foundation types and FFEs with respect to the BFE for the zone in which they are located, which is why they are called "full risk" rates in NFIP terminology. If the home was built in 1977 or earlier we used pre-FIRM rates, and post-FIRM rates were used for homes built in 1978 and later.

For homes within X500 zones, which are the annual 0.2% chance flood zones, we estimate NFIP premiums using both Preferred Risk Policy (PRP) and Standard Policy rates. Homes outside SFHAs may

[14] NFIP residential coverage limits for building and contents are $250,000 and $100,000, respectively.

be eligible for relatively inexpensive PRP premiums if they meet several conditions.[15] If X500 zone homes do not meet the criteria for PRP eligibility, then they are rated with Standard Policy rates. There are no considerations of structures' FFEs in any X500 zone premiums, and there are no flood elevations delineated within X500 zones.

We applied a deductible factor[16] of 1 to all estimated NFIP premiums. A deductible factor of 1 for post-FIRM policies means that the building/contents deductibles are $1,000/$1,000 for building coverages of $100,000 or less; and for pre-FIRM policies a deductible factor of 1 is $2,000/$2,000 building/contents deductibles. We assumed that all homes were owner-occupied so that we could compute building and contents premiums for primary residences using the NFIP rating tables.(12)

Normalizing NFIP annual premiums by coverage amounts enables one to make comparisons with surge risk-based AAL premiums that do not vary with the amount of coverage, and are not subject to coverage limits. To compare NFIP premiums with surge risk-based AAL premiums, we thus normalize NFIP annual premiums per $100 of building and contents coverage. NFIP basic rates apply for the first $60,000 of residential building coverage, and basic contents rates apply for the first $25,000 of contents coverage. Additional NFIP rates, which are lower than basic rates, apply for residential building coverage in excess

[15] A home in an X, B, or C flood zone qualifies for a PRP if none of the following conditions apply within any 10-year period: (a) 2 flood insurance claim payments for separate losses, each more than $1,000; or (b) 3 or more flood insurance claim payments for separate losses, regardless of amount; or (c) 2 Federal flood disaster relief payments (including loans and grants) for separate occurrences, each more than $1,000; or (d) 3 Federal flood disaster relief payments (including loans and grants) for separate occurrences, regardless of amount; or (3) 1 flood insurance claim payment and 1 Federal flood disaster relief payment (including loans and grants), each for separate losses and each more than $1,000.

[16] We used a deductible factor of 1 for all premium calculations, which equates to a $1,000/$1,000 deductible for building/contents for post-FIRM structures, and a $2,000/$2,000 deductible for building/contents for pre-FIRM structures (refer to the October 2016 NFIP manual page RATE 18 for further information).

of $60,000 up to the limit of $250,000; and additional rates for contents coverage are for amounts over $25,000 up to the limit of $100,000.

We do not consider NFIP premiums to be risk-based, but the premiums we estimate are generally likely to be higher than actual NFIP premiums charged for many policies in Pensacola that are subsidized for reasons other than pre-FIRM subsidization. Furthermore, it is very confusing that the NFIP calls post-FIRM rates "full risk" rates, because much of the motivation for this paper is to demonstrate how risk-based flood insurance premiums are calculated in a manner that is very different from the NFIP[17]. Another reason why our estimated NFIP premiums are probably higher than actual NFIP paid premiums is because we assume that coverages are for full building replacement values (and contents coverages that are half of building values). Policyholders may actually request less building and contents coverages to lower their premiums. For both surge risk-based premiums and NFIP premiums, we estimate pure premiums, defined as the dollar amounts that reflect flood-related damages. These premiums do not include loading factors that reflect an insurance company's overhead, administrative costs, fees, or other expenses.

2.5 Assessing Flood Risk Mitigation Costs and Benefits

Once NFIP and surge risk-based premiums were computed, we analyzed elevation as a mitigation measure for structures at risk from surge hazards. Based on FEMA publication P-312,[(14)] we estimated costs to elevate homes with two types of foundations and frames: slab foundations and open

[17] The NFIP calls post-FIRM rates "full risk" to differentiate post-FIRM rates from pre-FIRM rates that are not based on any FFE information.

foundations with crawlspace, and wood and masonry frames.[18] Cost estimates are based on area of the home in square feet and the type of foundation and frame, as provided in the ECPA parcel data.

We computed benefit-cost ratios with the benefits in the form of annual savings in surge risk-based AAL premiums for every year from 2017 to 2100 after elevating homes by four or eight feet according to the NOAA Low, Intermediate-High, and High sea level rise (SLR) scenarios and the USACE IWR depth-damage function. We the USACE IWR function because it produces higher surge risk-based AALs, and thus greater benefits, than the FIA function. As stated above, we examine reductions in surge risks from elevating homes out to 2100 because the CRS manual [(13)] recommends that community flood mitigation projects should consider SLR projection to 2100.

We calculated the benefit-cost ratio in two ways: if the homeowner was forced to pay the entire elevation cost upfront ($BCR_{\text{upfront costs}}$) at a cost $C_{\textit{upfront costs}}$ or if s/he was able to spread the upfront costs over time by taking out 30-year mitigation loans (BCR_{loan}) with the annual cost *C(i)* determined by an annual interest rate *i*=.01 or 0.[19] The relevant BCRs were calculated as follows:

$$BCR_{\textit{upfront costs}} = \sum_{t=1}^{T} \frac{B^t}{(1+r)^t} \; / \; C_{\textit{upfront costs}}$$

$$BCR_{\text{loan}} = \sum_{t=1}^{T} \frac{B^t}{(1+r)^t} \; / \sum_{t=1}^{T} \frac{C(i)^t}{(1+r)^t}$$

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[18] The cost estimates for elevating these two types of foundations and frames per square foot of home footprint are found in Table 3-3 on page 3-20 of publication P-213, also shown in Appendix B herein.

[19] A 30-year mitigation loan term was chosen because it is the typical term for a home mortgage and the 1% and 0% annual interest rates was based on a bill introduced in the U.S. Congress which includes allowances for zero- or low-interest mitigation loans. H.R.3285 - Sustainable, Affordable, Fair, and Efficient (SAFE) National Flood Insurance Program Reauthorization Act of 2017 (https://www.congress.gov/bill/115th-congress/house-bill/3285/text#toc-H51CD66E7895D43D4A9708180C8ACF776

where T = time frame from 2017 to 2100, t = year (with 2017 as year 0), B = benefits (savings in surge risk-based AAL premiums after elevating homes), and r = annual discount rate (either 4% or 7%).

Regarding the choice of annual discount rates, FEMA uses 7% for evaluating mitigation grant proposals(21) while the National Institute of Building Sciences used a discount rate of 2.2% in evaluating the cost effectiveness of hazard mitigation projects in the U.S.(22) We follow Aerts et al. (2014)(23) who analyzed flood mitigation options in New York City by using 4% and 7% annual discount rates as low and high rates: 4% as it is the rate used by the Netherlands for long-term projects reducing societal risk and funded by governmental entities, and 7% because it is the rate used by FEMA(21) for evaluating mitigation projects. (23)

3. RESULTS AND DISCUSSION

3.1 Comparison of NFIP and Surge Risk-Based Insurance Premiums for Sanders Beach and Pensacola

Summary statistics of attributes pertinent for flood risk assessment for homes in Sanders Beach and Pensacola are presented in Tables 2 and 3. Tables 2 and 3 include single-family homes at risk to storm surge, according to the U-Surge data. Table 2 shows statistics for continuous variables, while Table 3 shows counts and percentages for nominal variables.

Table 2. Summary statistics (count, minimums, maximums, averages, and standard deviations) for homes at risk to surge in Sanders Beach and Pensacola.

Sanders Beach homes at risk to surge	N	Min	Max	Average	St. Dev.
building replacement value	175	\$7,815	\$1,014,492	\$74,343	\$118,516
contents replacement value	175	\$3,908	\$507,246	\$37,172	\$59,258

year built	175	1885	2014	1948	35
heated square feet	175	545	5191	1,420.43	728.47
FFE	175	5.76	24.05	15.80	5.19
Pensacola homes at risk to surge	**N**	**Min**	**Max**	**Average**	**St. Dev.**
building replacement value	1,337	$1,386	$2,935,885	$137,485	$216,090
contents replacement value	1,337	$693	$1,467,943	$68,743	$108,045
year built	1,337	1810	2014	1958	31
heated square feet	1,337	252	12,725	2,044.26	1,388.18
FFE	1,337	3.81	28.38	15.44	4.55

Table 3. Counts and percentages of nominal attributes for homes at risk to surge in Sanders Beach and Pensacola.

		Counts		**Percentages**	
	Foundation types	**Sanders Beach**	**Pensacola**	**Sanders Beach**	**Pensacola**
	slab on-grade	51	446	29.14%	33.33%
	slab above grade	3	41	1.71%	3.21%
	wood with subfloor (crawlspace)	121	846	69.14%	63.09%
	Pilings	0	4	0.00%	0.37%
	Frame types				
	Wood	167	1,239	95.43%	92.69%
	Masonry	8	98	4.57%	7.31%
	Number of stories (floors)				
	1	144	897	82.29%	67.11%
	2	30	413	17.14%	30.80%
	3	1	27	0.57%	2.09%
FEMA flood zones	SFHA (A, AE, AH, AO zones) homes	60	268*	34.3%	20.06%
	X500 zone homes	115	1,066*	65.7%	79.72%
Pre- or post-FIRM	Pre-FIRM (built in 1977 or prior)	127	962	72.57%	71.74%
	Post-FIRM (built in 1978 and later)	48	375	27.43%	28.26%
Surge risk zones	10% annual chance	4	47	2.29%	3.50%
	4% annual chance	52	229	29.71%	17.15%
	2% annual chance	6	296	3.43%	22.07%
	1% annual chance	18	267	10.29%	19.91%

0.2% annual chance	95	498	54.29%	37.36%

***Note**: there are 3 homes in Pensacola in VE zones that are omitted from this table.

In Tables 4 and 5, we show counts and averages of normalized annual premiums for homes in Sanders Beach and Pensacola by surge risk zones and NFIP DFIRM zones. All annual premiums are normalized per $100 of building and contents coverage; and $1,000 and $1,000 building and contents deductibles are included in our surge premium calculations. Although NFIP A zone rates are calculated differently for pre- and post-FIRM homes, we average pre- and post-FIRM rates A zone rates to compare them with average surge premiums for homes in the same NFIP flood zone and surge risk zone.

Table 4. Counts and averages of normalized annual premiums for homes in Sanders Beach by surge risk zones and NFIP DFIRM zones.

Sanders Beach homes		A zones, NFIP premium (pre- and post-FIRM rates)		A zones, surge premium FIA function $1000 deductible		A zones, surge premium USACE IWR function $1000 deductible		X500 zones, PRP rates		X500 zones, standard rates		X500 zones, surge premium FIA function $1000 deductible		X500 zones, surge premium USACE IWR function $1000 deductible	
		Average	Count	Average	Count	Average	Count	Average	Count	Average	Count	Average	Count	Average	Count
Surge risk zones (% annual chance)	10%	$1.03	4	$1.22	4	$2.30	4		0		0		0		0
	4%	$0.78	52	$0.80	52	$1.37	52		0		0		0		0
	2%	$1.03	4	$0.31	4	$0.62	4	$0.26	2	$1.18	2	$0.38	2	$0.69	2
	1%		0		0		0	$0.30	18	$1.13	18	$0.05	18	$0.08	18
	0.20%		0		0		0	$0.29	95	$1.16	95	$0.02	95	$0.03	95

Table 5. Counts and averages of normalized annual premiums for homes in Pensacola by surge risk zones and NFIP DFIRM zones.

Pensa-cola homes		A zones, NFIP premium (pre- and post-FIRM rates)		A zones, surge premium FIA function ($1k/$1k deductibles)		A zones, surge premium USACE IWR function $1000 deductible		X500 zones, PRP rates		X500 zones, standard rates		X500 zones, surge premium FIA function $1000 deductible		X500 zones, surge premium USACE IWR function $1000 deductible	
		Average	Count	Average	Count	Average	Count	Average	Count	Average	Count	Average	Count	Average	Count
Surge risk zones (% annual chance)	10%	$0.92	46	$1.40	46	$2.33	46		0		0		0		0
	4%	$0.63	178	$0.64	178	$1.08	178	$0.17	51	$0.77	51	$0.52	51	$0.85	51
	2%	$0.91	38	$0.27	38	$0.48	38	$0.24	256	$0.97	256	$0.21	256	$0.37	256
	1%	$0.76	3	$0.03	3	$0.05	3	$0.25	264	$0.97	264	$0.07	264	$0.12	264
	0.20%	$1.04	3	$0.00	3	$0.00	3	$0.25	495	$1.01	495	$0.02	495	$0.03	498

Tables 4 and 5 show average NFIP premiums for pre- and post-FIRM homes in the A zone and PRP and standard premiums for homes in the X500 zone (outside SFHAs). For homes in X500 zones and the 1% and 0.2% annual chance surge zones, PRP premiums are lower and standard-rated premiums are higher than risk-based surge premiums based on both FIA and USACE functions. It would be helpful to know how many X500 zone Standard Policies actually exist in Pensacola since homeowners in X500 zones may simply drop their NFIP coverage if they lose PRP rate eligibility. Consequently, we obtained actual policy statistics from FEMA based on NFIP August 2017 active contracts.[20] In August 2017, there were 1,734 X500 zone NFIP contracts, and 1,587 X500 zone NFIP contracts rated with PRP rates (thus, about 92% of all X500 zone contracts are rated with PRP rates in the City of Pensacola in August 2017). This suggests that NFIP X500 zone policy holders in Pensacola drop coverage if they lose PRP rating.

The averages presented in Tables 4 and 5 indicate that for homes in both Pensacola and Sanders Beach in A flood zones and 10% annual chance surge zones, the surge risk-based premiums based on both depth-damage functions are somewhat higher than the NFIP rates. In the 4% annual chance surge zones, NFIP and surge premiums based on the FIA function are similar. In the 2% annual chance surge zones, A zone homes have a significantly higher NFIP premium than surge premiums based on either the FIA or USACE IWR depth-damage functions. Despite the differences in how NFIP and surge risk-based AAL premiums are estimated, it is striking how similar the rates for homes in the 4% annual chance zone are for NFIP and the surge premiums based on the FIA function. The USACE IWR function significantly overweighs expected damages compared to the FIA function.

[20] Email communication with a Federal Insurance and Mitigation Agency (FIMA) employee indicated that NFIP contracts and policies can be different figures, because some contracts are for multi-family or multi-unit structures with singular or multiple policies. Nevertheless, statistics on active contracts in X500 zones that are rated with PRP or standard rates indicate that there are very few standard rated contracts in X500 zones.

NFIP premiums are based on rating tables that differentiate between flood zones, date of home construction with respect to the date the community entered the NFIP (i.e., pre- and post-FIRM rates), foundation type, and number of floors. Calculations of surge risk-based AAL premiums are based on the choice of depth-damage function, number of floors, and foundation types. Both surge risk-based premiums and post-FIRM NFIP rates for homes in SFHAs take into account differences between structures' FFEs and flood elevations. Pre-FIRM NFIP premiums consider only the foundation type and number of stories. For homes at risk of surge, we have up to five annual chance surge probabilities with corresponding stillwater surge elevations. For example, a home at risk to surge with an annual 10% chance would also have the 4%, 2%, 1%, and 0.2% annual surge probabilities with corresponding flood elevations as a basis for the AAL risk-based premium calculation, while a home at risk to only the 0.2% annual chance surge event would only have one surge probability in determining its AAL. NFIP rates have only one annual chance event (1% annual chance event). As we have stated, many NFIP premiums are pre-FIRM A zone or X500 zone rating, neither of which account for structure-specific FFE information.

In addition to the differences between how NFIP and surge AAL risk-based premiums are calculated, there are also differences in how NFIP DFIRM data are developed in comparison with the U-Surge data. NFIP DFIRM data reflect composite riverine and storm surge risks, while U-Surge data comprise only surge risks. To gain a better understanding of the differences between the DFIRM and the U-Surge data, we examined the 2006 Flood Insurance Study [(24)] (FIS) that accompanies the 2006 DFRIM data. Figure 3 depicts a map showing water bodies in and adjacent to Pensacola, and the coastal transects[21] from the

[21] Coastal transects in terms of a Flood Insurance Study and DFIRM geodatabase are s defined as follows: "The transect lines indicate the location that was used to provide representative topographic information for the coastal flood models used. Hydraulic analyses of coastal flood effects are executed along transects, which are cross sections taken perpendicular to the shoreline, representing a segment of coast with similar characteristics.

2006 FIS. Escambia River, north of Pensacola, would be a source of riverine flood risk but it is located too far from Pensacola to have much, if any, influence on BFEs in Pensacola. The water bodies Bayou Texar and Bayou Chico would be subject to surge risks since they are connected to Pensacola Bay. There are three coastal transects along Pensacola Bay that coincide with our Pensacola study area. The transect locations are important because they are where detailed hydrologic and hydraulic modeling were implemented as part of the 2006 FIS, thus flood elevations and annual probabilities for more than just the 1% annual chance event are provided in the FIS at these transect locations. In Table 6 we show comparisons of stillwater flood heights between FIS and U-Surge data for transects 26, 27, and 28 for four annual chance events. We expect that flood heights for these transects would be similar to U-Surge surge heights for the same annual chance events, but all of the U-Surge flood elevations are much higher than those for the coastal transects. It is beyond the scope of this paper to provide a detailed discussion of the methodology employed in the 2006 Escambia County FIS and development of the DFIRM flood hazard data, but further research into why the U-Surge data reflect much greater risk than the DFIRM data is warranted. Nevertheless, we are aware that the U-Surge data are derived from only observed data [18, 19], while DFIRM data are based on observed data and simulations.[24]

Transect elevations are interpolated to delineate the coastal flood zones. The spatial elements representing coastal transects are lines that generally extend from offshore all the way across the coastal floodplain. Transects can also extend seaward when wave runup modeling is used to determine coastal flood hazards. This information is needed for the Transect Locator Map table and Coastal Transect Parameters table in the FIS report." This metadata is located online at https://hazards.fema.gov/gis/nfhl/rest/services/public/NFHL/MapServer/15.

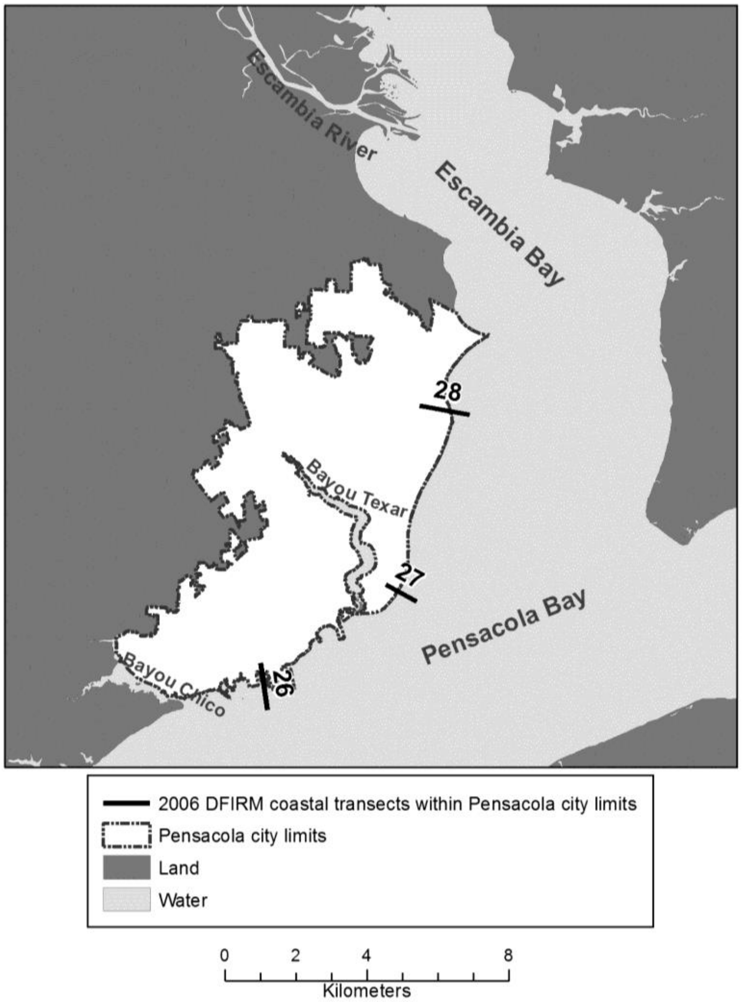

Figure 3. Map of Pensacola city limits, water bodies (with names labeled in black), and 2006 DFIRM coastal transects within Pensacola city limits (transects 26, 27, and 28 labeled with transect number in black).

Table 6. Stillwater flood heights for Transects 26, 27, and 28 from the 2006 FIS for Escambia County[22] and U-Surge data. All heights are in feet and the North American Vertical Datum of 1988 (NAVD88).

annual chance stillwater flood elevation	2006 FIS heights Transect 26	2006 FIS heights Transect 27	2006 FIS heights Transect 28	U-Surge
10%	*	2.8	3.0	4.9
2%	*	5.0	5.5	11.2
1%	8.0	5.9	6.5	13.9
0.2%	*	7.3	7.9	20.2

*Data not available.

3.2 Comparison of Surge Risk-based Premiums for Sanders Beach and Pensacola

Our premium comparisons in this section are based on U-Surge surge risk data, and NOAA sea level rise scenarios for 2017 through 2100. Estimates of the costs of elevating homes are based on 2015 parcel data and FEMA P-312.[(14)] First, we examine results for present-day surge risk-based AAL premiums for Sanders Beach and Pensacola, with average normalized premiums for homes in each surge risk zone

[22] Data for Transects 26, 27, and 28 can be found in Table 9 on page 37 of the Escambia County 2006 FIS (located online at https://map1.msc.fema.gov/data/12/S/PDF/12033CV000A.pdf?LOC=22c62b12955fa4b6efdcbbf19ca07a47).

(10%, 4%, 2%, 1%, and 0.2% annual chance zones). Figure 4 shows results for Sanders Beach homes, and Figure 5 shows results for Pensacola homes. Average surge risk-based AAL premiums are generally higher for homes in Sanders Beach than for Pensacola homes.

The differences in results between the two depth damage functions, FIA/FIA modified (abbreviated as FIA), and the US Army Corps of Engineers Institute of Water Resources (abbreviated as USACE IWR), are significant. The USACE IWR function overestimates AAL damages compared with the FIA function. The plot in Figure 6 demonstrates that for every foot of flood water inside a home, the USACE IWR function attributes a greater percentage of the building value lost to flood damages. The curve for contents damage is not shown herein, but the USACE IWR function also attributes more contents losses for every foot of flood depth inside homes than the FIA function. Previous research demonstrates that an important challenge of flood risk assessment is precisely specifying flood damages due to uncertainties in depth-damage functions.[25, 26]

We computed surge risk-based AAL premiums for every year from 2017 to 2100 using the three NOAA sea level rise (SLR) scenarios for Pensacola (Low, Intermediate-High, and High). Plots of the average values of our results can be found in Appendix C. We omit presentation of these results in the body of this paper because the trends in surge AAL premiums using each of the three SLR scenarios generally follow the trends observed in Figure 2 above. Therefore, we now discuss the results of our benefit-cost analyses of elevating homes at risk to surge.

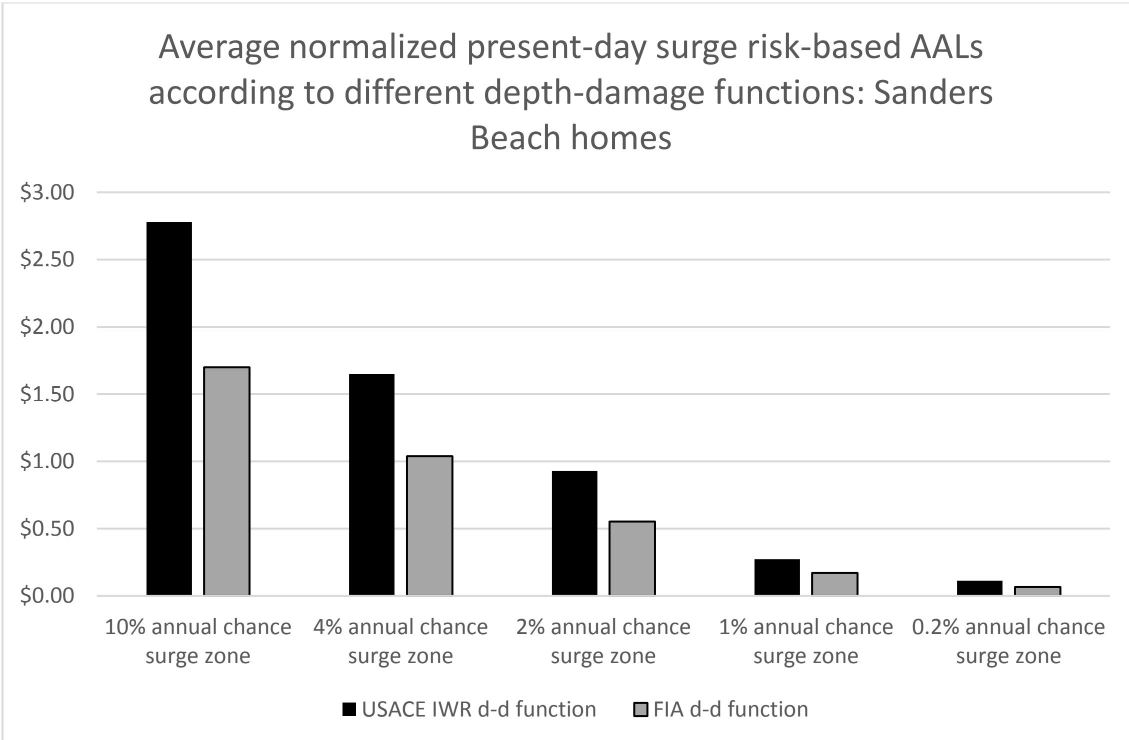

Figure 4. Average normalized surge risk-based AAL premiums (coverage per $100 of building and contents coverage) for homes in each surge risk zone (10%, 4%, 2%, 1%, and 0.2% annual chance zones) for Sanders Beach homes according to the USACE IWR and FIA depth-damage functions. (n=175 homes at risk of surge hazards)

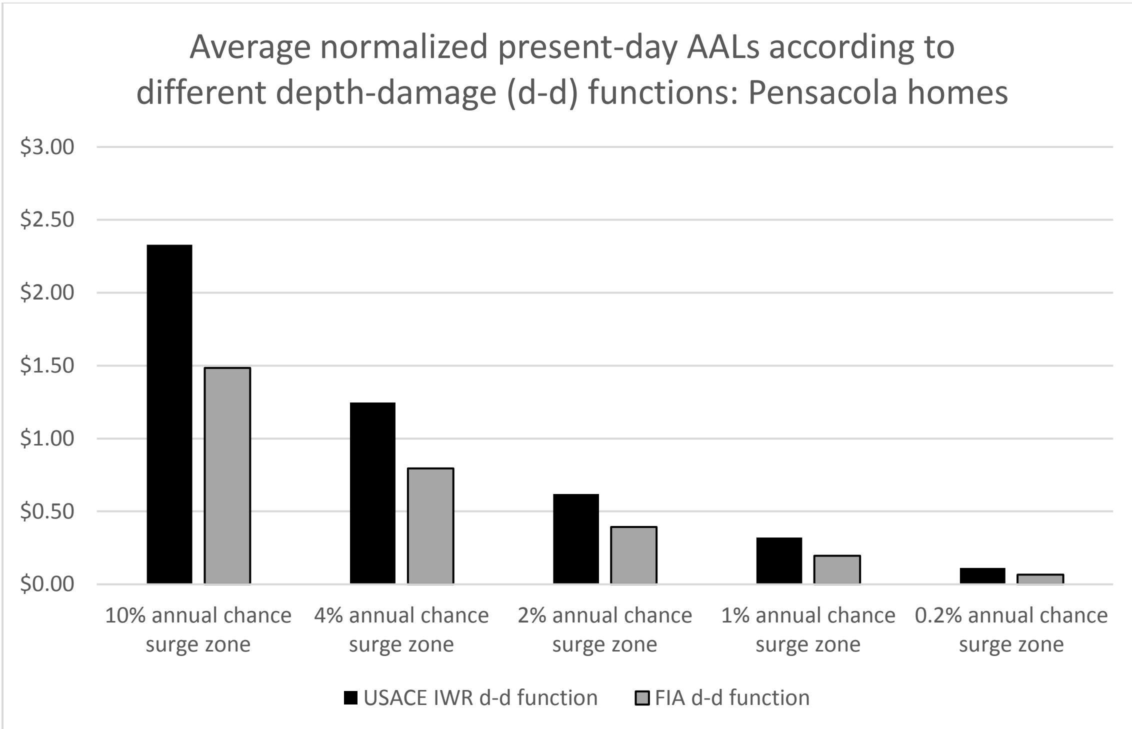

Figure 5. Average normalized surge risk-based AAL premiums (coverage per $100 of building and contents coverage) for homes in each surge risk zone (10%, 4%, 2%, 1%, and 0.2% annual chance zones) for Pensacola homes according to the USACE IWR and FIA depth-damage functions. (n=1,337 homes at risk of surge hazards)

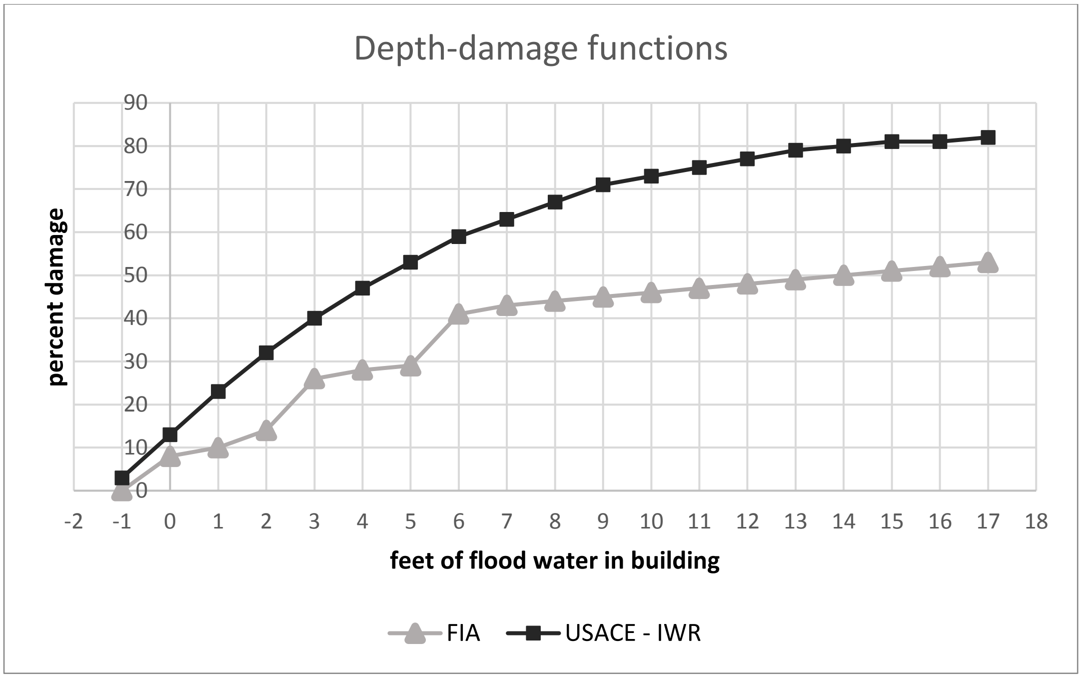

Figure 6. Depth-damage functions for single-family residential buildings with one story and no basement according to the FIA and USACE IWR. Damages are expressed as percentages of building values lost to feet of flood water in homes.

3.3 Benefit-Cost Analysis of Mitigation Based on Upfront Costs

Based on the calculated surge risk-based AAL premiums due to SLR, we now undertake a benefit-cost analyses of elevating homes to mitigate surge risks. Specifically, we employ the NOAA Low, Intermediate-High, and High SLR scenarios and the USACE IWR depth-damage function to estimate benefits into the future for every year from 2017 to 2100 using annual discount rates of 4% and 7%. We used the USACE IWR depth-damage function instead of the FEMA FIA function because the USACE IWR function produces higher surge AALs, thus the benefits in saved AALs from elevating homes are greater with the USACE IWR function. In this section we examine the cost-effectiveness of elevating single-family homes in Sanders Beach and Pensacola by four and eight feet, and benefits discounted to 2100 based on homeowners incurring the upfront cost of elevating their property. Figures 7, 8, and 9 show the average benefit-cost ratios [$BCR_{upfront\ costs}$] for Sanders Beach and Pensacola homes by surge zones based on the NOAA Low, Intermediate-High, and High SLR scenarios (respectively) and USACE IWR function. A BCR of 1 indicates cost-effectiveness, so we have highlighted the horizontal line for BCR =1 in all of our BCR charts.

The benefit-cost ratios [$BCR_{upfront\ costs}$] shown in Figures 7 through 9 are averaged for homes by surge zone. Disaggregating our results by surge zone as we have done in Figures 7 through 9 reveals that choice of SLR scenario affects BCRs most in the most likely surge risk zones: the 10% and 4% annual chance zones. This is expected since SLR will impact the greater likelihood surge risk zones (i.e., the 10% and 4% annual chance zones) more than the less likely surge zones (i.e., the 2%, 1%, and 0.2% annual chance surge zones). But, our average benefit-cost ratios [$BCR_{upfront\ costs}$] indicate that it is rarely cost-effective to elevate homes in the 2%, 1%, and 0.2% annual chance surge zones no matter the choice of SLR scenario or discount rate. For example, using the NOAA High SLR scenario and the lower discount rate of 4% results in average benefit-cost ratios [$BCR_{upfront\ costs}$] to elevate Pensacola homes at risk to 10% annual chance surge events by eight feet to be over 0.8. Conversely, average benefit-cost ratios [$BCR_{upfront\ costs}$] for homes in Sanders Beach and Pensacola in the 2%, 1%, and 0.2% annual chance surge zones are rarely over 0.2 with any SLR scenario or discount rate we have analyzed. Employing granual surge risk data with various SLR scenarios and discount rates enables more informed analyses of the cost-effectiveness of elevating homes at risk to surge flooding, and could be important for decision-makers to develop thresholds and criteria for benefit-cost analyses when considering mitigation actions.

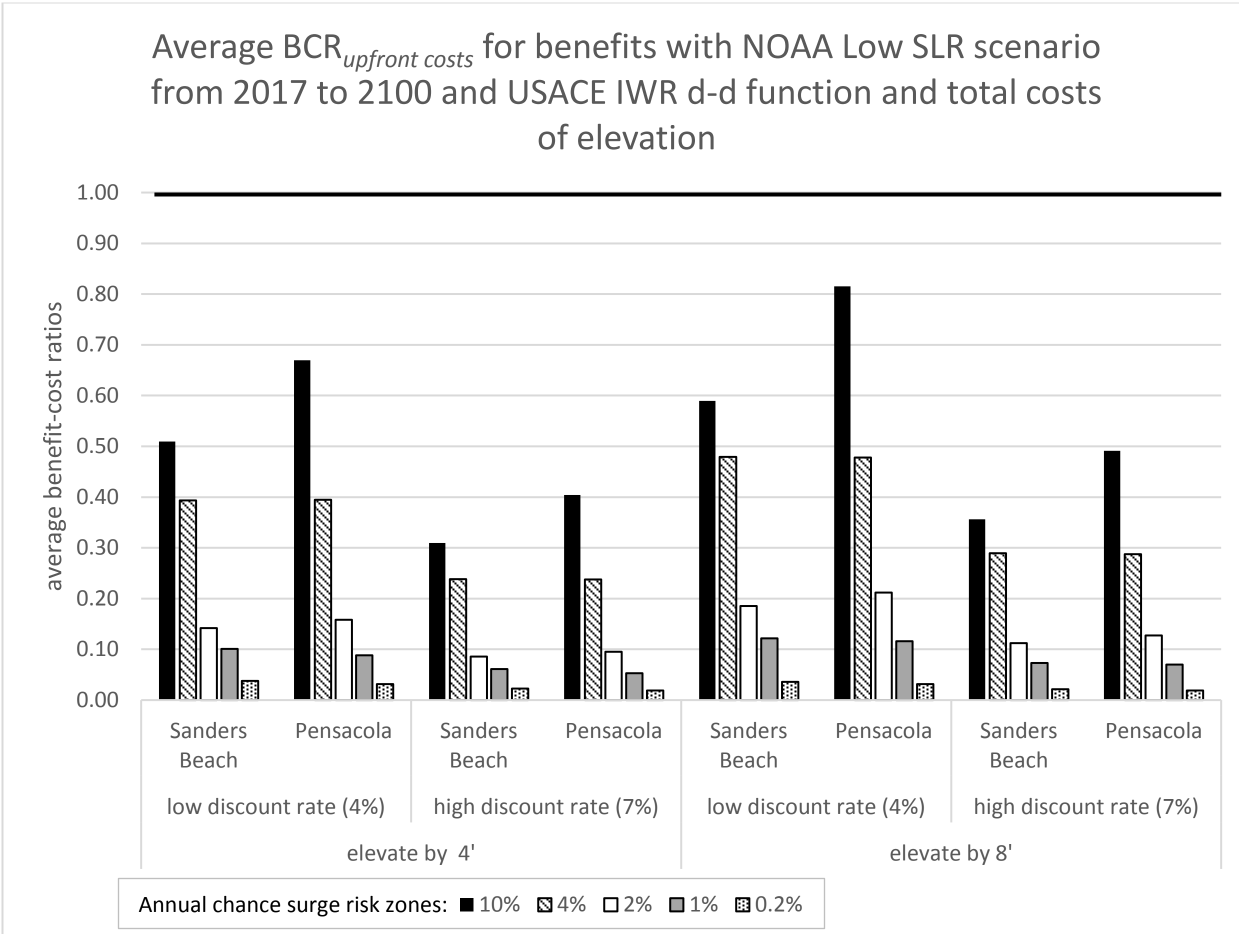

Figure 7. Average benefit-cost ratios (BCR$_{upfront\ costs}$) for Sanders Beach and Pensacola homes by annual chance surge zones for elevating homes by four feet or eight feet with low (4%) and high (7%) discount rates. Benefits are the savings in annual surge risk-based AAL premiums for every year from 2017 to 2100 with sea level rise according to the NOAA Low SLR scenario. Costs are the total costs to elevate homes by 4 and 8 feet. The horizontal line representing average BCR of 1 is highlighted with a heavy black line because a BCR equal or greater than 1 is cost-effective.

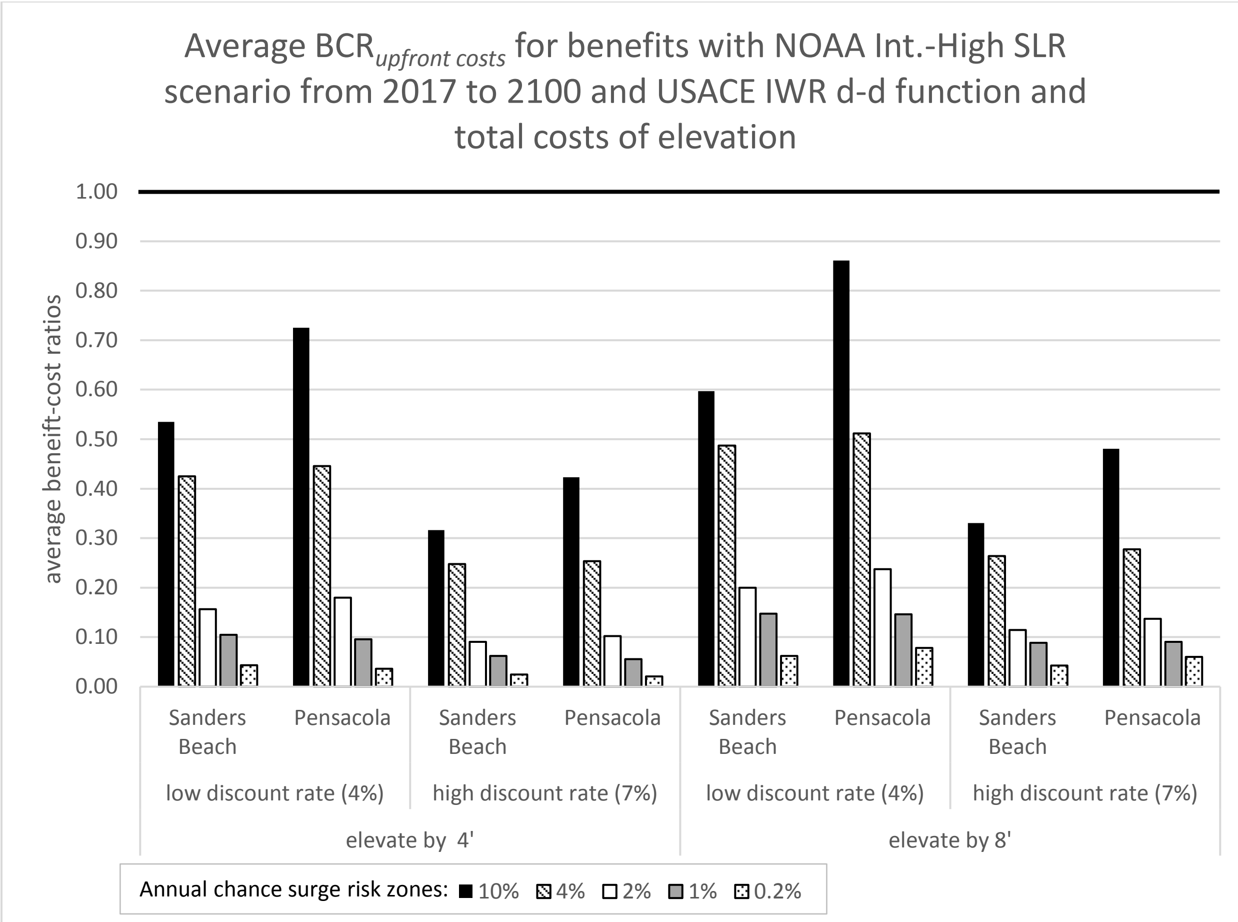

Figure 8. Average benefit-cost ratios (BCR$_{upfront\ costs}$) for Sanders Beach and Pensacola homes by annual chance surge zones for elevating homes by four feet or eight feet with low (4%) and high (7%) discount rates. Benefits are the savings in annual surge risk-based AAL premiums for every year from 2017 to 2100 with sea level rise according to the NOAA Intermediate (Int.)-High SLR scenario. Costs are the total costs to elevate homes by 4 and 8 feet. The horizontal line representing average BCR of 1 is highlighted with a heavy black line because a BCR equal or greater than 1 is cost-effective.

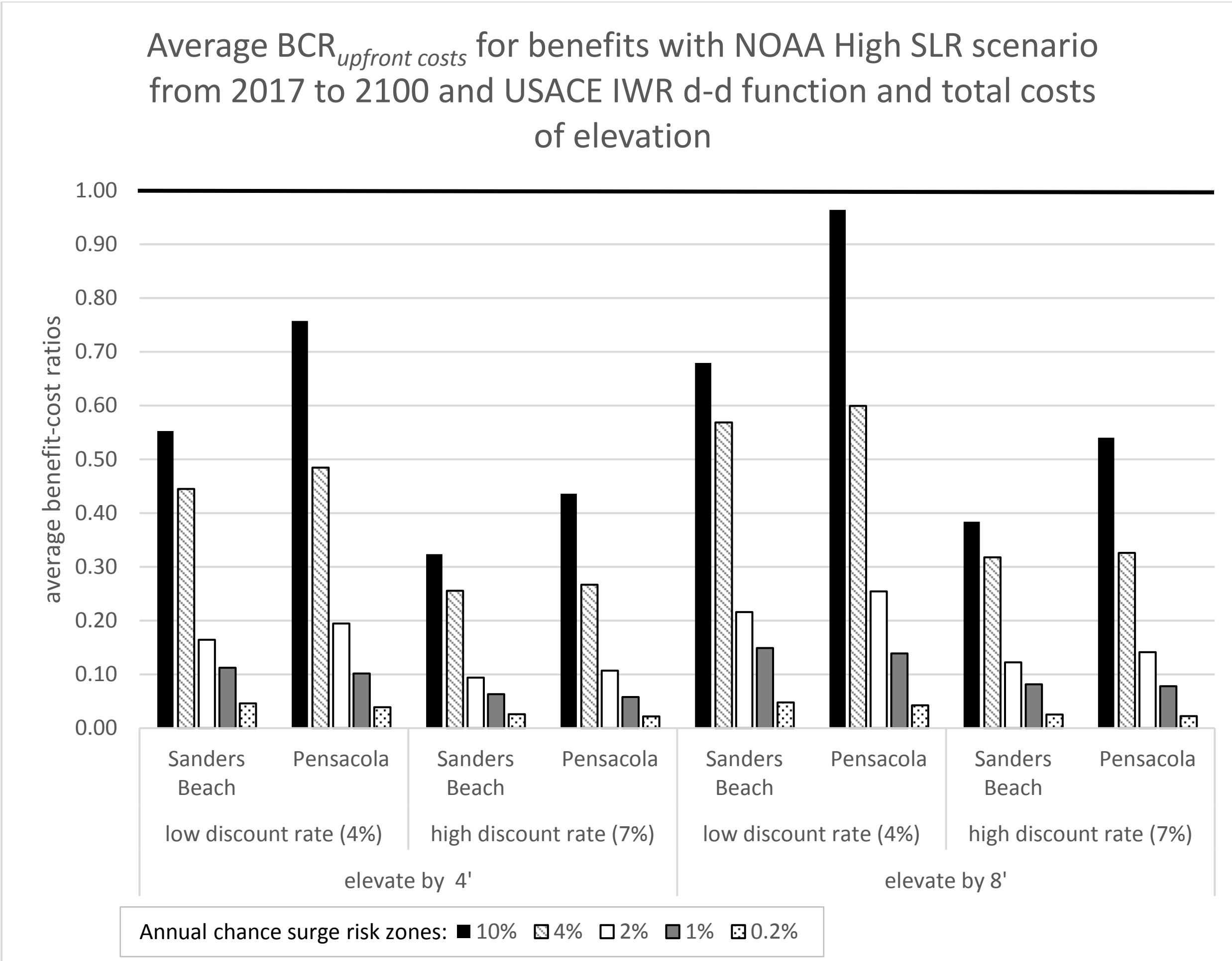

Figure 9. Average benefit-cost ratios (BCR$_{upfront\ costs}$) for Sanders Beach and Pensacola homes by annual chance surge zones for elevating homes by four feet or eight feet with low (4%) and high (7%) discount rates. Benefits are the savings in annual surge risk-based AAL premiums for every year from 2017 to 2100 with sea level rise according to the NOAA High SLR scenario. Costs are the total costs to elevate homes by 4 and 8 feet. The horizontal line representing average BCR of 1 is highlighted with a heavy black line because a BCR equal or greater than 1 is cost-effective.

As Figures 7 through 9 show, there are no average BCRs equal to 1, indicating cost-effectiveness. Nevertheless, it is more cost-effective to elevate homes by eight feet rather than four because most of the costs of elevating a home are incurred when raising it by the first foot with the marginal costs of raising each additional foot being very low. Additionally, the savings in surge risk-based AAL premiums are much greater with higher elevations. Homeowners elevating their property should raise it as high as possible to ensure that this mitigation action protects the home against flood risks into the future.

Although the surge risks are greater (by proportion of homes at risk) in Sanders Beach than in Pensacola, the mitigation costs are lower for Sanders Beach homes because the homes in Sanders Beach are smaller as shown in Table 2. The average area (heated square footage) of Sanders Beach homes is 1,420 square feet compared to an average of 2,044 feet for Pensacola homes. Nevertheless, average home values in Sanders Beach is $74,343 while that for Pensacola homes is $137,485. BCRs inherently favor elevating high value property, since benefits are determined by avoided losses due to surge that are directly related to building and contents values. Therefore, the benefits of mitigating homes in Pensacola are sufficiently high that their average BCRs are greater the average BCRs of Sanders Beach homes even though the costs of mitigation are higher for Pensacola than Sanders Beach.

To gain a better understanding of the types of homes for which it is cost-effective to elevate, we examined the characteristics of homes with BCRs of 0.9 or greater for elevating by four or eight feet, with the NOAA Low SLR and discount rate of 4%. We chose the Low SLR scenario to be conservative and the lower discount rate simply to obtain a larger sample of homes to assess their characteristics. Based on these criteria, 48 of the 1,337 homes (3.6%) in Pensacola at risk to surge hazards were selected. Of these 48 homes, 94% have a wood frame, and 54% have a crawlspace foundation, both of which are less expensive to elevate than masonry frames and slab foundations. However, 36% of the 48 homes have slab foundations, which are much more costly to elevate than open foundations with crawlspace or homes on pilings. Not surprisingly, ninety percent of these 48 homes are within the 10% and 4% annual chance surge zones as these are the homes most at risk to surge flooding. The average area of the 48 homes is 2,598 square feet, which is quite large and thus more costly to elevate than smaller-area homes, but the average replacement value for the buildings is $387,303 and the mean first-floor elevation (FFE) of these homes is only 9 feet according to the North American Vertical Datum of 1988 (NGVD88). These 48 homes therefore have an average building replacement value that is significantly higher than the average value of $137,485 for homes in Pensacola, and a much lower average FFE than the average for all 1,337 Pensacola homes in surge risk zones, which is 15 feet.

We conclude that being in the 10% or 4% annual chance surge zones, with high-value property and a low FFE are probably the most important home characteristics that contribute to cost-effectiveness of elevating the home to mitigate surge risks. This is somewhat concerning given that high property values are found closer to the waterfront in Pensacola and Sanders Beach, due to the amenity value of being adjacent to the coast. It may not be wise to elevate existing homes located in the most likely surge zones based solely on BCRs because there are other factors that must be considered, such as whether a home is strong enough to withstand the stress of elevation.

3.3 Benefit-Cost Analysis of Mitigation Based on Loans

We now examine benefit-cost ratios if the costs of home elevation were spread over time (thirty years) with loans having annual interest rates of 1% and 0%. Benefits were computed in the same manner as above: for every year, benefits are savings in surge risk-based AAL premiums after elevating homes by four or eight feet based on the NOAA Low, Intermediate-High, and High SLR scenarios and the USACE IWR depth-damage function. Because no average BCR_{loan} values exceed 0.55 when elevating homes by four or eight feet in the 2%, 1%, and 0.2% annual chance surge zones , we show average BCR_{loan} values only for homes in the 10% and 4% annual chance surge zones. Figures 10 and 11 shows average BCR_{loan} values to elevate homes by four feet in Sanders Beach and Pensacola homes respectively , Figures 12 and 13 present average BCR_{loan} for Sanders Beach and Pensacola homes respectively. Figures 10 through 13 present average BCR_{loan} values with the two different loan interest rates (0% and 1%) and low and high discount rates (4% and 7%) according to the NOAA Low, Intermediate-High, and High SLR scenarios.

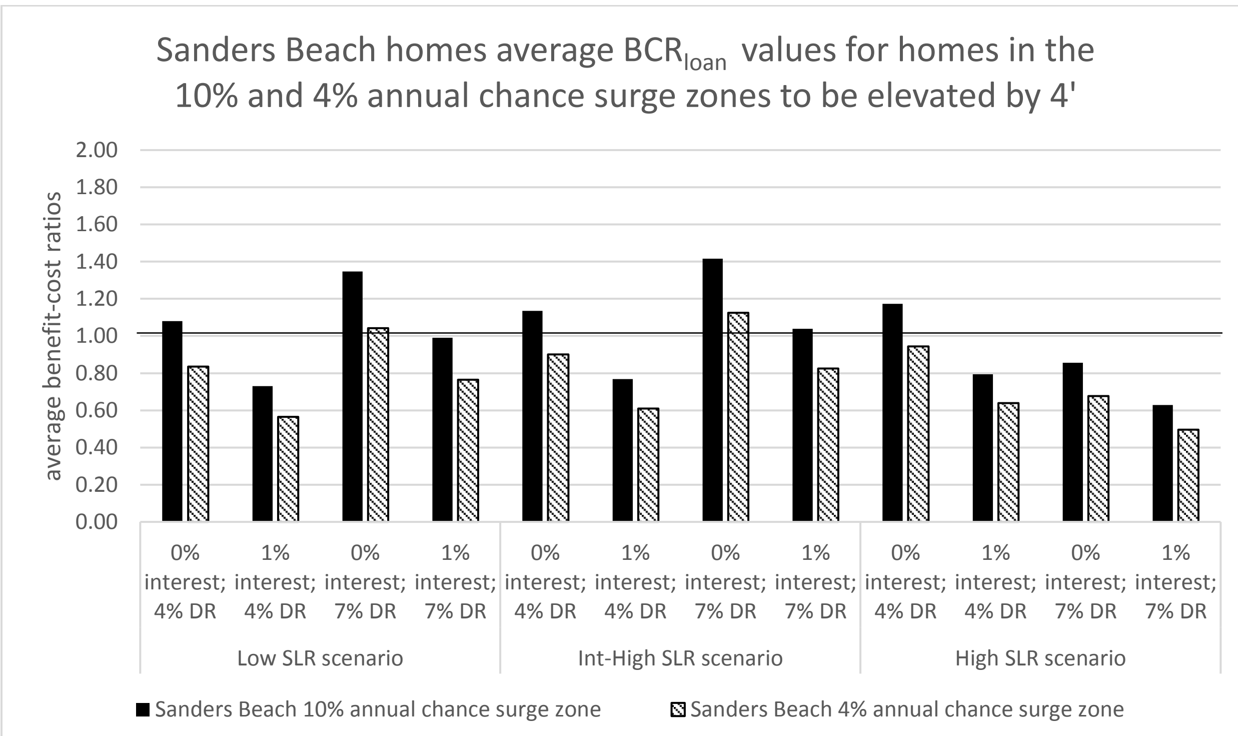

Figure 10. Average benefit-cost ratios (BCR_{loan}) for elevating Sanders Beach homes in the 10% (black bars) and 4% (diagonal line bars) annual chance surge zones by four feet. Benefits are assessed from 2017 to 2100 with increased surge hazards due to sea level rise (SLR) accounted for using the NOAA Low, Intermediate-High, and High SLR scenarios, and discount rates (DR) of 4% and 7%. Costs of elevating homes are spread over 30 years with mitigation loans with 0% and 1% annual interest rates, also discounted by 4% and 7%.

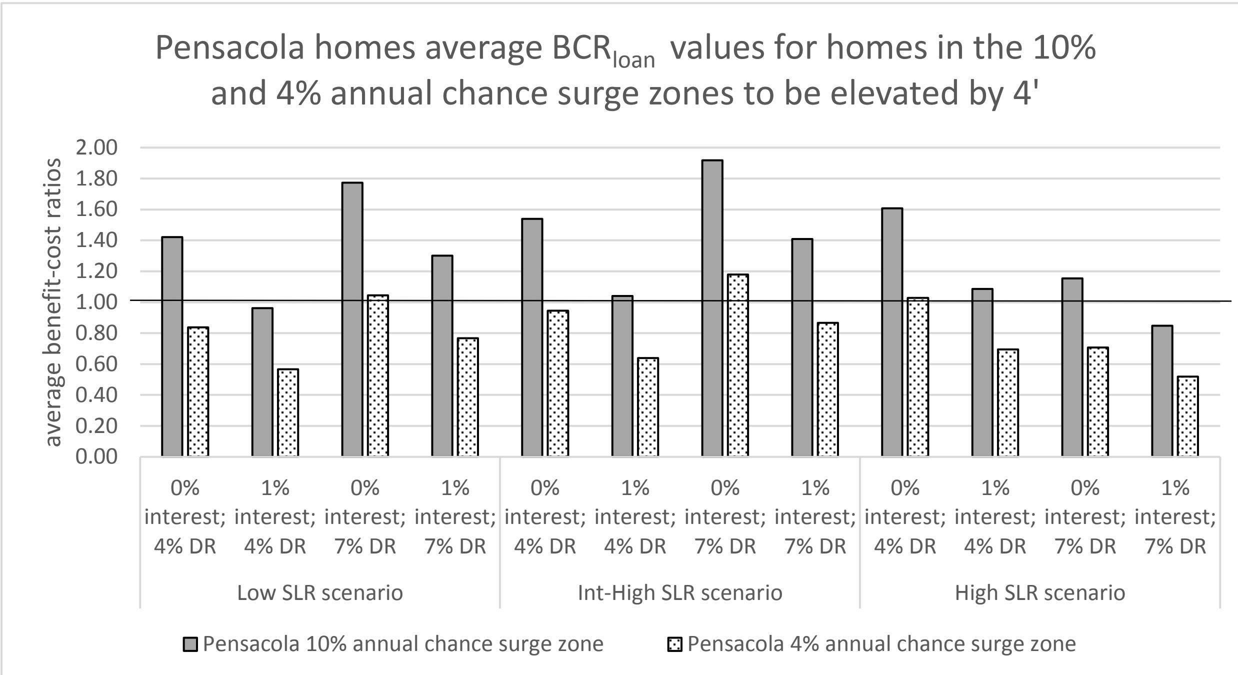

Figure 11. Average benefit-cost ratios (BCR_{loan}) for elevating Pensacola homes in the 10% (gray bars) and 4% (dotted bars) annual chance surge zones by four feet. Benefits are assessed from 2017 to 2100 with increased surge hazards due to sea level rise (SLR) accounted for using the NOAA Low, Intermediate-High, and High SLR scenarios, and discount rates (DR) of 4% and 7%. Costs of elevating homes are spread over 30 years with mitigation loans with 0% and 1% annual interest rates, also discounted by 4% and 7%.

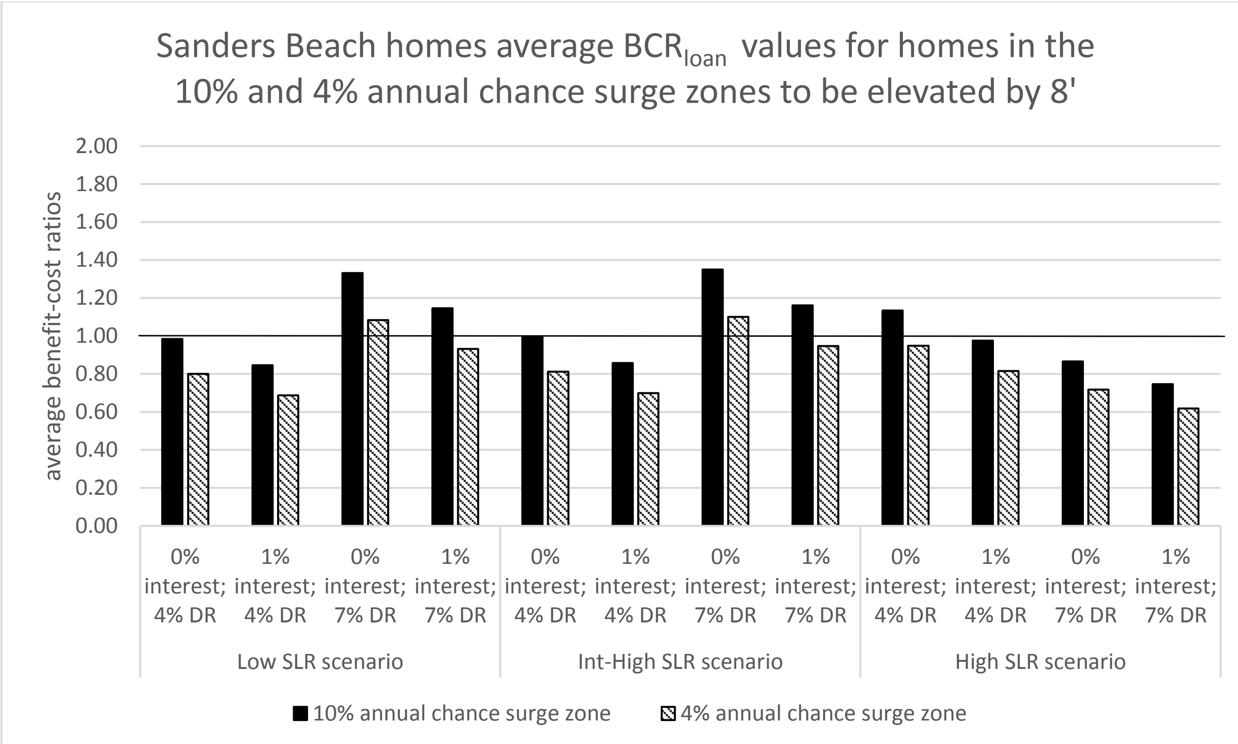

Figure 12. Average benefit-cost ratios (BCR_{loan}) for elevating Sanders Beach homes in the 10% (black bars) and 4% (diagonal line bars) annual chance surge zones by eight feet. Benefits are assessed from 2017 to 2100 with increased surge hazards due to sea level rise (SLR) accounted for using the NOAA Low, Intermediate-High, and High SLR scenarios, and discount rates (DR) of 4% and 7%. Costs of elevating homes are spread over 30 years with mitigation loans with 0% and 1% annual interest rates, also discounted by 4% and 7%.

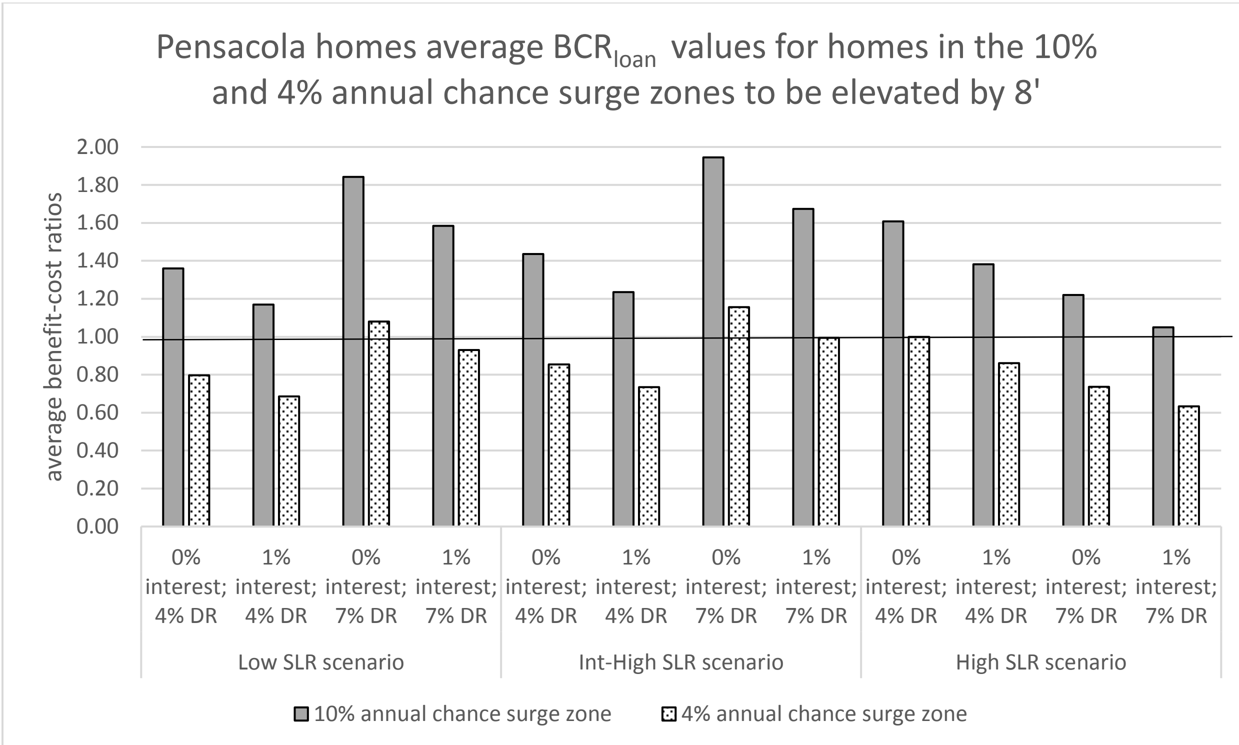

Figure 13. Average benefit-cost ratios (BCR_{loan}) for elevating Pensacola homes in the 10% (gray bars) and 4% (dotted bars) annual chance surge zones by eight feet. Benefits are assessed from 2017 to 2100 with increased surge hazards due to sea level rise (SLR) accounted for using the NOAA Low, Intermediate-High, and High SLR scenarios, and discount rates (DR) of 4% and 7%. Costs of elevating homes are spread over 30 years with mitigation loans with 0% and 1% annual interest rates, also discounted by 4% and 7%.

The 30-year mitigation loans with 0% interest rate and a discount rate of 7% result in the highest average BCR_{loan} values for elevating Pensacola and Sanders Beach homes by either four or eight feet when we use the NOAA Low and Intermediate-High SLR scenarios. In contrast, loans with 0% interest and the lower discount rate of 4% produce the highest average BCR_{loan} values when using the NOAA High SLR scenario.

When we examined homes with a BCR_{loan} equal or greater than 0.9 based on either elevation height or discount rate, or any of the three SLR scenarios, we observed similar home characteristics as those with $BCR_{upfront\ cost}$ of at least 0.9. There are 138 homes in Pensacola (10% of homes in our study area) that have a BCR_{loan} equal or greater than 0.9, the mean FFE of these 138 homes is 10' (compared with an average FFE for Pensacola homes of 15'), and 83% of these 138 homes are in the 10% and 4% annual chance surge zones. The average building value of the 138 homes is $294,467, which is much higher than the average of $137,485 of all building values in Pensacola at risk to surge. Both average values of $BCR_{upfront\ cost}$ and BCR_{loan} show that it is most cost-effective to elevate homes in the 10% and 4% annual chance surge risk zones that have high values and low FFEs.

As with our findings concerning $BCR_{upfront\ cost}$, average values of BCR_{loan} for elevating homes in Pensacola are generally greater than for those for homes in Sanders Beach because the average value of homes in Pensacola is greater than for residences in Sanders Beach. Since benefit-cost analyses generally favor high-value property, mitigation loans to elevate existing homes with long terms (such as 30 years) with low or zero interest rates should be directed at homeowners with lower value properties and/or low-income households. However, there are some low-value homes that should not be elevated, such as very old or structurally unsound homes. Expert opinions from construction experts and/or engineers for each and every potential elevation project of existing structures must be obtained to ensure that once an existing home is elevated, it is still safe and should have a useful life of several decades.

Elevating homes to mitigate surge risks has benefits for homeowners, but surge mitigation also yields benefits to society in reduced public expenditure on disaster relief. Employing lower discount rates when assessing societal benefits of flood mitigation activities that have a long useful life such as home elevation in communities vulnerable to sea level rise may be appropriate given the concern with impacts on future generations. In this regard the 2017 interim report(22) by the National Institute of Building Sciences used a very low discount rate of 2.2%, that revealed that for homes at risk to coastal surge[23], $7 is saved for every $1 spent on building new construction 1 foot above BFE. However, that 2017 report (22) focuses on elevating new construction, not existing buildings as we have done here.

In Escambia County, new construction in SFHAs must have a 3-foot freeboard, (27) meaning that the FFE of new construction must be 3 feet over the BFE. Since new construction must adhere to more recent building codes, it is generally most cost-effective to build new construction higher instead of elevating existing structures.(14) When planning for increased flood risks due to sea level rise, many different mitigation strategies must be considered.

4. CONCLUSIONS AND RECOMMENDATIONS

We have implemented a series of analyses to demonstrate that NFIP rate-setting methods are not risk-based, and have illustrated how flood risk data that are more granular than 1% and 0.2% annual probabilities currently used to characterize flood zones in DFIRMs can be used to estimate risk-based flood insurance premiums with the AAL approach.

We examined homes that coincide with both NFIP flood zones and surge risk zones according to our U-Surge data. Our results indicate that NFIP premiums for homes in 1% annual chance NFIP zones are higher than surge risk-based premiums for homes in the 2%, 1%, and 0.2 % annual chance surge zones. Although this comparison involving NFIP flood risk zones with surge risk zones is not strictly lateral, this finding demonstrates the importance of disaggregating NFIP 1% annual chance zones into more granular

[23] Homes at risk to coastal surge in the 2017 report (22) are defined as homes in V and VE NFIP flood zones.

flood risk zones with probabilities less than 1% to calculate risk-based insurance premiums. As we have noted, FEMA DFIRM data represent both surge and riverine flood risks, while U-Surge data only shows surge risks. We would consequently suspect that flood elevations from the NFIP data would be higher (more likely risk) than corresponding U-Surge surge elevations, but our study areas of Pensacola and Sanders Beach are more at risk to coastal surge than riverine flood risk. When and if more granular flood risk data for Pensacola become available, we intend to reassess how NFIP premiums might differ from risk-based insurance rating with the AAL method.

Nevertheless, another important finding relates to the high costs of X500 Standard rated policies. If X500 zone policies have NFIP Standard rating, these premiums are largely more costly than surge risk-based premiums. PRP rates, which are intended to be very affordable, are higher than surge risk-based rates for homes at risk to 1% and 0.2% annual chance surge events. We noted that about 92% of all X500 zone contracts are rated with PRP rates in the City of Pensacola in August 2017, therefore we suspect that policy holders in X500 zones in Pensacola simply drop coverage when they lose PRP eligibility, since Standard rated policies cost so much more than PRPs.

Additional research into cross-subsidization in the NFIP must be conducted. We posit that cross-subsidies exist between A and X500 zone policies, especially if X500 policies are Standard rated. However, since there is no regulation for homes outside the NFIP 1% annual chance zones to be insured with the NFIP, the cross-subsidization of NFIP premiums within 1% annual chance zones is potentially a more significant concern. Although subsidization keeps premiums low for high-risk homes, it is an inefficient way to manage a flood insurance program. In fact, it could eventually make the NFIP portfolio dense with undercharged high-risk policies if private insurers cherry-pick the low risk properties that would be charged higher than risk-based premiums by the NFIP. Rating flood insurance premiums with a structure-specific risk-based approach as we have done here would encourage homeowners to invest in cost-effective mitigation actions to lower their premiums and reduce federal disaster relief following flood-related disasters. Innovative use of Lidar technology, such as that used in North Carolina, [8] could be employed for efficient collection of structure-specific flood risk information.

Herein, we also examined the effect of different depth-damage functions on resulting AAL premiums. Depth-damage functions from the FIA and the USACE IWR resulted in significantly different surge risk-based AAL premiums. More research is required to develop more accurate depth-damage functions, and the importance of the choice of depth-damage functions for loss estimation must be emphasized.

Of the FIA and USACE IWR depth-damage functions we employed, the results of surge risk-based AAL premiums based on the FIA function are closer to the NFIP normalized premiums for homes within each annual chance surge zones and DFIRM SFHAs and non-SFHAs. Although the U-Surge surge data evidence much greater flood risks than the DFIRM data, the FIA function dramatically underweights damage from floodwater inside homes in comparison with the results from the USACE IWR function, resulting in surge premiums from the FIA function that are close in value to estimated NFIP premiums. Furthermore, our benefit-cost analyses are based on the USACE IWR function instead of the FIA function because the USACE IWR function results in more savings in surge risk-based AAL premiums after elevating homes. If we had used the FIA function in our benefit-cost analyses, we would show that home elevation is less cost-effective than using the USACE IWR function.

Future surge risk-based premiums increased significantly with sea level rise using both depth-damage functions. We recommend that the NFIP incorporate future conditions into their rate-setting and flood hazard mapping procedures with a recognition that there is uncertainty in estimating the magnitude of sea level rise over time. We also posit that benefit-cost analyses accounting for future conditions use depth-damage functions that overweight damages relative to other depth-damage functions to reflect worst case scenarios given the additional costs than just property damage from future flood-related disasters. Since the costs of elevating property is primarily associated with the first few inches of raising ones house, it is logical to elevate homes as high as feasible. Consequently, the NFIP should offer premium discounts for buildings with FFEs that are over four feet above BFE, unlike the current rating methodology that limits discounts for FFEs at four feet above BFE to encourage more cost-effective mitigation. Sensitivity analyses with different sea level rise scenarios and depth-damage functions should be undertaken for communities like Pensacola to better understand the potential costs and benefits of flood and storm surge risk mitigation projects.

Taking advantage of our granular surge risk data, we examined the cost-effectiveness of elevating existing homes by four and eight feet with benefits from 2017 to 2100 with sea level rise (SLR) according to the NOAA Low, Intermediate-High, and High SLR scenarios, discounted by 4% and 7% out to 2100. Costs were analyzed as the total costs to elevate homes by four and eight feet; and costs were either incurred upfront or spread over a 30-year loan term with 0% and 1% interest rates with 4% and 7% discount rates out to 2100. We examined spreading costs over 30 years because 30 years is the typical length of a home mortgage, and mitigation loans could be tied to home mortgages as previous research has proposed. [(4)] Benefits were the savings in surge risk-based AAL premiums after elevating homes by four and eight feet using the NOAA Low, Intermediate-High, and High SLR scenarios, and annual discount rates of 4% and 7%. Pensacola homes are more cost-effective to elevate on average than

Sanders Beach homes because there are many more homes in Pensacola than Sanders Beach located in the 10% annual chance surge zone, and Pensacola homes have greater building and contents replacement values than Sanders Beach homes.

Benefit-cost ratios intrinsically favor higher value property. If one incurs the costs of home elevation up front, high-value properties with a low FFE located in the 10% or 4% annual chance surge zones are the ones most likely to have BCRs equal or greater than 1 when using the lower discount rate of 4%, so it is cost-effective to elevate these homes. When a 30-year loan spreads the costs, it is cost-effective to elevate many more homes in Sanders Beach and Pensacola located in either the 10% and 4% annual chance surge zones with 0% loan interest. Although higher value homes are more likely to be cost-effective to elevate than lower value homes, mitigation loans should be directed at lower-income households to address affordability concerns.

Homes with smaller areas and open foundations are more likely to be cost-effective to elevate than larger homes with slab foundations. Many houses in Pensacola have slab foundations which are the most expensive type of foundation to elevate. It should be noted that there are concerns in elevating homes with any type of foundation: one cannot know if a home is constructed sturdily enough to withstand the stresses of elevation until it is attempted. Older homes may not fare as well as newer homes in an elevation project. Additionally, we used the FEMA P-312[14] as a guide for estimating the costs of elevating homes, and these are rough estimates for the entire United States. The costs of elevating homes in Pensacola could be lower or higher than what we estimated.

Our definition of benefits as savings in surge risk-based AAL premiums is conservative. Other benefits of home elevation would include reduced mortality risk for home occupants, and reduced immaterial benefits such as psychological impacts from floods. Additionally, home elevation could allow residents to remain on their property in their community for an indefinite amount of time, whereas rebuilding elsewhere would involve moving expenses and the stress of relocating to an unfamiliar neighborhood or community. Although these other benefits are difficult to quantify, they are worth noting.

Future research should obtain estimates of home elevation costs that are more specific to the study area, instead of using national averages to estimate costs. Other mitigation options in addition to home elevation should be explored, such as wet and dry floodproofing, changing building codes to raise freeboard requirements, building flood walls around the home, and elevating electrical and plumbing utilities as Aerts et al. 2014; [(23)] Kreibich et al. 2005; [(28)] and Poussin et al. 2015 [(29)]have done. Moreover, comparing the cost-effectiveness of elevating new structures with elevating existing structures should be examined. [(22, 23)] Further sensitivity analyses with different discount rates in benefit-cost analyses should be implemented in other cities with various sea level rise scenarios.

Methods of addressing affordability of risk-based insurance pricing include insurance designs with high deductibles to reduce premiums, and systems of vouchers coupled with long-term mitigation loans to spread upfront costs of mitigation over the length of mortgages. [(4)] The NFIP must develop a system of discounts to reward homeowners for flood mitigation activities other than elevation, such as raising electrical and plumbing utilities, to address potential cross-subsidization concerns and more accurate risk-based pricing. Risk-based flood insurance premiums could be linked to cost-effective mitigation activities in ways that are transparent to homeowners, so that homeowners are motivated to invest in flood mitigation to save on premiums and losses to floods.

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APPENDIX A: NFIP FLOOD ZONES APPEARING IN FLOOD INUSRANCE RATE MAPS (FIRMs) AND DEFINITIONS

High Risk Areas	Zone A		The 100-year or base floodplain. There are six types of A Zones:
		A	The base floodplain mapped by approximate methods, i.e., BFEs are not determined. This is often called an unnumbered A Zone or an approximate A Zone
		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).
		AE	The base floodplain where base flood elevations are provided. AE Zones are now used on new format FIRMs instead of A1-A30 Zones
		AO	The base floodplain with sheet flow, ponding, or shallow flooding. Base flood depths (feet above ground) are provided.
		AH	Shallow flooding base floodplain. BFEs are provided.
		A99	Area to be protected from base flood by levees or Federal Flood Protection Systems under construction. BFEs are not determined.
		AR	The base floodplain that results from the decertification of a previously accredited flood protection system that is in the process of being restored to provide a 100-year or greater level of flood protection.
High Risk Coastal Areas	Zone V and VE	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.
		VE	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.
Moderate to Low Risk Areas	Zone B and Zone X (shaded)--referred to as Zone X500 in paper.	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 the 100-year flood, or shallow flooding areas with average depths of less than one foot or drainage areas less than 1 square mile.	

Note that the special Flood Hazard Area (SFHA) includes only A and V Zones.

Source: Modified from page 3-33 of Unit 3: NFIP Flood Studies and Maps, Managing Floodplain Development Through the NFIP https://www.fema.gov/media-library-data/20130726-1535-20490-4172/unit3.pdf.

APPENDIX B: COST ESTIMATES USED TO CALCULATE TOTAL COSTS OF ELEVATING SINGLE-FAMILY HOMES TO MITIGATE FLOOD RISKS

Approximate Square Foot Costs of Elevating a Home

Construction Type	Existing Foundation	Elevate on Continuous Foundation Walls or Open Foundation	Cost (per square foot of house footprint)
Frame (for frame house with brick veneer on walls, add 10 percent)	Basement or Crawlspace	2 feet	$29
		4 feet	$32
		8 feet	$37
	Slab-on-Grade	2 feet	$80
		4 feet	$83
		8 feet	$88
Masonry	Basement or Crawlspace	2 feet	$60
		4 feet	$63
		8 feet	$68
	Slab-on-Grade	2 feet	$88
		4 feet	$91
		8 feet	$96

Source: Modified from Table 3-3, page 3-20. Homeowner’s Guide to Retrofitting Six Ways to Protect Your Home From Flooding. FEMA P-312, Second Edition / December 2009.

APPENDIX C: RESULTS OF SURGE RISK-BASED AAL PREMIUMS FOR SANDERS BEACH AND PENSACOLA HOMES FROM 2017 TO 2100 USING THE NOAA LOW, INTERMEDIATE-HIGH, AND HIGH SEA LEVEL RISE SCENARIOS

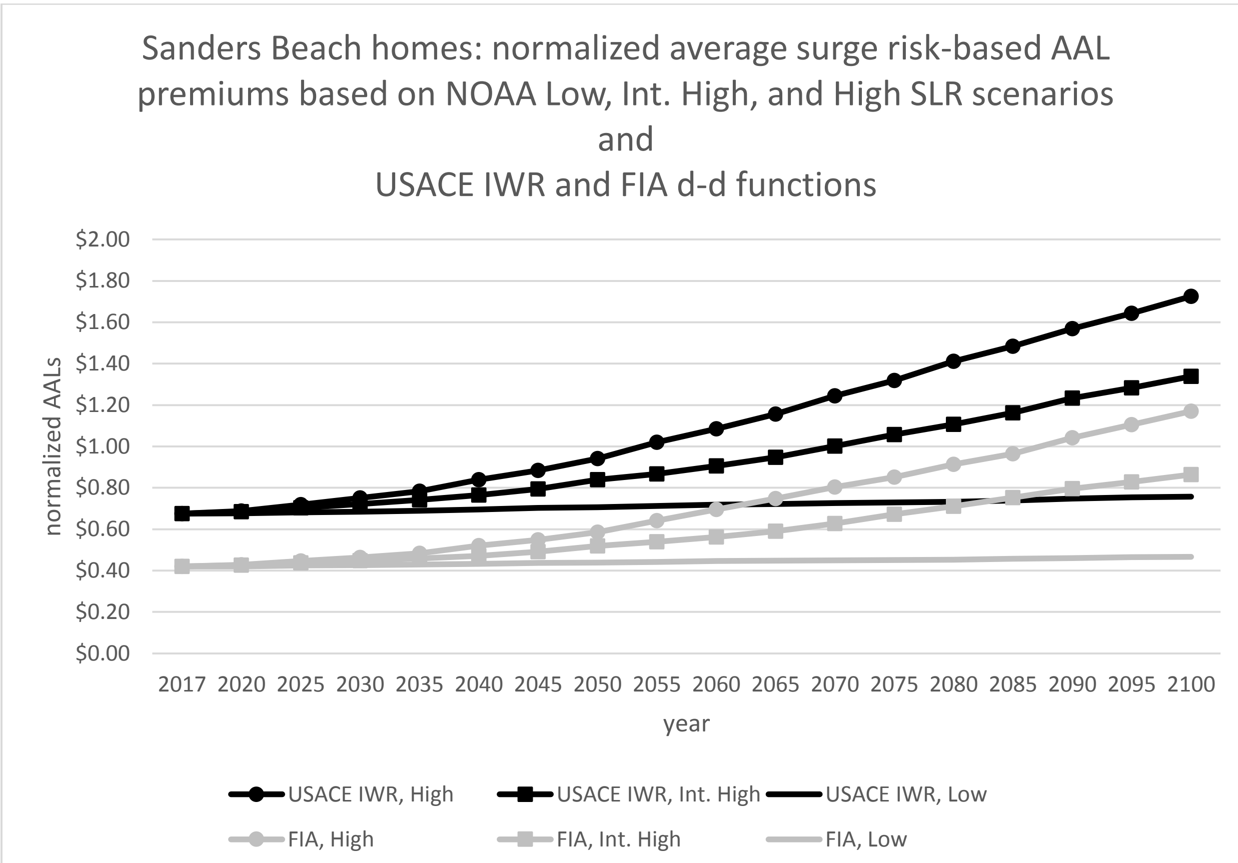

Figure A-1. Sanders Beach homes average normalized surge risk-based AAL premiums (per $100 of building and contents coverage) in 2017, and from 2020 to 2100 in five-year increments according to the NOAA Low, Intermediate-High, and High sea level rise (SLR) scenarios based on the FIA and USACE IWR depth-damage functions. Black lines represent the results based on the USACE IWR function, and gray lines represent the results based on the FIA function. (n=175 homes at risk of surge hazards)

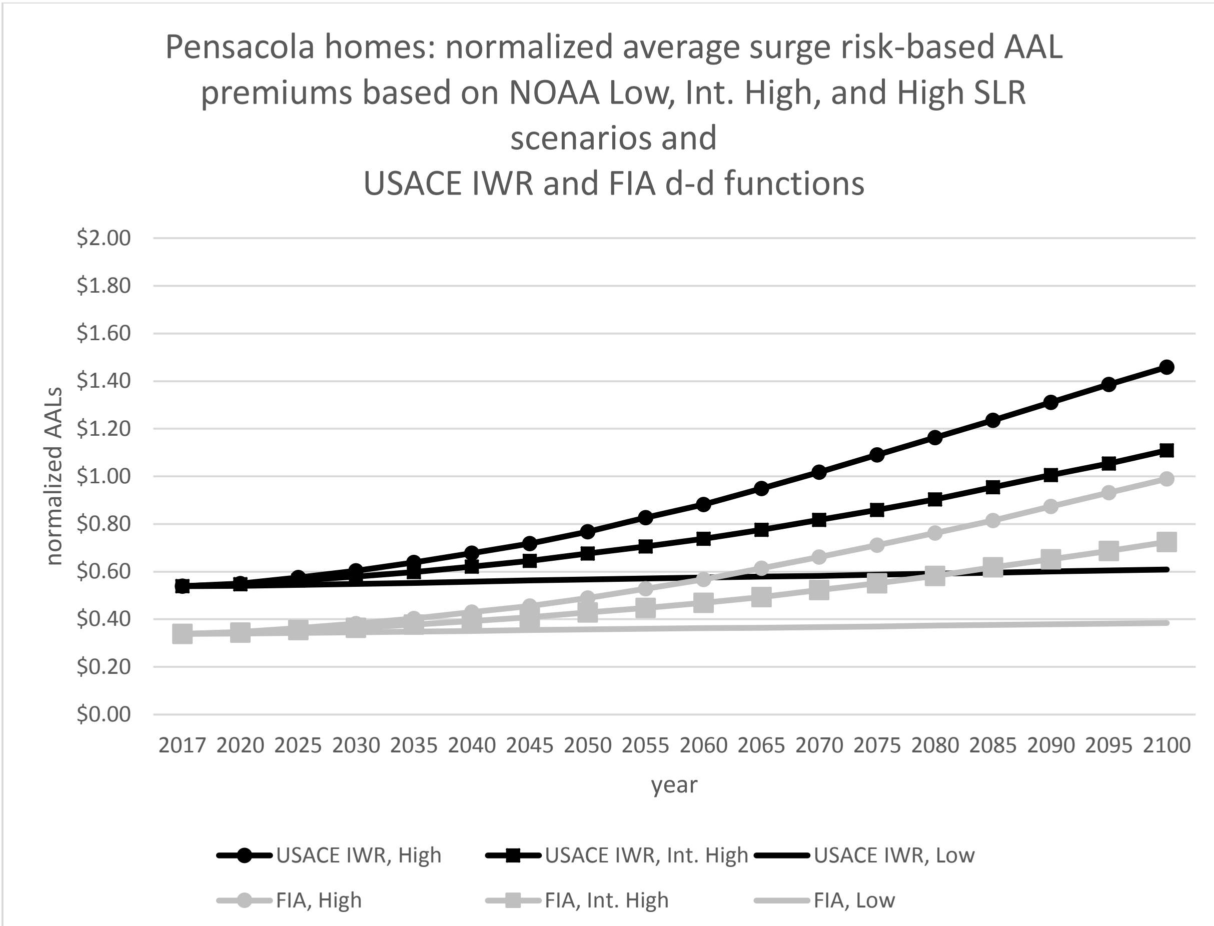

Figure A-2. Pensacola homes average normalized surge risk-based AAL premiums (per $100 of building and contents coverage) in 2017, and from 2020 to 2100 in five-year increments according to the NOAA Low, Intermediate-High, and High sea level rise (SLR) scenarios based on the FIA and USACE IWR depth-damage functions. Black lines represent the results based on the USACE IWR function, and gray lines represent the results based on the FIA function. (n=1,337 homes at risk of surge hazards)