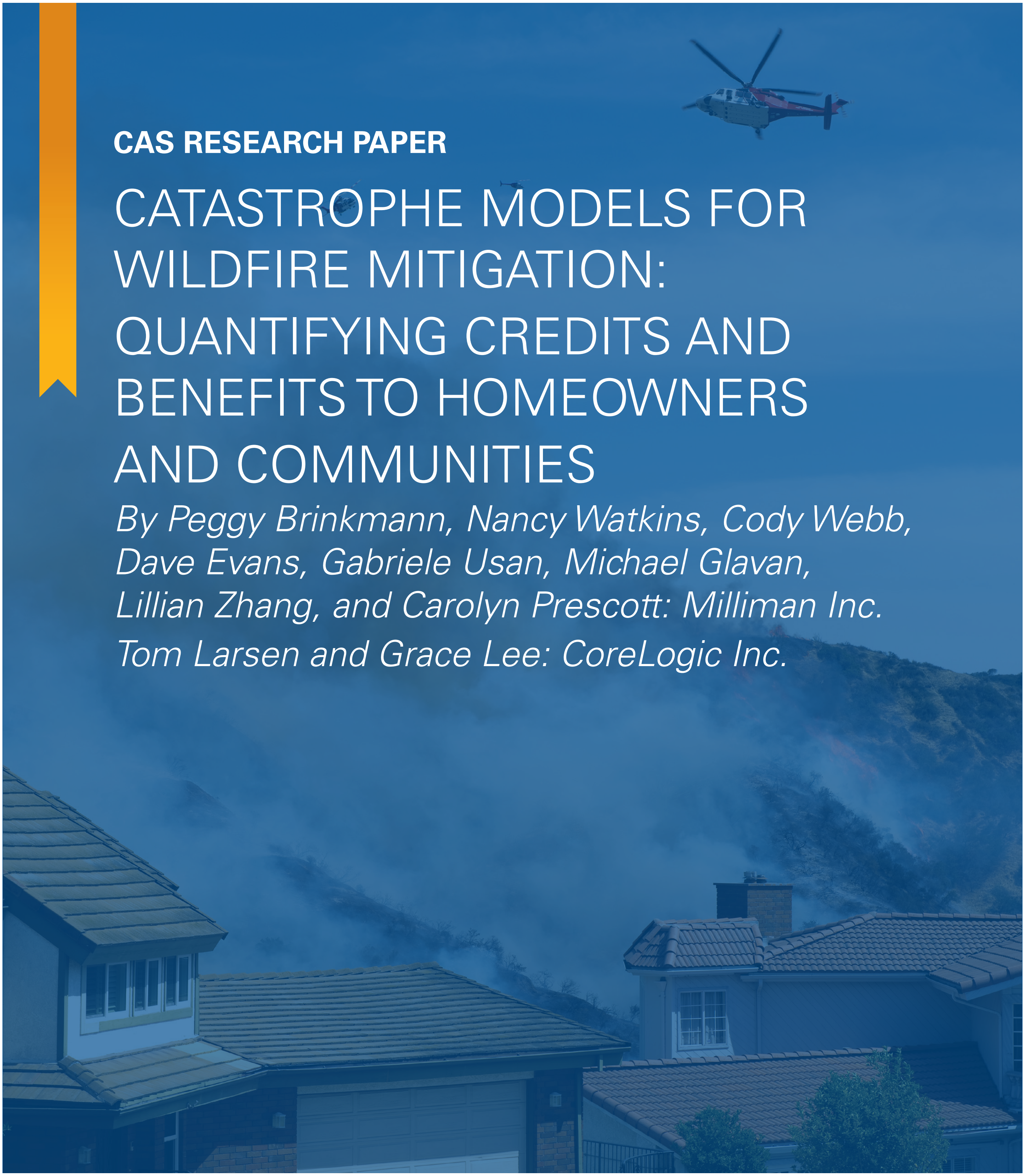

CAS RESEARCH PAPER

CATASTROPHE MODELS FOR WILDFIRE MITIGATION: QUANTIFYING CREDITS AND BENEFITS TO HOMEOWNERS AND COMMUNITIES

By Peggy Brinkmann, Nancy Watkins, Cody Webb, Dave Evans, Gabriele Usan, Michael Glavan, Lillian Zhang, and Carolyn Prescott: Milliman Inc.

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Catastrophe Models for Wildfire Mitigation: Quantifying Credits and Benefits to Homeowners and Communities

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Abstract: Unprecedented costs from wildfires in the American West have spurred a need for wildfire risk reduction in at-risk areas. Communities and homeowners need tools to understand the costs and benefits of various means of wildfire risk mitigation, and insurance rates must be updated to reflect resulting aggregate and relative reductions in risk for properties and communities.

Mitigation credits have long existed in insurance pricing algorithms for hurricanes, but wildfires have only recently become financially significant enough to necessitate action from the insurance industry. Also, wildfires are different from other types of natural catastrophes because there is a material cross-dependency between a risk and its surroundings. Because wildfires spread between properties and adjacent areas, the risk to any property both influences, and is influenced by, the risk of the surrounding community. This cross-dependency creates a complex challenge for individual homeowners, insurers, and communities seeking to quantify the benefits of wildfire mitigation measures.

Catastrophe simulation models have long proven to be powerful tools for insurers and reinsurers, but an opportunity may exist to extend their value to other stakeholders, including communities. Wildfire models are commercially available, but there are unique aspects to wildfire risk and mitigation that should be considered when using them. In particular, measuring the effects of community-level mitigation activities on wildfire risk presents a challenge for modelers, and new approaches need to be developed to extend the models to this purpose, which could also help extend the value of the models beyond insurance applications to areas such as public policy and operational public safety.

This paper illustrates several use cases for catastrophe models to measure the effects of wildfire mitigation on homeowners and communities. Focusing on a specific community in Northern California, it contains three case studies. The first explains how an insurer could use a catastrophe model to set credits for individual homeowner mitigation actions. The second uses a modified catastrophe model to extend the analysis to reflect community-level understory fuel reduction mitigation. The third shows how model results could be used to quantify the benefits of various community-scale mitigation projects under consideration. The paper concludes with a discussion of practical considerations for insurers and communities engaging in this type of analysis.

Keywords: Wildfires, mitigation, catastrophe models, ratemaking, fuel reduction, fire prevention, generalized linear models, catastrophe economics, community resilience, homeowners insurance, California, climate change

Contents

Foreword by Dave Winnacker

Fire is a natural and recurring part of our landscape, and like other forces of nature, we cannot prevent fires from burning. We can, however, learn to live with fire by implementing well-understood and effective defensible space- and home-hardening measures which dramatically reduce the potential for loss of life and property. In my work as a Hoover Institution Veteran Fellow and as a member of the California Fire Chiefs Association WUI Task Force, I have sought to identify opportunities for alignment between the key stakeholders as a necessary precondition to an incentive-based system which encourages adoption of mitigations that matter. This case study outlines a repeatable methodology which can be used to accurately assess a community's exposure to wildfire risk while valuing the various mitigations which have been adopted. Repeatable methodologies also encourage alignment between stakeholders with shared interests; namely, the reduction in wildfire damage.

Well-understood and transparent systems for valuing risk provide a community roadmap to reducing both the probability of wildfire loss and the certainty of insurance rate increases or non-renewals. Having been provided this information, residents are given agency to improve their condition, which can inform grassroots support for fire safety measures at speed and scale far exceeding anything we are capable of accomplishing through enforcement alone. In high and medium density WUI neighborhoods, a structure's exposure to risk is intrinsically linked to the conditions present beyond the property lines, and we must all do our part.

While there will continue to be a place for fire suppression resources, our efforts to remove fire from the landscape through an industrialized response have failed, and it will take an all-hands effort to undo the misguided practices of the past. I encourage the reader to study this case study carefully as it represents an important step forward and provides a framework to value, and thus encourage, community-wide adoption of proven defensible space- and home-hardening mitigations that matter.

—Dave Winnacker
Fire Chief, Moraga-Orinda Fire District, California

Foreword by Frank Frievalt

This case study represents the highwater mark of strategic actuarial analysis applied to parcel- and community-level mitigations against the peril of wildfire. It arrives not a moment too soon as my profession is searching for our next waypoint on the mission to reverse catastrophic life and property loss in the wildland urban interface. The case study is an actuarial attempt at evaluating three approaches toward community-level mitigation risk valuation. Much work will follow, we will know more in a year than we know now, but every inquiry starts with a question, and this seminal case study should appear in the literature review for cascading research in the field.

Ubiquitous mitigation implementation at a western states regional level must occur through property owner compliance. Our combined governance efforts of education, goodwill, code enforcement, climate change policy, and reactive direct-suppression efforts have proven insufficient to blunt growing WUI losses. To these governance efforts we must now add the physical science of evidence-based effective mitigations and the actuarial science of properly priced risk. We (property owners, emergency responders, consumer advocates, insurers, and reinsurers) all have a shared interest in properties and people surviving a wildfire. Aligning ourselves behind this shared interest has revealed powerful opportunities for giving consistent messaging to property owners from all directions, support completion through mitigation-defined grant scopes of work, timely assessments of mitigation implementation/maintenance and sustainable access to insurance.

As important as the actuarial science is, more important has been the collaborative position adopted by the profession. Before 2016, I had never professionally worked with actuaries. Since then, they have become one of my primary resources, and the knowledge from those relationships has made me a better fire chief; I hope our fire service contributions to them will have reciprocal value.

—Frank Frievalt
Former Fire Chief, Mammoth Lakes Fire Protection District, California
California State Director, Western Fire Chiefs Association

1. Executive Summary

Wildfire mitigation is an emerging subject of great importance in the insurance industry and in society as a whole. Over many years, wildfire suppression and changes in the environment and housing stock have all contributed to steady increases in wildfire risk. In recent years, numerous devastating wildfires have made it apparent that the risk is much larger than once thought. Particularly in California, the property insurance market has experienced issues of repricing, dislocation, and lack of availability. This has led to calls for individuals and communities to take significant actions to mitigate the risk of wildfires and for insurers to respond with appropriate premium reductions, or mitigation credits. Additionally, there is a need to consider scientific cost-benefit analyses when evaluating grant funding of wildfire mitigation projects.

To date, the extent of wildfire mitigation credits in the marketplace is limited, and there is considerable uncertainty in estimating the financial benefits of mitigation techniques for homeowners and communities. This report presents a series of case studies to quantify risk reduction from wildfire mitigation actions using a stochastic catastrophe simulation model. We also illustrate how the risk reduction estimates from a catastrophe model can be reflected in insurance premiums via mitigation credits and how they can inform community cost-benefit analyses. Each case study in this report focuses on single-family homeowners in two adjacent communities in the San Francisco Bay Area—the city of Orinda and the town of Moraga. The key findings from these case studies are presented in this executive summary.

The results show that individual mitigation actions related to installing fire-resistant roofs and maintaining defensible space can lead to actuarially indicated homeowners insurance premium discounts and a significant reduction in risk, particularly in high-risk areas. Aggressive community-level mitigation activities around fuel reduction can also substantially reduce risk and increase actuarially indicated insurance premium discounts. In particular, the following results were found.

1. The first case study discusses the most impactful actions homeowners can take to reduce risk: clearing flammable materials from around the house (known as maintaining defensible space) and upgrading roofing to a fire-resistive type. Table 4.3 presents the calculated mitigation credits, ranging between 4% and 95% premium reductions compared to a property without mitigation. These indicate that, in some instances, up to 95% of wildfire risk could be eliminated through individual mitigation actions, potentially making wildfire insurance premiums significantly lower and more affordable.

   For a selected base risk in the highest-risk territory group with estimated building replacement costs of $400,000, the estimated reduction to wildfire average annual losses (AALs) could be as high as $509 if all defensible space recommendations are met within 100 feet of the home and a Class A roof is installed in place of an unrated roof. Assuming a 65% loss ratio and a starting wildfire premium of $870, this would equate to an insurance premium reduction of $783 (or 90% of wildfire premium). These estimates scale directly with the building replacement cost, meaning that if all else is equal, a homeowner who fully insures a home that costs twice as much to replace as the base risk ($800,000) would see premium reductions twice as large ($1,566). Even for homeowners that do not have a fire-resistive roof of any type, meeting all defensible space recommendations could decrease the AAL for a base risk by $216 and the premium by $332, using the same 65% loss ratio assumption.

Some mitigation actions may cost more than others, and such actions may happen in sequence instead of simultaneously. Specifically, roof replacements are more expensive and infrequent than clearance maintenance. Further, mitigation activities are not always independent of one another, and a minimum level of mitigation must be met to be effective in resisting fire damage. Table 4.4 presents the credits of clearance actions only and considers how model results could be used to consider the path a homeowner's risk may take if mitigation actions are performed in sequence.

2. Mitigation actions available for communities are explored in the second case study. In addition to individual property mitigation efforts, communities may engage in broader-scale projects that could include management of the understory of forested areas surrounding the community. The second case study discusses the mechanics of wildfire models and how modifications to data inputs can be used to simulate such community-level mitigation actions and quantify the result (shown in Table 5.1). An aggressive fuel modification regime is assumed, so results should be interpreted as the outer bound of what is possible.

   For the same selected base risk with estimated building replacement costs of $400,000, community mitigation could result in individual credits varying between 26% and 97%, a decrease of up to $535 of AAL, and a reduction in premium of as much as $823. The additional effect that community mitigation could have after individual mitigation (presented in Table 5.2) ranges between 1% and 43%, up to a $244 decrease of AAL, and as much as $375 in premium reduction. It is important to note that the largest AAL and premium reductions from community mitigation would be experienced by the highest-risk properties that have not undertaken the individual mitigation measures.

3. Beyond credits, communities must be able to evaluate trade-offs between various mitigation actions, which can be achieved by calculating total benefits at scale. The third case study illustrates this type of analysis, using a cross section of the marketplace and varying individual- and community-level mitigation scenarios. The results are contrasted in Table 6.3 to provide a general idea of the magnitude of risk reduction available from mitigation. For example, a modeled 39% reduction from a community-level fuel reduction action is compared with a 37% reduction that could occur if all homeowners were to meet perfect compliance with defensible space recommendations.

When applying both individual-level defensible space mitigation and community-level fuel reduction in the study area, we estimated an overall 62% reduction in wildfire AALs to $2.400 million compared with $6.267 million under estimated current conditions. This AAL reduction of $3.867 million could equate to premium reductions of $5.949 million. When including upgraded Class B fire-resistant roofs on all homes, we estimated an 87% overall reduction in wildfire AALs compared to current conditions, leaving only $824,000 in annual wildfire AAL remaining and reducing premiums by $8.374 million.

In evaluating these findings, several caveats and limitations should be considered:

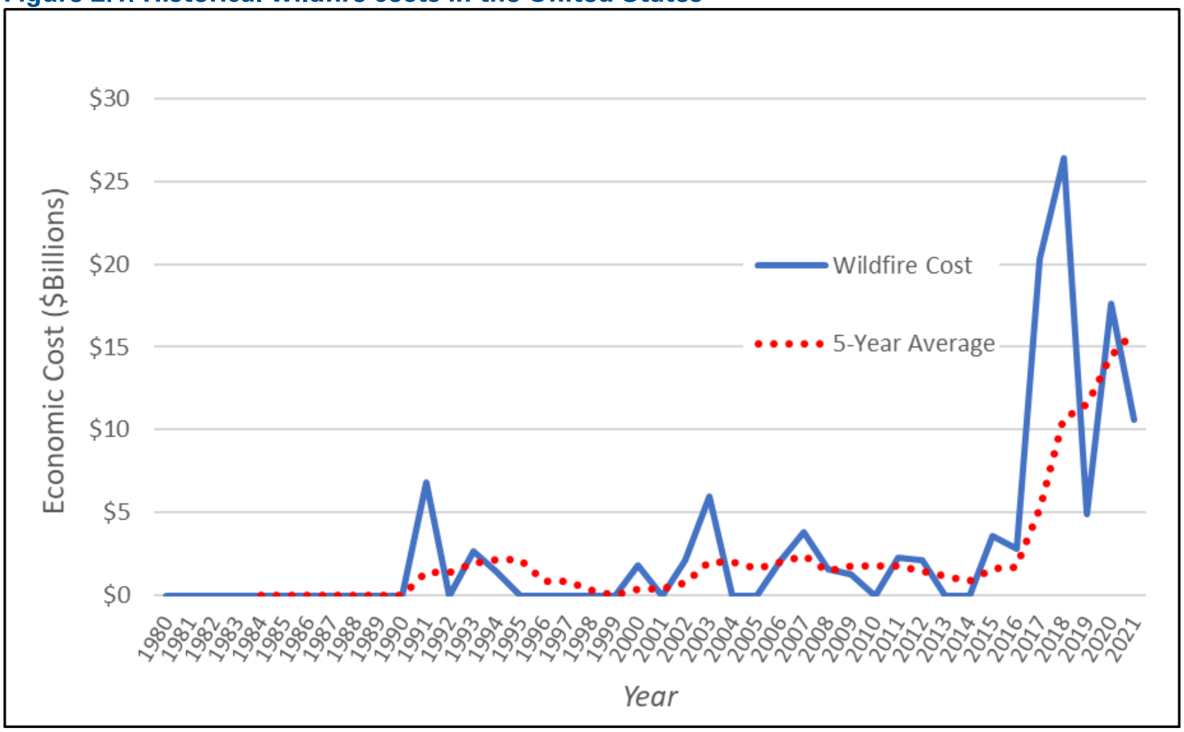
- There are many ways to construct mitigation credit tables. This study is intended to be illustrative and not prescriptive.
- These findings are specific to the Orinda/Moraga study area and may not apply to other geographies. Other communities may have material differences in home density or proximity to historical fire perimeters that may also impact the value of mitigation. Further, although the topography and wildfire conditions of this community are real, the analysis described in this paper was done for a synthetic portfolio of homes that will not precisely mimic the actual risk from wildfire this community faces.
- Our estimates are based on available data on individual housing stock and realistic assumptions regarding unknown information, such as the distribution of roof types and coverage amounts. Different reasonable assumptions or different risk portfolios may yield materially different results.
- These findings are specific to the CoreLogic wildfire catastrophe model and might differ significantly based on other wildfire models.
- In this study, we assume that wildfire insurance premiums are priced consistently with loss estimates from the CoreLogic wildfire model, and we assume a 65% loss ratio and a 35% provision for expenses and profit. If the starting premiums are inconsistent with the CoreLogic model and/or the expense and profit provisions assumed are not sufficient to reflect all the costs of risk transfer for a given insurer, the mitigation credits in this study may not be appropriate.
- The science of wildfire risk modeling is continuously evolving, and we would expect estimates such as the ones we present in this study to change as new data becomes available and models are enhanced.

2. Background

2.1. History of wildfire losses

For homeowner insurers, wildfire was long thought of as an attritional or incidental peril. For decades, wildfire losses were small enough compared with total homeowners insurance premiums that wildfires were not a main consideration for pricing or underwriting. Despite the sparsity of costly fires during this time, steady changes in the environment and growth in high-risk areas combined to produce increases in risk (Williams et al. 2019; Radeloff et al. 2018). The accumulation of risk was abruptly manifested starting in 2017, when California and other states in the American West experienced a series of wildfires that caused unprecedented destruction and extraordinary financial losses. Figure 2.1 shows U.S. economic costs due to wildfires between 1980 and 2021 for events with costs exceeding 1 billion dollars (NCEI 2022). Annual losses for the period 2017–2021 far exceeded those in all the prior years with the exception of 2019, although 2019 still ranks among the costliest years of all time.

Figure 2.1. Historical wildfire costs in the United States



Source: NCEI (2022).

The consistently high losses in recent years have made it clear that 2017 was not a passing anomaly; rather, the observed losses are indicative of an increase in the underlying risk, likely to persist, and are crucial to the decisions of the insurance industry, communities, and homeowners. In order to address the rising cost of premiums in high-risk areas, greater attention has been focused on wildfire risk mitigation by homeowners and communities. To appropriately match insurance premium rates to the risk, these mitigation actions need to be accurately reflected in insurance rating plans.

2.2. Wildfire risk by state

Wildfires occur throughout the United States, but historical costs are much higher in Western states—especially California. Table 2.1 provides a breakdown of NCEI's 1980–2021 economic cost estimates by state and also per capita and per square kilometer.

Table 2.1. Historical wildfire statistics by state

State	Wildfire Cost (Billions)	Percentage of U.S. Total	Annual Cost per Capita (Dollars)	Annual Cost per Square Km (Dollars)
California	$87.29	73%	$53	$4,902
Colorado	$5.27	4%	$22	$465
Oregon	$4.97	4%	$28	$464
Montana	$2.91	2%	$65	$182
Texas	$2.85	2%	$2	$97
Idaho	$2.85	2%	$39	$313
Washington	$2.51	2%	$8	$324
Alaska	$2.03	2%	$66	$28
Tennessee	$1.64	1%	$6	$357
New Mexico	$1.42	1%	$16	$108
Utah	$1.25	1%	$9	$135
Arizona	$1.17	1%	$4	$95
Nevada	$1.11	1%	$9	$92
Wyoming	$0.98	1%	$40	$92
Alabama	$0.66	1%	$3	$116
Oklahoma	$0.31	0%	$2	$41
Florida	$0.28	0%	$0	$39
Georgia	$0.27	0%	$1	$41
South Dakota	$0.10	0%	$3	$11
Minnesota	$0.09	0%	$0	$10
North Carolina	$0.08	0%	$0	$14
Nebraska	$0.05	0%	$1	$6
Mississippi	$0.04	0%	$0	$7
North Dakota	$0.01	0%	$0	$2
United States	$120.13	100%	$9	$21

Source: NCEI (2022).

As this history shows, most of the wildfire losses in the United States have occurred in California, with 73% of nationwide costs being incurred in this single state. This is unsurprising, given that California is both the most populous state and is exposed to wildfire risk through a variety of factors, including its Mediterranean climate with dry summers. Because of differences in risk and density, wildfires present varying degrees of need and opportunity for mitigation, so state and local mitigation strategies need to be tailored accordingly. Though historical losses have mostly occurred in California, recent events in a number of Western states make it clear that wildfire risk is not solely confined there. For example, in December 2020 over 1,000 structures were destroyed in Colorado in a remarkably late season fire event (Daley 2022). Additionally, through July 2022, Alaska and New Mexico were having historic wildfire seasons with approximately 2 million and 700,000 acres burned in each state, respectively ("National Fire News" 2022).

Thus, while there are a number of states for which wildfire mitigation is a relevant issue, California is by far the most critical in terms of size and mitigation potential. The state has unique statutes and regulations related to ratemaking[1] and a stressed residual market (CDI

[1] For an overview of California's Prop 103, which governs ratemaking for personal lines and includes strict prior approval rules, along with a unique intervenor process, see "Information Sheet" (2022).

2021). The recent change in perceived wildfire risk has created a broad repricing trend. When combined with other regulatory constraints, such as a prohibition on the use of catastrophe models in rate indications and the reflection of net reinsurance costs in rates,[2] the California market is currently experiencing a mismatch between insurer risk appetites and consumer demand. This has led to significantly decreased insurance availability for homeowners in wildfire-affected areas throughout the state and increased attention on how insurers establish wildfire rates in California.[3]

2.3. Wildfire mitigation in the California insurance market

With many policyholders receiving drastic rate increases or nonrenewals or unable to obtain coverage, much of the public frustration with the insurance industry has been directed at a lack of recognition by insurers of the mitigation actions that individuals or communities have taken. The public has a general understanding that the cost of insurance is related to the risk of the policy, which means those who invested in mitigation should expect to see the return for that investment in the form of increased insurance availability and reduced insurance premiums. These adjustments to insurance premiums based on the mitigation characteristics of the structure, property, and/or community are known as "mitigation credits."

Unfortunately, it is usually not the case that mitigation results in insurance premium credits. Of the 115 insurers listed as homeowners insurance writers by the California Department of Insurance (CDI), only 14 offer credits for individual mitigation and 15 offer credits for community mitigation ("Insurance Companies" 2022; "Insurers Currently Offering Discounts" 2022).

Regrettably, the figures above may even overstate the degree to which a community's mitigation actions could be expected to result in commensurate premium reductions. For 10 of the 15 insurers offering community mitigation credits, the only credit available is for a community designated a Firewise USA community by the National Fire Protection Association (NFPA) ("Firewise USA" 2022). Firewise programs largely focus on community education about best practices and may be an important tool for reducing risk and thus deserving of a premium credit. Nevertheless, the credits are usually small, as they focus only on the community's participation in the program and would not otherwise reduce rates for additional mitigation projects that could be physically demonstrated to have altered the community's actual risk characteristics. As such, Firewise participation represents a proxy for mitigation actions rather than actual mitigation actions.

Of the remaining community-level mitigation credits in the marketplace, the majority are offered for Shelter-in-Place communities (Rancho Santa Fe 2016). These are communities

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[2] For an overview of the use of catastrophe models to set wildfire premiums in California, see Frazier (2021).

[3] For a more complete discussion, see Webb and Xu (2018).

that either were built, or are being built, to withstand wildfires. The Shelter-in-Place distinction cannot be attained by the majority of existing communities, so it is not relevant in the majority of cases. In fact, only four communities in California currently have this distinction and they are self-designated in each case.

Due to the limitations of both Firewise and Shelter-in-Place programs, even though 15 insurers offer credits for community mitigation, there are essentially no insurers who directly offer credits for changes in risk that result from specific community mitigation projects. And while individual-level mitigation credits consider a wider variety of activities, the activities eligible for discounts vary widely by company, and many companies offer no credits at all.

The perceived inadequacy of mitigation credits in the marketplace has culminated in public calls for these credits to be required in rating plans. In 2022, the California insurance commissioner proposed regulations that would effectively require all insurers to reflect and take into account specific community and individual mitigation actions in their rating plans (CDI 2022). Many insurers and catastrophe modelers have endorsed the intent of these regulations, but have pointed out that the data and modeling necessary to measure the commensurate risk reduction is not sufficiently evolved to implement the community mitigation credit structure under consideration in the short term.

2.4. Wildfire catastrophe models

Like other natural catastrophes, wildfire losses are sparse and extreme, rendering historical data inadequate for measuring risk on its own, either for individual risks or in the aggregate. Instead, stochastic simulation models must be used to measure catastrophic loss potential. These models, known as "catastrophe models," are widely relied upon by the insurance industry for wildfires and other perils such as hurricanes, earthquakes, and floods (Ackerman, Brentlinger, and Davis 2021; American Academy of Actuaries 2022). Because of the complexity of the risk, communities wishing to quantify the benefits of community- or individual-level mitigation may be well advised to utilize these models or to engage modelers or actuaries to use them on their behalf.

Catastrophe models provide a breadth of potential outputs; for example, the ability to generate an estimate for AALs for a risk of any given characteristics at any location. Thus, although the utility of historical data is limited for catastrophe claims compared to non-catastrophe claims, models provide ample data for catastrophe analysis. As described in sections 2.4.2 and 2.4.3, today's wildfire models already allow for quantification of many, but not all, possible mitigation actions. For mitigation activities that are not explicitly modeled, customized analysis is necessary. Thus, the "how" of quantifying the effect of wildfire mitigation certainly includes catastrophe models, but currently may involve modifications or variations to those models to reflect some types of mitigation activities.

For the case studies presented in this report, we used the Risk Quantification and Engineering U.S. Wildfire Model, version 19.2 (CoreLogic model), provided by CoreLogic

Inc. This section describes some of the aspects of wildfire models relevant to modeling wildfire risk and calculating mitigation credits, using the CoreLogic model for examples. This is not a complete list of variables in the CoreLogic model or factors that drive wildfire risk but is intended as an overview of the model data sources and inputs related to mitigation and analysis in this report.

2.4.1. Land cover/fuel

In addition to the local ignition sources, climate, topography, and other factors, wildfire risk is driven by the presence or absence of vegetation, such as the growth of trees or forests nearby, as well as the relative susceptibility of that vegetation to fire. Each modeled event consists of an *ignition*, which considers the probability of a fire starting at a given location, and a *spread*, which considers the likeliness of that fire spreading into adjacent areas. The spread model utilizes a *land cover* layer, which provides information about the presence, type, and condition of flammable vegetation at any given location.

The CoreLogic model uses the 40 Scott and Burgan Fire Behavior Fuel Model (FBFM40), which designates 40 different land cover classifications based on Landsat imagery ("40 Scott" 2022). The methodology was developed in 2005, but the underlying data has been updated many times. The CoreLogic model reflects conditions up to 2019.

The FBFM40 classifies land cover by predominant fire-carrying fuel type, such as grass, grass/shrub, shrub, slash-blowdown (fallen trees), timber litter, timber understory, and nonburnable. These groups are further subdivided by factors impacting fire spread, such as depth and moisture content. Changes in wildfire behavior/risk resulting from fuel treatments such as burning, thinning, pruning, and physically removing fuels can be simulated by modifying the land cover classification.

2.4.2. Property characteristics

Many property characteristics relevant to wildfire risk relate to the structures on the property. However, some of these characteristics are impossible or very difficult to change, and thus would not represent a retrofit mitigation opportunity for a property or community. Characteristics that cannot be mitigated by retrofitting include the construction material of a house (frame versus masonry or other less combustible types) and the number of stories (for a given square footage, a two-story structure has a smaller footprint than a one-story structure, making it less susceptible to ignitions from wildfire embers). Significant characteristics that can be mitigated for existing structures include the following:

- Type of roof (four classifications—unrated and Classes A, B, and C—represent different degrees of fire resistiveness for roof coverings)
- Fire-resistive siding
- Fire-resistive vents
- Fire-resistive windows

Planners of new communities can establish buffers around communities to reduce the likelihood of a fire entering the community, adapt the community to fire using internal fire breaks to slow the spread of fire within it, and make fire easier to combat by establishing property mitigation standards. Residents in established at-risk communities are generally limited to mitigating wildfire risk at the parcel level. While mitigation such as the installation of new siding or a new roof should be encouraged, these changes can be very expensive for homeowners; the typical roof installation can cost $6,000 (or much more). In many cases, it would be cost prohibitive for homeowners to install these features merely in the interest of wildfire mitigation, which means that mitigation through the retrofitting of existing structures is unlikely to occur immediately. Rather, it occurs over a long period of time as replacements are needed on the existing housing stock. Adoption of mitigation measures, especially more costly measures like upgrading the roofing fire class, can be encouraged through grants.

2.4.3. Clearance/defensible space

Because wildfires spread to a structure from its surroundings, the landscaping that encircles the structure is a major determining factor in its risk. Unlike upgrades to property characteristics, which can be expensive and infrequent, maintenance of property landscaping may be less expensive and can be done on an ongoing basis to mitigate against wildfire risk. While there can be some resistance to the aesthetics of fire-hardened construction and landscaping, an opportunity exists for builders and landscapers to redefine what constitutes attractive design in the context of home hardening, particularly for defensible space. One of the most important mitigation actions that homeowners can take is to clear the surrounding area of debris that would contribute to wildfire spread.

This landscape maintenance concept is known as *clearance* (also known as *defensible space*) and is one of the most important drivers of wildfire risk. The most common defensible space recommendations used by the Insurance Institute for Business and Home Safety (IBHS) and many wildfire advocacy organizations divide the area around a structure into three zones (CAL FIRE 2019). Maintaining defensible space involves creating distance between the home and a potential fire by using different standards of maintenance for flammable materials at different distances around the home. For example, a property adhering to the recommended defensible space would have no wooden attachments or anything flammable within a 5-foot radius of the structure or building, a high standard of maintenance for all plants and vegetation within 5–30 feet, and a more relaxed standard of maintenance for those within 30–100 feet.

The CoreLogic model accepts a *yes* or *no* input for each risk and zone that indicates whether the recommended clearance activities have been performed. The IBHS descriptions of these zones are as follows (IBHS 2022):

- Zone 0 is the *noncombustible, home ignition zone* (0–5 feet from the building) (Noncombustible Zone). The 0-5 foot Home Ignition Zone (HIZ) is one of the most critical aspects of wildfire mitigation and includes the area from the edge of the exterior walls to a distance of 5 feet from the building footprint. Note that when decks and/or covered porches are present, the HIZ zone must extend beyond them. IBHS recommends this zone must meet and maintain monthly:

  - Noncombustible ground cover (i.e., hardscape such as gravel or paver stones) and must be kept free of debris.
  - No vegetation present within or overhanging this zone.
  - No combustible items such as furniture, firewood, trash cans, etc. should be stored in this zone.
  - No boats, RVs, or other vehicles should be parked in this zone.

- Zone 1 is the *lean, clean, and green zone* (5–30 feet from the building). Beyond the 0-5 foot HIZ, the property must have defensible space that is regularly maintained. Defensible space separates fuels to reduce flame intensity near a home. IBHS recommends the following maintenance criteria must be met within this zone:
  - Routinely remove fallen pine needles, leaves, and other debris from trees and bushes accumulated in the yard.
  - Trees with a trunk of 4 inches in diameter or greater:
    - Must be pruned to have a canopy-to-canopy distance of at least 10 feet to other trees. Tree limbs and branches must be pruned to a height of 6 feet off the ground.
    - Must have a spacing between the tree canopy and the next closest shrub, bush, or tree with a trunk diameter of less than 4 inches at least twice the height of the bush, shrub, or tree (or 10 feet, whichever is less).
  - Shrubs, bushes, and trees with a trunk diameter less than 4 inches:
    - Must not be placed under larger trees.
    - Must have a spacing that is at least twice the height of the tallest bush or shrub. Rows of shrubs and bushes are not allowed.
  - Routinely remove any dead vegetation.
- Zone 2 is the *reduced fuel zone* (30–100 feet from the building). Maintaining plants in this zone will help slow down and reduce the energy of a wildfire, slowing its advance to a building. Tree and brush spacing should force any fire in the tops of the trees or crowns of brush or shrubs to drop to the ground. The rate of fire spread and flame length is affected by slope. A steeper slope will result in a faster-moving fire with longer flame lengths. IBHS recommends the following criteria must be met within this zone:
  - Remove dead plant material and tree branches from vegetation on a regular maintenance schedule.
  - Create islands or groupings of vegetation.
  - Remove lower tree branches.

- Maintain trees with a minimum horizontal spacing of 10 feet between crown edges.

3. Mitigation Credits—Actuarial Considerations

3.1. Risk classification considerations

"Actuarial Standard of Practice No. 12: Risk Classification" (ASOP 12) describes the desirable characteristics of insurance rating variables that are applicable to the design of mitigation credit plans for wildfires and other natural catastrophes (Litow et al. 2005).

One consideration of ASOP 12 is the relationship of risk characteristics to expected outcomes. For catastrophic perils, the most direct relationship to risk could theoretically be delivered by running a catastrophe model for each risk and using the AAL directly as a component of the premium. However, while catastrophe models allow a flexible range of inputs and outputs, they are also complicated and computationally intensive, making regulatory reviews and implementation in a company's information technology systems time consuming and challenging. As an alternative, the output from a catastrophe model can often be approximated within a rating plan via a simple, more transparent algorithm or table of factors representing the appropriate credits. The ratemaking process in this case involves designing these tables and using the catastrophe model to generate the needed data to populate them with rating factors. There is some flexibility in this process, but certain actuarial considerations for ratemaking are particularly relevant for designing mitigation credit plans for wildfires and other catastrophe perils:

- *Completeness*—The rating plan should be able to calculate a rate for any location and combination of risk characteristics.

- *Representativeness*—The factors should be calculated with consideration of the characteristics of the portfolio or line of business for which they will be used.

- *Geographic granularity*—Exposure to natural catastrophes can vary widely within a small area, so traditional territorial rating (for example, based on ZIP codes) is not likely to produce a good match of rate to risk because traditional territories contain both high-risk and low-risk policies. Instead, more granular types of geographies can be used to improve accuracy.

- *Analytical manageability*—Given the endless possibilities for portfolio construction and table design, it is important to keep data set sizes manageable for analysis.

- *Rating table simplicity and interpretability*—When rating tables become too complex, they can be difficult to update or interpret. While rating plans should be as accurate as possible, they should also be simplified to the extent possible without sacrificing accuracy.

- *Interaction effects versus standalone variables recognition*—Some variables have significant interaction effects which should be recognized via the rating tables. Variables that do not can appear on a stand-alone basis.

Another ASOP 12 consideration relevant to wildfire mitigation is the idea that rating variables should be measurable, cost effective, and practical to maintain. To be properly considered in pricing and not jeopardize the solvency of insurers, mitigation credits must be actuarially reasonable and not just driven by political considerations. In the case of wildfire mitigation, at both the individual and community levels, achieving these goals may be difficult. Insurers implementing wildfire mitigation credits will need to decide how to verify that mitigation has been done. For homeowners insurance, detailed property inspections are not always performed on a regular basis. Since vegetation can grow, clearance can change on a year-to-year basis, and a credit given for defensible space one year should not be given the following year unless the requirements continue to be met. Similarly, fuel layer assumptions (which drive differences in expected risk by geography/community) must also be kept up to date. Thus, insurers will face complex operational decisions about balancing data accuracy with operational costs. While this challenge seems daunting, there are encouraging innovations that may assist insurers with the task of verification. For example, there are analytics vendors who offer machine learning–based solutions to classify a property's clearance based on satellite or aerial imagery. As with property inspections, the ability to collect the most up-to-date information remains a challenge for these solutions at present, but that challenge could potentially be solved in the coming years.

3.2. Other actuarial considerations

In addition to calculating rating credits, there are a number of additional considerations to take into account when modifying insurer rating plans.

3.2.1. Rate adequacy

Accurate credits will not produce a good match of rate to risk if they are applied to inadequate rates. Thus, actuaries and insurers should consider overall rate level indications to assess whether rates may be excessive or inadequate before implementing credits. If overall rate level adjustments are needed, they should be performed; or, if they cannot be performed, it may be necessary to temper the credit amounts to avoid severely inadequate rates.

3.2.2. Base rate offset

Implementing mitigation credits will cause dislocation in an insurer's portfolio. Assuming that existing rates are accurate in the aggregate but do not reflect risk differences for existing mitigation, implementing credits will cause some policies to be reclassified and receive premium reductions, causing aggregate premiums to be reduced. To restore the portfolio to overall rate adequacy, the base rates will need to be offset such that less mitigated properties receive rate increases. This offset would generally depend on the degree of mitigation that exists today, which would be reflected by the new mitigation credits.

In determining the base rate offsets, it is important to distinguish between the concepts of *hardening* and *reclassification.*

Hardening refers to actual changes to the housing stock or actual measures that change risk. Either a community could have drastically reduced its risk via a fuel management program or the prevalence of mitigation could have been increased once incentivized by insurer credits. In either case, the result would be reduced assessment of total risk, not reallocation of existing risk, so no offset to the base rates would be needed.

Reclassification refers to the reflection of existing mitigation once credits are added to a plan. So long as an insurer's estimates of the prevalence of mitigation features is accurate, adding credits will allow them to allocate the aggregate effect of those features more accurately to the policy level. The credits combined with the base rate offset will produce premium decreases when mitigation features are present and increases when they are not.

In Florida, the state with the most prominent and impactful mandatory mitigation credit policy, critics have pointed to a lack of distinction between hardening and reclassification as a key issue driving financial struggles for the state's insurers (Young et al. 2010). The extent of hardening effect was overestimated compared with the reclassification effect, resulting in years of downward premium trends without corresponding reductions in aggregate risk.

3.2.3. By-peril rating

Modern homeowners insurance rating plans are generally organized on a *by-peril* basis, meaning the total rate is the sum of rates for individual perils like water, fire, wind, and wildfire. The effects of individual rating factors are applied at the peril level, which produces an optimal match between the risk drivers and predicted risk. While by-peril rating is generally considered the best practice, it is not necessarily the norm. Many homeowners insurers use rates that either have all perils combined into a single rating calculation or are by-peril but separate the perils by very coarse classifications, such as combining wildfire and other types of house fire into a single category of fire peril. In this case, the rating plan would have mixed performance, as those perils share some risk drivers (like the construction type, which is predictive of a structure's likelihood to burn regardless of the ignition source) but diverge on others (like territory, which is predictive of the probability of ignition for a wildfire but not an ordinary house fire in forested areas).

A by-peril rating plan, with wildfire as a specific peril, would be the ideal starting point for the application of mitigation credits like those contemplated in this report. For actuaries and insurers operating without by-peril rates, we would strongly advise restructuring rates to a by-peril basis, with wildfire premiums separately estimated within the rate indications and rating algorithm, before proceeding.

If by-peril rates cannot be adopted, and the wildfire rates are combined with other perils, credits like the ones calculated in this report would need to be modified to apply on a combined-perils basis. This is typically achieved by estimating the weights associated with each peril and the degree to which each peril would be affected by the rating features. For example, if wildfire and other house fire are each 50% of a combined fire peril, and there is a 20% credit indicated to wildfire for certain clearance activities, then the correct credit to apply to the combined fire peril would be 50% × 20% = 10%. If, on the other hand, there were a 30% credit indicated for the wildfire peril for a Class A roof, it may be thought that such a roof is also reductive of risk to the other house fire peril by 50% as much as the wildfire peril, in which case the credit could be calculated as 50% × 30% + 50% × 30% × 50% = 22.5%.

3.2.4. Territory factors

Areas with differing risk hazard may realize varying risk reductions from mitigation that will not be recognized with a one-size-fits-all approach. In such cases, we can expect the mitigation credits to vary by geography. Different communities may have material differences in home density or proximity to historical fire perimeters that may also impact the value of mitigation, as the primary exposure to fire in some areas may be structure-to-structure rather than ember cast (Wildland Urban Interface Group 2021). Actuaries implementing mitigation credits will also likely need to review and revise territory definitions and relativities to coordinate territorial differentiation between the mitigation credits and the underlying rating plan.

When accounting for community mitigation projects, the ratemaking process will need to take extra care not to undercount or double count. For example, a territory factor update deriving from a fuel layer update may inherently give credit for a fuel management program that has already reduced loads effectively enough to result in a change to the layer. However, it would not be appropriate to apply additional community mitigation credits, as the reduction in risk would already be recognized in the territory relativity.

3.2.5. Expenses

There may be additional operation expense associated with measuring and verifying that mitigation procedures are in place, so actuaries should consider modification of rates to provision for this expense.

3.3. Regulatory considerations for ratemaking

Finally, there are a number of items that policymakers or regulators involved with mitigation quantification should consider when enacting laws and regulations or allocating mitigation funds.

First, regulators who review rate mitigation proposals, or policymakers considering imposing mandatory mitigation credits, should consider the holistic relationship between the credits and other rating elements. As described, a precondition for successful mitigation programs includes overall rate level adequacy, and it is very desirable to have by-peril rating structures that are sufficiently granular to reflect variations in risk and variations in expected credit amounts. Insurers may have these conditions in place to varying degrees and face complex trade-offs (such as extreme policyholder dislocations) in implementing them. Thus, a heavy-handed one-size-fits-all approach either mandating certain credits or specifying the credits themselves may not work well for many insurers and could exacerbate existing disparities between rate and risk, worsening availability issues. Such was the case in Florida with respect to wind mitigation, creating significantly adverse unintended consequences.[4] Policymakers should be advised to heed lessons learned from this experience instead of inflexibly mandating credits and presenting them as an unambiguous public good.

Second, regulators should recognize that many different views of the risk exist, based on different models and different parameters. As a result, mitigation rating strategies may vary widely from insurer to insurer. This should be encouraged, as matching the premium as closely as possible to the risk bearer's particular view of risk is the best way to ensure that the number of policies that can be accepted is maximized. In short, while regulators may consider encouraging, or even mandating, insurers to implement credits, they should be flexible as to which approaches are allowed. This would encourage an innovative market and could help alleviate some of the availability issues that have existed.

Third, policymakers could consider large-scale data collection or verification programs. As described, operational costs associated with verifying clearance may be the biggest blocker of widespread implementation today, so policymakers could consider investing public funds into a collective effort to assess and report clearance. Beyond decreasing insurance costs and possibly allowing for increased efficiency through economies of scale, such an effort could result in increased transparency and a faster reduction of wildfire risk by individuals and communities.

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[4] For further discussion of the impacts of the initial mitigation credit framework, see Windstorm Mitigation Committee (2021) and Young et al. (2020).

Lessons learned from Florida

A framework of mitigation discounts for hurricane premiums was implemented in Florida in the early 2000s, with unanticipated and disastrous results to the Florida insurance industry and consumers. The mitigation credits promulgated by regulators at the time often resulted in illogically low, or even negative hurricane premiums. Generally, this was caused by the following:

- the assumption that premiums were already 100% adequate before application of the mitigation discount, which was not the case, especially for the riskiest policies;
- large differences in how insurers rated their existing policies;
- large differences in the adequacy of existing premiums by peril;
- the failure to consider overlaps and interactions between mandatory mitigation discounts and existing rating factors, especially territorial relativities;
- mismatches among the catastrophe models used to create the discount, the models used by the companies to manage their businesses, and the models used by reinsurers to price catastrophic reinsurance coverage;
- the inability of insurers to know which of their policies would qualify for the discounts as the necessary data had not been captured before;
- widespread abuse and fraud in the initial capture of mitigation data through a process with insufficient controls; and
- mandatory rate rollbacks as a result of an expansion of the state-backed reinsurance facility, instituted simultaneously with the mitigation discounts.

Florida insurers were forced to take across-the-board rate decreases without a corresponding reduction in actual risk. This led to the depletion of surplus for property insurers, several company insolvencies despite a decade of no hurricane activity, several ensuing years of enormous rate increases for hurricane premiums, and a resulting counterintuitive but common trend among insurers to avoid writing mitigated homes because the premiums were too low. Additionally, the property insurance market of last resort, Citizens Property Insurance Corporation, grew to 1.4 million policies. This created an enormous concentration of risk for Florida taxpayers and businesses, even as Citizens' customers were generally concerned about its limited coverage and high prices.

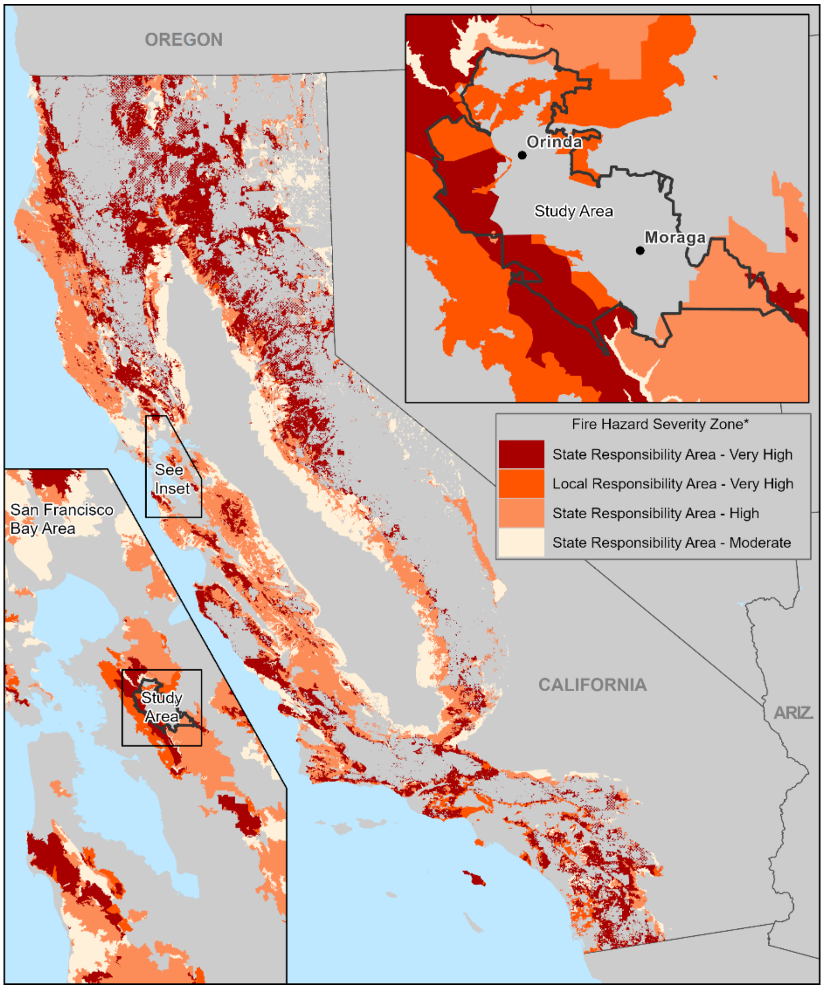
4. Case Study 1: Calculating Individual Property Mitigation Credits

This case study for individual credits begins with the selection of a sample study area, then proceeds with the specification of catastrophe model inputs and outputs. Catastrophe model outputs are analyzed using generalized linear models (GLMs) to determine an appropriate mitigation table structure and territories. Then, catastrophe model outputs are used to calculate mitigation credits for each mitigation class and territory combination.

4.1. Selection of study area

The selected study area includes the Northern California city of Orinda and town of Moraga, two adjacent communities with significant wildfire risk in a medium-density region outside of an urban area. This community sits partially in forested hills northeast of San Francisco and Oakland. It is nearby, and similar in features to, the Oakland Hills area of Alameda County, which in 1991 witnessed the state's costliest wildfire of all time (until 2017). Because of this community's proximity to a major urban area, property values are very high, and housing density is fairly high. However, because of the topographical features of the area, much of it is covered with forested hillside and wildfire risk is substantial. Due to this mixed land cover and medium density, this area is one of the major contributors to aggregate risk in the state and is representative of many other communities where the total financial risk of wildfires, and potential benefits from mitigation actions, are high. Figure 4.1 depicts the location of the study area within in the state and relative to the San Francisco Bay area.

Figure 4.1. Study area



Source: California Department of Forestry and Fire Protection.

4.2. Specification of input data

Generating catastrophe model output requires selecting or constructing an appropriate input portfolio. In the instance of a wildfire mitigation credit table, this selection needs to allow for the calculation of rating factors and any additional desired analysis. Each record requires a location (typically specified as a latitude and longitude from a geocoded address) and a specification of all the policy attributes of that location. To specify the locations, there are several methods available, including the following:

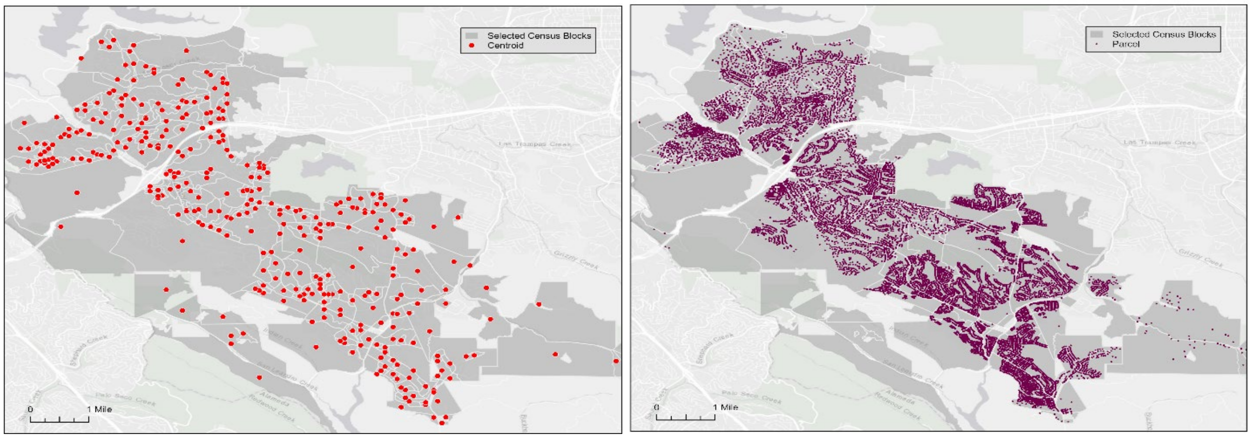
- *Sampling based on actual locations*—This includes either using an insurer's actual portfolio or a sample from a more complete data set that includes all the locations in a region. Most insurers do not have large enough portfolios for this task, so a *notional data set*, a hypothetical portfolio intended to reflect a representative cross section, is used based on parcel locations. The advantage of this type of data set is its representativeness of true locations, which enables more accurate estimates of aggregate portfolio statistics. A disadvantage of this type of sampling can be the size. Using every single location, combined with variations in risk characteristics, can create an intractable analysis. These data sets can be downsampled without sacrificing representativeness, but that often comes at the expense of leaving "holes" in sparsely populated areas for which a rate is desired.

- *Grid-based sampling*—This consists of specifying a grid of equally spaced points. The grid will have a specified resolution, such as 100 meters between points. The advantage of this method is that if the grid resolution is sufficiently granular, it allows a fine-grained match of the risk gradients in the model. Since the grid points are close together, there is a model result generated for a point in close proximity to any hypothetical risk that could be rated. A disadvantage of this method can be that irrelevant points are generated in places where residences do not exist, and the risk in such areas can be very different from actual residential areas. For example, a grid may place a location for modeling in a densely vegetated area with extreme wildfire risk where a home may be unlikely to exist. For grid-based sampling, extra care must be taken when assessing aggregates or weighting or combining results.
- *Centroid-based territory sampling*—This consists of sampling one point per geographic unit, such as per ZIP code, county, or census geography. The single point is usually the *centroid* of that geography. Conceptually, the centroid is the center of a complex polygon, but it is assigned to a geography by geographic information system software via geometric formulas applied to a shape file. While this concept can be applied to territories of any size, it is generally used for more granular types like census tracts or census blocks. The advantage of this type of sampling is that it ensures completeness without sacrificing very much in terms of representativeness or granularity. If the rate tables are to be based on a particular geography, this method ensures there will be at least one point for each territory and that there will be no units that cannot be analyzed. There is a mismatch between the sample locations and actual risks, but since census tracts or blocks are small, all points in the territory will tend to be close to their centroid. Similar to a grid method, this method can create biased results when calculating aggregates or combining results because the actual number of risks in each geographic unit may vary (for example, one census block could contain 100 risks and another could contain 10). Fortunately, since census estimates are available for all these counts, it is possible to avoid these biases.

Setting credits is a multistep process; the first step is to set rating factors and the second step is to offset the base rates to account for the impact of those factors. As described, different data sets may be more suited to one of these steps than others. For this case study, we needed a very complete portfolio to estimate mitigation credits but also desired a portfolio that would be representative for estimating aggregates. As a result, we proceeded with two portfolios of locations, one for each of these purposes. The first data set was based on census block centroids, and the second was based on actual residential locations for the study area. In our study area, there are 343 census blocks and 12,612 residential parcels. The study locations are depicted in Figure 4.2.

Figure 4.2. Study input locations

Census Block Centroids *Parcels*



Source: Esri basemap data, 2010 U.S. Census Bureau TIGER

After specifying input locations, the next step was to determine the property characteristics for model input. The centroid-based data set is much smaller than the parcel-based data set, which allows for more combinations of risk characteristics to be considered at each location while keeping data sizes manageable. The parcel-based data set is more representative and intended for aggregate measurement, so property characteristics on it should be as accurate as possible. With these goals, the attributes for each data set were selected (see Table 4.1).

Table 4.1. Model input characteristics

Model Input Data		
Model Variable	Centroid Locations	Parcel Locations
Occupancy	Residential	Residential
Coverage A (Dwelling)	$400,000	Actual
Coverage B (Other Structures)	$40,000	7.5% of A
Coverage C (Contents)	$200,000	60.0% of A
Coverage D (Loss of Use)	$100,000	20.0% of A
Deductible	$1,000	0.5% of A
Structure Type	Frame, Noncombustible, Fire Resistive	Estimated Distribution
Year Built	1955	Actual
Number of Stories	1, 2	Estimated Distribution
Roofing Fire Class	Classes A, B, C, and Unrated	Estimated Distribution
Clearance—Noncombustible Zone	Yes, No	Estimated Distribution
Clearance—Lean, Clean, and Green Zone	Yes, No	Estimated Distribution
Clearance—Reduced Fuel Zone	Yes, No	Estimated Distribution
Fire-Resistive Siding	Yes, No	Estimated Distribution
External Fire Extinguisher	No	Estimated Distribution
Combustible Attachments	Yes, No	Estimated Distribution
Fire-Resistive Windows	Yes, No	Estimated Distribution

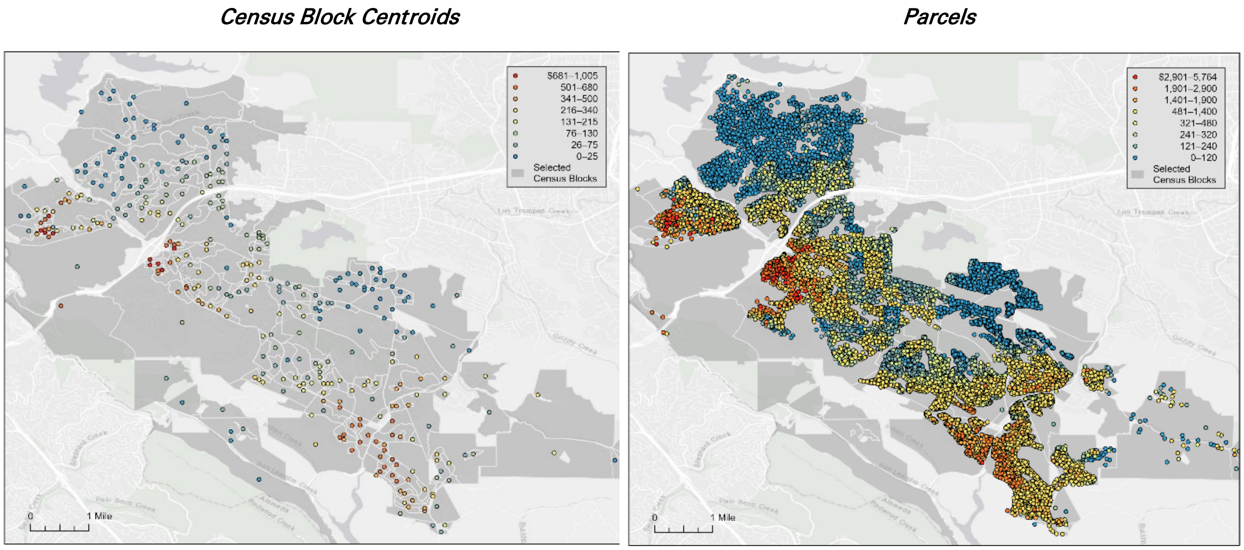
Source: Values selected by authors; estimated distributions from Corelogic.

We populated the centroid-based data set using a *base risk* approach, in which some attributes are held fixed and some attributes are varied by creating additional records across all possible or relevant mitigation levels. Since it was not our goal to calculate factors for policy attributes such as Coverage A or deductible, we did not vary those, but instead specified fixed values intended to be representative of a typical policy. With respect to the mitigation attributes for which we were calculating factors, we then created one record for each possible combination of attributes. For the parcel-based data set, CoreLogic provided an inventory that contains best estimates of many variables (for example, the actual year built or Coverage A at each location). In many cases this information is not available (for example, the clearance attributes at every location are not known). Instead, model inputs are set to "unknown," so that the model will apply a damage function that is based on the estimated distribution of properties in this area that have this type of clearance. Thus, these results will not differentiate risks based on their clearances or roofing classes, but will yield aggregates that reflect the CoreLogic model's best estimates of the prevalence of those features.

4.3. Model results

Using the selected study locations and attribute combinations, we created a data set to be run through the wildfire model. Since the goal was to use the centroid-based data set to calculate rates for residential locations, the first step was to examine the model results to consider the alignment between them. We mapped the resulting AALs for all parcels and for a base risk at all centroids, as depicted in Figure 4.3.

Figure 4.3. Modeled AAL by location



Source: Esri basemap data, 2010 U.S. Census Bureau TIGER, CoreLogic model

In Figure 4.3, the highest-risk locations are red and orange, medium-risk locations are yellow, and low-risk locations are blue. Comparison of the spatial patterns between the two data sets in Figure 4.3 shows that the results are fairly consistent. That is, the relationship between risk and location is similar across both centroids and parcels, and there does not appear to be so much variation within individual census blocks that the centroids would not provide a good fit. We proceeded with the centroids-based data set.

4.4. Table structure design

The next step was to determine the mitigation credit table structure. As described in section 3.1, our goal was for the table structure to be complex enough to recognize all significant interactions, but otherwise as simple as possible. As a result, our first step was to determine what the significant interactions were. To accomplish this, we used a GLM and the output of the centroids-based data set.

The variables in the GLM were all the ones that were varied in the data set—structure type, number of stories, roofing fire class, fire-resistive windows, fire-resistive siding, combustible attachments, and the three clearance zones: noncombustible; lean, clean, and green; and reduced fuel. The first step was to run the GLM, including parameters for every level, only on the main effects and examine the results to determine whether all effects were significant.[5] Once satisfied with the main effects model, to determine significant interactions, we fit individual models consisting of every possible two-way interaction

[5] Please note that, unlike a data set satisfying the assumption that records be independent and identically distributed, our data is hypothetical, and thus the GLM outputs such as *p*-values do not lend themselves to the same statistical interpretation. Nevertheless, regression statistics such as *p*-values serve as powerful exploratory guides for complex multivariate data sets.

paired with the main effects model. For example, if there were 10 possible two-way interactions, there were 10 models, each with that interaction specified along with the main effects model. We then examined the statistical diagnostics associated with the interaction parameters, fit in each model. The results are depicted in Table 4.2.

Table 4.2. Interaction test results

Interaction Number	Variable—Level	Coefficient	Standard Error	Pr(>|t|)
1	Roofing Fire Class B: Clearance—Lean, Clean, and Green (No)	-0.13	0.00	0.0000
1	Roofing Fire Class C: Clearance —Lean, Clean, and Green (No)	-0.15	0.00	0.0000
1	Roofing Fire Class U: Clearance—Lean, Clean, and Green (No)	-0.15	0.00	0.0000
2	Roofing Fire Class B: Clearance—Reduced Fuel Zone (No)	-0.11	0.00	0.0000
2	Roofing Fire Class C: Clearance—Reduced Fuel Zone (No)	-0.14	0.00	0.0000
2	Roofing Fire Class U: Clearance—Reduced Fuel Zone (No)	-0.13	0.00	0.0000
3	Roofing Fire Class B: Clearance—Noncombustible Zone (No)	-0.07	0.00	0.0000
3	Roofing Fire Class C: Clearance—Noncombustible Zone (No)	-0.09	0.00	0.0000
3	Roofing Fire Class U: Clearance—Noncombustible Zone (No)	-0.09	0.00	0.0000
4	Roofing Fire Class B: Combustible Attachments (No)	0.07	0.00	0.0000
4	Roofing Fire Class C: Combustible Attachments (No)	0.09	0.00	0.0000
4	Roofing Fire Class U: Combustible Attachments (No)	0.09	0.00	0.0000
5	Clearance—Lean, Clean, and Green (No): Clearance—Reduced Fuel Zone (No)	-0.26	0.00	0.0000
6	Clearance—Lean, Clean, and Green (No): Clearance—Noncombustible Zone (No)	-0.05	0.00	0.0000
7	Clearance—Lean, Clean, and Green (No): Combustible Attachments (No)	0.05	0.00	0.0000
8	Clearance—Reduced Fuel Zone (No): Clearance—Noncombustible Zone (No)	-0.04	0.00	0.0000
9	Clearance—Reduced Fuel Zone (No): Combustible Attachments (No)	0.04	0.00	0.0000
10	Clearance—Noncombustible Zone (No): Combustible Attachments (No)	0.37	0.00	0.0000
11	Structure Noncombustible: Roofing Fire Class B	0.00	0.00	0.9509
11	Structure Fire Resistive: Roofing Fire Class B	0.00	0.00	0.9194
11	Structure Noncombustible: Roofing Fire Class C	0.00	0.00	0.7137
11	Structure Fire Resistive: Roofing Fire Class C	0.00	0.00	0.5451
11	Structure Noncombustible: Roofing Fire Class U	0.00	0.00	0.6435
11	Structure Fire Resistive: Roofing Fire Class U	0.00	0.00	0.4504
12	Structure Noncombustible: Clearance—Lean, Clean, and Green (No)	0.00	0.00	0.7792
12	Structure Fire Resistive: Clearance—Lean, Clean, and Green (No)	0.00	0.00	0.6610
13	Structure Noncombustible: Clearance—Reduced Fuel Zone (No)	0.00	0.00	0.8151
13	Structure Fire Resistive: Clearance—Reduced Fuel Zone (No)	0.00	0.00	0.6813
14	Structure Noncombustible: Clearance—Noncombustible Zone (No)	0.00	0.00	0.8707
14	Structure Fire Resistive: Clearance—Noncombustible Zone (No)	0.00	0.00	0.7932
15	Structure Noncombustible: Fire-Resistive Siding (No)	0.00	0.00	0.9974
15	Structure Fire Resistive: Fire-Resistive Siding (No)	0.00	0.00	0.9778
16	Structure Noncombustible: Combustible Attachments (No)	0.00	0.00	0.8707
16	Structure Fire Resistive: Combustible Attachments (No)	0.00	0.00	0.7932
17	Structure Noncombustible: Fire-Resistive Windows (No)	0.00	0.00	0.9652
17	Structure Fire Resistive: Fire-Resistive Windows (No)	0.00	0.00	0.9601
18	Roofing Fire Class B: Fire-Resistive Siding (No)	0.00	0.00	0.9680
18	Roofing Fire Class C: Fire-Resistive Siding (No)	0.00	0.00	0.8189
18	Roofing Fire Class U: Fire-Resistive Siding (No)	0.00	0.00	0.7801
19	Roofing Fire Class B: Fire-Resistive Windows (No)	0.00	0.00	0.9895
19	Roofing Fire Class C: Fire-Resistive Windows (No)	0.00	0.00	0.9310
19	Roofing Fire Class U: Fire-Resistive Windows (No)	0.00	0.00	0.9135
20	Clearance—Lean, Clean, and Green (No): Fire-Resistive Windows (No)	0.00	0.00	0.9703
21	Clearance—Reduced Fuel Zone (No): Fire-Resistive Siding (No)	0.00	0.00	0.8926
22	Clearance—Reduced Fuel Zone (No): Fire-Resistive Windows (No)	0.00	0.00	0.9713
23	Clearance—Noncombustible Zone (No): Fire-Resistive Siding (No)	0.00	0.00	0.9284
24	Clearance—Noncombustible Zone (No): Fire-Resistive Windows (No)	0.00	0.00	0.9783
25	Fire-Resistive Siding (No): Combustible Attachments (No)	0.00	0.00	0.9284
26	Fire-Resistive Siding (No): Fire-Resistive Windows (No)	0.00	0.00	0.9580
27	Combustible Attachments (No): Fire-Resistive Windows (No)	0.00	0.00	0.9783
28	Clearance—Lean, Clean, and Green (No): Fire-Resistive Siding (No)	0.00	0.00	0.8886

Source: Authors' analysis.

For ease of reference, the terms we considered statistically significant are shaded green,[6] and those we considered insignificant are shaded red. Examining the compiled results, we noted that there was a group of variables that tended to cluster together in terms of significant interactions and a number of variables that did not appear in significant interactions at all. Specifically, the three clearance variables, roof class, and combustible attachments all cross-interact, whereas fire-resistive siding and fire-resistive windows do not significantly interact with any other characteristics. Thus, we decided to proceed with a rate table structure (see Table 4.3) that included a major interaction table to include all the variables that interact with each other, and we decided to treat the variables that do not appear in interactions as stand-alone variables.

4.5. Territory dimension

In addition to interaction effects between variables, the next question was whether the mitigation credits for property upgrades or clearance variables could also meaningfully vary by geography, and if so, whether a geographic dimension should be added to the rate tables. We first examined our data to assess the relationship between credits for mitigation and AAL. Since there did appear to be a correlation, where credits for particular mitigation actions varied based on the risk to a policy, we decided it was likely that interactions did exist and that segmenting the geography based on risk would be a good way to capture them.

As described, our data set consisted of 343 census block centroids, each with modeled records at an unmitigated base risk, as well as modeled records for every possible combination of mitigation attributes for that base risk and location. Our general observation was that credit amounts vary based on risk, but since our data was based on only one location per census block, too fine-grained of a treatment (for example, giving each census block its own rating factors) would likely produce overfit results. Instead, our desire was to group the census blocks into territories in such a way that they broadly captured this relationship and could also be simply implemented into rate tables.

There are an immense number of possibilities for how 343 census blocks can be grouped. Additionally, there were many dimensions to what was being grouped—with different credit amounts for different mitigation combinations at each location. To address this complexity, we decided to proceed in two steps. First, we would use an automated step to coarsely group the census blocks based on their base risk AALs. We then examined the interaction effects between these census block groups and the mitigation variables to determine whether more or fewer territory groups would be needed to adequately capture the variation in credits.

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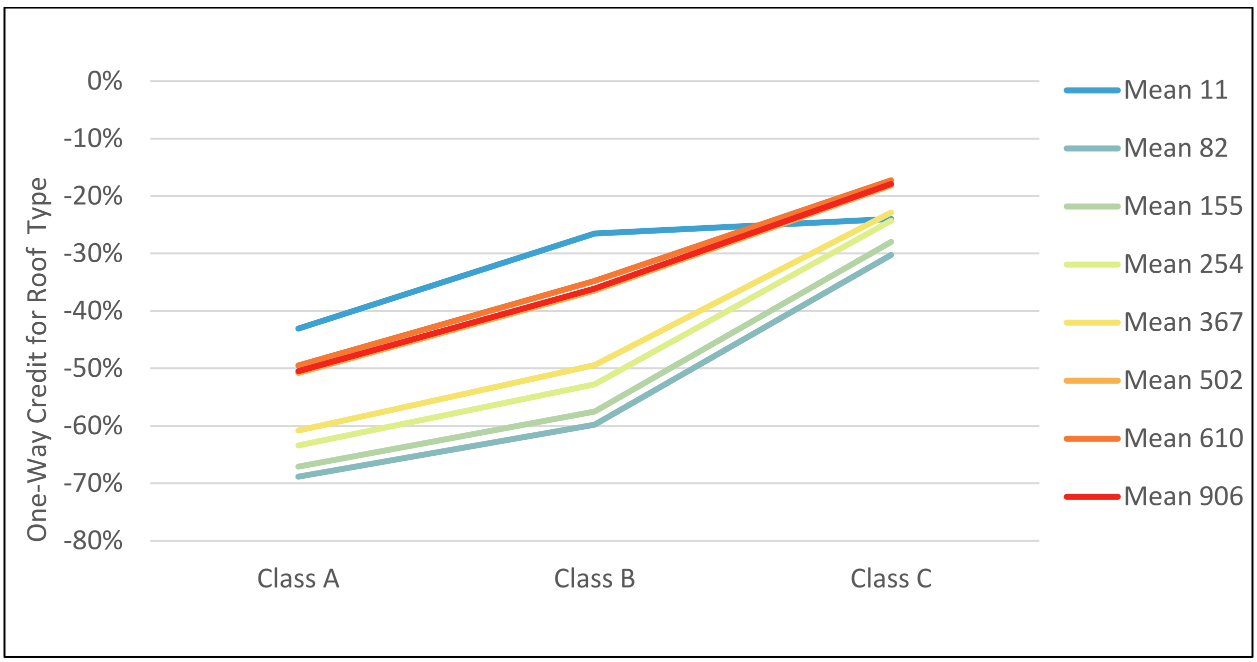
[6] Statistical significance was assessed with a Bonferroni-adjusted *p*-value of 0.05 / 28 = 0.001786, where 0.05 represents the desired test-level *p*-value and 28 represents the number of unique interactions tested.

For the first step, we used a *k*-means analysis to group the 343 census blocks into 8 groups, based on the fact that little additional geographic variation was captured by more than 8 groups. Using the 8 groups, we then proceeded with a GLM in a similar fashion as the interactions test. We first fitted a GLM on main effects, including the interaction terms that were selected in the prior step. We then added interaction terms for the 8 territory clusters, and we based our decisions about further grouping or separating the territories on the results. This was based on an examination of the modeled one-way credit amounts for certain attributes (for example, the clearance and roof types). Using the modeled parameters, we calculated base risk and credited predicted AALs for the base risk and mitigated classes, and we examined the indicated credit amounts for each of the 8 territory clusters. This examination is depicted in Figures 4.4 and 4.5. Each cluster is labeled with the mean base risk AAL for the cluster.

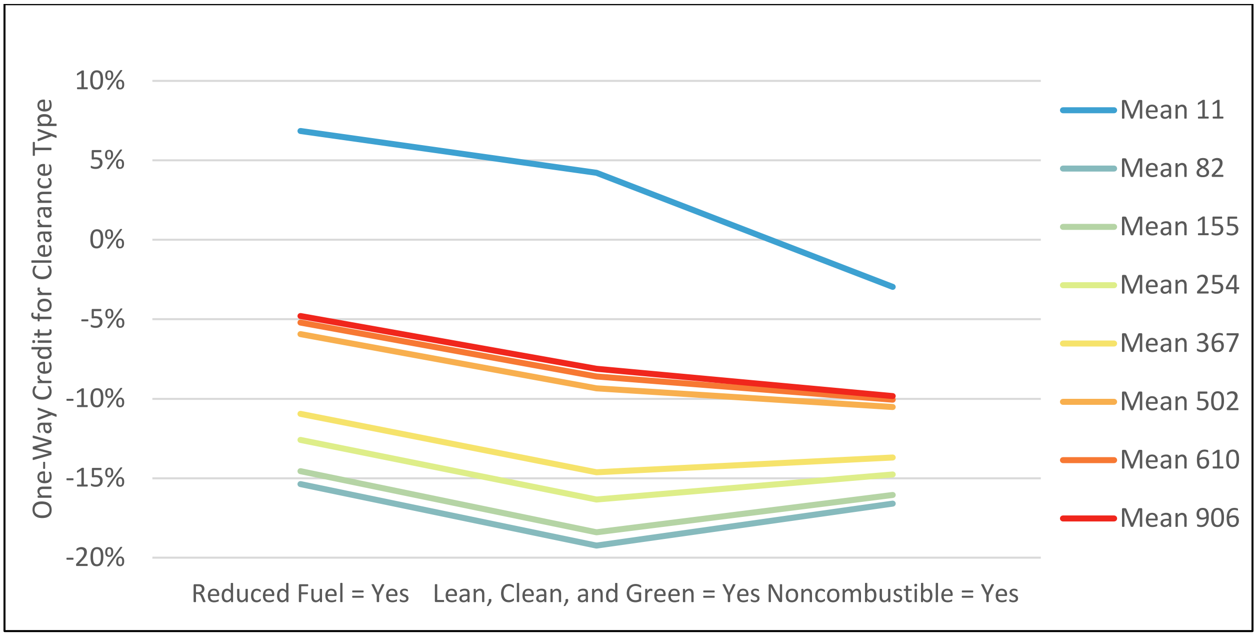
Figure 4.4 represents the indicated one-way credit by roof type for each of the 8 clusters. We noted that the high mean (610 and 906, shaded orange and red) clusters tend to have similar credits for each roof type, the middle mean clusters (82, 155, 254, and 367, shaded yellow and green) clustered together, and the low-mean group (11, shaded blue) stood alone. We similarly considered the indicated credits by clearance type, depicted in Figure 4.5.

Figure 4.4. Cluster credit by roof type



Source: Authors' analysis.

Figure 4.5. Cluster credit by clearance

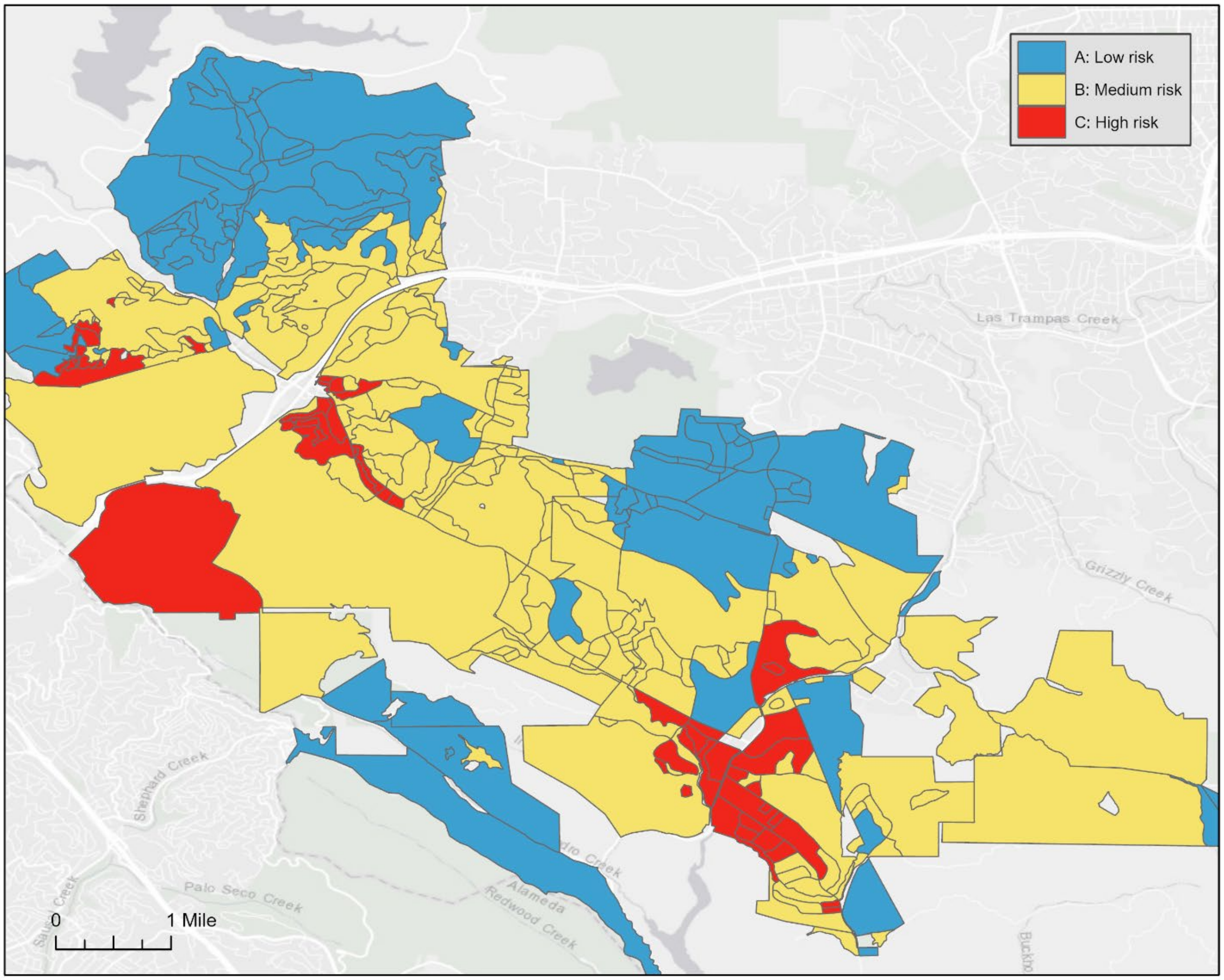


Source: Authors' analysis.

Based on this, we ultimately decided on three groupings. Our rationale was that the differentiation between the credits for the high-risk group was very low, so those could be grouped, and no more differentiation was needed. The medium-risk group didn't group together quite as well, but it could be viewed with slightly lesser importance, as it is associated with lower risk. The low-risk group, being very isolated, could probably yield additional differentiation if broken into smaller groups, but that group is likely of the least importance as the AALs for the group are so low. Ultimately, based on this examination, we decided the three territory groupings produced sufficient homogeneity within territories. Finally, we mapped the result, depicted in Figure 4.6, and compared it with the modeled AALs in Figure 4.3 to consider the alignment between groupings and AALs. We named the resulting clusters Territory Groups A, B, and C for low, medium, and high risk, respectively.

For ease of presentation in this paper, we selected three territory groups in this area consisting of two ZIP codes. This is not a recommendation on the optimal number of territory groups; we could have selected more. Nor should this selection be extended to other geographies in California, which could produce significantly different results.

Figure 4.6. Selected census block clusters—Territory Groups A (low risk), B (medium risk), and C (high risk)



Source: Esri basemap data, 2010 U.S. Census Bureau TIGER, Authors' analysis using the CoreLogic model

4.6. Calculating rate credits

Finally, with our rating structure and territories determined, we were ready to populate the mitigation credit table. Our data available for doing so was at the census-block level, and our desire was to calculate credits for territory groups that were census block groups. The credits are first calculated for each census block using the ratio of the AAL for each mitigation cell to the unmitigated base risk. Then, noting that not all census blocks are equally populated, we calculated the territory group credits using a weighted average across the census blocks in the territory group, with census housing units as the weights.

The resulting credit table, which interacts territory group, clearance variables,[7] and roof type, appears in Table 4.3. In addition to the indicated percentage credits, we have presented the dollar amount credits for the base risk to provide an idea of the likely magnitude of each credit. Please note when considering dollar amounts that the ultimate premium reduction would be larger than the AAL reduction shown because the premium includes allowances for expense and profit as well as the underlying AAL. In a typical case in California, the provision for AAL may be 65%[8] of the premium, so the reduction in premium would be calculated as 1.0 / 65%, or around 1.54 times the reduction in AAL. For ease of reference, we have shaded the percentage credits green and the dollar credits orange, based on their amounts.

[7] Please note that the *combustible attachments* variable (which indicates the presence of a flammable structure like a wood deck attached to the home) is redundant with the *noncombustible zone* variable (which indicates the absence of all combustible material, including attachments). That is, a property with combustible attachments is automatically considered not to have cleared its noncombustible zone. As a result, we dropped combustible attachments, retaining only the noncombustible zone in the tables.

[8] A 65% loss ratio is assumed based on the 2020 California Efficiency Standard for homeowners insurance. The standard generally allows for approximately 35% of premium to be allocated to expenses in addition to losses for an insurer with a captive agency force but excludes the cost of reinsurance, which is not currently allowed for wildfire premium ratemaking in California. For information regarding the efficiency standard, see CDI (2008).

Table 4.3. Calculated mitigation credits

Individual Mitigation Credits									
Mitigation Variables				Percentage Credit			AAL Dollar Credit		
Clearance—Reduced Fuel Zone (30–100 feet)	Clearance—Lean, Clean, and Green Zone (5–30 feet)	Clearance—Noncombustible Zone (0–5 feet)	Roof Fire Class	Territory Group A Low Risk	Territory Group B Medium Risk	Territory Group C High Risk	Territory Group A Low Risk	Territory Group B Medium Risk	Territory Group C High Risk
Yes	Yes	Yes	Class A	95%	95%	90%	$9	$170	$509
			Class B	86%	85%	76%	8	152	427
			Class C	78%	69%	52%	7	124	296
			Unrated	69%	54%	38%	6	98	216
		No	Class A	90%	88%	81%	8	157	456
			Class B	79%	75%	65%	7	135	367
			Class C	68%	58%	43%	6	104	244
			Unrated	52%	41%	29%	5	74	164
	No	Yes	Class A	91%	89%	82%	8	159	465
			Class B	80%	77%	67%	7	138	377
			Class C	69%	60%	45%	6	107	253
			Unrated	55%	44%	31%	5	78	173
		No	Class A	78%	69%	55%	7	125	311
			Class B	61%	50%	37%	6	89	207
			Class C	40%	28%	19%	4	50	107
			Unrated	8%	6%	4%	1	12	25
No	Yes	Yes	Class A	92%	90%	84%	8	161	474
			Class B	81%	78%	69%	7	140	387
			Class C	71%	62%	46%	6	110	261
			Unrated	58%	46%	32%	5	82	182
		No	Class A	79%	71%	57%	7	127	320
			Class B	62%	51%	38%	6	92	217
			Class C	42%	30%	20%	4	53	115
			Unrated	11%	9%	6%	1	15	34
	No	Yes	Class A	80%	72%	58%	7	129	329
			Class B	64%	53%	40%	6	95	227
			Class C	44%	32%	22%	4	57	124
			Unrated	14%	11%	8%	1	19	43
		No	Class A	76%	66%	51%	7	118	285
			Class B	58%	45%	32%	5	81	179
			Class C	35%	22%	15%	3	40	82
			Unrated	0%	0%	0%	0	0	0

Source: Authors' analysis.

Based on our initial observations, it appears that the roof class (moving from an unrated roof to a rated one) is very significant, and in many cases is similar or greater in magnitude than all the clearance variables.

For Territory Group A (low risk), the potential credit amounts are quite significant. However, the dollar credits are immaterial, given the low AALs for the group. Similarly, while the potential percentage credits for Territory Group C are always lower, the dollar credits are quite substantial, representing several hundred dollars for some mitigation combinations, and Territory Group B is between C and A in these regards. Ultimately, it seems that although properties in Territory Group A are given the biggest credits, it likely wouldn't be in the homeowners' best interest to invest in mitigation, whereas the benefits for homeowners in Groups B and C may be sufficient to merit such an investment.

As the dollar amount of credits will scale with the premium amounts, homeowners' incentives to mitigate will change depending on the premium amounts, as well as other factors, such as the costs of mitigation. For example, higher-value homes and lower-value homes could have similar incentives to mitigate if their premium amounts were relatively proportional to the cost of the mitigation. This could be the case for some roof replacements: larger homes would have greater replacement costs and premium amounts relative to smaller homes, but also a higher cost to perform the mitigation given a larger roof area. There are also scenarios where lower-value homes have less incentive to mitigate than higher-value homes; for example, the cost of vegetation clearing will not always scale with replacement costs and premium amounts. Thus, higher-value homes could have higher benefits for equal costs of mitigation relative to lower-value homes.

4.7. Base rate offset

We estimated the base rate offsets for the individual-level mitigation credits using aggregate AALs from the data set with actual representative parcel locations. Setting all the individual mitigation characteristics to "no" resulted in an aggregate AAL of $4.140 million, while the current aggregate AAL using an expected distribution of individual mitigation was $3.134 million. Thus, implementing credits could be expected to result in an average updated premium that is 76% of the original premium (3.134 / 4.140 = 76%). Therefore, the base rates before application of mitigation credits should be increased to 132% of their previous levels (1.0 / 76% = 132%).

4.8. Credits for only clearance and path to risk reduction

Although a roof replacement may be the most impactful mitigation action a homeowner can take, roofs can have a useful life of over 30 years, and roofing replacements are expensive and cannot be performed often. To provide an idea of the expected magnitudes of risk reduction, starting with clearance and then later replacing a roof, this final section provides a different presentation than the other parts of Section 4.

If the roof cannot be replaced, maintaining the clearance zones is the most relevant action a homeowner can take. Table 4.4 presents the credits from Table 4.3, but with an uncleared property as the base for each roof type. Thus, the table provides mitigation credits only for clearance, not for roof replacement.

Table 4.4. Mitigation credits for clearance

Credits for Clearance, Keeping Existing Roof—Territory Group A														
Clearance Variables			AAL				Percentage Credit				AAL Dollar Credit			
Reduced Fuel Zone (30–100 feet)	Lean, Clean, and Green Zone (5–30 feet)	Noncombustible Zone (0–5 feet)	Class A Roof	Class B Roof	Class C Roof	Unrated Roof	Class A Roof	Class B Roof	Class C Roof	Unrated Roof	Class A Roof	Class B Roof	Class C Roof	Unrated Roof
Yes	Yes	Yes	$0	$1	$2	$3	79%	67%	66%	69%	$2	$3	$4	$6
		No	1	2	3	4	60%	51%	50%	52%	1	2	3	5
	No	Yes	1	2	3	4	63%	53%	53%	55%	1	2	3	5
		No	2	3	5	8	9%	8%	8%	8%	0	0	0	1
No	Yes	Yes	1	2	3	4	66%	56%	55%	58%	1	2	3	5
		No	2	3	5	8	12%	11%	11%	11%	0	0	1	1
	No	Yes	2	3	5	8	15%	13%	13%	14%	0	0	1	1
		No	2	4	6	9	0%	0%	0%	0%	0	0	0	0
Credits for Clearance, Keeping Existing Roof—Territory Group B														
Clearance Variables			AAL				Percentage Credit				AAL Dollar Credit			
Reduced Fuel Zone (30–100 feet)	Lean, Clean, and Green Zone (5–30 feet)	Noncombustible Zone (0–5 feet)	Class A Roof	Class B Roof	Class C Roof	Unrated Roof	Class A Roof	Class B Roof	Class C Roof	Unrated Roof	Class A Roof	Class B Roof	Class C Roof	Unrated Roof
Yes	Yes	Yes	$10	$28	$56	$82	84%	72%	60%	54%	$51	$71	$84	$98
		No	22	45	76	105	64%	55%	46%	41%	39	54	64	74
	No	Yes	20	42	72	101	67%	58%	48%	44%	41	57	67	78
		No	55	90	129	168	10%	9%	7%	6%	6	8	10	12
No	Yes	Yes	18	39	69	97	71%	60%	51%	46%	43	60	71	82
		No	53	87	126	164	13%	11%	10%	9%	8	11	13	15
	No	Yes	51	84	123	160	17%	14%	12%	11%	10	14	17	19
		No	61	98	139	179	0%	0%	0%	0%	0	0	0	0

Source: Authors' analysis.

Table 4.4. Mitigation credits for clearance, continued

Credits for Clearance, Keeping Existing Roof—Territory Group C														
Clearance Variables			AAL				Percentage Credit				AAL Dollar Credit			
Reduced Fuel Zone (30–100 feet)	Lean, Clean, and Green Zone (5–30 feet)	Noncombustible Zone (0–5 feet)	Class A Roof	Class B Roof	Class C Roof	Unrated Roof	Class A Roof	Class B Roof	Class C Roof	Unrated Roof	Class A Roof	Class B Roof	Class C Roof	Unrated Roof
Yes	Yes	Yes	$54	$137	$268	$348	80%	64%	44%	38%	$224	$248	$214	$216
		No	108	197	320	399	61%	49%	34%	29%	171	188	162	164
	No	Yes	99	187	311	391	64%	51%	35%	31%	180	198	171	173
		No	252	357	457	539	9%	7%	5%	4%	26	28	25	25
No	Yes	Yes	90	177	302	382	68%	54%	37%	32%	189	208	179	182
		No	243	347	448	530	13%	10%	7%	6%	35	38	33	34
	No	Yes	234	337	440	521	16%	13%	9%	8%	44	48	42	43
		No	278	385	482	564	0%	0%	0%	0%	0	0	0	0

Source: Authors' analysis.

As expected, the dollar reductions for clearance in Territory Group A are not meaningful. The amounts for Territory Groups B and C are much larger: close to $100 for Group B and over $200 for Group C when clearance is performed for all three defensible space zones.

While these maximums consider reductions to risk if all clearance were performed simultaneously, in reality, clearance may initially be performed for only one or two zones, or clearance may be performed, then the roof replaced at a later date. How should homeowners decide where to start, or which actions to take? One way would be to model the effect of sequentially performing mitigation actions. Figure 4.7 depicts a typical path to risk reduction for an unmitigated risk, starting with clearing defensible space within the 5-foot zone, then the 30-foot zone, then the 100-foot zone, then later upgrading the roof if required. As noted, the benefit of clearance in Territory Group A is trivial, so it is not shown. Instead, the base risk for Groups B and C are compared. The Group C example assumes replacement of an unrated roof with a Class B, as required by many building codes. Since no such mandate would typically exist in territories like Group B, no replacement is contemplated.

Figure 4.7. Sequential AAL and reduction for performing clearance, then upgrading roof if required

Source: Authors' analysis.

In Territory Group C, an immediate reduction could be achieved by clearing the noncombustible zone ($43), and then the lean, clean, and green zone ($139). The reduction in the reduced fuel zone ($35) is meaningful, but requires clearing a larger area to get a benefit that is smaller than that for the inner zone, so homeowners in territories like this may be well advised to focus on the inner zones first to capture the maximum mitigation benefit.

Even after clearance has been performed, homes in Group C can still receive a material benefit ($210 reduction in AAL) from a roofing upgrade, so the benefits may well merit the costs in this case.

As expected for Territory Group B, the effect of each mitigation action is smaller. Nevertheless, clearing at least the noncombustible zone and the lean, clean, and green zone ($19 and $63) would likely be worthwhile. It should be noted, given the higher density of Group B, that the reduced fuel zone may exist beyond the property line, and thus not be within the homeowner's purview to clear. With clearance performed, the AAL to Group B is substantially reduced, meaning the additional expense of a fire-resistive roof may not be significantly offset by reduced insurance premiums.

As can be seen in these examples, the incremental effect of any given home mitigation action may be highly sensitive to geographic location and mitigation actions already undertaken.

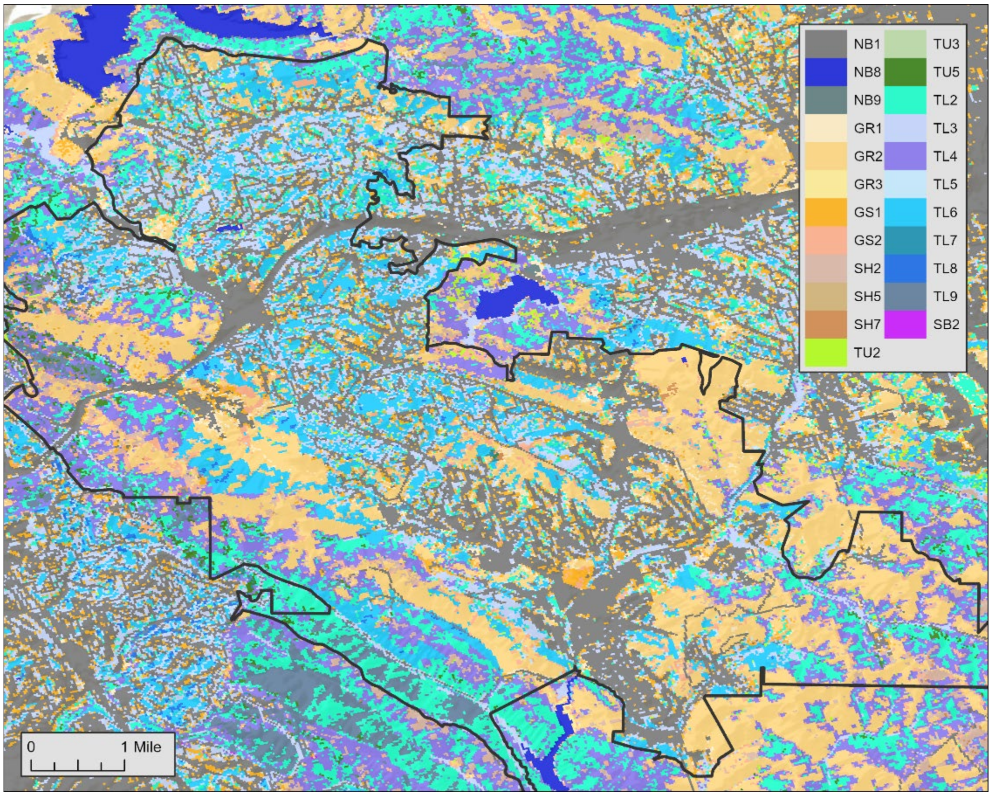
5. Case Study 2: Credits for Community Mitigation

The previous section focused on calculating credits for individuals who invested in mitigation measures, using results from a model that contains individual-level parameters. As described in section 2, mitigation can also be done at the community level, where community resources are used to mitigate or maintain areas common to the community or surrounding it. To measure the impact of this type of mitigation effort, it must be translated into appropriate model terms. This section focuses on a potential methodology to measure the effect of community-level fuel reduction program by modifying the CoreLogic model fuel layer and a method to calculate the resulting mitigation credits.

5.1. Fuel modification approach

As with other models, wildfire models allow the input of individual property characteristics for a straightforward way to evaluate risk relativities. For communities, models do not typically contain such a straightforward approach because large mitigation projects cannot be summarized with simple parameters. The risk to any community is derived from simulation and based on the specific layout and fuel characteristics of the community. Spread is based on a fuel layer, so if a community were to engage in projects to reduce spread, these actions would need to be translated into the terms of the fuel layer to obtain modeled results. As previously described, the FBFM40 fuel layer used in the CoreLogic model classifies land cover into 7 types, each comprised of several categories, for a total of 40 categories. The 7 types are nonburnable (NB), grass (GR), grass-shrub (GS), shrub (SH), timber-understory (TU), timber litter (TL), and slash-blowdown (SB) (Scott and Burgan 2005). Types relate to the fundamental characteristics of the area and can be treated as constant. For example, grass cannot easily be changed to forest or vice versa. For our study area, the fuel cover is mapped in Figure 5.1. All fuel categories in the study area appear in the legend.

Figure 5.1. Study area fuel model categories



Source: Authors' analysis using the CoreLogic model and FBFM40.

The fires that destroyed the California towns of Paradise (Camp Fire) and Greenville (Dixie Fire) had a similar characterization: explosive fire growth driven by dry, hot, and windy conditions. Both communities were older (both were established in the 1880s, although Paradise experienced significant growth in the 1960s and 1970s) and were situated next to or in forested land. The age of the communities influences street layouts and defensible features. These communities share a common risk element with many other communities in California: low to middle elevations along the western slope of the Sierra Nevada mountains—areas associated with warm to hot Mediterranean summer climates and cool to cold winters—in a foothill woodland vegetation zone. The Orinda/Moraga region in this study is lower elevation with a climate that includes a stronger coastal influence, but the hot summers and semirural housing density make it a useful study area for lessons in risk mitigation.

The study area is comprised of 23 categories from the 7 fuel layer types. As described, the Orinda/Moraga area is heavily vegetated but is suburban to a major city and, as a result, offers a wide variety of fuel types. Some of the area, further from the perimeter, is quite developed and the risk is lower, but some of the area includes substantial tree cover which is uncharacteristic of typical urban or suburban settings.

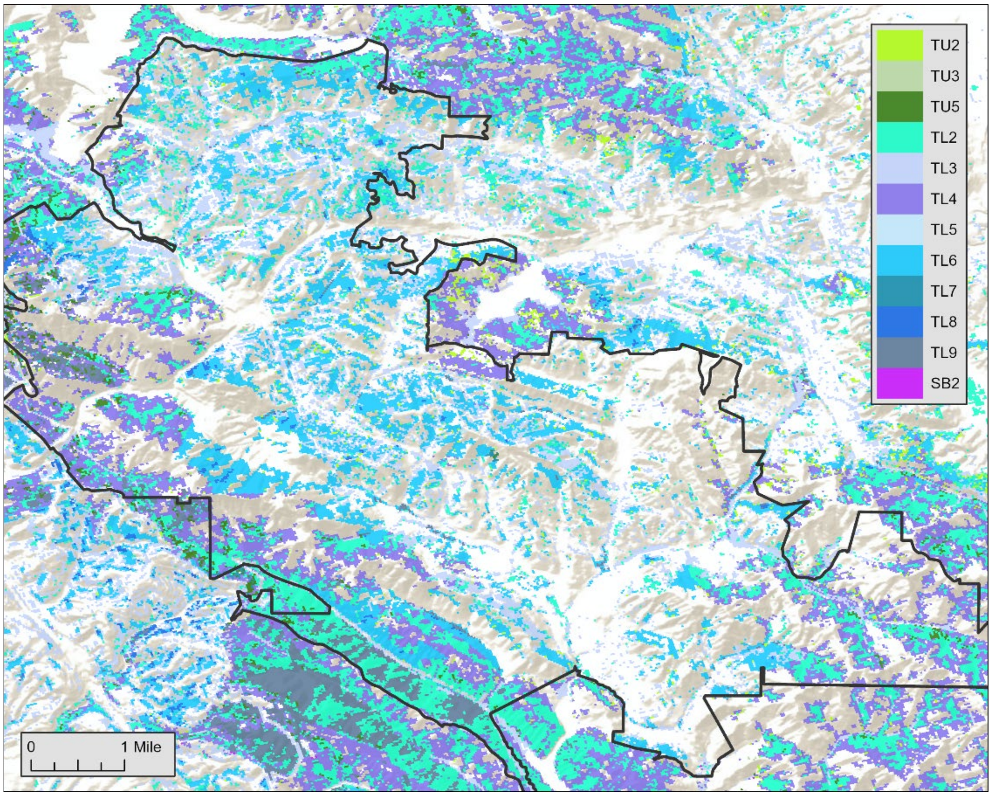
The categories within a type are numbered (for example, TU1 through TU5), with the lower numbers generally representing lower *load*, meaning understory debris has been cleared, and indicating a lower spread potential. Unlike the land cover type, the load is something that could potentially be changed, either due to a wildfire incinerating it or due to a management program to clear it. Management of land cover and understory fuel loads are among the most important community-level mitigation actions that can be performed. If understory management transformed some or all of the areas' moderate loads into light loads, the areas would be reclassified from TU5 to TU1, and the model simulation could be rerun.

In particular, the fuel types corresponding to wildfire risk and present in a high-risk forested area are TU, TL, and SB. Figure 5.2 depicts the study area with only these types. In terms of fire risk, the area is mainly covered with substantial coverage of the TL category, comprised mostly of TL6 (indicating a moderate fuel load), but also of TL2 (indicating a low load) and TL4 (indicating a moderate load with small diameter downed logs). There are many other categories present, but the other TL types, as well as the TU and SB types, present minimal coverage in the study area. To simulate a community mitigation project for our study area, the underlying layer was modified so the lowest load category of each type would apply. Specifically, the following steps were taken:

- TU2, TU3, and TU5 were modified to TU1;
- TL2 through TL9 were modified to TL1; and
- SB2 was modified to SB1.

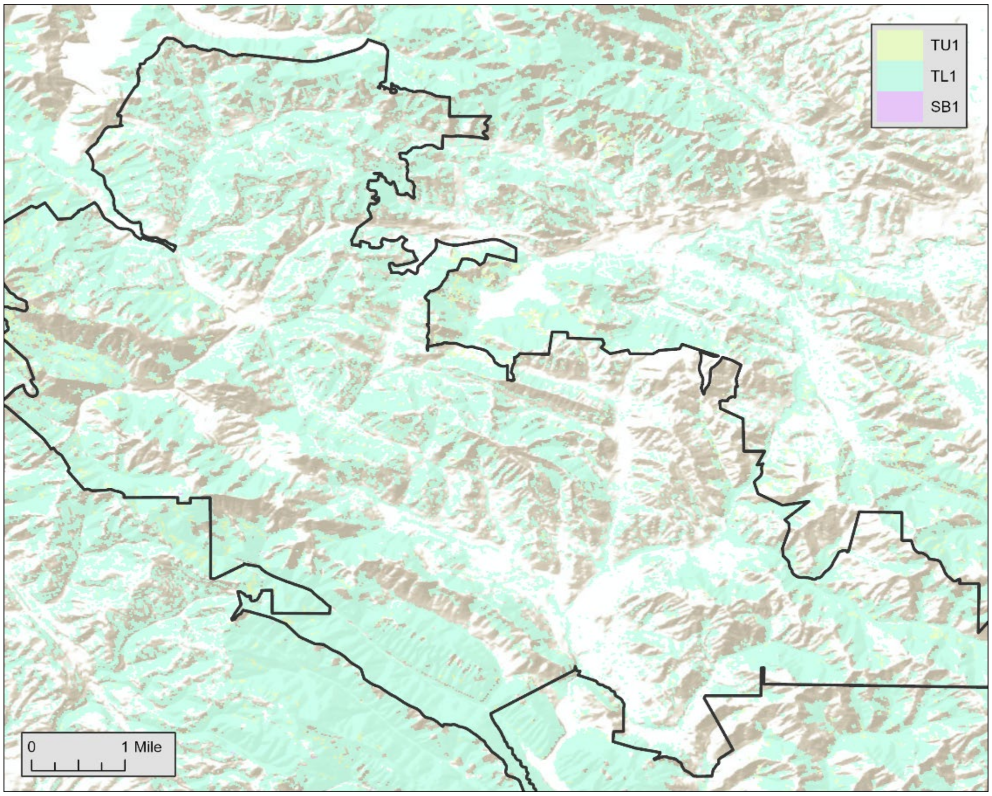
The resulting fuel layer is depicted in Figure 5.3; the original in Figure 5.2. Note that the entire Orinda/Moraga study area shown, as well as nearby surrounding areas, were modified as described above. Also note that these community mitigation actions are in addition to, and do not overlap with, the various home-level mitigation actions previously modeled.

Figure 5.2. Study area actual TU, TL, and SB fuel categories



Source: Authors' analysis using the CoreLogic model and FBFM40.

Figure 5.3. Study area modified to lowest TU, TL, and SB fuel categories



Source: Authors' analysis using the CoreLogic model and FBFM40.

This example represents a scenario in which the fundamental nature of the landscape wasn't changed, but a fairly aggressive fuel maintenance project was undertaken, such that 100% of moderate- or high-load territory was modified to low load. Thus, while the scenario depicted is possible, it likely represents an aggressive hypothetical situation in terms of what would be achievable or cost effective for the community. In practice, a community's particular mitigation actions could be used to modify the fuel layer, or effects could be calculated for gradations of load clearance.

5.2. Rate credits for community mitigation

Using this as the new layer underlying the catastrophe simulation and the same portfolios as before, results were rerun and recalculated. Our initial assessment considered the credits in a similar fashion as before, and we compared them with the prior results. The credits that follow depict the combined effect of mitigation credits with the community fuel modification project, so the credits can be interpreted as the incentives an insurer could provide if the base premium reflected the community's prior state, and these credits could be offered for both the community and individual mitigation actions. We note that this is one potential approach, but approaches could vary based on the procedures for pricing. For example, if the territory factors were updated to reflect the community's new fuel characteristics, then the effect of community mitigation would be double counted with this approach because it would be reflected in the territory factors as well as the credits. Improved community mitigation provides numerous benefits beyond insurance, such as support for municipal bond ratings and municipal service reviews within Local Agency Formation Commissions, as well as clear, obvious benefits like protection of life and property ("What Are LAFCos?" 2022).

The resulting credits appear in Table 5.1 and are presented in a similar fashion as the individual credit case study.

Table 5.1. Mitigation credits after fuel modification

Individual Mitigation Credits—Modified Fuel Scenario									
Mitigation Variables				Percentage Credit			AAL Dollar Credit		
Clearance—Reduced Fuel Zone (30–100 feet)	Clearance—Lean, Clean, and Green Zone (5–30 feet)	Clearance—Noncombustible Zone (0–5 feet)	Roof Fire Class	Territory Group A Low Risk	Territory Group B Medium Risk	Territory Group C High Risk	Territory Group A Low Risk	Territory Group B Medium Risk	Territory Group C High Risk
Yes	Yes	Yes	Class A	96%	97%	95%	$9	$174	$535
			Class B	90%	91%	87%	8	163	490
			Class C	84%	82%	74%	8	146	417
			Unrated	78%	72%	66%	7	130	371
		No	Class A	93%	93%	90%	8	166	506
			Class B	85%	85%	81%	8	152	457
			Class C	77%	74%	69%	7	133	387
			Unrated	66%	64%	60%	6	114	341
	No	Yes	Class A	94%	93%	91%	8	167	511
			Class B	86%	86%	82%	8	154	462
			Class C	78%	75%	70%	7	135	392
			Unrated	68%	65%	61%	6	116	346
		No	Class A	85%	81%	76%	8	146	426
			Class B	72%	69%	65%	6	124	366
			Class C	57%	54%	54%	5	98	307
			Unrated	32%	40%	46%	3	72	259
No	Yes	Yes	Class A	94%	94%	92%	8	169	516
			Class B	86%	87%	83%	8	156	468
			Class C	79%	77%	70%	7	137	397
			Unrated	70%	66%	62%	6	119	351
		No	Class A	85%	82%	76%	8	147	431
			Class B	73%	70%	66%	7	125	371
			Class C	58%	56%	55%	5	100	312
			Unrated	34%	42%	47%	3	75	264
	No	Yes	Class A	86%	83%	77%	8	149	436
			Class B	74%	71%	67%	7	127	377
			Class C	59%	57%	56%	5	102	317
			Unrated	37%	43%	48%	3	77	269
		No	Class A	83%	79%	73%	7	142	411
			Class B	70%	66%	62%	6	118	349
			Class C	53%	51%	52%	5	91	293
			Unrated	26%	36%	43%	2	65	244

Source: Authors' analysis.

The pattern and magnitudes of the credits are similar to before, but the indicated credit percentages and amounts increased for all classes compared to the scenario with only individual mitigation. Of note, the minimum credit is now 26% for the least mitigated class, indicating the potential benefit of community mitigation even with no individual mitigation.

To get a better sense of how the community mitigation results compared with the individual mitigation results, we calculated the differences between the mitigation credits both in percentage and dollar terms.[9] Table 5.2 depicts these differences.

Table 5.2. Mitigation credits: Additional benefit of community mitigation beyond individual mitigation

Individual Mitigation Credits—Benefit of Modified Fuel Scenario Compared to Standard									
Mitigation Variables				Percentage Credit			AAL Dollar Difference		
Clearance—Reduced Fuel Zone (30–100 feet)	Clearance—Lean, Clean, and Green Zone (5–30 feet)	Clearance—Noncombustible Zone (0–5 feet)	Roof Fire Class	Territory Group A Low Risk	Territory Group B Medium Risk	Territory Group C High Risk	Territory Group A Low Risk	Territory Group B Medium Risk	Territory Group C High Risk
Yes	Yes	Yes	Class A	1%	2%	5%	$0	$4	$26
			Class B	4%	6%	11%	0	11	64
			Class C	6%	13%	21%	1	23	121
			Unrated	9%	18%	28%	1	32	155
		No	Class A	3%	5%	9%	0	9	50
			Class B	6%	10%	16%	1	17	90
			Class C	9%	16%	25%	1	29	143
			Unrated	13%	22%	31%	1	40	177
	No	Yes	Class A	2%	4%	8%	0	8	46
			Class B	5%	9%	15%	0	16	85
			Class C	9%	16%	25%	1	28	139
			Unrated	13%	21%	31%	1	38	173
		No	Class A	7%	12%	20%	1	22	114
			Class B	11%	19%	28%	1	34	159
			Class C	17%	27%	36%	1	48	201
			Unrated	24%	34%	41%	2	61	234
No	Yes	Yes	Class A	2%	4%	7%	0	7	42
			Class B	5%	8%	14%	0	15	81
			Class C	8%	15%	24%	1	27	136
			Unrated	12%	21%	30%	1	37	169
		No	Class A	6%	12%	20%	1	21	111
			Class B	11%	19%	27%	1	33	155
			Class C	16%	26%	35%	1	47	197
			Unrated	23%	33%	41%	2	59	230
	No	Yes	Class A	6%	11%	19%	1	20	107
			Class B	10%	18%	27%	1	32	150
			Class C	16%	25%	34%	1	45	193
			Unrated	23%	32%	40%	2	58	227
		No	Class A	7%	13%	22%	1	24	126
			Class B	12%	21%	30%	1	37	171
			Class C	18%	29%	37%	2	51	211
			Unrated	26%	36%	43%	2	65	244

Source: Authors' analysis.

A comparison of the differences reveals that the benefit of community mitigation is generally larger for the less-mitigated classes, and much smaller for the mitigated classes, in all territory groups, and the benefit (in percentage and dollar terms) increases with risk. This result makes intuitive sense, as those who reduce their risk through individual

[9] For both dollars and percentages, the differences are simple differences. For example, if the credit changed from 75% to 80%, the difference would be shown as 5%.

mitigation will have less risk to be reduced by community mitigation. If the community were to undertake fuel modification, then it would be those in closest proximity to the fuel (Territory Group C) whose risk would be most reduced.

6. Case Study 3: Measuring Results at the Community Level

The previous sections focused on how mitigation credits could be calculated for individual and community mitigation projects and provided amounts based on a base risk at 343 census block centroids. While this base risk approach allows a consistent way to calculate credits, it does not lend itself to consideration of changes in the aggregate, which would be necessary for ratemaking activities such as offsetting the base rates, or non-ratemaking activities such as analyzing costs and benefits or comparing results between potential mitigation scenarios.

This section focuses on estimating and comparing results in the aggregate for these purposes. Please note that the numbers in this section can be treated only as illustrative and representative of the high end of what could be achievable through fuel modification. In practice, the fuel modification of the underlying layer would need to be matched to the community's actual activities. Our intent is to depict the methodology with which the total benefits of a community's mitigation actions could be quantified and then compared to cost.

While the fuel modification itself likely reflects a high-end scenario, the inclusion of only residential risk reflects a very low-end scenario in terms of the benefit to society as a whole. Residential losses represent the most significant fraction of wildfire risk in financial terms, but there are several other exposures, such as commercial and government structures and infrastructure, and other consequences, including health risks and loss of life. For example, when wildfire disrupts a local water system, otherwise undamaged homes may become uninhabitable and local businesses may fail.

We would expect that a fuel modification project such as the one contemplated here would provide benefits to these other exposures, so in practice, these would need to be considered in terms of estimating the total benefit to the community. Commercial and government structures should be included in the analysis, and/or a multiplier could be used to estimate a more comprehensive value of prepared parcels and hardened homes in the context of the greater community.

6.1. Quantifying aggregate results

As described in section 4, the base risk data set exists at limited points (343 locations) and has simplified variation in some rating attributes (such as Coverage A, for which all points were set to $400,000) and maximum variation in others (such as the mitigation characteristics, for which all variations were modeled at every point). For this case study, we also prepared a data set with actual parcel locations, intended to reflect an accurate representation of the total marketplace either by using a best estimate of the true value for every rating attribute or by using a best estimate of the true distribution of that attribute. Our data set of 12,612 actual parcel locations was provided by CoreLogic and assumed an average home replacement cost of approximately $500 per square foot.

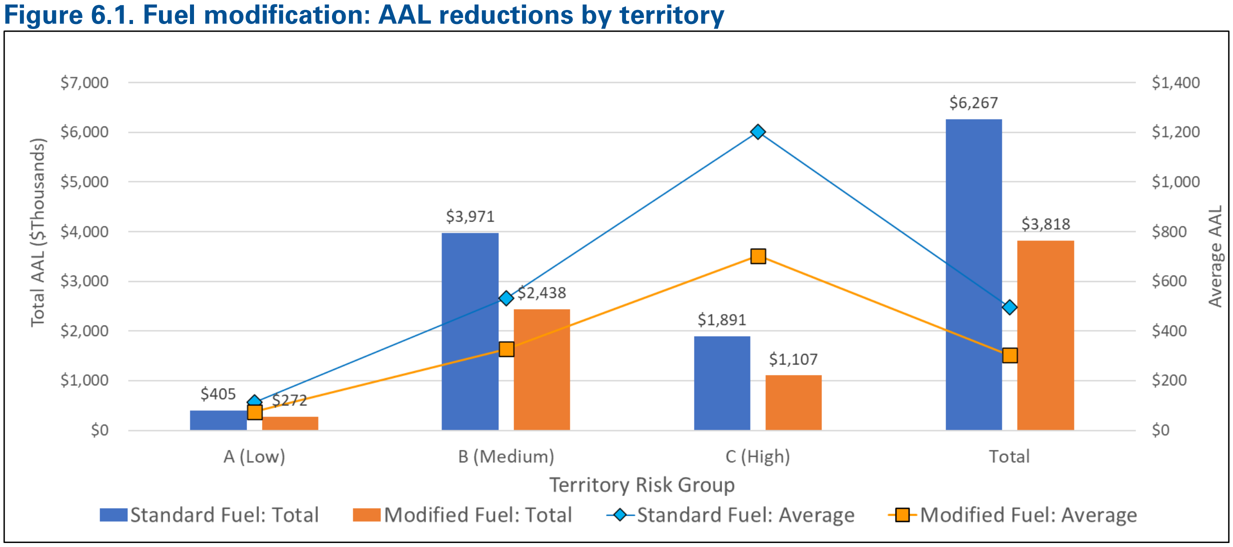
Since the effects of this mitigation seem to vary by AAL, we examined the results in total, and by Territory Groups A, B, and C, clustered in the prior step. The aggregate results of the fuel modification, by territory group, appear in Table 6.1 and Figure 6.1.

Table 6.1. Modeled results after fuel modification

	Community Mitigation Scenario							
	Standard Fuels				Modified Fuels			
	Territory Risk Group							
	A (Low)	B (Medium)	C (High)	Total	A (Low)	B (Medium)	C (High)	Total
Parcel Count	3,588	7,451	1,573	12,612	3,588	7,451	1,573	12,612
Average AAL	$113	$533	$1,202	$497	$76	$327	$704	$303
Total AAL ($000s)	$405	$3,971	$1,891	$6,267	$272	$2,438	$1,107	$3,818
Total $ AAL Reduction from Fuel Reduction ($000s)					$132	$1,533	$785	$2,450
Average $ AAL Reduction from Fuel Reduction					$37	$206	$499	$194
% AAL Reduction from Fuel Reduction					-33%	-39%	-41%	-39%
Total $ Premium Reduction from Fuel Reduction ($000s)					$203	$2,358	$1,207	$3,769
Average $ Premium Reduction from Fuel Reduction					$57	$316	$767	$299

Source: Authors' analysis.

Figure 6.1. Fuel modification: AAL reductions by territory



Source: Authors' analysis.

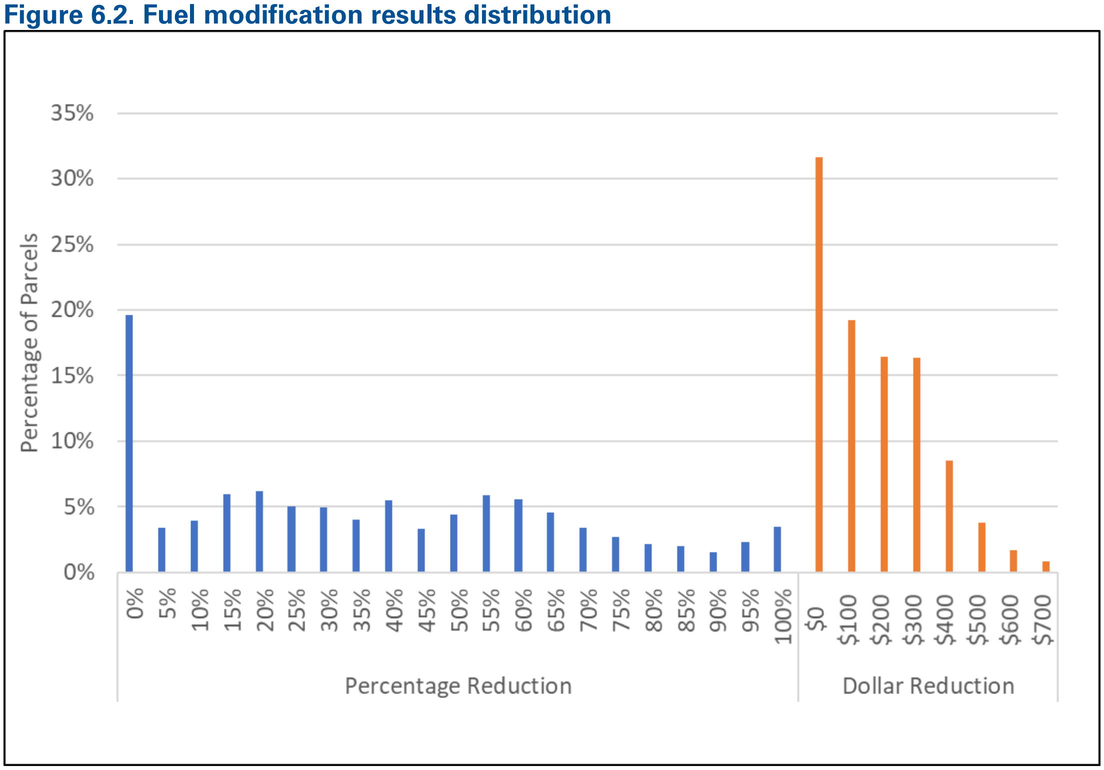
In the aggregate, the modeled reduction in AAL for this community resulting from this fuel modification is 39%, a reduction of around $2.45 million, compared with an initial AAL of $6.27 million. Assuming a 65% loss ratio, the total annual premium reduction for all homes in the study area is $3.77 million.

On average, the modeled percentage risk reduction resulting from fuel modification is similar across the territory groups, ranging between 33% for Group A to 41% for Group C. In premium dollar terms, the per home reduction for Group A is minimal, around $57 on average, whereas the reductions are much larger in the higher risk territories, $316 and $767 for Groups B and C, respectively.

Of the 12,612 parcels, only 12.5% (1,573) are in Group C, but they represent 30% of the total AAL ($1.89 million) and see 32% of the reduction in aggregate risk resulting from community mitigation ($785,000). While Group C certainly contributes a disproportionately high share of risk and enjoys a disproportionately high share of the benefit from community mitigation, it cannot be said that the costs or benefits are isolated to these high-risk areas. The majority of the parcels (59%) are in medium-risk Group B, and they still enjoy a noticeable benefit on average ($206 reduction in AAL) and receive the lion's share of the aggregate benefit ($1.53 million). For the 28% of parcels in Group A, the benefit is minimal: only a $37 average reduction in AAL and an aggregate benefit of $132,000, which is only 5% of the total benefit of community mitigation.

Beyond the differences by territory group, it can be informative to consider the distributions of the risk reductions when considering how the benefits of a fuel modification program would apply. Figure 6.2 provides two histograms, one in percentage terms and one in dollar terms, of how the AAL reduction from fuel modification is distributed throughout the study area.

Figure 6.2. Fuel modification results distribution

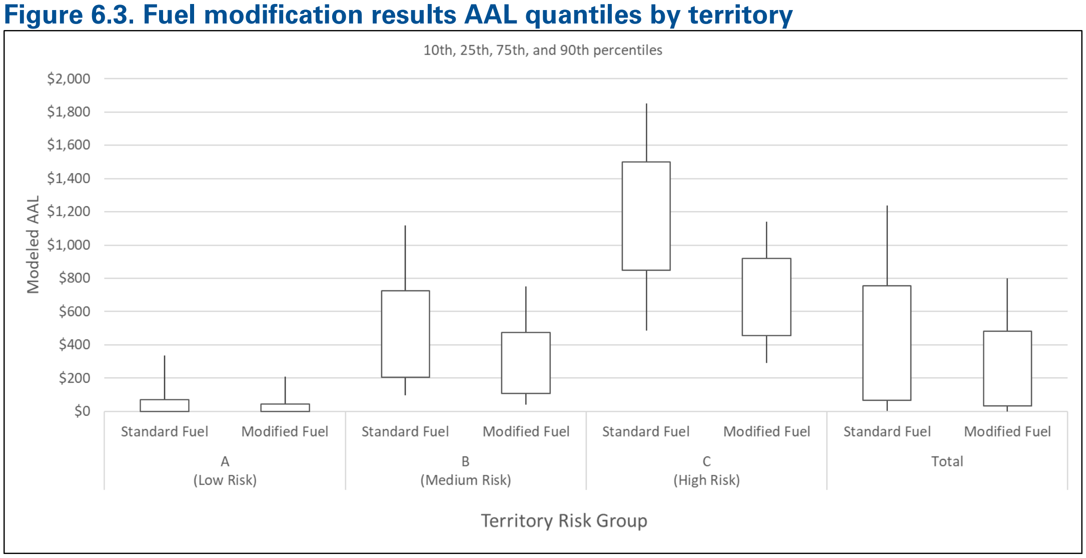


Source: Authors' analysis.

In percentage terms, close to 20% of parcels are at 0%, meaning there is little direct benefit from the project. Otherwise, there is a fairly even spread or percentage reductions, from 5% all the way up to 100%, with a meaningful number of parcels in each 5% interval, but with most parcels receiving reductions either in the 10%–25% range or in the 50%–65% range. In dollar terms, over 30% of parcels receive a benefit less than $50 (the $0 category is rounded to the nearest $100). Around 20% receive a benefit between $50 and $150, and the remaining 50% receive more significant benefits. As previously mentioned, this is measuring direct benefits to the homeowners, but indirect benefits to the community may be much greater.

Considering the distribution by territory can also be helpful in discerning how the hypothetical action would affect the members of the community. Figure 6.3 provides box plots giving the risk quantiles before and after community mitigation.

Figure 6.3. Fuel modification results AAL quantiles by territory



Source: Authors' analysis.

As described above, the benefit to Territory Group A is minimal: less than $50 for most homes. For Group B, the fuel modification eliminates substantial risk for most homes, with the majority seeing $100–$300 annual reductions. For Group C, the most common observations are indicative of substantial benefits: above $300 for the majority of Group C parcels. Please note that these results are based on AAL reductions, whereas the corresponding premium reductions could be approximately 54% higher given our assumed 65% loss ratio.

6.2. Comparing community and individual mitigation scenarios

The previous section focused on how wildfire catastrophe model inputs and outputs could be used to measure the total benefits to a community resulting from an understory fuel management project and how those benefits would be distributed throughout the population. This section extends the example by comparing the results for the community-level project with modeled scenarios reflecting individual-level mitigation.

To create this comparison, we created three additional versions of the parcel-level data set in addition to the version described in Section 6.1. The four data sets are as follows:

1. a *current* case version, intended to reflect the current degree of mitigation;
2. a *no mitigation* version, intended to reflect a worst-case scenario with less mitigation than is currently assumed;
3. a *current with clearance* version, intended to reflect a scenario where no upgrades are made but all clearance is performed; and
4. a *clearance and upgrades* version, intended to reflect a best-case scenario with not only clearance performed, but also upgrades to fire-resistive siding, windows, and a Class B roof.[10]

The inputs to each parcel-level data set are detailed in Table 6.2.

Table 6.2. Model inputs for community mitigation scenarios

Mitigation Scenario Inputs for Parcel Locations				
Model Variable	No Mitigation	Current Case	Current with Clearance	Clearance and Upgrades
Occupancy	Residential	Residential	Residential	Residential
Coverage A (Dwelling)	Actual	Actual	Actual	Actual
Coverage B (Other Structures)	7.5% of A	7.5% of A	7.5% of A	7.5% of A
Coverage C (Contents)	60.0% of A	60.0% of A	60.0% of A	60.0% of A
Coverage D (Loss of Use)	20.0% of A	20.0% of A	20.0% of A	20.0% of A
Deductible	0.5% of Coverage A	0.5% of Coverage A	0.5% of Coverage A	0.5% of Coverage A
Structure Type	Estimated Distribution	Estimated Distribution	Estimated Distribution	Estimated Distribution
Year Built	Actual	Actual	Actual	Actual
Number of Stories	Estimated Distribution	Estimated Distribution	Estimated Distribution	Estimated Distribution
Roofing Fire Class	Unrated	Estimated Distribution	Estimated Distribution	Class B
Clearance—Noncombustible Zone	No	Estimated Distribution	Yes	Yes
Clearance—Lean, Clean, and Green Zone	No	Estimated Distribution	Yes	Yes
Clearance—Reduced Fuel Zone	No	Estimated Distribution	Yes	Yes
Fire-Resistive Siding	No	Estimated Distribution	Estimated Distribution	Yes
External Fire Extinguisher	No	Estimated Distribution	Estimated Distribution	Estimated Distribution
Combustible Attachments	Yes	Estimated Distribution	No	No
Fire-Resistive Windows	No	Estimated Distribution	Estimated Distribution	Yes

Source: Authors' model inputs.

[10] Though some municipal building codes require all new construction in areas with wildfire risk to have a Class A roof, we expect that a housing stock comprised of Class B roofs reflects the most reasonable best-case scenario at this time.

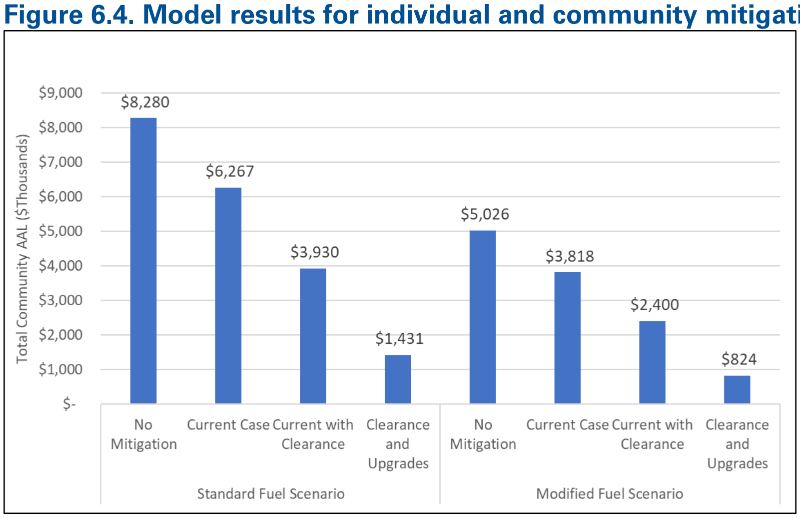
Model results were generated for each of the four portfolios above, with and without the community level modifications to the fuel layer (referred to as *standard fuels* and *modified fuels*). The resulting modeled AALs and calculated benefits for each scenario appear in Table 6.3 and Figures 6.4, 6.5, and 6.6.

Table 6.3. Model results for community mitigation scenarios

	Community Mitigation Scenario							
	Standard Fuels				Modified Fuels			
	Individual Mitigation Scenario							
	No Mitigation	Current Case	Current with Clearance	Clearance and Upgrades	No Mitigation	Current Case	Current with Clearance	Clearance and Upgrades
Average AAL	$656	$497	$312	$113	$399	$303	$191	$66
Total AAL ($000s)	$8,280	$6,267	$3,930	$1,431	$5,026	$3,818	$2,400	$824
Average Premium	$1,010	$765	$479	$175	$613	$466	$294	$101
Total Premium ($000s)	$12,738	$9,642	$6,046	$2,201	$7,733	$5,873	$3,693	$1,268
AAL Reduction from Community Mit.(%)					-39.3%	-39.1%	-38.7%	-42.2%
AAL Reduction from Individual Mit. (%)	32.1%	0.0%	-37.3%	-77.2%	31.7%	0.0%	-36.9%	-78.3%
AAL Reduction from Both (%)					-19.8%	-39.1%	-61.6%	-86.8%

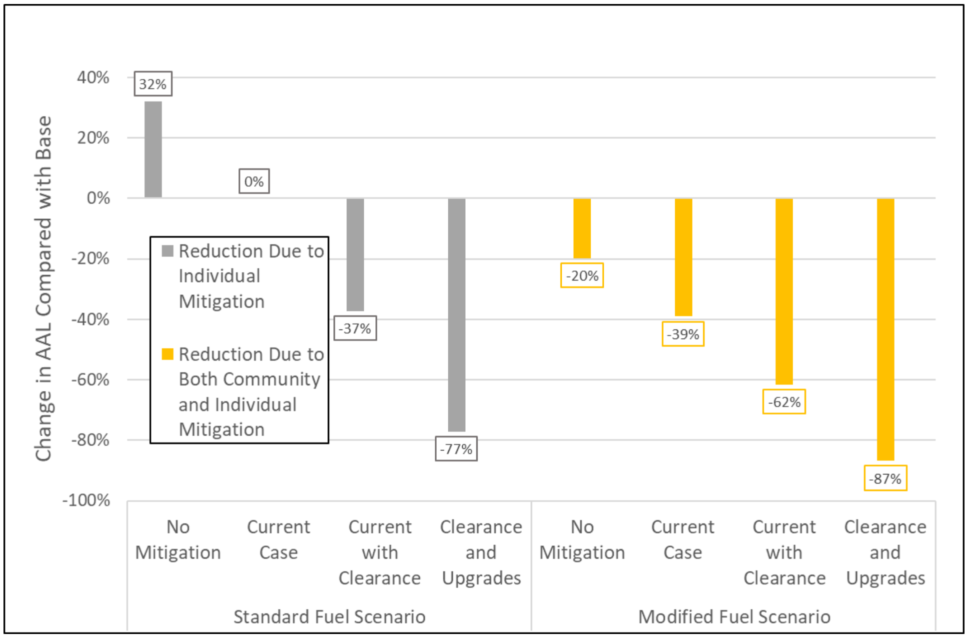
Source: Authors' analysis.

Figure 6.4. Model results for individual and community mitigation scenarios



Source: Authors' analysis.

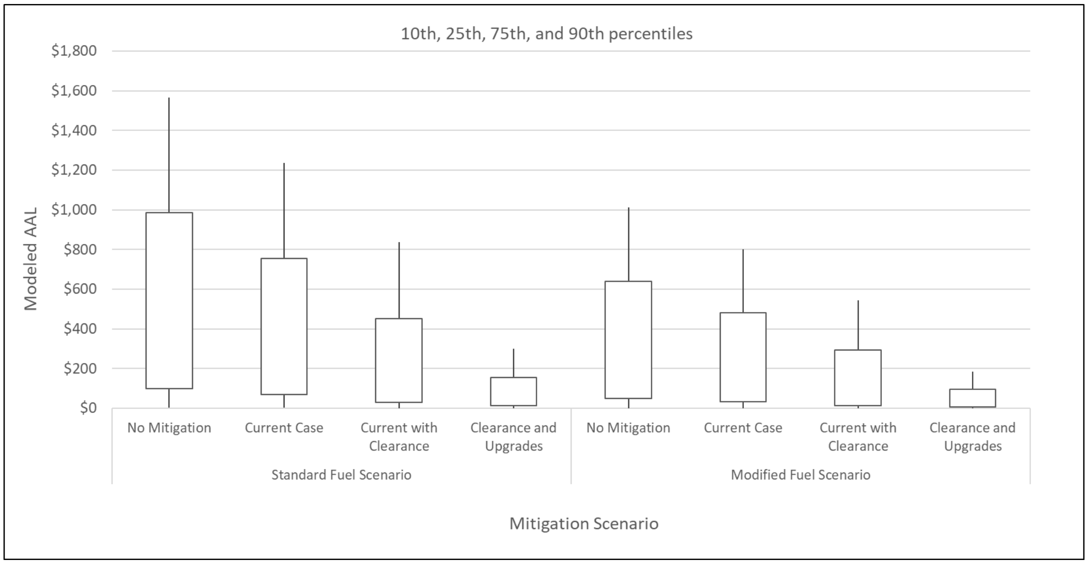
Figure 6.5. Model results: Change for individual and community mitigation scenarios (%)



Source: Authors' analysis.

As described in section 6.1, the modeled AAL associated with the community-mitigation fuel reduction project is $3.818 million (current case, modified fuels scenario), compared with the current scenario AAL of $6.267 million (current case, standard fuels scenario). The improvement in community-level risk based on fuel modification is similar to the case where clearance is performed on all parcels (current with clearance, standard fuels scenario, with an AAL of $3.930 million), meaning that in aggregate, the best-case scenarios for community versus individual mitigation are of a similar magnitude. If this community were to have a choice between developing a program to help homeowners ensure adequate clearance on their properties and engaging in a fuel management project, it could consider these estimates against the costs of the programs to determine which ones to proceed with. Of course, in this example, both of the hypotheticals are fairly extreme. It may be too optimistic to expect clearance to be performed on *all* parcels, or for the fuel to be reduced to light loads in all of the TL, TU, and SH land cover types in a given area. For a community performing a cost-benefit analysis, gradations in the degree of mitigation could be recognized—for example comparing results for 50%, 75%, or 90% of parcels performing individual clearance versus different community fuel management projects of varying cost and scope.

Figure 6.6. Model results: Change in AAL, quantiles comparison



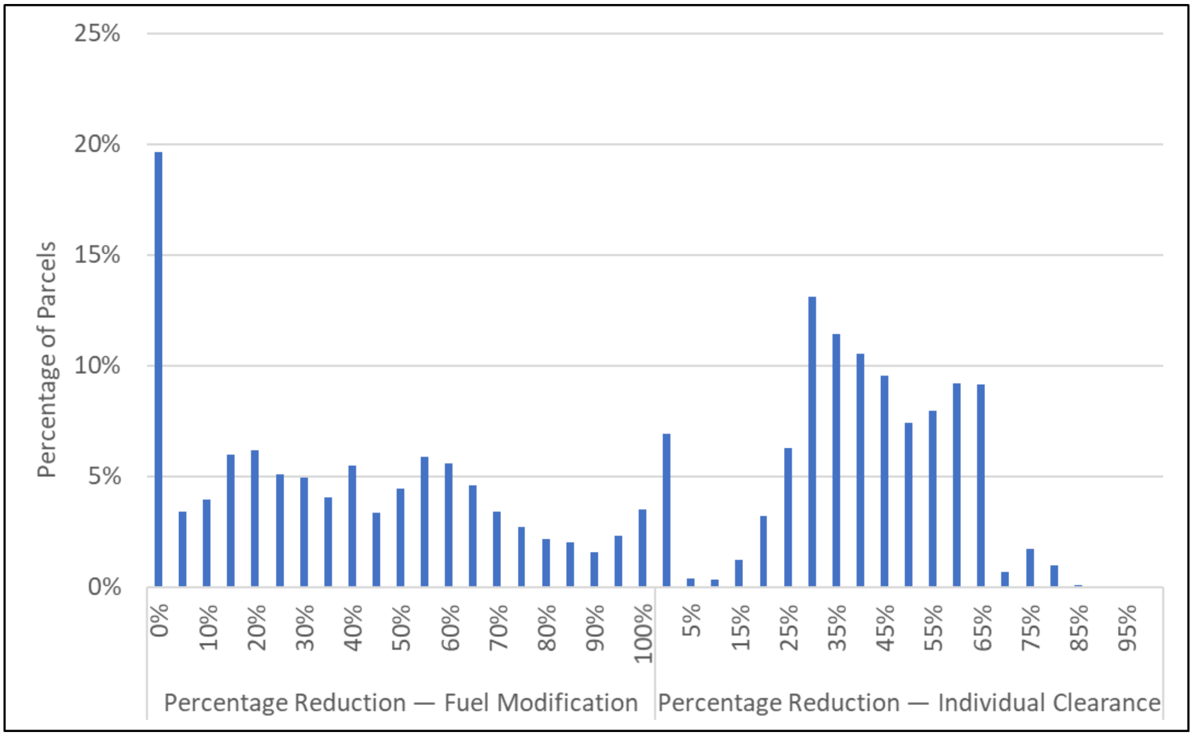
Source: Authors' analysis.

Such a comparison can also be used to consider points of diminishing returns. For example, the benefits of fuel modification and individual clearance scenarios may be similar, each reducing modeled loss by around $2.3–$2.4 million, but when combined (current with clearance, modified fuels), the additional reduction is only around $1.4 million, meaning the benefit of either program would be substantially reduced if the other had been performed first.

In the case of clearance and upgrades, assuming all parcels have not just clearance but Class B roofs or better, along with fire-resistive windows and siding, reduces the risk so substantially that the benefit from any additional community-level project would be minimal. We modeled these upgrades, especially a roof upgrade, which is the biggest-ticket item both in terms of risk reduction and cost, because they cannot be expected to be made immediately, as it would generally not be economical to replace an existing roof with remaining useful life merely in the interest of wildfire mitigation. Clearance may be associated with a cost, but is not associated with the same issue of useful life and could theoretically be performed immediately. Nevertheless, as described, replacement of existing roofs with fire-resistive ones is mandated by building codes in most high-risk areas. Roofs may have a useful life of 20–30 years, meaning that while the roof replacement scenario may not be realistic in the immediate term, a realistic longer-term projection may consider that at some point in the future, substantially all roofs in high-risk areas could be Class B or better.

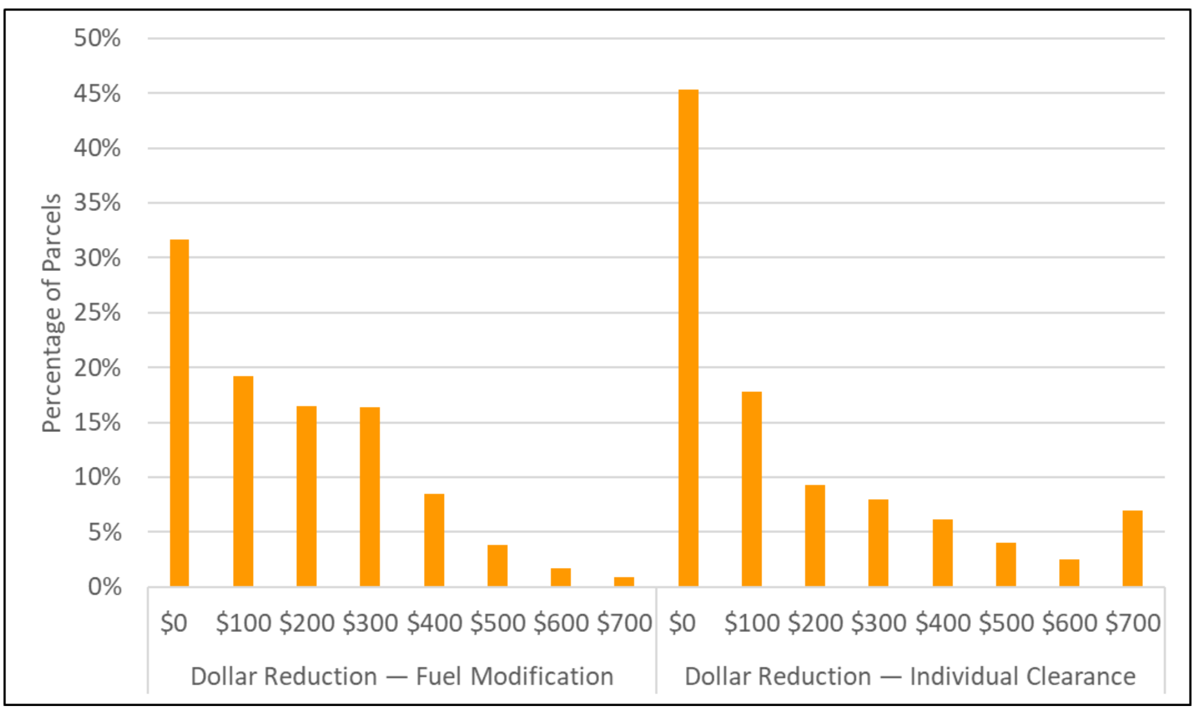
As with the fuel modification scenario, assessment of benefits should also consider how those benefits are distributed throughout the population. A comparison of the fuel modification scenario with individual mitigation is given in Figures 6.7 and 6.8.

Figure 6.7. Change in AAL, distribution comparison (%)



Source: Authors' analysis.

Figure 6.8. Change in AAL, distribution comparison ($)



Source: Authors' analysis.

In the case of fuel modification, the reduction percentage amounts are more spread out, meaning some citizens would have their risk substantially reduced and others would barely see a benefit. In the case of individual clearance, the reduction percentages are more concentrated, most ranging between 30% and 65%.

In some sense, the individual mitigation scenario could be considered more equitable. Assuming that individual homeowners perform their own clearance and that a community-level mitigation project would be paid for by shared tax contributions, both offer very uneven benefits relative to the costs. Figure 6.8 shows that, from a dollar perspective, many parcels see little direct benefit in both cases, especially the individual clearance case with a benefit of under $50. Given the small benefit, the owners of these parcels may be unlikely to perform individual mitigation, which wouldn't raise the community risk profile by much since these are the low-risk parcels. At the same time, they would still receive a benefit under community mitigation, even if it were small. As a result, the benefits of mitigation may be more readily captured through a community-level program rather than relying on the participation of individual homeowners to do mitigation themselves. Ultimately, the costs of each mitigation action could be weighed against the estimated benefits through methodologies similar to those presented in this paper in order to prioritize the most impactful and efficient mitigation activities.

6.3. Additional community considerations

Beyond quantifying aggregate benefits of mitigation, communities using catastrophe models to evaluate mitigation actions will need to engage in complex cost-benefit analyses to determine the optimal degree and type of mitigation. Communities will need to consider the potential cost of various measures and will also need estimates of the useful life of various improvements to determine whether they are justified. For example, clearance maintenance or fuel reduction may need to be performed annually or periodically and have recurring costs, whereas infrastructure projects would more often have one-time costs. Communities' use of cost-benefit analysis could optimally be reflected in building codes: for example, not only requiring fire-resistive roofing where long-term risk reductions justify costs, but also avoiding requirements in low-risk areas where extra costs are not justified. Communities should also consider unmodeled benefits to account for the stock and infrastructure that are not explicitly recognized by a model as well as intangible benefits, such as improved peace of mind, health, and safety of community members.

Communities may also consider the equity inherent in various mitigation strategies, including how costs and benefits are distributed throughout the community, and the likelihood that individual mitigation will be performed. As with insurers, communities face a difficult task in measuring the prevalence of certain mitigation activities, such as clearance, but obtaining reliable data on this prevalence may prove invaluable when considering available options.

7. Limitations

7.1. Use of report

The data and exhibits in this report are provided to support the conclusions contained herein, limited to the scope of work specified by the CAS, and may not be suitable for other purposes. Milliman is available to answer any questions regarding this report or any other aspect of our review.

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7.3. Data reliance

In performing this analysis we relied upon information obtained from CoreLogic, CDI, IBHS, NOAA, and other sources. We have not audited or verified this data and information. If the underlying data or information is inaccurate or incomplete, the results of our analysis may likewise be inaccurate or incomplete. In that event, the results of our analysis may not be suitable for the intended purpose.

We performed a limited review of the data used directly in our analysis for reasonableness and consistency. We did not find material defects in the data. If there are material defects in the data, it is possible that they would be uncovered by a detailed, systematic review and comparison of the data to search for data values that are questionable or relationships that are materially inconsistent. Such a detailed review was beyond the scope of our assignment.

7.4. Model reliance

Our analysis is based on a catastrophe model. We have reviewed the model output for reasonableness and consistency. However, no catastrophe model is entirely accurate. To the extent that the model used is biased, the resulting analysis may be biased.

7.5. Uncertainty

Our analysis was intended to be realistic enough for the purpose of illustrating how catastrophe models can measure mitigation actions in practice, but it does not reflect all factors and may not be indicative of actual experience, rate history, or rate level for any given company. Different portfolios, catastrophe models, and assumptions would produce different results, and the differences could be material.

We based our results on generally accepted actuarial procedures and our professional judgment. Our results reflect assumptions that are built into the catastrophe models used, as well as assumptions such as those regarding expense. However, due to the uncertainty associated with the estimation of rates and future loss payments and the inherent limitations of the data, actual results will vary from our projections. Our indications are based on long-term averages and results for any single year may vary significantly from those implied by the indications.

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