AGU 2023 Conference

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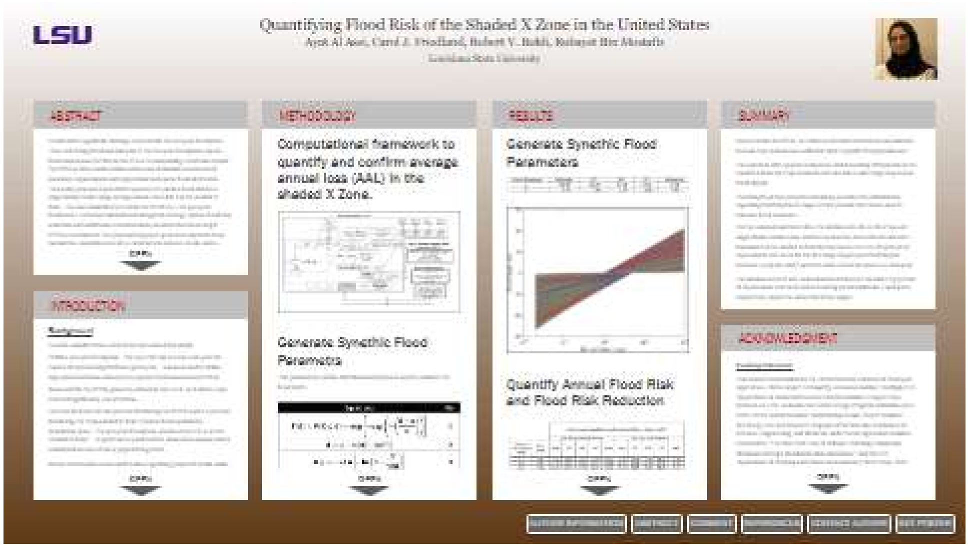
January 17, 2023

Quantifying Flood Risk of the Shaded X Zone in the United States



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PRESENTED AT:

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). To further inform flood mitigation strategy, annual flood risk reduction with additional elevation above an initial first-floor height (FFH0) 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 for a one-story, single-family home without and with basement, respectively, at FFH0 and 500-year flood depth less than 1 foot. Elevating homes one and four feet above FFH0 substantially mitigates this risk, generating savings of 0.07–0.18 and 0.09–0.23 percent of replacement cost value 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 FFH0 in the shaded X Zone.

INTRODUCTION

Background

Flood is considered the costliest natural hazard worldwide.

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).

Areas outside the SFHA, generally known in the U.S.A. as X Zones, have received significantly less attention.

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.

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

Calculating flood risk is challenging due to data limitations in shaded X Zone

Objectives:

Provide a meaningful estimate of the range of expected annual flood risk in the shaded X Zone.

Calculate the reduction in annual flood risk via elevation for homes in the shaded X Zone.

Contributions:

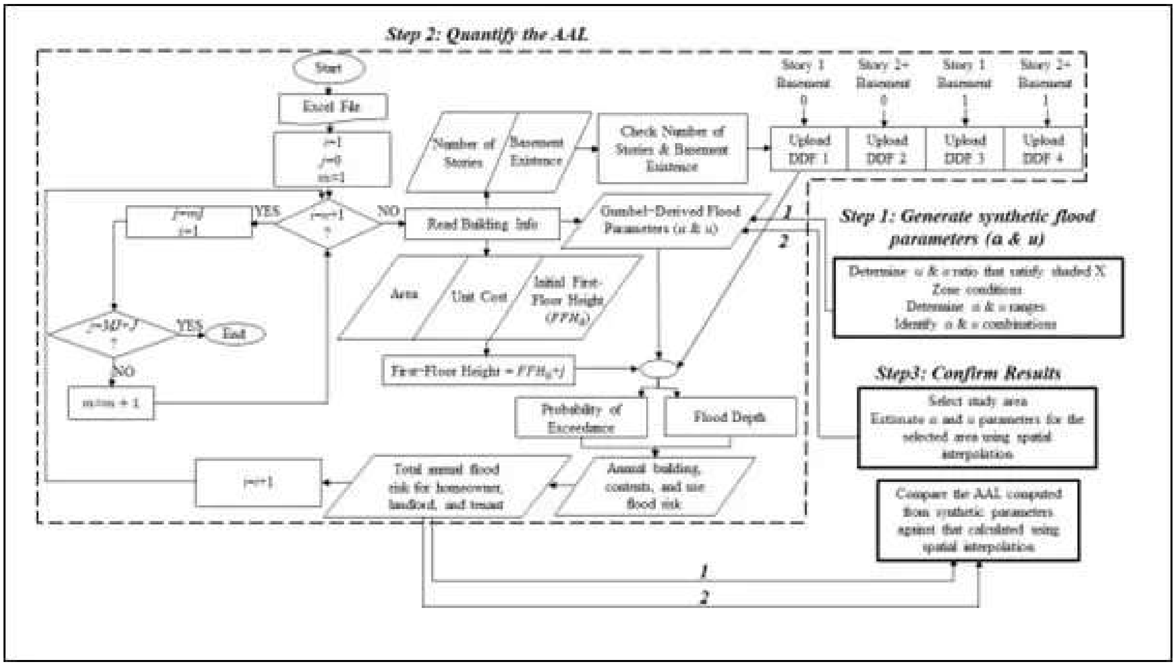
A novel conceptualization and implementation of annual flood risk assessment in the shaded X Zone – a location where little flood risk information has been generated.

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.

METHODOLOGY

Computational framework to quantify and confirm average annual loss (AAL) in the shaded X Zone.



Generate Synethic Flood Parametrs

Two parameters Gubmel distribution function is used to estimate the flood depth

Equations	No.
$\mathbf{F(d) = P(X \leq d) = exp\left[-exp\left(-\left(\frac{d-u}{\alpha}\right)\right)\right]}$	1
$\mathbf{d = u - a\,l\,n[-\ln(P)]}$	2
$\mathbf{0 \geq u - a\,l\,n\left[-\ln\left(1-\frac{1}{100}\right)\right]}$	3
$\mathbf{0 < u - a\,ln\left[-\ln\left(1-\frac{1}{500}\right)\right]}$	4
$\mathbf{-6.214 < \frac{u}{a} \leq -4.600}$	5

Where P is the annual non-exceedance probability, d is flood depth, and u and a are flood parameters

Quantify Annual Flood Risk and Flood Risk Reduction

Equations	No.
$\mathbf{AAL_{B/V_R}} = \int_{\mathbf{P\,min}}^{\mathbf{Pmax}} \mathbf{L_B(P)dP}$	6
$\mathbf{AAL_{C/V_R}} = \int_{\mathbf{Pmin.}}^{\mathbf{Pmax}} \mathbf{L_C(P)dP}$	7
$\mathbf{AAL_{use,months}} = \int_{\mathbf{Pmin}}^{\mathbf{Pmax}} \mathbf{L_{use}(P)dP}$	8
$\boldsymbol{V_R = A \times C_R}$	9
$\boldsymbol{\Delta AAL = AAL_{FFH_0} - AAL_{FFH}}$	10

Where $AAL_{B/VR}$ is the Sum of the expected annual flood risk to a building as a prportion of building value (VR) , $AAL_{B/VR}$ is the Sum of the expected annual flood risk to contents as a prportion of building value, and $AAL_{use/months}$ is the Sum of the expected annual flood risk to use.

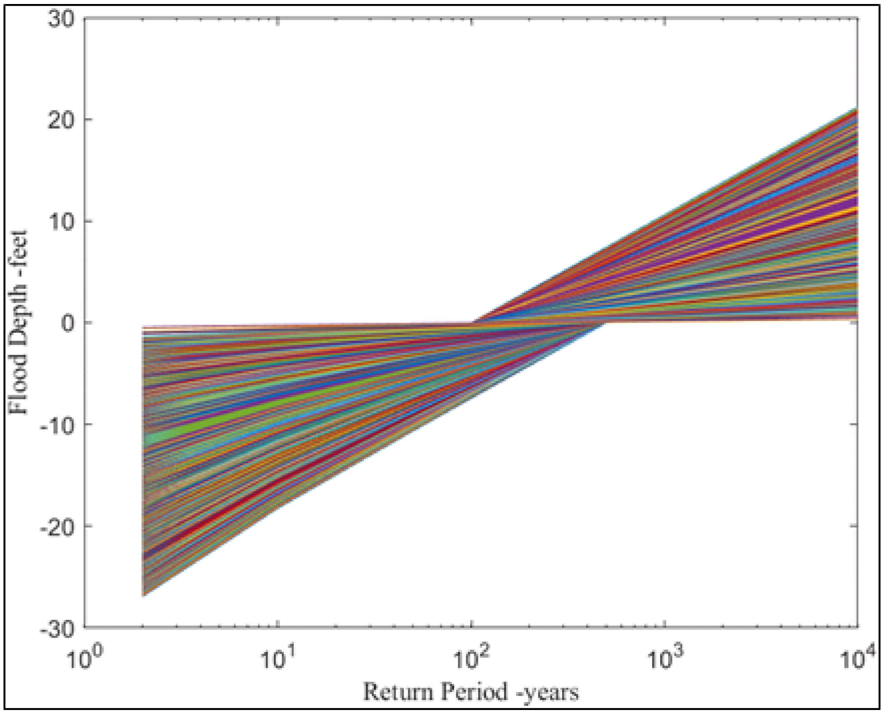
Confirm Results

Spatial interpolation is used to characterize the flood hazard in the shaded X Zone for a known location where multiple return period flood depth data are available.

RESULTS

Generate Synthetic Flood Parameters

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



Quantify Annual Flood Risk and Flood Risk Reduction

		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	25th	50th	75th	Max	Min	25th	50th	75th	Max
< 1	FFH_0	0.82	10.68	13.31	15.08	18.17	1.40	14.59	17.20	19.15	27.55
1–2	FFH_0	14.97	18.17	19.84	21.65	31.96	20.27	22.88	25.16	27.40	45.40
2–3	FFH_0	22.68	24.97	27.30	29.88	41.31	27.16	30.89	33.84	38.61	55.47
3–4	FFH_0	28.36	32.48	35.47	39.51	51.05	33.74	39.53	43.54	49.93	65.86
4–5	FFH_0	35.23	40.96	44.44	48.88	59.42	41.92	49.55	54.05	60.40	74.38
5–6	FFH_0	43.77	50.36	54.01	57.89	64.94	52.08	60.56	65.35	70.67	79.41
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

		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	25th	50th	75th	Max	Min	25th	50th	75th	Max
< 1	FFH_0	0.63	7.94	9.97	11.46	14.06	1.11	12.14	14.11	15.47	21.80
1–2	FFH_0	11.08	13.73	15.01	16.40	23.61	15.88	19.06	20.69	22.20	35.60
2–3	FFH_0	17.19	18.98	20.71	22.41	30.59	22.29	25.69	27.67	31.33	43.47
3–4	FFH_0	21.99	24.80	26.93	29.84	38.12	27.69	33.11	35.99	40.78	51.91
4–5	FFH_0	27.32	31.35	33.89	36.93	44.85	34.40	41.82	45.05	49.86	59.20
5–6	FFH_0	33.94	38.82	41.44	44.17	49.57	42.74	52.07	55.12	58.75	63.95
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

	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	50th+	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

	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

Confirm Results

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

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

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	25th	50th	75th	Max	Min	25th	50th	75th	Max
500-year flood depth	< 1	22	288	359	407	490	38	394	464	517	744
	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

SUMMARY

Areas outside the SFHA are often overlooked in flood risk assessments because they seldom have sufficient data to predict flood parameters

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 replacement cost value 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 replacement cost value when elevating by an additional 1 and 4 feet, respectively, above the initial first-floor height.

ACKNOWLEDGMENT

Funding Statement

This research was funded by the USDA National Institute of Food and Agriculture, Hatch project LAB 94873, accession number 7008346, U.S. Department of Homeland Security (Award Number: 2015-ST-061-ND0001-01), the Louisiana Sea Grant College Program (Omnibus cycle 2020–2022; Award Number: NA18OAR4170098; Project Number: R/CH-03), the Gulf Research Program of the National Academies of Sciences, Engineering, and Medicine under Grant Agreement number: 200010880, "The New First Line of Defense: Building Community Resilience through Residential Risk Disclosure," and the U.S. Department of Housing and Urban Development (HUD; 2019–2022; Award No. H21679CA, Subaward No. S01227-1). Any opinions, findings, conclusions, and recommendations expressed in this manuscript are those of the authors and do not necessarily reflect the official policy or position of the funders. The publication of this article is subsidized by the LSU Libraries Open Access Author Fund

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ABSTRACT

Flood events cause significant damage outside the special flood hazard area (SFHA), making the use of SFHA as an indicator of flood risk misleading. Furthermore, people outside the SFHA underestimate flood risk because there are few flood-related insurance requirements or regulations for their homes. The lack of available data regarding flood depth at longer-return periods has limited the scope of research that has estimated flood risk outside the SFHA. Therefore, there is a need to develop a new framework to estimate flood risk beyond the SFHA that considers the full range of potential flood parameters. This study proposes a novel systematic approach to predict the flood risk in terms of average annual loss (AAL) in the shaded X Zone for a single-family home, where the shaded X Zone is the area immediately outside the SFHA – the 500-year floodplain, which lies between the limits of the one percent and 0.2-percent annual flood probability. To further inform flood mitigation planning, annual flood risk reduction with additional elevation above an initial first-floor height (FFH_0) is estimated. The proposed approach is divided into three main steps: (1) generate synthetic flood parameters that represent a wide range of 500-year flood depths, (2) quantify AAL for a hypothetical slab-on–grade single-family home with varying attributes and scenarios, and at varying elevations above the slab-on-grade elevation, and (3) compare the flood risk results for two separate areas using the flood parameters generated by this synthetic method vs. an existing spatial interpolation technique. Results reveal that the median AAL in the shaded X Zone is 0.13 and 0.17 percent of the replacement cost value for a one-story, single-family home without and with basement, respectively, at FFH_0 and 500-year flood depth less than 1 foot. This risk is largely mitigated by elevating homes above FFH_0 to minimize the median AAL, with savings of 0.07 to 0.18 and 0.09 to 0.23 percent of replacement cost value for a one-story, single-family home without and with basement, respectively, by elevating 1 and 4 feet, respectively, above FFH_0. The results of this study enhance the understanding of flood risk and the benefits of elevating homes above FFH_0 in the shaded X Zone.

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