Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Apportionment of Average Annual Flood Loss between Homeowner and Insurer

Md Adilur Rahim (mrahim6@lsu.edu)
Louisiana State University
Carol Friedland
LaHouse Home and Landscape Resource Center, Louisiana State University Agricultural Center
Rubayet Bin Mostafiz
Louisiana State University
Robert Rohli
Louisiana State University
Nazla Bushra
Louisiana State University

Article

Keywords:

Posted Date: March 28th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1483728/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Abstract

Accurate economic loss assessment for natural hazards is vital for planning, mitigation, and actuarial purposes. The widespread and costly nature of flood, with the economically disadvantaged disproportionately victimized, makes flood loss assessment particularly important. A shortcoming in existing flood loss models is absence of partitioning the building economic value of average annual loss (AAL) into that borne by the homeowner and by flood insurance. This research models the flood AAL incurred by the homeowner vs. by the insurer, focusing on the National Flood Insurance Program in the U.S., using Monte Carlo simulation at the individual homeowner scale. A hypothetical case study reveals that a $1500 or $3000 deductible is associated with a homeowner portion of 13 or 24 percent of the AAL, respectively, with homeowner proportion relatively insensitive to the combinations of coverage, AAL, and increase in first-floor height evaluated. In general, results inform the proactive decision-making process that allows homeowners to self-assess their degree of preparation and vulnerability to the devastating economic impacts of flood. By upscaling the results to the community level, results also assist planners and leaders in understanding the degree of community-level flood vulnerability and resilience, thereby affording possibilities for improved preparation.

Introduction

Flooding is among the costliest natural hazards globally and nationally, in terms of loss of life and property, with impacts felt disproportionately by the economically disadvantaged [1]. Flooding affected 99 percent of U.S.A. counties between 1996 and 2019 [2]. The 35 flood events in the U.S.A. from 1980 through October of 2021 that each caused over $1 billion (consumer price index- (CPI-) adjusted to 2020$) in damage generated a total of more than $161.9 billion (CPI-adjusted) [3] in impacts. Even worse, flood vulnerability in the U.S.A. is likely much greater than currently realized, as Wing et al. [4] found that FEMA flood maps may undercount Americans who live in the 100-year floodplain by as much as a 300 percent, with 41 million being a more likely number. The extent to which insurance and homeowners pay for the impacts of flood losses has not been well established.

Existing research tends to emphasize quantification of total flood loss rather than the direct economic impact on homeowners. Most research on flood loss that includes flood insurance focuses on premium setting. Hsu et al. [5] applied an integrated flood risk assessment model in which the average annual loss (AAL) and risk tolerance are considered when setting the premium. In the first macro-scale quantification of risk-based premiums for residences prone to either storm surge or inland flooding, Michel-Kerjan et al. [6] used commercially developed probabilistic catastrophe models to conclude that the National Flood Insurance Program (NFIP) may overcharge or undercharge homeowners relative to the expected loss that a representative private insurer could offer. Zhao et al. [7] examined affordability of flood insurance under Biggert-Waters Flood Insurance Reform Act. Ermolieva et al. [8] modeled residential insurance premiums using a well-integrated catastrophe risk management model that considers a range of offerings from the insurer, involvement of individuals, and the complex interplay between multivariate spatially- and temporally-explicit probability distributions of flood losses and risk exposures of the stakeholders.

Ermolieva et al. [8] found this technique to be advantageous over the traditional AAL-based approach because of the integration of spatially-explicit financial arrangements for sharing flood losses, which guarantees the program's solvency under all relevant flood scenarios rather than one average event. Research that focuses on the cost benefit analysis of flood mitigation techniques through the reduction of flood AAL either do not specifically consider homeowner benefit [9, 10, 11] or consider that the entire AAL is borne by the homeowner [12, 13, 14]. Agent-based modeling approaches have also been used to enhance understanding of flood insurance decision-making, particularly the role of public-private partnerships in the UK [15] and the interactive relationships between costs, premiums, and housing prices in the U.S.A. [16]. However, little attention has been paid to the role of insurance coverage and deductible choices in influencing homeowner flood loss.

This paper presents a method to derive apportionment factors that are useful in assigning average annual residential building flood loss to the homeowner or the insurer. Flood loss events are modeled at the individual building level using a Monte Carlo simulation [17, 18, 19, 20, 21, 22, 23, 24], in which the flood hazard is characterized by the Gumbel extreme value distribution function [25, 26, 27, 28, 29]. A depth-damage function (DDF) from United States Army Corps of Engineers [30] is used to estimate the building loss of each flood event, which is apportioned to the homeowner or the insurer. The homeowner and insurer AAL portions are then estimated by averaging apportioned values over the simulation events. A case study is presented to demonstrate the methodology.

Researchers can use either the method or the derived factors to better estimate the impacts of floods experienced by homeowners. Results from this work can be incorporated into webtools or other education/outreach material for the general public, realtors, homebuilders, and community leaders.

Methods

The method consists of a Monte Carlo simulation to model AAL and the allocation of the homeowner's and NFIP shares of the mean annual cost due to flood. The simulation generates random flood event probabilities. Then, flood loss is calculated for each flood event and apportioned to either the homeowner or the NFIP. The apportioned losses are averaged over all flood events to estimate the AAL for the homeowner and NFIP.

Flood Hazard Parameters

To estimate the annual flood hazard occurrence probability at the individual building level, the Gumbel extreme value distribution function is used, with special attention given to the location (u) and scale (α) parameters. The cumulative distribution function (CDF) of this distribution is the annual probability that a stochastic variable X is less than or equal to a flood event of depth D (annual non-exceedance probability), and is written as:

$$F(D) = P(X \leq D) = exp\left[-exp\left(-\left(\frac{D-u}{\alpha}\right)\right)\right]$$

1

Solving the CDF yields the quantile of the distribution:

$$D = F^{-1}(F(D)) = u - \alpha(\ln(-\ln(p)))$$

2

where$p = P(X \leq D)$. The annual exceedance probability of the flood event with depth D is $(1-p)$.

The method used for Gumbel parameter estimation in this paper is a modified version of that described in Mostafiz et al. [31]. Mostafiz et al. [31] proposed an area-specific Gumbel parameter estimation method while this paper calculates building-specific (i.e., point-based) parameters. The Gumbel distribution is fit using the available flood depth data for the building. A linear least-squares regression is performed to estimate the parameters in Eq. 2. The Gumbel parameters u and α are the intercept (i.e., location) and the slope (i.e., scale) value of the regression line, respectively.

For most residential buildings, the u value should be negative, as flood depth at zero damage would only be possible for waterlogged terrain. For any cell in which the u value is positive, a 2-year return period flood depth threshold value of − 0.1 feet is incorporated with other flood depth data for that cell. Because a double logarithmic transformation is used, 2 years is the lowest return period that can be considered. The Gumbel distribution is again fit using the additional 2-year return period flood depth data and the u value is checked. If the u value is still positive, the threshold value is decreased by increments of − 0.1 until u becomes negative.

Monte Carlo Simulation

Monte Carlo simulation of N flood events is conducted, with the simulation generating a random annual non-exceedance probability ($\hat{p}$) value between 0 and 1 for each run i, such that

$$\hat{p}(i) = random(0, 1)$$

3

Using the probability from Eq. 3, the flood depth for each simulated flood event ($\hat{D}_i$) is estimated using Eq. 2.

Loss Estimation

The DDFs are used to estimate flood loss by relating flood depth above the first floor ($\hat{D}_S$) to the damage as a percentage of building value. The $\hat{D}_S$ is estimated using Eq. 4, where FFH is the first-floor height above the ground.

$$\hat{D}_{S_i} = \hat{D}_i - FFH$$

4

The $\hat{D}_{S_i}$ value is then input to the loss function to estimate flood loss as a percentage of the building value. This percentage loss is multiplied by the building value to yield the dollar value of the flood loss (Eq. 5). The building value is estimated by multiplying the livable area of the building by the unit replacement cost.

$$Loss(\$)_i = Loss(\%)_i * BuildingValue(\$)$$

5

Loss Allocation

The values for insurance coverage and deductible in the scenario under consideration are input so that $Loss(\$)_i$ is partitioned into that cost borne by the homeowner vs. that assigned to the NFIP. Three decision rules are used to allocate the flood loss between the homeowner and the NFIP. Specifically, 1) if the loss does not exceed the deductible, then the homeowner suffers the entire loss and NFIP's share is zero; 2) if the loss exceeds the deductible but not the insurance coverage, the homeowner portion of the loss is considered to be the deductible, and the NFIP portion is the difference between the loss and the deductible; 3) if the loss exceeds the insurance coverage, the homeowner's portion of the loss is equal to the deductible plus the difference between the loss and the coverage, and the NFIP's share of the loss is the coverage minus the deductible.

Average Annual Losses by Party

The values from these N runs are then averaged to calculate the AAL and the portion of the AAL that would be expected to be borne by the homeowner and by the NFIP, according to Equations 6 through 8, respectively. The homeowner proportion of the total AAL is calculated using Eq. 9.

$$AAL = \frac{1}{N}\sum_{i=1}^{N} Loss(\$)_i$$

6

$$AAL_{homeowner} = \frac{1}{N}\sum_{i=1}^{N} Loss(\$)_{i_{homeowner}}$$

7

$$AAL_{NFIP} = \frac{1}{N}\sum_{i=1}^{N} Loss(\$)_{i_{NFIP}}$$

8

$$Homeownerproportion = \frac{AAL_{homeowner}}{AAL}$$

9

Results

Case Study

A one-story, single-family home with 1,800 sq. ft. of living area in Metairie, Louisiana, a suburb of New Orleans, is selected for analysis. The ground elevation is − 7.0 ft. NAVD88 and the base flood elevation (BFE; i.e., the 100-year flood elevation) is − 4 ft. NAVD88, giving a FFH of 3 ft., as the building lowest floor elevation (i.e., FFH) should be at or above the BFE by federal government requirement in the U.S.A. [32]. In 2019, the unit replacement cost of a single-family residence in the New Orleans area was $92.47 per sq. ft. [33], which yields an estimated building value of $166,446.

Flood hazard parameters

The flood hazard parameters are estimated using the Gumbel extreme value distribution function. The u and α parameters of the Gumbel distribution are calculated using the available flood depth data for the building. Flood depth grids for this site are developed by FEMA through its Risk MAP program. Flood depths for the 10-, 50-, 100-, and 500-year return periods, with 0.1, 0.02, 0.01, and 0.002 annual exceedance probabilities, are 2.3, 2.8, 3.1, and 3.6 ft. above local ground, respectively. As the building is located in a levee protected area, the flood depths are relatively large. The calculation of Gumbel parameters requires several iterations to achieve a negative value for u. The final Gumbel parameters are estimated as $u = -0.0475$ and $\alpha = 0.6658$.

Monte Carlo Simulation

A Monte Carlo simulation of 50,000 flood events is then run using the FFH, u, and α. The USACE [30] building DDF is used to fit a loss function (Eq. 10, $R^2 = 0.9971$) to calculate the flood loss percentages for each event. The value from Eq. 10 is multiplied by the building value to estimate the corresponding flood loss in dollars (Eq. 5).

$$Loss(\%)_i = \frac{0.0015{D_{S_i}}^3 - 0.3373{D_{S_i}}^2 + 9.0339D_{S_i} + 15.413}{100} \text{ for } D_{S_i} > -2 \quad (10)$$

To reveal the effect of the method on the AAL calculation, different coverage, deductible, and increase in FFH were considered, with simulated results shown in Table 1. For a $1500 deductible, the homeowner portion is on the order of 13% of total AAL, while a $3000 deductible is associated with approximately

24% of the total AAL borne by the homeowner. For the combinations of coverage, AAL, and increase in FFH evaluated, these parameters have a relatively small effect on the homeowner portion.

Table 1
Average annual loss allocation by insurance coverage, deductible, and increase in FFH, based on Monte Carlo simulation

Coverage ($)	Deductible ($)	Increase in FFH (ft.)	Total AAL ($)	Homeowner AAL ($)	NFIP AAL ($)	Homeowner proportion
150,000	1,500	$BFE + 0$	1,190	154	1,036	0.13
150,000	1,500	$BFE + 0.5$	589	74	515	0.13
150,000	1,500	$BFE + 1$	272	34	238	0.12
150,000	3,000	$BFE + 0$	1,172	285	887	0.24
150,000	3,000	$BFE + 0.5$	570	141	429	0.25
150,000	3,000	$BFE + 1$	275	65	210	0.24
100,000	1,500	$BFE + 0$	1,196	153	1,044	0.13
100,000	1,500	$BFE + 0.5$	598	76	522	0.13
100,000	1,500	$BFE + 1$	284	37	246	0.13
100,000	3,000	$BFE + 0$	1,195	285	909	0.24
100,000	3,000	$BFE + 0.5$	555	133	422	0.24
100,000	3,000	$BFE + 1$	261	66	196	0.25

Discussion

Flood loss for an individual building is modeled using a Monte Carlo approach, with the annual flood hazard occurrence probability represented by the Gumbel extreme value distribution function. Based on the insurance coverage, deductible, and increase in FFH, the homeowner and NFIP shares of the AAL are determined. For the case study example identified here, the homeowner proportion amounts to less than 25% of the total loss. While little refereed literature exists regarding the relationship between insured and uninsured flood losses, Brotman [34] recently explored this topic, finding that income is negatively correlated with mortgage insurer losses. This finding is important because insolvency of one or more of the few mortgage insurers in the U.S.A. would cause reduced competition for flood insurance policies, possibly resulting in increased premiums, in addition to any increases caused by other factors. The present research takes the next step forward by filling the research gap regarding the allocation of homeowner and NFIP shares of residential flood loss. Thus, these results will be of interest to homeowners, insurance companies, and lending institutions, as all seek to minimize risk and optimize cost-benefit ratio in the pursuit of economic sustainability vis-à-vis the most important investment that most will ever make.

These findings are very promising, as a larger study might find that homeowner AAL proportion can be reasonably pre-calculated and applied to total AAL value, which is relatively straightforward to calculate. This capability would facilitate estimation of flood losses experienced by homeowners, particularly if uncertainty can be incorporated [14], adding to research that attempts to understand adaptive strategies in flood risk management [35] and factors affecting flood loss recovery and mitigation decisions in their proper context [36].

Declarations

Acknowledgments

This research was funded by the 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 (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 author and do not necessarily reflect the official policy or position of the funders.

Author Contributions

M.A.R., C.J.F., and R.B.M. contributed to the design of the research and the interpretation of the results. M.A.R. wrote the code. M.A.R., C.J.F., and R.B.M. analyzed the results. M.A.R., R.B.M., R.V.R., and N.B. wrote the paper. M.A.R., C.J.F., R.B.M., and R.V.R. discussed the results and commented on the manuscript. M.A.R., R.B.M., R.V.R., and N.B. worked on the literature review.

Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher by requesting to the corresponding author.

Additional Information

The authors declare no competing interests.

References

1. United Nations. *Guidelines for Reducing Flood Losses*. Geneva: United Nations, 83 pp. https://sdgs.un.org/publications/guidelines-reducing-flood-losses-16964 (2004).

2. FEMA. Historical flood risk and costs. https://www.fema.gov/data-visualization/historical-flood-risk-and-costs (2021).

3. NOAA National Centers for Environmental Information (NCEI). U.S. billion-dollar weather and climate disasters. https://www.ncdc.noaa.gov/billions/ (2022).

4. Wing, O. E., Pinter, N., Bates, P. D. & Kousky, C. New insights into US flood vulnerability revealed from flood insurance big data. *Nat. Commun.* **11**, 1444; 10.1038/s41467-020-15264-2 (2020).

5. Hsu, W. K. et al. An integrated flood risk assessment model for property insurance industry in Taiwan. *Nat. Hazards* **58**(3), 1295–1309 (2011).

6. Michel-Kerjan, E., Czajkowski, J. & Kunreuther, H. Could flood insurance be privatised in the United States? A primer. *Geneva Pap. R. I.- Iss. P.* **40**(2), 179–208 (2015).

7. Zhao, W., Kunreuther, H. & Czajkowski, J. Affordability of the National Flood Insurance Program: Application to Charleston County, South Carolina. *Nat. Hazards Rev.* **17**(1), 04015020; 10.1061/(ASCE)NH.1527-6996.0000201 (2016).

8. Ermolieva, T. et al. Flood catastrophe model for designing optimal flood insurance program: Estimating location-specific premiums in the Netherlands. *Risk Anal.* **37**(1), 82–98 (2016).

9. de Moel, H., van Vliet, M. & Aerts, J. C. Evaluating the effect of flood damage-reducing measures: A case study of the unembanked area of Rotterdam, the Netherlands. *Reg. Environ. Change* **14**(3), 895–908 (2014).

10. de Ruig, L. T., Haer, T., de Moel, H., Botzen, W. W. & Aerts, J. C. A micro-scale cost-benefit analysis of building-level flood risk adaptation measures in Los Angeles. *Water Resour. Econ.* **32**, 100147; 10.1016/j.wre.2019.100147 (2020).

11. Ward, P. J. et al. A global framework for future costs and benefits of river-flood protection in urban areas. *Nat. Clim. Change* **7**(9), 642–646 (2017).

12. Foster, J. H. Flood management: Who benefits and who pays. *J. Am. Water Resour. As.* **12**(5), 1029–1040 (1976).

13. Xian, S., Lin, N. & Kunreuther, H. Optimal house elevation for reducing flood-related losses. *J. Hydrol.* **548**, 63–74 (2017).

14. Zarekarizi, M., Srikrishnan, V. & Keller, K. Neglecting uncertainties biases house-elevation decisions to manage riverine flood risks. *Nat. Commun.* **11**(1), 5361; 10.1038/s41467-020-19188-9 (2020).

15. Dubbelboer, J., Nikolic, I., Jenkins, K. & Hall, J. An agent-based model of flood risk and insurance. J *JASSS-J. Artif. Soc. S.* **20**(1), 6; 10.18564/jasss.3135 (2021).

16. de Koning, K., Filatova, T. & Bin, O. Capitalization of flood insurance and risk perceptions in housing prices: An empirical agent-based model approach. *South Econ. J.* **85**(4), 1159-1179 (2019); 10.1002/soej.12328

17. Brodie, I. M. Rational Monte Carlo method for flood frequency analysis in urban catchments. *J. Hydrol.* **486**, 306-314 (2013).

18. Hennequin, T. et al. (2018). A framework for performing comparative LCA between repairing flooded houses and construction of dikes in non-stationary climate with changing risk of flooding. *Sci. Total Environ.* **642**, 473–484 (2018).

19. Kind, J. M. Economically efficient flood protection standards for the Netherlands. *J. Flood Risk Manag.* **7**(2), 103–117 (2014).

20. Kind, J., Botzen, W. W. & Aerts, J. C. Social vulnerability in cost-benefit analysis for flood risk management. *Environ. Dev. Econ.* **25**(2), 115–134 (2020).

21. Qi, H., Qi, P. & Altinakar, M. S. GIS-based spatial Monte Carlo analysis for integrated flood management with two dimensional flood simulation. *Water Resour. Manag.* **27**(10), 3631–3645 (2013).

22. Rahman, A. et al. Monte Carlo simulation of flood frequency curves from rainfall. *J. Hydrol.* **256**(3–4), 196-210 (2002).

23. Taghinezhad, A., Friedland, C. J. & Rohli, R. V. Benefit-cost analysis of flood-mitigated residential buildings in Louisiana. *Hous. Soc.* **48**(2), 185–202 (2020).

24. Yu, J. J., Qin, X. S. & Larsen, O. Joint Monte Carlo and possibilistic simulation for flood damage assessment. *Stoch. Env. Res. Risk. A.* **27**(3), 725–735 (2013).

25. Bhat, M. S. et al. Flood frequency analysis of river Jhelum in Kashmir basin. *Quatern. Int.* **507**, 288-294 (2019).

26. Kim, S. U. & Lee, C. E. Incorporation of cost-benefit analysis considering epistemic uncertainty for calculating the optimal design flood. *Water Resour. Manag.* **35**(2), 757–774 (2021).

27. Manfreda, S., Miglino, D. & Albertini, C. Impact of detention dams on the probability distribution of floods. *Hydrol. Earth Syst. Sci.* **25**(7), 4231–4242 (2021).

28. Prasanchum, H., Sirisook, P. & Lohpaisankrit, W. (2020). Flood risk areas simulation using swat and Gumbel distribution method in Yang catchment, northeast Thailand. *Geogr. Tech.* **15**(2), 29–39 (2020).

29. Singh, P. et al. Vulnerability assessment of urban road network from urban flood. *Int. J. Disast. Risk Re.* **28**, 237–250 (2018).

30. USACE. *Economic Guidance Memorandum (EGM) 01-03, Generic Depth Damage Relationships*. 1–3. In: Memorandum from USACE (United States Army Corps of Engineers), Washington, DC (2000).

31. Mostafiz, R. B. et al. A data-driven, probabilistic, multiple return period method of flood depth estimation. In AGU Fall Meeting Abstracts, American Geophysical Union (2021).

32. Amini, M. & Memari, A. M. Comparative review and assessment of various flood retrofit methods for low-rise residential buildings in coastal areas. *Nat. Hazards Rev.* **22**(3), Art. No. 04021009; 10.1061/(ASCE)NH.1527-6996.0000464 (2021).

33. Moselle, B. 2019 National Building Cost Manual. Craftsman Book Company. https://www.craftsman-book.com/media/static/previews/2019_NBC_book_preview.pdf (2019).

34. Brotman, B. A. Insurance losses caused by residential housing flood events. *Int. J. Hous. Mark. Anal.* **15**(2), 277–289 (2022).

35. Davids, P. R. & Thaler, T. Flood-resilient communities: How we can encourage adaptive behaviour through smart tools in public-private interaction. *Urban Plan.* **6**(3), 272–282 (2021); 10.17645/up.v6i3.4246

36. Rufat, S. et al. Swimming alone? Why linking flood risk perception and behavior requires more than "it's the individual, stupid." WIREs-WATER **7**(5), e1462; 10.1002/wat2.1462 (2020).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementaldoc.docx