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Freeboard Life-Cycle Benefit-Cost Analysis of a Rental Single-family Residence for Landlord, Tenant, and Insurer

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Abstract

Flood risk to single-family rental housing remains poorly understood, leaving a large and increasing population underinformed to protect themselves, including regarding insurance. This research introduces a life-cycle benefit-cost analysis for the landlord, tenant, and insurer (i.e., National Flood Insurance Program (NFIP)) to optimize freeboard (i.e., additional first-floor height above the base flood elevation (BFE)) selection for a rental single-family home. Flood insurance premium; apportioned flood risk among the landlord, tenant, and NFIP by insurance coverage and deductible; rental loss; moving and displacement costs; freeboard construction cost; and rent increase upon freeboard implementation are considered in estimating net benefit (NB) by freeboard. For a 2,500 square-foot case study home in Metairie, Louisiana, a two-foot freeboard optimizes the combined savings for landlord and tenant, with joint life-cycle NB of $23,658 and $14,978, for a 3% and 7% real discount rate, respectively. Any freeboard up to 2.5 feet benefits the tenant and NFIP, while the landlord benefits for freeboards up to 4.0 feet. Collectively, results suggest that at the time of construction, even minimal freeboard provides substantial savings for the landlord, tenant, and NFIP. The research provides actionable information, supporting the decision-making process for landlords, tenants, and others, thereby enhancing investment and occupation decisions.

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1. Introduction

Floods are among the most commonly occurring and costliest natural disasters (Witt et al., 2015; Wang & Sebastian, 2021). The impact of flooding on single-family rental homes is important to understand, because of the large and increasing share of rentals within the housing industry in the U.S.A. (Charles, 2020), with 14.9 million renter-occupied, single-family homes as of 2017 (Rosen, 2018), and many millions of homes in multi-family buildings. Moreover, many of the inhabitants of rental homes are among the most vulnerable to economic and social impacts from flood (Pelling, 1997, 1999; Masozera et al., 2007; Mee et al., 2014; Deria et al., 2020; Larson et al., 2021). Thus, understanding the true risk of flooding, the possible mitigation measures, and the economic implications of flooding in renter-occupied single-family homes is likely to influence investment choices and occupation decisions (Warren-Myers et al., 2018).

Yet, flood risk to single-family rental housing has been largely neglected by the scientific community. Federal Emergency Management Agency (FEMA) has acknowledged that the nation's flood policies neglect rental housing and focus only on owner-occupied housing (Hamideh et al., 2018). While the FEMA (2013) Hazus-MH tool and FEMA (2009) BCA Reference Guide provide useful benefit-cost analyses (BCA), they consider losses to landlords only instead of disaggregating losses among the affected parties – landlords, tenants, and the (U.S.) National Flood Insurance Program (NFIP; FEMA, 2019). The dearth of studies conducted on rental housing leaves a large segment of the population without adequate information to protect them, with landlords and tenants unaware of their flood risk (Hollar, 2017) even as they invest substantial sums (Warren-Myers et al., 2018). This necessitates development of a comprehensive flood risk assessment that quantifies flood losses for single-family rentals and provides actionable information to landlords, tenants, and insurers.

In this research, life-cycle BCA (LCBCA) is conducted separately from the perspective of the landlord, tenant, and insurer (i.e., NFIP), over the home's 30-year mortgage period, for comprehensive evaluation of the most economically advantageous option at the time of construction regarding implementation of freeboard – elevation above the base flood elevation (BFE) – with multiple scenarios evaluated. The expected benefits and costs over the useful life of the home for each freeboard height are estimated and discounted to the present value (DPV). In these calculations, net benefit (NB) is the difference between the life-cycle benefits and costs for each freeboard scenario compared to "at BFE, no action" scenario. The optimal scenario is the freeboard with the largest joint life-cycle NB for landlord and tenant. The NB-to-cost ratio (NBCR) is defined as NB divided by the cost of the freeboard. The optimal freeboard scenario is the one that maximizes NBCR when NB is similar for multiple freeboard scenarios.

For the landlord, the NB and NBCR of implementing freeboard is evaluated through LCBCA considering freeboard cost, increase in rent, building flood insurance premiums, building average annual loss (AAL), and loss of rental income when the rental unit is withdrawn from the market. For the tenant, the benefit-cost of freeboard is evaluated through consideration of content AAL, content flood premiums, displacement cost, moving cost, and increase in rent. Additionally, the LCBCA is calculated separately for the flood insurance policyholder and the NFIP, as the policyholder is liable for the deductible and loss above coverage of flood loss while the NFIP covers the remainder of the loss within coverage.

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Here, LCBCA is conducted on a micro-scale (i.e., single-building-level) basis, which allows for a greater level of detail than in bulk calculations (Bubeck et al., 2011; Lorente, 2019). A one-story, single-family residence in Metairie, Louisiana, is used to demonstrate the method presented. The study is motivated by the need to establish a methodology for estimating freeboard LCBCA for the landlord, the tenant, and NFIP. The methodology delivers actionable information and supports the decision-making process.

2. Methodology

The methodology consists of estimating the freeboard life-cycle benefit-cost for the landlord, tenant, and insurer determined through LCBCA, performed for each 0.5-foot increment of freeboard above the BFE up to 4.0 feet, evaluated over a 30-year period – the expected useful life of a mitigation project (FEMA, 2009).

It is assumed here that as the flood risk will decrease with increasing freeboard, the landlord will increase the rent of the home and the tenant will accept the rent increase. Table 1 summarizes the benefits and costs from the perspectives of the landlord, tenant, and NFIP. For landlords, the benefit of freeboard is the decrease in the building insurance premium, landlord portion of the building's AAL, and rental income loss, and increased in the rental income. The cost to the landlord is the freeboard construction cost (C_{U_I}). For tenants, the benefit of freeboard is the decrease in the content insurance premium, portion of content AAL, displacement cost, and moving cost. The tenant cost is the increase in rent. For the NFIP, the benefit of freeboard is the decrease in the NFIP portion of the building and content AAL. The cost to the NFIP is the decrease in building and content insurance premium.

Table 1. Costs and benefits to the landlord, tenant, and NFIP.

Entity	Benefits	Costs
Landlord	Decrease in building premium, building AAL, and rental loss and increase in rent	Freeboard construction cost
Tenant	Decrease in content premium, content AAL, displacement, and moving cost	Increase in rent
Insurer (i.e., NFIP)	Decrease in building and content AAL	Decrease in building and content premium

The methodology consists of the following steps: (i) determining the expected benefits and costs at BFE vs. the benefits and costs of each freeboard scenario for the landlord, tenant, and NFIP, considered separately; with all benefits and costs estimated on an annualized basis; (ii) conducting LCBCA.

2.1 Freeboard Benefits

Benefits of freeboard are generally defined here as the future costs prevented or reduced and future income increased by implementing freeboard at the time of construction. These are

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determined by comparing the DPV of all costs and income over the useful life of the building with vs. without freeboard.

2.1.1 Landlord Freeboard Benefits

<u>Building Flood Insurance Premiums</u>

For buildings with federally-backed loans located in a special flood hazard area (SFHA), the landlord is required to have flood insurance on the building only, but not the contents (Federal Deposit Insurance Corporation (FDIC), 2016). The annual building insurance premium (P_b) for each freeboard increment (I) is calculated using the NFIP (2021) Flood Insurance Manual's post-FIRM (i.e., flood insurance rate map) rates for a single-family residence. For single-family homes, $60,000 is the basic building coverage, with a limit of $250,000 and a minimum deductible of $1,250 is required for coverage above $100,000 (NFIP, 2021).

<u>Building AAL</u>

The building AAL (AAL_b) is estimated using the method presented in Gnan (2021) and Gnan et al. (2022a). Flood depths derived from Monte Carlo simulations (e.g., Brodie, 2013; Hennequin et al., 2018; Kind, 2014; Kind et al., 2020; Qi et al., 2013; Rahim et al., 2021, 2022a; Rahman et al., 2002; Taghinezhad et al., 2020; Yu et al., 2013) with the fitted Gumbel extreme value distribution (e.g., Al Assi et al., 2022; Bhat et al., 2019; Gnan et al., 2022b; Kim & Lee, 2021; Manfreda et al., 2021; Mostafiz et al., 2021a; 2022a; 2022b; Rahim et al., 2022b; Singh et al., 2018) are translated to building loss percentages using the U.S. Army Corps of Engineers (USACE; 2000) depth-damage function (DDF) designed for the home's attributes (e.g., one-story or two-or-more stories, with or without basement). The loss percentages are then multiplied by the structure replacement cost (i.e., building value, BV), and the average of the resulting losses of all Monte Carlo-simulated flooding events is the AAL.

While the USACE DDFs assign losses to the structure below the first-floor elevation (FFE) i.e., at negative flood depths – below the building's first floor), it is assumed that when flood depths are below the FFE, the tenant will not relocate and there is no loss of rental income. However, losses are assumed to occur and are estimated for flood depths at –1 feet and greater.

The flood premium deductible for a building is represented within the flood loss, as the policyholder is liable for the specified deductible and loss above coverage while NFIP covers the remaining balance within coverage. Thus, the building AAL is apportioned as either landlord loss (AAL_{b_L}) or NFIP loss ($AAL_{b_{NFIP}}$) using the methodology presented in Gnan (2021) and Gnan et al. (2022a).

<u>Loss of Rental Income</u>

The magnitude of rental loss (R_l) is a function of restoration time (S_t), the latter of which is derived from the FEMA (2013) depth-time (in months) function (Supplementary Table 1). To estimate R_l, flood depths derived from Monte Carlo simulations are used to estimate S_t for each simulated event (S_{t_i}), which is divided by 12 months per year. Next, BV is divided by the price to rent ratio (R_R, U.S. Census Bureau, 2019) to calculate the annual rent (AR) of the home. The

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AR is multiplied by the annual restoration time to derive the R_l for each simulation (R_{l_i}). The average of the resulting R_{l_i} of all simulated flooding events is the annual R_l, such that

$$R_l = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{S_{t_i}}{12} \times \frac{BV}{R_R}\right) \quad (1)$$

where i is the Monte-Carlo-simulated event among N total events.

<u>Increase in Rental Income</u>

The increase in rental income to the landlord (RI) is attributed to implementation of freeboard, which reduces the impact of flood loss and makes the rental more attractive to renters. For a risk-neutral decision, the rental rate of a home with flood risk should be lower than the reduced risk alternative. This is calculated by subtracting the AR of the home for the BFE and freeboard scenario I (Equation 2). The BV for each freeboard scenario (BV_I) equals the BV at BFE (BV_{BFE}) plus the freeboard construction cost (C_{U_I}; Equation 3), which is described in Section 2.2.1.

$$RI_I = \frac{BV_I}{R_R} - \frac{BV_{BFE}}{R_R} \quad (2)$$

$$BV_I = BV_{BFE} + C_{U_I} \quad (3)$$

<u>Landlord Freeboard Benefit Calculation</u>

The annual landlord benefit for each freeboard scenario (L_{B_I}) is estimated as the difference between the sum of the building insurance premium (P_b), building AAL for the landlord (AAL_{b_L}), and loss of rental income (R_l), for the BFE scenario and freeboard scenario I; plus the RI_I (Equation 4).

$$L_{B_I} = [(P_{b_{BFE}} + AAL_{b_{L_{BFE}}} + R_{l_{BFE}}) - (P_{b_I} + AAL_{b_{L_I}} + R_{l_I})] + RI_I \quad (4)$$

2.1.2 Tenant Freeboard Benefits

For the tenant, the benefit of freeboard is evaluated through consideration of content flood insurance premiums, content AAL, and displacement and moving costs, for the BFE and freeboard scenarios. Although it is unlikely that the tenant will relocate when flood depths are below FFE, any greater depth is likely to cause the tenant to be displaced. Tenants bear displacement costs due to flood damage to the residence (Arcadis, 2019). However, the tenant likely will cease rent payment to the landlord and instead seek another rental (Arcadis, 2017). Displacement and moving costs are considered in addition to the content loss and content insurance premium.

<u>Content Flood Insurance Premiums</u>

In this study, tenants are assumed to have a separate content-only flood policy, because standard renters' insurance generally does not cover flood loss (NFIP, 2021) and tenants are responsible

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for any flood loss to their personal belongings (FDIC, 2016). Annual content insurance premiums (P_c) are calculated using the NFIP (2021) Flood Insurance Manual's post-FIRM rates for a single-family residence. For single-family homes, \$25,000 is the basic content coverage, with a limit of \$100,000. A minimum deductible of \$1,000 is required for coverage of \$100,000 or less (NFIP, 2021). NFIP (2021) covers the actual cash value (ACV) of contents, which is the replacement cost minus the depreciation value at the time of loss. On average, ACV is half of the replacement cost over the contents' useful life, assuming here a linear depreciation and replacement of the contents after their useful life expires (Supplementary Table 3).

<u>Content AAL</u>

Average annual content loss (AAL_c) is estimated using the method presented in Gnan (2021) and Gnan et al. (2022a; 2022b). To estimate AAL_c, depths derived from Monte Carlo simulations are translated to content loss percentages using the appropriate USACE (2000) DDF, with the estimate then partitioned between the tenant (AAL_{c_T}) and NFIP ($AAL_{c_{NFIP}}$) for each simulation (Gnan, 2021; Gnan et al., 2022a). The loss percentages are then multiplied by BV, and the average of all the simulated events is the AAL_c.

<u>Displacement Cost</u>

Tenants victimized by flood damage to their residence will be displaced temporarily and seek a shelter until finding another place to live. While some tenants may use public shelters or reside with families or friends, others will resort to lodging. This study considers only lodging in the loss assessment.

Berger (2017) assumed the displacement cost to be linearly proportional to the flooded residence's rental cost, where the displacement cost is estimated also as a one-time (one month) cost on the basis of square-footage of the damaged residence. The displacement cost in this study is estimated as a one-time cost equivalent to one month – the minimum time required to find another place (Chaplin, 2019) – based on lodging rate, which is more reflective of variable lodging costs than the cost based on the residence's square footage (FEMA, 2016). This study uses the U.S. General Service Administration (2021) current lodging per day rates for each state with a current national average of \$140 per day. This value for a given simulated event (D_{d_i}) is converted to a monthly rate to estimate the one-time displacement cost for each simulated event. The average of the resulting displacement cost of all simulated flooding events is the expected annual displacement cost (D_c; Equation 5), such that

$$D_c = \frac{1}{N}\sum_{i=1}^{N}(D_{d_i} \times 30) \quad (5)$$

<u>Moving Cost</u>

Moving cost is associated with relocating the contents from the flooded residence. It is estimated based on the square footage of the flooded residence. A moving cost of \$1.20 per-square-foot (Arkin, 2021) is used in this study. The moving cost-per-square-foot (M_{cq_i}) is multiplied by the building's total square footage (B_q) to estimate the moving cost for each simulated event. The average of the resulting moving costs of all simulated flooding events is the annual moving cost (M_c; Equation 6), or

$$M_c = \frac{1}{N}\sum_{i=1}^{N}(M_{cq_i} \times B_q) \tag{6}$$

Tenant Freeboard Benefit Calculation

The annual tenant benefit for each freeboard scenario (T_{B_I}; Equation 7) is the difference between the sum of the content annual insurance premium (P_c), the tenant's share of the content AAL (AAL_{c_T}– 100 percent of the AAL_c if the tenant does not have insurance), annual expected displacement cost (D_C), and annual expected moving cost (M_C), for the BFE and freeboard scenarios.

$$T_{B_I} = (P_{c_{BFE}} + AAL_{c_{T_{BFE}}} + D_{c_{BFE}} + M_{c_{BFE}}) - (P_{c_I} + AAL_{c_{T_I}} + D_{c_I} + M_{c_I}) \tag{7}$$

2.1.3 NFIP Freeboard Benefit

NFIP benefit for each freeboard scenario ($NFIP_{B_I}$; Equation 8) is calculated as the difference in the NFIP portion of AAL for building ($AAL_{b_{NFIP}}$) and content ($AAL_{c_{NFIP}}$), for the BFE and freeboard scenarios.

$$NFIP_{B_I} = (AAL_{b_{NFIP_{BFE}}} + AAL_{c_{NFIP_{BFE}}}) - - (AAL_{b_{NFIP_I}} + AAL_{c_{NFIP_I}}) \tag{8}$$

2.2 Freeboard Costs

2.2.1 Landlord Freeboard Costs

The landlord cost for freeboard is estimated as a percentage of BV and is based on FEMA (2008) guidance for new, single-family residences. While FEMA (2008) reports the cost for each freeboard increment (I) as a range of percentage estimates of total building cost, this work applies the upper limit as a conservative measure (Supplementary Table 2). Landlord annual freeboard cost (L_{C_I}) and total upfront freeboard cost (C_{U_I}) are calculated using the methodology presented in Gnan (2021) and Gnan et al. (2022a).

2.2.2 Tenant Freeboard Costs

Tenant freeboard cost (T_C) is calculated based on the difference between the tenant rent for freeboard scenario (T_{R_I}) and the BFE scenario ($T_{R_{BFE}}$; Equation 9). The landlord rental income and tenant rent will increase with the increasing freeboard.

$$T_{C_I} = T_{R_I} - T_{R_{BFE}} \tag{9}$$

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2.2.3 NFIP Freeboard Costs

NFIP freeboard cost ($NFIP_C$) is calculated based on the difference between the insurance premiums (building (P_b) and content (P_c)) at BFE and in freeboard scenario I (Equation 10). The NFIP insurance premium will decrease with increasing freeboard.

$$NFIP_{C_I} = \left(P_{b_{BFE}} + P_{c_{BFE}}\right) - \left(P_{b_I} + P_{c_I}\right) \quad (10)$$

2.3 Life-cycle Benefit-Cost Analysis (LCBCA)

To determine whether incorporating freeboard results in life-cycle benefit, all annualized benefits and costs are discounted to the present value (DPV), thus enabling the comparison of mitigation costs with the expected future benefits (Tate et al., 2016) by transforming the expected future costs and benefits to present-value terms (Frank, 2000). LCBCA is performed through consideration of NB and NBCR. The scenario with largest positive life-cycle NB is the optimal option. In contrast, NBCR expresses the life-cycle cost effectiveness of the mitigation scenario by showing the ratio between NB and cost.

2.3.1 Discounted Present Value (DPV)

The DPV of generalized benefits (B_{DPV}; Equation 11) or costs (C_{DPV}; Equation 12) is the discounted annualized benefits (B_t) or costs (C_t) using a discount rate (R_D) over a time horizon in years (t), or

$$B_{DPV} = \sum_{t=1}^{T} \frac{B_t}{(1+R_D)^t} \quad (11)$$

$$C_{DPV} = \sum_{t=1}^{T} \frac{C_t}{(1+R_D)^t} \quad (12)$$

A sensitivity analysis is conducted to contrast results that assume a 7% real discount rate with those generated assuming a 3% real discount rate. This approach is consistent with the requirements of the U.S. Office of Management and Budget (1992) for BCA analyses.

2.3.2 Net Benefit (NB)

The NB to the landlord (L_{NB}), tenant (T_{NB}), and NFIP ($NFIP_{NB}$) of including freeboard is the difference between the benefit to the landlord (L_B), tenant (T_B), and NFIP ($NFIP_B$) and cost to the landlord (L_C), tenant (T_C), and NFIP ($NFIP_C$), for each freeboard scenario I (Equation 13-15).

$$L_{NB_I} = L_{B_I} - L_{C_I} \quad (13)$$

$$T_{NB_I} = T_{B_I} - T_{C_I} \quad (14)$$

$$NFIP_{NB_I} = NFIP_{B_I} - NFIP_{C_I} \quad (15)$$

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2.3.3 Net Benefit to Cost Ratio (NBCR)

The life-cycle cost effectiveness of the freeboard (i.e., benefit per dollar spent) is expressed by NBCR to the landlord (L_{NBCR}), tenant (T_{NBCR}), and NFIP ($NFIP_{NBCR}$), which is the total NB of a freeboard scenario divided by its total cost (Equation 16-18).

$$L_{NBCR_I} = \frac{L_{NB_I}}{L_{C_I}} \quad (16)$$

$$T_{NBCR_I} = \frac{T_{NB_I}}{T_{C_I}} \quad (17)$$

$$NFIP_{NBCR_I} = \frac{NFIP_{NB_I}}{NFIP_{C_I}} \quad (18)$$

3. Case Study

A one-story, single-family residence with 2,500 ft^2 of living area within the AE flood zone, located in Metairie, Louisiana, at coordinates 29°5'39"N, 90°1'05"W, is used to demonstrate the presented methodology. The ground elevation of the site is –7.0 feet (NAVD88), with –4 feet BFE (NAVD88). Using the area's average construction cost of $92.47 per square foot (Moselle, 2019), the total estimated construction cost is $231,175. The site's flood elevations are determined from FEMA's Risk Mapping, Assessment and Planning (Risk MAP) project (FEMA, 2022), and the corresponding flood depths above ground are shown in Table 2.

Table 2. Case Study Site Flood Elevations and Corresponding Depth Above Ground.

Annual Probability of Exceedance	Flood Elevation (NAVD88)	Flood Depth (feet)
0.002	–3.4	3.6
0.01	–3.9	3.1
0.02	–4.2	2.8
0.1	–4.7	2.3

4. Results and Discussion

Results are presented in two steps: (i) annual benefits and costs for landlord, tenant, and NFIP are calculated, with all annual estimates discounted to the PV for the life cycle of the building; (ii) the LCBCA is conducted, where NBs and NBCRs are obtained for multiple freeboard scenarios and real discount rates, with NB and NBCR also apportioned between landlord, tenant, and NFIP. LCBCA of freeboard insurance savings is performed separately.

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4.1 Expected Freeboard Benefit

The difference in life-cycle benefits and costs with vs. without adding freeboard is the freeboard benefit. LCBCA is conducted for the landlord, tenant, and NFIP.

4.1.1 Landlord Freeboard Benefit

The landlord total annual benefit ranges from 0 (at BFE+0 ft. of freeboard) to $2,310 (at BFE+4.0 ft. of freeboard); benefit increases with increasing freeboard (Table 3). The landlord total annual benefits shown in Table 3 must be compared against the costs to identify the NB. The cost for each freeboard increment is estimated based on a total construction cost of $231,175 paid over a 30-year mortgage with fixed rate of 3.375%, and 7% payment-related fees. The corresponding annual flood insurance building premiums are calculated based on maximum BV of $231,175, with the minimum deductible of $1,250 and Community Rating System (CRS; NFIP, 2020) discount of 25% (rating of 5). The building AAL is apportioned as landlord and NFIP AAL.

Table 3. Landlord's Expected Total Annual Benefits by Freeboard Height.

Freeboard (feet)	Building Annual Insurance Premium Decrease	Building AAL Decrease	Annual Rental Loss Decrease	Annual Rent Increase	Total Annual Benefit
0.0	$0	$0	$0	$0	$0
0.5	$0	$35	$56	$120	$211
1.0	$773	$48	$74	$241	$1,136
1.5	$773	$55	$85	$356	$1,269
2.0	$1,078	$58	$88	$471	$1,695
2.5	$1,078	$60	$90	$591	$1,819
3.0	$1,185	$60	$90	$712	$2,047
3.5	$1,185	$61	$91	$832	$2,169
4.0	$1,205	$61	$91	$953	$2,310

As shown in Table 4, annual losses (i.e., landlord building AAL and rental loss) are reduced with each additional freeboard increment. The landlord annual building insurance premium decreases with one foot of freeboard (Table 4). Annual rent increases with freeboard increment (Table 4) as freeboard reduces flood risk and carries extra cost. Greater avoided losses occur with smaller freeboard because the largest proportion of losses occurs at lesser flood depths. Loss of rental income is based on the time required to restore the building and increases with the severity of the expected damage. However, it is limited to flood depths above the FFE.

Table 4. Landlord's Expected Annual Costs and Income by Freeboard Height.

Freeboard (feet)	Freeboard Cost (Loan/Annual)	Building Annual Insurance Premium	Building AAL	Landlord Building AAL	Annual Rental Loss	Annual Rent

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0.0	$0	$1,788	$1,090	$61	$91	$10,475
0.5	$158	$1,788	$443	$26	$35	$10,595
1.0	$316	$1,015	$226	$13	$17	$10,716
1.5	$467	$1,015	$95	$6	$6	$10,831
2.0	$619	$710	$44	$3	$3	$10,946
2.5	$777	$710	$21	$1	$1	$11,066
3.0	$935	$603	$13	$1	$1	$11,187
3.5	$1,093	$603	$4	$0	$0	$11,307
4.0	$1,251	$583	$2	$0	$0	$11,428

4.1.2 Tenant Freeboard Benefits

For the tenant, the annual content premiums are calculated based on a maximum content value of $100,000, with the minimum deductible of $1,250 and CRS discount of 25%. The content AAL is apportioned between the tenant and the NFIP. Displacement cost is estimated as a one-time, one-month cost, assuming a conservative one-room estimate with a two-member household. The tenant total benefit ranges from 0 (at BFE+0 ft. of freeboard) to $621 (at BFE+4.0 ft. of freeboard); benefit increases with increasing freeboard (Table 5). The tenant benefit is always lower than the landlord’s benefit, except for the 0.5 ft. freeboard scenario (Table 3 and 5). On an average, the tenant benefit is 35% of the landlord benefit.

Table 5. Tenant Total Annual Benefits for Each Freeboard Scenario.

Freeboard (feet)	Content Annual Insurance Premium Decrease	Tenant Content AAL Decrease	Annual Displacement Cost Decrease	Annual Moving Cost Decrease	Total Annual Benefits
0.0	$0	$0	$0	$0	$0
0.5	$0	$236	$28	$20	$284
1.0	$107	$317	$37	$27	$488
1.5	$107	$365	$43	$31	$546
2.0	$142	$384	$44	$32	$602
2.5	$142	$393	$45	$33	$613
3.0	$142	$397	$45	$33	$617
3.5	$142	$399	$46	$33	$620
4.0	$142	$400	$46	$33	$621

Tenant annual losses (i.e., content AAL, displacement and moving cost) are reduced with each additional freeboard increment (Table 6) and are relatively smaller than those for the landlord (Table 4 and 6). Content AAL is almost eliminated at the second foot of freeboard and displacement cost and moving cost are almost eliminated with the first foot of freeboard (Table 6). The content annual insurance premium decreases only with 1.0 and 2.0 ft. of freeboard and it remains constant after 2.0 ft. of freeboard (Table 6). Tenant’s annual rent increases with increase of freeboard (Table 6) as it reduces the flood risk and carries additional cost.

Table 6. Tenant Annual Costs for Each Freeboard Height Scenario.

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Freeboard (feet)	Content Annual Insurance Premium	Content AAL	Tenant Content AAL	Annual Displacement Cost	Annual Moving Cost	Annual Rent
0.0	$356	$680	$401	$46	$33	$10,475
0.5	$356	$278	$165	$18	$13	$10,595
1.0	$249	$142	$84	$9	$6	$10,716
1.5	$249	$60	$36	$3	$2	$10,831
2.0	$214	$28	$17	$2	$1	$10,946
2.5	$214	$13	$8	$1	$0	$11,066
3.0	$214	$7	$4	$1	$0	$11,187
3.5	$214	$3	$2	$0	$0	$11,307
4.0	$214	$1	$1	$0	$0	$11,428

4.1.3 NFIP Freeboard Benefits

NFIP's expected annual benefits (i.e., aggregated NFIP's building and content annual benefits from flood loss reduction) is increases with freeboard increment (Table 7). Although results show that incorporating freeboard yields substantial benefits to landlord, tenant, and NFIP, it is evident that the losses are primarily borne by the NFIP.

Table 7. NFIP Total Annual Benefits for Each Freeboard Scenario.

Freeboard (feet)	NFIP Building AAL	NFIP Content AAL	NFIP Building AAL Decrease	NFIP Content AAL Decrease	Total Annual Benefits
0.0	$1,029	$279	$0	$0	$0
0.5	$417	$113	$612	$166	$778
1.0	$213	$58	$816	$221	$1,037
1.5	$89	$24	$940	$255	$1,195
2.0	$41	$11	$988	$268	$1,256
2.5	$20	$5	$1,009	$274	$1,283
3.0	$12	$3	$1,017	$276	$1,293
3.5	$4	$1	$1,025	$278	$1,303
4.0	$2	$1	$1,027	$278	$1,305

4.2 Expected Freeboard Cost for Landlord, Tenant, and NFIP

While landlord and tenant annual freeboard costs increase with each increment of freeboard, the NFIP annual freeboard cost increases only with each additional one-foot increment above BFE (Table 8). This is because there are no premium savings for half-foot increments (NFIP, 2021).

Table 8. Expected Annual Freeboard Cost for Landlord, Tenant, and NFIP.

Freeboard (ft.)	Landlord Freeboard Cost	Tenant Annual Rent	Tenant Freeboard Cost	Total NFIP Annual Premium	NFIP Freeboard Cost

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0.0	$0	$10,475	$0	$2,144	$0
0.5	$158	$10,595	$120	$2,144	$0
1.0	$316	$10,716	$241	$1,264	$880
1.5	$467	$10,831	$356	$1,264	$880
2.0	$619	$10,946	$471	$924	$1,220
2.5	$777	$11,066	$591	$924	$1,220
3.0	$935	$11,187	$712	$817	$1,327
3.5	$1,093	$11,307	$832	$817	$1,327
4.0	$1,251	$11,428	$953	$797	$1,347

4.3 Life-cycle Benefit-Cost Analysis (LCBCA)

Once all annual benefit and cost estimates are discounted to the PV for the life of the building, the cumulative DPVs of benefits and cost are calculated for the "at BFE no action" scenario and for each freeboard scenario. The LCBCA calculations are carried out using a baseline 7% real discount rate, with 3% real discount rate also calculated, to test the sensitivity of results. LCBCA results are presented as NB and NBCR for each freeboard scenario using both real discount rates (Table 9).

The landlord life-cycle NBs of freeboard ranging between $658 (0.5 ft. of freeboard) and $13,799 (3.0 ft. of freeboard), with total NBCRs ranging from 0.3 (0.5 ft. of freeboard) to 2.6 (1.0 ft. of freeboard), when assuming the baseline real discount rate of 7%, and between $1,039 (0.5 ft. of freeboard) and $21,796 (3.0 ft. of freeboard), when assuming a 3% real discount rate (Table 9). The NB for landlord, tenant, and NFIP are greatest at 3.0, 1.0, and 0.5 feet of freeboard, respectively (Table 9). Beyond 2.5 feet of freeboard, the tenant experiences negative NB as few or no further reductions are realized in content annual premium, content AAL, displacement, and moving costs. Therefore, annual rent increase outweighs the reductions in this case study, resulting in a negative NB. Likewise, there are no further reductions in NFIP's building and content losses beyond 2.5 feet of freeboard, and estimates depend only on NFIP cost, resulting in a negative NB.

Table 9. LCBCA Results for Each Freeboard Scenario by Stakeholder and Real Discount Rate, with Optimal Freeboard Shown in Boldface.

Freeboard (ft.)	First-Floor Elevation (ft.)		Landlord		Tenant		(Landlord + Tenant)		NFIP	
			3%	7%	3%	7%	3%	7%	3%	7%
0.5	–3.5	NB	$1,039	$658	$3,214	$2,035	$4,253	$2,693	**$15,249**	**$9,654**
		NBCR	0.3	0.3	1.4	1.4	0.8	0.8	–	–
1.0	–3.0	NB	$16,072	$10,175	**$4,841**	**$3,065**	$20,914	$13,240	$3,077	$1,948
		NBCR	2.6	2.6	1.0	1.0	0.7	0.7	0.2	0.2
1.5	–2.5	NB	$15,720	$9,952	$3,724	$2,358	$19,444	$12,310	$6,174	$3,909
		NBCR	1.7	1.7	0.5	0.5	0.6	0.6	0.4	0.4
2.0	–2.0	NB	$21,090	$13,352	$2,568	$1,626	**$23,658**	**$14,978**	$706	$447
		NBCR	1.7	1.7	0.3	0.3	0.5	0.5	0.0	0.0
2.5	–1.5	NB	$20,424	$12,930	$431	$273	$20,855	$13,203	$1,235	$782
		NBCR	1.3	1.3	0.0	0.0	0.4	0.4	0.1	0.1
3.0	–1.0	NB	**$21,796**	**$13,799**	($1,862)	($1,179)	$19,934	$12,620	($666)	($422)

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		NBCR	1.2	1.2	–0.1	–0.1	0.3	0.3	0.0	0.0
3.5	–0.5	NB	$21,090	$13,352	($4,155)	($2,631)	$16,935	$10,721	($470)	($298)
		NBCR	1.0	1.0	–0.3	–0.3	0.3	0.3	0.0	0.0
4.0	0.0	NB	$20,757	$13,141	($6,507)	($4,120)	$14,250	$9,021	($823)	($521)
		NBCR	0.8	0.8	–0.3	–0.3	0.2	0.2	0.0	0.0

All freeboard scenarios outperform the "at BFE no action scenario." The landlord and tenant combined/joint life-cycle NBs of freeboard ranges between $2,693 (for 0.5 feet) and $14,978 (for 2.0 feet), with total NBCRs ranging from 0.2 (at 4.0 feet) to 0.8 (at 0.5 feet), when assuming the baseline real discount rate of 7%, and between $4,253 (for 0.5 feet) and $23,658 (for 2.0 feet), when assuming a 3% real discount rate. The peak NB for landlord and tenant combined/joint at 2.0 feet of freeboard indicates that the economically optimal freeboard is 2.0 feet. The NB is $14,978 when applying a 7% real discount rate, and $23,658 when assuming a real discount rate of 3%. However, at that increment, total life-cycle NBCR is 0.5 at either real discount rate, so this freeboard scenario is less preferred than the 0.5- and 1.0-foot scenarios when considering the NBCR metric (Table 9). The largest NBCR is observed in the smallest freeboard scenario and then shows an incremental decrease, indicating that benefit per dollar of cost declines as FFE increases, likely because the largest share of flood losses occurs for lower FFEs.

Even if the other benefits are neglected, the savings in annual flood insurance premiums alone are sufficient to offset the freeboard construction cost. Except for the first half-foot increment for which no premiums savings are realized, the life-cycle NB from flood premium savings ranges between $10,920 and $16,715, with NBCRs ranging from 1.1 to 2.8 when assuming a 7% real discount rate, and from $17,248 to $26,402 when using a 3% real discount rate (Table 10).

Table 10. Flood Insurance Premium LCBCA Results for Each Freeboard Scenario by Real Discount Rate.

Freeboard (feet)		3%	7%
0.5	NB	$0	$0
	NBCR	0	0
1.0	NB	$17,248	$10,920
	NBCR	2.8	2.8
1.5	NB	$17,248	$10,920
	NBCR	1.9	1.9
2.0	NB	$23,913	$15,139
	NBCR	2.0	2.0
2.5	NB	$23,913	$15,139
	NBCR	1.6	1.6
3.0	NB	$26,010	$16,467
	NBCR	1.4	1.4
3.5	NB	$26,010	$16,467
	NBCR	1.2	1.2
4.0	NB	$26,402	$16,715
	NBCR	1.1	1.1

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5. Summary and Conclusion

With no comprehensive flood risk assessment that quantifies flood losses and provides actionable information (Mostafiz et al., 2022c), landlords and tenants are unlikely to be aware of flood risk to which they are exposed and the possible benefits from mitigation measures. Being aware of the full flood risk, mitigation options, and economic implications enhances investment and occupation decisions. For a risk-neutral decision, the rental rate of a home with flood risk should be lower than of the risk-free alternative by an amount equal to the expected flood losses (Moser, 1985). For a risk-averse decision, the rental rate of a home with flood risk should be less than the risk-free alternative by an amount greater than the expected flood losses, as it includes the assessed risk premium to compensate for bearing the risk (Moser, 1985).

In this study, an LCBCA methodology is demonstrated to determine the life-cycle benefits of adding freeboard for landlord, tenant, and NFIP in single-family rental housing. The aim is to support the decision-making process by providing actionable information. In the case study home in Metairie, Louisiana, this study found:

- The landlord and tenant combined/joint life-cycle NB is $14,978 with NBCR of 0.5, assuming the baseline real discount rate of 7%, and $23,658, assuming a 3% real discount rate.
- Elevation to the optimal height of 2.0 feet reduces annual building premiums by 60% and annual content premiums by 40%.
- In addition to savings on insurance premiums, landlords and tenants would also enjoy benefits by reducing direct physical loss and the other losses due to loss of function.
- Elevating a home to the optimal height significantly reduces annual building and rental losses for landlord and tenant annual content, displacement, and moving losses.

In addition to the previously discussed benefits including increase in rental income, the landlord will experience other benefits from avoiding or reducing flood losses. Increased flood risk to the rental house can result in a loss of demand, increased vacancy, and decreased property value due to the expected risk cost liabilities associated with owning or occupying such a property (Warren-Myers et al., 2018). Similarly, tenants experience indirect benefits from the added level of safety and loss reduction, avoiding temporary relocation. Forced displacement on short notice causes insecurity and stress, both emotionally and physically (Hollar, 2017). Moreover, tenants may not be able to relocate within their immediate area, removing individuals and families from their communities (Hollar, 2017).

Several assumptions have been made in this analysis. It is assumed that as soon as the building is restored, it will be rented immediately. Further, although this study is comprehensive in its assessment of the economic impacts of including freeboard on direct losses (building and contents) and indirect losses (rent, displacement cost, and move cost) for the different constituents, the environmental, social, and psychological impacts of enhanced home security, along with increases in future asset values and the potential negative effects of climate change are not considered here. Thus, the estimates likely underrepresent the true benefits of adding freeboard.

These flood loss assessments rely on uncertain variables such as the unpredictable nature of flood and the generality of flood loss and restoration time functions. Furthermore, these types of analyses are strongly constrained by flood data quality and availability (Mostafiz et al., 2021b). LCBCA requires future projections of real discount rates that are also uncertain.

While acknowledging the limitations, the methodology proposed in this study provides a novel framework for quantifying life-cycle benefit of freeboard for single-family rentals through LCBCA. The results highlight the need to evaluate the life-cycle benefits of freeboard at a single-building level, to allow for a more localized and detailed assessment. Extending this method to multi-family rentals and upscaling to estimate community-level will further assist in enhancing resilience to the flood hazard.

6. Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

7. Author Contributions

RBM selected the study area, prepared the base flood data, organized the paper, edited and improved the manuscript. EG developed the methodology, interpreted the findings, and drafted the manuscript. MAR code the method, verified the results, and edited the manuscript. CF conceptualized the research idea, helped refine the methodology, and reviewed and edited the manuscript. RR reviewed and edited earlier versions of the manuscript. AT provided advice and contributed to the literature review. AAS edited the text.

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9. 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.

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