RISK MODELING ADVISORY WORKGROUP REPORT

The Risk Modeling Advisory Workgroup was formed pursuant to Assembly Bill 642 (Chapter 375, Statutes of 2021) to act in an advisory capacity to the California Department of Forestry and Fire Protection in consultation with the State Fire Marshal and the California Insurance Commissioner on wildfire risk modeling.

Risk Modeling Advisory Workgroup

October 10, 2023

The California Department of Forestry and Fire Protection serves and safeguards the people and protects the property and resources of California.

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BACKGROUND

PURPOSE

The Risk Modeling Advisory Workgroup (hereafter "Workgroup") was formed pursuant to Assembly Bill 642 (Chapter 375, Statutes of 2021) to act in an advisory capacity to the California Department of Forestry and Fire Protection (CAL FIRE) in consultation with the State Fire Marshal and the California Insurance Commissioner on wildfire risk modeling. The Workgroup reports to the Wildfire Mitigation Advisory working group.[1]

The Workgroup's purpose is 1) to provide science-based insights and a review of relevant model attributes to enable CAL FIRE, in consultation with the State Fire Marshal and the Insurance Commissioner; 2) to make recommendations on understanding and modeling wildfire risk for a community and specific parcels within the local responsibility area or state responsibility area; and 3) to include a strategy to account for mitigating factors designed to reduce risk.

The Workgroup focused on modeling the risk to structures and communities. The Workgroup did not address the modeling of susceptibility to human life loss/injury risks, nor the second-order components such as economic, social and health impacts, ecological/biophysical effects, and compounding natural hazards. Additionally, this report does not attempt to address the use of catastrophe models in insurance pricing.

OBJECTIVES

The agreed-upon objectives of the Workgroup are as follows:

- Provide science-based solutions to enable CAL FIRE, in consultation with the State Fire Marshal and the Insurance Commissioner, to make recommendations on understanding and modeling wildfire risk on or before July 1, 2023.
- Provide a discussion on how parcels can affect the risk of other parcels in close proximity to each other and what impacts that has on wildfire risk modeling.
- Provide an evaluation of the effectiveness of using natural infrastructure as a community buffer and what impacts that has on wildfire risk modeling.
- Review and provide a list of other jurisdictions' applicable wildfire risk models and their modeling components.
- Review and provide a list of relevant wildfire risk research models from science, academia, industry, and other sources and their purpose and relevant attributes.

[1]https://osfm.fire.ca.gov/boards-committees/risk-modeling-advisory-workgroup/

- Provide a list of identified barriers to determining the wildfire risk of a community and specific parcels.

INTENDED AUDIENCE

The report was required by AB 642 (2021), with the primary audience being the State Legislature, CAL FIRE, Office of the State Fire Marshal, and the Insurance Commissioner; however, the Workgroup intends this report to be helpful to a variety of stakeholders in the California wildfire space, including but not limited to:

- Regulators
- Consumers
- Local jurisdictions
- California Native American Tribes and tribal organizations
- Fire services professionals
- Firewise/Fire Safe Community organizations
- Utilities
- Insurance professionals
- Developers

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EXECUTIVE SUMMARY

This Workgroup was established by the Legislature in 2021 to make recommendations on 1) how to understand and model wildfire risk for a community and specific parcels within the local responsibility area or state responsibility area and 2) include a mechanism to account for mitigating factors. The Legislature asked that the Workgroup:

- Identify mitigation factors that are necessary to determine risk.
- Discuss how parcels can affect other parcels in close proximity to each other.
- Evaluate the effectiveness of natural infrastructure as a community buffer.
- Review other jurisdictions' applicable wildfire risk models.
- Identify barriers to determine the wildfire risk of specific parcels and at a community scale.

In the wake of unprecedented destructive wildfires that have damaged or destroyed tens of thousands of California homes, businesses, and infrastructure over the past several years, the Workgroup recognizes that the ability to measure and reduce wildfire risk has become increasingly important and approaches this task focusing on mitigations that reduce risk to property, and the spread and propagation of fires in communities.

To frame the discussion, the Workgroup highlights the inherent challenges in measuring and reducing risk, including:

- There is a need for data to inform evaluating wildfire risk with accuracy and transparency. This report discusses the value of high-quality, cost-effective data for accurate modeling.
- Wildfire risk is complex, significant, and changing fast, making risk challenging to measure with precision.
- There are many uncoordinated stakeholders in the wildfire space, resulting in significant disconnects between who is exposed to wildfire risk, who understands it, and who is in a position to take action to reduce it.
- Community support for risk reduction activities will vary, reflecting local capacity, resources, and interest differences. Property owners may be subject to risks beyond their control. Further, risk reduction actions are often poorly understood and only effective for a limited period of time, and broader socialization of the benefits of specific actions is likely required. Potential risk reduction may come in the form of more robust building standards, changes to defensible space standards, and/or new ordinances imposing requirements on homeowners and landowners.

- Mitigated parcels may continue to be exposed to significant community-level risk due to conditions present on surrounding parcels, meaning that collective action at a community scale is required to be truly effective. However, the benefits and costs of mitigation are not always distributed equally across a community.
- Designating specific communities as high-risk is challenging due to the complexity associated with making those designations and the uncertainty regarding the resulting implications.
- The offensive and defensive actions carried out by wildland-urban interface (WUI) fire suppression resources significantly limit losses. Yet, there is no standardized way to quantify how their potential contributions bring down risk in a given community.
- The achievable downstream benefits of reducing wildfire risk (e.g., stabilized local economies, improved health outcomes, avoidance of disruptions threatening quality of life, reduced migration to other areas) are enormous but even more difficult to measure.

To resolve these challenges and achieve measurable and meaningful risk reduction at scale, the Workgroup proposes that future efforts follow an integrated framework designed to *measure*, *communicate*, and *mitigate* wildfire risk in a cycle of continuous improvement.

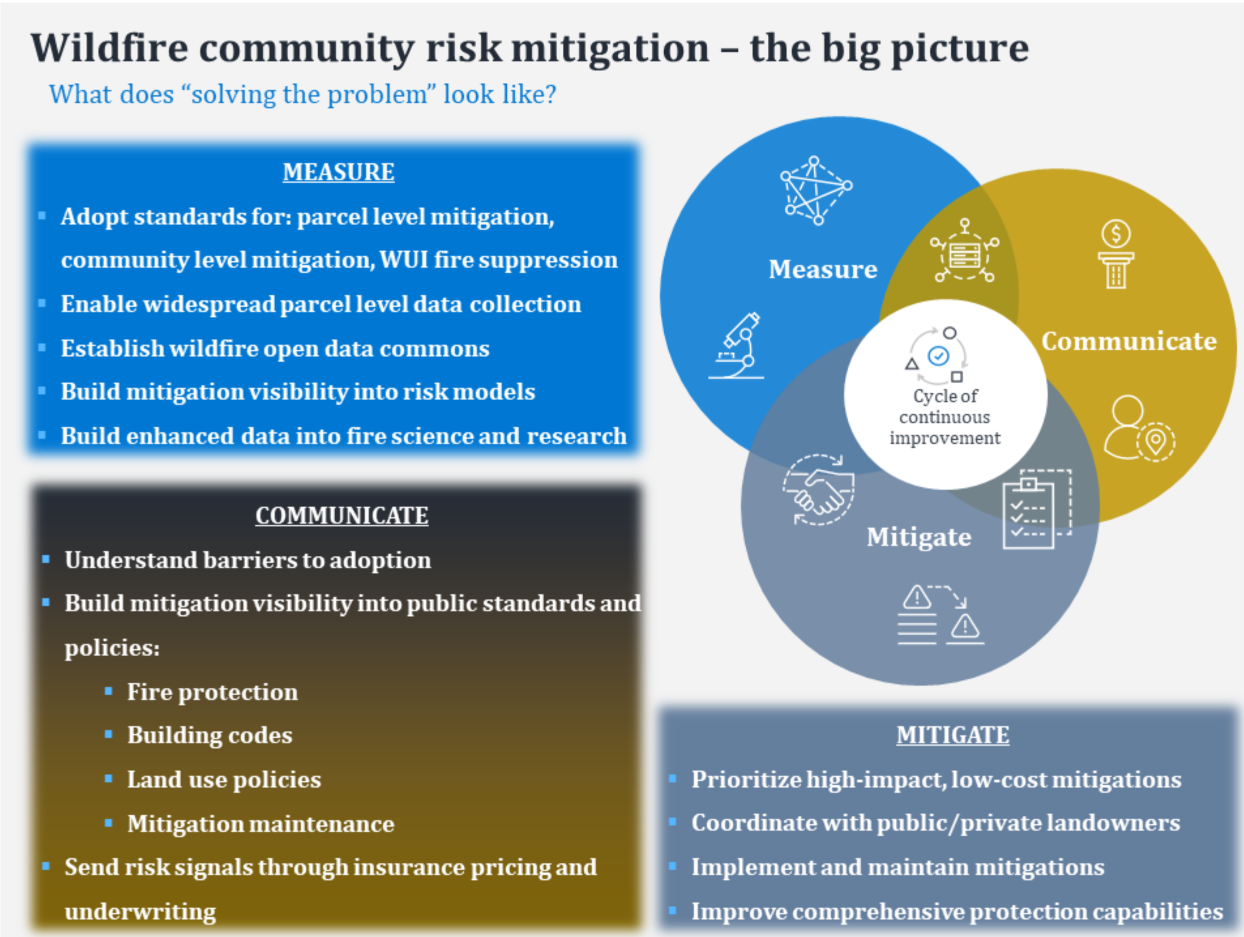
The components of the framework are as follows:

1. *Measure* baseline risk:
    - Adopt publicly understood standards for effective:
        - Parcel level mitigation, such as defensible space maintenance and structure hardening.
        - Community-level mitigation, such as installation and maintenance of fuel breaks.
        - WUI fire suppression capability and capacity.
    - Enable widespread standards for data collection at the parcel and community level that tracks base-level conditions and mitigations.
    - Establish a wildfire open data commons to aggregate parcel-level data, incorporate large-scale mitigation efforts, and provide an agreed-upon data source.
    - Incorporate implemented mitigation data into baseline risk models.

2. *Communicate* risk consistently to drive better decisions:
    - Use consistent, science-supported terminology to describe risk components.
    - Use enhanced data to support research to evaluate changing conditions and a better understanding of fire behavior in the WUI.
    - Provide secure access to parcel-level data for property owners to promote transparency and understanding of critical information collected and used to evaluate risk.
    - Allow appropriate levels of security to access parcel-level data for fire protection and fire management personnel to help inform and guide mitigation actions within the community.
    - Continue to educate residents and communities about risk reduction opportunities and priorities.
    - Understand barriers to adoption and tailor communications accordingly.
    - Send risk signals and associated incentives through insurance pricing.
    - Use the available data to support improvements in fire mitigation policies and regulations that inform fire protection and building standards, land-use development, and the maintenance of mitigations.
3. *Mitigate* risk:
    - Support efforts to incentivize implementing and maintaining mitigations at the landscape, parcel, and structure levels.
    - Pace and scale of implementation is essential. Prioritize high-impact, low-cost mitigations pairing parcel and community-level actions across California's WUI.
    - Develop implementation strategies to support community-level mitigations at scale and support vulnerable populations, such as low-income and elderly populations.
    - Improve comprehensive fire protection and suppression capabilities to complement passive mitigations.

As a main part of this framework, it is critical to come to an agreed-upon set of standards to capture consistent data on mitigation and protection actions at the parcel level and specifications to ensure data collected is verifiable, comprehensive, consistent, continuous, and collected in a cost-beneficial manner. These data will help various stakeholders engaged in risk measurement and/or risk reduction – such as fire scientists, risk modelers, communities, and government entities – incorporate and utilize these data within an adaptive framework. In this way, a continuous cycle of improvement and re-evaluation can be used to track progress, drive prioritization and implementation, and refine the value of mitigations (see Figure 1 below).

Figure 1: A framework for addressing the issues[2]



The Workgroup recognizes that fire adaptation will take time and risk models will play a critical role, as they 1) enable the measurement of risk on a forward-looking basis using current data and the best available science; and 2) provide a robust means to quantify the effectiveness and refinement of risk mitigation actions.

[2] Milliman, Inc.; Western Fire Chiefs Association; California Fire Chiefs Association; Cal Poly San Luis Obispo WUI Fire Institute

SECTION 1: UNDERSTANDING WILDFIRE RISK

1.1: RISK VERSUS HAZARD

"Risk" and "hazard" are often used interchangeably, and their misuse can create confusion. Hazard is defined as "any agent that can cause harm or damage to humans, property, or the environment."[3] In the case of the topic addressed in this report, the hazard is wildfire. Risk is "the probability that exposure to a hazard will lead to a negative consequence."[4] In this case, risk is the probability of wildfire occurring at sufficient intensity or relative speed in critical areas so that it causes harm to people, property, infrastructure, or the environment.

As such, any work in this area must begin with a careful review to ensure "hazard" is not being used interchangeably with "risk." The need for this review is further reinforced by Fire Hazard Severity Zone (FHSZ) maps, which are neither designed nor intended to consider mitigations that may prevent fires or reduce the intensity with which they burn in any given area. Data products like the FHSZ maps can be misunderstood as showing risk, when they are only showing hazard, which is only a component of risk. As California is a fire-adapted landscape in which wildfire is both natural and recurring, it is important to begin any risk categorization project with clarity regarding the desired goals. Further, the term "risk" can be overgeneralized and/or used ambiguously, so within a given context it must be well-defined in terms of time and geographic scales.

California Governor's Office of Planning and Research published a view of the relationship between wildfire risk and wildfire hazard and the types of risk that might be modeled, as summarized in Figure 2 below:[5]

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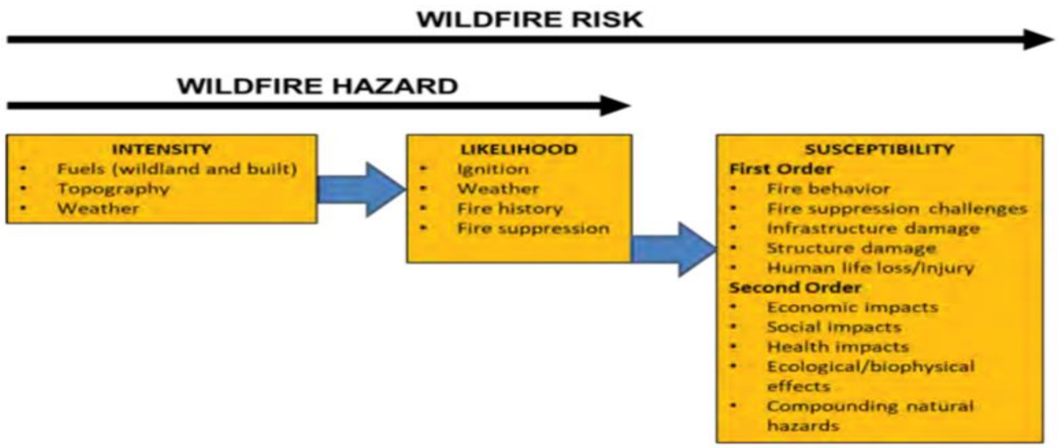
[3]https://encyclopedia.pub/entry/31441

[4]*Ibid*.

[5]California Governor's Office of Planning and Research 2022 publication Fire Hazard Planning Technical Advisory (Source: Wildland Professional Solutions): https://opr.ca.gov/docs/20220817-Fire_Hazard_Planning_TA.pdf

Figure 2: Wildfire risk versus wildfire hazard



In this report, the Workgroup has chosen to focus on modeling all components of wildfire hazard (intensity and likelihood) and the first-order elements of susceptibility to risk (i.e., fire behavior, fire suppression challenges, infrastructure damage, and structure damage) listed above. The Workgroup does not address the modeling of susceptibility to the risks to human life loss/injury, nor the second order components (e.g., economic, social and health impacts, ecological/biophysical effects, compounding natural hazards). Although these are significant and must be considered within a statewide risk mitigation framework, the Workgroup believes that many of the underlying concepts that build a base of understanding will overlap and that focusing on modeling and mitigating the risk of damage to structures and infrastructure provides a helpful starting point for understanding the issues involved.

1.2: COMPONENTS OF WILDFIRE RISK

Wildfire risk is identified through a variety of components. Wildfire risk experts will consider and evaluate different components depending on the context. The Workgroup finds the description of the USDA Wildfire Risk to Communities Framework[6] as a helpful example of the many factors that are important to consider when evaluating risk. These factors include:

- **Hazard: Likelihood + Intensity of a Wildfire**
  - **Likelihood:** Wildfire likelihood is the annual probability of a wildfire burning in a specific location. Wildfire likelihood can be estimated using a variety of modeling approaches and is often based on statistical methods

[6]https://wildfirerisk.org/understand-risk/

where Monte Carlo sampling is used to model fire behavior across thousands of simulations of possible fire seasons. In each simulation, factors contributing to the probability of a fire occurring, including weather, topography, and ignitions, are varied based on patterns derived from observations in recent decades. Wildfire likelihood is not operationally predictive and does not reflect any currently forecasted weather or fire danger conditions but are rather based on the general distribution of variables that drive fire occurrence and spread.

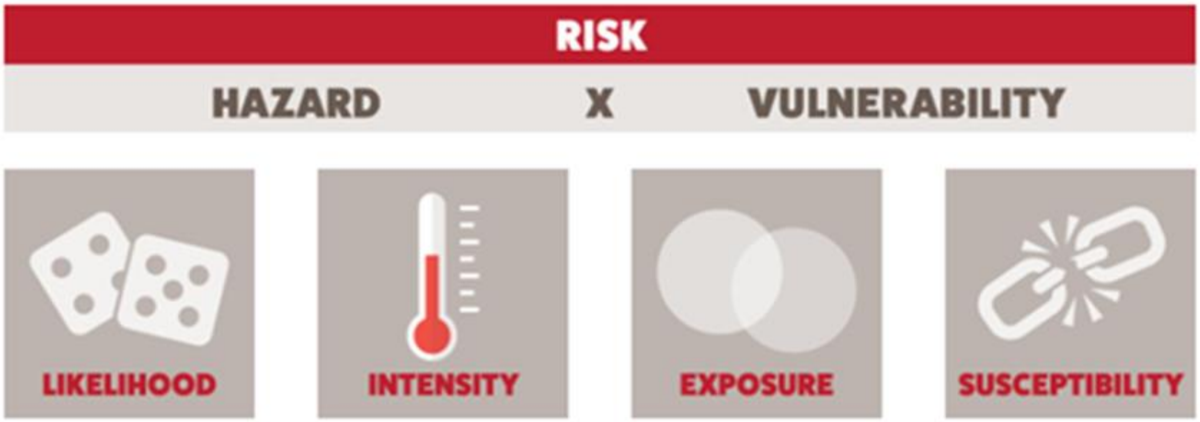
    - **Intensity:** Wildfire intensity is a measure of the energy (both release rate and total) expected from a wildfire. Intensity is largely a condition of the physical landscape (topography) and vegetative fuel available to burn. Wildfire intensity can be reduced by modifying the home ignition zone, land use planning, wildfire response, and fuel treatments.

- **Vulnerability: Exposure + Susceptibility to a Wildfire**
    - **Exposure:** Exposure is the spatial coincidence of wildfire likelihood and intensity with resources or assets that will be impacted by wildfire. For the purposes of this report, these assets are defined by houses and other community-level infrastructure. Any community where wildfire likelihood is greater than zero (in other words, where there is a chance wildfire could occur) is exposed to wildfire. For example, a home in a flammable forest is exposed to wildfire. Communities can be directly exposed to wildfire from adjacent wildland vegetation or indirectly exposed to wildfire from embers and home-to-home ignition and spread.

      Communities can reduce their exposure to wildfire by modifying the home ignition zone, home hardening, land use planning tools, and wildfire preparedness.

    - **Susceptibility:** Susceptibility is the propensity of a home or community to be damaged if a wildfire occurs. Actions that affect susceptibility include home hardening, modifying the home ignition zone, applying land use planning tools, wildfire preparedness, community health strategies, natural infrastructure, and planning for post-fire recovery.

Figure 3: Risk can be measured as a product of hazard and vulnerability[7]



<u>Additional Components of Risk</u>

Beyond the components defined above and considered in the USDA Forest Service's community fire modeling, several additional risk components include relative wildfire speed, ignition, and spread.

- **Relative speed:** The speed with which a wildfire moves is expressed as the rate of spread, which measures how quickly a fire travels across the landscape.[8] This measurement is typically expressed in chains per hour (1 chain = 66 feet) and is influenced primarily by the quantity and arrangement of fine surface fuels, fuel moisture, wind, and slope. With increases in slope percent and wind speed and a decrease in fuel moisture, the rate of spread will increase proportionally and predictably. The rate of spread is also different for different parts of a fire and is influenced by how fuel is pre-heated and then combusts primarily due to exposure to convective and radiant heat.

  Wildfire speed is a component of understanding the relationship between a fire's arrival at the perimeter of a community or other value at risk and the arrival of an effective firefighting response. This response must be of sufficient size and capacity to prevent the transition of a vegetation fire into an urban conflagration characterized by significant ignition of multiple structures, and their associated contribution to fire spread. In some cases where housing density supports it, these fires become dominated by structural fuel combustion leading to direct house-to-house spread. Understanding the time component of fire spread and firefighting

[7] USDA Forest Service website "Wildfire Risk to Communities"

[8] https://www.nwfirescience.org/sites/default/files/publications/FIREFACTS_Measures%20of%20fire%20behavior%20FINAL.pdf

resources' arrival is critical to establishing relative speed. Relative speed provides an understanding of what effect fire suppression resources may have on the outcome of a wildfire's arrival in a community. Jack Cohen's *Wildland-Urban Interface Fire Problem* offers a good review of the topics as a part of the WUI disaster sequence.[9]

- **Ignition**: Understanding wildfire likelihood must consider the source and location of knowable ignitions, which can be derived from historical records, as well as stochastic ignition locations caused by unknowable events such as dry lightning and low-frequency human behavior, which are not well represented in historical ignition patterns.

  While it is appropriate to consider the source of ignitions, it is also appropriate to be realistic regarding the limitations of ignition reduction programs. Human-caused fires can extend the fire season beyond the period when lightning-caused fires are prevalent, extending the wildfire season. In California's Mediterranean climate, the percentage of human-caused ignitions is over 97%[10], further increasing the probability of an extended fire season. As a result, while long-term efforts to reduce ignitions are beneficial – particularly regarding successful ongoing efforts to reduce utility-caused ignitions – any future risk modeling project should start with the assumption that fires will continue to burn throughout California.

- **Wildfire spread:** Beyond identifying areas with increased probability of ignitions, wildfire spread depends on the interrelated and potentially complementary effects of topography, weather, and fuel. Under conditions during which a fire may be wind-dominated,[11] the same ignition point may produce fires that burn in opposite directions depending on the weather conditions and seasonality present at the time of ignition. The dominant example of this distinction is seasonal Foehn winds, which bring elevated wind speeds and lowered relative humidity in the fall months from different directions than typical weather patterns.[12]

[9]Cohen, Jack. 2010. The wildland-urban interface fire problem. Fremontia. 38(2)-38(3): 16-22

[10]National Academies of Sciences, Engineering, and Medicine. 2017. A Century of Wildland Fire Research: Contributions to Long-term Approaches for Wildland Fire Management: Proceedings of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/24792. Pages 27-30

[11]Keeley, J.E., Syphard, A.D. Twenty-first century California, USA, wildfires: fuel-dominated vs. wind-dominated fires. fire ecol 15, 24 (2019). https://doi.org/10.1186/s42408-019-0041-0

[12]Alex W. Dye and John B. Kim and Karin L. Spatial heterogeneity of winds during Santa Ana and non-Santa Ana wildfires in Southern California with implications for fire risk. modeling. https://doi.org/10.1016%2Fj.heliyon.2020.e04159

It is important to understand how wildfire will move across the landscape under different conditions and how it will behave in proximity to communities, critical infrastructure, or sensitive habitats. Specifically, if the fireline intensity, measured in either (Btu/sec/ft)[13] or (KW/M), falls below the threshold at which damage to selected resources will occur, while fire may occur, it is considered unlikely to be a destructive fire. Further, the spread rate, measured in (ch/h),[14] significantly impacts effective evacuations and the time required to aggregate an effective firefighting force, measured against the resource-protected requirements derived from the modeled size and intensity of the fire.

SECTION 2: MITIGATING WILDFIRE RISK

FEMA defines mitigation as activities that reduce the loss of life and property by lessening the impacts of disasters. In this context, the Workgroup approaches wildfire mitigations as actions that can reduce risk and fire spread (or propagation) in communities to protect properties and lives.

Due to the complexity of wildfire spread, mitigation measures must be proposed and implemented at the appropriate scale to reduce wildfire impacts. For example, to reduce the spread of a fire, fuel breaks are commonly developed to use as control features to slow the path of an advancing fire or to stage crews for fire suppression activities. Where fuel breaks and Strategically Placed Landscape Area Fuel Treatments[15] (SPLATs) are considered, existing research and programs provide decision support tools to make strategic placement decisions of mitigations. In populated WUI areas, location-level determinations must be made considering structure density,[16] the presence of hardened (or unhardened) utility assets, surrounding fuel types, terrain, weather, modeled fireline intensity (see definition in 1.2 Wildfire Spread above), and spread rates, and availability of fire suppression resources to ensure mitigations are being implemented at sufficient scale to protect values at risk and prevent loss.

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[13]https://datainventory.doi.gov/explorer/tbl/glossary.editor

[14]8.3 Rate of Spread | NWCG.

[15]Tubbesing, C. L., Fry, D. L., Roller, G. B., Collins, B. M., Fedorova, V. A., Stephens, S. L., Battles, J. J., 2019. Strategically placed landscape fuel treatments decrease fire severity and promote recovery in the northern Sierra Nevada. Forest Ecology and Management. 436, 45–55. https://doi.org/10.1016/j.foreco.2019.01.010

[16]Maranghides, A., Johnsson, E. (2008) Residential Structure Separation Fire Experiments. NIST Technical Note 1600. National Institute of Standards and Technology. Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.1600

The minimum effective area calculation for mitigations is of even greater importance when structures are present since a failure to prevent fire spread may increase fireline intensity as structures are involved and contribute to additional fire spread. Risk in WUI areas changes dramatically with the inclusion of structures as a fuel source. Structural ignition increases both fire intensity and ember production which contribute to significantly increased fire spread. Consequently, to avoid large scale structure involvement one must take into account threshold scales of mitigation to preclude structures from increasing spread and intensity beyond the potential from wildland fuels alone.

For developed WUI areas, it is recommended that the determination be made on a neighborhood scale of at least 10 to 100 homes, depending on the factors listed above. Due to the large variation in wildfire vulnerability within a community or municipal boundary, smaller neighborhood designations may strike a balance between science-based minimum efficacy and the realities of achieving sustained mitigations across a large and diverse community-level population.

Figure 4: Mitigations are appropriate at many scales[17]

As we view wildfire risk, it is critical to use the appropriate context by understanding the distinct but interrelated factors of the risk to a structure, the risk of fire burning through a parcel, and the risk to the community. Mitigations can be applied at many scales (Figure 4).

[17]Yana Valachovic, UC Cooperative Extension

Compounding issues

There are limited standards for fuel management in the wildland-urban interface. To date, state fire safety laws and regulations in the form of defensible space creation and fuel reduction have focused on risk reduction measures in the areas within 100' (or a property line, whichever is closer) of a structure. While effective at reducing risk to buildings, existing fire safety laws and regulations are limited on conditions beyond 100' aside from the standards in the California Forest Practices Act that governs fuel reduction standards for timber harvest activities on state or private lands. As stated above, structures can provide significant sources of fuel. In wildfire losses in areas of moderate and high structure density with structure separation distances (SSD) of 50' or less, the Workgroup recognizes the need to account for the risk of structure-to-structure fire propagation[18] where heat flux may significantly exceed that produced by burning vegetation. Details are shown in Figure 5 included below from NIST TN 2205:

Figure 5: NIST framework for assessing the effectiveness of mitigations

Table 3. Structure and parcel hardening effectiveness.

#	WUI Type	Probability of Structure Survivability if Neighboring Structure Ignites	Potential Fire[a] Exposure from Burning Neighboring Structure	Exposure from Other Parcel Fuels	Exposure[b] from Wildlands	Impact of Structure Ignition on Fire spread in Community	Likely Effectiveness of Partial Structure/ Parcel Hardening	Community/ Neighborhood Participation
1	HD Interface – Perimeter	Low	High	ƒ(fuels, dist.)[c]	Variable	High	Low	Necessary
2	HD Interface – Interior	Low	High	ƒ(fuels, dist.)[c]	Low	High	Low	Necessary
3	MD Interface – Perimeter	ƒ(hardening)	Moderate	ƒ(fuels, dist.)[e]	Variable	Moderate	ƒ(wildland fuels, parcel fuels)	Desired
4	MD Interface – Interior	ƒ(hardening)	Moderate	ƒ(fuels, dist.)[e]	Low	Moderate	ƒ(parcel fuels)[d]	Desired
5	MD Intermix	ƒ(hardening)	Moderate	ƒ(fuels, dist.)[e]	Variable	Moderate	ƒ(wildland fuels, parcel fuels)	Desired
6	LD Interface	ƒ(hardening)	Low	ƒ(fuels, dist.)[e]	Variable	Low[f]	ƒ(parcel fuels)	Desired
7	LD Intermix	ƒ(hardening)	Low	ƒ(fuels, dist.)[e]	Variable	Low[f]	ƒ(parcel fuels)	Desired

HD = high density, MD = medium density, LD = low density
ƒ(X) indicates "a function of X" (e.g., the level of exposure from other parcel fuels is a function of the fuels and distance from the target structure)
[a] flames and radiation
[b] based on fire history, fuel loading, wind, and topography/aspect; wildland fuel treatments may not be at the control of the community
[c] parcel-level mitigation will have limited impact if nearby upwind structures catch on fire
[d] would be a function of wildland fuel treatment AND hardening of most/all perimeter structures and parcels
[e] parcel-level mitigation, including wildland fuel treatment, together with home hardening, will enhance structure ignition resistance
[f] ignitions due to embers from burning residential structures have been observed as far as 200 ft to 300 ft downwind

[18]Maranghides, A., et al. (2022) WUI Structure/Parcel/Community Fire Hazard Mitigation Methodology. NIST Technical Note 2205. National Institute of Standards and Technology. Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.2205

Vegetation and structures provide pathways for fire to impact communities.

Mitigations are typically designed to interrupt or slow the pathways for fire to travel through the vegetation or connect to structures. Rather than viewing risk on a pixel-by-pixel (or location-by-location) basis, it is important to consider risk as a network of connected high-risk pixels capable of transmitting destructive fire, such as the connection of wood fences between buildings or from the wildland to the structure.

Mitigations can be planned and prioritized at the points where changes in the presence of combustible material (or fuels) capable of carrying wildfire will have the greatest potential impact on the community's residual risk. Of note, the fuels can come in many forms and include vegetation, structures, fences, and other materials, such as vehicles or RVs. Given the dynamic nature of vegetation, it is important for mitigations to be assessed on an annual basis with a regular return interval for maintenance work based on the predominant fuel model/type.

Wildfire mitigations differ from efforts to reduce the impacts of other natural disasters such as earthquakes and hurricanes. For example, while upgrading foundations on individual houses to withstand earthquakes is unlikely to impact the fate of nearby houses positively or negatively during an earthquake, wildfire mitigations on one property can positively affect the neighboring property. Further, the more wildfire mitigations within one community, the stronger the likelihood that these efforts will support the outcomes of the community as a whole.

SECTION 3: MITIGATIONS THAT MATTER

Fuels, topography, and weather conditions drive fire behavior. As a result, mitigations have focused on fuel reduction. Historically, wildfire mitigation efforts have focused on remote areas with low structural density but with high vegetative fuel loads; however, recent fire losses show that up to 50% of structures lost are occurring in interface areas where non-vegetative fuels such as fences, woodpiles, propane tanks, and cars contribute to structural ignition. [19] With over 40,000 structures lost to wildfire in California over the last ten years, the Workgroup is aware that mitigations are required across California in communities with identified Fire Hazard Severity Zones. To illustrate how mitigation can be designed, Figure 6 offers a list of actions designed for different types of fire exposures (i.e., embers, radiant heat, and direct flame contact) to reduce pathways for fire to transmit to structures.

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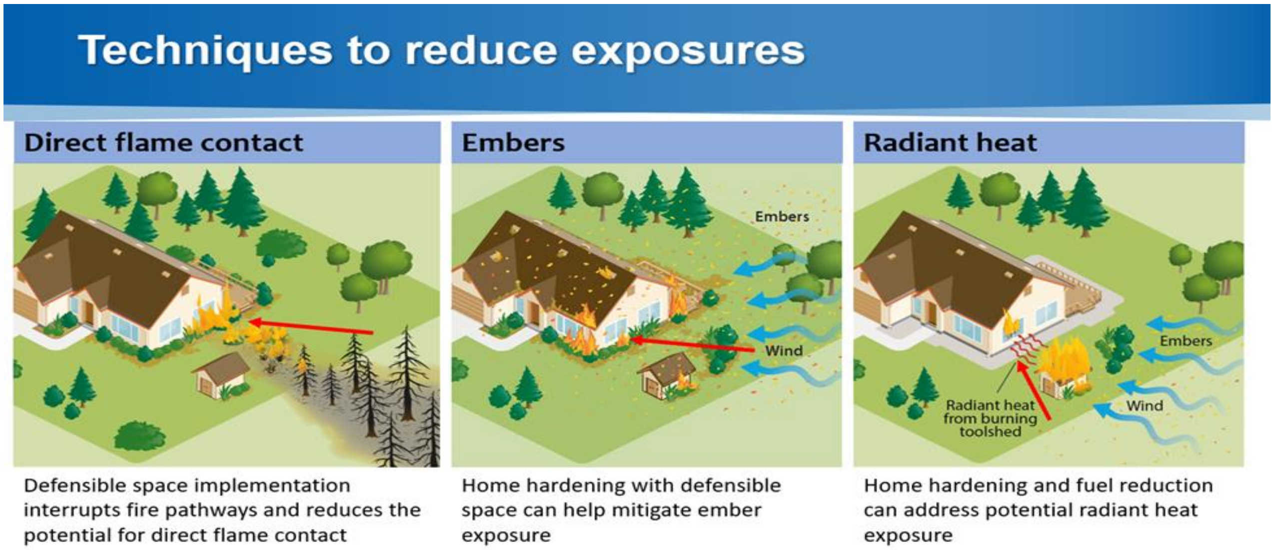
[19] National Institute of Standards and Technology Technical Note 1635 Natl. Inst. Stand. Technol. Technical Note 1635, 59 pages (June 2009) https://nvlpubs.nist.gov/nistpubs/Legacy/TN/nbstechnicalnote1635.pdf

Figure 6: Mitigations to address the three types of fire exposures[20]



As stated in a previous section, fuels can also be the structures in the pathway of the fire. In areas with high and moderate structure density, fire may be transmitted directly from structure to structure regardless of the presence or absence of vegetative fuels. Modeling the range of potential radiant heat exposure is a challenging task as it requires an assumption of how much heat will be produced by the vegetation, buildings, and other stored fuels on the property, which can be highly variable. Radiant heat from adjacent burning structures, fences, or cars can compromise some aspects of a building due to both the intensity and duration of the burning component. For example, single-pane or double-pane annealed glass windows can break with modest heat exposure (112 degrees C). Existing buildings can be upgraded to meet a higher performance standard by installing flame and ember-resistant vents, double-paned tempered glass windows, or other fire-hardening actions. These actions can be concurrent with a strategy of preventing wildfire from entering a higher-density community through the creation of fuel breaks or strategic placement of fuel treatments (known as SPLATS). These efforts can help buy time to slow a fire's spread and create a location where fire personnel can directly work to prevent a fire from entering a community. However, as firefighting resources may be spread thin when multiple fires are burning concurrently or when there is a significant travel distance to bring fire personnel to the incident, the Workgroup recognizes that vegetation modification and home hardening actions are warranted across California.

[20]Adapted from Valachovic, Y., Quarles, S. L., & Swain, S. V. 2021. Reducing the Vulnerability of Buildings to Wildfire: Vegetation and Landscaping Guidance. UC ANR Publication #8695. https://doi.org/10.3733/ucanr.8695

Below, the Workgroup discusses three scenarios that require varying approaches to mitigation, depending on the distance of separation between structures. In each scenario, there is the potential for an aggregated effect as fire is propagated by burning structures in a manner that overwhelms mitigations intended to reduce ignition from vegetative fuels. These scenarios include not only convective and radiant heat produced by burning structures but also significant increases in ember production.[21] In this manner, the conditions on neighboring parcels are intrinsically linked to the survivability of surrounding structures, just as conditions in the near community space ¼ to ½ mile from the edge of developed parcels are linked to the probability of high-intensity fire reaching structures.

3.1: STRUCTURE SEPARATION DISTANCE LESS THAN 30 FEET

For all distances between structures, some combination of fuel reduction and home hardening is recommended to reduce the potential for direct flame contact, ember, and radiant heat exposures.

Home hardening: The Workgroup recommends developing strategies to incentivize retrofitting existing structures to increase these building's ability to withstand exposure to embers, radiant heat, and direct flame contact. The standards for ember-resistant construction can be found in Chapter 7A of the California Building Code, and recent research has resulted in the publication of updated recommendations in the National Institute for Science and Technology's (NIST) Hazard Mitigation Methodology[22] contained in NIST TN 2205[23]. Significant research on this topic has been conducted by NIST[24] and IBHS[25].

Defensible Space: Fuel reduction reduces pathways for fire to travel to the structure and creates a safer place for fire personnel to take defensive action (Figure 7). Fuel mitigation involves compliance with California's Defensible Space standards for the first 100 feet around a structure (Public Resources Code 4291), including the pending Zone 0 or the upcoming "ember resistant" zone where strict standards will limit fuels within the first 5 feet of a structure.

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[21]Institute for Business and Home Safety. (2020, July). The Built Environment. IBHS Primer Series on Wildfire Primer Part 2. Retrieved May 4, 2023, from https://ibhs.org/wp-content/uploads/member_docs/wildfire-primer-series-part-2_environment.pdf

[22]https://www.nist.gov/el/fire-research-division-73300/wildland-urban-interface-fire-73305/hazard-mitigation-methodology-2

[23]https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2205.pdf

[24]IBID

[25]https://ibhs.org/wp-content/uploads/member_docs/Near-Building_Noncombustible_Zone_Report_IBHS.pdf

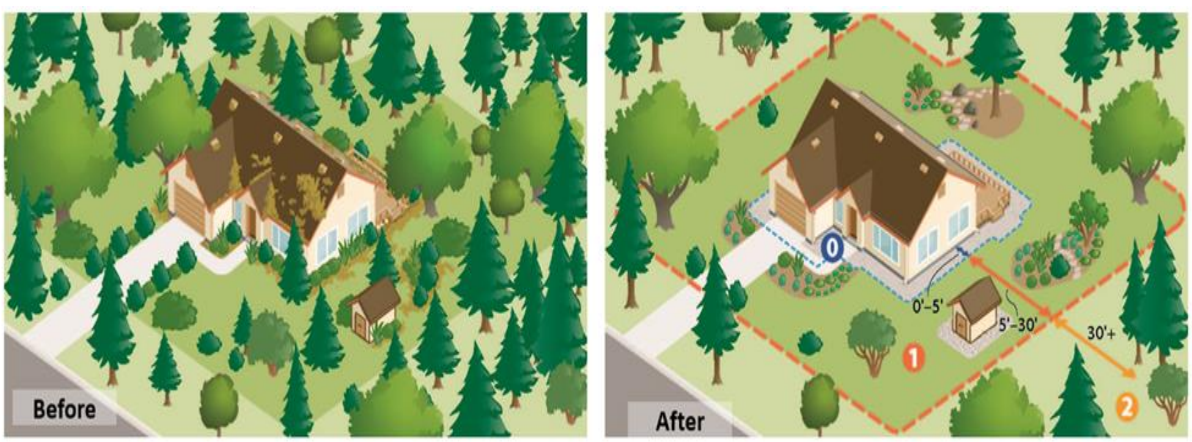
In those areas characterized by high structural density where structure separation distances of 30’ or less exist (i.e., between two houses, between a house and a garage, or a house and an outbuilding), mitigations could emphasize preventing wildfire from entering a community. However, because embers can travel long distances and land within communities, radiant heat exposures significantly increase. Home hardening can be used to mitigate radiant heat exposures.

These external or community perimeter defensive measures should then be reinforced by efforts to create full compliance with defensible space and home-hardening best practices at the points of transition into the built environment. In this setting, not all homes have the same risk, and homes on the perimeter of the community that sit within fire pathways could receive higher priority for mitigations.

3.2: STRUCTURE SEPARATION DISTANCE BETWEEN 30 FEET AND 100 FEET

Home hardening and defensible space mitigations remain important in areas with common structure separation in the range of 30’ to 100’. However, radiant heat exposures may be lessened unless outbuildings are clustered around the primary structure. In areas of greater density or clusters of structures on large lots, the same methodology should be applied as in the high-density setting to create fuel mitigations and prioritize home hardening actions.

Figure 7: California has developed a three-zone approach to defensible space[26]



[26]Valachovic, Y., Quarles, S. L., & Swain, S. V. 2021. Reducing the Vulnerability of Buildings to Wildfire: Vegetation and Landscaping Guidance. UC ANR Publication #8695. https://doi.org/10.3733/ucanr.8695 or https://anrcatalog.ucanr.edu/pdf/8695.pdf

3.3: STRUCTURE SEPARATION DISTANCE GREATER THAN 100 FEET

For structures in low-density settings, building or retrofitting to ember-resistant construction standards has been proven to be effective against embers and low-intensity surface fires, which are responsible for most structure losses in the WUI[27]. When combined with separation from outbuildings and 100' defensible space, removing all combustible materials within five feet of a structure, also known as Zone 0[28], can dramatically reduce structure losses.[29]

Structure separation does, however, assume structures are placed on the parcel in a manner that allows for creating 100' of defensible space. In circumstances where structures are closer than 100' to property lines and adjacent parcels have not completed mitigations, moderate-or high-density methodologies should be used to account for the inability of the parcel owner to complete the full suite of recommended mitigations.

3.4: EVACUATION AND SUPPRESSION RESPONSE CAPABILITIES

Fire modeling can assess fuel type, topography, the built environment, and the potential for structural and vegetative fuels to carry the fire. However, from the structure loss perspective, an additional assessment of the capacity of local road networks to support simultaneous evacuation and suppression response is important. This assessment should include fire agencies with jurisdiction resources, auto-aid resources, and regional and out-of-area mutual aid resources through the lens of capability, capacity, availability, and interoperability. While less important than in Public Protection Classification[30] ratings used for structural firefighting models, the availability and distribution of firefighting water access points are also relevant to how effective suppression efforts may be.

3.5: EFFECTIVENESS OF USING NATURAL INFRASTRUCTURE AS A COMMUNITY BUFFER

Natural infrastructure like wetlands, urban greening, and ecological forest strategies can reduce damages by creating areas for limiting fire spread or changing fire behavior to improve the potential for direct fire suppression activities. These approaches are best addressed at the community scale.

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[27]Caton, S.E., Hakes, R.S.P., Gorham, D.J. et al. Review of Pathways for Building Fire Spread in the Wildland Urban Interface Part I: Exposure Conditions. Fire Technol 53, 429–473 (2017). https://doi.org/10.1007/s10694-016-0589-z

[28] https://www.fire.ca.gov/dspace

[29]Patek, G. (2021, September 30). Reducing the Destructiveness of Wildfires: Promoting Defensible Space in California. Retrieved May 3, 2023, from https://lao.ca.gov/Publications/Report/4457.

[30]https://www.isomitigation.com/ppc/

It should be noted that most California ecosystems are not only fire-adapted but are fire-dependent[31]. The development of managed areas characterized by lower fuel density in varied mosaics and multi-age class vegetation, which mimics the natural state, offers the potential to reduce fire spread rates and intensity. However, it must be recognized that the natural state included regular fire return intervals to maintain equilibrium. Significant research has been done recommending "green fuel breaks"[32] made up of maintained native vegetation or even "edible fuel breaks", as well as the use of prescribed grazing or prescribed fire in strategic buffers[33] to reduce the continuity and density of fuels and related speed and intensity of fire. As with other mitigation strategies, efforts to reduce a community's exposure to wildfire risk must be maintained regularly and reported in a digestible manner to allow models to reflect potential fire behavior accurately.

SECTION 4: WILDFIRE RISK MODELS

4.1: WHY MODELS ARE NEEDED

Models are used to evaluate potential outcomes based on historical conditions or expected future conditions. Methods of evaluating the risk of a destructive event can be divided into historical models and catastrophe models. Historical models are useful for predicting losses caused by perils with relatively high frequency, like water damage; they work well in cases where there is sufficient historical data and where past occurrences are good predictors of future results. Certain catastrophic perils, such as hurricanes, wildfires, floods, or severe convective storms, do not fit this description. Because high loss wildfire events are almost always associated with severe fire weather (low humidity and wind), and because these conditions are relatively infrequent, this means the limited historical record does not represent the full range of possible events. This hurdle would exist even in the absence of climate change. However, climate change can make historical data even less predictive of future results, as certain perils may become more frequent or severe.

Models help overcome these challenges by allowing some level of extrapolation of scientific understandings of the important drivers of wildfire risk to present a range of scenarios

[31]VAN WAGTENDONK, J. W., SUGIHARA, N. G., STEPHENS, S. L., THODE, A. E., SHAFFER, K. E., & FITES-KAUFMAN, J. A. (Eds.). (2018). Fire in California's Ecosystems (2nd ed.). University of California Press. http://www.jstor.org/stable/10.1525/j.ctv1wxrxh

[32]Curran, T. J., Perry, G. L., Wyse, S. V., & Alam, M. A. (2017). Managing fire and biodiversity in the wildland-urban interface: A role for green firebreaks. Fire, 1(1), 3.

[33]Moritz, M. A., Hazard, R., Johnston, K., Mayes, M., Mowery, M., Oran, K., Parkinson, A. M., Schmidt, D. A., & Wesolowski, G. (2022, May 11). Beyond a Focus on Fuel Reduction in the WUI: The Need for Regional Wildfire Mitigation to Address Multiple Risks. Frontiers in Forests and Global Change, 5. https://doi.org/10.3389/ffgc.2022.848254

beyond those specifically present in historical datasets. Models allow for an ability to measure and manage wildfire risk under changing conditions.

Wildfire models can come in many forms, depending on the intended use cases, available input, and desired output. In considering the various types of models, it is important to note the distinction between the terms “hazard” and “risk” to ensure the appropriate model is being used. As explained above, hazard is defined as a condition, situation, or behavior that presents the potential for harm or damage to people, property, the environment, or other valued resources. Hazard doesn’t change much in the long term. For example, the steepness of topography, which can be correlated with fire intensity[34], doesn’t change.

On the other hand, risk is a measurement of the anticipated adverse effects from a hazard considering the consequences and frequency of the hazard occurring. Risk can change frequently based on modifications in exposure (structures and their characteristics), and mitigations can impact vulnerability. For example, suppose a homeowner in a high-hazard wildfire region installs a new fire-resistant roof. In that case, their hazard doesn’t change (they are still located in the same high-hazard area), but the risk of their home burning may be lowered due to the roof upgrade and improved functionality to decrease ignition likelihood. As noted previously in this document, risk can also change based on the level of fuels surrounding the structure, which can vary significantly during a year or over a decade. Regardless, both the condition of the structure and the management of vegetation require ongoing maintenance to retain desired effects.

4.2: HISTORY OF WILDFIRE MODELS

Wallace Fons developed the first numerical model of fire behavior in the 1940s. His work in the field later influenced Richard Rothermel, who focused on understanding the interactions between fire, fuel, and weather conditions and produced the 1972 seminal publication A Mathematical Model for Predicting Fire Spread in Wildland Fuels[35]. This publication introduced the Rothermel fire spread model, which is still the most widely used tool for wildfire behavior modeling. This model was based on the physical principles of fire spread, such as the amount of fuel available, the fuel’s moisture content, the terrain’s slope, and wind speed. The Rothermel model’s input requirements have also led to many industry standards still used today. This work was further advanced by C.E. Van Wagner’s research

[34] Wildland Fire Behavior (U.S. National Park Service) (nps.gov)

[35] https://www.fs.usda.gov/research/treesearch/32533

into crown fire ignition in 1977[36] and crown fire spread by Rothermel in 1991[37] and made widely available in a 2-D digital platform by Mark Finney's 1998 introduction of FARSITE[38].

FARSITE is a fire growth simulation model that automatically computes wildfire growth and behavior for long time periods under heterogeneous conditions of terrain, fuels, and weather. It uses existing fire behavior models for surface and crown fires, post-frontal combustion, and fuel moisture. It is a deterministic model; you can directly relate simulation results to your inputs. FARSITE produces outputs compatible with PC and Workstation graphics and GIS software for later analysis and display. It can simulate air and ground suppression actions, be used for fire gaming, ask multiple 'what-if' questions, and compare the results.[39]

4.3: TYPES OF WILDFIRE MODELS

Wildfire modeling has become an important tool in measuring and managing wildfire risk, helping overcome several challenges associated with understanding the potential consequences of this peril. Because of the expansion of development into the WUI, it is critical to understand how wildfire spreads in the built environment. With the larger number of recent destructive wildfires, there are increasing opportunities to understand structure-loss dynamics; however, there is still limited data about the pre-event conditions, making it challenging to draw conclusions about the drivers of fire spread and building survival. Wildfire risk modeling approaches can include historical and mathematical risk models to increase understanding of the risks associated with infrequent events.

4.3.1: STATIC VERSUS DYNAMIC MODELS

Two broad ways to categorize wildfire models are static and dynamic.

Static Models

Static wildfire models categorize a given location's hazard relevant to geographical and climate variables considered by the model. Static models do not include the location of structures or whether they have been mitigated against wildfire. They also don't account for a full range of possible scenarios (i.e., housing development, fuel management or house condition, climate change, etc.). In contrast, dynamic wildfire models allow for a broader range of inputs, including actual structure placement and the individual structures'

[36]https://cdnsciencepub.com/doi/10.1139/x77-004

[37] https://www.fs.usda.gov/research/treesearch/26696

[38]https://www.fs.usda.gov/research/treesearch/4617

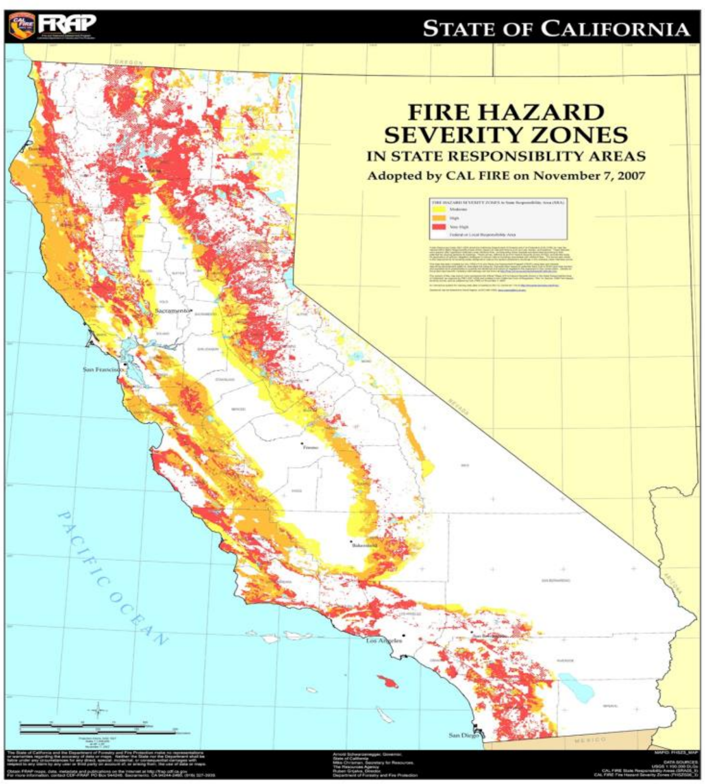
[39]https://www.frames.gov/catalog/908#:~:text=Farsite%20is%20a%20fire%20growth,frontal%20combustion%2C%20and%20fuel%20moisture.

vulnerability to fire. They can also simulate multiple scenarios of an event and estimate structural damage under each event.

Static models can further be categorized into ordinal and cardinal models. Ordinal models rank hazards into some meaningful relative order, such as "low", "medium," and "high," a way to compare the hazard of one area to that of another. Modelers can use statistics to determine the hazard ranks, such as the probability of wildfire occurrence. The order of the categories is meaningful, but the distance between them is not necessarily equal.

An example of an ordinal wildfire hazard map is the Fire Hazard Severity Zone (FHSZ) Hazard Map (Figure 8) produced by CAL FIRE.[40] These maps give geographical areas a FHSZ designation of moderate (yellow), high (orange), or very high (red) hazard. They also distribute land into three responsibility areas based on what party is responsible for preventing and suppressing the wildfire in that location: federal, local, or state. Users can find these maps on the CAL FIRE website and search for any address to determine the FHSZ and the party responsible for the area.

Figure 8: Fire Hazard Severity Zones are applied across California[41]



[40]https://osfm.fire.ca.gov/divisions/community-wildfire-preparedness-and-mitigation/wildfire-preparedness/fire-hazard-severity-zones/fire-hazard-severity-zones-map/

[41]CAL FIRE Fire Hazard Severity Zone map. Source: CAL FIRE

The FHSZ maps are developed using a science-based and field-tested model that assigns a hazard score based on the factors influencing fire likelihood and fire behavior. Many factors are considered, such as fire history, existing and potential fuel (natural vegetation), predicted flame length, ember distribution, terrain, and typical local fire weather distributions using the Weather and Research Forecasting (WRF) numerical weather model.[42]The FHSZ map evaluates long-term hazard, not risk, based on the physical conditions that create a likelihood and expected fire behavior over a 30 to 50-year period, without considering mitigation measures such as home hardening, utility infrastructure hardening, recent wildfire, or fuel reduction efforts. The zones are used for several purposes, including designating areas where California's defensible space standards and wildland-urban interface building codes are required. The zones are a factor in real estate disclosure, and local governments must consider them in their general planning.

Whereas the FHSZ maps are directed toward long-term planning – as exemplified by building construction standards that last the life of the house -- other ordinal maps promote near-term planning. For example, the National Interagency Coordination Center Predictive Services Program produces daily, weekly, monthly, and seasonal fire outlook maps. These maps identify fire potential in the short term as weather and fire behavior fluctuate. Their purpose is to provide operational decision support information needed to be more proactive in anticipating significant fire activity and determining resource allocation needs.[43]

Cardinal models describe hazard using a value on a numerical scale with a true zero point, such as the actual probability or amount of expected loss in a given area, not just the relation of the hazard compared to another. Cardinal models can also be used to create risk maps. For example, a map created with a cardinal model can show the probability of a wildfire occurring in a region. In this format, the map may still use colors to distinguish higher or lower probabilities, but relative to the actual values rather than relative to other regions.

An example of a cardinal model risk map is the United States Forest Services Wildfire Hazard Potential map (Figure 9). This map depicts the potential for wildfire using spatial datasets of wildfire likelihood, intensity, fuel data, vegetation data, and past fire occurrence

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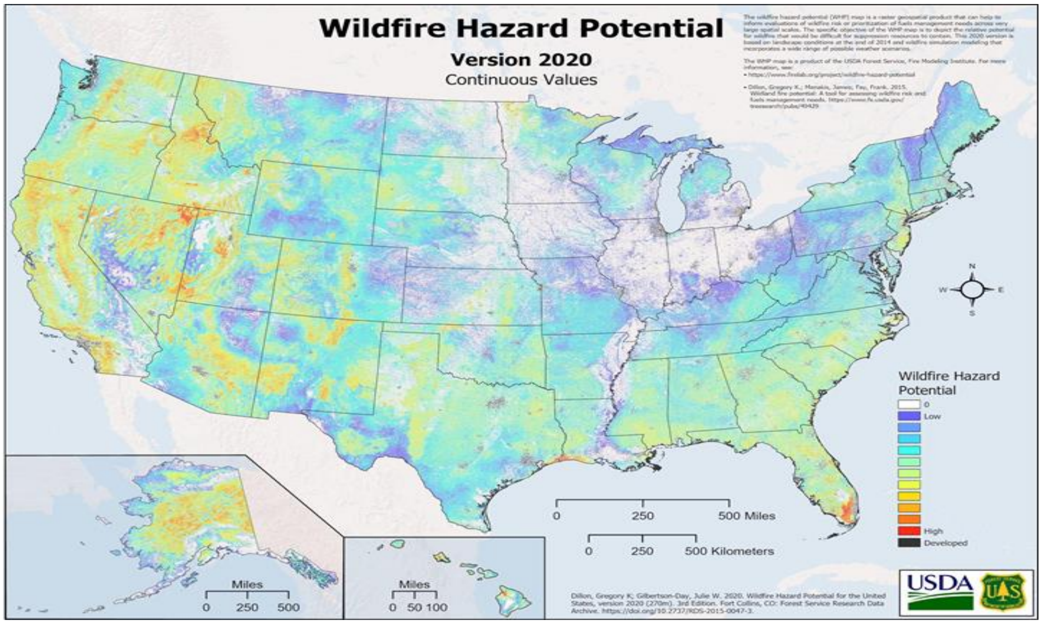
[42] Desert Research Institute, 2020. WRF Climatology Development Project final report. Report prepared under data development contract for California Department of Forestry and Fire Protection, Fire and Resource Assessment Program. 8 p.

[43]https://www.predictiveservices.nifc.gov/outlooks/outlooks.htm

locations.[44] The map gives continuous integer values and five classes: very low, low, moderate, high, and very high.

Figure 9: The potential for wildfire has been assessed across the US



Dynamic models

Dynamic wildfire models can consider not only hazards but also the actual exposure and vulnerability to measure risk. Dynamic models can be further categorized into deterministic models and probabilistic models. Deterministic models produce outcomes that are precisely determined through known relationships without any room for random variation. Deterministic models calculate risk at the location level; they do not factor in any correlation with simultaneous or recent events. Probabilistic models build on deterministic models by considering entire portfolios of exposure (e.g., all the properties an insurance company covers) and the correlation within them. Probabilistic models are based on multiple (typically 10,000 - 50,000) simulations of events, allowing for random variation. Thus, there is always an element of uncertainty involved. Probabilistic models that estimate the potential economic losses resulting from a catastrophic event are called catastrophe models.

4.3.2: DETERMINISTIC MODELS

Deterministic models collect data from historical events and apply observed relationships to potential future events. Given a historical event, a deterministic model can answer the question, "How much damage would occur if this event took place today?" One of the first

[44] Wildfire Hazard Potential | Missoula Fire Sciences Laboratory (firelab.org)

widely accepted demonstrations of deterministic models came after Hurricane Andrew struck Florida in 1992. Modelers used a deterministic model to reconstruct the event and predict losses, which was far more accurate than predictions based on other methodologies. Deterministic models answer "what-if" questions like in the Hurricane Andrew story: "How much damage would occur in an extreme scenario, such as a 1 in 250-year event?"[45]. Asking this question of multiple return periods (1 in 50-year event, 1 in 100-year event, etc.) will enable the user to calculate an average annual loss (AAL). AAL is the overall expected loss for the entire set of events and is calculated as the sum of the expected losses of each of the individual events for a given year[46]. This output can be useful for determining the cost-benefit ratio of proposed mitigations relative to a modeled reduction in potential future losses.

Deterministic models' output can be used to create risk scores or maps. A risk score identifies the relative risk of a property by assigning it a number on a specified scale, such as 0 to 30 or 5 to 100. Commercially available risk scores might consider such factors as slope, aspect, vegetation/fuel, and surface composition, as well as proximity to higher risk areas that could affect the property via windblown embers. They might also incorporate building materials and additional features such as roofing material, tree cover, shape, condition, year built, solar panels, decks, and exterior finish. Depending on the model, these factors are all incorporated and weighted differently to form risk scores, which insurers frequently use for underwriting, inspection decision-making, and risk classification.

A publicly available example of a hazard map using a deterministic model is FlamMap, a desktop software available from the U.S. Department of Agriculture (USDA) at www.firelab.org[47] FlamMap can simulate burn probabilities and fire characteristics, such as growth, spread rate, and flame length, under one weather scenario. The weather scenario considers fuel moisture contents, wind speed, and wind direction.[48] Fire behavior is calculated for each pixel within a given landscape file. FlamMap outputs contain the critical information on fire hazard required for quantitative risk assessment.

4.3.3: PROBABILISTIC MODELS

Probabilistic catastrophe models were developed for the insurance industry to provide a way of measuring and managing low-frequency, high-severity risks that are dependent on

[45]A 1 in 250-year event is an event that has a probability of occurring once every 250 years, or a probability = 1/250 (250 is called the return period). See, e.g., 02_humphreys.pdf (casact.org)

[46]02_humphreys.pdf (casact.org)

[47]FlamMap | Missoula Fire Sciences Laboratory (firelab.org)

[48]http://pyrologix.com/wp-content/uploads/2015/01/Understanding-Stochastic-Simulations.pdf

surrounding exposures. Catastrophe models use significant computing power to analyze many potential scenarios in a specific geography to estimate risk and potential loss. Fully probabilistic catastrophe models simulate thousands of stochastic events, often simulating thousands of possible years.[49]

These models incorporate a scientific understanding of risk drivers and detailed information about exposures for a given peril. For wildfire, property characteristics that allow the probabilistic model to measure vulnerability include location (latitude/longitude), year built (associated with building code requirements), construction, occupancy, replacement cost, insurance policy terms, and secondary modifiers. Secondary modifiers may include property-level mitigation measures such as the type of roof, enclosed eaves, and/or the existence of defensible space. To the extent included, these characteristics all help the model differentiate results based on the vulnerability of the exposure, given the predicted flame length and direction.

Each simulated event produced by a model is translated into an effect on the modeled exposures, usually in the form of structural damage. Calculated damage is then interpreted as estimates of financial losses. By evaluating losses over thousands of events over thousands of simulated years, catastrophe models can calculate both average annual loss (AAL) and exceedance probabilities (EP) for a given property and exposure[50].

Most probabilistic risk models used by the private sector to manage and measure wildfire risk are developed by commercial vendors, who may produce similar models for other perils such as hurricanes, earthquakes, and floods. There are also public and government-sponsored probabilistic wildfire models, including FSPro and Fsim,[51] although neither are standalone catastrophe models because they do not compute financial loss estimations. FSPro is only available within the Wildland Fire Decision Support System (WFDSS). It simulates a single fire event but can account for various weather scenarios, and it has limited ability to model suppression effects. It can provide fire spread probability maps, fire size information, and values at risk information based on overlays with GIS data on assets and key high value watershed resources.[52]

FSim can be found at www.firelab.org. Rather than simulating a single fire event, FSim simulates fire in the modeling area across an entire season. FSim pulls in weather data that can create a full range of all possible weather scenarios that the area may encounter. It

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[49]Taking catastrophe models out of the black box

[50]Ibid

[51]https://firelab.org/project/fsim-wildfire-risk-simulation-software

[52]Microsoft Word - FSPro - Overview.doc (usgs.gov)

iterates 10,000 - 50,000 versions of the fire season. FSim calculates annual probabilities of burning and fireline intensity distributions at any point on the landscape. Distributions of intensity can be combined with assets (homes, watersheds) using their susceptibility at each intensity level to quantify the risk.[53] Output may include the annualized expected impact of fire on assets, fire size distributions, geospatial event sets, the transmission of fire from start location to final impact, and risk change based on fuel management activities.

4.3.4: CATASTROPHE MODELS

Catastrophe models estimate the financial losses that could be sustained due to catastrophic events, including wildfires. Insurers use catastrophe models to assess their risk in assessing their underwriting strategies and purchase of reinsurance. In some states, insurers use catastrophe models in their rate filings to help determine how to price the insurance product. Reinsurers and reinsurance brokers also use catastrophe models to help price and structure reinsurance contracts. Participants in the capital markets, such as catastrophe bond investors and investment banks, use these models in the pricing and structuring of catastrophe bonds.

Outside the insurance context, catastrophe models have been increasingly used by public and private entities attempting to understand physical risk in their decision-making, for example:

- Agencies determining municipal bond ratings
- Investors deciding where to allocate capital
- Lenders understanding the risk of default on their loans
- Government entities targeting regulation and funding towards areas at greater risk
- Communities deciding how to adapt to risk

As the demand for catastrophe models expands, the models will continue to evolve to meet this demand and address the new use cases that arise.

Wildfire catastrophe models in the United States have a relatively short history compared to catastrophe models for other perils, such as hurricanes and earthquakes. Wildfire catastrophe models bridge the gap between wildfire models that predict the physical attributes of an event and the financial loss that can be expected from an event. Elements of the insurance industry have become increasingly focused on catastrophe models since the

[53] FSim-Wildfire Risk Simulation Software | Missoula Fire Sciences Laboratory (firelab.org)

2020 wildfire season. However, given their infancy, these models are still less widely accepted than models for other perils.

More sophisticated models can incorporate satellite imagery to understand an area's geography and topography, weather models to understand factors such as soil moisture levels, quantify the impact of smoke damage on properties, and other physics-based approaches to model wildfire propagation, among many other predictive modeling techniques.

Wildfire catastrophe models are used by private industry to evaluate catastrophic risk, but given their infancy, they are still less widely accepted than models for other perils. Catastrophe models have been developed and evaluated over several decades for some perils, such as hurricanes. As a result, these models will tend to vary less than immature models because the inputs and approaches have been validated over time. Two different mature models will typically produce results that, in aggregate, are very similar, although results for individual risks may vary widely. On the other hand, some perils, such as wildfire, have not been the focus of catastrophe modeling for as long. The models are less mature and may show greater variability in results from one model to another.

Models are dependent upon the availability and quality of the data, their base assumptions, and methodology. Using them effectively may require more evaluation and comparison, a deeper analysis of how they arrive at results, and, in some cases, an adjustment to fit the circumstances. In some cases, models may differ in their output, and are not necessarily "wrong," even if they disagree. They each reflect an estimate of risk based on various inputs, sensitivities, and calculations. New models will be tested and improved over time, and their results will likely converge as they become more accurate in varying scenarios.

4.3.5: INTEGRATION WITH CLIMATE MODELS

Risk models for wildfire and other perils can be enhanced through integration with climate projections and models to make predictions about events under future climate scenarios. The State provides climate projections and models through the California Climate Assessments, currently in their fifth iteration, and hosts current projections, scenarios, and data at cal-adapt.org. Climate models simulate various climate scenarios based on an input set of conditions and output projection values for weather variables, including temperature, rainfall, humidity, etc. The key difference between climate models and risk models is that climate models are generally designed to simulate atmospheric conditions, whereas risk models simulate specific destructive events. When risk models are used to simulate wildfire event expectations in the future, it is important to consider the underlying projected future climate, how it may affect significant risk elements such as fuels, weather, and fire spread, and how those effects will impact risk. Over the coming decades, there may be changes in non-climate-related elements such as exposure, ignition, mitigation, and fire suppression. Since each of these elements is unpredictable, the level of uncertainty will be quite high; however, understanding the core model assumptions and running multiple scenarios will allow users to understand better the range of possibilities they may face. A useful example of such scenarios is CAL FIRE's carbon accounting for fuel treatments program[54], which uses fire probability models[55] to help site forest mitigation activities.

4.3.6: PREDICTIVE MODELS

Electric utilities are deploying predictive modeling to inform operational and asset-hardening decisions. For example, consequence models are used by electric utilities to understand the impact of a wildfire should a utility asset cause an ignition. Such models seek to show wildfire spread given an ignition over various durations up to approximately the first eight hours of spread, although evaluations beyond 8 hours are being developed. Operational models consider real-time or near-term conditions such as weather, fuel moisture content, fuel load, wind speeds, etc. The utility industry also leverages models that determine the ignition risk of individual utility assets or circuits to facilitate risk-informed mitigations. Hardening assets by taking a risk-informed approach reduces community exposure to a high-consequence source of anthropogenic ignitions.

4.4: MODEL VALIDATION TECHNIQUES

4.4.1: CHALLENGES OF LESS MATURE MODELS

While techniques are available to help modelers and users of risk model output, the lack of sufficient historical data for wildfire, in some cases, restricts robust validation. The lack of convergence in model results for results in the lower probability scenarios is of particular importance. These are scenarios where the most severe losses may occur, and the greatest variance in results between risk models exists. Models tend to converge for less adverse, more likely scenarios where more historical data exists to validate against; however, the upper/right tail for extreme conditions and impacts is still sparse. Also challenging is validating models in areas with no historical data available due to an extended fire return

[54] Fire Probability for Carbon Accounting

[55] Park, I.W., Mann, M.L., Flint, L.E., Flint, A.L. and Moritz, M., 2021. Relationships of climate, human activity, and fire history to spatiotemporal variation in annual fire probability across California. PloS one, 16(11), p.e0254723.

interval and/or the effects of suppression resources. As a result, there is no record of fire in many high-risk areas.

When working with less mature models, comparing different model options, and analyzing the results can improve the likelihood of finding a model or combination of models that predict risk appropriately for a user's specific needs. Understanding why models vary and their respective strengths and weaknesses enable one to choose the best tools for the situation. The level of validation required depends on the use case for the model. When evaluating these models, extra care should be taken in determining the exposures that are used. The exposure dataset should be sufficiently comprehensive for the task at hand; however, if actual exposure data is unavailable, representative structure locations or a uniform grid of locations can be used instead. Once the exposure dataset has been defined, some of the most effective validation techniques include reasonability checks, geospatial visualization, sensitivity analyses, and outlier analyses.

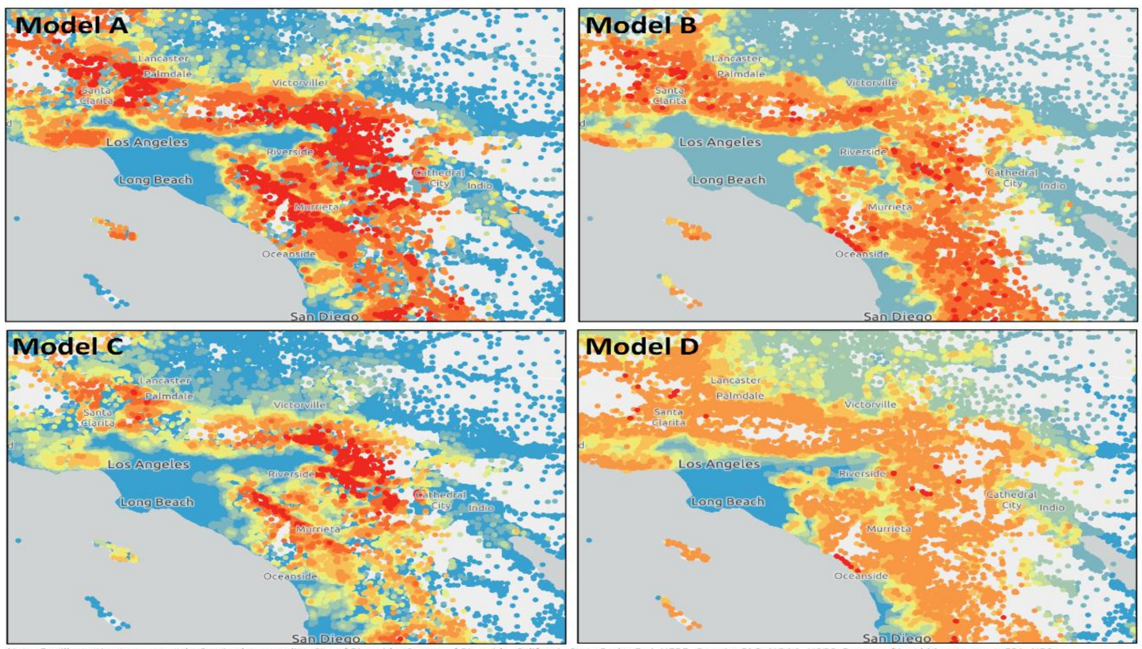
4.4.2: REASONABILITY

While interpreting model results, it is important to take a step back and ensure the results pass basic reasonability checks. Does the model produce low estimates in known high-risk areas or vice versa? For example, do houses in the WUI have similar estimates to homes in dense urban areas removed from wildlands? If so, perhaps there is a reasonable explanation for this, but more likely, the model may not be producing appropriate results. Another reasonability check that can be performed is to look for zero-loss results. If a model shows many zero-loss results in unexpected areas, it may indicate a systematic underestimate of risk. In general, the reasonability checks would indicate whether important drivers of the risk, such as the type of construction and proximity to potential ignition sources, are integrated into the model.

4.4.3: GEOSPATIAL VISUALIZATION

Geospatial visualization of model results can be considered an extension of reasonability checking (Figure 10). This is often the simplest way to visualize model estimates and assess their reasonability. Geospatial visualization is especially useful with access to multiple models' results. Comparing model results side-by-side can help spot irregularities and inconsistencies more easily than through numerical analysis. It also enables the analyst to see abrupt changes in model results across a given geographic area, which are called discontinuities. An example of this is significantly different results on either side of a county border when looking at a wildfire model's results. A reasonable explanation for such a difference could be that one county enforces stricter building codes to mitigate wildfire damage. If there are no reasonable explanations for the discontinuity, there may be some aspect of the modeling approach that needs to be further investigated.

Figure 10: A comparison of example output from four different catastrophe models



Note: For illustrative purposes only. Service layer credits: City of Riverside, County of Riverside, California State Parks, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS

4.4.4: SENSITIVITY ANALYSIS

Another approach to evaluating risk models is through sensitivity analysis. Sensitivity analysis is done by changing an input characteristic of a model and measuring how dramatically the results change. Performing this analysis on multiple models and comparing the outcomes will allow the analyst to check if the models are shifting as expected. An example of wildfire models is how model estimates change as an exposure moves further from the WUI. Results can be reviewed to see whether loss estimates decrease and how the rates of decrease compare across models.

4.4.5: OUTLIER ANALYSIS

Outlier analysis can be performed when you can compare results from three or more models. Outliers can be defined in any way the analyst deems relevant to their analysis. One simplistic way to define outliers would be to set a threshold based on the maximum value of the other models available for a given exposure. If the output from your primary model is greater than the threshold, it can be classified as an outlier. Small outliers can also be determined similarly by comparing the model output with the minimum of the other models.

4.4.6: BLENDING

Finally, blending multiple models can be used to create a more reliable estimate of risk. In blending, more than one model allows insurers to consider multiple views of risk produced by one or more models with different strategies and strengths.[56]

4.4.7: TRAINING AND RESOURCES

There are many actuaries and experts in the insurance industry who are familiar with catastrophe risk models and have developed rigorous protocols for testing model input and output to assess the reasonableness, consistency, and reliability of results. Insurers often test model results against their actual catastrophic claims to better understand their strengths and weaknesses. There is extensive guidance on this subject in Actuarial Standard of Practice (ASOP) No. 38, *Catastrophe Modeling (for All Practice Areas)* issued in 2021 by the Actuarial Standards Board of the American Academy of Actuaries.

Additionally, the National Association of Insurance Commissioners (NAIC), which serves the public interest by setting standards and regulatory best practices regarding insurance, has led several efforts to help its stakeholders understand and leverage catastrophe models, including:

- Established the Catastrophe Modeling Center of Excellence (COE) in 2022 within the Center for Insurance Policy and Research to provide regulators with technical training and expertise regarding catastrophe models and information regarding their use within the insurance industry. The COE also conducts research utilizing outputs from catastrophe models to assess the risk of loss from natural hazards.
- Formed the Climate and Resiliency (EX) Task Force, which, among other charges, is evaluating the use of modeling within various work streams such as solvency, pre-disaster mitigation, innovation, and technology.
- Incorporated wildfire catastrophe risk charges based on catastrophe models into risk-based capital requirements for informational purposes, in addition to requiring catastrophe-modeled risk charges for the perils of hurricanes and earthquakes.

[56] Taking catastrophe models out of the black box

- Published a Catastrophe Computer Modeling Handbook in 2011 to provide recommendations for regulators on catastrophe models. (Note: At the time of publication of this report, the NAIC is currently engaged in an update of this handbook to provide a high-level overview of catastrophe modeling and how insurers use these tools to assess and manage their catastrophe risk).

4.5: WILDFIRE MODELING CHALLENGES

It can be difficult to quantify and model wildfire risk for several reasons. First, wildfires can be exceptionally dynamic and highly localized due to fuel conditions, weather, and suppression activities. Second, extreme weather events are infrequent, which means that, depending on the frequency and magnitude of the event in question, there may be limited historical records of the extent of physical damage to land, structures, and infrastructure. Third, climate change is contributing to unprecedented wildfire conditions and consequences previously unobserved in historical records, which may result in less accurate predictions based on past events.

Models also require accurate inputs about the fuel, which will allow a fire to spread. Vegetation is highly variable and can be difficult to collect with fine-scale accuracy. Vegetation data also requires regular updates to account for changes to the available fuels. In turn, vegetation models describing composition and structure must then be translated into fuel models that describe material as it relates to combustion and spread.

Further, electric utility infrastructure in California is a known contributor to wildfire ignitions, yet many risk models may not have fully integrated the ignition hazard from nearby individual utility assets on surrounding communities nor the impact of utility hardening measures.

SECTION 5: HOW MODELS CAN BE USED TO DRIVE MITIGATION

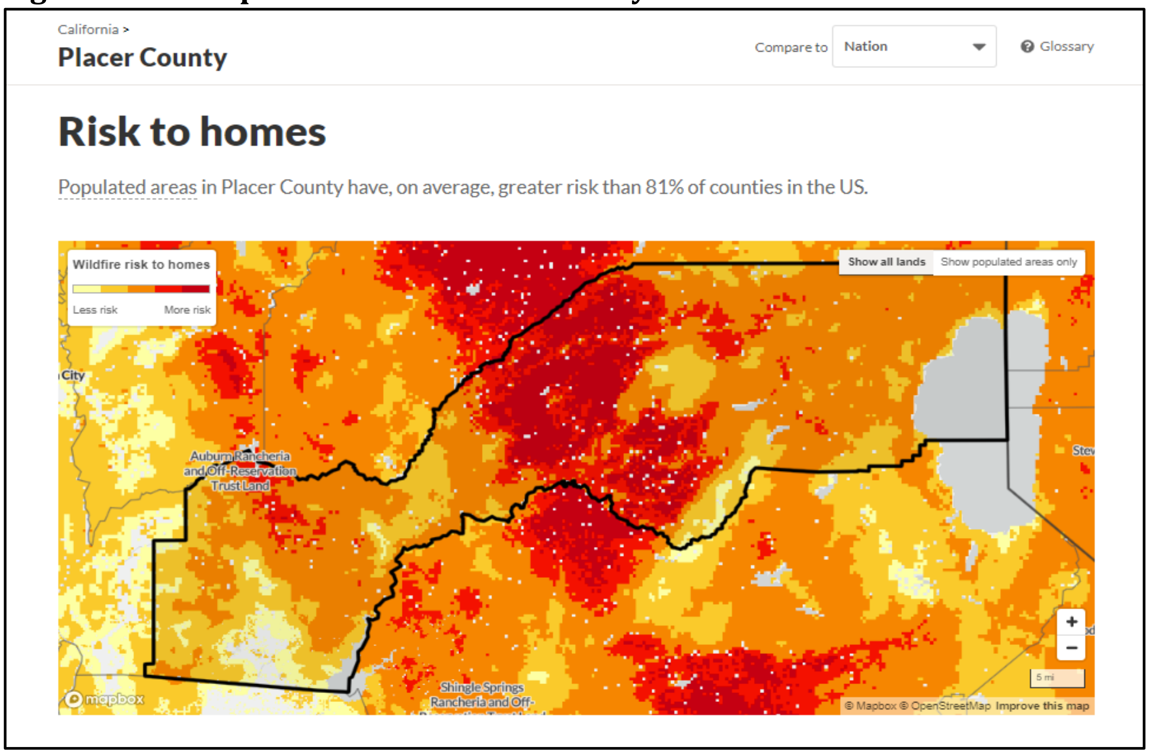
Wildfire models are an important tool for determining what mitigation actions should be taken and where, across many different geographic scales, from the landscape to the individual home. For example, fire managers can use the fire simulation model FSim[57] to prioritize and plan for wildfire mitigation actions, such as prescribed fire, mechanical thinning, managing suppression resources, and identifying egress routes. FSim can be used

[57] https://www.firelab.org/project/fsim-wildfire-risk-simulation-software

by communities along with the help of fire scientists to create data-driven Community Wildfire Protection Plans to inform risk reduction planning.[58]

Informing residents about their wildfire risk is one of the best ways to encourage mitigation. As discussed in a prior section, wildfire models can form the basis of hazard maps, risk scores, and scales that make understanding and visualizing risk easier. Many of these are made publicly available so homeowners and communities can better understand their area's risk and what mitigation measures they should consider. For example, the *Wildfire Risk to Communities* website[59] allows users to explore maps of model output for the entire United States for metrics such as risk to homes, wildfire likelihood, and exposure (Figure 11).

Figure 11: Example risk model at the county scale



Wildfire models that consider highly detailed information about existing buildings and can make predictions based on different building materials, vegetation surrounding buildings, and the spatial arrangement of other nearby structures are useful for understanding how mitigation actions taken by individuals on their own properties reduce the risk, both to the property itself and to those that surround it. By understanding the amount of risk

[58]https://www.tracplus.com/blog/mapping-us-wildfires/

[59]https://wildfirerisk.org/

reduction from specific actions at specific locations, mitigation actions can be prioritized, and results can be communicated to homeowners and community planners. While understanding the most effective mitigation actions is important, quantifying the avoided financial losses associated with the reduction in risk that the mitigation provides can help incentivize these actions, especially at the community level. Wildfire catastrophe models can demonstrate the risk reduction and avoided cost associated with various mitigation actions because they estimate the damage to structures and the financial cost of replacing them.

A few recent pilot studies that use wildfire models to measure the impact of mitigation include:

- A wildfire risk model was recently used in the California Resilience Challenge study on rebuilding the town of Paradise, California, following the Camp Fire of 2018. A goal of the California Resilience Challenge study was to determine the ideal locations to rebuild structures within the town using fire science, historical fire data, and new building code regulations. The exposures (structures and their building characteristics) within Paradise that existed before the Camp Fire were input into the wildfire model. The model was run numerous times with different settings, including various levels of mitigation, variations of spacing of the structures, and multiple climate conditions. From this model output, researchers made recommendations to the town on actions that most reduced the potential for future losses, informing decisions on rebuilding to promote greater wildfire resilience[60].
- A prior study evaluated the implementation of risk reduction buffer zones at the perimeter of Paradise, where entire areas were cleared of wildfire fuel. A supplemental study then used wildfire models to translate the risk reduction into loss reduction terms expressed in financial terms. The risk map created in the study displays a Wildland Probability Index with possible values ranging from 2 to 6. This index was created based on prior fire variable relationship research and the use of climate models. A probabilistic wildfire model was run various times, each reflecting a different buffer zone being cleared. The results were then compared to see if one

[60]Chamberlain, M., Lee, R., Deacon, T., Watkins, N., David, K., Lei, F., Meftah, I. (2023) *Town of Paradise, California Resilience Challenge, Task 1 to Task 4: Risk Reduction, Climate Change, and Insurance Premiums.* A Milliman and CoreLogic Report, Prepared with funding from the California Resilience Challenge Grant. (link)

specific buffer or a combination of buffers lowered the losses significantly more than others.[61]

- Another study published by the Casualty Actuarial Society (CAS) provided the first road map of how actuaries would use catastrophe model outputs to analyze the cumulative value of parcel level mitigations expressed in AAL. This analysis incorporated location and geographic hazard to quantify and illustrate three use cases for wildfire models' ability to measure the effects of wildfire mitigation. The first case shows how insurers might use a probabilistic wildfire catastrophe model to value mitigation actions. The second case extends this analysis to reflect community-level understory fuel reduction mitigation. The final case shows how model results can help quantify the benefits of other community-scale mitigation projects.[62]
- A similar study conducted by the National Association of Insurance Commissioners (NAIC) Center for Insurance Policy Research demonstrates that "building science research can be reflected in a catastrophe model framework to proactively inform decision-making around the reduction of wildfire risk for residential homeowners in wildfire zones." A wildfire catastrophe model was used to quantify hypothetical loss reduction benefits in California, Colorado, and Oregon. The modeled reduction in losses was then compared to the cost of implementing the associated mitigation measure to conclude a cost-benefit analysis.[63]
- Another study was conducted to assess whether and to what extent the severe wildfire risk reduction benefit of ecological forestry can be accounted for in insurance modeling and structuring. The study uses a forestry project in Placer County, California, called the French Meadows Project. The risk reduction is quantified using a risk score based on USFS's FSIM model.[64]

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[61]Chirouze, M., Clark, J., Hayes, J., Roberts, K., Chamberlain, S., Heard, S., Shive, K., Jones, D., Newkirk, S. (2021). *Quantifying Insurance Benefits of a Nature-based Approach to Reducing Risk: Wildfire Risk Reduction Buffers*. The Nature Conservancy and Marsh McLennan. (link)

[62]Brinkmann, P., Watkins, N., Webb, C., Evans, Larsen, T., Lee, G., D., Usan, G., Glavan, M., Zhang, L., & Prescott, C. (2022). *Catastrophe Models for Wildfire Mitigation: Quantifying Credits and Benefits to Homeowners and Communities*. CAS Research Paper. (link)

[63]Czajkowski, J., Young, M., Giammanco, I., Nielsen, M., Russo, E., Cope, A., Brandenburg, A., Groshong, L. (2020). *Application of Wildfire Mitigation to Insured Property Exposure*. CIPR Research Report. (link)

[64]Martínez, N., Young, S., Carroll, D., Williams, D., Pollard, J., Christopher, M., Carus, F., Jones, D., Heard, S., Franklin, B., Smith, E., Porter, D. (2021). *Wildfire Resilience Insurance: Quantifying the Risk Reduction of Ecological Forestry with Insurance.* The Nature Conservancy and Willis Towers Watson. (link)

Even with these examples, data availability remains a hurdle to overcome for models to accurately reflect the risk posed by conditions on the ground. Data is needed to be able to reliably model the impact of property-level mitigations on residual community wildfire risk. Modelers have historically collected or estimated property features such as construction material and year built but have not comprehensively collected data related to the age, type, or condition of the roof, the date of last renovation, ember-resistant vents, or the presence of maintained defensible space.

Community risk reduction efforts, such as creating and maintaining fuel breaks and community buffers, prescribed burns, and nature-based solutions, are important data points that must be considered to understand the speed and intensity with which wildfire may enter a community. However, modelers may not have access to timely, consistent, and complete data regarding these community mitigation measures and their maintenance. As a result, community risk reduction efforts may effectively be excluded from risk measurements.

Lessons Learned from Other States and Perils

History has shown that state insurance regulators, working together with property insurers and catastrophe modelers, can influence individual homeowners to take steps to mitigate their homes against other natural catastrophes, such as earthquakes, hurricanes, and floods. California's approach to managing the wildfire crisis can benefit from the lens of both its own response to the 1994 Northridge Earthquake and the response of other states to incorporate catastrophic models with mitigation strategies to reduce risk.

- **California Earthquake**

  After the 1994 Northridge earthquake in California resulted in $20 billion dollars in damages, the California Earthquake Authority (CEA) was established shortly thereafter to provide Californians with access to affordable earthquake insurance. Since its inception, the CEA has sought to reduce earthquake damage through mitigation. Its efforts have been viewed as highly successful – with policy counts increasing alongside people's awareness of the need for insurance and the expanded availability of mitigation grants and discounts. The CEA did extensive modeling to better understand the benefits of earthquake building retrofits and is now able to offer qualified policyholders up to a 25% discount on earthquake premiums for implementing retrofits that reduce their risk. To complement the discounts, the CEA also offers a "Brace + Bolt" grant program to provide financial assistance for earthquake mitigation, and since inception, 19,000 buildings have been retrofitted with the help of these grants.

- **Florida Hurricane**

  Another instance where catastrophe models provided significant value was in predicting hurricane-related losses. In 1992, Hurricane Andrew caused $30 billion in losses and caused 11 insurers to become insolvent. The state's response was multi-faceted: it adopted more rigorous building codes, established state-sponsored insurance and reinsurance organizations, implemented better catastrophe modeling, and promoted hurricane risk mitigation.

  In 1996, the state established the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM), which developed best practices for catastrophe modelers as well as a review and certification process for model use in Florida.

  Florida policymakers recognized that individual home mitigation actions would play an important role in reducing hurricane risk and the cost of insurance. In 2002, the Florida legislature began requiring insurance companies to offer premium discounts to incentivize homeowners to make their homes more resistant to hurricanes. It should be noted that the state's implementation of these requirements contained a number of flaws that produced adverse consequences and took years to unwind. However, catastrophe models enabled the calibration of mitigation discounts and, ultimately, insurers were able to develop actuarially sound premiums that effectively made insurance more affordable for hardened homes.

- **Federal Emergency Management Agency (FEMA)**

  The Federal Emergency Management Agency (FEMA) has been working in partnership with local and state governments for decades to reduce losses from natural disasters by developing risk-based hazard maps. The maps help communities reduce risk by planning developments away from high-risk areas and identifying locations to adopt risk mitigation measures.

  FEMA also develops recommendations for making building codes more hazard-resistant, largely through FEMA's Mitigation Assessment Teams (MATs). For more than 30 years, MATs have been working with state and local officials to investigate the performance of buildings and infrastructure after disasters. The investigations have shown that strengthening buildings reduces losses. MAT reports develop recommendations for changes in construction methods based on field investigations and building science research. Priority recommendations are then adapted into building code amendment proposals.

In 2011, FEMA initiated a four-phase study, "Building Codes Save: A Nationwide Study – Losses Avoided as a Result of Adopting Hazard Resistant Building Codes." The pilot and demonstration phases were used to develop the National Methodology for this final phase. The BCS Study hypothesis was that communities with significant hazard exposure have realized financial benefits by adopting building codes. The hypothesis was tested by modeling quantifiable losses avoided (i.e., the money that was saved by avoiding physical damage) resulting from the use of building codes.

The study methodology is built on FEMA's Hazus multi-hazard loss modeling methodology and software. Hazus provides a consistent framework for modeling the three dominant hazards in the areas where these hazards are the most prevalent: (1) floods in every state and Washington, DC; (2) hurricane wind in the 22 hurricane-prone states and Washington, DC, and (3) earthquakes for six states in the U.S. West. The modeling required extensive data compilation, aggregation, processing, and analysis of the 18.1 million buildings constructed since 2000. The analysis calculates the Average Annualized Losses Avoided (AALA) from adopting and enforcing building codes with hazard-resistant provisions. AALA is a risk-based metric of the aggregated savings for a community derived from comparing reduced I-Code damage to pre-I-Code construction damage.

The goal of the BCS Study is to help inform community officials and the public about the value of adopting the I-Codes to increase resilience against natural hazards.65

SECTION 6: WILDFIRE RISK MODELS USED BY OTHER JURISDICTIONS

Risk modeling products can vary based on their intended use and audience. Some models provide property-specific wildfire risk information to consumers, including homeowners, commercial property owners, and businesses. Academic and government consortiums have also developed open-source risk models that incorporate short- and long-term projections of fire hazards, primarily for use by state agencies. Additionally, many companies have developed their own proprietary, for-profit risk models that are generally intended to help the insurance industry manage their wildfire risk.

While the methodologies and input data that private companies use to develop proprietary risk, models are not available for analysis, here we can provide a brief overview of some of

[65] https://www.fema.gov/sites/default/files/2020-11/fema_building-codes-save_study.pdf

the methodologies used by governments and academic consortiums to better understand risk at the local government and community levels.

Example models follow.

- The Pyregence consortium's datasets and modeling framework were created to advance research in two areas critical to fire modeling, namely issues related to weather and fuel, to develop a next-generation open-source model. The result is more accurate forecasts of near-term wildfire hazard, active fire spread over periods as long as seven days, and projections of long-term (end of the century) wildfire hazard in support of California's Fifth Climate Change Assessment. Target users are grouped by the following: utilities, land/fire managers, policymakers, and the public.[66] The Pyrecast tool allows investigation of a variety of fire hazard-based risk factors, although querying by specific parcel addresses is not currently supported.
- Another open-source and publicly available source for datasets and model results is the USFS Wildfire Risk to Communities website. Their goal is to help communities understand, explore, and reduce wildfire risk through interactive maps and resources for local mitigation activities. The emphasis is on long-term modeled hazard patterns, although USFS does highlight home loss potential. In this approach, and like the Pyregence tool, vulnerabilities of structures are not specifically mapped or addressed, and the frequency and severity of fire exposure are assumed to affect all homes equally. However, risk in a social vulnerability context is integrated into the mapped outputs. Furthermore, parcel-level queries are not supported, although every community in the US is included in their web-GIS system.

SECTION 7: LIMITATIONS OF MODELS

Wildfire risk models have become increasingly sophisticated in the last several years, but they still have limitations. While these wildfire models are continuously improving, no one model can perfectly capture every detail about a real scenario, limiting the conclusions that can be drawn from any particular model. There are likely to be known considerations that are not captured by the model due to limitations in data, computing capabilities, or modeling techniques. Furthermore, it can take considerable time to update a model based

[66] Note that Pyregence informational materials frequently use the term "risk;" however, based on the committee's definition (i.e., involving exposure and/or vulnerabilities of structures to loss) it appears that outputs are generally referring to some aspect of fire hazard.

on new information, and therefore, a model may not reflect our improved understanding of the peril or current conditions on the ground.

The American Academy of Actuaries report *Wildfire an Issue Paper. Lessons Learned from the 2017 to 2021 Events* described some challenges in accurately modeling wildfire, including some recent factors:[67]

- Accurately modeling the local impacts of Diablo, Santa Ana, and other high winds and their impact on fire spread through embers.
- Effectiveness of early detection and fire suppression efforts
- Determining the return period or likelihood of the 2017 and 2018 events and weather conditions
- Uncertainty around human-related ignition
- Lack of comprehensive exposure information such as community mitigation and enforcement, individual mitigation measures, or building information (such as the presence of appurtenant structures)
- Incorporating the impacts of risk-mitigation efforts where supporting data is limited.
- Post-event factors such as changes in coverage for additional living expenses, demand surge, building code changes, potential for subrogation, and administrative/legislative rulings (e.g., mudslides deemed covered)
- Potential impacts of climate risk[68]

Additionally, the process of creating and updating models is complex and time-consuming, often requiring expertise from a broad range of disciplines. Building models utilize the skills of meteorologists, seismologists, geologists, engineers, mathematicians, actuaries, decision scientists, and statisticians. Users need proper training, subject matter expertise, and a sufficient understanding of the model's purpose and limitations to understand and interpret results correctly.

[67]American Academy of Actuaries, Extreme Events and Property Lines Committee (2022). *Wildfire An Issue Paper. Lessons Learned from the 2017 to 2021 Events.* (link)

[68]CA Climate Assessment: https://www.opr.ca.gov/climate/icarp/climate-assessment/ (5th) https://climateassessment.ca.gov/ (4th)

SECTION 8: BARRIERS AND RECOMMENDATIONS FOR DETERMINING AND REDUCING WILDFIRE RISK

8.1: BARRIER: LACK OF AGREED-UPON STANDARDS

There is currently no consistent way to measure or mitigate wildfire risk in the WUI once structure-to-structure ignition becomes a significant component of fire spread. This is partly due to the current lack of mathematical models capable of simulating fire spread amongst structures. This contrasts with the well-established science on how the interplay between topography, weather, and vegetative fuels drives wildfire ignition and spread across a landscape. Researchers are working towards understanding how wildfires spread from structure to structure and the risk factors contributing to urban conflagrations. The Insurance Institute of Business and Home Safety (IBHS), the National Institute of Standards and Technology (NIST), and CAL FIRE have done extensive work in recent years to move the needle on our understanding of how building construction and proximity to other buildings as well as vegetation contribute to wildfire risk.[69]

However, there is still more research to do, specifically with respect to the interplay between these different variables and their relative contribution to risk. Furthermore, local fire protection resources play a major role in wildfire mitigation, yet there is no standardized way to quantify how their potential contributions bring down the risk in a given community. As research converges to an agreed-upon set of risk factors, a consistent measurement protocol based on various data collection methodologies can be established.

A confounding problem is that wildfire risk and its drivers are not consistently communicated to homeowners and communities via building codes, defensible space/home ignition zone requirements, local amendments to the fire code, state fire safety laws, local ordinances, and insurance premiums. For example, a municipality might have specific ordinances that homeowners must follow to reduce their wildfire risk, and while these ordinances exceed state minimums, they might not align with the mitigations recognized in rating or underwriting by insurers, none of which might align with the latest available science and understanding of wildfire risk. This conflicting information, delivered by authoritative sources, confuses homeowners, and erodes trust between the public and the fire chiefs enforcing the ordinances as well as the insurance companies.

Recommendations: The Workgroup recommends a collective effort among stakeholders to continually support and fund data collection and scientific research that seeks to better understand wildfire spread and risk factors in the WUI. The most rigorous science should

[69]https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2205.pdf

drive what municipalities and insurance companies communicate to homeowners and community members about mitigation recommendations or requirements. The framework of mitigation requirements and recommendations should be consistent across entities while recognizing that those requirements and recommendations must be appropriately adapted to local conditions and will evolve as the science evolves. Furthermore, the Workgroup recognizes the need to understand and account for the role of fire protection services in assessing risk at the community level.

8.2: BARRIER: INCONSISTENT MITIGATION DIRECTIVES

Prioritization of parcel-level mitigations can feel overwhelming to homeowners. They commonly seek information about where to start, the value and benefit of each recommended mitigation, and confirmation that implementation of mitigations will reduce the risk to their property and family. Recommended mitigations often vary and, for example, can be different for two different properties given the inherent differences in building type and landscape context. As indicated in the IBHS report *Suburban Wildfire Adaptation Roadmaps, "*[b]ecause there is a 90% chance of total loss if a single-family dwelling is ignited by embers, a suite of must-change actions need to be put in place first to have any reduction of risk … after those critical elements are addressed, choices can be made to align investment with mitigation."[70] Wildfire mitigation in the WUI should not be viewed as either a "one-size-fits-all," which is often cost-prohibitive or impractical, or as a voluntary "every little bit helps" effort, which provides a false sense of security and leaves significant gaps.[71]

While existing building regulations in California enforce some wildfire mitigations under certain conditions (e.g., Chapter 7A of the California Building Code), these laws were not written with the intention of being a homeowner's decision guide for mitigating risk. Likely unbeknownst to many home buyers, not all materials or construction elements that comply with regulation offer the same level of fire protection. Furthermore, the Chapter 7A defensible space requirements leave room for homeowners to make judgment calls about how to best maintain their defensible space – something that should not be left to guesswork. Local jurisdictions may have their own building codes or ordinances that impose additional requirements that go beyond the State law. However, these local ordinances can vary in language and requirements from one jurisdiction to another, even if they are in nearby areas with similar wildfire risk, further confusing homeowners about what mitigations are really the most important. Insurance companies may encourage

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[70] https://ibhs.org/wp-content/uploads/member_docs/ibhs-suburban-wildfire-adaptation-roadmaps.pdf

[71] https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2205.pdf

homeowners to undertake certain mitigations via underwriting or premium discounts, but these mitigations might also differ from state and local requirements.

While IBHS, NIST, UC Cooperative Extension[72], and CAL FIRE have taken the lead in distilling mitigation research to define the critical mitigations and IBHS has taken the next step to create a framework for homeowners[73] and has introduced a pilot certification program through the Wildfire Prepared Home[74]. However, the public is not broadly aware of the "mitigations that matter" (as discussed in Section 3), and these mitigations are not consistently communicated to homeowners due to the inconsistent and sometimes contradictory information provided via state building codes, local jurisdictional regulations, and insurance pricing signals.

The confusion over "mitigations that matter" is not restricted to homeowners. Insurance companies often find it difficult to know which mitigations are most important and the degree to which different mitigations offer fire protection for specific situations. Furthermore, insurance companies could utilize this information to provide premium credits for mitigation actions. Catastrophe modelers could incorporate mitigation information into their wildfire models. Additionally, fire managers and organizations that work with the public could better inform their communities about where and when to prioritize mitigation actions.

Recommendation: Agreement is needed across the wildfire risk management community around the value and priority of mitigations to reduce wildfire risk. Further, an agreed-upon framework is needed to address unique situations and how to apply these mitigations at the property- and community level to achieve cost-effective and efficient wildfire resilience.

The "Mitigations that Matter" described in Section III of this report serves as a starting point, but implementing the other recommendations regarding agreed-upon mitigation standards and data availability and consistency will help drive a better and more unified way of communicating requirements. As both structures and vegetation contribute to fire spread, these mitigations must include the implementation of progressive building codes,

[72] https://anrcatalog.ucanr.edu/pdf/8393.pdf

[73] https://ibhs.org/wp-content/uploads/member_docs/ibhs-suburban-wildfire-adaptation-roadmaps.pdf

[74] https://wildfireprepared.org/

high-impact structural retrofits, maintenance of structures and surrounding vegetation, and regional coordination of mitigation efforts.[75]

8.3: BARRIER: DATA AVAILABILITY AND CONSISTENCY

Even assuming a set of agreed-upon WUI risk factors, lack of access to appropriate data is a major barrier to assessing risk at scale. The dependencies between risk at the parcel, neighborhood, and community level mean that there must be a consistent means of collecting and aggregating data with which to measure that risk. To achieve this, the state will require an ongoing coordinated data collection effort. The main data-related considerations for determining wildfire risk include defining what data to collect as well as how and when to collect it, data access restrictions and privacy concerns, and costs to collect and store data.

Many different entities currently collect wildfire risk data to different degrees. Federal agencies such as NASA, USGS, NOAA, and the USFS collect data across the country, often using remote sensing, and develop derived products. The data produced by the LANDFIRE[76] program is one of the most widely used datasets for wildfire modeling, both by public and private entities. These datasets are important for modeling wildfire across landscapes and are utilized for assessing wildfire risk by many different entities – especially because federal products are often freely available with limited use restrictions. However, these products generally have a spatial resolution of 30x30 meters at best, rendering them less useful for assessing many small-scale parcel factors (such as defensible space in the 0-30 ft zone).

Entities such as academic researchers, fire practitioners, insurance companies, data vendors, and wildfire mitigation contractors may all collect fine-scale data in different ways, e.g., via on-the-ground parcel inspections, high-resolution remote sensing, and/or homeowner self-reporting. While many building attributes can be detected using satellite imagery, ground inspections allow for the capture of data that aerial imagery may not be able to detect, such as clearance under decks, the condition and type of vent coverings, or structures where vegetation occludes the view.

If parcel-level data is collected consistently and widely across a community, it may be possible to develop a much more informed view of the wildfire risk within a community – instead of using lower-resolution and/or outdated products that may obscure important

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[75]Moritz, M. A., Hazard, R., Johnston, K., Mayes, M., Mowery, M., Oran, K., Parkinson, A. M., Schmidt, D. A., & Wesolowski, G. (2022, May 11). Beyond a Focus on Fuel Reduction in the WUI: The Need for Regional Wildfire Mitigation to Address Multiple Risks. Frontiers in Forests and Global Change, 5. https://doi.org/10.3389/ffgc.2022.848254

[76]https://landfire.gov/

and effective mitigation efforts. Unfortunately, this fine-scale data is often collected sporadically, may not be verified (e.g., self-reported), may not consider real-time changes, and is not available consistently to different entities assessing wildfire risk. As a result, the beneficial impacts of fuel breaks, mitigated buffers, and hardened parcels are not generally included in current fire risk models. This often contributes to a disconnect between the view of risk held by various stakeholders due solely to differences in the data available to them, as opposed to differences in interpretation of that data.

As discussed earlier in this report, there are numerous wildfire models that can be used to assess risk. However, many of these models are based on different input datasets at different degrees of resolution. Wildfire risk models need not come to the exact same answer for a given community or parcel, as all models will have some variation based on the quality and availability of the data, model assumptions, and methodology used for the analysis. However, if models were based on the same starting place – a common base set of data about current conditions – then confusion surrounding risk, mitigation efforts, and modeling could be significantly reduced.

Recommendation: To accurately gauge the most current state of wildfire risk in WUI communities, there needs to be a common data set upon which consumers of data can rely. The Workgroup recommends the establishment of a "**Wildfire Open Data Commons**" to overcome many of the challenges associated with the availability of and access to wildfire risk data discussed above. The Workgroup believes that there is widespread agreement among users of wildfire risk data – including catastrophe modelers, fire managers, the insurance industry, and public and private wildfire research organizations – on the value of this type of shared data. The key components of the proposed data commons include:

- *Establishment of data collection standards and data specifications.* Prior to establishing a data commons, the wildfire risk management community needs to come to an agreed-upon set of standards and specifications to ensure data collected moving forward is done so in a correct, comprehensive, consistent, continuous, and cost-beneficial manner. This would need to address numerous questions such as what data should be collected, when during the year to collect them, how frequently to re-measure, who should collect data, how data should be collected, and how data should be verified. Building in an adaptive framework can help support changes over time.
- *Data synthesis.* Once consistently specified, verifiable data can be collected at the parcel level and can be aggregated up to meaningful levels that allow users to understand conditions surrounding a parcel. The exact level of aggregation (e.g., 90-

meter pixels, 10-parcel grids) and data to be aggregated (e.g., percentage of homes with Zone 0 clearance) will be an iterative process that responds to the needs of stakeholders and the evolving scientific understanding of community risk factors. The data commons would also allow the progression of mitigation efforts to be tracked over time and available for reporting at appropriate levels. It would further allow benchmarking to give additional perspective across communities.

- *Data access.* The data should be hosted on a secured data-sharing platform where all stakeholders can access the data under appropriate permissions to facilitate the ability to assess wildfire risk from a common base set of conditions. Homeowners should be able to access their own detailed data at no cost, to know how and when they are being assessed, and to update their information when conditions change. Local fire professionals should be able to access data within their areas of oversight at no or low cost to be able to support their wildfire risk reduction planning efforts. Access rights for other stakeholders – e.g., communities, state agencies, insurers, modelers, and researchers – will need to be worked out with respect to cost, extent, and level of detail. However, privacy issues must be considered, and data must be abstracted and aggregated accordingly.
- *Ownership and control.* The data commons would need to be managed in a way that allows for effective governance, management, access, and control. In order to succeed, it needs to be trusted by a wide variety of public and private stakeholders.

Establishing a data commons is a necessary precondition for more accurate risk models that will allow modelers to capitalize on the efforts of all the different entities currently collecting exceptionally useful data. In the current environment, this data may not be transferable or usable by another entity purely because of small differences in when and how the data was collected. If the community participating in the data commons experiences a wildfire, knowing the detailed pre-fire and post-fire conditions can allow for inferences to be made about which parcel and building attributes may have prevented the structure from succumbing to wildfire or contributed to its level of damage – bolstering our understanding of WUI risk factors. As more and more data are loaded into the commons, stakeholders can develop more complete and well-rounded views of risk instead of having to make assumptions based on limited information.

8.4: ADDITIONAL BARRIERS

There are many other barriers to reducing wildfire risk. While the resolution of all these additional barriers is challenging and complex, it is important to identify the issues to be better able to find workable solutions.

- Inconsistent enforcement: Different jurisdictions do not equally enforce wildfire mitigation regulations.
- Financial concern for mitigation: Fuel reduction projects and home hardening can be a financial burden for communities and homeowners alike, and long-term assistance programs are limited.
- Coordination challenges: Due to the nature of how wildfires spread, wildfire mitigation may be more effective when a critical number of homes and community spaces within a vulnerable area are mitigated because parcel level mitigations may be inadequate to reduce wildfire loss in the absence of similar mitigations on surrounding parcels. However, it is very challenging to coordinate efforts across property boundaries and jurisdictions. Oftentimes, both private and public landowners/managers must be involved.
- Homeowner and community disapproval: Not everyone is expected to be an early adopter of the "mitigations that matter." For example, removing fuels as a part of implementing a 0–5-foot zone as a part of the update to California's defensible space standards may take time for community adoption. Homeowners may be invested in the sense of place created by their current landscaping and have resistance to the "look" of wildfire-mitigated homes. This can manifest in emotional connections to certain components of their properties that are not wildfire resilient (e.g., vegetation surrounding buildings) that exceed their fear of wildfire loss. It can be challenging to convince people to change their landscaping and harden their homes when they may not like the visual outcomes. Similarly, communities with a history or codes, covenants, and restrictions (CCRs) of a certain aesthetic will need to adapt to a new future.
- Environmental considerations: Many different environmental considerations can pose obstacles to wildfire mitigation, especially with respect to large-scale fuels mitigation work. Certain state and federal environmental laws, such as the California Environmental Quality Act (CEQA), as well as the National Environmental Policy Act, can make implementing fuel projects a lengthy and challenging process. Projects must consider impacts on special status species and habitat, archaeological considerations, air quality, water quality, soil stability, and recreation, as well as the changes in carbon sequestration considering statewide mandated GHG targets. Some program-level CEQA documentation may enable some CEQA streamlining for individual forest fuel reduction projects, such as the programmatic Environmental

Impact Report prepared for the California Vegetation Treatment Program[77] that was approved by the California Board of Forestry and Fire Protection in 2019.

CONCLUSION

California has many wildfire challenges, and multi-faceted approaches are needed. At the core of the work is having access to high-quality, appropriately scaled, publicly available data that can help everyone better evaluate wildfire mitigation efforts and inform risk. This data, paired with a widely agreed-upon framework for analysis, is a key ingredient in moving California toward greater fire adaptation. Combining elements of the above recommendations, the Workgroup suggests that the next level of engagement in this topic takes an integrated approach to *measure*, *communicate*, and *mitigate* wildfire risk.

[77] California Board of Forestry and Fire Protection. 2019. California Vegetation Treatment Program Environmental Impact Report. State Clearinghouse #2019012052. Available: https://bof.fire.ca.gov/projects-and-programs/calvtp/calvtp-programmatic-eir/. Accessed: May 26, 2023.

GLOSSARY

ABBREVIATIONS

AAL - Average Annual Loss

AEP - Aggregate Exceedance Probability

CAL FIRE - California Department of Forestry and Fire Protection

EP - Exceedance Probability

FCHLPM: Florida Commission on Hurricane Loss Projection Methodology

FEMA - Federal Emergency Management Agency

FHSZ - Fire Hazard Severity Zone

FSim - Wildfire Risk Simulation Software

FSPro - Fire Spread Probability Model

GIS - Geographic Information System

IBHS - Insurance Institute for Business & Home Safety

NAIC - National Association of Insurance Commissioners

NASA - National Aeronautics and Space Administration

NIST - National Institute of Standards and Technology

NOAA - National Oceanic and Atmospheric Administration

OEP - Occurrence Exceedance Probability

USFS - United States Forest Service

USGS - United States Geological Survey

WUI - Wildland–urban interface

TERMS

Average Annual Loss (AAL): The sum of the modeled expected losses of each of the individual events for a given year.

Aggregate Exceedance Probability (AEP): The probability that the sum of losses in a year exceeds a certain amount of loss.

Catastrophe Model: Probabilistic models that estimate the potential losses that could result from a catastrophic event.

Exceedance Probability (EP): The probability that a loss random variable exceeds a certain amount of loss.

Exceedance Probability (EP) curve: Visually display the probability that loss will exceed some amount within some period of time.

Exposure: An individual, business, or entity's susceptibility to various losses or risks they might encounter in life or in the ordinary course of business. Exposure is the spatial coincidence of wildfire likelihood and intensity with communities. In this paper's context, the primary exposure focused on is the property and its characteristics.

Fuel density: Mass of fuel (vegetation) per area that could combust in a wildfire.

Fuel management: Removal or thinning of vegetation to reduce the potential rate of propagation or intensity of wildfires.

Hazard: A condition, situation, or behavior that presents the potential for harm or damage to people, property, the environment, or other valued resources.

Interface: An interface WUI is where development, such as structures, is grouped near areas with wildland fuels. There is a clear line of demarcation between development and vegetation, which may appear as an abrupt edge between a highly urbanized or suburban neighborhood and a wildland area—for example, when development borders public lands or when urban growth boundaries are in place.

Intermix: An intermix WUI is where development, such as structures, is interspersed or scattered throughout wildland vegetation. An intermix WUI is often found in rural, exurban, or large-lot suburban developments.

Mitigation: Activities to reduce the loss of life and property from natural and/or human-caused disasters by avoiding or lessening the impact of a disaster and providing value to the public by creating safer communities.

Occurrence Exceedance Probability (OEP): The probability that the largest loss in a year exceeds a certain amount of loss.

Return period: An estimated average time between events, typically based on historical data over an extended period.

Risk: A measure of the anticipated adverse effects from a hazard considering the consequences and frequency of the hazard occurring. Wildfire risk is based on several factors: likelihood, intensity, exposure, and susceptibility.

Structure hardening: Construction or the modifications of the exterior of a building with building materials and installation techniques to reduce impacts from direct flame contact, embers, or radiant heat exposures. New construction in some wildfire-prone areas in California must comply with the California Building Code's Chapter 7A for exterior performance in the WUI.

Susceptibility: Susceptibility is the propensity of a home or community to be damaged if a wildfire occurs.

Underwriting: The process of evaluating, assessing, and classifying risks associated with an insurance policy.

Wildfire intensity: A measure of the energy expected from a wildfire.

Wildfire likelihood: The annual probability of wildfire burning in a specific location. At the community level, wildfire likelihood is averaged where housing units occur.

Wildland-urban interface (WUI): The zone of transition between unoccupied land and human development. It is the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels.

Zone 0: The horizontal area within the first five feet around the structure and any outbuildings and attached decks and stairs. This zone also includes the area under attached decks and stair landings.

HELPFUL RESOURCES

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3. California Department of Insurance Climate Insurance Working Group (2021). *Protecting Communities, Preserving Nature, and Building Resiliency* (link)

4. California Governor's Office of Planning and Research (2022). *Fire Hazard Planning Technical Advisory* (link)

5. Chamberlain, M., Dietzen, G. (2022) *Taking catastrophe models out of the black box* (link)

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15. NAIC Catastrophe Modeling Center of Excellence (link)

16. NIST Investigation of the California Camp Fire (link)

17. Quarles, Stephen L., et al. "Home survival in wildfire-prone areas: building materials and design considerations." (2010), UC ANR Publication #8393. (link)

18. USDA Wildfire Risk to Communities (link)

19. Valachovic, Y., Quarles, S. L., & Swain, S. V. 2021. Reducing the Vulnerability of Buildings to Wildfire: Vegetation and Landscaping Guidance. UC ANR Publication #8695. (link)