Homeowner Flood Risk and Risk Reduction from Home Elevation between the 100- and 500-year Floodplains

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Abstract

Floods inflict significant damage even outside the 100-year floodplain. Thus, restricting flood risk analysis to the 100-year floodplain (special flood hazard area (SFHA) in the U.S.A.) is misleading. Flood risk outside the SFHA is often underestimated because of minimal flood-related insurance requirements and regulations and sparse flood depth data. This study proposes a systematic approach to predict flood risk for a single-family home using average annual loss (AAL) in the shaded X Zone – the area immediately outside the SFHA (i.e., the 500-year floodplain), which lies between the 1.0- and 0.2-percent annual flood probability. To further inform flood mitigation strategy, annual flood risk reduction with additional elevation above an initial first-floor height (FFH_0) is estimated. The proposed approach generates synthetic flood parameters, quantifies AAL for a hypothetical slab-on–grade, single-family home with varying attributes and scenarios above the slab-on-grade elevation, and compares flood risk for two areas using the synthetic flood parameters vs. an existing spatial interpolation-estimated flood parameters. Results reveal a median AAL in the shaded X Zone of 0.13 and 0.17 percent of replacement cost value (V_R) for a one-story, single-family home without and with basement, respectively, at FFH_0 and 500-year flood depth < 1 foot. Elevating homes one and four feet above FFH_0 substantially mitigates this risk, generating savings of 0.07–0.18 and 0.09–0.23 percent of V_R for a one-story, single-family home without and with basement, respectively. These results enhance understanding of flood risk and the benefits of elevating homes above FFH_0 in the shaded X Zone.

Key words: Flood risk, Average annual loss (AAL), Flood mitigation strategy, Special flood hazard area (SFHA), Shaded X Zone.

1. Introduction

Flood is considered the costliest natural hazard worldwide (Wang & Sebastian, 2021). Between 1980 and 2021, the U.S.A. was affected by 36 catastrophic floods that caused a total $173.3 billion (consumer price index adjusted) in direct losses (NOAA, 2022). FEMA's floodplain maps are used to determine flood risk zones and their base flood elevations (BFEs), which have been used to define flood risk regions around the U.S.A. (Xian et al., 2015). FEMA's 100-year floodplain – the area that has at least a one-percent chance of experiencing flood in a given year – has been used to define high-risk flood zones, known as the special flood hazard area (SFHA). Many efforts have been made to quantify flood risk (Armal et al., 2020; Habete & Ferreira, 2017), determine minimum first floor elevation requirements (American Society of Civil Engineers (ASCE), 2014; FEMA, 2019), and identify the benefit of applying mitigation strategies in the SFHA (Rath et al., 2018), including regulations on development such as the mandatory purchase of flood insurance for those with a federally-backed mortgage (Wing et al., 2022).

Areas outside the SFHA, generally known in the U.S.A. as X Zones, have received significantly less attention because they have been considered as moderate-to-low flood risk areas, with less than a one-percent annual chance of flood occurrence (Technical Mapping Advisory Council, 2015). However, average annual flood losses outside the SFHA have mounted to a $19.1 billion and are projected to increase by 21.2 percent in the U.S.A. by 2050 because of climate change (Wing et al., 2022). Thus, significantly more attention must be devoted to understanding flood risk in these areas in order to reduce flood losses.

The area between the one-percent (bordering the SFHA) and 0.2-percent (bordering the "non-shaded X Zone") annual flood probability inundation areas – the 500-year floodplain, known in the U.S.A. as the "shaded X Zone" – is particularly preferred for dense development and is considered an area of likely population growth (Association of State Floodplain Managers, 2020). Clearly, it is important to assess the flood risk outside the SFHA, particularly in the shaded X Zone. Notable examples of research on flood hazards in the shaded X Zone include that of Hagen and Bacopoulos (2012), who identified tropical storm characteristics that induce flooding in Florida's Big Bend Region. Likewise, Ferguson and Ashley (2017) evaluated residential development in Atlanta, Georgia. Kiaghadi et al. (2020) investigated the relation between hurricane events and the housing price depreciation in Miami-Dade County. Goldberg and Watkins (2021) analyzed flood risk among three watersheds in the lower St. Johns River basin landscape, and Hemmati et al. (2021) examined how flood risk assessment affects residents' location choices. However, there is a dearth of research focusing on flood risk evaluation for residential buildings in the shaded X Zone. Without a better understanding of flood risk for areas in the shaded X Zone, the true costs and benefits of flood mitigation strategies cannot be realized.

Flood risk is assessed as the product of flood occurrence probability and the associated consequences (Šugareková & Zeleňáková, 2021). Average annual loss (AAL) has been used in past research to represent flood risk (Armal et al., 2020; Bowers et al., 2022; Hallegatte et al., 2013; Mostafiz et al., 2022a; Rahim et al., 2021, 2022; Wing et al., 2022; Yildirim & Demir, 2022) in terms of costs associated with direct building loss, direct contents loss, and indirect losses such as use loss while the building is being renovated (Al Assi et al., 2022). AAL is calculated as the integral of flood loss as a known function of the flood probability (or flood return period), and the Gumbel distribution function is one of the most widely accepted probability functions (Patel, 2020; Singh et al., 2018). The Gumbel parameters are the regression coefficients (slope and y-intercept, respectively) in the relationship between flood depth above the ground (d) and the double natural logarithm of probability of non-exceedance probability (P) (Gnan et al., 2022a; 2022b).

Calculating flood risk in the shaded X Zone can be challenging due to data limitations. As the shaded X Zone lies between the limits of the one-percent and 0.2-percent annual chance of flood, land in this zone is by definition unflooded until the 100-year flood event is exceeded. Therefore, in the shaded X Zone, d is zero or null (i.e., d would be negative and is therefore undefined) for flood events with return periods less than 100 years. Given that return period depth grids typically include the 10-, 50-, 100-, and 500-year events, all locations within the shaded X Zone have a d value that is therefore zero or "null" for return periods shorter than the 500-year event. Thus, locations within the shaded X Zone have a d value for only one return period (i.e., 500 years), with the consequence that the Gumbel flood parameters cannot be generated from the Gumbel distribution for any location within the shaded X Zone. Without the Gumbel parameters, annual flood risk (or even the probable range of annual flood risk) cannot be estimated in the shaded X Zone. Further, although flood loss has been often observed in the shaded X Zone, risk reduction from elevation cannot be estimated due to the lack of flood risk estimates. Therefore, comparison of benefits and costs to support mitigation decision making in the shaded X Zone is not possible.

To overcome these challenges, this paper presents a systematic approach to 1) provide a meaningful estimate of the range of expected annual flood risk in the shaded X Zone; and 2) calculate the reduction in annual flood risk via elevation for homes in the shaded X Zone. The lack of flood hazard data in the shaded X Zone is addressed by developing a library of combinations of synthetic, regression-derived Gumbel parameters that meet the mathematical definition of the shaded X Zone. These are used here by hypothetical type of single-family homes in the U.S.A. (i.e., one vs. two-plus stories, with vs. without basement) as input to the framework methodology presented in Al Assi et al. (2022). The results of two case studies are compared with the results generated from the Gumbel regression parameters produced using Mostafiz et al.'s (2021, 2022b) method, who extrapolated the Gumbel parameters in the shaded X Zone using spatial interpolation, to confirm the results of this method for a range of 500-year flood depths in inland and coastal areas.

The contribution of this research is a novel conceptualization and implementation of annual flood risk assessment in the shaded X Zone – a location where little flood risk information has been generated. This improved risk assessment provides a clearer perception of the advantages of applying mitigation strategies in those areas. The methodology and results generated in this paper will benefit homeowners, builders, developers, community planners, and other partners in the process of enhancing resilience to the flood hazard via risk-informed construction techniques.

2. Background

Recent catastrophic events and studies regarding projected trends under environmental change scenarios reveal that the area outside the presently designated SFHA is subjected to rapidly increasing flood risk. For example, in 2005 Hurricane Katrina inflicted severe damage outside the SFHA across Louisiana, Mississippi, and Alabama including massive structural damage (Xian et al., 2015). Likewise, only seven years later Hurricane Sandy caused flooding far above the BFE and beyond the SFHA in New York and New Jersey (FEMA, 2013). Only five years later, amazingly, 68 percent of the 31,000 homes that Hurricane Harvey flooded in the Houston, Texas, area were outside the SFHA (Kousky et al., 2020b). In the next year, 24 percent of the area flooded and 43 percent of the residential structures damaged in North Carolina by Hurricane Florence were outside the SFHA (Pricope et al., 2022). And in 2019, 62 percent of the 1,000+ Texas homes flooded in Tropical Storm Imelda were outside the SFHA (Kousky et al., 2020b). Kennedy et al. (2020) reported that Hurricane Michael in Florida caused major wave and surge damage in X Zones. In a more general sense, a trained model to predict flood damage probability in the conterminous U.S.A. using a suite of geospatial predictors and the location of historical reported flood damage revealed that an astounding 68 percent of flood damage was outside of FEMA's high-risk zone (Collins et al., 2022). Significant attention has been devoted to reducing flood damage exacerbated by climate change and sea level rise (Botzen & van den Bergh, 2008; Hino & Hall, 2017; Kousky et al., 2020a; Xian et al., 2017). Therefore, a need exists to evaluate flood risk in the shaded X Zone more comprehensively through improved assessment of economic consequences to better identify and mitigate the risk.

Recent studies show that using the refined numerical integration method shows promising results to predict AAL because it accounts for losses across the full range of exceedance probabilities, and it addresses the limitations of other approaches (Gnan et al., 2022a). This refined numerical integration method models the annual probability of exceedance for the expected flood depth using available flood depth data. The Gumbel distribution is used to determine the annual probability of exceedance at each given depth. AAL is then estimated using trapezoidal Riemann sums to aggregate the area under the loss-exceedance probability curve (Meyer et al., 2009; Gnan et al., 2022a).

Specifically, the refined numerical integration method has been used to estimate annual flood risk for multiple home elevation scenarios above the initial first-floor height to determine flood risk reduction (Gnan et al., 2022a). Optimizing the effectiveness of the elevation strategy using such scenarios is important for maximizing the benefit of federal government grants, such as from FEMA or the U.S. Department of Housing and Urban Development (HUD), for elevating such homes, to as many people as possible. These elevation scenarios conform to or surpass the National Flood Insurance Program (NFIP) requirement that the minimum lowest-floor elevation is at the BFE, which is approximately equal to the 100-year flood elevation (E_{100}) (FEMA, 2019). However, because ASCE (2014) national technical standard stipulates that adding one foot above E_{100} as the minimum recommended elevation requirement for residential buildings in the U.S.A., higher elevation scenarios must also be considered in assessing flood risk and risk reduction.

Elevating above FFH_0 is often cost-effective (Taghinezhad et al., 2021), especially at the time of construction (Rath et al., 2018). It is already well-established that increasing first-floor heights in A and V Zones (i.e., inundation and high-velocity zones within the SFHA, respectively in the U.S.A.) at the time of construction is wise, with costs recoverable in as few as 6 and 3 years, respectively, through insurance premium reduction (Rath et al., 2018). The value of implementing a "smart" flood risk mitigation strategy (Taghinezhad et al., 2020) applies equally to homes in the shaded X Zone, especially now that it is becoming apparent that these homes are not as flood safe as was recently assumed, by using the refined numerical integration technique. Flood risk reduction in dollars, represented as the difference between the AAL before and after applying the mitigation strategy, can be promulgated as a means of increasing awareness for homeowners and communities in the shaded X Zone regarding the flood risk and the importance of considering the mitigation strategies to decrease that risk.

3. Methodology

The computational framework to quantify AAL in the shaded X Zone consists of three major steps (Figure 1). First, synthetic flood parameters are generated based on shaded X Zone properties. Second, AAL is quantified using the computational framework developed by Al Assi et al. (2022). In that approach, AAL is partitioned to homes (I = 1 through n) separately for building, contents, and use, with the AAL reduction calculated for M increases of increment J in first-floor height above the FFH_0 (Al Assi et al., 2022). Third, the results are confirmed using two separate areas by comparing the AAL computed from synthetic data in this framework against that calculated using the flood parameters generated through the Mostafiz et al. (2021) method.

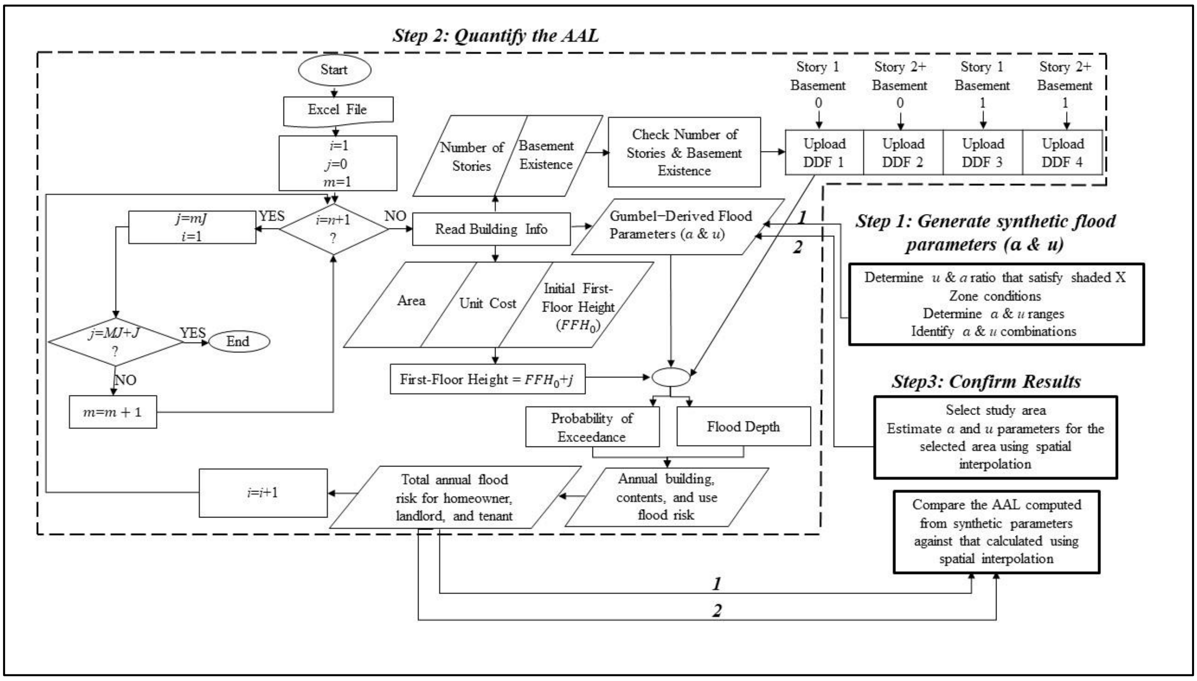

Figure 1. Computational framework to quantify and confirm AAL in the shaded X Zone.

<u>Generate synthetic flood parameters</u>

This research uses the two-parameter Gumbel distribution function to estimate flood depth. Eq. 1 shows the cumulative distribution function (CDF) of the Gumbel distribution, which represents the annual non-exceedance probability (P).

$$F(d) = P(X \leq d) = exp\left[-exp\left(-\left(\frac{d-u}{a}\right)\right)\right] \quad (1)$$

Solving Eq. 1 for d yields:

$$d = u - a \ln\left[-\ln(P)\right] \quad (2)$$

In Eqs. 1 and 2, d is flood depth, u represents the location parameter or y-intercept of the Gumbel-generated regression line (noting that Eq. 2 takes the form $y = b + mx$ where x is $-\ln\left[-\ln(P)\right]$, m is a, and b is u) of d as a function of the double natural logarithm of P, and a is the scale parameter or slope of the same Gumbel-generated regression line. P is expressed as a function of flood return period (T) by:

$$P = 1 - \frac{1}{T} \quad (3)$$

To overcome the absence of u and a values in shaded X Zone, synthetic values of u and a are generated to estimate the range of these parameters expected in the shaded X Zone.

Generating the synthetic, unique u and a for the shaded X Zone begins with substituting for P from Eq. 3 into Eq. 2, for the 100 (i.e., T)-year return period, for which d is assumed to be less than or equal to zero in the shaded X Zone, as shown in Eq. 4:

$$0 \geq u - a \ln\left[-\ln\left(1 - \frac{1}{100}\right)\right] \quad (4)$$

Simplifying Eq. 4 yields:

$$0 \ \geq u + 4.600a \quad (5)$$

Likewise, if it is assumed that a point within the shaded X Zone does flood within the 500 (i.e., T)-year flood, the generalized Eq. 2 can be expressed for this specific scenario as:

$$0 < u - a \ln\left[\ -\ln\left(1 - \frac{1}{500}\right)\right] \quad (6)$$

Simplifying Eq. 6 yields:

$$0 < u + 6.214\ a \quad (7)$$

Solving Eq. 5 for u gives:

$$-4.600a \ \geq u \quad (8)$$

Solving Eq. 7 for u yields:

$$-6.214\ a < u \quad (9)$$

Dividing both sides by a in Eq. 8 shows:

$$-4.600 \ \geq \frac{u}{a} \quad (10)$$

Dividing both sides by a in Eq. 9 yields:

$$-6.214 < \frac{u}{a} \tag{11}$$

Therefore, the ratio between u and a in the shaded X Zone flood zone:

$$-6.214 < \frac{u}{a} \leq -4.600 \tag{12}$$

Thus, the range of the ratio of u to a in the shaded X Zone is known, but the range of u and the range of a remain unknown. By definition, a (i.e., the slope of the Gumbel-generated regression) must be positive because longer-return-period flood events always have higher d than shorter-return-period d. The upper limit of a is assumed to occur in coastal areas. Therefore, this study updates d values from flood events in Bohn's (2013) data set that expresses stillwater elevation at 10-, 50-, 100-, and 500-year return periods for thirteen counties along the Gulf and Atlantic coasts (Supplementary Table 1). This data set is then used to identify the upper limit of a (Supplementary Table 2).

Because a is positive, by Eq. 8–12, u must be negative. A negative u meets expectations, as this value represents the y-intercept of the Gumbel-generated regression, with an equivalent return period of 2.72 years. The maximum allowable value of u is therefore determined, subject to the restraints of Eq. 12.

Each combination of u and a values within the acceptable range of each variable, as described above, at increments of 0.1 feet for each, are initially considered as potentially acceptable values to describe the d vs. return period relationship. Those simultaneous combinations that have a u vs. a ratio that falls outside the range of acceptability (Eq. 12) are discarded. The remaining combinations of u and a are used to calculate d, with the result considered potentially acceptable for inclusion, as described in the next section.

Each combination of u and a that is derived and potentially acceptable is used to determine possible d values at the 2-, 10-, 50-, 100-, 500-,1,000-, 5,000-, and 10,000-year return periods (Eq. 2), noting that d values for the 100-year and shorter return periods are negative or zero. A plot of d vs. the double natural logarithm of return period based on these calculations is then used to confirm the assumption that d is less than or equal to zero for the 100-year and more than zero for the 500-year flood events, in addition to visualizing d at longer return periods (i.e., 500-, and 1,000- year).

Quantify annual flood risk and flood risk reduction

Refined numerical integration method

AAL represents the sum of the expected annual flood risk to a building (AAL_{B}), its contents (AAL_{C}), and its loss of use while unoccupied due to flood (AAL_{U}). While AAL_{B}, AAL_{C}, and AAL_{U} likely differ based on owner-occupant category (i.e., homeowner, landlord, tenant), this study considers only AAL from the perspective of a homeowner.

The method of Gnan et al. (2022a, 2022b) is used to calculate AAL_{B} and AAL_{C} as a proportion of home replacement cost value (V_R) by integrating the flood loss over all probabilities, as shown in Eqs. 13−14:

$$AAL_{\mathrm{B}/V_R} = \int_{P_{min}}^{P_{max}} L_B(P)dP \tag{13}$$

$$AAL_{\mathrm{C}/V_R} = \int_{P_{min}}^{P_{max}} L_C(P)dP \tag{14}$$

where L_B and L_C represent the building and contents losses as a proportion of V_R, which is the unit replacement cost per square foot (C_R) multiplied by the home area (A):

$$V_R = A \times C_R \tag{15}$$

By contrast, AAL_{U} is calculated from the number of months that the building is inoperable, as shown in Eq. 16:

$$AAL_{U\,(\mathrm{months})} = \int_{P_{min}}^{P_{max}} L_U(P)dP \tag{16}$$

where L_U represents the use loss in months.

Then, the three components of AAL are converted to absolute currency values (in USD) for building ($AAL_{B\$}$), contents ($AAL_{C\$}$), and use ($AAL_{U\$}$), as described by Eqs. 17–19:

$$AAL_{\mathrm{B}\$} = AAL_{\mathrm{B}/V_R} \times V_R \tag{17}$$

$$AAL_{\mathrm{C}\$} = AAL_{\mathrm{C}/V_R} \times V_R \tag{18}$$

$$AAL_{U\$} = AAL_{\mathrm{U(months)}} \times R_l \tag{19}$$

where R_l is the monthly rent incurred by the homeowner, calculated by assuming that one year of rent is equal to one-seventh of V_R (Amoroso & Fennell, 2008; Eq. 20).

$$R_l = \frac{V_R}{84\,months} \tag{20}$$

These values are then summed to give the total AAL as a proportion of $V_R(AAL_{T/V_R})$ as shown in Eqs. 21–22:

$$AAL_{T/V_R} = (AAL_{\mathrm{B}/V_R} + \ AAL_{\mathrm{C}/V_R} + \frac{AAAL_U}{84}) \quad (21)$$

$$AAL_{T\$} = AAL_{T/V_R} \times V_R \quad (22)$$

To quantify the economic benefit of elevating above FFH_0, AAL is calculated with and without elevation, to reveal the annual flood risk reduction, as generally expressed by Eq. 23:

$$\Delta AAL = AAL_{FFH_0} - AAL_{FFH} \quad (23)$$

Data processing

The MATLAB algorithm developed by Al Assi et al. (2022) is utilized here to analyze all simultaneously valid u and a combinations; these combinations remain constant by home type (i.e., one or two-or-more stories, with and without basement). The input data include number of stories (1 or 2+), basement existence (0 = No, 1 = Yes), living area in square feet (A), unit cost per square footage (C_R, in USD/sf), FFH_0, and flood parameters (u and a). United States Army Corps of Engineers (USACE; 2000) depth damage functions (DDFs) are incorporated by home type (i.e., number of stories and basement existence). The AAL reduction is calculated for each additional elevation J through MJ feet (Figure 1) above FFH_0.

Confirm results

Spatial interpolation is used to characterize the flood hazard (u and a) in the shaded X Zone (Mostafiz et al., 2021; 2022b) for a known location where multiple return period flood depth data are available. The flood parameters (u and a) are used to calculate annual flood risk by using Eq. 2 and 13–23 and confirming the result produced from the synthetic data.

4. Case Study

Jefferson Parish, Louisiana, and Santa Clarita, California, are selected as these areas have multiple return period (10–, 50–, 100–, and 500–year) flood depth data, which are needed to estimate flood parameters using spatial interpolation. Flood depth grids were developed at a scale of 3.048 m x 3.048 m, by FEMA through its Risk Mapping, Assessment and Planning (Risk MAP) program (FEMA 2021). To demonstrate all possible scenarios for synthetic and estimated flood parameters to quantify annual flood risk and flood risk reduction in the shaded X Zone, a hypothetical slab-on-grade, single-family home with 2000 sq. ft. of living area is used, with the four scenarios of home type (i.e., one or two-or-more stories, with and without basement) calculated separately. Each combination in the collection of synthetic and estimated Gumbel parameters is input to evaluate the range of annual flood risk for each home type. C_R is assumed to be $135 according to the projected 2022 average construction cost of single-family homes in the U.S.A. (Doheny, 2021), and FFH_0 is assumed to be 0.5 feet above the ground for slab-on grade foundations. This assumption is made because there is no regulatory BFE in the shaded X Zone and it is assumed that most homes are built on non-elevated slab foundations. The flood damage initiation point in the depth-damage function is assigned at a fixed flood depth of zero in the structure, as suggested by Pistrika et al. (2014). Annual flood risk for homes with basements is calculated in the same way; thus, it is assumed that the basement is not flooded until water is above the FFH. The annual flood risk reduction is calculated for each additional first floor height of 1 to 4 feet above FFH_0.

5. Results

Generate synthetic flood parameters

The ratio of flood parameters (Eq. 12) along with the updated Stillwater elevation for coastal data are used to determine the flood parameters' range and combinations that satisfy shaded X Zone properties. The analysis updating the results of Bohn (2013) suggests that the maximum a is 4.60 (Eq. 24). Thus, the range of u, subject to the constraints of Eq. 12, is shown in Eq. 25.

$$0 < a \leq 4.60 \tag{24}$$

$$-28.58 \leq u < 0 \tag{25}$$

A total of 1740 combinations of u and a satisfies the flood parameter ratio for the shaded X Zone (Eq. 12). Table 1 shows the descriptive statistics for u and a values resulting from all possible combinations. Because the dataset is very large and it is not normally distributed, percentiles are provided along with the minimum and maximum values. Possible values of u and a fall between −28.58 and −0.48 feet and between 0.10 and 4.60, respectively.

Table 1. Descriptive statistics for synthetic flood parameters in the shaded X Zone.

Flood Parameter	Minimum	25th	50th	75th	Maximum
u	−28.58	−21.58	−17.58	−12.48	−0.48
a	0.10	2.30	3.30	4.00	4.60

The flood depth-return period relationships generated at the 2-, 10-, 50-, 100-, 500-, 1,000-, 5,000- and 10,000-year return periods for these 1740 scenarios are shown in Figure 2. The d at return periods less than or equal to 100 years is negative or zero, and d at 500 years and longer return periods is positive, as expected. Descriptive statistics of d at the 500-, 1,000-, 5,000-, and 10,000-year return periods are shown in Table 2.

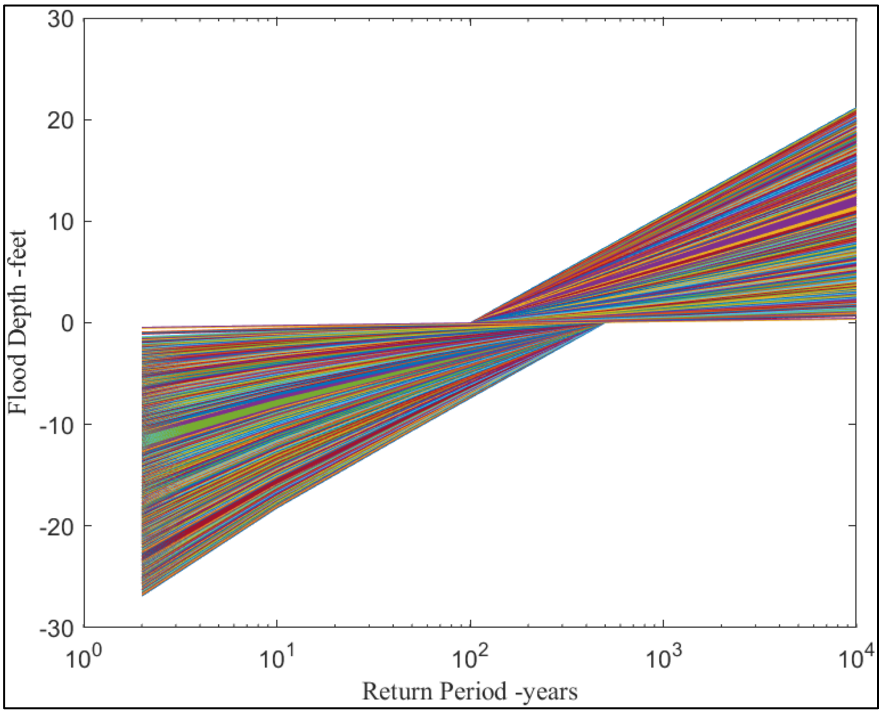

Figure 2. Flood depth-return period relationship for synthetic data.

Table 2. Descriptive statistics of flood depth at long return periods using synthetic data in the shaded X Zone.

Return Period	Minimum (feet)	25th (feet)	50th (feet)	75th (feet)	Maximum (feet)
500-year	0.003	1.003	2.196	3.749	7.400
1,000-year	0.110	2.942	4.387	6.236	10.593
5,000-year	0.272	6.986	9.879	12.376	17.999
10,000-year	0.341	8.654	12.224	15.093	21.187

Quantify annual flood risk and flood risk reduction

For the 1740 scenarios of valid u and α combinations, annual flood risk and flood risk at additional elevations above FFH_0 are calculated as a proportion of V_R by using FFH_0= 0.5 foot, and the corresponding DDF for each home type. The results are presented for the shaded X Zone for homes without and with basement by categories of 500-year flood depths for one- and two-plus-story homes (Tables 3 and 4, respectively), and by categories of α for one- and two-plus-story homes (Tables 5 and 6, respectively). The annual flood risk reduction is considered as the mean avoided AAL, calculated at each additional increment above FFH_0 for each single-family home type (Tables 7 and 8). Because the data set is not normally distributed, the percentiles are provided along with the minimum and maximum values to describe the annual flood risk (Tables 3–6) and flood risk reduction (Tables 7–8) at each category.

Table 3. Descriptive statistics of annual flood risk as a proportion of V_R (i.e., AAL_{T/V_R}) for slab-on-grade one-story single-family home with and without basement using synthetic data, categorized based on 500-year flood depth.

		Total Average Annual Loss as a Proportion of V_R (i.e., AAL_{T/V_R}) x10^{-4}									
		One Story without Basement					One Story with Basement				
500-year Flood Depth (feet)	FFH (feet)	Min	25^{th}	50^{th}	75^{th}	Max	Min	25^{th}	50^{th}	75^{th}	Max
< 1	FFH_0	0.82	10.68	13.31	15.08	18.17	1.40	14.59	17.20	19.15	27.55
	FFH_0+1	0.00	5.19	8.56	11.24	14.55	0.00	7.17	11.16	13.84	17.36
	FFH_0+2	0.00	2.53	5.78	8.50	11.65	0.00	3.58	7.43	10.46	13.90
	FFH_0+3	0.00	1.26	3.87	6.39	9.37	0.00	1.74	4.98	7.87	11.15
	FFH_0+4	0.00	0.62	2.59	4.84	7.54	0.00	0.86	3.31	5.96	8.97
1–2	FFH_0	14.97	18.17	19.84	21.65	31.96	20.27	22.88	25.16	27.40	45.40
	FFH_0+1	4.64	11.50	13.70	15.28	18.17	7.17	15.20	17.47	19.12	21.68
	FFH_0+2	1.11	6.84	9.48	11.58	14.55	1.72	9.16	12.04	14.16	17.40
	FFH_0+3	0.27	3.95	6.58	8.83	11.65	0.41	5.35	8.37	10.79	13.90
	FFH_0+4	0.06	2.30	4.64	6.77	9.37	0.10	3.08	5.88	8.27	11.15
2–3	FFH_0	22.68	24.97	27.30	29.88	41.31	27.16	30.89	33.84	38.61	55.47
	FFH_0+1	14.97	18.05	19.60	21.17	24.43	20.27	22.62	24.37	26.39	32.81
	FFH_0+2	7.35	12.34	14.22	15.57	18.17	10.33	15.89	17.74	19.24	21.68
	FFH_0+3	3.60	8.12	10.17	11.91	14.55	5.06	10.56	12.78	14.51	17.36
	FFH_0+4	1.76	5.34	7.38	9.23	11.65	2.48	6.95	9.29	11.10	13.90
3–4	FFH_0	28.36	32.48	35.47	39.51	51.05	33.74	39.53	43.54	49.93	65.86
	FFH_0+1	22.68	24.66	26.39	28.23	34.25	27.16	30.20	32.59	35.19	44.19
	FFH_0+2	15.22	18.18	19.55	21.07	23.07	20.27	22.48	24.11	25.94	29.65
	FFH_0+3	8.99	13.13	14.66	15.88	18.17	12.08	16.50	18.04	19.48	21.68
	FFH_0+4	5.32	9.41	10.93	12.22	14.55	7.14	11.81	13.51	14.86	17.36
4–5	FFH_0	35.23	40.96	44.44	48.88	59.42	41.92	49.55	54.05	60.40	74.38
	FFH_0+1	28.36	31.71	33.88	36.17	43.07	33.74	38.44	41.36	44.86	53.93
	FFH_0+2	22.68	24.15	25.74	27.44	31.22	27.16	29.49	31.62	33.51	39.09
	FFH_0+3	16.19	18.37	19.63	21.05	22.68	20.56	22.48	23.95	25.65	28.32
	FFH_0+4	11.09	13.84	15.09	16.21	18.16	14.23	17.06	18.33	19.72	21.68
5–6	FFH_0	43.77	50.36	54.01	57.89	64.94	52.08	60.56	65.35	70.67	79.41
	FFH_0+1	35.23	39.59	42.00	44.44	49.61	41.92	47.70	50.93	54.08	60.66
	FFH_0+2	28.36	30.94	32.52	34.50	37.88	33.74	37.48	39.51	41.67	46.32
	FFH_0+3	22.68	23.88	25.30	26.87	28.92	27.10	29.17	30.88	32.47	35.37
	FFH_0+4	16.63	18.59	19.72	21.06	22.68	20.74	22.50	23.87	25.45	27.33
6–7.4	FFH_0	54.37	60.77	64.34	67.47	73.65	64.69	72.90	77.56	81.62	87.62
	FFH_0+1	43.77	48.23	50.74	53.38	59.30	52.08	58.05	61.04	64.09	70.55
	FFH_0+2	35.23	38.29	40.13	42.55	47.74	41.92	46.03	48.19	50.90	56.80
	FFH_0+3	28.35	30.28	31.73	33.82	38.43	33.74	36.22	38.07	40.36	45.72
	FFH_0+4	22.79	23.84	25.15	26.97	30.93	27.16	28.70	30.18	32.32	36.80

Table 4. As in Table 3, except for two-plus-story home.

		Total Average Annual Loss as a Proportion of V_R (i.e., AAL_{T/V_R}) x10^{-4}									
		Two-plus-story without Basement					Two-plus-story with Basement				
500-year Flood Depth (feet)	FFH (feet)	Min	25^{th}	50^{th}	75^{th}	Max	Min	25^{th}	50^{th}	75^{th}	Max
< 1	FFH_0	0.63	7.94	9.97	11.46	14.06	1.11	12.14	14.11	15.47	21.80
	FFH_0+1	0.00	3.84	6.44	8.58	11.26	0.00	6.10	9.10	11.34	14.22
	FFH_0+2	0.00	1.87	4.32	6.48	9.03	0.00	3.02	6.07	8.57	11.38
	FFH_0+3	0.00	0.93	2.89	4.87	7.26	0.00	1.49	4.06	6.46	9.16
	FFH_0+4	0.00	0.46	1.93	3.69	5.84	0.00	0.75	2.70	4.89	7.36
1–2	FFH_0	11.08	13.73	15.01	16.40	23.61	15.88	19.06	20.69	22.20	35.60
	FFH_0+1	3.46	8.58	10.31	11.64	14.06	5.66	12.65	14.35	15.51	17.75
	FFH_0+2	0.83	5.06	7.12	8.82	11.26	1.36	7.62	9.83	11.70	14.22
	FFH_0+3	0.20	2.93	4.95	6.77	9.03	0.33	4.43	6.86	8.92	11.38
	FFH_0+4	0.05	1.71	3.47	5.17	7.26	0.08	2.68	4.82	6.82	9.15
2–3	FFH_0	17.19	18.98	20.71	22.41	30.59	22.29	25.69	27.67	31.33	43.47
	FFH_0+1	11.08	13.63	14.86	16.12	18.10	15.88	19.00	20.20	21.58	25.71
	FFH_0+2	5.43	9.21	10.75	11.87	14.06	8.10	13.26	14.67	15.74	17.75
	FFH_0+3	2.66	6.07	7.68	9.10	11.26	3.97	8.88	10.55	12.01	14.22
	FFH_0+4	1.30	3.99	5.58	7.04	9.03	1.94	5.82	7.67	9.26	11.38
3–4	FFH_0	21.99	24.80	26.93	29.84	38.12	27.69	33.11	35.99	40.78	51.91
	FFH_0+1	17.19	18.68	20.05	21.45	25.58	22.29	25.57	27.02	28.84	34.83
	FFH_0+2	11.28	13.77	14.87	16.06	17.56	15.94	19.08	20.13	21.28	23.37
	FFH_0+3	6.66	9.92	11.15	12.12	14.06	9.47	13.98	15.10	16.02	17.75
	FFH_0+4	3.94	7.08	8.35	9.41	11.26	5.60	10.00	11.26	12.39	14.22
4–5	FFH_0	27.32	31.35	33.89	36.93	44.85	34.40	41.82	45.05	49.86	59.20
	FFH_0+1	21.99	24.33	25.87	27.53	32.51	27.69	32.86	34.67	36.96	42.92
	FFH_0+2	17.19	18.48	19.62	20.97	23.56	22.29	25.56	26.47	27.67	31.11
	FFH_0+3	12.15	14.02	15.03	16.12	17.56	16.28	19.48	20.33	21.25	22.54
	FFH_0+4	8.30	10.53	11.55	12.40	14.06	11.23	14.77	15.62	16.38	17.75
5–6	FFH_0	33.94	38.82	41.44	44.17	49.57	42.74	52.07	55.12	58.75	63.95
	FFH_0+1	27.32	30.50	32.22	34.03	37.86	34.40	41.29	43.30	45.41	48.84
	FFH_0+2	21.99	23.80	25.05	26.42	28.91	27.69	32.81	33.85	35.03	37.30
	FFH_0+3	17.19	18.38	19.44	20.67	22.21	22.29	25.70	26.41	27.50	28.48
	FFH_0+4	12.58	14.30	15.20	16.23	17.56	16.54	20.12	20.76	21.41	22.20
6–7.4	FFH_0	42.17	46.99	49.60	52.07	57.12	53.09	69.62	70.37	71.14	71.91
	FFH_0+1	33.94	37.34	39.03	41.26	45.99	42.74	56.05	56.66	57.28	57.90
	FFH_0+2	27.32	29.48	30.88	32.80	37.02	34.40	45.12	45.62	46.11	46.62
	FFH_0+3	21.99	23.32	24.49	26.18	29.80	27.69	36.32	36.72	37.12	37.52
	FFH_0+4	17.45	18.40	19.41	20.81	23.99	22.29	29.23	29.56	29.87	30.20

Table 5. As in Table 3 but categorized based on the a parameter.

		Total Average Annual Loss as a Proportion of V_R (i.e., AAL_{T/V_R}) x10^{-4}									
		One Story without Basement					One Story with Basement				
a	FFH (feet)	Min	25th	50th	75th	Max	Min	25th	50th	75th	Max
< 1	FFH_0	0.82	5.30	8.05	12.65	25.04	1.40	8.11	12.52	19.43	37.47
	FFH_0+1	0.00	0.77	1.84	3.29	8.26	0.00	1.27	2.83	5.03	12.36
	FFH_0+2	0.00	0.11	0.46	0.92	2.72	0.00	0.18	0.72	1.39	4.07
	FFH_0+3	0.00	0.02	0.11	0.26	0.90	0.00	0.02	0.17	0.40	1.34
	FFH_0+4	0.00	0.00	0.02	0.08	0.29	0.00	0.00	0.04	0.12	0.44
1–2	FFH_0	5.87	11.27	16.73	24.98	43.53	8.66	15.72	23.17	34.75	58.45
	FFH_0+1	2.16	5.60	8.43	12.72	25.75	3.19	7.81	11.70	17.64	34.58
	FFH_0+2	0.80	2.83	4.28	6.84	15.23	1.17	3.89	5.93	9.32	20.45
	FFH_0+3	0.29	1.31	2.18	3.66	8.99	0.43	1.86	3.06	5.05	12.08
	FFH_0+4	0.11	0.62	1.16	1.99	5.32	0.16	0.88	1.59	2.72	7.14
2–3	FFH_0	9.39	15.63	23.10	34.75	56.76	12.56	20.15	30.26	45.05	71.71
	FFH_0+1	5.70	10.38	15.50	23.05	40.24	7.59	13.43	20.06	29.92	50.85
	FFH_0+2	3.46	6.93	10.30	15.39	28.52	4.61	8.92	13.33	19.87	36.04
	FFH_0+3	2.10	4.59	6.87	10.24	20.21	2.79	5.93	8.87	13.25	25.54
	FFH_0+4	1.27	3.05	4.57	6.87	14.32	1.69	3.97	5.89	8.87	18.10
3–4	FFH_0	11.96	19.03	28.25	42.42	67.22	15.04	23.41	35.07	52.27	81.63
	FFH_0+1	8.57	14.21	21.23	31.75	52.05	10.78	17.52	26.24	39.15	63.22
	FFH_0+2	6.14	10.66	15.90	23.76	40.30	7.73	13.13	19.62	29.26	48.95
	FFH_0+3	4.40	7.97	11.89	17.80	31.20	5.54	9.82	14.70	21.96	37.90
	FFH_0+4	3.15	5.94	8.90	13.33	24.15	3.97	7.35	11.08	16.44	29.34
4–4.6	FFH_0	14.00	21.38	31.85	47.66	73.65	16.95	25.65	38.44	57.28	87.62
	FFH_0+1	10.91	16.95	25.35	37.78	59.30	13.20	20.33	30.24	45.45	70.55
	FFH_0+2	8.49	13.43	20.05	30.27	47.74	10.29	16.13	24.07	36.01	56.80
	FFH_0+3	6.62	10.65	15.90	23.78	38.42	8.01	12.78	19.18	28.65	45.72
	FFH_0+4	5.15	8.44	12.62	18.83	30.93	6.24	10.13	15.13	22.66	36.80

Table 6. As in Table 4 but categorized based on a parameter.

		Total Average Annual Loss as a Proportion of V_R (i.e., AAL_{T/V_R}) x10^{-4}									
		Two-plus-story without Basement					Two-plus-story with Basement				
a	FFH (feet)	Min	25th	50th	75th	Max	Min	25th	50th	75th	Max
< 1	FFH_0	0.63	3.93	6.03	9.43	18.57	1.11	6.40	9.87	15.33	29.50
	FFH_0+1	0.00	0.54	1.29	2.41	6.12	0.00	1.00	2.24	3.96	9.73
	FFH_0+2	0.00	0.06	0.33	0.67	2.02	0.00	0.14	0.57	1.09	3.20
	FFH_0+3	0.00	0.00	0.07	0.20	0.66	0.00	0.02	0.13	0.32	1.06
	FFH_0+4	0.00	0.00	0.02	0.06	0.22	0.00	0.00	0.03	0.10	0.35
1–2	FFH_0	4.35	8.33	12.38	18.47	32.24	6.81	12.32	18.20	27.26	45.81
	FFH_0+1	1.60	4.15	6.23	9.39	19.07	2.51	6.12	9.19	13.90	27.10
	FFH_0+2	0.59	2.10	3.17	5.05	11.28	0.92	3.06	4.66	7.30	16.02
	FFH_0+3	0.22	0.97	1.61	2.71	6.66	0.34	1.46	2.20	3.95	9.47
	FFH_0+4	0.08	0.46	0.86	1.47	3.94	0.12	0.69	1.25	2.13	5.60
2–3	FFH_0	6.96	11.68	17.32	25.95	42.68	9.81	15.92	23.79	35.55	56.87
	FFH_0+1	4.22	7.73	11.55	17.20	30.26	5.95	10.61	15.81	23.53	40.32
	FFH_0+2	2.56	5.16	7.69	11.51	21.45	3.61	7.02	10.52	15.70	28.58
	FFH_0+3	1.55	3.43	5.14	7.65	15.20	2.19	4.68	6.97	10.50	20.26
	FFH_0+4	0.94	2.29	3.41	5.15	10.77	1.33	3.12	4.64	6.98	14.35

3–4	FFH_0	9.01	14.41	21.47	32.22	51.49	11.95	18.81	28.05	42.09	66.00
	FFH_0+1	6.46	10.80	16.13	24.08	39.87	8.56	14.09	21.05	31.40	51.12
	FFH_0+2	4.63	8.12	12.09	18.07	30.87	6.14	10.51	15.74	23.47	39.59
	FFH_0+3	3.32	6.05	9.05	13.57	23.90	4.40	7.87	11.79	17.61	30.64
	FFH_0+4	2.38	4.53	6.77	10.11	18.50	3.15	5.89	8.85	13.17	23.72
4–4.6	FFH_0	10.75	16.49	24.50	36.84	57.12	13.74	20.92	31.22	46.62	71.91
	FFH_0+1	8.37	13.07	19.60	29.18	45.99	10.70	16.58	24.76	37.02	57.90
	FFH_0+2	6.52	10.36	15.54	23.31	37.02	8.33	13.14	19.65	29.56	46.62
	FFH_0+3	5.08	8.21	12.28	18.36	29.80	6.49	10.42	15.57	23.28	37.52
	FFH_0+4	3.95	6.52	9.70	14.53	23.99	5.06	8.26	12.37	18.45	30.20

Table 7. Annual flood risk reduction by FFH elevation for one-story single-family home with and without basement using synthetic data.

	Total Average Annual Loss Reduction as a Proportion of V_R (i.e., $\Delta AAL_{T/V_R}$) x 10^{-4}									
	One Story without Basement					One Story with Basement				
FFH (feet)	Min	25th	50th	75th	Max	Min	25th	50th	75th	Max
FFH_0	0	0	0	0	0	0	0	0	0	0
FFH_0+1	0.82	4.81	7.20	10.78	18.22	1.39	6.11	9.14	13.66	26.07
FFH_0+2	0.82	8.09	12.14	18.15	28.78	1.39	10.28	15.45	23.07	38.56
FFH_0+3	0.82	10.37	15.62	23.46	36.79	1.39	13.17	19.79	29.63	47.15
FFH_0+4	0.82	12.08	18.10	27.27	43.33	1.39	15.28	22.93	34.36	53.90

Table 8. Annual flood risk reduction by FFH elevation for two-plus-story single-family home with and without basement using synthetic data.

	Total Average Annual Loss Reduction as a Proportion of V_R (i.e., $\Delta AAL_{T/V_R}$) x10^{-4}									
	Two-plus-story without Basement					Two-plus-story with Basement				
FFH (feet)	Min	25th	50^{th+}	75th	Max	Min	25th	50th	75th	Max
FFH_0	0	0	0	0	0	0	0	0	0	0
FFH_0+1	0.63	3.65	5.45	8.18	13.46	1.11	4.88	7.30	10.94	20.48
FFH_0+2	0.63	6.15	9.20	13.79	21.46	1.11	8.20	12.34	18.46	30.20
FFH_0+3	0.63	7.90	11.82	17.82	27.82	1.11	10.55	15.80	23.71	37.08
FFH_0+4	0.63	9.16	13.67	20.70	33.20	1.11	12.21	18.31	27.44	42.87

Confirm results

Table 9 demonstrates u and α parameters, and the 500-year flood depths, in the shaded X Zone located in Jefferson Parish, Louisiana, and Santa Clarita, California, using spatial interpolation (Mostafiz et al., 2021). The α parameter and 500-year flood depth for Jefferson Parish are less than 1 while these values range from 0.97 to 1.37 and 1.00 to 1.70 feet, respectively, in Santa Clarita. The AAL (i.e., annual flood risk) results for a hypothetical home located in Jefferson Parish and Santa Clarita, calculated through spatially interpolated and synthetic parameters, are summarized in Tables 10 and 11, respectively.

Table 9. Flood parameters and 500-year flood depth for the shaded X Zone located in Jefferson Parish, Louisiana, and Santa Clarita, California, using spatial interpolation.

Location	u	a	500-Year Flood Depth (feet)
Jefferson	–1.09	0.19	0.10
	–0.85	0.18	0.30
Santa Clarita	–6.84	1.34	1.40
	–6.13	1.26	1.70
	–6.19	1.28	1.70
	–6.02	1.25	1.70
	–5.71	1.15	1.40
	–5.63	1.08	1.00
	–4.89	0.97	1.10
	–4.93	1.01	1.30
	–5.35	1.04	1.10
	–5.87	1.14	1.20
	–7.02	1.35	1.30
	–7.13	1.37	1.30
	–6.45	1.32	1.60
	–6.37	1.31	1.70

Table 10. Average annual loss (i.e., annual flood risk) by type of single-family home in Jefferson Parish, Louisiana, and Santa Clarita, California, implementing spatial interpolation parameters.

	Average Annual Loss ($)			
Location	One-story without Basement	One-story With Basement	Two-plus-story without Basement	Two-plus-story with Basement
Jefferson	23	36	18	30
	54	86	41	68
Santa Clarita	567	803	419	629
	715	1,020	528	800
	712	1,015	526	796
	721	1,030	532	808
	594	859	439	674
	429	627	317	492
	483	717	358	563
	573	844	424	664
	471	690	348	542
	501	726	370	570
	525	742	388	582
	523	738	387	578
	657	933	485	731
	708	1,005	523	788

Table 11. Descriptive statistics of average annual loss ($; i.e., annual flood risk) by type of single-family home, after implementing synthetic flood parameters, by 500-year flood depth and *a* parameter.

		Average Annual Loss ($)									
		One Story without Basement					One Story with Basement				
		Min	25^{th}	50^{th}	75^{th}	Max	Min	25^{th}	50^{th}	75^{th}	Max
500-year	< 1	22	288	359	407	490	38	394	464	517	744

flood depth	1–2	404	491	536	585	863	547	618	679	740	1,226
a parameter	< 1	22	143	217	341	676	38	219	338	525	1,012
	1–2	155	304	452	674	1,175	234	424	626	938	1,578
		Two-plus-story without Basement					Two-plus-story with Basement				
		Min	25th	50th	75th	Max	Min	25th	50th	75th	Max
500-year flood depth	< 1	17	214	269	309	380	30	328	381	418	589
	1–2	299	370	405	443	638	429	514	559	599	961
a parameter	< 1	17	106	162	254	501	30	173	267	414	797
	1–2	117	225	334	499	870	184	333	491	736	1,237

6. Discussion

The derivation of the synthetic flood parameters (i.e., u and a) for the shaded X Zone (Table 1) for establishing the relationship between flood depth and return period (Figure 2) is useful for providing decision-makers (e.g., construction specialists and regional planners) sufficient information across a range of return periods. Results suggest that generating u and a is obviate the need for representing the relationship between flood depth vs. building, contents, and use loss separately, as in most conventional DDF-based flood risk analyses. Instead, the approach shown here provides estimates for total loss (i.e., building, contents, and use) for wide range of 500-year flood depths (Table 2) and thus the flood risk assessment (Tables 3, 4, 5, and 6) in the shaded X Zone. The applications are even more valuable for risk assessment for construction with long expected life spans and/or grave consequences for flooding, such as sites of cultural or historical importance, hospitals, nursing homes, and bridges, in which partitioning the loss into its components is less important than estimating the long-term total loss.

Another strength of this approach is that it overcomes complications associated with changing value of assets over time. This is because the relationships between flood depth and total annual flood risk (building, contents, and use) for single-family homes in the shaded X Zone are expressed proportionally to V_R. It is anticipated that providing the results in this format will garner more attention to the long-term flood risk in the shaded X Zone with the actionable outcome of increasing awareness of the benefits of applying mitigation actions.

The results show that the median AAL at FFH_0 falls between only 0.097 and 0.172 percent of V_R, for a single-family home with 500-year flood depth less than one foot, regardless of home type. These results are mainly affected by the unique DDFs based on home type.

Not surprisingly, flood depth is the primary factor involved flood risk, with greater depth causing more damage. Thus, elevating the home is the primary strategy for flood risk reduction, but the improvements vary by 500-year flood depth. For example, while the flood risk reduction is approximately 36, 57, 71, and 81% for one through four feet above FFH_0, respectively, when the 500-year flood depth less than 1 foot for all home types (Tables 3 and 4), that risk is reduced by less and less with additional feet of elevation in 500-year categories (i.e., 1 to 2 feet above FFH_0, 2 to 3 feet, etc.; Tables 3 and 4).

The AALs for the case study subsets of Jefferson Parish (Louisiana) and Santa Clarita (California) generated by spatial interpolation-estimated flood parameters are within the range of AAL results using synthetic flood parameters. In the case of Jefferson Parish, the mean AAL values of $39, $61, $30, and $49 for one-story without basement, one-story with basement, two-plus-story without basement, and two-plus-story with basement single-family home, respectively, calculated using the spatial interpolation-estimated flood parameters are between the minimum and 25th percentile AAL for the appropriate 500-year flood depth and a values. For Santa Clarita, the mean AAL values of $584, $839, and $658 for one-story without basement, one story with basement, and two-plus-story with basement single-family home, respectively, calculated using the spatial interpolation-estimated flood parameters are between the 75th quartile and maximum AAL for the appropriate 500-year flood depth and a values, while the mean AAL value of $432 for two-plus-story without basement single-family home is between the 50th and 75th quartiles. While both techniques lead to similar results, the spatial interpolation method requires multiple return period flood depth data and is computationally intensive. Additional work to confirm the range of areas for which synthetic flood parameters are appropriate will further justify the use of this technique.

7. Conclusions

Although areas outside the SFHA may be highly susceptible to destructive and unanticipated floods at return periods beyond 100 years, they are often overlooked in flood risk assessments, often because they seldom have sufficient data to predict flood parameters. The increased need to have meaningful data outside the SFHA to understand flood hazard risk motivated this new approach to estimate AAL within the shaded X Zone using synthetic flood parameters. The derivation of synthetic flood hazard parameters enables the estimation of flood risk values in the shaded X Zone to assist stakeholders in minimizing flood risk. The major findings are:

- The synthetic data approach improves understanding of flood risk in the shaded X Zone for 1740 scenarios that include a wide range of 500-year flood depths.
- Flood depth-return period relationships provide vital information regarding flood depths at longer return periods that can be used to enhance flood resilience.

- For the analyzed synthetic data, the median AAL for all four types of single-family homes (one- and two-plus-story, each without and with basement) in the shaded X Zone falls between 0.10 to 0.78 percent of V_R for the full range of 500-year flood depths between 0.003 feet and 7.400 feet and a values between 0.10 and 4.60.
- The median value of AAL reduction falls between 0.06 and 0.23 percent of V_R when elevating by an additional 1 and 4 feet, respectively, above FFH_0.
- For case study areas within Jefferson Parish (Louisiana) and Santa Clarita (California), AAL values calculated from spatial interpolation-estimated flood parameters fall within the range of those computed from synthetic flood parameters.

Although this study provides an important first step for predicting and enhancing community understanding of the flood risk in the shaded X Zone, some cautions need to be considered. First, the numerical results will differ from those suggested here in areas where the a parameter exceeds 4.60. Also, the spatial interpolation-estimated flood parameters derived here require depth grids for 10-, 50-, 100-, and 500-year events; these results would be refined if 200- or 250- year depth grids are available. Furthermore, location-specific and recent inflationary trends may result in C_R much higher than the assumed \$135/sf, but AAL could be updated easily for future work. Despite these cautions, this research contributes to the mitigation of the damage and loss experienced outside the SFHA and to improved awareness of the magnitude of flood risk in this region and the benefit of applying mitigation strategies.

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9. Author Contribution Statement

AAA developed the methodology, analyzed the data, interpreted the findings, and developed the initial text. RBM selected the case study area, prepared the input data, and supervised the research. CJF supervised the research, provided insight and recommendation for the research, and reviewed and edited the manuscript. RVR reviewed and edited the writing of the manuscript and provided insight and recommendation for the research. MAR reviewed and edited the manuscript.

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