County Wildfire Risk Ratings in Northern California: FAIR Plan Insurance Policies and Simulation Models vs. Red Flag Warnings and Diablo Winds

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Abstract:
Because of increasing wildfire risk and associated losses, fire insurance has become more difficult to obtain in Northern California. Policy cancellations have risen dramatically and several large insurance companies have announced that they will no longer issue new policies. The only insurance alternative for homeowners who are unable to find conventional home insurance is the limited and costly coverage available through the California FAIR Plan. Counties located in the Central Sierras have been particularly hard hit with insurance cancellations. Statewide, only 3% of fire insurance policies were covered by the FAIR Plan in 2021. But in several Central Sierra counties, that figure was more than 20%, not including homeowners who had to forego fire insurance entirely.

Three recent studies, based on wildfire simulation models, support the view that counties in the Central Sierras are at the highest risk for wildfire-caused structure loss in Northern California. Those models give considerable weight to the frequency of large fires and to the percentage of houses with potential exposure to wildfires. The Central Sierras have had a number of large fires and have a high percentage of homes located near wildland vegetation, but those fires have been primarily fuel-driven with few structure losses. Most housing losses in Northern California in the 2013-2022 decade have been the result of wind-driven fires in the Northern Sierras and in the Northern San Francisco Bay Area. 85% of all losses occurred in fires where a Red Flag Warning (RFW) for high winds had been issued by the National Weather Service. The Northern Sierras and the North Bay Area averaged 60% more RFW days during the fall fire season compared to the Central Sierras.

Strong downslope “Diablo” winds, originating in the Great Basin deserts to the east of the Sierras, were involved in seven of the highest loss fires in the 2013-2022 decade, including the Camp Fire in the Northern Sierras (13,600 houses destroyed) and the Tubbs fire in the North Bay Area (4,600 houses destroyed). Records from 109 weather stations throughout the Sierras and the Bay Area were examined to determine the location and frequency of strong Diablo wind events (40+ mph) during the fall for the years 2006 through 2022. The Jarbo Gap weather station, located near the Camp Fire, recorded the highest frequency of strong Diablo wind events, averaging 1.6 days per year. The station with the second highest frequency, Knoxville Creek, was located in the North Bay Area and averaged 0.9 days per year. Overall, weather stations in the Sierras recorded strong Diablo winds on 50% more days compared to the Bay Area stations. Although several stations in the Central Sierras registered strong Diablo wind events, those stations were almost all at elevations above 6,000 feet where few homes are located. Strong Diablo winds were not detected at any weather stations in the Southern Sierras, with the exception of the Bear Peak station located at the very southern extent of the range at 8,000 feet. Climate models predict that Diablo-type winds should be decreasing due to the warming of the interior deserts, but weather stations in both the Bay Area and the Sierras witnessed a large increase in the number of strong DiabIo wind days in the 2017 – 2021 years. All seven of the Diablo wind fires occurred during that time span.

Fires driven by strong Diablo winds fit into a category of disasters referred to as “black swan” events – rare occurrences that have very large effects. Because these fires occur so infrequently, they have minimal effect on risk estimates produced by averaging together the results of thousands of simulations. Exceedance probability analysis (Ager et al., 2021), offers a way to use wildfire simulations to identify the communities most at risk from such high-loss, low-probability events. Application of the exceedance probability approach, coupled with simulation models that accurately capture the occurrence and effects of extreme wind events, should result in risk assessments that more closely match actual losses in the 2013-2022 decade while reducing the relative risk ratings (and FAIR Plan policies) assigned to the Central Sierras.

1. Fire Insurance Availability and Risk Analysis Based on Simulation Models

Figure 1A displays the percentage of FAIR Plan insurance policies issued for each county in Northern California in 2021 (California Department of Insurance), expressed as a percentage of housing units that have the potential to be exposed to wildfire (Scott et al., 2020). Central Sierra counties from Amador County south to Mariposa County had the highest portion of FAIR Plan policies, ranging from 20 to 32%. (A table with the 2021 FAIR Plan data listed by county can be found in Appendix I).

Central Sierra counties saw large increases in FAIR Plan policies following the 2018 Camp Fire disaster. In Tuolumne County, for example, FAIR Plan policies increased from 2.9% policies for exposed houses in 2018 to 31.9% in 2021. Counties in the Bay Area, in contrast, experienced relatively few policy cancellations. Lake County had the highest percentage of FAIR Plan policies at 7.8%. FAIR Plan policies in Sonoma County and Napa County represented only 1.1% and 2.8% of policies for exposed houses in those counties in 2021.

Verisk (www.verisk.com), a company which provides property risk rating services to insurers, confirms the view that the Central Sierras are high risk. In their 2021 Fireline Report for California, Verisk listed Alpine, Tuolumne, and Mariposa counties among the California counties with the highest percentage of homes at high risk from wildfires. Several recent studies based on wildfire simulations have reached similar conclusions. A 2020 assessment by the US Forest Service (USFS) used the FSIM simulation model to produce a nationwide map of the Risk to Potential Structures (RPS) (Scott et al., 2020). Community risk ratings from that study can be found at www.wildfirerisk.org. Figure 1B shows county risk ratings for Northern California, based on the percentage of buildings in each county located in a high RPS area. High RPS values are defined here as those that exceed the 75th percentile RPS value for all buildings in Northern California. Buildings are derived from the Microsoft Building Footprints (2018).

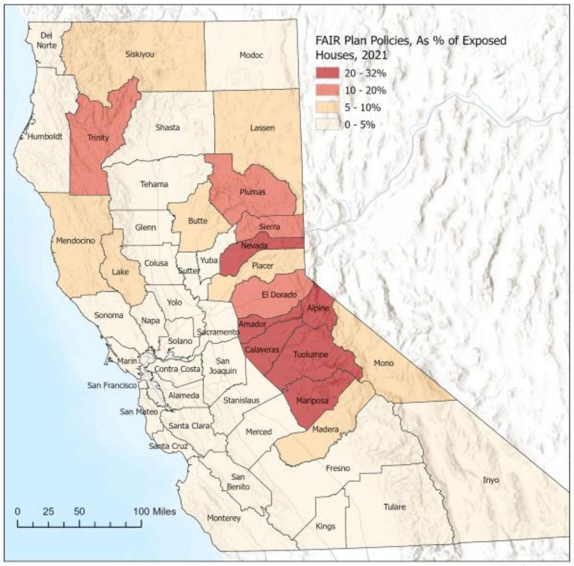
A more detailed estimate of RPS values for California, also using the FSIM model but with some modifications, was completed in 2021 by the Pyrologix Corporation under contract to the US Forest Service (Vogler et al., 2021). Figure 1C displays the ranking of counties using the RPS values derived from the Pyrologix study.

Figure 1D displays county risk ratings produced by the First Street Foundation (First Street Foundation, 2022) using the ELMFIRE simulation model in 2022. Risk ratings were based on the percentage of properties within each county having an annual risk of exposure to wildfires of 0.03% or higher over a 30-year period.

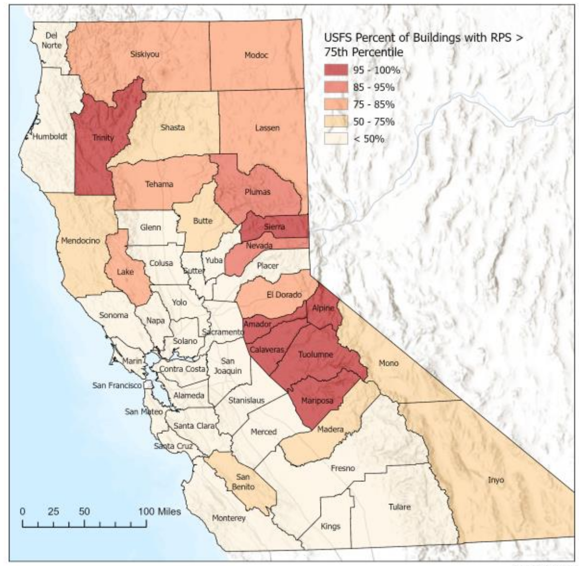
The three simulation studies, despite variations in modelling techniques and data sources, are in remarkable agreement regarding the highest risk counties in Northern California. The counties identified as high risk also tend to correspond with the counties having the highest FAIR Plan policy percentages. Of the five Central Sierra counties with FAIR Plan policy percentages above 20% in Figure 1A (Amador, Alpine, Calaveras, Tuolumne and Mariposa), all five are identified as the highest risk counties based on the USFS 2020 study (Figure 1B). Four are ranked among the highest risk counties in the FSF study (Figure 1D). Three are ranked among the highest risk counties based on the Pyrologix study (1C) and the two other counties are in the top 10. The simulation studies are also in agreement with FAIR Plan data showing that counties in the Bay Area are low risk, with the possible exception of Lake County. Results for the Northern Sierra counties are mixed, with the 2020 USFS study having the best match to the FAIR Plan data.

Figure 1: FAIR Plan Policies by County Compared to Risk Ratings Based on Simulation Models

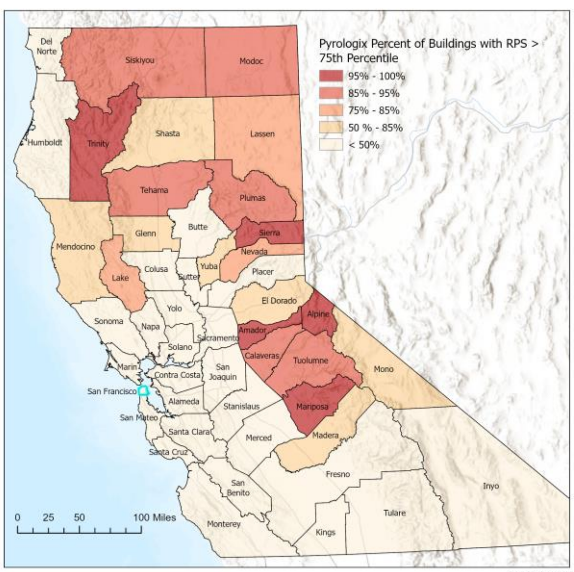
1A. FAIR Plan Policies As % of Exposed Houses, 2021



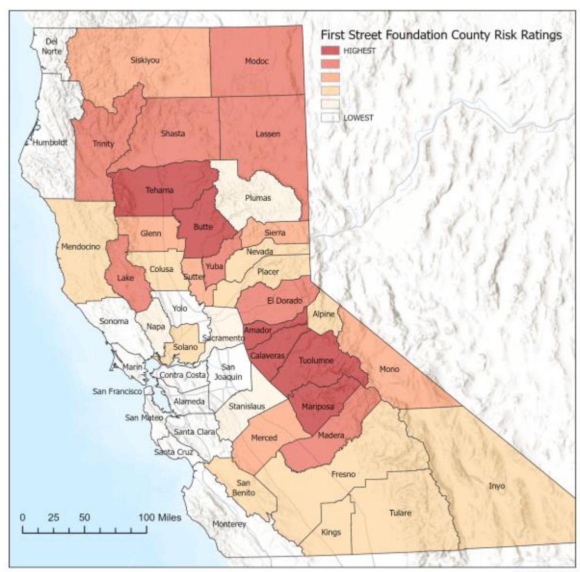
1B. County Risk Ratings Based on RPS Values From USFS, 2020



1C. County Risk Ratings Based on RPS Values from Pyrologix, 2021



1D. First Street Foundation County Risk Ratings, 2022



Sources: ***1A****: FAIR Plan data From California Department of Insurance. Potential Exposure from USFS, (Short et al.,2020).*

1B*: RPS from 2020 USFS analysis, (Short et al.,2020). Buildings from Microsoft Building Footprints (2018).*

1C: *RPS From 2021 Pyrologix analysis (Vogler, et al., 2021). Buildings from Microsoft Building Footprints (2018).*

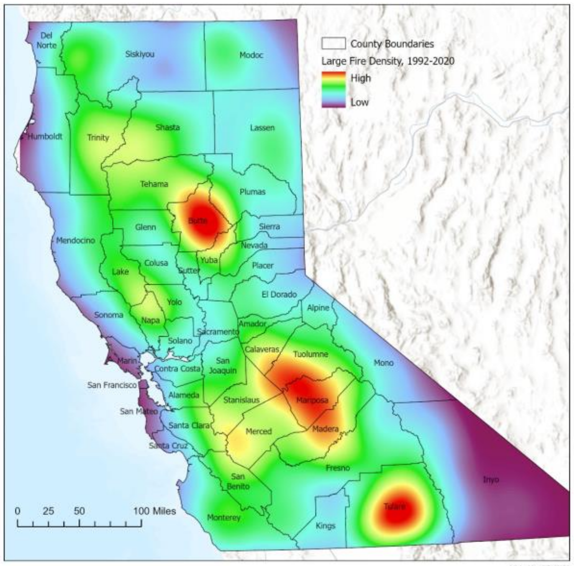
1D*: Based on percent of properties with a 0.03% annual risk of exposure to wildfires over 30 years. Derived from California map, p.28 of Fifth National Risk Assessment, (2022).*

Two factors appear to have a strong influence on the county risk ratings produced by these simulation models: past fire frequency and the percentage of homes with direct fire exposure. Figure 2A displays the density of large fire starts for Northern California based on data from 1992 through 2020 (Short et al., 2022). All fires greater than 100 hectares (247 acres) in size are included. (The density map was produced with the kernal density routine in the ArcPro GIS software using a search radius of 75 km.) Figure 2B displays the percentage of housing in each county with the potential for direct wildfire exposure (Scott et al., 2020). Houses are considered to have potential for direct exposure if located outside of an urban area and within 135 meters of burnable vegetation. Those counties having a combination of high ignition density and a high percentage of houses with a potential for direct exposure to wildfires are concentrated in the Central Sierras (Figure 2C).

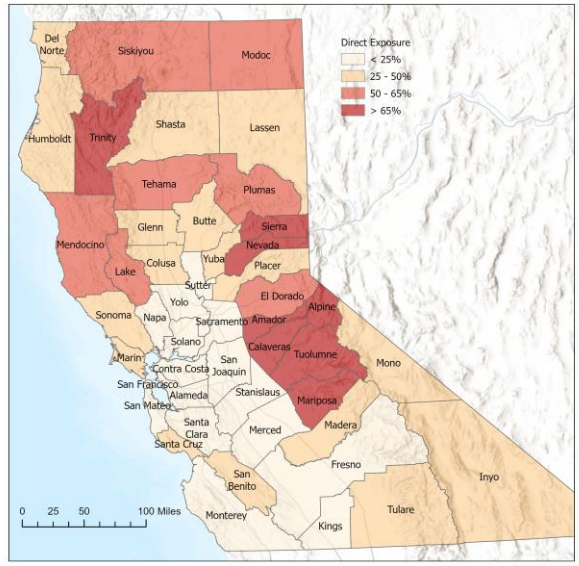
In contrast to the risk ratings, loss rates in the 2013-2022 decade were the highest in the Northern Sierras and the Bay Area. Figure 2D displays the estimated wildfire-related building losses for 2013-2022 by county as a percent of all structures derived from the Microsoft Building Footprint data. Northern Sierra counties of Butte (22.3%) and Plumas (7.3%) and Lake County in the Bay Area (6.8%) had loss rates far higher than the highest loss rates in the Central Sierras (2.7% for Calaveras County and 2.3% for Mariposa County). Loss rates for Bay Area counties of Napa and Sonoma (4.5% and 4.1% respectively) also exceeded the loss rates for any counties in the Central Sierras.

Figure 2: Components of Fire Risk vs. Actual Losses by County, 2015-2022

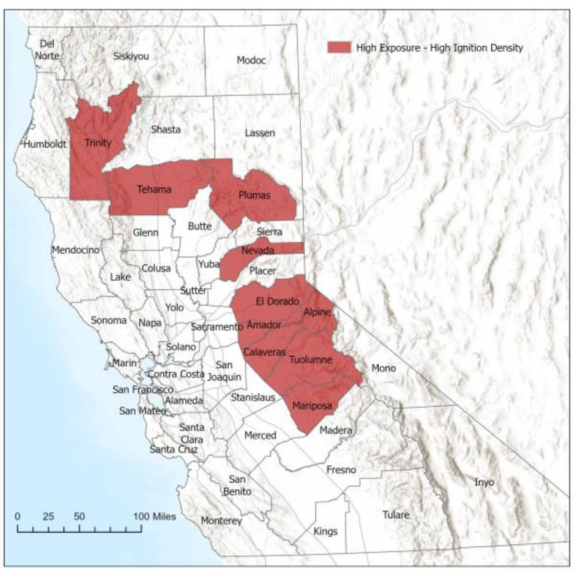
2A. Large Fire Ignition Density, 1992-2020



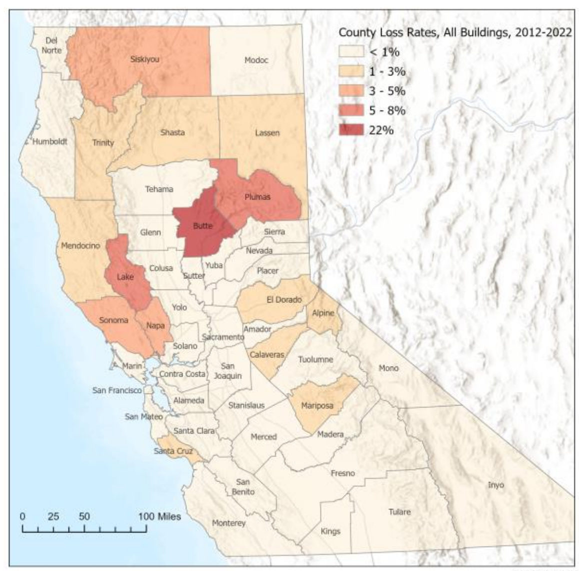
2B. Direct Housing Exposure by County, USFS



2C. High Ignition Density and High Direct Housing Exposure



2D. Building Loss Rates by County, 2013 – 2022



Sources:

***2A**. Kernal density based on fires greater than 100 hectares (247 acres) from Short et al., (2020) and a search radius of 75 km.*

***2B**: From Scott et al., (2020).*

***2C**: Derived from Figures 2A and 2B. Counties with a large fire ignition density greater than 0.006 per square kilometer and a direct housing exposure of 55% or greater are highlighted.*

***2D**: All buildings destroyed by county from CALFIRE Damage Inspection database (DINS) divided by buildings per county from Microsoft Building Footprints (2018).*

2. The Most Destructive Wildfires in Northern California, 2013 - 2022

Table 1 lists the 20 most destructive fires in Northern California in the 2013-2022 decade, ranked by the number of single residences destroyed. Those 20 fires account for only 30.5% of the acres burned but 92.2% of single home losses during this time period. The map in Figure 3 displays the location and extent of the listed fires.

Table 1: The 20 Wildfires with the Highest Single Home Losses, Northern California. 2013-2022

Fire	Year	Acres	Fatalities	Single Homes Destroyed
Camp	2018	153,336	85	13,624
Tubbs	2017	36,702	22	4,597
Valley	2015	76,085	4	1,275
North Complex	2020	318,797	15	1,176
Carr	2018	229,651	7	1,105
CZU Lightning Complex	2020	86,553	1	893
Caldor	2021	221,786	0	785
LNU Lightning Complex	2020	360,561	6	761
Dixie	2021	963,405	0	670
Nuns	2017	55,798	3	650
Glass	2020	67,484	0	644
Butte	2015	70,847	2	551
Creek	2020	379,842	0	506
Atlas	2017	51,625	6	422
Redwood Valley	2017	36,523	9	299
Slater	2020	157,430	2	193
Clayton	2016	3,928	0	191
Kincade	2019	77,762	0	183
SQF Complex	2020	171,489	0	171
Boles	2014	516	0	158
Totals		**3,520,121**	**162**	**28,854**
% of N. Calif. Total		**30.5%**		**92.2%**

Sources: Single homes destroyed derived from the California Department of Forestry and Fire Protection (CALFIRE) Damage Inspection Database (DINS). Acres from California Fire and Resource Assessment Program GIS maps. Fatalities from CALFIRE website: https://www.fire.ca.gov/our-impact/statistics and news sources.

Figure 3: The 20 Wildfires with the Highest Single Home Losses, Northern California, 2013-2022

Source: California Forest and Resource Assessment Program (FRAP)

3. Wildfire Losses and Red Flag Warnings

Wildfires in California tend to fall into two categories: 1. Fuel-driven fires with low structure loss and 2. Wind-driven fires that account for most structure losses (Keeley and Syphard, 2019). An examination of the 20 fires listed in Table 1 confirms that most structure losses are associated with high winds. Red Flag Warnings (RFWs) issued by the National Weather Service (NWS) provide a useful way to identify wind-driven fires. RFW's are issued when low relative humidity (RH), low fuel moisture, and elevated wind speeds are predicted to cause an unusual risk of wildfire spread. Table 2 lists the general guidelines for RFW's in Northern California, west of the Cascade-Sierra crest. Although the guidelines refer to sustained wind speeds, Jakober et al., (2023) found that, in actual practice, the RFW's are more often based on the expected strength of wind gusts.

Red Flag Warnings are issued by local NWS offices and application of the guidelines may vary somewhat between offices (Jakober et al., 2023). Three NWS offices cover most of Northern California west of the Sierra crest. The Sacramento office issues RFW's for the Northern Sierras and the Sacramento Valley. The San Francisco office is responsible for the San Francisco Bay Area while the Hanford office covers the Southern Sierras and the San Joaquin Valley.

Table 2: Criteria for Red Flag Warnings, Northern California, West of the Cascade-Sierra Crest

Relative Humidity	**Sustained Wind 6-11 mph**	**Sustained Wind 12-20 mph**	**Sustained Wind 21-29 mph**	**Sustained Wind 30+ mph**
Daytime Minimum RH 29-42% and/or Nighttime Maximum RH 60-80%				W
Daytime Minimum RH 19-28% and/or Nighttime Maximum RH 46-60%			W	W
Daytime Minimum RH 9-18% and/or Nighttime Maximum RH 31-45%		W	W	W
Daytime Minimum RH < 9% and/or Nighttime Maximum RH < 31%	W	W	W	W

Source: National Interagency Fire Center: https://gacc.nifc.gov/oscc/predictive/weather/myfiles/Watches_and_Warnings_for_California.htm

The dry, windy conditions that trigger RFW's threaten structures in multiple ways. Those conditions are more likely to:

- Increase fire starts by causing damage to the electrical grid and to increase the likelihood of escaped fires arising from burning trash piles, etc.
- Increase the speed of fire spread, causing more structures to be exposed and to ignite at the same time and overwhelming available defensive resources. Protecting lives and assisting in evacuations during rapidly spreading fires can often take precedence over protecting structures.
- Increase fire intensity and ember cast, causing a higher percentage of exposed structures to ignite.
- Decrease the effectiveness of defensive measures such as fire breaks, backfires, and retardant drops.

For 16 of the 20 fires listed in Table 3, RFW's had been issued for the days when the greatest structure loss occurred. Losses in those 16 fires represent 85% of the total losses in the decade.

(*Note: Although no RFW was issued during the Valley Fire, high winds were a primary factor in that fire as well. Neil Lareau of the Fire Lab at San Jose State noted that 25 mph sustained winds and 35 mph gusts from the northwest were recorded on 9/12/2015 at the nearby Kelseyville weather station, possibly caused by the unusual influence of Hurricane Linda taking place near Baja California. (https://www.fireweather.org/blog). Inclusion of the Valley Fire would raise the total losses in wind-driven fires to 89% of the total*).

In at least 7 of the 20 fires listed in Table 3, wind was the direct cause of the fire ignition, either by damaging powerlines or by causing other electrical failures. In two of the three arson-caused fires, high winds may have been the motivation for the arson.

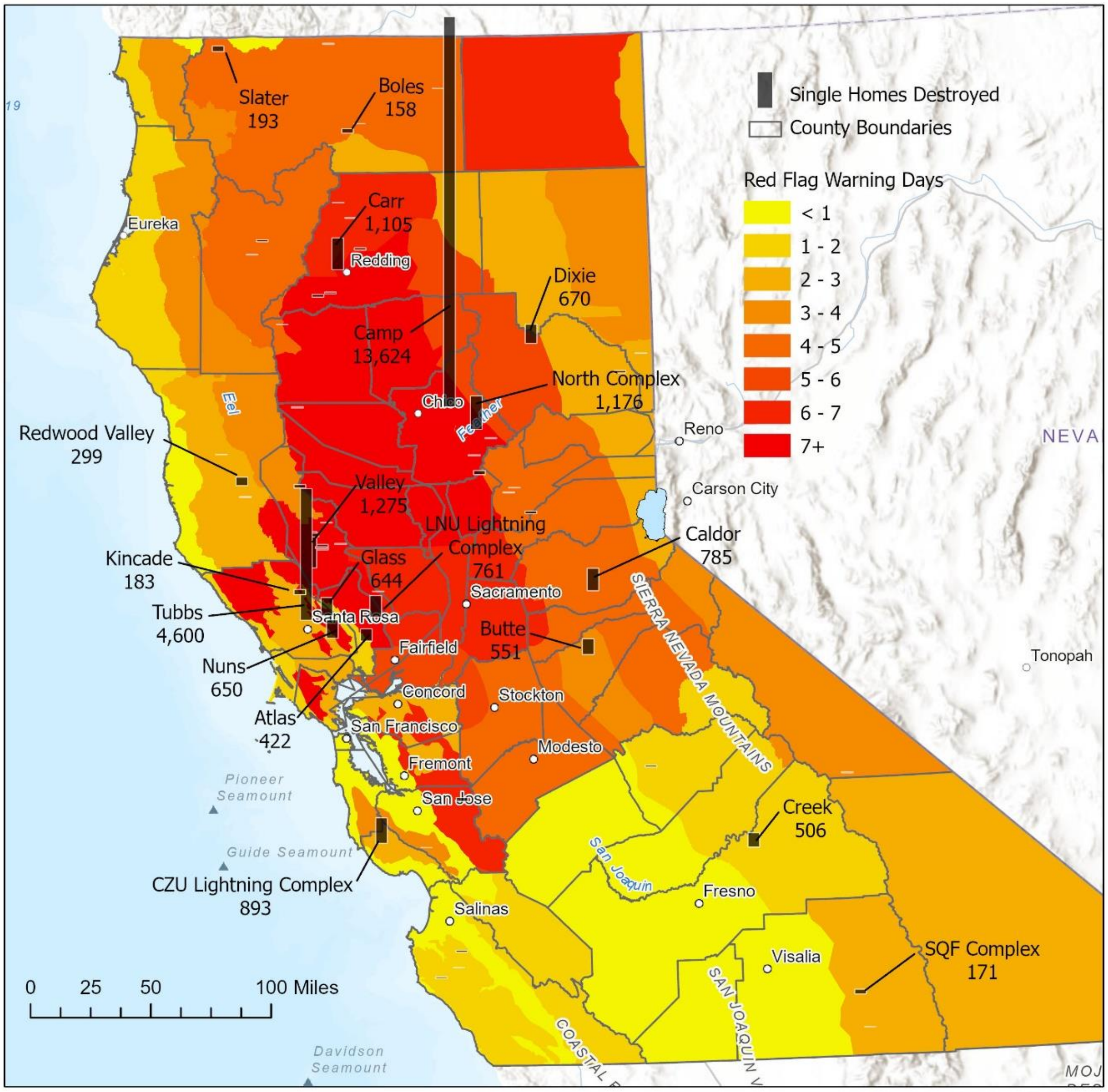
Table 3: The Top 20 Home Loss Fires and Red Flag Warnings, Northern California. 2013-2022

Fire	Single Homes Destroyed	Cause	Highest Loss Day	RFW In Effect On Highest Loss Day
Camp	13,624	Powerline	11/08/18	X
Tubbs	4,597	Electrical	10/09/17	X
Valley	1,275	Electrical	09/12/15	
North Complex	1,176	Lightning	09/08/20	X
Carr	1,105	Human Related	07/26/18	X
CZU Lightning Complex	893	Lightning	08/16/20	X
Caldor	785	Human Related	08/17/21	X
LNU Lightning Complex	761	Lightning/Arson	08/19/20	X
Dixie	670	Powerline	08/04/21	X
Nuns	650	Powerline	10/08/17	X
Glass	644	Undetermined	09/27/20	X
Butte	551	Powerline	09/10/15	
Creek	506	Undetermined	09/08/20	X
Atlas	422	Powerline	10/08/17	X
Redwood Valley	299	Powerline	10/08/17	X
Slater	193	Undetermined	09/08/20	X
Clayton	191	Arson	08/13/16	
Kincade	183	Powerline	10/23/19	X
SQF Complex	171	Lightning	08/19/20	
Boles	158	Arson	09/15/14	X
Totals	**28,854**			**26,666**
% of NorCal Total	**92.0%**			**85.0%**

Sources: Single homes destroyed from CALFIRE DINS database. Cause from CALFIRE Statistics (https://www.fire.ca.gov/our-impact/statistics). Maximum loss dates from news reports and Incident Management Reports. Red Flag Days from Iowa State Mesonet.

The map in Figure 4 displays the number and general location of single residences lost to wildfires in Northern California for the fires listed in Table 3. Also displayed are the average RFW days per year, from 2006 through 2022 (Iowa State Mesonet) during the months of September through November – that time of year when winds are most likely to combine with dry conditions and when 80% of housing losses occurred in the 2013-2022 decade.

Figure 4: Single Homes Destroyed by Wildfire, Northern California, 2013-2022, and Red Flag Warning Days Per Year, Sept.1 – Nov. 30, 2006-2022



J.Schmidt, 12/04/2023

Sources: Residences destroyed based on CALFIRE Damage Inspection Database (Single Residences with more than 10% damage). RFW days from Iowa State Mesonet.

Destroyed homes were concentrated in those areas of Northern California with the highest number of RFW days in the fall months. 60% of overall structure losses in the last decade occurred in the areas where RFW days averaged more than 7 days per year. Those areas are located in the Northern Sierras and portions of the Bay Area. Central Sierra counties averaged 1 to 4 RFW days per year.

3. Recent Wildfire Losses and Diablo Winds

The most destructive fires in Northern California have occurred during the dry, downslope wind events known as Diablo winds. Like the Santa Ana winds of Southern California, Diablo winds originate in the Great Basin deserts east of the Sierras. High atmospheric pressure in the interior regions coupled with low pressure along the coast causes air movement in a northeast-to-southwest direction over the Sierras and the coastal mountains. Unlike typical fuel-driven wildfires which tend to burn uphill, Diablo wind fires travel downhill, often toward populated areas (Abatzoglou et al., 2023). Houses exposed to fires during strong Diablo winds have loss rates that are 20 to 30 percent higher compared to houses involved in fires with more moderate winds (Schmidt, 2023).

Two previous studies have used weather station data to examine the frequency and strength of Diablo wind events in the Central and Northern Sierras and the Bay Area. Smith et al., (2018), based on 11 weather stations and 18 years of data, concluded that Diablo winds were just as common in the Sierras as in the Northern Bay Area and often occurred at the same time. McClung and Mass (2020), based on 49 weather stations, found that Diablo winds occurred at a higher frequency in the Bay Area than in the Sierras, with a peak in October for the Bay Area and October to January for the Sierras.

The present analysis focuses on the strongest Diablo wind events which are identified using the criteria proposed by McClung and Mass (2020):

- Three successive hours with maximum wind gusts greater than 35 knots (18 m/s or 40 mph)
- Relative humidity less than 20%
- Wind direction from the north to northeast (between 10 degrees and 100 degrees in the Sierras and between 320 degrees and 70 degrees in the Bay Area).

Two additional criteria are applied:

- Only strong wind events that coincide with Red Flag Warning days are included, to limit the analysis to those wind events that are the result of broad scale atmospheric conditions.
- Only strong wind events during the months of September through November are tallied, to focus on the time of year when those winds are most likely to combine with dry conditions.

In total, records from 109 weather stations (listed in Appendix II) were examined in the Bay Area and the Sierras, including the Southern Sierras. The analysis was limited to the years 2006 through 2022 corresponding to the availability of Red Flag Warning data. Table 4 identifies the weather stations that recorded at least one qualifying strong Diablo wind event during that time span. The map in Figure 5 displays the location and number of strong Diablo wind events per decade for all of the 109 weather stations included in this analysis.

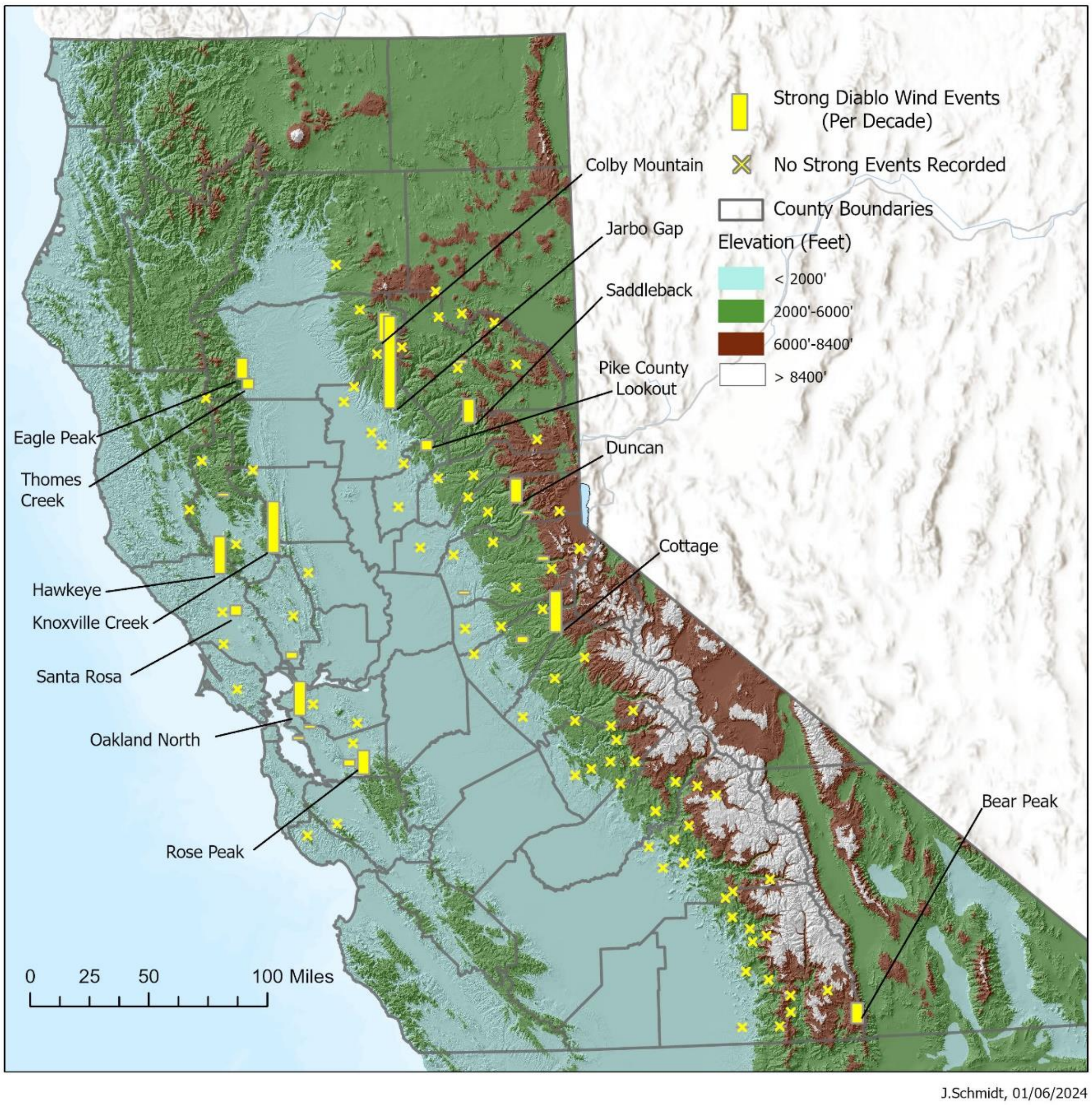
Table 4: Strong Diablo Wind Events Occurring During Red Flag Warning Days, September-November, 2006 through 2022

		BAY AREA			
Station	**County**	**Elevation (feet)**	**Strong Events**	**Years of Data**	**Strong Events Per Decade**
Knoxville Creek	Lake	2,200	15	17	8.8
Hawkeye	Sonoma	2,024	11	17	6.5
Oakland North	Alameda	1,403	10	17	5.9
Rose Peak	Alameda	3,342	7	17	4.1
Eagle Peak	Tehama	3,713	6	17	3.5
Santa Rosa	Sonoma	599	3	17	1.8
Thomes Creek	Tehama	1,029	3	17	1.8
Calaveras Road	Alameda	1,230	2	17	1.2
Napa Airport	Napa	33	2	17	1.2
Oakland Airport	Alameda	3	1	17	0.6
Oakland South	Alameda	1,095	1	17	0.6
High Glade Lookout	Lake	4,807	1	17	0.6
Average		**1,790**			

		SIERRAS			
Station	**County**	**Elevation (feet)**	**Strong Events**	**Years of Data**	**Strong Events Per Decade**
Jarbo Gap	Butte	2,535	27	17	15.9
Cottage	Calaveras	6,064	12	17	7.1
Colby Mountain	Tehama	6,004	4	8	5.0
Duncan	Placer	7,182	7	17	4.1
Saddleback	Sierra	6,670	7	17	4.1
Bear Peak	Tulare	8,228	6	17	3.5
Pike County Lookout	Yuba	3,701	3	17	1.8
Banner Road	Calaveras	2,803	2	17	1.2
Sugarloaf	El Dorado	5,653	1	13	0.8
Ben Bolt	El Dorado	905	1	17	0.6
Hell Hole	Placer	5,240	1	17	0.6
Cashman	Plumas	4,478	1	17	0.6
Average		**4,955**			

Source: Synoptic Weather Station Archive

Figure 5: Strong Diablo Wind Days Per Decade Recorded by Weather Stations on Days with Red Flag Warnings, September-November, 2006-2022;



Sources: Weather station data from RAWS network plus selected airport weather stations archived at Synoptic Weather Station Archive.

No qualifying wind events were detected in the Sierras between the Cottage station in Calaveras County and the Bear Peak station in Tulare County (Figure 5). In this portion of the Sierras, known as the "High Sierras", the crest of the Sierras rises above 8,400 feet in elevation and appears to function as a barrier to high winds from the northeast during the fall season.

The Jarbo Gap station in the Northern Sierras had the highest frequency of strong Diablo wind events (15.9 per decade). At 2,525 feet in elevation, the Jarbo Gap station is also the only station in the Sierras below 6,000 feet to record more than 2 strong Diablo wind events per decade. Of the 27 total strong Diablo wind events recorded for the Jarbo Gap station over 17 years (Table 4), 22 were recorded by at least one other Sierra station. On 10 of the 27 strong Diablo wind days at Jarbo Gap, at least one weather stations in the Bay Area also recorded a strong Diablo wind event.

Based on data from nearby weather stations, seven of the twenty fires in Table 3 occurred during strong Diablo wind events. Those seven fires are listed in Table 5 along with recorded wind speeds at a nearby weather station on the day of highest structure loss. The Tubbs, Nuns, Atlas, and Redwood Valley fires (the so-called "Wine Country Fires") all started during a strong Diablo wind event spanning October 8th and 9th in 2017. The Kincade fire in 2019 experienced two separate strong Diablo events, the first on October 24th and the second, three days later on October 27th.

Table 5: Strong Diablo Wind Event Fires, Northern California, 2013-2022

Fire	Fatalities	Single Homes Destroyed	Highest Loss Days	Weather Station	Max Sustained Wind (mph)	Max Wind Gust (mph)	Region
Tubbs	22	4,597	10/8-9, 2017	Santa Rosa	26	68	Bay Area
Nuns	3	650	10/8-9, 2017	Santa Rosa	26	68	Bay Area
Atlas	6	422	10/8-9, 2017	Napa County Airport	35	43	Bay Area
Redwood Valley	9	299	10/8-9, 2017	Hawkeye	48	79	Bay Area
Camp	88	13,624	11/8/2018	Jarbo Gap	32	52	Sierras
Kincade	0	183	10/27/2019	Knoxville	36	62	Bay Area
North Complex	18	1,176	9/8/2020	Jarbo Gap	45	66	Sierras
Totals	**146**	**20,951**					
% of N. Calif. Losses	**87%**	**67%**					

The seven Diablo wind fires listed in Table 5 accounted for 67% of the single residence losses and 87% of wildfire-related fatalities in the 2013-2022 decade in Northern California. Those losses are in line with an estimate by Abatzoglou et al., (2023) that downslope wind fires have been responsible for 60.1% of all structures destroyed and 52.4% of lives lost in the western US since 1999.

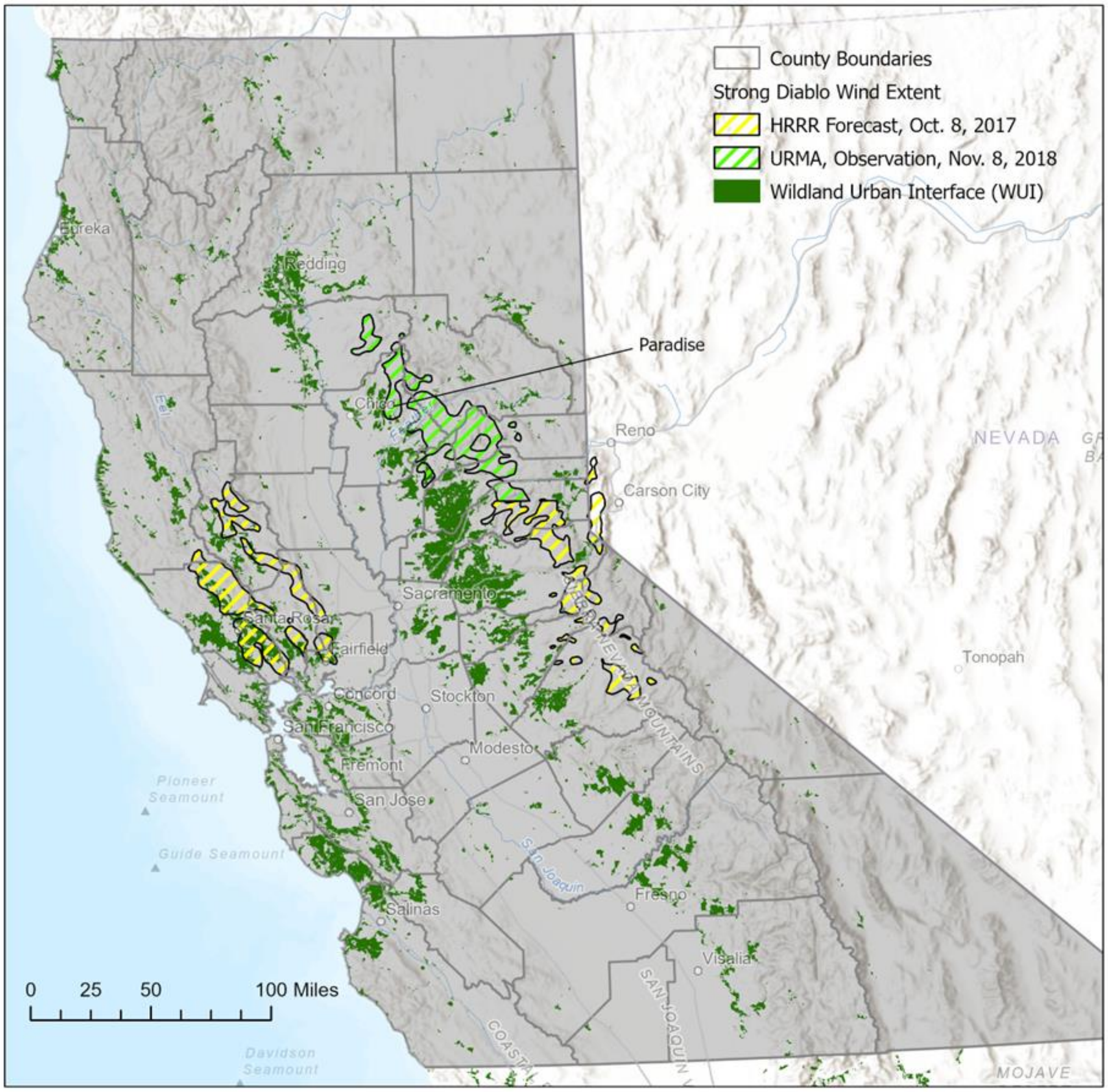
Weather stations that recorded a strong event during one of the fires listed in Table 5 are identified in Table 6. The strong Diablo winds that drove the Wine Country fires of 2017 registered at the largest number of stations – 10 in total, including four in the Bay Area and six in the Sierras. The Kincade fire was a close second with nine stations registering strong wind events on October 27, 2019. The Cottage station in the Sierras is the only station that recorded strong Diablo winds during all of the Diablo wind fires.

Table 6: Weather Stations Recording Strong Diablo Wind Events During Selected Fires

Station	Wine Country Fires 10/8-9/2017	Camp Fire 11/8/2018	BAY AREA Kincade Fire 10/24/2019	Kincade Fire 10/27/2019	North Complex Fire 9/8/2020	Total Count By Station
Knoxville Creek	X	X		X	X	**4**
Hawkeye	X		X	X		**3**
Oakland North	X	X		X		**3**
Rose Peak				X		**1**
Eagle Peak		X			X	**2**
Santa Rosa	X			X		**2**
Thomes Creek	X			X		**2**
High Glade Lookout				X		**1**
			SIERRAS			
Jarbo Gap	X	X			X	**3**
Cottage	X	X	X	X	X	**5**
Duncan	X	X			X	**3**
Saddleback	X	X			X	**3**
Bear Peak	X	X				
Pike County Lookout	X					
Banner Road				X		**1**
Ben Bolt				X		**1**
Hell Hole					X	**1**
Total Count By Fire	**11**	**8**	**2**	**10**	**7**	

The map in Figure 6 approximates the extent of 40+ mph Diablo winds forecast for the Central Sierras and the Bay Area on Oct. 8-9, 2017 (yellow crosshatch), during the Wine Country Fires. Also shown are the observed 40+ mph winds in the vicinity of the Camp Fire on Nov. 8, 2018 (green crosshatch). Wildland Urban Intermix (WUI) areas, populated areas adjacent to wildlands (Silvis Lab, 2020), are shown in dark green. Note that the strong wind areas in the Sierras south of Paradise were generally located at higher elevations, well away from most of the WUI areas. In contrast, high wind areas overlapped multiple WUI areas in the Bay Area in the Oct. 8-9, 2017 forecast.

Figure 6: Extent of Strong Diablo Winds During the Wine Country Fires of October, 2017 and the Camp Fire of November, 2018 in Relation to the Wildland Urban Interface (WUI)



Sources: Strong Diablo Wind Extent based on NOAA's High-Resolution Rapid Refresh (HRRR) 40 mph gust forecast for Oct 8-9, 2017 (Figure 20 in Mass and Ovens, 2017) augmented north of the Saddleback weather station by data from Figure 4 in the National Weather Service Assessment, November 2018 Camp Fire, (2020): UnRestricted Mesoscale Analysis (URMA) 40 mph Observed Gusts, Nov. 8, 2018.

4. History of Diablo Wind Fires

Prior to 2013, there have been several instances of highly destructive fires associated with Diablo winds in the Bay Area. The Oakland Hills Fire of October, 1991 (also known as the Tunnel Fire) was pushed by northeast winds in excess of 65 mph and resulted in the loss of 2,843 single residences, 433 apartments, and 25 lives (Parker, 1992). (The Oakland North weather station is located near the site of the Oakland Hills Fire but did not begin operating until 1999. Since 2006, that weather station has recorded 10 strong Diablo wind events, third most in the Bay Area). The September, 1923 Berkeley Fire occurred only a few miles to the northeast of the Oakland Hills Fire. Also propelled by Diablo winds, the Berkeley fire destroyed 640 structures but resulted in no fatalities (McDonald, 2019). The 1964 Hanley Fire, with 70 mph winds from the northeast, burned much of the same area as the 2017 Tubbs fire in Santa Rosa, but there were few homes in the area at that time. (Kovner, *The Press Democrat*, 2013).

Diablo wind fires in the Sierras prior to 2013 resulted in relatively few structure losses compared to fires in the Bay Area. The Poe Fire in Butte County destroyed 133 structures in 2001 (Pera, 2023). That fire was located just south of Jarbo Gap in an area that re-burned in the Camp Fire. The Jarbo Gap weather station was not in operation in 2001, but the Knoxville weather station in the Bay Area recorded gusts of 36 mph from the northeast on September 6th, 2001, the day that the Poe Fire started.

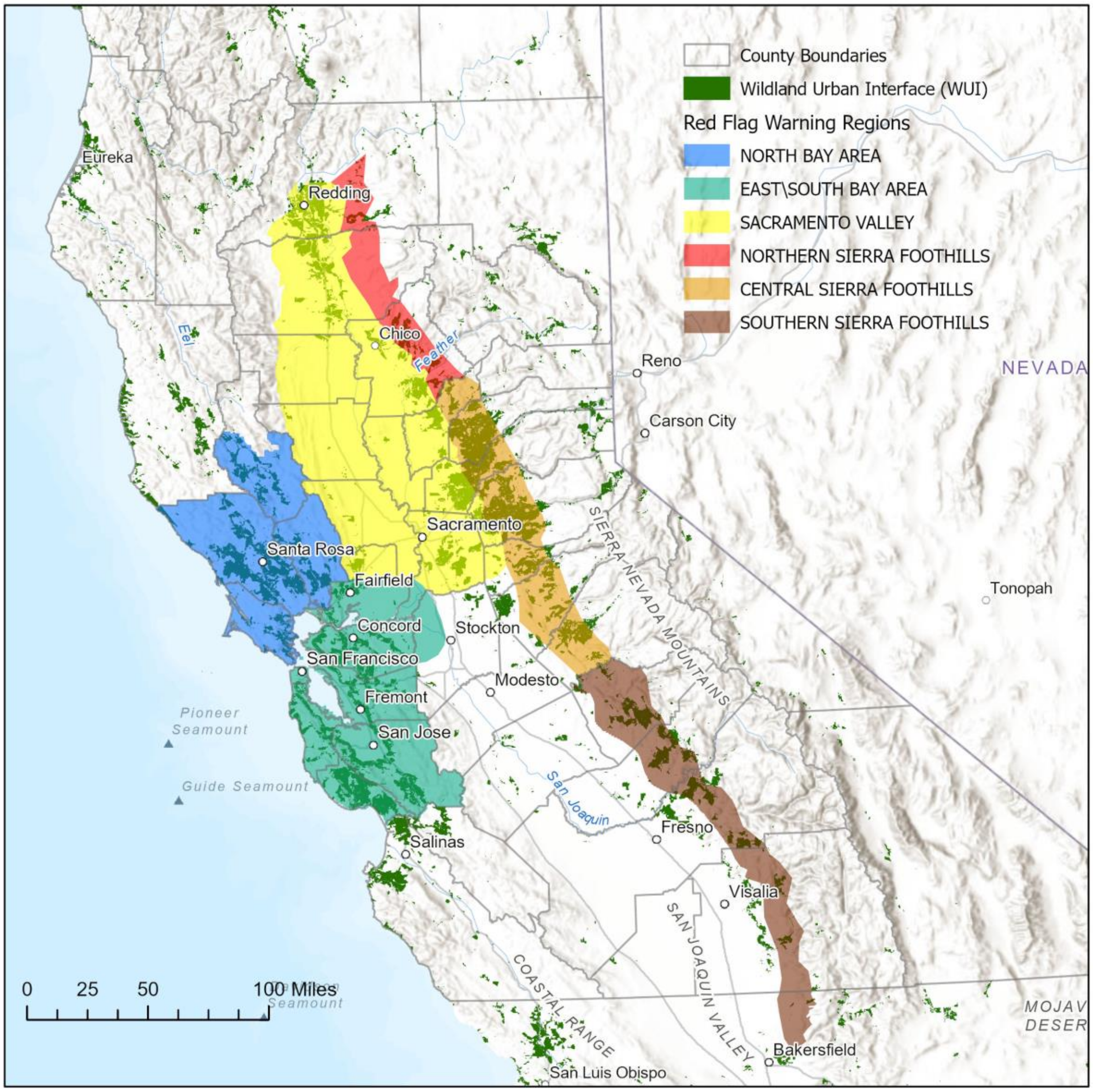
The 49er fire located in Nevada County, burned over 140 homes in September, 1988. At the time, it was the third most destructive fire in state history. Strong northeast winds were reported (CBS News, Sacramento, https://www.cbsnews.com/sacramento/news/49er-fire-destruction/).

Maps produced by Abatzoglou et al., (2023) show that acreage burned in downslope wind fires from 1992 - 2020 has been concentrated in the Northern Sierras\Southern Cascades and in the Northern Bay Area. Downslope wind fires accounted for little of the burned acreage in Central and Southern Sierras during the same time period.

5. Wind Trends – Red Flag Warning Days and Strong Diablo Wind Events

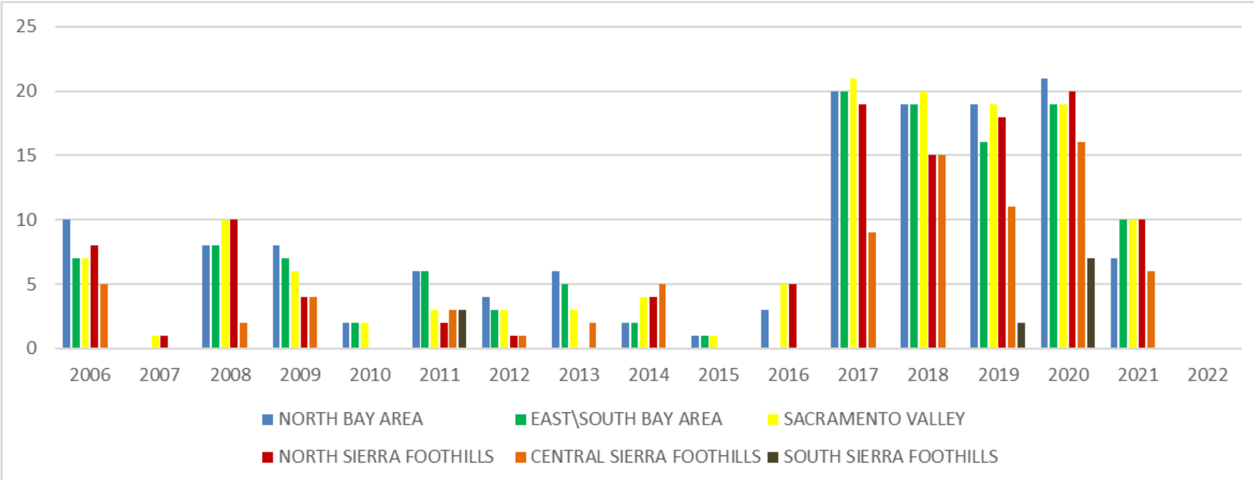
Figure 7 displays groupings of Red Flag Warning regions used here to compare trends in RFW days in areas with concentrations of WUI areas. The chart in Figure 8 shows the frequency of RFW days in the fall for the regions displayed in Figure 7 during the period from 2006 to 2022. The North Bay region had the highest number of RFW days during this time period (136) while the Sacramento Valley region was a close second at 134. Total RFW days for the East\South Bay, North Sierra Foothills, Central Sierra Foothills and South Sierra Foothills were 125, 117, 79 and 12, respectively. All regions except for the Southern Sierra Foothills regions saw a large increase in RFW days in the 2017-2021 years compared to the average for the 2006-2016 time period. 91% of the housing losses in the 2013-2022 decade in Northern California occurred during those five years. Winds largely subsided in 2022. No RFW days were recorded in 2022 in any of these regions and no high-loss fires occurred.

Figure 7: Regions Used For Analysis of Red Flag Warning Trends



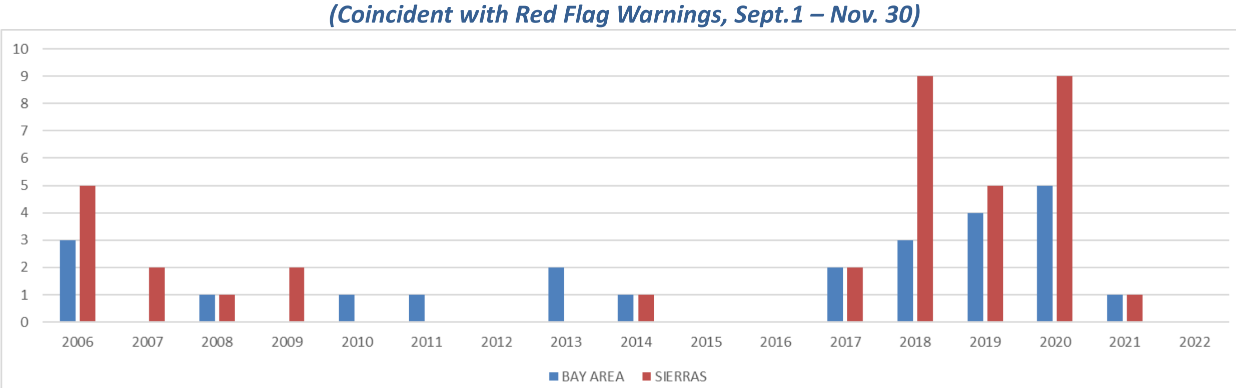
J.Schmidt, 01/23/2024

Figure 8: Red Flag Warning Days Per Year by Region, (September 1 – November 30)



The chart in Figure 9 shows the frequency of strong Diablo wind event days by year for the Bay Area and the Sierra for the 109 weather stations examined. Strong Diablo wind events in 2017-2020 were about three times the average frequency of the 2006-2022 period in both the Bay Area and the Sierras. All of the seven Diablo wind fires listed in Table 5 occurred in the 2017-2020 years. In total, the Sierra weather stations recorded about 50% more strong Diablo wind days than did stations in the Bay Area (37 vs. 24) in the 2006-2022 decade.

Figure 9: Strong Diablo Wind Days per Year by Region
(Coincident with Red Flag Warnings, Sept.1 – Nov. 30)



Guzman-Morales & Gershunov (2019) noted that eight different global climate models project a decrease in Santa Ana wind frequency, particularly in the fall and spring, due to a decrease in the pressure gradient between the Great Basin deserts and the coastal regions. Mass and Owens (2019) suggested that the projected warming of interior regions would also likely reduce the occurrence of Diablo winds.

Liu et al., (2020) detected no long-term trend in the frequency or strength of Diablo winds in the Bay Area, based on data from the 1979-2018 period. The associated relative humidity, however, decreased significantly, possibly leading to an increased chance of fires with destructive potential. The Liu study noted a possible link between strong, dry Diablo winds in the fall and the co-occurrence of a La Nina and the westerly phase of Quasi-Biennial Oscillation (QBO) in the preceding spring.

Prein et al., (2021) found that northeast wind events had increased in frequency in the 20th century in California, especially in the Bay Area and in San Diego. But that study attributed the increase to natural variation in weather patterns and predicted that, based on climate models, such events were likely to decrease in the future. Those same climate models projected some increase in winds in the Sierras during the summer months, due to temperature and pressure differences between the Sierras and the coastal regions.

Abatzoglou et al., (2021) examined downslope winds on a global basis and found no coherent trend in global annual frequency in the 1979-2018 period but noted a reduction in downslope winds in the summer throughout most of California. Abatzoglou et al., (2023) found no significant trend in annual downslope wind days or downslope wind speeds in Northern California over the 1992-2020 time period. That study also found no significant trend in the number or acreage of downslope fires in any region except for a decrease in the number of fires in the North Bay Area. The study did find that conditions were getting significantly drier during downslope wind days throughout Northern California.

A study by Thompson, et al., (2023) detected a small increase in night-time downslope winds on the western slopes of the Sierra mountains in the autumn season since 1979. The increase was attributed to a sharper gradient in air temperature aloft between the Sierra crest and adjacent foothills, rather than to more frequent Diablo winds.

6. Discussion

A. Risk Estimates vs. Losses - The three simulation-based analyses discussed previously all reached similar conclusions: the Central Sierras are a relatively high risk area for wildfire structure loss, the Bay Area is a relatively low risk area (with the possible exception of Lake County), and the Northern Sierras lie somewhere in between. The FAIR Plan policy percentages largely reflect those findings. However, wildfire structure losses in the 2013-2022 decade have followed a much different pattern. Structure loss rates have been highest by far in two Northern Sierra counties, followed by three counties in the Bay Area. High loss rates been concentrated in areas of the state where strong wind events, as measured by both Red Flag Warning days and strong Diablo wind events in the fall months, have been most frequent – the northern Sierras and the northern portions of the Bay Area. The mismatch between risk estimates produced by simulation models and actual losses points to limitations in the way that simulation models are constructed and used to predict structure loss.

B. Houses as Fuel - The simulation models discussed here were designed primarily to predict fire spread and intensity based on vegetation cover and weather. None of these models explicitly take into account the contribution of houses themselves to the fuel load. The First Street Foundation did modify fuel types to better approximate wildfire spread in developed areas, but "the fuel layers do not take into account fuel estimates for the structures themselves…that could lead to increased house-to-house ignition probability; such an approach could be incorporated into a future effort." (Kearns, et al., 2022, p.9).

Areas with a density of 2 or more houses per acres have a significant fraction of the fuel load consisting of residential structures (Maranghides et al., 2022). The housing fuel load can result in structure loss rates much higher than would be expected just based on vegetation cover. In strong Diablo wind fires, loss rates for houses in light vegetation cover were estimated to increase from 49% to 84% when housing densities increased from 0.5 houses per acre to 2.0 houses per acre (Schmidt, 2023). Knapp et al., (2021) found that distance to the nearest burned structure was one of the best predictors of housing loss in the Camp Fire.

The risk of loss among those structures exposed to wildfire is sometimes referred to as the Conditional Risk to Structures or CRPS. CRPS estimates are typically combined with exposure probabilities (aka, "Burn Probability" or BP) to give an overall estimate of loss risk, the RPS mentioned earlier. Because houses are not counted as fuel in the models discussed here, CRPS values in developed areas are likely to be underestimated, especially in high wind fires. In those situations, the rapid spread of fire between and among structures can quickly surpass the capacity of fire fighters to respond, leading to the very high loss rates among exposed houses. Loss rates exceeded 80% for exposed houses in the Tubbs and Camp fires where housing densities averaged 2.5 and 1.9 houses per acre, respectively (Schmidt, 2023).

C. Diablo Winds As Black Swan Events - Calculating risk by averaging together the results of thousands of simulations obscures the importance of rare “black swan” events that have major consequences (Ager et al., 2021). Fires during strong Diablo wind events are perfect examples of “black swan” events. These fires may occur only once every decade or more in Northern California, but still account for a major share of housing losses. To assess the risks from extreme weather events such as these, Ager suggests using simulation results to estimate the “exceedance probability”: the probability that specific levels of community exposure to wildfire will be exceeded. Ager demonstrates the approach using simulations from the 2020 USFS assessment to estimate the likelihood that fires will result in structure exposure that exceeds specified levels (5%, 25%, 75%, and 95%) in communities for the western US.

Ager’s study does appear to show more communities at risk for high exposure levels in the Northern Sierras than in the Central Sierras, but there are indications that the results may be too conservative. Few communities in the Bay Area, outside of Lake County, are identified as having the possibility of exposure levels above 5%. Ager acknowledges that the exceedance probabilities calculated for the town of Paradise were underestimated since no simulation caused more than 60% of the Paradise community to be exposed to a wildfire. These results suggest that the simulation model did not fully account for the effects of strong Diablo wind events.

In the 2020 USFS simulation model, a single weather station within each simulation area (termed “pyrome”) was the source for the estimates of wind speed and direction. Figure 10 displays the Northern California pyromes and weather stations used in the model. Weather stations were generally chosen to represent average conditions within the pyrome (Scott et al., 2018). As a result, the weather record used for modelling may not capture the location and frequency of the most extreme wind conditions that occur within the pyrome. For example, the Cohasset station, used to model winds for the Northern Sierra Foothills pyrome, did not record any strong Diablo wind events in the 2006 – 2022 time period while the Jarbo Gap station recorded 27 events.

The Thomes Creek weather station, used to model weather for the northern Bay Area, (the North Central Foothills and Coastal Mountain pyrome) did record three strong Diablo wind events during the 2006 – 2022 time period. But that number was far below the 15 events recorded at the Knoxville Creek station in Lake County and the 11 events at the Hawkeye station in Sonoma County (Table 4).

Simulation results from the Pyrologix or FSF models might be better suited for the application of exceedance probability analysis. Those models both employed gridded hourly weather data to estimate wind speeds and direction for simulation purposes. The Pyrologix model used a 2-km gridded hourly weather dataset from the Desert Research Institute in a stand-alone model called WILDEST to refine the effects of wind on fire intensity. (Vogler et al.,2021). The FSF model employed a 2.5 km gridded hourly weather data from NOAA’s Real Time Mesoscale Analysis (RTMA) for its simulations (Kearns, et al., 2022). The use of gridded weather datasets allows the models to portray wind conditions at a relatively high spatial and temporal resolution. The interpolation methods used to produce those datasets can, however, result in some loss of accuracy in the representation of the most extreme measurements (Behnke et al., 2016).

As we saw in Figures 1C and 1D above, the use of gridded datasets to represent winds in the Pyrologix and FSF models did not result in large changes in county risk ratings compared to the 2020 USFS model results in Figure 1B. However, application of the exceedance probability approach to the Pyrologix or the First Street Foundation simulations should provide a more accurate picture of those areas most at risk from “black swan” wind events compared to the USFS model.

It should be noted that the Ager study only focuses on the probability of exposure. For a complete picture of risk in extreme wind events, the effects on the CRPS would need to be considered as well. Since loss rates in exposed structures generally rise as winds increase (due to increased flame lengths, ember exposure, and house-to-house spread), inclusion of conditional loss probabilities would increase the distinction between exceedance probabilities in high-wind vs. low-wind areas.

Figure 10: Pyromes and Weather Stations Used to Simulate Wildfire Risk (US Forest Service, 2020)

Source: Short, et al., (2020), Pyromes of the coterminous United States

D. Ignition Probability - In all three simulation models, wind events and fire starts are treated as independent variables. But as noted in Table 3, at least seven of the most destructive fires were caused by wind events. Two of high wind fires were caused by arson. Abatzoglou et al., (2023) found that 10.3% of downslope wind fires were caused by arson and 3.5% were caused by damage to the electrical system. The institution of power shutoffs during high wind events may reduce the number of fires resulting from damage to the electrical grid in the future, but it is too soon to tell if those shutoffs will be successful in reducing total wind-related fire starts. In the meantime, models should take into account the fact that high winds increase the probability of fire starts.

6. Summary

- In the absence of high winds, there is little likelihood of large structure losses in wildfires in Northern California. Of the 20 fires with the highest housing losses in the 2013-2022 decade, 16 had Red Flag Warnings in effect on the day of greatest loss. Red Flag Warnings are significantly more frequent in the Bay Area and in the Northern Sierras than in the Central Sierras.

- Fires during strong Diablo downslope winds are responsible for the majority of structure losses. Although climate models project a decrease in Diablo winds as the climate warms, that decrease is not yet evident in weather station records. The Northern Sierras and the Bay Area are at the highest risk for Diablo wind fires that will impact communities. With its high population densities, the Bay Area presents the greatest risk for large numbers of structure losses.

- In order to better account for the role of winds in wildfire structure losses, simulation modelling should:
  1). Incorporate weather data that accurately depicts the spatial distribution and frequency of strong wind events.
  2). Adjust loss rates to reflect the role of house-to-house fire spread in developed areas.
  3). Increase ignition probabilities during high winds.
  4). Employ exceedance probability analysis to identify communities most at risk for a high proportion of structure losses.

- The recognition that wind-driven fires are less likely in the Central Sierras than in the Northern Sierras or the Bay Area should result in a downward revision of risk estimates for Central Sierra counties and an increase in fire insurance availability.

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References:

Abatzoglou, JT., Hatchett, BJ., Fox-Hughes, P., Gershunov, A., & Nauslar, NJ. (2021). Global climatology of synoptically-forced downslope winds. *International Journal of Climatology*, 41, 31 - 50. https://doi.org/10.1002/joc.6607

Abatzoglou, JT., Kolden, CA., Williams, AP., Sadegh, M., Balch, JK., & Hall, A. (2023). Downslope wind-driven fires in the western United States. *Earth's Future*, 11, e2022EF003471. https://doi.org/10.1029/2022EF003471

Ager, AA., Day, MA., Alcasena, FJ., Evers, CR., Short, KC., & Grenfell, I. (2021). Predicting Paradise: Modeling future wildfire disasters in the western US. *Science of the Total Environment*, *784*, 147057. https://doi.org/10.1016/j.scitotenv.2021.147057

Behnke, R., Vavrus, S., Allstadt, A., Albright, T., Thogmartin, WE., & Radeloff, VC. (2016). Evaluation of downscaled, gridded climate data for the conterminous United States. *Ecological Applications*, *26*(5), 1338-1351. https://doi.org/10.1002/15-1061

CALFIRE Forest and Resource Assessment Program (FRAP) fire history data: https://www.fire.ca.gov/what-we-do/fire-resource-assessment-program

California Department of Insurance, FAIR Plan Statistics, (https://www.insurance.ca.gov/01-consumers/200-wrr/DataAnalysisOnWildfiresAndInsurance.cfm)

First Street Foundation (2022). The 5th National Risk Assessment, Fueling the Flames. https://report.firststreet.org/fire

Guzman-Morales, J., & Gershunov, A. (2019). Climate change suppresses Santa Ana winds of Southern California and sharpens their seasonality. *Geophysical Research Letters*, *46*(5), 2772-2780. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018GL080261

Iowa State Mesonet (Red Flag Warning Data) (https:/mesonetagron.iastate.edu/request/gis/watchwarn.phtml)

Jakober, S., Brown, T., & Wall, T. (2023). Development of a Decision Matrix for National Weather Service Red Flag Warnings. *Fire*, *6*(4), 168. https://doi.org/10.3390/fire6040168

Kearns, EJ., Saah, D., Levine, CR., Lautenberger, C., Doherty, OM., Porter, JR., Amodeo, M., Rudeen, C., Woodward, KD., Johnson, GW. and Markert, K., 2022. The construction of probabilistic wildfire risk estimates for individual real estate parcels for the contiguous United States. *Fire*, 5(4), p.117. https://doi.org/10.3390/fire5040117

Keeley, JE., and Syphard, AD. (2019). Twenty-first century California, USA, wildfires: fuel-dominated vs. wind-dominated fires. *Fire Ecology*, *15*(1), 1-15. https://doi.org/10.1186/s42408-019-0041-0.

Knapp, EE., Valachovic, YS., Quarles, SL., and Johnson, NG. (2021) Housing arrangement and vegetation factors associated with single-family home survival in the 2018 Camp Fire, California. *Fire Ecology* **17,** 25 https://doi.org/10.1186/s42408-021-00117-0

Kovner, Guy (September 1, 2013). "Redwood Empire fire history remains visible in wild spots". The Press Democrat. Santa Rosa, California

Maranghides, A., Link, ED., Nazare, S., Hawks, S., McDougald, J., Quarles, S., & Gorham, D. (2022). WUI Structure/Parcel/Community Fire Hazard Mitigation Methodology. *NIST Technical Note*, *2205*. 2022 https://doi.org/10.6028/NIST.TN.2205)

Mass, Clifford F., and David Ovens. (2019). "The Northern California wildfires of 8–9 October 2017: The role of a major downslope wind event." *Bulletin of the American Meteorological Society* 100.2 (2019): 235-256. https://doi.org/10.1175/BAMS-D-18-0037.1

McClung, B. and Mass, CF. (2020). The strong, dry winds of central and northern California: Climatology and synoptic evolution. *Weather and Forecasting*, *35*(5), 2163-2178. https://doi.org/10.1175/WAF-D-19-0221.1

McDonald, C. (2019). September 17, 1923: The Day that Berkeley Burned. *California Magazine*, Spring, 2019. https://alumni.berkeley.edu/california-magazine/spring 2019/september-17-1923-day-berkeley-burned

Microsoft Building Footprints (2018). (https://www.microsoft.com/en-us/maps/building-footprints)

National Weather Service Assessment, November 2018 Camp Fire, January 2020. https://www.weather.gov/media/publications/assessments/sa1162SignedReport.pdf

Parker, DR. (1992) The Oakland-Berkely Hills Fire: An Overview. http://www.sfmuseum.org/oakfire/overview.html

Pera, M. (2023). Exploring the Conditions that Led to the Camp Fire, Five Years Later *The Lookout* https://the-lookout.org/2023/11/09/exploring-the-conditions-that-led-to-the-camp-fire-five-years-later/

Prein, AF., Coen, J., & Jaye, A. (2022). The character and changing frequency of extreme California fire weather. *Journal of Geophysical Research: Atmospheres*, *127*(9), e2021JD035350.

RAWS USA Climate Archive, Western Regional Climate Center (2023). https://raws.dri.edu/

Schmidt, J. (2023). Defensible Space, Housing Density, and Diablo-North Wind Events: Impacts on Loss Rates for Homes in Northern California Wildfires, Munich Personal RePEc Archive, https://mpra.ub.uni-muenchen.de/116166/

Scott, JH., Short, KC, Finney, M. FSIM Best Practices version 0.3.1 (2018). http://pyrologix.com/downloads/

Scott, JH.; Gilbertson-Day, JW.; Moran, C.; Dillon, GK.; Short, KC.; Vogler, K. C. (2020). Wildfire Risk to Communities: Spatial datasets of landscape-wide wildfire risk components for the United States. Fort Collins, CO: Forest Service Research Data Archive. Updated 25 November 2020. https://doi.org/10.2737/RDS-2020-0016

Smith, C., Hatchett, BJ., Kaplan, M. (2018). A Surface Observation Based Climatology of Diablo-Like Winds in California's Wine Country and Western Sierra Nevada *Fire*, 1, 25. https://doi.org/10.3390/fire1020025

Short, KC.; Grenfell, I.C.; Riley, KL.; Vogler, KC. (2020). Pyromes of the conterminous United States. Forest Service Research Data Archive. Fort Collins, CO: https://doi.org/10.2737/RDS-2020-0020

Short, KC. (2022). Spatial wildfire occurrence data for the United States, 1992-2020 [FPA_FOD_20221014]. 6th Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2013-0009.6

Silvis Lab, University of Wisconsin (2020). Wildland-Urban Interface (WUI) Change 1990-2020. https://silvis.forest.wisc.edu/data/wui-change/

Synoptic Weather Station Data Archive: https://synopticdata.com/

Tukman, M. New Statewide Wildfire Data from Pyrologix (2022). https://storymaps.arcgis.com/stories/32de73f1cfb040c79f80c189ccefe061

Thompson, CF., Jones, C., Carvalho, LM., Trugman, AT., Lucas, D., Seto, D., & Varga, K. (2023). Autumn Surface Wind Trends over California during 1979-2020. *Climate*. https://doi.org/10.3390/cli11100207

Vogler, KC., Brough, A., Moran, CJ., Scott, JH., Gilberson-Day, JW. (2021). Contemporary Wildfire Hazard Across California, Pyrologix LLC, http://pyrologix.com/reports/Contemporary-Wildfire-Hazard-Across-California.pdf

Note: Basemap for all maps from ESRI.

Appendix I: FAIR Plan Policy Percentages by County, Adjusted for the Percentage of Housing Units with Potential for Wildfire Exposure

County	FAIR Plan Policies (% of All Policies)	Housing Units Exposed to Wildfire (%)*	FAIR Plan Policies (% of Exposed Housing Units)	Primary Region
				BAY AREA
Lake	7.1%	99.2%	7.2%	North Bay
Marin	1.7%	91.2%	1.9%	North Bay
Napa	2.3%	82.0%	2.8%	North Bay
Solano	0.1%	67.9%	0.2%	North Bay
Sonoma	1.1%	84.9%	1.3%	North Bay
Alameda	0.8%	36.9%	2.1%	East Bay
Contra Costa	0.4%	68.2%	0.6%	East Bay
San Francisco	0.3%	8.9%	3.1%	South Bay
San Mateo	0.4%	40.4%	1.1%	South Bay
Santa Clara	0.4%	28.7%	1.2%	South Bay
Santa Cruz	3.2%	85.2%	3.7%	South Bay
				SIERRAS (Westside)
Butte	6.1%	89.5%	6.8%	Northern Sierras
Nevada	23.6%	100.0%	23.6%	Northern Sierras
Plumas	13.3%	100.0%	13.3%	Northern Sierras
Shasta	3.7%	90.4%	4.1%	Northern Sierras
Sierra	17.2%	100.0%	17.2%	Northern Sierras
Yuba	4.0%	93.9%	4.3%	Northern Sierras
Alpine	21.9%	100.0%	21.9%	Central Sierras
Amador	21.6%	100.0%	21.6%	Central Sierras
Calaveras	23.7%	100.0%	23.7%	Central Sierras
El Dorado	17.9%	99.9%	17.9%	Central Sierras
Mariposa	26.6%	100.0%	26.6%	Central Sierras
Placer	6.8%	81.7%	8.3%	Central Sierras
Tuolumne	31.9%	100.0%	31.9%	Central Sierras
Fresno	1.4%	47.8%	2.9%	Southern Sierras
Madera	6.5%	77.4%	8.4%	Southern Sierras
Tulare	1.2%	81.8%	1.5%	Southern Sierras
				OTHER REGIONS
Inyo	0.8%	99.4%	0.8%	Eastern Sierras
Lassen	6.7%	100.0%	6.7%	Eastern Sierras
Mono	8.2%	100.0%	8.2%	Eastern Sierras
Del Norte	1.9%	100.0%	1.9%	North Coast
Humboldt	2.6%	93.7%	2.8%	North Coast
Mendocino	6.1%	100.0%	6.1%	North Coast
Tehama	2.2%	100.0%	2.2%	Sacramento Valley
Colusa	0.3%	93.1%	0.3%	Sacramento Valley
Glenn	0.3%	73.5%	0.4%	Sacramento Valley
Sacramento	0.1%	43.5%	0.2%	Sacramento Valley
Sutter	0.1%	76.4%	0.1%	Sacramento Valley
Yolo	0.2%	50.3%	0.3%	Sacramento Valley
Kings	0.1%	67.4%	0.1%	San Joaquin Valley
Merced	0.1%	75.7%	0.2%	San Joaquin Valley
San Joaquin	0.2%	27.0%	0.9%	San Joaquin Valley
Stanislaus	0.2%	71.4%	0.3%	San Joaquin Valley
Siskiyou	5.1%	97.3%	5.2%	Klamath Mountains
Trinity	18.5%	100.0%	18.5%	Klamath Mountains
Monterey	2.5%	87.0%	2.8%	South Coast
San Benito	0.7%	100.0%	0.7%	South Coast
Modoc	1.5%	98.4%	1.6%	Eastern Cascades

* Potential Exposure, Direct and Indirect

Sources: FAIR Plan data from California Department of Insurance. Exposure from Scott, et al., (2020).

Counties with a FAIR Plan policy percentage greater than 20% are highlighted.

Appendix II: Strong Downslope Wind Events on Red Flag Warning Days, Sept. 1 – Nov. 30, by Region and Weather Station

		BAY AREA			
Station	**County**	**Elevation (feet)**	**Strong Events**	**Data Years**	**Strong Events Per Decade**
Knoxville Creek	Lake	2200	15	17	8.82
Hawkeye	Sonoma	2024	11	17	6.47
Oakland North	Alameda	1403	10	17	5.88
Rose Peak	Alameda	3342	7	17	4.12
Eagle Peak	Tehama	3713	6	17	3.53
Santa Rosa	Sonoma	599	3	17	1.76
Thomes Creek	Tehama	1,029	3	17	1.76
Calaveras Road	Alameda	1230	2	17	1.18
Napa Airport	Napa	33	2	17	1.18
Oakland Airport	Alameda	3	1	17	0.59
Oakland South	Alameda	1095	1	17	0.59
High Glade Lookout	Lake	4807	1	17	0.59
Livermore Airport	Alameda	397	0	17	0.00
Stonyford	Colusa	1540	0	17	0.00
Mallory Ridge	Contra Costa	1948	0	17	0.00
Briones	Contra Costa	1450	0	17	0.00
Konocti	Lake	2149	0	17	0.00
Lyons Valley	Lake	3355	0	17	0.00
Soda Creek	Lake	1725	0	17	0.00
Barnaby	Marin	810	0	17	0.00
Mendocino Pass	Mendocino	5382	0	17	0.00
Atlas Peak	Napa	1934	0	12	0.00
Los Gatos	Santa Clara	2000	0	17	0.00
Ben Lomond	Santa Cruz	2598	0	17	0.00
La Honda	Sonoma	804	0	17	0.00
Santa Rosa Airport	Sonoma	125	0	17	0.00
Brooks	Yolo	354	0	17	0.00

		SIERRAS			
Station	**County**	**Elevation (feet)**	**Strong Events**	**Data Years**	**Strong Events Per Decade**
Jarbo Gap	Butte	2535	27	17	15.88
Cottage	Calaveras	6064	12	17	7.06
Colby Mountain	Tehama	6004	4	8	5.00
Duncan	Placer	7182	7	17	4.12
Saddleback	Sierra	6670	7	17	4.12
Bear Peak	Tulare	8228	6	17	3.53
Pike County Lookout	Yuba	3701	3	17	1.76
Banner Road	Calaveras	2803	2	17	1.18
Sugarloaf	El Dorado	5653	1	13	0.77
Ben Bolt	El Dorado	905	1	17	0.59
Hell Hole	Placer	5240	1	17	0.59
Cashman	Plumas	4478	1	17	0.59
Beaver Camp Loc	Amador	4651	0	17	0.00
CFA Raws	Amador	660	0	17	0.00
Mount Zion	Amador	2967	0	17	0.00
Bangor	Butte	803	0	17	0.00
Carpenter Ridge	Butte	4816	0	17	0.00
Cohasset	Butte	1733	0	17	0.00
Humbug Summit	Butte	6714	0	11	0.00
Openshaw	Butte	268	0	17	0.00
Chico Airport	Butte	236	0	17	0.00
Oroville Airport	Butte	180	0	17	0.00
Campo Seco	Calaveras	399	0	17	0.00
Bald Mtn Loc	El Dorado	4613	0	17	0.00
Baron	El Dorado	6336	0	12	0.00
Meyers	El Dorado	6310	0	13	0.00
Owens Camp Loc	El Dorado	5240	0	17	0.00
Pilot Hill	El Dorado	1249	0	17	0.00
Steely Fork	El Dorado	4010	0	17	0.00
Cedar Grove	Fresno	4720	0	17	0.00
Fancher Creek	Fresno	916	0	17	0.00
Fence Meadow	Fresno	5240	0	17	0.00
High Sierra	Fresno	7431	0	17	0.00
Hurley	Fresno	1228	0	17	0.00
Mount Tom	Fresno	8982	0	17	0.00
Mountain Rest	Fresno	4110	0	17	0.00
Pinehurst	Fresno	4066	0	17	0.00
Shaver	Fresno	5746	0	17	0.00
Trimmer	Fresno	1487	0	17	0.00
Westwood	Lassen	6155	0	17	0.00
Batterson	Madera	3176	0	17	0.00
Metcalf Gap	Madera	3118	0	17	0.00
Minarets	Madera	5313	0	17	0.00
North Fork	Madera	2721	0	17	0.00

		SIERRAS (Continued)			
Station	**County**	**Elevation (feet)**	**Strong Events**	**Data Years**	**Strong Events Per Decade**
Catheys Valley	Mariposa	1234	0	17	0.00
Crane Flat Lookout	Mariposa	6634	0	17	0.00
El Portal	Mariposa	2073	0	17	0.00
Jerseydale	Mariposa	3762	0	17	0.00
Mariposa	Mariposa	2231	0	17	0.00
Smith Peak	Mariposa	3871	0	11	0.00
Wawona	Mariposa	4309	0	17	0.00
Reader Ranch	Nevada	1968	0	17	0.00
Secret Town	Nevada	2757	0	17	0.00
White Cloud	Nevada	4302	0	17	0.00
Foresthill	Placer	4355	0	17	0.00
Homewood	Placer	7121	0	13	0.00
Lincoln	Placer	210	0	17	0.00
Chester	Plumas	4547	0	17	0.00
Coyote	Plumas	5570	0	17	0.00
Pierce	Plumas	5811	0	17	0.00
Quincy Rd	Plumas	3652	0	17	0.00
Swain Mountain	Plumas	6099	0	10	0.00
Whitmore	Shasta	2499	0	17	0.00
Rice Canyon	Sierra	6943	0	7	0.00
Lassen Lodge	Tehama	4159	0	17	0.00
Ash Mountain	Tulare	1730	0	17	0.00
Blackrock	Tulare	8114	0	17	0.00
Case Mountain	Tulare	6450	0	17	0.00
Fountain Springs	Tulare	794	0	17	0.00
Johnsondale	Tulare	4684	0	17	0.00
Milo	Tulare	1923	0	17	0.00
Oak Opening	Tulare	3091	0	17	0.00
Park Ridge	Tulare	7540	0	17	0.00
Peppermint	Tulare	7385	0	17	0.00
Shadequarter	Tulare	4340	0	17	0.00
UHL / Hot Springs	Tulare	3768	0	17	0.00
Wolverton	Tulare	5240	0	17	0.00
Green Spring	Tuolumne	1108	0	17	0.00
Mount Elizabeth	Tuolumne	4942	0	17	0.00
Pinecrest 2	Tuolumne	5706	0	11	0.00
White Wolf	Tuolumne	8038	0	17	0.00

Source: RAWS USA Climate Archive, Western Regional Climate Center, (https://raws.dri.edu/) and Synoptic: https://synopticdata.com/.