CITY SCALE WILDFIRE LOSS AND RELATIVE FIRE SPEED

A FRAMEWORK FOR MEANINGFUL COMMUNITY-SCALE RISK REDUCTION

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Abstract

Analysis of recent disaster fires shows that five ingredients are necessary for a fire to turn from a wildfire into an urban disaster with city-scale losses: sustained strong winds, rapid fire spread through vegetation, structures that lack defensible space and home hardening, delayed or overtaxed firefighting response, and tightly-spaced and contiguous structural fuels. We argue that considering time as the key common denominator of the problem of urban disaster fires provides a useful framework to evaluate how to design policies, programs, and optimization strategies to prevent future widespread losses. Maximum risk reduction is achieved when activities alter the relative timing of key phases of the incident lifecycle. Because wildfire mitigation resources are limited, leveraging multiple forms of risk reduction activities and network effects can achieve critical changes in relative timing with high return on investment.

Ingredients for City-Scale Fire Loss

Every year, tens of thousands of wildland fires occur nationally. In 2024 alone, there were 8,024 wildfires recorded in California[1] and 64,897 nationwide[2]. However, only a small number of these fires resulted in significant losses. Most incidents were small roadside ignitions, escaped campfires, isolated lightning strikes and other minor fires that local fire departments quickly extinguished. A small fraction of all fires - those that occur during high-severity fire weather conditions and during the times of year when fuels are most receptive to fire spread - impact human development and the environment. These potentially high-consequence fires, of which there are hundreds per year in the United States, may become very large and impact structures in rural and wildland-urban interface or intermix communities. However, only a handful of fires - less than one per year, on average - result in city-scale losses.

In the past twenty years, over 124,732 structures have been destroyed by wildfires in the United States, but just six fires account for more than 35% of the total structure losses:
- The Tubbs Fire (Santa Rosa, CA 2017, 5,636 structures burned),
- Camp Fire (Paradise, CA 2018, 18,804 structures burned),
- Marshall Fire (Boulder, CO 2022, 1,084 structures burned),
- Lahaina Fire (Maui, HI 2023, 2,719 structures burned),
- Palisades Fire and Eaton Fire (Los Angeles, CA 2025, 16,255 structures burned, combined).

These catastrophic urban fire disasters destroyed thousands of structures and caused the displacement of entire communities[3,4,5,6].

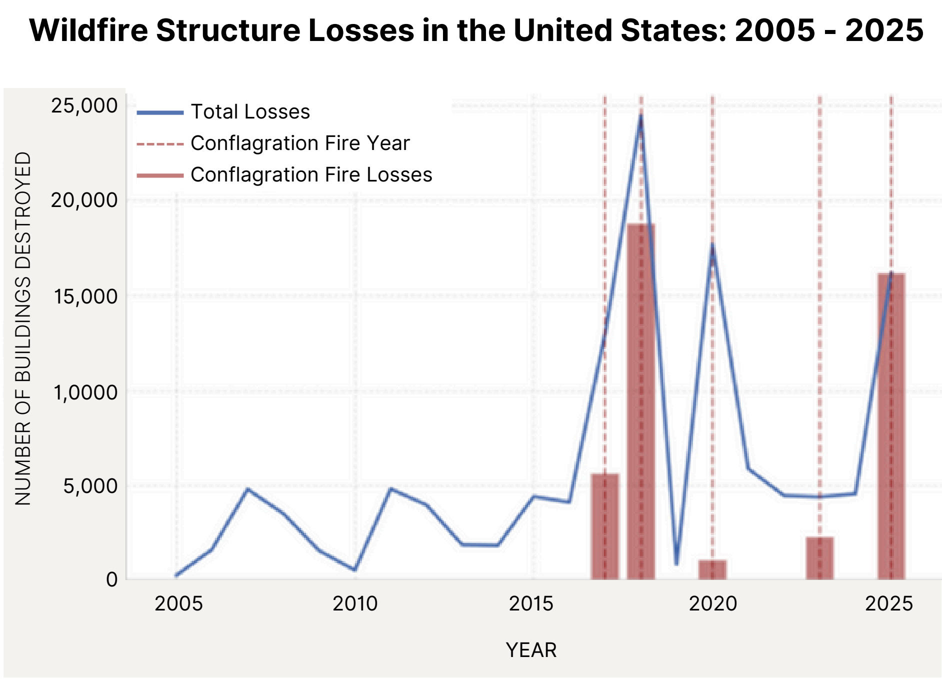

Figure 1: Wildfire losses in the United States between 2005 and the beginning of 2025. Approximately 35% of the structural losses have been caused by just six fires[7].

City-scale fire loss requires an extraordinary alignment of factors: in addition to dry, windy fire weather, receptive fuels, and other conditions necessary to support "normal" high-severity wildfire fire behavior, fires that result in catastrophic city-scale losses require the presence of at least five additional factors outlined below. These factors do not alter the likelihood of a fire occurring or relate to the intensity of the fire. Instead, as originally described by Jack Cohen, the factors associated with city-scale losses revolve around the rate of fire growth, the presence of vulnerabilities at the points of vegetation to structure transition, and the relative timing of key events in the incident lifecycle which result in firefighting resources becoming overwhelmed and ineffective[8]. These factors often come together in times outside of the normal fire season. For example, few wildfire analysts would have suggested that critically dry fuels in January would lead to the most damaging wildfire in Colorado history. Yet the Marshall Fire in Boulder County, despite having only modest flame lengths and low fireline intensity, consumed portions of Louisville, destroying over 1000 structures valued at over $2 billion. Compared to the fifty-plus foot flames commonly produced in fires in the forested regions of Colorado, this fire activity would not have ranked as particularly dangerous in most contemporary wildfire risk assessments.

We argue that city-scale loss requires all of the additional ingredients listed below. Removing one or more of these conditions dramatically reduces the likelihood of achieving and sustaining urban conflagration.

1. **Sustained Extreme Wind Event:** Fire growth is driven by wind. Wind provides combustion with ample oxygen, preheats fuels ahead of the fire front, and transports embers. Strong local and mesoscale winds accompany numerous fires that don't result in large-scale losses. However, extreme wind events that produce near-hurricane force winds for an extended period of time are a necessary precursor to vegetation fires that initiate conflagration and subsequent city-scale losses. These events, such as Foehn wind events (Santa Ana, Diablo, and Chinook winds), are often accompanied by very dry air and can result in extreme rates of fire spread and long-range spotting, causing fires to spread rapidly and exhibit resistance to control.

   The duration of the wind event is a critical factor in large-scale structure loss. Short-duration winds that last just a few hours are often insufficient to result in catastrophic damage within the built environment. During the 2025 Los Angeles Fires, wind speeds near the Eaton Fire ignition point exceeded 75 miles per hour for more than eight hours[9]. Extended periods with wind speeds approaching 100 miles per hour and low relative humidities were also observed in the Marshall Fire[10] and Lahaina Fire[11].

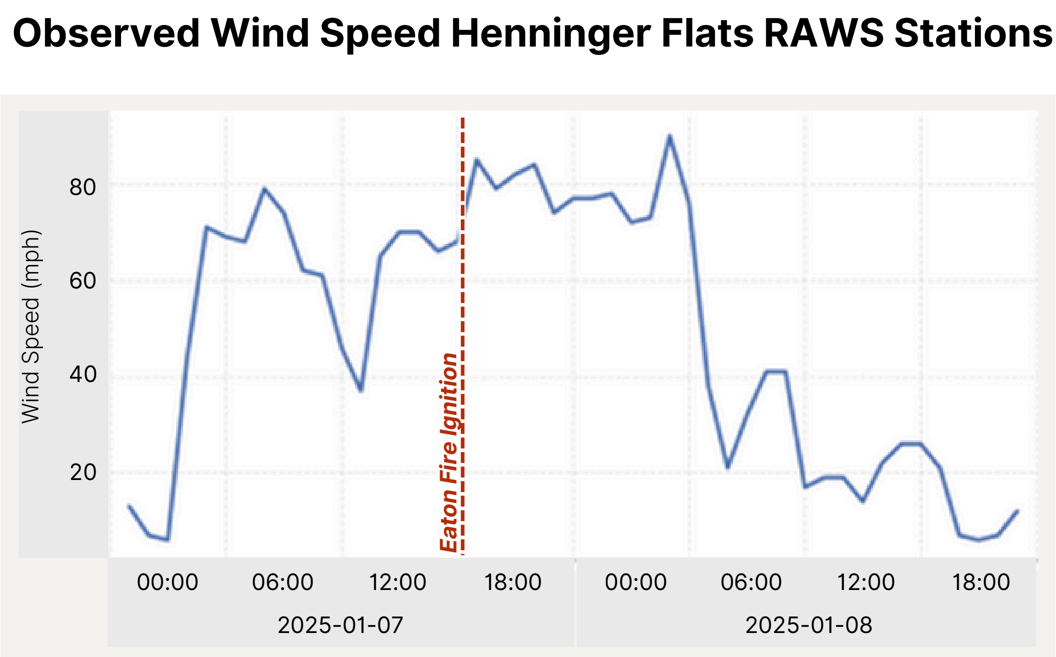

Figure 2: Observed wind speeds at the Henninger Flats Remote Automated Weather Station (RAWS) during the first two days of the 2025 Eaton Fire. This station is located just outside of the community of Altadena.

2. **Fast Moving Vegetation Fire**: Fires that result in city-scale loss tend to move rapidly through vegetative fuels surrounding a community (the "wildland" in the wildland-urban interface) and quickly expose structures to flames and embers. Alignment between the wind direction, the fire's ignition point, and the community's values at risk is the critical factor in initiating structure-to-structure fire spread. The Eaton Fire likely started just over 600 meters from the nearest structures along Altadena Drive[12,13], giving firefighters very little time to respond before structures were threatened. Other catastrophic fires also exhibited similar characteristics - starting close to the community and spreading very rapidly through light fuels such as grass and brush before exposing structures. The Marshall Fire started approximately 2 miles from the community of Superior, Colorado, but impacted that community within an hour; the Camp Fire started about 7 miles from Paradise but, due to widespread long-range spotting, reached the community in less than two hours.

3. **Insufficient Structural Resistance to Ignition**: Defensible space and home hardening significantly reduce (but do not eliminate) the probability of structure ignition due to radiant heating, flame contact, and ember exposure from wildland fuels. City-scale loss events are typically associated with the "domino effect," where structure-to-structure fire spread causes one house to ignite the next[14]. Defensible space and home hardening, especially on the edge of the community, where the threat of ignition is primarily in the form of direct flame and embers from vegetation fire (as opposed to radiant heat from an adjacent structure) can substantially reduce the likelihood of wildfire transitioning to structures and becoming established within the built environment. During the Camp Fire, structures that adhered to home hardening requirements specified in the California Building Code Chapter 7A were nearly three times more likely to survive than structures that were built prior to the rigorous 2008 code[15]. Similarly, a post-fire analysis of the Lahaina conflagration found that both the materials of construction and the presence of connective combustible materials were significant contributors to structure ignition, particularly on the edge of the community[16,17].

4. **Fire Protection Effectiveness Reduced or Nonexistent**[18]: Firefighters play a critical role in defending structures and performing offensive fire suppression activities, such as firing operations, around communities. With adequate quantities of firefighters, suppression actions can prevent the transition into the built environment required to initiate structure-to-structure fire spread. However, to be effective, firefighters must be in position in sufficient numbers to engage the fire before the fire becomes established in the community. Fire protection effectiveness is a race between firefighters and fire to the critical entry points. Recent city-scale loss fires were all associated with a quantity of firefighters that was insufficient for the scale of the fire they were assigned to fight at the critical time and place. Put simply - the pace and scale of fire spread exceeded the pace and scale of the firefighting response. As a result, the overall firefighting response experienced reduced effectiveness due to insufficient resources at key locations in time and space. In recent conflagration fires, post-fire surveys and firefighter interviews commonly reference firefighters being "overwhelmed" and unable to effectively engage the fire due to resource constraints and fire behavior[19,20,21,22]. This is further compounded when extreme wind speeds reduce the effectiveness of aerial firefighting resources, removing a critical adjunct to ground suppression resources.

5. **Continuous Structural Fuels**: For urban structure-to-structure fire spread to occur, structures must be arranged such that the domino effect of cascading structural ignitions can be initiated and maintained. Based on post-fire surveys and experimental studies of burning buildings, structures located within 25 feet of one another are highly likely to exceed the thermal flux needed for ignition[23,24], given the ignition of a neighboring structure. Structures located further apart than this threshold, and particularly those located more than 50 feet from one another, are much less likely to ignite from the combustion of neighboring structures.

In new construction, the strategic placement of non-burnable features such as parks, parking lots, and other non-burnable features can create community compartmentation by breaking the domino chain to limit downstream fire growth. In recent city-scale loss fires, the arrangement of structures allowed structure-to-structure fire spread to continue for miles into the community with few natural or passive man-made barriers to growth. A FEMA study of the patterns of structure losses in the Marshall Fire found that “building configuration, siting, and spacing” were key issues leading to structure-to-structure ignition and buildings “placed closely together in densely-developed areas can ignite one another by direct flame contact or radiant heat.” In Lahaina, the presence of “dense construction with little fire resistance” was a significant contributor to the large-scale losses[25].

Removing any one of these five factors can dramatically reduce the fire’s potential to cause city-scale loss. For example:

- Limited-duration wind events are generally not capable of producing city-scale loss, because the conditions for propagation within the built environment are only present for a short period of time which is insufficient to cause and maintain community ignition.
- The presence of defensible space and home hardening at the points of vegetation fire to structure transition fire impedes the fire’s growth in key locations and dramatically lowers the probability of fire rapidly establishing itself in the community and exhibiting structure-to-structure fire spread.
- Firefighters in sufficient numbers can engage in offensive and defensive activities around the community and at points of entry to limit the potential for conflagration initiation and can interrupt chains of structure-to-structure fire spread.
- Communities with separation distances of more than 25 feet between most structures are generally incapable of sustaining fast-moving urban fire spread because structures cannot contribute sufficient radiant heat to their neighbors to achieve ignition.

Common Denominator

The common denominator of these critical ingredients is time. The combined effects of fast-moving fire through vegetation fuels, the relative timing and quantity of firefighter arrival, and the rapidity and scale of initial structure ignition and subsequent structure-to-structure fire spread combine to result in city-scale wildfire losses. In this section, we develop a conceptual framework that uses relative time to identify key phases in potentially catastrophic fires. We argue that the timing of those events relative to one another is the primary determinant of whether catastrophic damage occurs. This framework provides a useful basis for evaluating risk to communities and developing policies and programs to mitigate the risk of city-scale loss events based on a community’s unique characteristics.

The key time events in the evolution of a WUI-initiated urban fire are (a) the time elapsed between a fire’s ignition/detection and the time it arrives in the community, (b) the time to evacuate a community’s population, (c) the time for firefighters to arrive in sufficient numbers to engage the fire safely and effectively, and (d) the time required to initiate self-sustaining community ignition. Large-scale losses are possible if fire arrival and community ignitions outpace evacuation and suppression response. Conversely, if the pace of fire arrival and initiation of community ignition is slower than the evacuation and firefighting response, conflagration is unlikely to be initiated and damages are likely to be small.

- **Time of Evacuation:** It is critically important to preserve life safety during a wildfire. Rapidly spreading fire into unprepared or under-prepared communities can turn orderly evacuations into chaotic scrambles. According to a recent survey, “the majority of recent civilian fatalities [in wildfires] in the United States have occurred when people attempted to evacuate too late or chose not to evacuate and were overtaken by fire or smoke.”[26] Further, if evacuations are underway, firefighting response efficacy will be reduced as firefighters will likely be pulled away from fire suppression to perform life safety actions and evacuation support. Therefore, systems to effectively alert residents and facilitate rapid egress are critical to ensuring safe evacuation and minimizing civilian injuries and death in the event of a rapidly spreading fire. The time to evacuate a community depends on the community’s size, the types, characteristics, and carrying capacities of roads, available notification systems, and the fire’s location relative to key routes of egress[27,28].

- **Time of Fire Response:** Most wildfires, particularly those occurring on extreme fire weather days when conflagration is possible, require more firefighters than local jurisdictions can supply. These fires require response from neighboring jurisdictions and mutual aid partners, and often, fire resources from more distant agencies ordered as part of the incident command process. These resources, which contribute both quantity and capabilities to the overall fire response, take time to reach the portions of the community exposed to fire. This time, defined here as the requisite fire response time, is of critical importance. If a requisite response precedes the arrival of the fire into the built environment and prevents initial home ignitions, cascading effects of structure-to-structure fire spread are much less likely. While firefighters often struggle to contain fires once they begin to burn in the built environment under extreme wind events, they can be exceptionally effective when performing offensive and defensive actions prior to and during initial community exposure.

  The requisite fire response time depends heavily on the community's location in relation to populated urban centers. For a California example, communities in the Bay Area are likely to receive numerous firefighters and other fire response resources within hours. In contrast, more rural communities, such as those in the Sierra Foothills, require additional time for fire response resources to muster and travel from the densely populated metropolitan areas. Finally, communities located in remote areas far from developed areas, such as those on the eastern side of the Sierra Nevada range or in the mountains of the Klamath watershed, will have very few resources available within the first operational period (typically 12 hours) and may not have an effective firefighting force until days into the incident. To a lesser degree, fire response time may depend on the capacity of the roads to support emergency vehicles, fire behavior, and other factors; however, these factors tend to be relatively minor compared to the location of the community and its relationship to mutual aid resources.

- **Time of Fire Arrival:** The timing of the arrival of the fire in the community depends on the location of the ignition, the vegetation type and availability (configuration and fuel moisture), and the wind driving fire growth. Although the location of ignition cannot be reliably predicted, the speed of fire travel and the rate of fire growth can be modeled using standard fire behavior growth models. Further, while the wind and weather driving fire growth are forces of nature, the type of vegetation through which fire burns is an important factor determining the fire growth rate that can be directly modified through vegetation management. In many cases, strategic vegetation management and fuel treatments in high rate of spread fuels can slow fire growth by a factor of 10 or more, leading to dramatic changes in fire arrival times.

- **Time of Community Ignition:** Cascading ignitions leading to city-scale loss events necessarily start with the ignition of structures via wildland fuels or embers. These initial ignitions can then lead to structure-to-structure fire spread dynamics, which are driven by radiant heating between structures, connective fuels such as wooden fences, and the deposition of structural embers on downwind properties. These embers, produced by burning structures, can travel longer distances and carry more thermal energy than embers produced by wildland vegetation[29]. Communities with high rates of home hardening and defensible space are less likely to ignite when exposed to wildland fire[30] and may ignite more slowly than communities with lower rates of on-parcel mitigation[31]. Once fires have become established within the built environment, they tend to spread very rapidly, even if a community has a high rate of mitigation compliance due to radiative heat transfer between buildings that exceed the design parameters of defensible space and home hardening approaches designed to protect against wildland fire exposures[32,33].

Within this framework, the factors over which communities have the most agency are the time of fire arrival and the time of community ignition. Because the requisite fire response time depends largely on the community's location, it cannot be altered by most jurisdictions, even with the acquisition of new firefighting equipment. In most cases, the benefits of new apparatus are likely to be small compared to the number of apparatus and specialty equipment (e.g., helicopters, dozers, handcrews, etc) needed during a major fire. The time of evacuation depends on community size and layout; while this timing can be modified through evacuation route improvements and the construction of new roads, it is largely static without large-scale community investment that transcends wildfire preparedness.

In contrast, the time of fire arrival can be directly modified by land managers through strategic application of vegetation management, including grazing, prescribed burning, manual and mechanical thinning, and mowing operations34. Moreover, resident action and local ordinances work together to increase community ignition time by altering parcel-level characteristics to improve defensible space, integrating structural hardening, and employing fire-safe landscaping techniques that slow fire growth across private parcels and decrease the ignition likelihood of each structure exposed to wildland fire and embers.

Mitigation Activities and the Incident Lifecycle

All communities, even those that are well-resourced, are constrained in their ability to complete risk-reduction activities at scale. Mitigation of all fuels and all structures quickly runs into the millions of dollars, even for small communities. Such large-scale mitigation efforts quickly become financially unfeasible. However, barriers to risk mitigation extend beyond the financial: many communities also lack the physical resources required to perform the mitigation work (such as handcrews, curtain burners, and chippers) and community buy-in on mitigation projects and strategies. It is important to develop a prioritized plan that does not rely on unrealistic expectations for initial implementation and maintenance of mitigations. Numerous fuel and fire breaks were built throughout the Western United States without a plan for ongoing maintenance, often using one-time grant money. As vegetation regrows, the effectiveness of treatments rapidly decays over time.

Because a community’s capacity to mitigate is limited, mitigation projects must be focused on the activities with the greatest potential to alter the relative timing of the critical events in the incident lifecycle. Effective application of vegetation management, home hardening and defensible space, and evacuation route clearance and alerting can fundamentally alter the relationships between fire arrival time, community ignition time, and community evacuation time and reduce the likelihood of city-scale losses. Just as different fuels and topographic positions produce different fire behaviors, mitigation activities of different types in different locations provide varying levels of benefit in changing the course of the incident.

Based on our combined wildfire policy, modeling, and operations experience, we argue that two strategies for risk mitigation are particularly important in changing the relative timing of conflagration loss events with a high return on investment:

- **Vulnerabilities at Entry Points:** If a fire arrives at the built environment before the requisite fire response, a transition from vegetation growth to structure-to-structure fire spread may occur if on-parcel vulnerabilities are present at the points of initial fire exposure. These vulnerabilities include non-Class A-rated roof coverings, lack of ember-resistant vents, lack of a non-combustible zone within five feet of the structure, attached combustible fences or other attachments, and the lack of well-maintained defensible space.

  In the absence of these vulnerabilities, homes at the edge of the community initially exposed to a wildfire are much less likely to ignite. Further, structures located in the community's interior are likely to be exposed only to wildland ground fire and embers rather than the intense and sustained radiant and convective heat fluxes of adjacent burning structures. These changes reduce the likelihood of immediate community ignition and provide more time for evacuation and the assembly of the firefighting response.

- **Strategically-Located Vegetation Management**: Large-scale vegetation treatment is not always necessary to effectively increase the time of fire arrival in WUI communities. Focusing on vegetation management treatments that reduce the fire's rate of spread in strategic locations through patterns of disconnected fuel treatment patches35, rather than widespread reduction in fire intensity around a community, is critical to protecting lives and property. Modeling in many different contexts has shown that treating just several hundred strategically located acres can be as or more effective at slowing fire growth than the treatment of thousands of acres and can dramatically change the timing of fire arrival relative to evacuation and fire response. Additionally, if these treatments are located along roads and other anchor points, they can be effectively used by firefighters in suppression operations, providing both active benefits to suppression and passive benefits by slowing the fire.

Minimum Threshold and Diminishing Marginal Returns

When landscape treatments are combined with defensible space and home hardening activities that reduce vulnerability at fire entry points, the benefits to community risk reduction can be substantial. Perhaps most important, however, is the flexibility provided by a strategic layered application of different mitigation strategies that allows practitioners to estimate the minimum thresholds required to achieve community resilience and prevent large-scale loss.

Wildfire risk reduction activities, including both home hardening and defensible space and strategic vegetation management in open spaces, have a threshold below which implementation contributes little to overall risk reduction. For example, if a resident has ten cypress trees within five feet of the home, removing one of them is unlikely to contribute to a 10% reduction in risk on that parcel. The remaining nine vulnerabilities still threaten the structure, each capable of structural ignition resulting in a total loss. However, if the same home has ten cypress trees forming a line leading to the structure from the property's edge, removing the eight closest to the home is likely to result in a substantial reduction in risk because fire has far fewer vulnerabilities to exploit from a greater distance. This risk reduction activity can be of even greater benefit if accompanied by a complimentary hardening of the home, such as the installation of ember-resistant vent screens.

Similarly, when too few acres of open space are treated, fire can burn around or spot over treated areas, resulting in little benefit to the community. Moreover, treated locations that are not capable of carrying fast moving fire into the community will have little impact on the relative timing of fire arrival. Evaluating the potential minimum thresholds for mitigation can ensure communities invest in sufficiently impactful programs that contribute to community resilience.

After implementing the minimum threshold, additional mitigation investments contribute to increased community resilience and risk reduction up to the point of diminishing marginal returns. Each additional hardened parcel or acre of vegetation management will further reduce risk and decrease the likelihood of large-scale community loss. However, as more and more mitigations are applied, the marginal effectiveness of each is reduced. For example, when the majority of acres capable of supporting rapid fire spread upwind of the community are treated, additional vegetation management is unlikely to result in substantial changes in fire arrival time at the community. At this point, resources should be shifted to other mitigation approaches or new geographies.

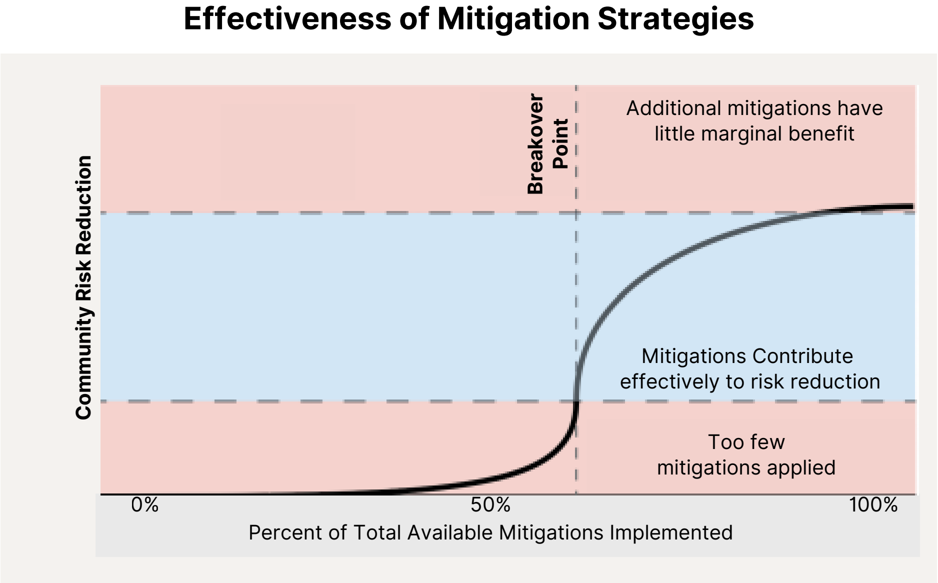

Figure 3: Conceptual illustration of the effectiveness of mitigation strategies. Once the quantity of mitigations has exceeded the breakover point, additional implementation contributes to community risk reduction until the point of diminishing marginal returns has been reached.

Working Towards Meaningful Risk Mitigation

The tools to build meaningful mitigation strategies that alter the relative timing between key events in the incident lifecycle exist today; however, they must be thoughtfully combined to provide a useful assessment of where, how, and how much mitigation to pursue given a community's unique topographic, climatic, and population characteristics. In this section, we present an operational conceptual framework that can help practitioners create mitigation programs that maximize return on investment while adapting to the community's specific needs. Like any modeling approach, this framework leverages computational tools that may not capture the behavior of any specific historical event but can provide objective and quantitative data for evaluating cost-benefit tradeoffs.

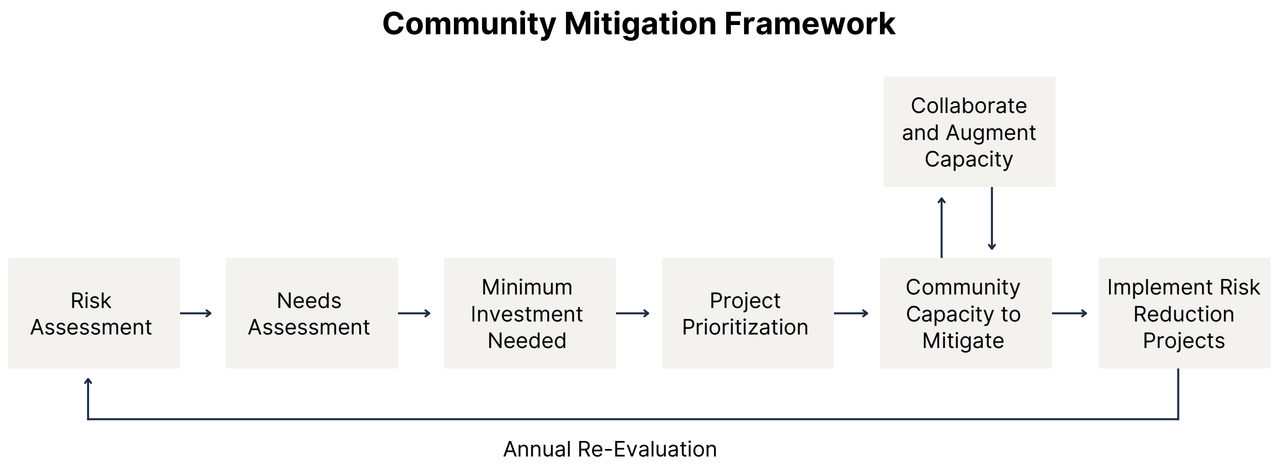

Figure 4: Conceptual illustration of the effectiveness of mitigation strategies. Once the quantity of mitigations has exceeded the breakover point, additional implementation contributes to community risk reduction until the point of diminishing marginal returns has been reached.

Risk Assessment

The first step in evaluating a community's mitigation strategy is to create a risk assessment that focuses on the time of fire arrival and the time of community ignition. While many communities today have wildfire risk assessments that evaluate the potential fire behavior in and around the community, most focus on the assessment of flame lengths, fireline intensity, and other extreme fire behavior associated with high heat release rates. Rather than, or in addition to, focusing on intensity, we argue that the risk assessment should address the following questions:

- Which portions of the community are most vulnerable to rapidly spreading wildfire? These areas are often, but not always, located on the edges of the community and are typically adjacent to wildland vegetation that could carry fire rapidly when aligned with the wind. Directionality is important in this assessment: depending on fire weather characteristics unique to that community, an expanse of natural vegetation may be a corridor for rapid fire spread under one weather pattern (such as a Santa Ana or Chinook wind event) but of little concern under other weather conditions, particularly if those conditions are accompanied by high relative humidity. This assessment should also assess the continuity of the fuels in the area. Simply being near wildland fuels is insufficient to result in large-scale urban fire loss. When non-burnable elements of the built environment, such as golf courses, water features, and wide roads or highways interrupt the fuel continuity between the vegetation and the built environment, rapid wildfire transition into structural fuels is less likely.

- Which portions of the community are most vulnerable to rapid community ignition? These areas of the community typically have low structure separation distances (<25') and low rates of defensible space and home hardening compliance. If fire reaches these areas, cascading ignitions are possible.

The risk of large-scale structure losses is greatest where these two patterns intersect: areas where unmitigated structures are in close proximity to one another and are adjacent to wildland fuels capable of carrying fire quickly under high-severity fire weather conditions. The tools to model these characteristics have existed for decades. Standard fire modeling packages, such as Flammap, FarSite[36], and ELMFIRE[37], enable practitioners to evaluate fuel continuity and spread rate. The network of surface weather stations[38,39], widely available remote sensing data, and large-scale reanalysis projects allow a precise assessment of the speed, direction, and moisture content of high-severity fire weather in a given area. Finally, geographic information system (GIS) analysis facilitates detailed assessment of structure separation distances and incorporation of data from defensible space inspections and home evaluations.

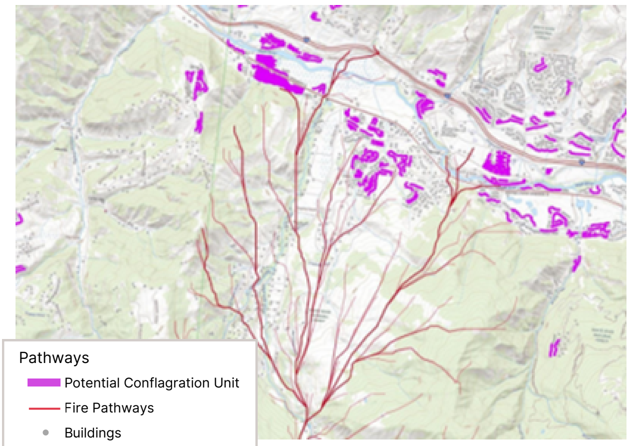

Figure 5: An example of a risk assessment that incorporates both the relative speed and continuity of wildland fire spread (red lines) and the continuity of structural fuels (purple polygons) to delineate areas where wildland fire could transition into the built environment and initiate urban conflagration.

Needs Assessment

Second, and often overlooked, communities should perform a requirements assessment to evaluate how long it will take residents to evacuate and for fire response resources to arrive:

- Evacuation time: How long does it take to evacuate the community under worst-case conditions? How do schools, places of worship, businesses, and other aspects of the community change with time of day or season? For example, how different is the evacuation around an elementary school in the mid-afternoon compared to the middle of the night? Where are the critical roadways and intersections that facilitate rapid evacuation? What would happen if those roadways were blocked due to an accident and, perhaps most importantly, which road segments will take the longest to clear? Evacuation simulations can be performed with tools built into common GIS packages, such as ESRI's Network Analyst or the PGRouting Postgres package[40]. Purpose-built evacuation tools, such as Ladris[41], are also increasingly available.

- Fire ingress: How long will it take for fire engines to arrive in sufficient quantities to prevent large-scale community ignition? While GIS analyses that evaluate fire response time from one or several stations in a jurisdiction are common and a useful tool, they typically do not capture the response capabilities of the mutual aid resources that will be required to successfully respond to a fast-moving wildfire as it enters the built environment. The WUI Response Rating, an initiative of the Western Fire Chiefs Association, is designed to help characterize the timing, quantity, capabilities, and command structure of mutual aid resources in WUI communities. Projects like this can help communities understand the time it will take to assemble a sufficient firefighting response for the types of fires evaluated in the risk assessment.

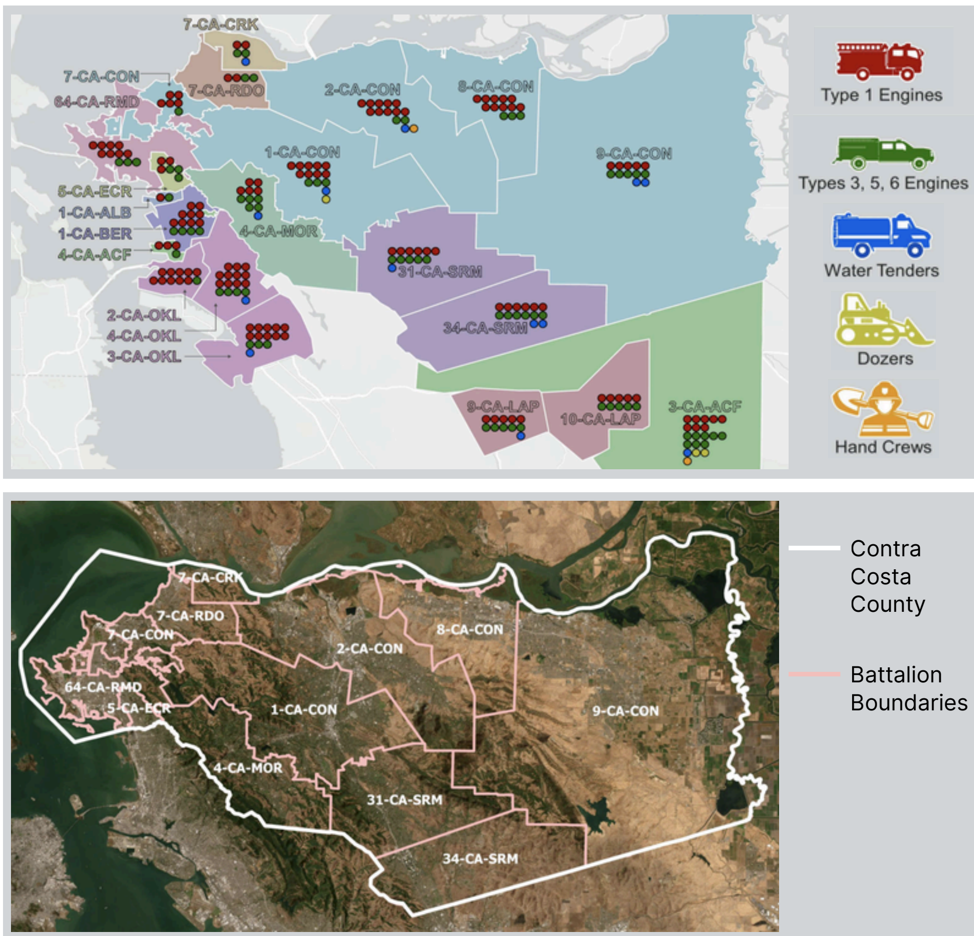

Figure 6: An example of a time-weighted mutual aid assessment in the California Bay Area to help communities assess the regional firefighting response.

Investment Needed

The investment required to achieve community resilience is the difference between the requirements assessment (the time needed for safe evacuation and a requisite fire response) and the risk assessment (the time of fire arrival and potential initiation of urban fire spread). Working within this structured framework allows communities to evaluate the amount of risk mitigation required to reduce the likelihood of city-scale loss. The framework provides an actionable target based on the type and location of mitigations to alter the relative timing of key points in the incident lifecycle.

Prioritized Planning

Simulation modeling and optimization tools can help communities understand the quantity, types, and locations of risk reduction activities that will create the greatest return on investment (ROI) in risk reduction activities. Communities should design prioritized projects that achieve the desired risk reduction with the minimum amount of cost. Development of prioritized projects draws heavily on the risk assessment and highlights:

- How many acres of vegetation management are needed to sufficiently delay fire arrival time in order to facilitate a safe evacuation and requisite fire response? Where are they located? High ROI acres are often located in high rate of spread fuels, complement natural barriers to fire spread, such as roads, rivers, orchards, and golf courses, and create a network where fire must burn perpendicular to the wind to advance. Fire growth and behavior comparisons with hypothetical project plans can quantify the fire arrival time changes attributed to vegetation management projects.

- Which areas of the community are most vulnerable to fire exposure and would provide the most benefit when brought into defensible space and home hardening compliance? Modeling tools to evaluate the effectiveness of home hardening and defensible space on urban fire spread are rapidly advancing[42,43,44]. High ROI parcels tend to include those at the edge of the tightly-spaced communities that will be exposed to rapidly spreading wildland fire and are capable of igniting other structures.

Modeling tools can also highlight the threshold when additional investment begins to result in diminishing marginal returns. Practitioners should ensure that their proposed actions build upon completed or planned projects and, when viewed as a system, produce maximum community resilience benefits. Once diminishing marginal returns have been reached in any particular area, shifting resources to complementing projects provides the greatest ROI.

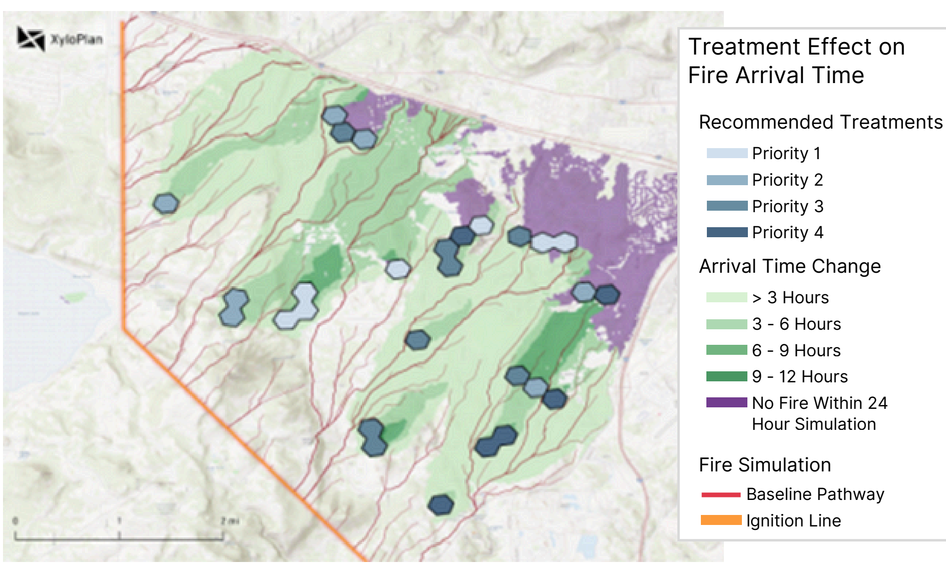

Figure 7: An example of a vegetation management plan designed to increase fire arrival time to the built environment.

Community Capacity to Mitigate

Armed with an understanding of the high ROI projects needed to achieve community resilience, communities should assess their capability to execute the prioritized risk mitigation projects. This assessment should incorporate:

- What resources are available for vegetation management, home hardening, defensible space, and other risk reduction programs?
- What equipment, tools, and expertise are available to undertake mitigation activities? Is the capacity primarily in-house with government crews and equipment or contracted to third parties?
- What logistical, regulatory, or social limitations are present in the community that limit the ability to implement risk-reduction activities?
- What is the community willingness and capacity to undertake home hardening and defensible space mitigations around homes?

If the community's capacity to mitigate is substantially lower than the investment needed, the community should evaluate whether external resources may augment local capacity. Federal and state grants programs, such as the federal Community Wildfire Defense Grants[45], can provide valuable financial resources that can expand the community's local resources to achieve meaningful mitigations. Cross-boundary collaboration can also extend the capabilities of a community or agency. Public-private partnerships, collaborations with federal and state land managers, and joint projects with adjoining jurisdictions can unlock tools, capabilities, and knowledge sharing that result in substantial increases in risk reduction capacity.

Implementation and Annual Re-Evaluation

Working within the framework outlined here helps communities develop plans that meaningfully reduce the risk of city-scale wildfire loss and match the community's capacity for mitigation. However, implementation and maintenance are critical: well-planned projects often languish at the planning stage. As projects are implemented, ongoing reevaluation of risks, needs, and capacity is important. As the landscape changes - due to unplanned disturbances, such as wildfires or disease, planned fuel treatments, population growth, and other factors - the community's planning should also change. Annual re-evaluations of the planning process ensure that communities are continually investing in high ROI risk mitigation programs that adequately meet the community's needs and prevent widespread loss in the built environment.

Conclusion

There are factors that make communities susceptible to wildfire loss we can't change. Climate change is projected to increase the receptivity of fuels, compress wet seasons, and increase the frequency of strong, dry wind events in fire-prone locations[46]. In existing communities, we can't change the structure separation distances, arrangement of evacuation routes, and continuity of structural fuel sources. Moreover, in most communities, we can't change fire response capabilities, even with substantial investment.

However, pursuing wildfire adaptation through the strategic application of vegetation management and on-parcel hardening can dramatically change the relationships between the relative timing of fire arrival, community ignition, requisite fire response, and orderly evacuation. If fire outpaces the evacuation of residents and the arrival of the necessary type and number of firefighters, community ignition is possible, and structure-to-structure fire spread may be initiated, ultimately resulting in city-scale loss. In contrast, if fire growth and initial structure ignitions are slowed enough to delay community ignitions until after residents have evacuated and firefighters have arrived, city-scale loss is far less likely.

We encourage local leaders, land managers, and fire departments in WUI communities to evaluate exposure to fast-moving fire and invest in achievable strategic solutions that delay fire arrival and reduce the likelihood of community ignition.

About XyloPlan

XyloPlan is a wildfire intelligence and modeling company dedicated to bridging the gap between science, development, and resilience. We partner with developers, planners, and insurers to bring clarity and confidence to building in wildfire-prone regions. Our platform transforms cutting-edge wildfire science into actionable insights—modeling how fires are likely to spread, where intervention matters most, and what design decisions can measurably reduce risk.

At the core of our work is a scenario-based approach that captures how fire behaves at the community scale, including structure-to-structure ignition, fire pathways, ember threats, and response timelines. This level of resolution helps our partners design and site developments that not only withstand local fire conditions but actively contribute to regional risk reduction.

We believe that the path to wildfire resilience is not retreat, but smarter planning. By integrating risk-aware community layouts, ignition-resistant construction, defensible space, and coordinated vegetation management, developers can help solve California's housing crisis without exacerbating wildfire vulnerability. Our tools and data support approvals, de-risk insurance conversations, and ensure that today's housing investments are built to last.

To learn more about our work or request a site-specific wildfire risk assessment, visit info@xyloplan.com.

About Dave Winnacker, XyloPlan Chief Wildfire Risk Officer

Dave Winnacker brings over two decades of operational fire service leadership to XyloPlan. As Fire Chief of the Moraga-Orinda Fire District (2017–2024), he spearheaded wildfire preparedness initiatives across high-risk communities. Dave has served in key statewide roles, including as Western Fire Chiefs Association California Director, Chair of the California Fire Chiefs WUI Task Force, and advisor on the AB9 and AB642 mandated wildfire mitigation committee and wildfire mitigation modeling workgroup. He is a Hoover Institution Veteran Fellow at Stanford University, where his research focuses on the intersection of wildfire risk and property insurance. A Marine Corps Infantry officer from 1997–2004, Dave continues to serve in the reserves. Prior to co-founding XyloPlan, he was a co-founding advisor at ZoneHaven, the evacuation platform now used widely across California.

About Scott Farley, XyloPlan, Head of Research and Development

Scott Farley leads XyloPlan's modeling and technical development with a focus on applying scientific rigor to wildfire risk analysis. A former wildland firefighter with the U.S. Forest Service, Scott combines real-world fireline experience with deep expertise in geospatial data science. His background includes roles as a software engineer and machine learning specialist at Mapbox and as founder of Willow Labs, a wildfire analytics consultancy. Scott holds a master's in GIS and physical geography from the University of Wisconsin–Madison and a BA in geography from UC Berkeley. His work powers XyloPlan's unique ability to simulate the speed, direction, and consequences of fast-moving fires.

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