Reax Engineering Inc.
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De-energization Thresholds for Prevention of Catastrophic Wildfires

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1.0 INTRODUCTION

Reax Engineering Inc. (Reax) has been retained by Liberty Utilities to recommend thresholds for proactive de-energization of overhead electrical utilities in Liberty Utilities' Public Safety Power Shutoff (PSPS) zones as established by others. This work inherently assumes that all PSPS Zones present equivalent risk of structure loss under analogous fire weather conditions. It is our understanding that Liberty Utilities has identified 46 PSPS zones that can be separately isolated and de-energized.

This report is organized as follows:

- Section 2.0 provides background information that is subsequently applied in Section 3.0 for establishing baseline de-energization thresholds.
- In Section 4.0, historical weather observations and archived forecast data are analyzed to quantify the frequency at which the recommended de-energization thresholds have been exceeded in the past.
- Section 5.0 analyzes fire weather conditions associated with fires of historical significance in and near Liberty's service territory.
- Section 6.0 provides de-energization thresholds and decision trees for each of Liberty Utilities' PSPS zones.
- A summary of this work and concluding remarks are presented in Section 7.0.
- Section 8.0 contains references cited in this report.
- Appendix A contains the fuel moisture sampling plan that is used to support this work.

2.0 BACKGROUND

2.1 Correlation between wind speed and occurrence of electrical outages

Correlation of outage occurrence with wind gust speed shows that wind-caused outages are infrequent for wind gust speeds below 30 mph, but for distribution lines an inflection point exists at a gust speed of approximately 30 mph (13 m/s) [1]. Above 30 mph, outage probability increases by approximately a factor of 10 for every 15 mph increase in wind gust speed [1]. This means that at a wind speed of 45 mph (20 m/s) there is approximately a 10× increase in outage frequency compared to 30 mph winds. This is shown graphically in Figure 1 [2]. Since the same mechanisms that cause outages (flying debris, vegetation contact with conductors, line slap, etc.) may also cause fires, it is reasonable to assume that fire ignition probability also scales similarly with wind gust speed.

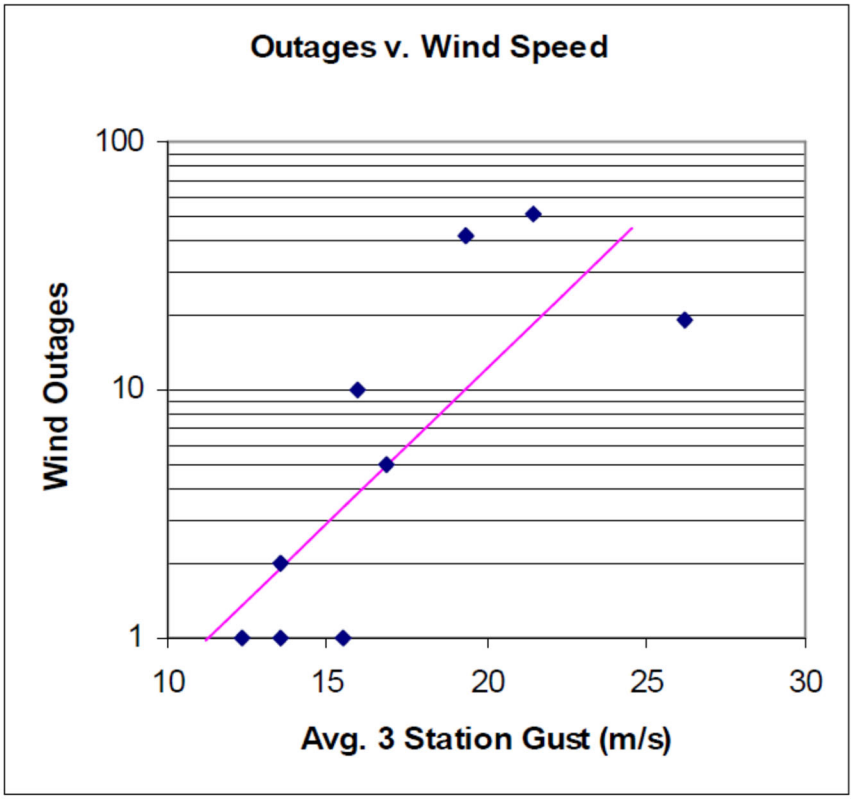


Figure 1. Increase of Outages with gust wind speed [2].

2.2 Wind gust speeds associated with suspected large-loss powerline fires

Surface weather station observations around the time of ignition were analyzed for several catastrophic suspected powerline fires. The results of this analysis are shown in Table 1. Measured gust speed for stations near the suspected ignition locations ranged from 32 mph to 79 mph,

although gust speeds may have been higher at the ignition location, particularly for the lower readings.

Table 1. Observed wind gust speed around time of ignition for weather stations near ignition of suspected powerline fires.

Year	Fire	Wind gust (mph)
2011	Bastrop Complex (TX)	34 - 43
2017	Starbuck (OK, KS)	46 - 53
2017	Tubbs	41 - 79
2017	Atlas, Nuns	32 - 43
2017	Thomas	32 - 40
2018	Woolsey	32 - 52
2018	Camp	52

2.3 Thresholds from California Senate Bill 901 Utility Wildfire Mitigation Plans

Wildfire Mitigation Plans (WMPs) submitted to the California Public Utilities Commission (CPUC) by several utilities on February 6, 2019 were reviewed. The following utilities submitted WMPs:

- Pacific Gas and Electric Company
- Southern California Edison
- San Diego Gas & Electric
- Liberty Utilities/CalPeco Electric
- Bear Valley Electric Service
- PacifiCorp
- NextEra Energy Transmission West
- Trans Bay Cable

Only three of the WMPs provided specific criteria for de-energization. These de-energization thresholds are provided in Table 2:

Table 2. Quantitative de-energization thresholds from CPUC WMPs.

Utility	Wind speed threshold	Additional thresholds
Bear Valley Electric Service	3-second gust > 50 mph	-
Liberty Utilities	3-second gust > 50 mph	-
PacifiCorp	Sustained wind speed of 11 – 17 mph or gust wind speed of 17 – 26 mph	Keetch Byram Drought Index (KBDI) > 282 to 386 and 6-hour averaged Fosberg Fire Weather Index (FFWI) > 15 - 30

3.0 BASELINE PROACTIVE DE-ENERGIZATION THRESHOLD RANGES

The recommended approach for triggering de-energization protocols involves a three part test:

1. Seasonal considerations: Are seasonal conditions associated with intermediate to long term drying (*e.g.*, live fuel moisture content) such that rapidly spreading fires are possible?
2. Wind gusts: Are wind gust speeds high enough to increase the probability of powerline-associated fire ignition?
3. Fire weather: Are fire weather conditions (including temperature and relative humidity) conducive to rapidly spreading fires?

Each of these components is broken down separately in the following sections.

3.1 Seasonal considerations and intermediate to long-term drying

Energy Release Component (ERC) is a key index calculated from Remote Automated Weather Station (RAWS) observations as part of the US National Fire Danger Rating System (NFDRS). The physical meaning of an ERC value is 4% of the energy per unit area that would be released during a fire in units of Btu/f^2. In other words, multiplying an ERC value by 25 gives the number of Btus per square foot that would be released in a fire, *e.g.*, an ERC of 10 corresponds to 250 Btu/sq ft.

ERC depends on live and dead fuel loading by size class (as characterized by an NFDRS fuel model) as well as fuel moisture content of live and dead fuels. In forested areas, ERC values are usually calculated for NFDRS fuel model G which includes a heavy loading of 1000-hour fuels (dead fuels between 3 and 8 inches in diameter). Consequently, ERC for fuel model G (or ERC(G) for short) is therefore quite sensitive to 1000-hour fuel moisture values.

In addition to depending on fuel loading / fuel model, ERC varies daily due to changes in moisture content of both live and dead fuels, which are in turn dependent on antecedent precipitation, relative humidity, and temperature. ERC is a "build up" index that, in the Western US, typically peaks during summer months and drops off after rains return and temperatures drop. Figure 2 shows an example seasonal variation of ERC. Since ERC depends on fuel loading/fuel model at each RAWS station, absolute ERC values are commonly converted to percentiles to facilitate comparison of seasonal ERC trends between RAWS stations with different fuel models. Conversion of an absolute ERC value to a percentile ERC value is accomplished by analyzing historical weather station observations using software developed by the USDA Forest Service known as Fire Family Plus [3].

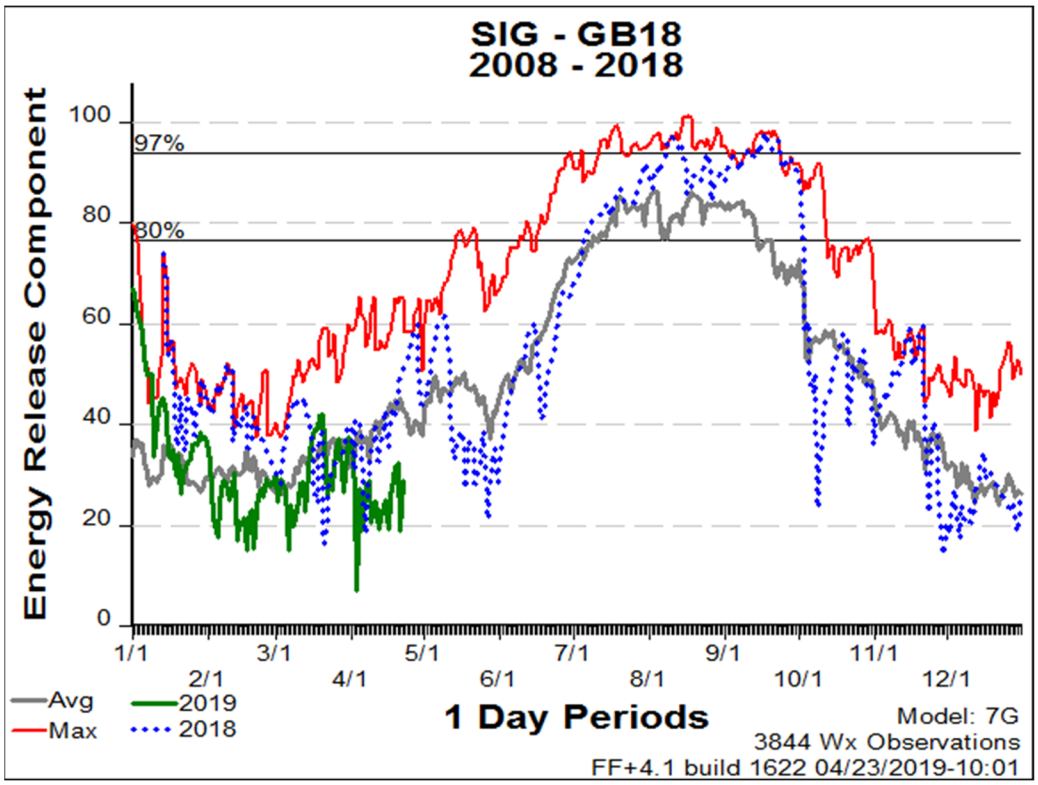


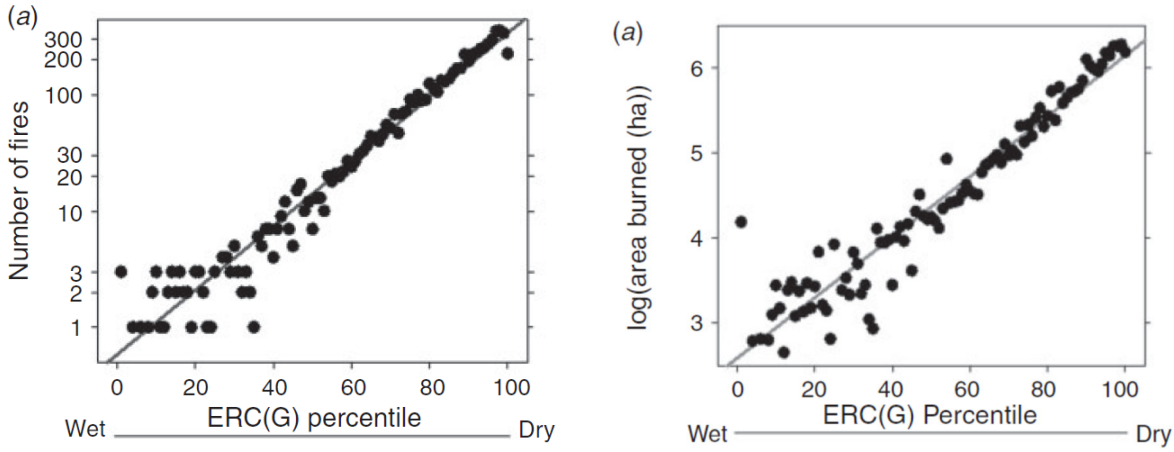
Figure 2. Sample seasonal variation of ERC.

ERC can be thought of as a measure of intermediate to long term drying. It is correlated with the Keetch Byram Drought Index (KBDI), a widely-used measure of drought that is used in the NFDRS to increase fuel loading under drought conditions. KBDI is explained by the United States Forest Service (USFS) Wildland Fire Assessment System (WFAS) as follows [4]:

> Keetch and Byram (1968) designed a drought index specifically for fire potential assessment. It is a number representing the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff and upper soil layers. It is a continuous index, relating to the flammability of organic material in the ground.
>
> The KBDI attempts to measure the amount of precipitation necessary to return the soil to full field capacity. It is a closed system ranging from 0 to 800 units and represents a moisture regime from 0 to 8 inches of water through the soil layer. At 8 inches of water, the KBDI assumes saturation. Zero is the point of no moisture deficiency and 800 is the maximum drought that is possible. At any point along the scale, the index number indicates the amount of net rainfall that is required to reduce the index to zero, or saturation.

Fire occurrence (number of fires) and fire size (area burned) are both strongly correlated with ERC. Figure 3 demonstrates the strong correlation between ERC and fire occurrence/size [5]. Noting that the *y* axes are logarithmic, the relation between ERC and fire occurrence and area burned is

exponential. Comparing ERC percentiles of 50% to 100% shows a 30× increase in number of fires and a 100× increase in fire area.



(a) **(b)**

Figure 3. Correlation of ERC with fire occurrence (a) and fire size (b). From Ref. [5].

Based on these considerations, it is recommended that seasonal factors associated with intermediate to long term drying be quantified here via ERC. The USFS WFAS provides two real-time sources of ERC values. The first provides NFDRS indices – including ERC – based on current observations [6] as well as a one-day weather forecast [7]. Data are provided in tabular form for each reporting RAWS station. As an example, Figure 4 shows forecast NFDRS indices from 7/29/19 for a subset of RAWS stations in Nevada. ERC values are absolute – not percentiles – and 10-hour, 100-hour, and 1000-hour fuel moistures (TEN, HUN, THOU in Figure 4) are given in percentages.

***** California *****	Elev	Lat	Long	Mdl	Tmp	RH	Wind	PPT	ERC	BI	SC	KBDI	HUN	THOU	TEN	STL	ADJ	IC	(Staffing Specs)
40101 CAMP SIX LOOKOUT	3698	41.8	123.8	7G	81	48	5	.00	49	47	8	665	12	12	9	3	M	18	BI / 58/ 66/90/97
40102 GASQUET 2	452	41.8	123.9	7G	85	46	2	.00	41	34	5	789	14	14	9	3	M	15	BI / 42/ 46/90/97
40105 SHIP MTN L.O.	5151	41.7	123.7	7G	76	49	3	.00	59	47	7	595	9	10	8	3	M	15	BI / 71/ 86/90/97
40106 CRAZY PEAK	3970	41.9	123.6	7G	86	39	3	.00	55	46	7	594	10	11	7	4	H	21	ERC/ 44/ 55/90/97
40203 BLUE RIDGE (KNF)	5859	41.2	123.1	7G	81	25	6	.00	71	78	17	230	7	9	5	3	H	50	BI / 93/106/90/97
40217 MT SHASTA	3573	41.3	122.3	7G	88	26	5	.00	64	60	10	537	10	10	6	3	M	36	BI / 68/ 75/90/97
40221 ROUND MOUNTAIN	5255	41.4	121.4	7G	85	24	7	.00	79	68	11	266	6	8	4	4	H	43	ERC/ 79/ 96/90/97
40222 SAWYERS BAR	2455	41.3	123.1	7G	98	20	10	.00	77	96	24	733	7	8	4	4	V	68	BI / 93/104/90/97
40225 SLATER BUTTE	4621	41.8	123.3	7G	85	34	2	.00	70	66	12	701	8	8	6	3	M	31	BI / 80/ 91/90/97
40228 WEED AIRPORT	2929	41.4	122.4	7A	92	23	16	.00	3	42	114	595	7	8	5	4	H	42	BI / 41/ 49/90/97
40231 SOMES BAR	915	41.3	123.4	7G	101	25	4	.00	55	62	13	778	12	11	6	3	H	46	BI / 79/ 86/90/97
40233 INDIAN WELL	4777	41.7	121.5	7F	83	35	4	.00	24	30	6	283	6	7	6	2	M	28	BI / 81/ 97/90/97
40237 COLLINS BALDY LO	5476	41.7	122.9	7G	82	35	4	.00	71	57	8	430	7	8	6	3	M	25	BI / 71/ 83/90/97
40239 QUARTZ HILL	4225	41.5	122.9	7G	89	28	2	.00	81	41	4	575	6	7	5	3	M	21	BI / 55/ 66/90/97
40240 JUANITA	5173	41.8	122.1	7G	83	32	1	.00	69	40	4	250	7	9	6	3	M	17	BI / 60/ 71/90/97
40242 BRAZIE RANCH	3090	41.6	122.6	7B	93	24	6	.00	58	89	27	416	6	7	5	4	H	46	BI / 54/ 98/90/97
40243 VAN BREMMER	5303	41.6	121.7	7G	86	18	5	.00	74	67	12	401	7	9	4	3	H	46	BI / 84/ 96/90/97
40244 ASH CREEK	3677	41.2	121.9	7G	86	29	3	.00	53	40	5	622	11	12	6	3	M	24	BI / 52/ 56/90/97
40245 CALLAHAN #2	3910	41.3	122.8	7G	92	22	9	.00	78	82	17	422	7	7	5	5	V	52	BI / 62/ 68/90/97
40246 DUTCH INDY	2296	41.6	123.4	7G	93	26	6	.00	66	75	17	765	9	9	6	3	H	48	BI / 80/ 91/90/97

Figure 4. Sample USFS NFDRS indices forecast data in tabular form [7].

The second set of real-time ERC values available through the USFS WFAS is a gridded map that is derived from discrete RAWS observations [6]. A web map [8], updated daily at 10:00 UTC, displays ERC values by Spatial Preparedness Level (SPL). As an example, ERC SPL for 7/29/19 is shown in Figure 5. The SPL categories are as follows:

- SPL-I: Less than 58th percentile ERC
- SPL-II: 58th – 78th percentile
- SPL-III: 78th – 92nd percentile
- SPL-IV: 92nd to 97th percentile
- SPL-V: 97th – 99th percentile
- SPL-VI: > 99th percentile

SPL of 4 or higher corresponds to an increased probability of fires escaping initial attack and becoming extended attack fires. For that reason, an ERC percentile of 92 is recommended for use as a de-energization threshold. In other words, if ERC in a PSPS zone is less than 92nd percentile, proactive de-energization would not be initiated because seasonal conditions are such that rapidly spreading fires that become large, extended attack fires are unlikely to occur. In Figure 5, areas that are yellow, orange, or red are at a SPL of 4 or higher, meaning relative ERC values are 92nd percentile or greater.

Operationally, discrete ERC values (Figure 4) and gridded ERC rasters (Figure 5) are ingested into the weather analytics and monitoring system used by Liberty Utilities to monitor current and forecasted weather conditions. The gridded ERC rasters are made available by WFAS via the Web Map Service (WMS) protocol. As an example, the following URL is the http query that provides today's (day 0) ERC values:

https://www.wfas.net/cgi-bin/mapserv?&SERVICE=WCS&20&VERSION=1.0.0&REQUEST=GetCoverage&COVERAGE=erc0percnew&CRS=EPSG:4326&BBOX=-130,20,-60,52&WIDTH=2144&HEIGHT=1376&FORMAT=GEOTIFF_FLOAT

Tomorrow's (day 1) values are obtained by replacing "erc0percnew" in the above query with "erc1percnew", and so on. Currently WFAS provides a 3-day ERC forecast which is used operationally in Liberty Utilities' weather analytics and monitoring system for ERC forecasting. Current and forecast ERC values are assigned to each proactive de-energization zone by running zonal statistics for each of Liberty Utilities' PSPS zones.

As described in Appendix A, fuel moisture sampling will be conducted at six different locations in the Truckee/Tahoe region. This sampling will be conducted during "fire season" at 10 – 14 day intervals or after wetting rains. The purpose of this sampling is to continuously monitor live and dead (primarily 1000-hour) fuel moisture contents. These data provide inputs necessary to calculate ERC percentiles based on field observations when can then be compared to automated values from nearby NFDRS stations.

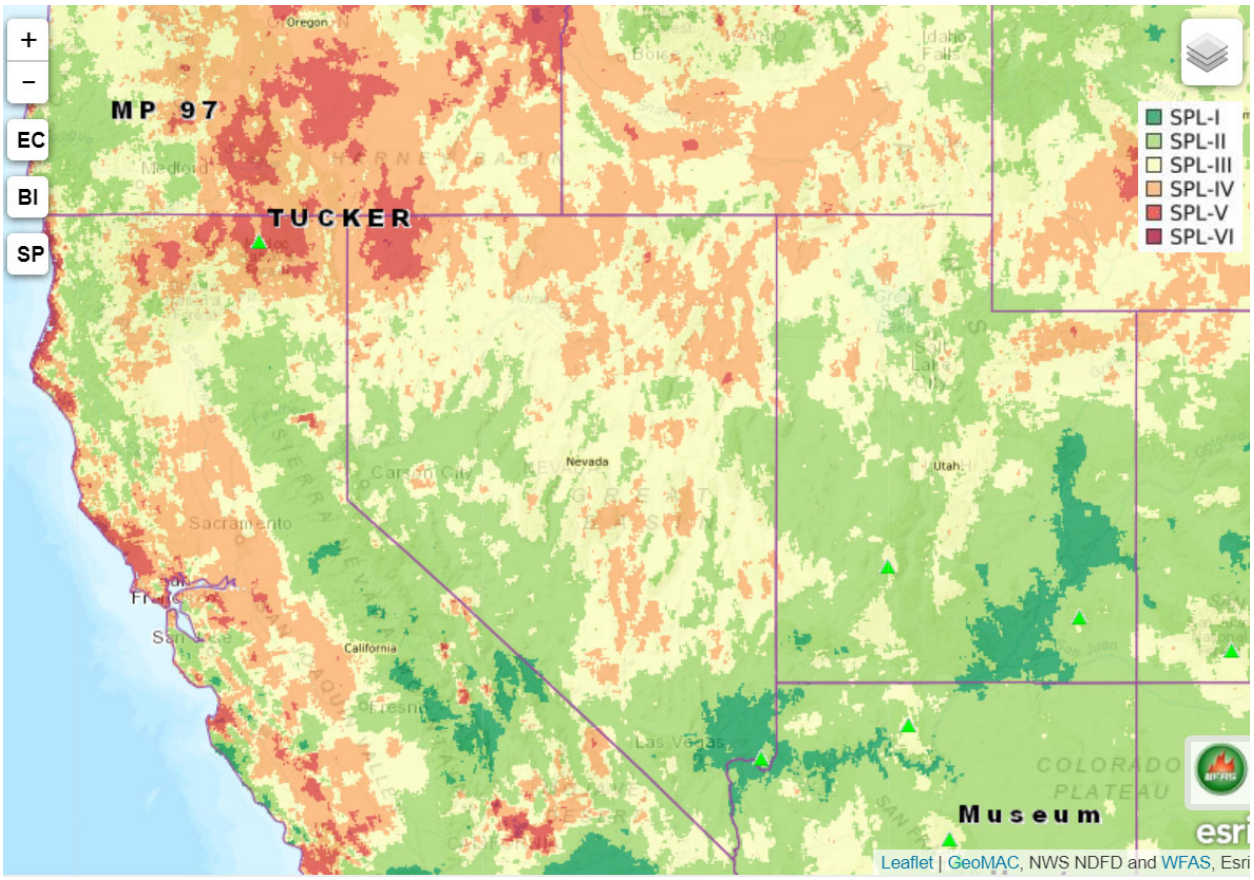


Figure 5. ERC Spatial Preparedness level on 7/29/19.

3.2 Wind gusts

Based on the analyses presented in the background section of this report, a wind gust speed threshold of 40 – 45 mph is recommended as a threshold for de-energization of distribution lines. This value has been shown to correspond to a statistically significant increase in outage occurrence (which is viewed as a proxy for ignition occurrence). Although this value is lower than that identified as a de-energization threshold by Liberty Utilities and BVES (50 mph) in their wildfire mitigation plans, gust speeds measured around the time of ignition of large loss suspected powerline were as low as 32 mph, although wind gusts near the suspected ignition locations may have been higher.

Gust factors are empirically derived equations or graphs that relate wind speed at one averaging interval to wind speed at another averaging interval. A 10-minute average wind speed will be lower than the peak 3-second gust that occurred within that same 10-minute interval. The "Durst curve" [9] (shown in Figure 6) is the most commonly-used source of gust factors. As can be seen from the Durst curve below, the ratio of 3-second gust wind speed to 10-minuted average wind speed (which is what RAWS measures) is approximately 1.43. This means that the 40 mph gust wind speed threshold is equivalent to a 10-minute average wind speed of approximately 40 mph / 1.43 ≈ 28 mph. Therefore, the 40 mph gust threshold can also be viewed as a 28 mph sustained wind speed and a 45 mph gust threshold can be viewed as a 31 mph sustained winds speed.

Since transmission lines typically have less encroaching vegetation than distribution lines, it may be appropriate to use a gust wind speed higher than 40 – 45 mph as a trigger for de-energization of transmission lines. However, unless transmission-specific outage data show a different inflection point when plotted as outage frequency vs. wind gust, the 40 – 45 mph wind gust distribution line threshold is also recommended for application to transmission lines.

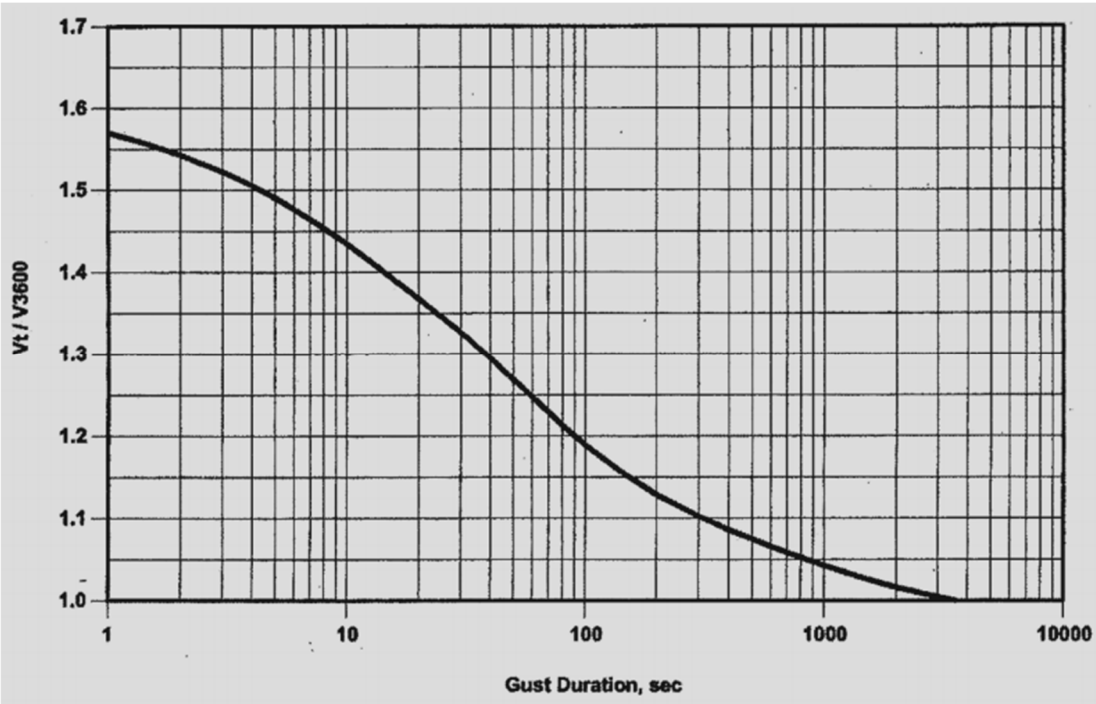


Figure 6. Conventional wind gust factors - Durst curve [9].

3.3 Fire weather

The final criterion that must be met to initiate de-energization protocol is related to fire weather. Essentially, this last test is meant to preclude de-energization during high winds that occur contemporaneously with high humidity and low temperature as such conditions are not conductive to rapidly spreading fires.

The Fosberg Fire Weather Index [10] (FFWI or FWI) is a widely-used index that quantifies the effect of short-term variations in meteorological conditions (temperature, relative humidity, and wind speed) on the potential for wind-driven fire spread. FFWI is based on instantaneous fire weather considerations so it does not consider other factors that may affect fire spread potential such as fuel type, topography, live fuel moisture, or recent precipitation.

Fosberg index is scaled from 0 to 100 such that 100 corresponds to a 30 mph sustained wind and a dead fuel moisture content of zero. Generally, Fosberg indices above 50 – 60 are considered conducive to rapid wind-driven fire spread. For example, NOAA Storm Prediction Center (SPC) personnel wrote [11]: "Generally, for national guidance purposes, temperatures above 60 F, RH

values less than 20%, and sustained surface winds above 20 mph will result in Fosberg values above 50, which is a minimum threshold for critical fire weather conditions. As a general rule, SPC forecasters tend to pay special attention to areas expected to have 3 or more hours of a FWI above 50."

4.0 Historical Exceedance of De-energization Criteria in Liberty Utilities' PSPS Zones

Liberty Utilities has designated 46 PSPS zones:

1) 111 Line
2) 132 Line
3) Portola
4) Sierra Brooks
5) Stampede
6) Russel Valley
7) Hobart
8) Sagehen tap
9) Fir Crags
10) Sunnyside
11) Ward Canyon east
12) Tahoe Park Heights
13) Alpine backside
14) Alpine Meadows and 629
15) Squaw Valley
16) Ward Canyon west
17) Tah 73-17
18) Tah 73-36
19) Tah 73-45
20) Tah 7300 r1
21) Tah 73-60
22) Tah 73-74
23) Angora Ridge and Lily Lake
24) Cathedral Spring Creek Emerald Bay
25) Mey 3400 Angora Creek
26) Mey3300 r3
27) Mey3300 r1
28) Mul 1296 r4
29) Sorensons tap
30) Mul1296 r3
31) Topaz
32) Heavenly lateral
33) Tier 3
34) 640 tier 2
35) 650 Line
36) 669 Line
37) 609 and underbuild
38) 625 Line
39) Bky 5200
40) Old Country Road
41) Tah 52-68
42) The grid

43) Canterbury and Commonwealth
44) Bky 5100 to NVE
45) Beacon tap
46) Glenshire and 608

For the purposes of quantifying historical exceedance frequencies and developing PSPS-specific de-energization thresholds, we have identified five separate groupings:

1) West and north shore
2) South shore
3) Truckee, Glenshire, and Hobart Mills
4) Portola and Sierra Brooks
5) Topaz & Markleeville

The baseline proactive de-energization threshold ranges described in Section 3.0 provide a starting point for developing PSPS zone-specific reasonable risk de-energization thresholds. Historical weather station observations and archived weather forecast data can be analyzed to quantify how frequently various de-energization thresholds have been exceeded in the past so that PSPS zone-specific thresholds can be developed.

Given that proactive de-energization is a last resort for fire prevention, de-energization thresholds must be sufficiently high to prevent unnecessary and/or frequent service interruptions. Through an iterative process, the thresholds shown in Table 3 have been established and are tested against historical weather station observations (Section 4.1) and archived weather forecast data (Section 4.2) to assess historical threshold exceedance frequencies.

Table 3. Thresholds to be assessed in historical threshold exceedance analysis.

Region	ERC(G)	Wind gust (mph)	FFWI (-)
West and north shore	> 92nd percentile	> 40 mph	> 50
South shore	> 92nd percentile	> 40 mph	> 50
Truckee, Glenshire, and Hobart Mills	> 92nd percentile	> 40 mph	> 50
Portola and Sierra Brooks	> 92nd percentile	> 40 mph	> 50
Topaz & Markleeville	> 92nd percentile	> 40 mph	> 50

4.1 Historical weather station observations

4.1.1 West and North shore

Liberty Utilities' PSPS zones on the West and North Shores of Lake Tahoe are shown in Figure 7 relative to the locations of Homewood and Knox 2 RAWS. To provide an estimate of the historical frequency at which the proposed de-energization thresholds have been exceeded, energy release component and wind speed / Fosberg Fire Weather Index statistics are analyzed separately below.

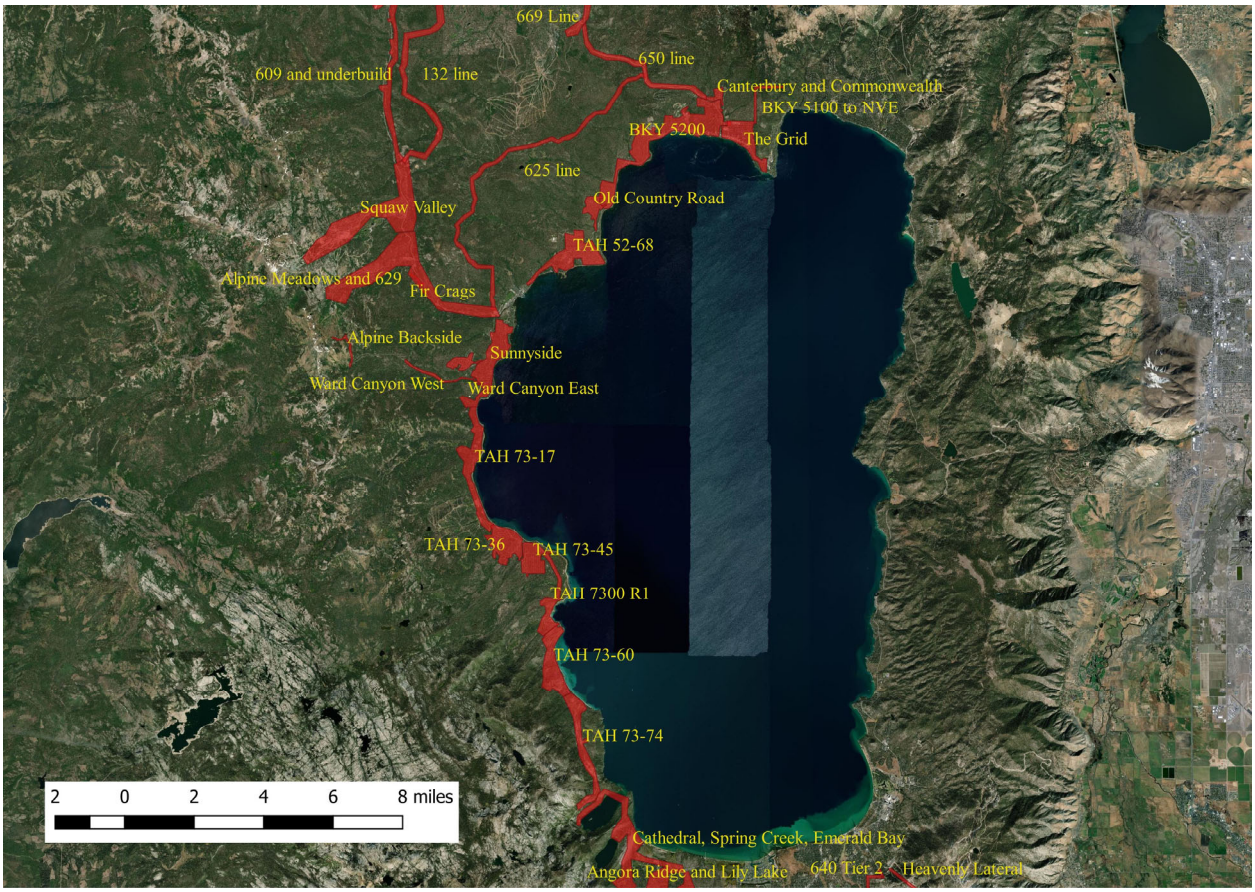


Figure 7. Locations of Liberty Utilities' West and North shore PSPS zones relative to Homewood and Knox 2 RAWS.

Data from Knox 2 and Homewood RAWS were used to create a "Special Interest Group" (SIG), which is a common practice when conducting climatological analyses. Nine years (2010 – 2018) of observations from this SIG were processed to analyze seasonal variations in ERC (using NFDRS Fuel Model G), and the result is plotted in Figure 8. In an average year, ERC does not exceed the 92nd percentile, but in years with below average precipitation and/or higher than average temperatures ERC will likely exceed the 92nd percentile maximum. Figure 8 shows that the maximum ERC has historically exceeded the 92nd percentile from approximately mid-June through late September.

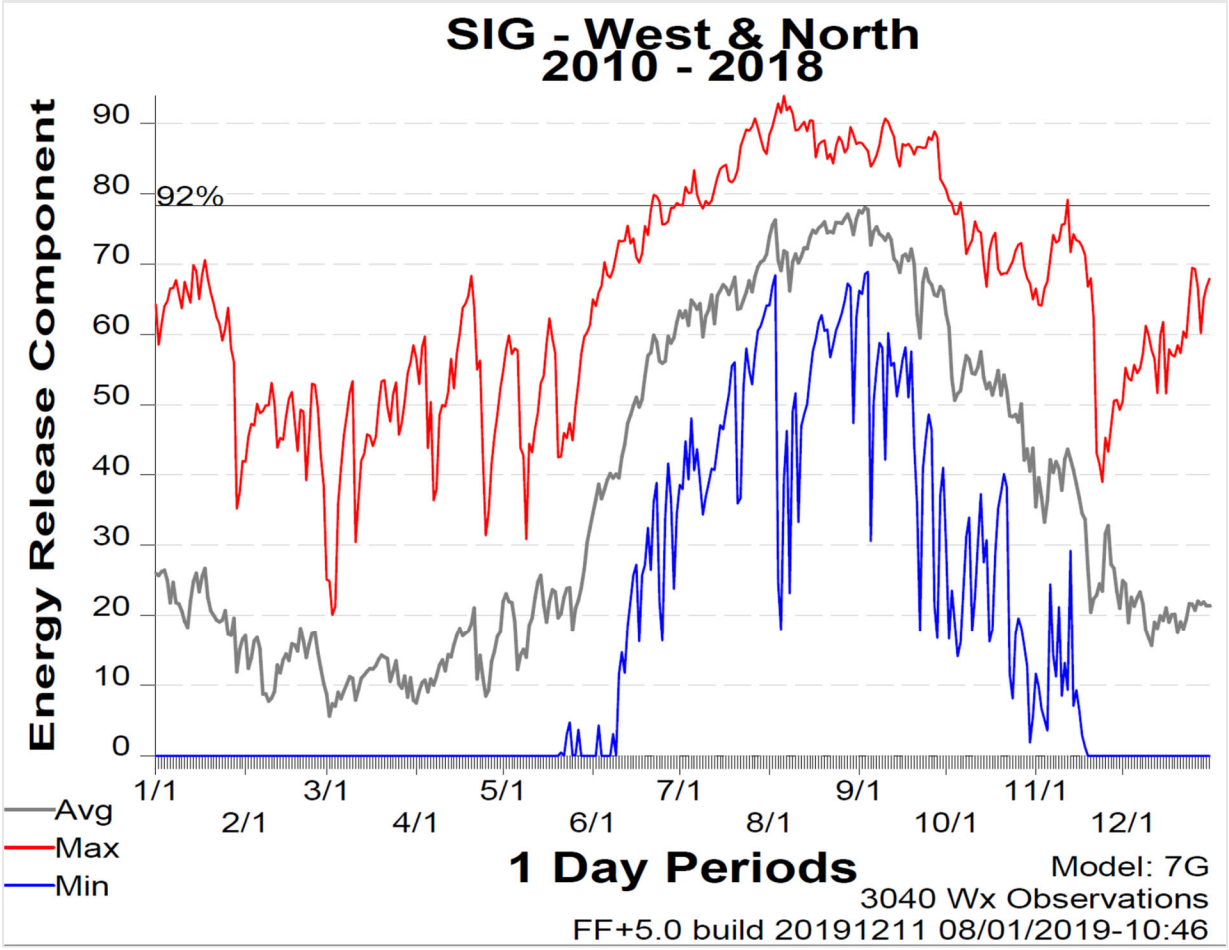


Figure 8. Seasonal variations in ERC (Fuel Model G) in Lake Tahoe SIG.

Scatter plots of measured wind gust vs. FFWI are shown in Figure 9 (Knox 2 / KNXN2) and Figure 10 (Homewood / HMDC1). The period of record plotted for each of these stations is as follows:

- Knox 2 / KNXN2: 2010 – 2018
- Homewood / HMDC1: 2010 – 2018

No exceedances were recorded at Knox 2 RAWS. Although there were several observations at Homewood RAWS where gust & FFWI thresholds were exceeded, they were all "off season" meaning they did not occur in June, July, August, or September when maximum ERC has exceeded 92nd percentile.

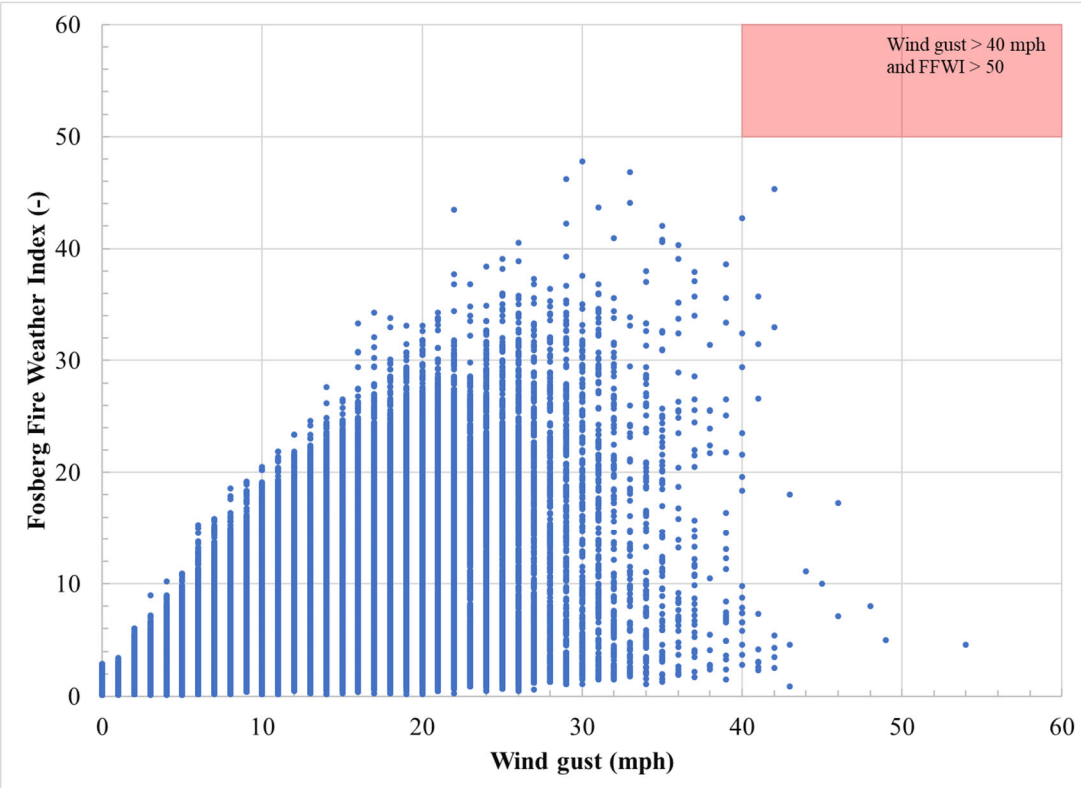


Figure 9. Knox 2 (KNXN2) wind gust vs. FFWI (2010 – 2018).

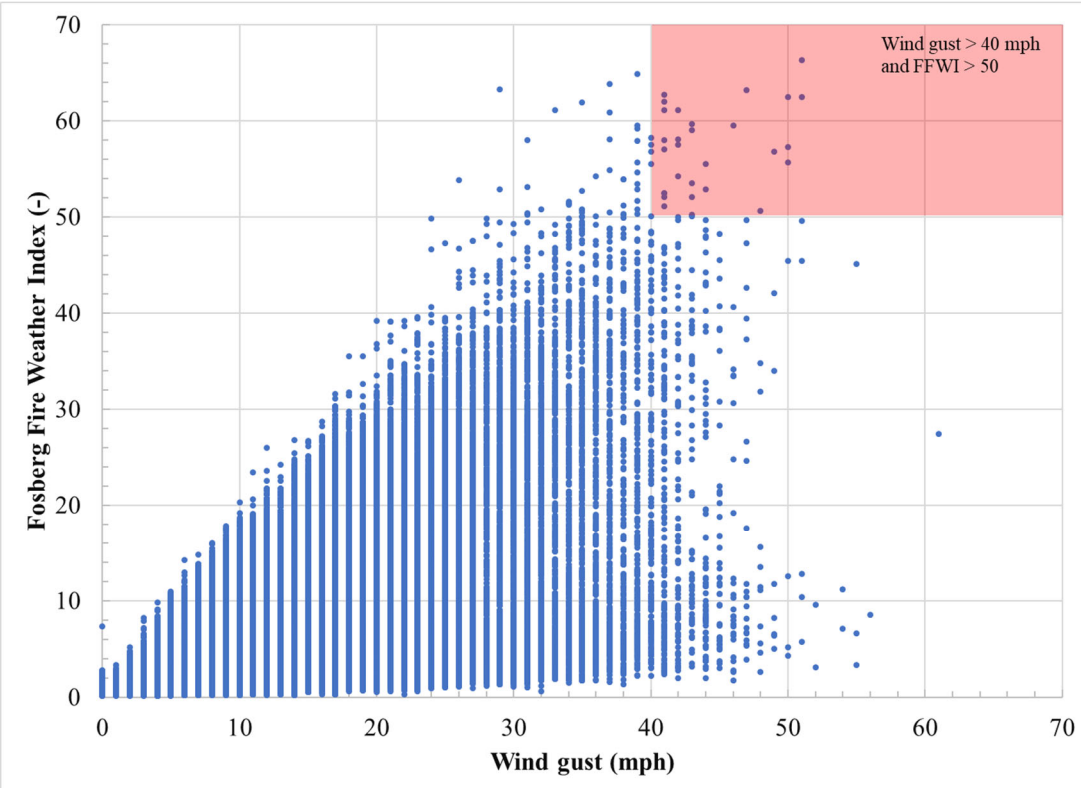


Figure 10. Homewood (HMDC1) wind gust vs. FFWI (2002 – 2018).

4.1.2 South shore

The locations of Baron RAWS and the NWS station at South Lake Tahoe airport relative to Liberty Utilities' South Shore PSPS zones are shown in Figure 11.

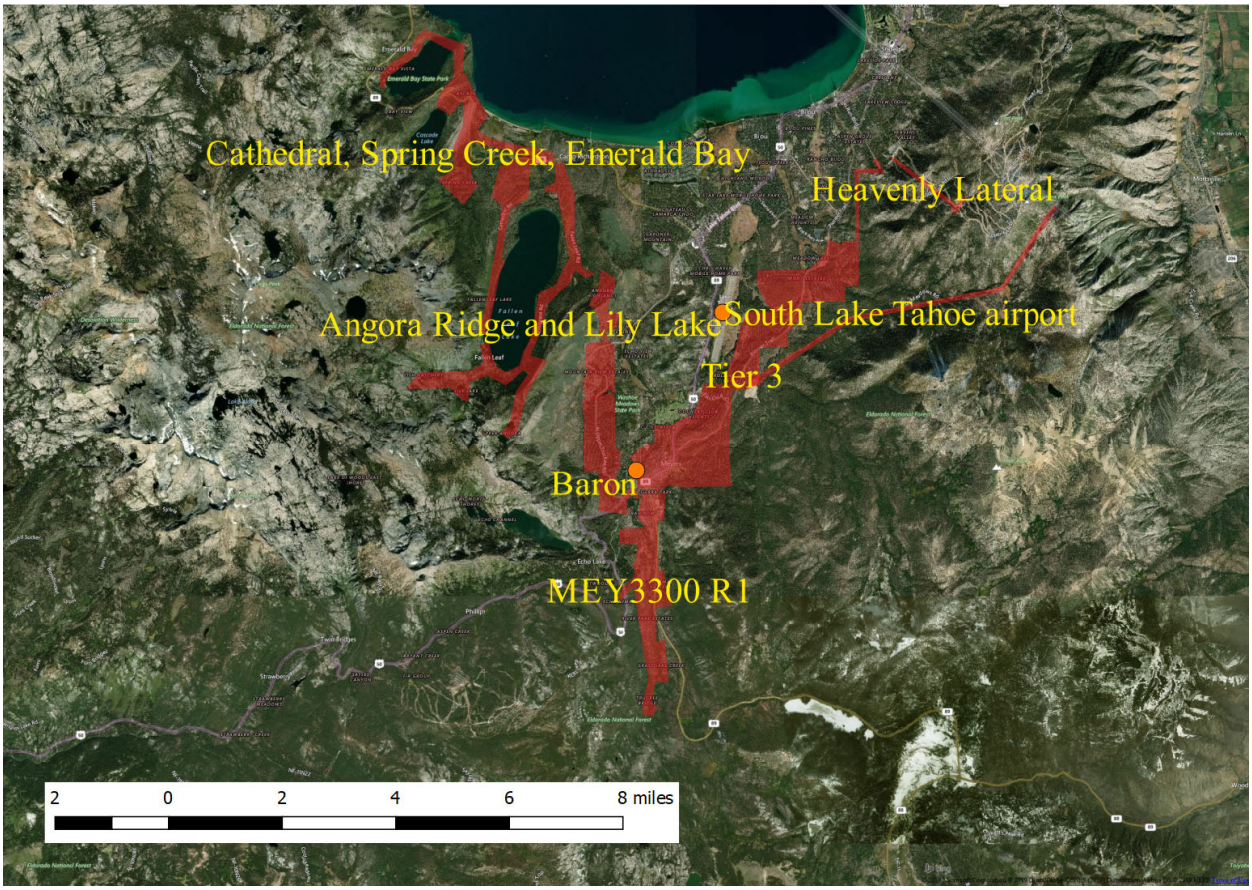


Figure 11. Locations of Liberty Utilities' South shore PSPS zones relative to Meyers/Baron RAWS and SLT airport weather station.

Scatter plots of wind gust against Fosberg Fire Weather Index are given in Figure 12 for Meyers/Baron RAWS and Figure 13 for South Lake Tahoe airport. In the 8 year period of record at Meyers/Baron RAWS, no exceedances occurred.

In the 21-year period of record at South Lake Tahoe airport, there were 410 observations where FFWI and wind gust exceeded baseline thresholds. However, this includes "off-season" winds where ERC would not be above 92nd percentile. After filtering these observations for "summer" months (June, July, August, and September), there were 15 separate days where one or more observation exceeded de-energization thresholds.

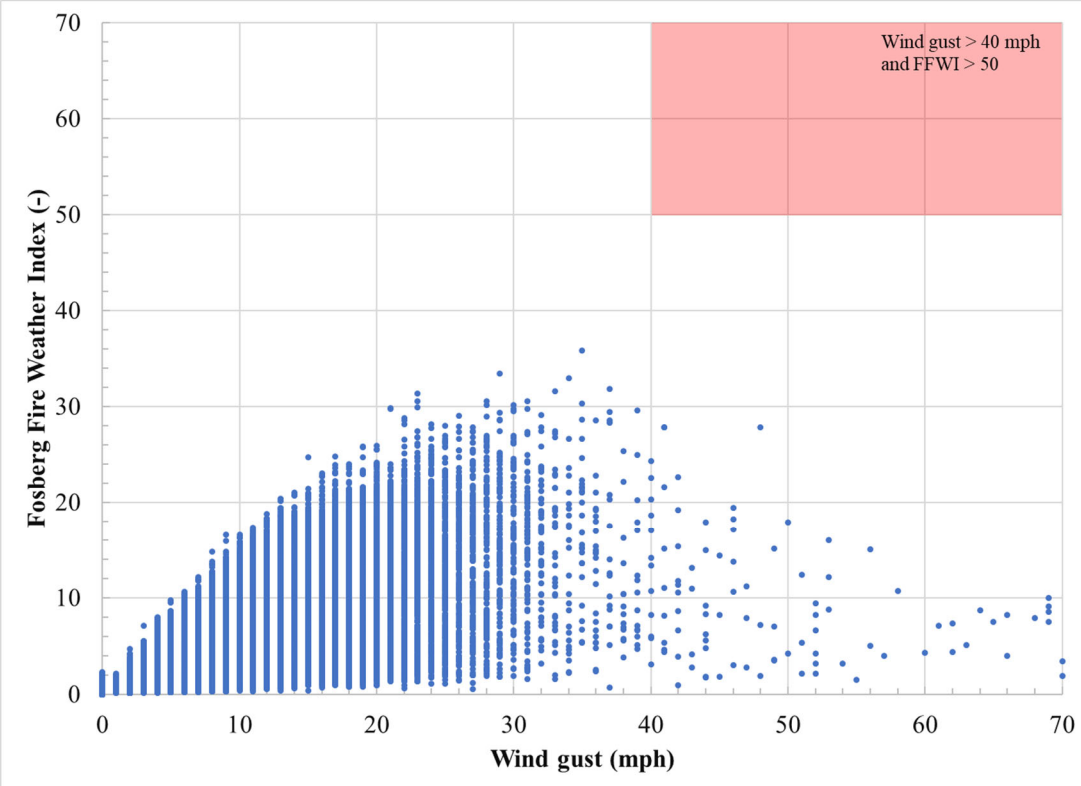


Figure 12. Baron RAWS wind gust vs. FFWI (2011 – 2018).

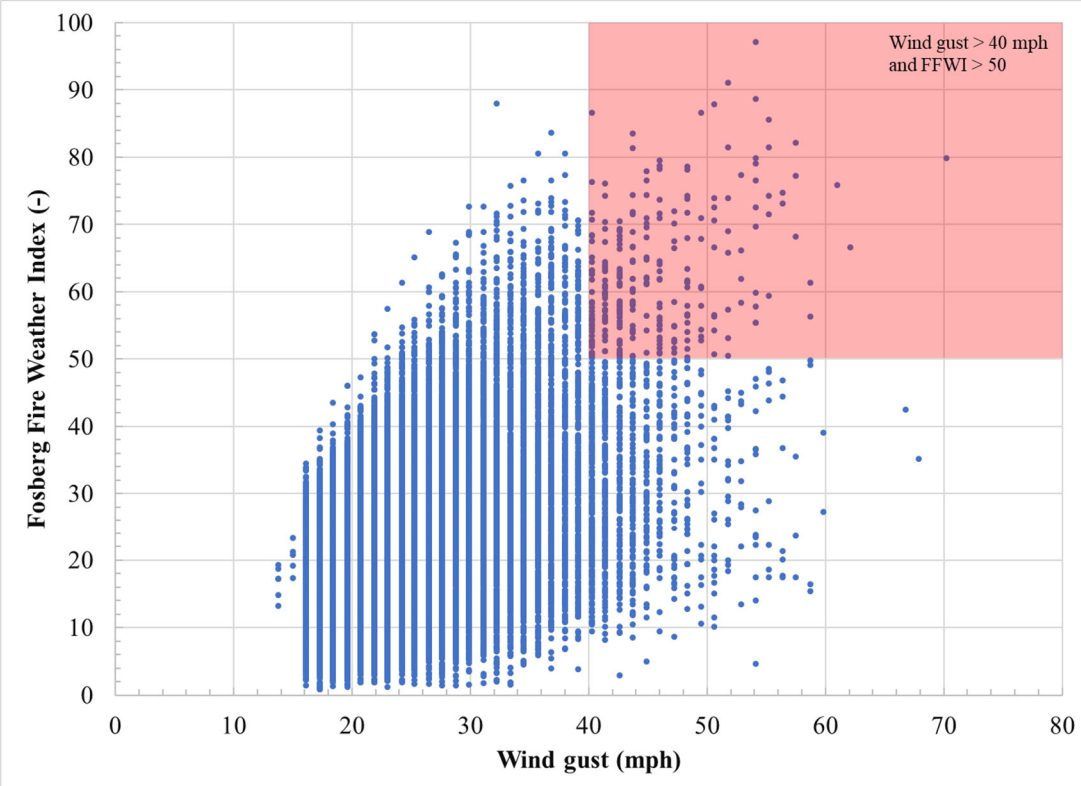


Figure 13. South Lake Tahoe airport wind gust vs. FFWI (1997 – 2018).

4.1.3 Truckee, Glenshire, and Hobart Mills

Liberty Utilities' Truckee/Glenshire/Hobart Mills PSPS Zones are shown in Figure 14. To provide an estimate of the historical frequency at which the proposed de-energization thresholds have been exceeded, energy release component and wind speed / Fosberg Fire Weather Index statistics are analyzed separately below.

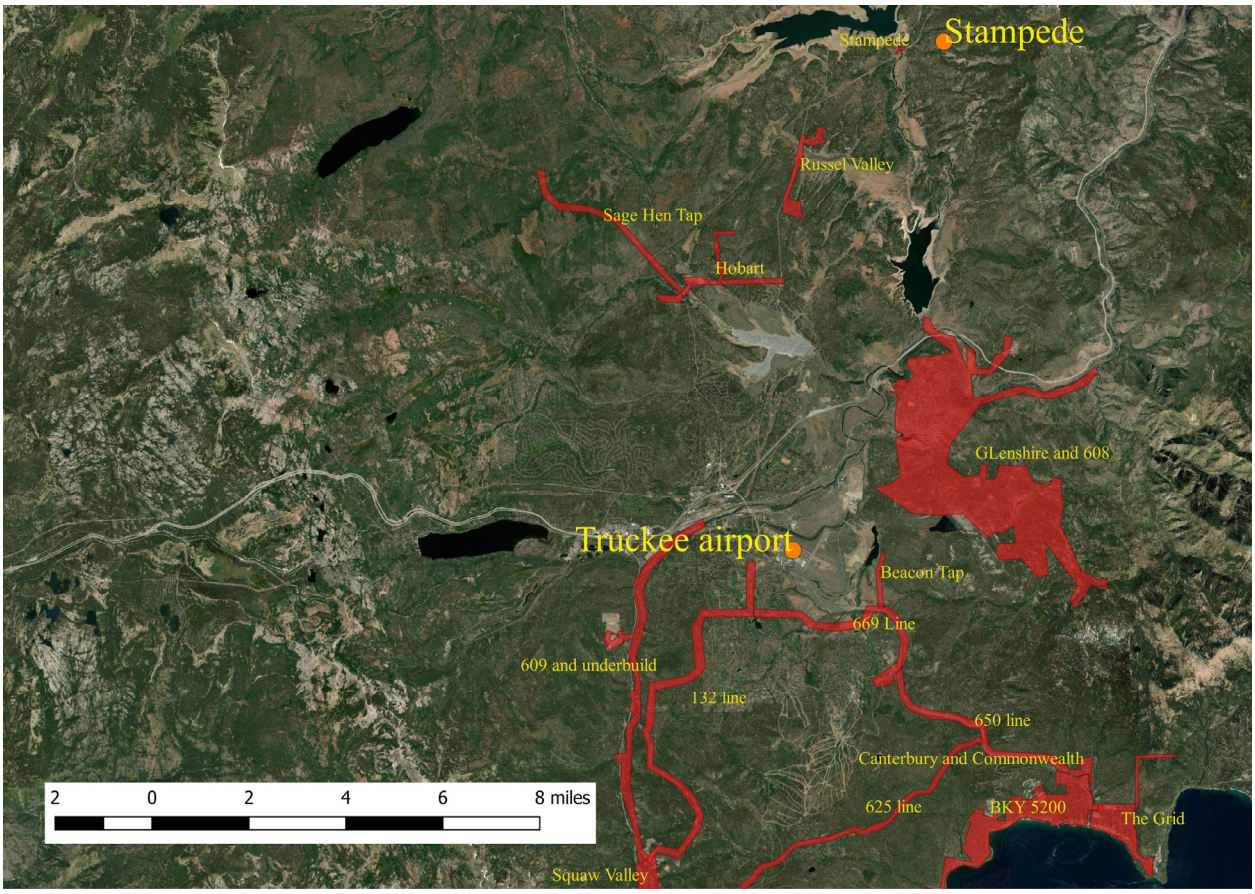


Figure 14. Truckee/Glenshire/Hobart Mills PSPS Zones and location of Stampede weather station.

Thirteen years (2006 – 2018) of observations from Stampede RAWS were processed to analyze seasonal variations in ERC (using NFDRS Fuel Model G), and the result is plotted in Figure 15. The maximum historical ERC exceeded the 92nd percentile threshold from early June through late September, but as with the Lake Tahoe SIG the 92nd percentile was not exceeded in the average year.

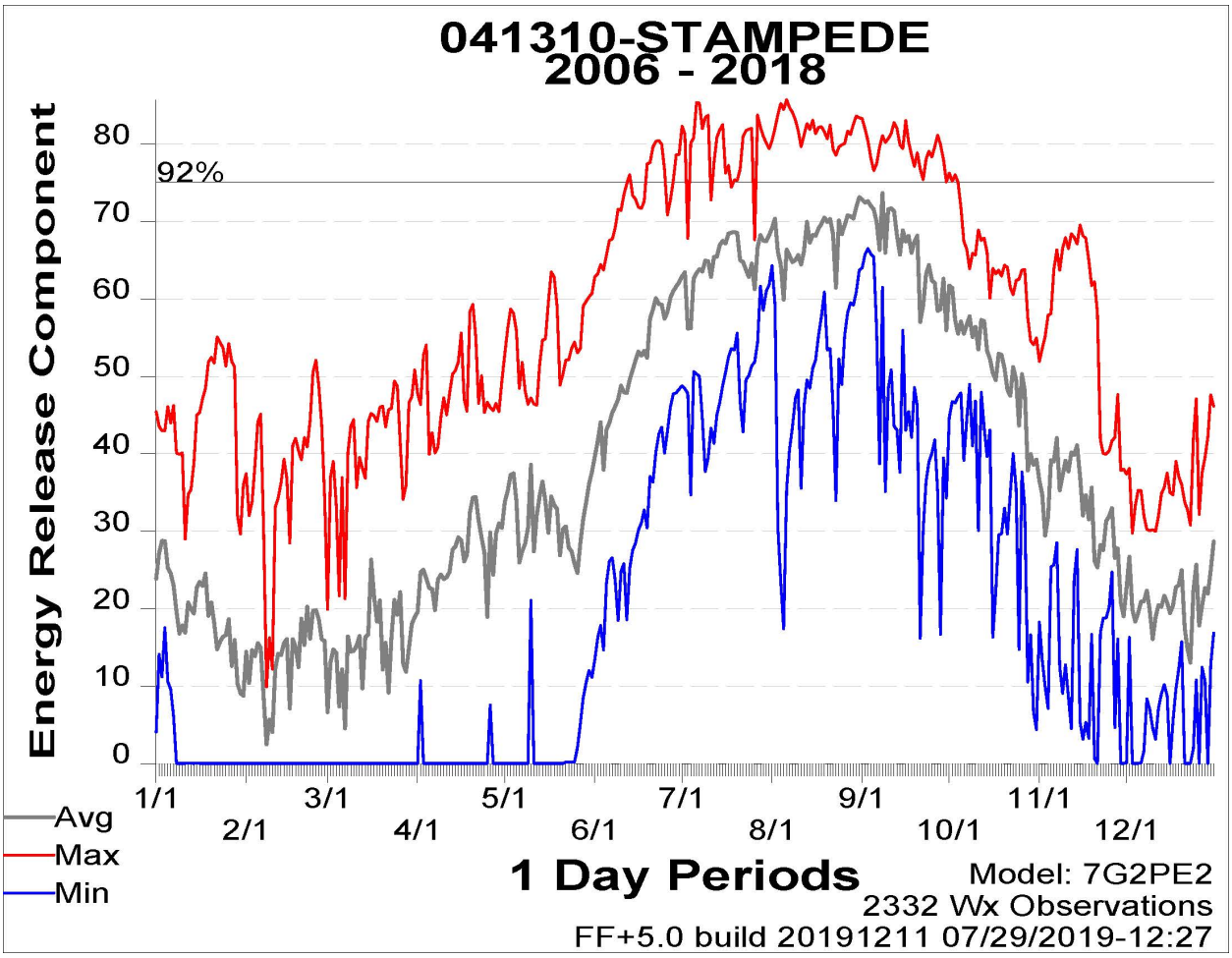


Figure 15. Seasonal variations in ERC (Fuel Model G) at Stampede RAWS.

Measured wind gust speed plotted against Fosberg Fire Weather index for Stampede RAWS from 1999 to 2018 is shown in Figure 16. The wind gust / FFWI threshold exceedances are presented in Table 4. ERC values are not available prior to 2006 so no ERC values are available for the 2004, 2005, or 2006 exceedances and ERC data are missing for 2010, so no ERC values are available for the exceedances shown in Table 4. However, since these exceedances occurred in June, it is possible that ERC values exceeded the 92nd percentile. In an average year the 92nd percentile ERC would not have been exceeded. The dates and duration of the three exceedance events is summarized below:

1. June 17, 2005: 8 hourly records
2. June 16, 2010: 2 hourly records

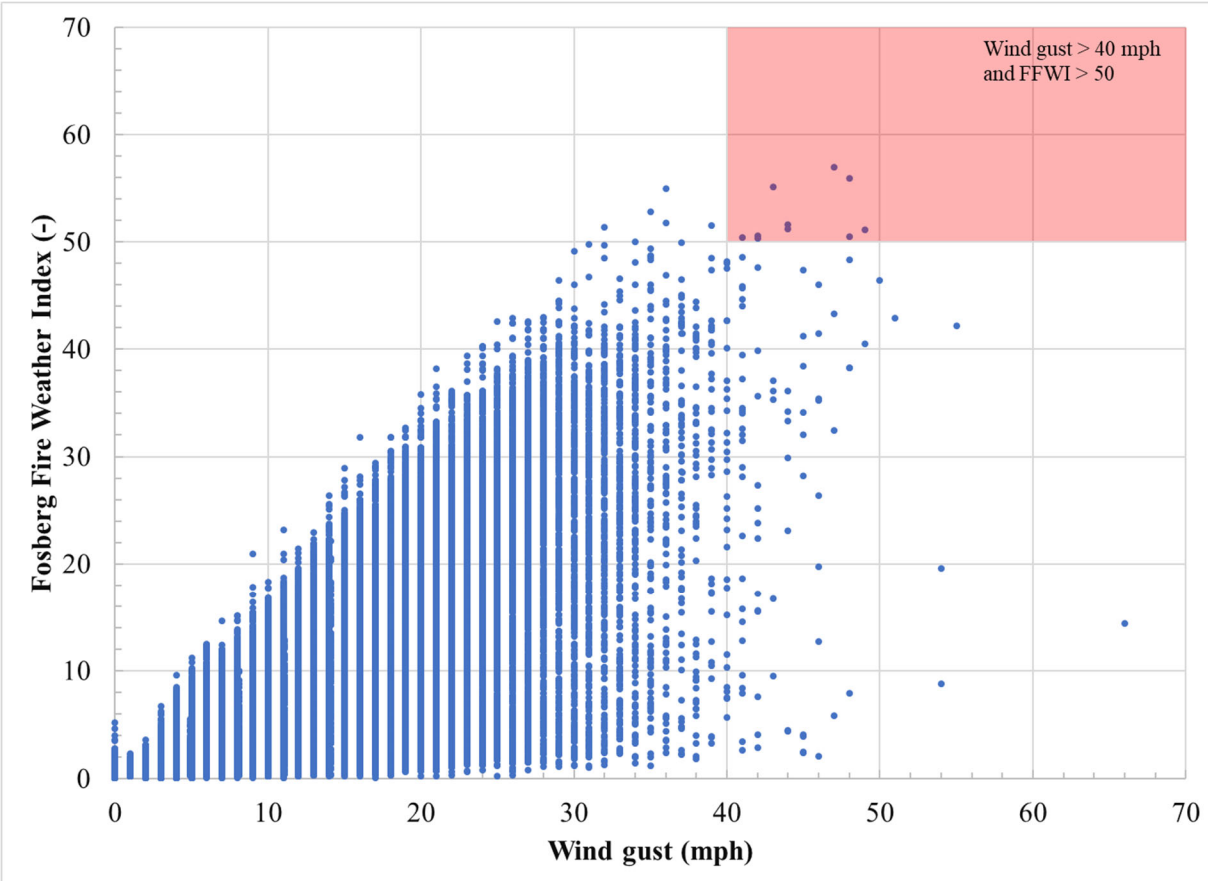


Figure 16. Stampede (SMDC1) wind gust vs. FFWI (1999 – 2018).

Table 4. Weather observations from Stampede RAWS where wind gust and FFWI de-energization thresholds were exceeded.

Station	Date PST / PDT	T F	RH %	WS mph	WG mph	FFWI -	ERC
SMDC1	2005-06-17_12:15	58	36	25	57	50	-
SMDC1	2005-06-17_14:15	58	31	25	48	53	-
SMDC1	2005-06-17_15:15	63	12	21	47	56	-
SMDC1	2005-06-17_16:15	61	13	22	50	58	-
SMDC1	2005-06-17_17:15	64	11	19	50	51	-
SMDC1	2005-06-17_19:15	66	11	19	43	52	-
SMDC1	2005-06-17_20:15	65	17	20	43	51	-
SMDC1	2005-06-17_23:15	63	16	20	41	51	-
SMDC1	2010-06-16_11:16	57	18	21	47	52	-
SMDC1	2010-06-16_18:16	65	11	20	42	54	-

Additional data from Truckee airport was also analyzed (Figure 17). The available period of record is 21 years. During this time, there were 225 observations that exceeded de-energization thresholds. However, most of these were off-season. After constraining these observations to

"summer" months (June, July, August, and September) when ERC may have exceeded 92%, 10 days were identified where one or more observation exceeded de-energization thresholds.

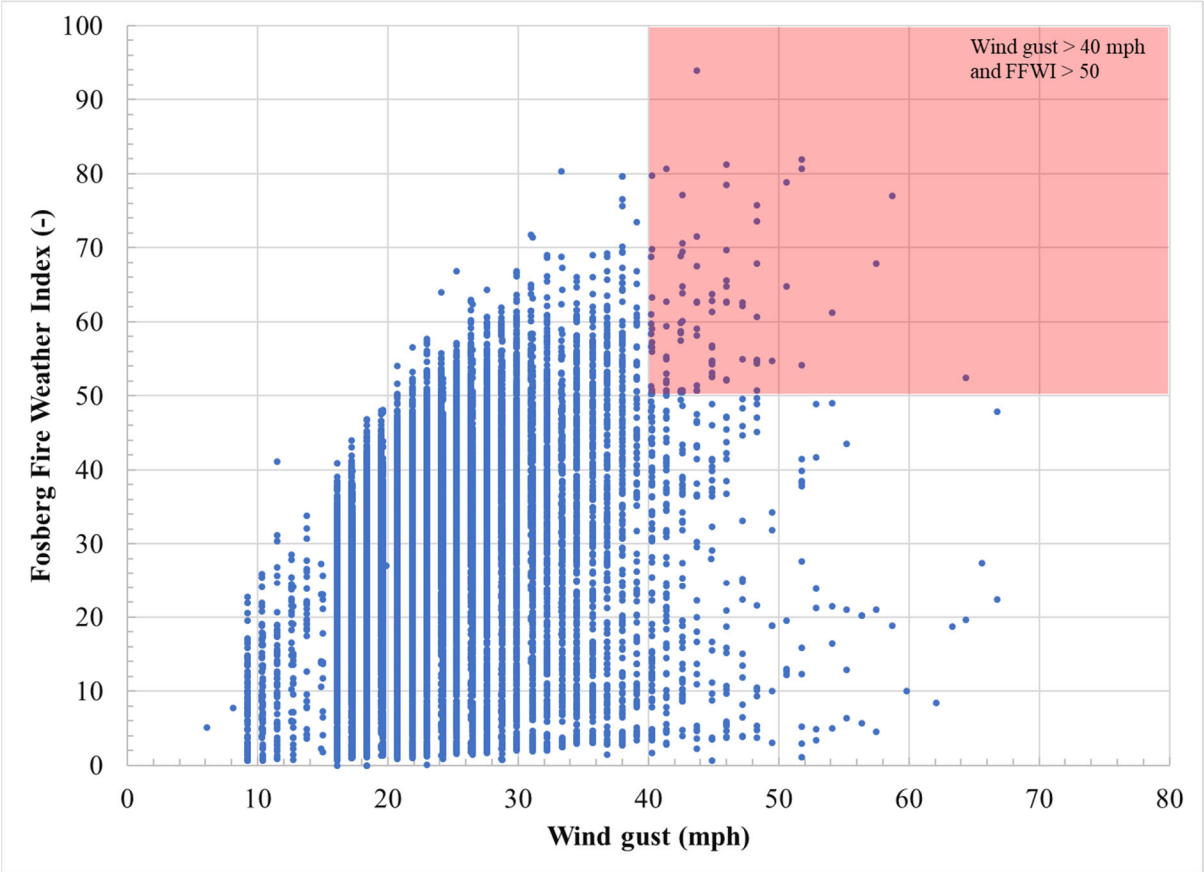


Figure 17. Truckee airport (KTRK) wind gust vs. FFWI (1997 – 2018).

4.1.4 Portola and Sierra Brooks

The Portola and Sierra Brooks PSPS zones are shown in Figure 18. There is one weather station in the surrounding area with a period of record that enables analysis of historical exceedance frequencies.

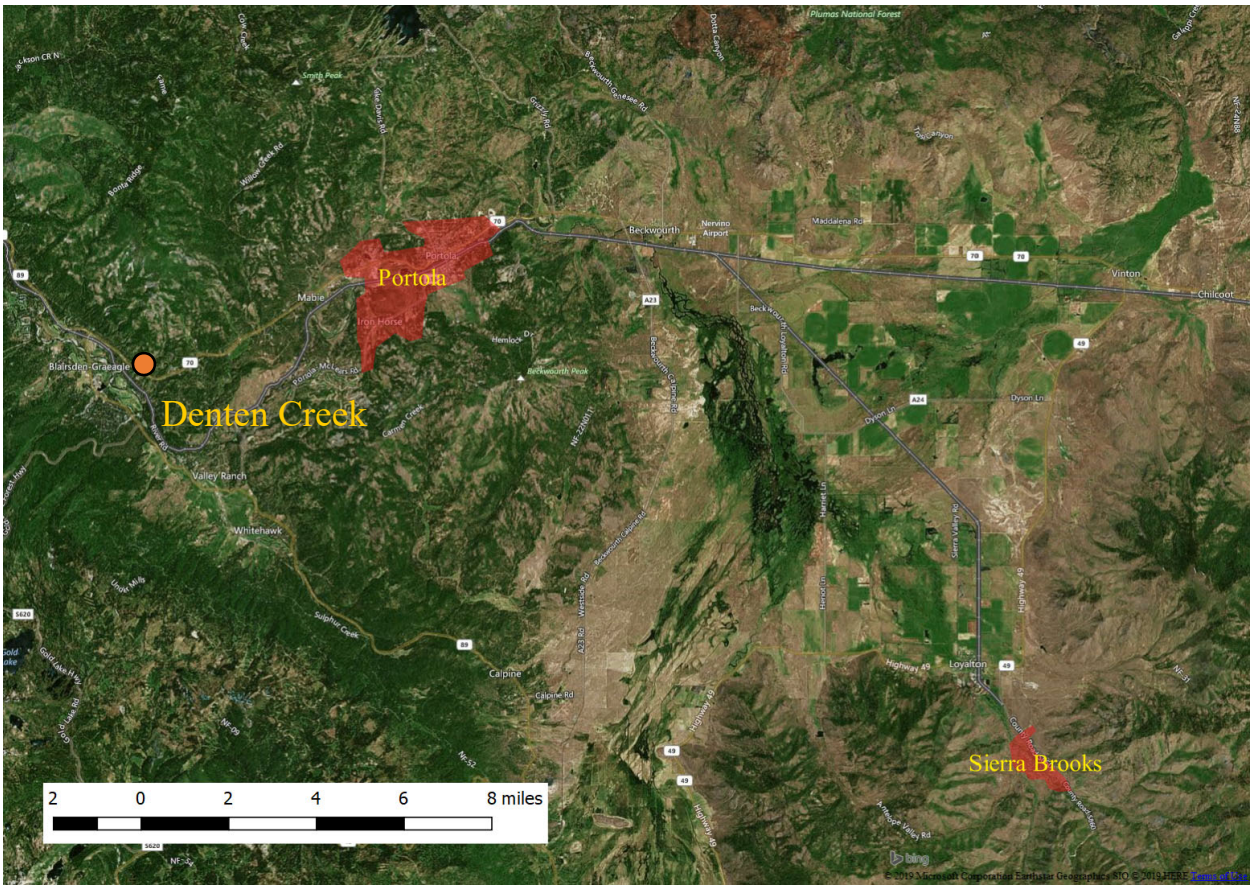


Figure 18. Portola and Sierra Brooks PSPS Zones and location of nearby weather stations.

Four years (2014-2018) of observations from Denten Creek RAWS were processed to analyze seasonal variations in ERC. This ERC analysis was completed using NFDRS Fuel Model G. The result is plotted in Figure 19. The maximum historical ERC exceeded the 92nd percentile threshold intermittently from approximately early July through late September. As with previous station analyses, the 92nd percentile was not exceeded in the average year.

Measured wind gust speed plotted against Fosberg Fire Weather Index for Denten Creek RAWS from 2014 to 2018 is shown in Figure 20. For the available period of record, FFWI and wind gust thresholds have not been exceeded.

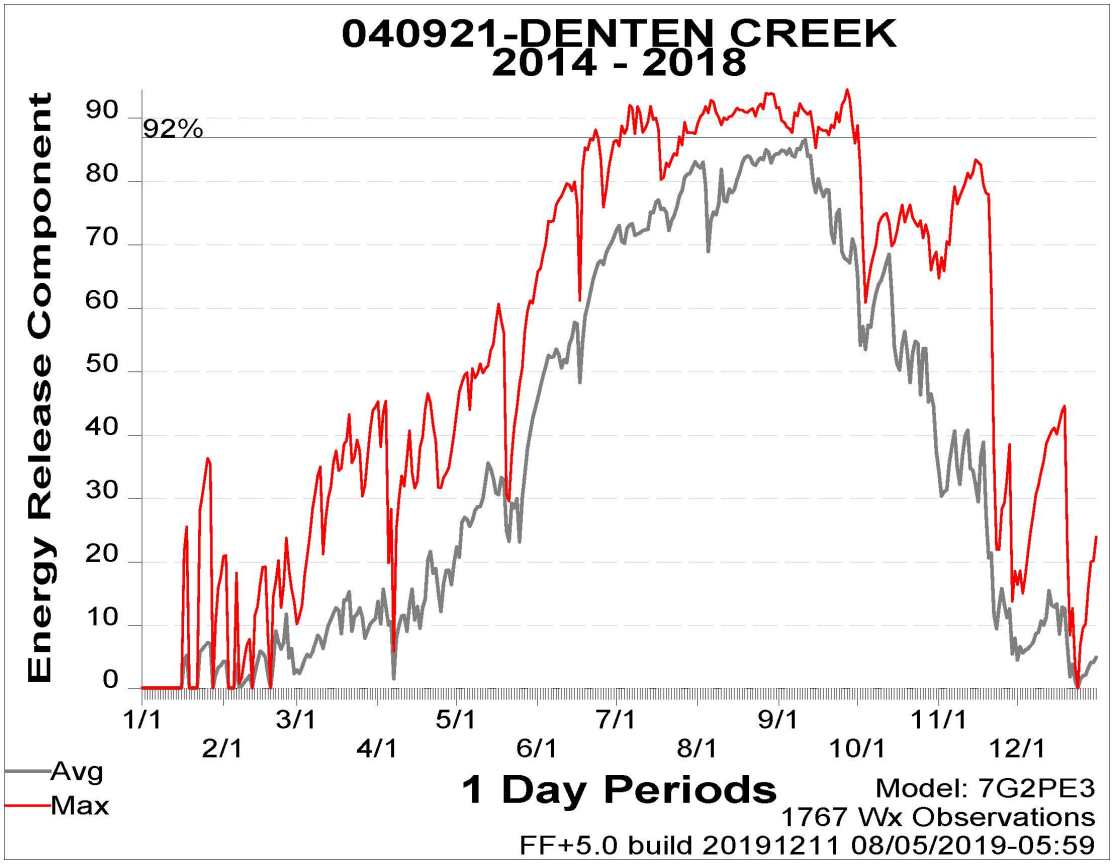


Figure 19. Seasonal variations in ERC (Fuel Model G) from Denten Creek RAWS.

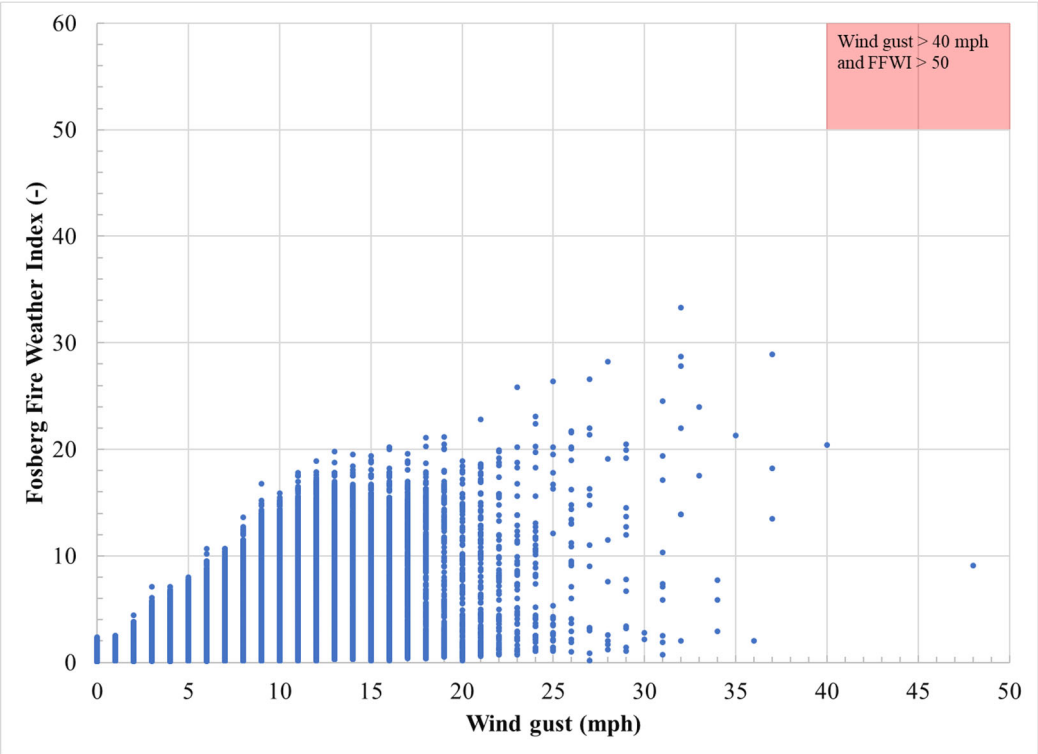


Figure 20. Denten Creek RAWS (MWKC1) wind gust vs. FFWI (2014 – 2018).

4.1.5 Topaz & Markleeville

The Topaz & Markleeville PSPS zones are shown in Figure 20. There are two weather stations, Markleeville and Walker RAWS, with a sufficiently long period of record in this area to analyze historical exceedance frequencies. Liberty Utilities has installed two weather stations in this area (LIB03 and LIB05), but these are relatively new stations with a short period of record.

Seasonal variations in ERC (for fuel model G) at Markleeville RAWS are shown in Figure 22. ERC has exceeded the 92nd percentile from approximately early June through late October. Measured wind gust speed plotted against Fosberg Fire Weather Index is shown in Figure 23. One threshold exceedance occurred in December 2002 when ERC would not have been above 92nd percentile.

Seasonal variations in ERC (for fuel model G) at Walker RAWS from 1975-2018 are shown in and Figure 24. The 92nd percentile ERC threshold has been exceeded from mid-June through mid-October. Figure 25 plots wind gust against Fosberg Fire Weather Index. Data quality from this station is questionable. Approximately 500 hourly records were identified wherein wind gust and FFWI thresholds were exceeded between June and October. Additional analysis is required to understand if these readings are affected by data quality and whether Walker RAWS is representative of conditions in the Topaz PSPS Zone.

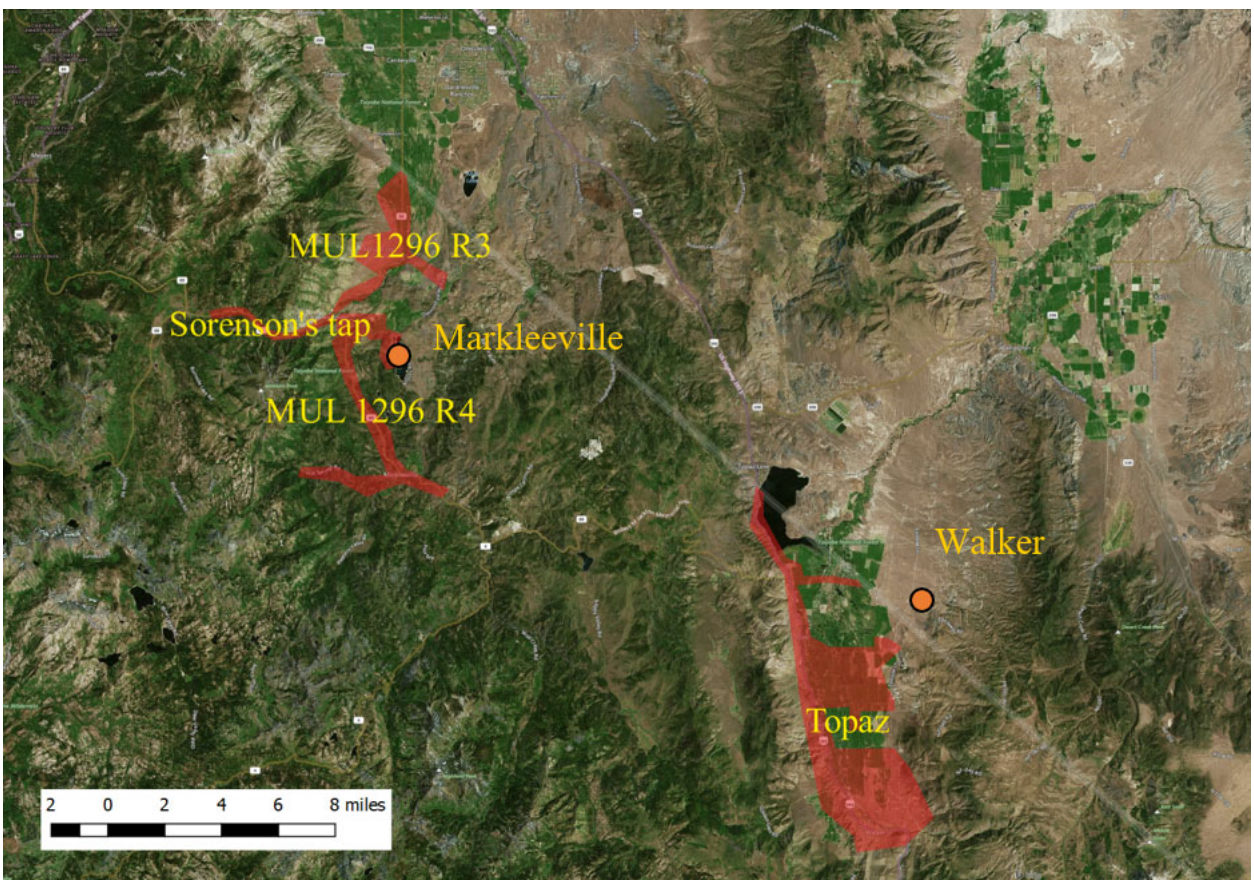


Figure 21. Liberty Utilities' PSPS Zones in Topaz / Markleeville.

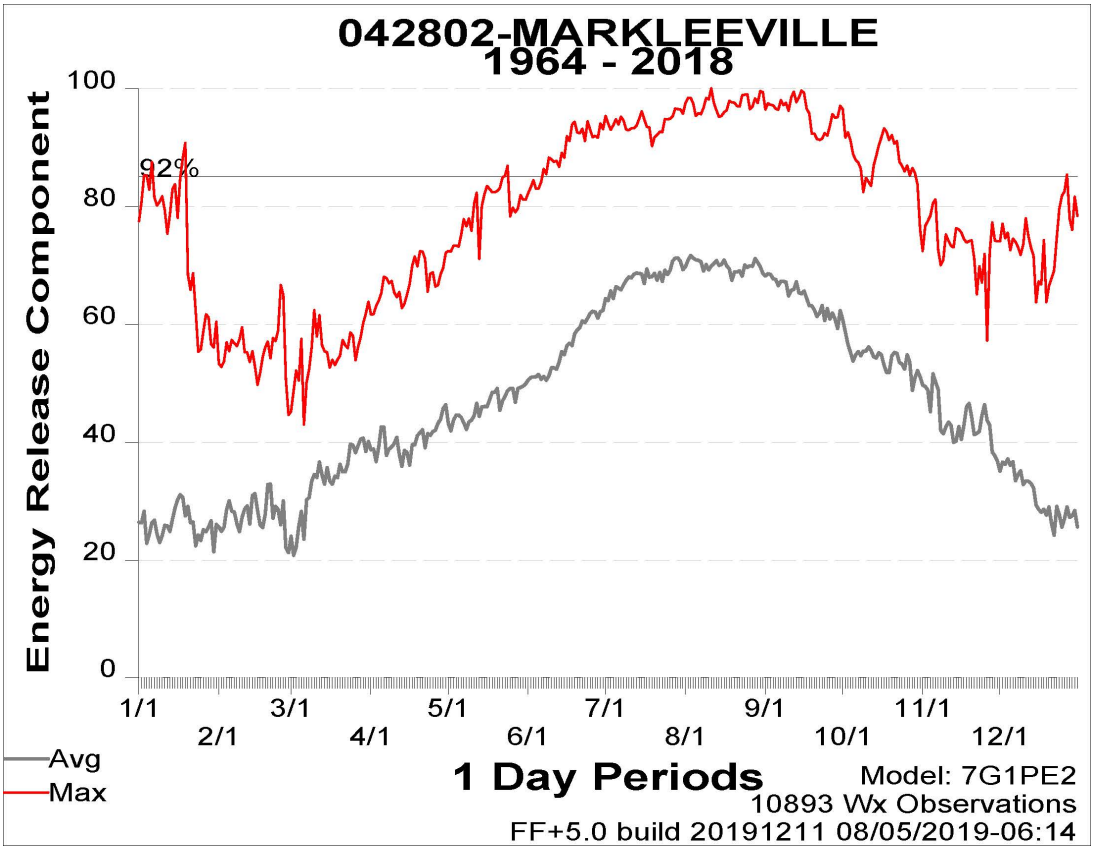


Figure 22. Seasonal Variations in ERC (Fuel Model G) from Markleeville RAWS

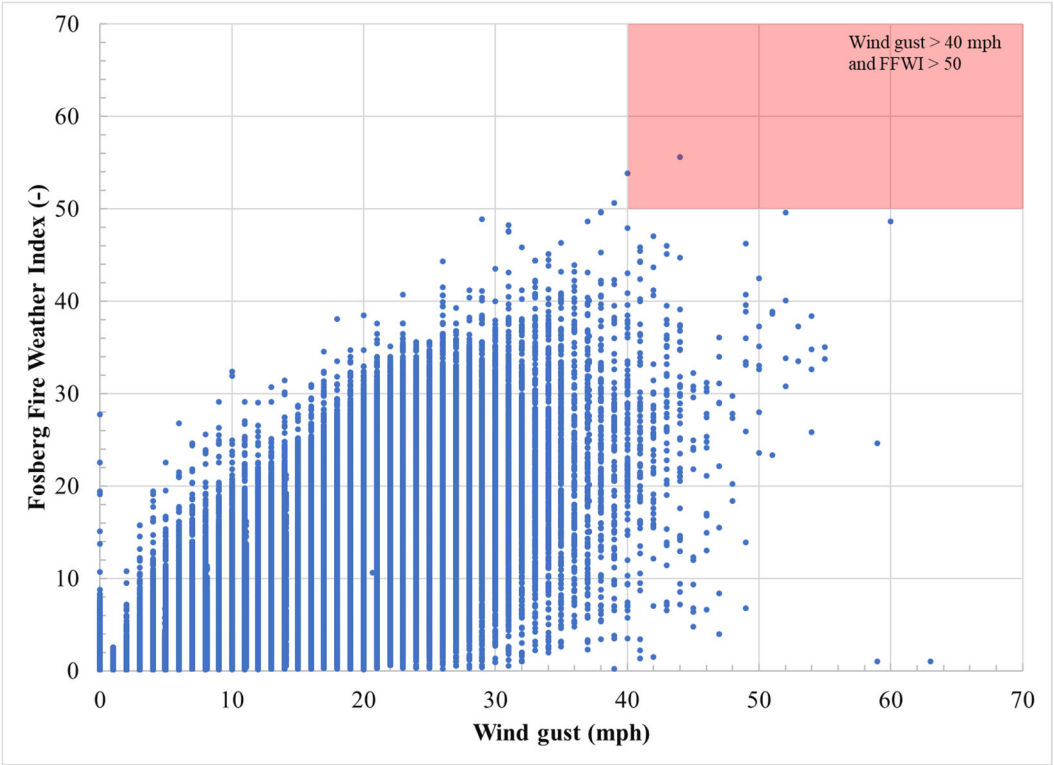


Figure 23. Markleeville RAWS (MKEC1) wind gust vs. FFWI (1999 – 2018).

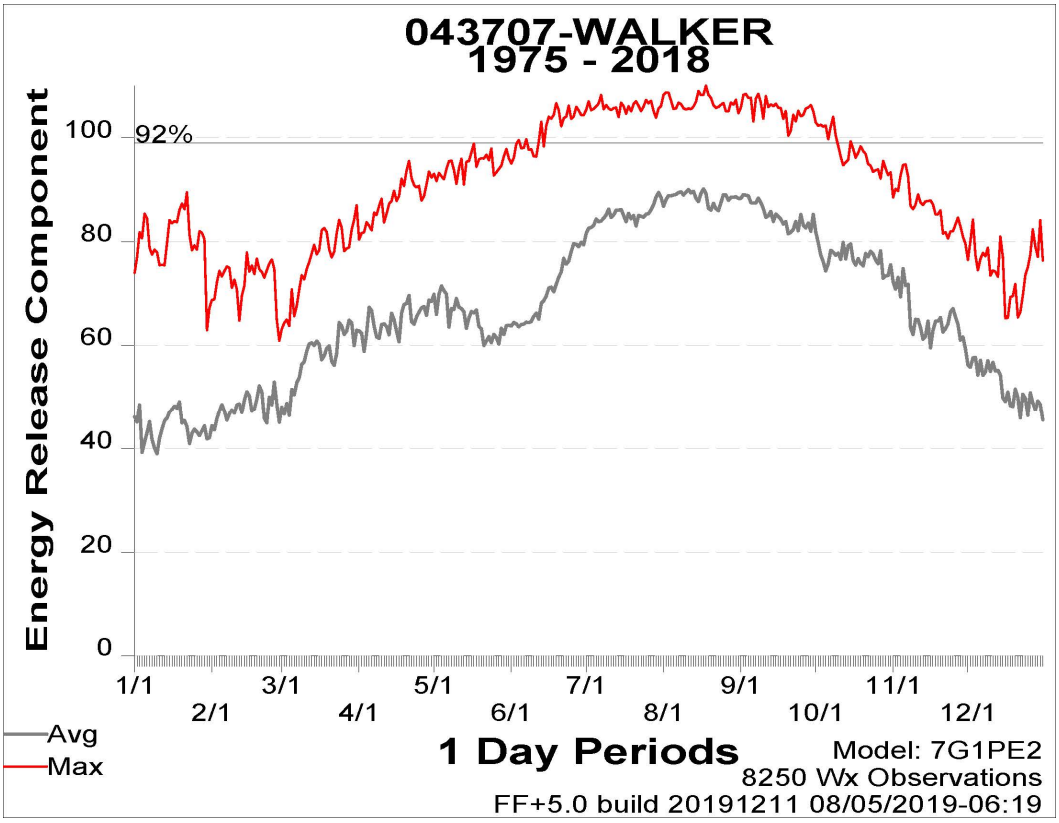


Figure 24. Seasonal variation in ERC (Fuel Model G) from Walker RAWS

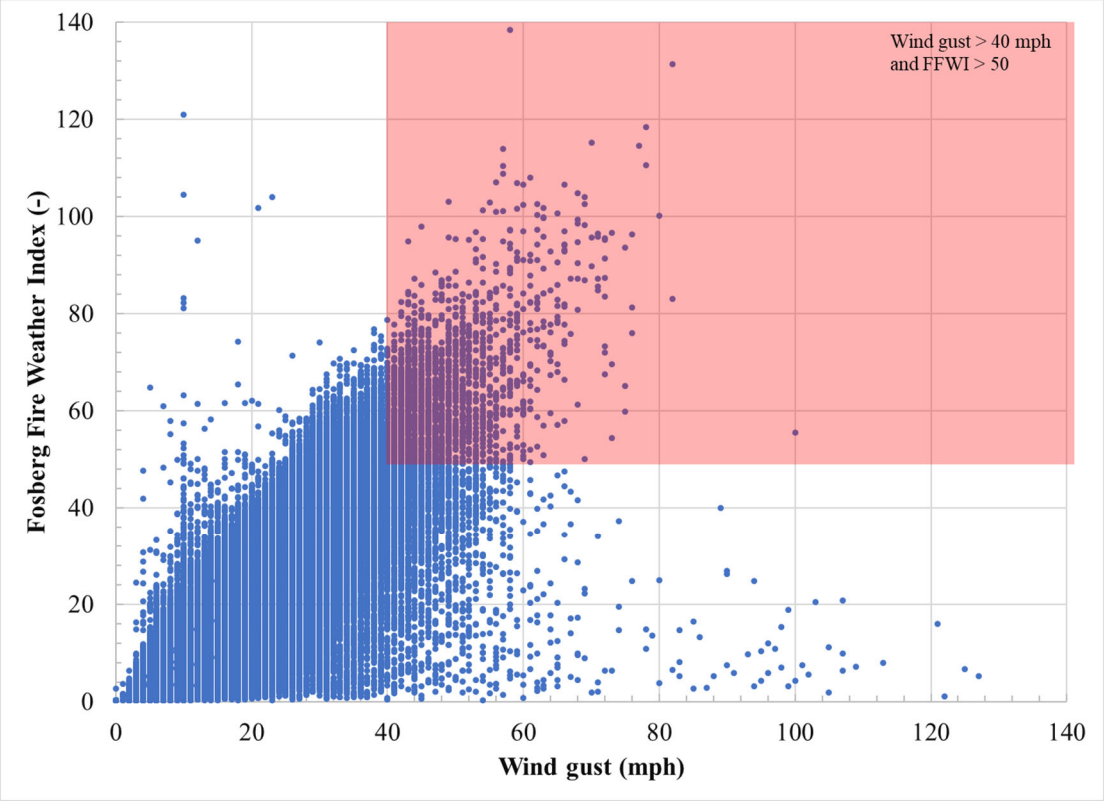


Figure 25. Walker RAWS (WALC1) wind gust vs. FFWI (1999 – 2018).

4.2 Archived weather forecast data

Operationally, times where weather conditions may exceed de-energization thresholds are identified by analyzing wind gust and FFWI forecasts from four different weather forecast models having different spatial/temporal resolutions and forecast durations:

a. 0-36 hours: High Resolution Rapid Refresh (HRRR) weather model. Spatial resolution is 3 km, temporal resolution is 1 hour, and forecast duration is 36 hours.
b. 37-60 hours: North American Mesoscale Model (NAM) high resolution CONUS nest. Spatial resolution is 3 km and temporal resolution is 1 hour.
c. 61-84 hours: After 60 hours, the NAM's spatial resolution decreases to 12 km. Temporal resolution is 3 hours.
d. 87-192 hours: After 84 hours, data from the Global Forecast System (GFS) is used. Spatial resolution is 0.25° (approximately 27 km), temporal resolution is 3 hours.

De-energization decisions would be made based on the "closest in" forecast (HRRR, which provides almost 34 hours of lead time). However, experience has shown that HRRR tends to over-estimate wind speed and FFWI in some of Liberty Utilities' PSPS zones when compared to weather station observations. A typical example is shown in Figure 26 where the 6/26/19 12z HRRR wind gust forecast is compared to measurements at Knox 2 RAWS in Incline Village. The wind speed forecast for 03:00 UTC on 6/27 was approximately 33 mph whereas the observed wind speed was approximately 50% of the forecast wind speed.

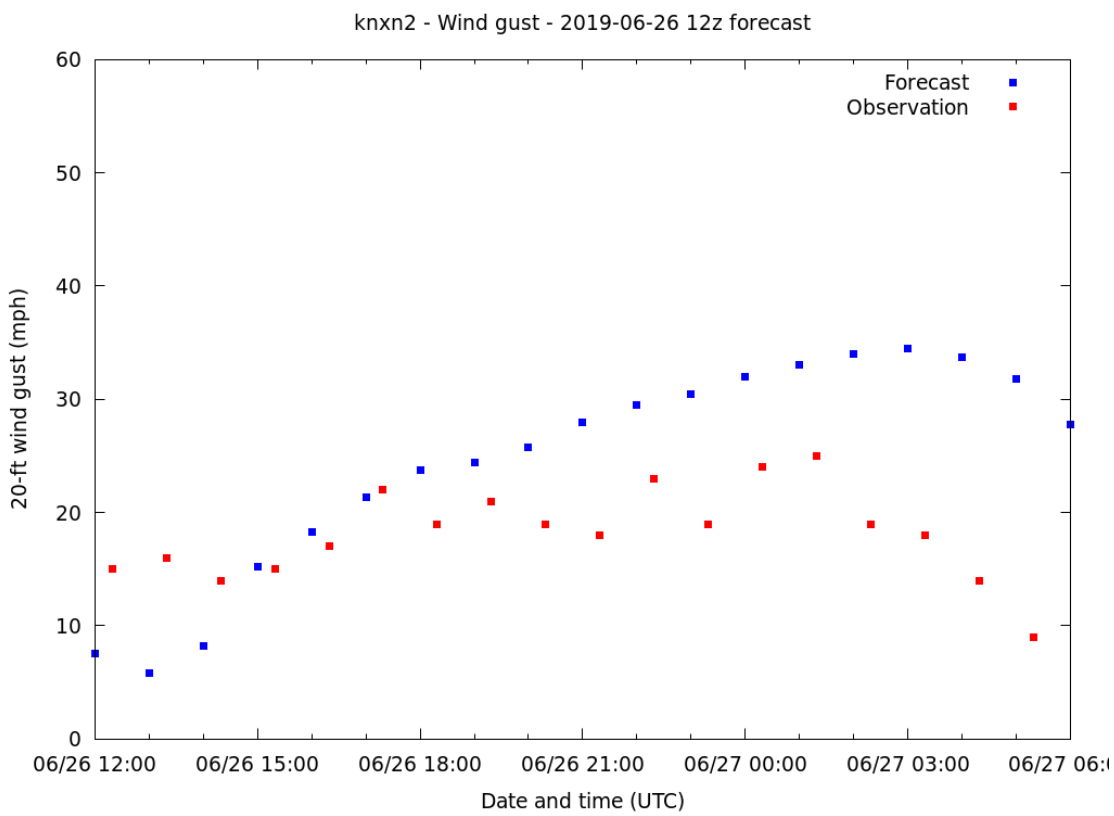


Figure 26. HRRR wind gust forecast compared with observations.

Three years of archived HRRR forecast data were analyzed to determine how frequently de-energization thresholds were forecast to be exceeded. The available period of record is July 15, 2016 through current.

Table 5 shows wind gust and FFWI thresholds by PSPS zone as well as the average number of hours per year that these screening criteria were forecast to be exceeded in the 3 years of available HRRR forecast data. These exceedance frequencies were tabulated for 80%, 90%, and 100% of the de-energization thresholds. De-energization thresholds are the same in all PSPS zones, except "Topaz" and "Mul 1296 r4", which have been assigned de-energization thresholds higher than the baseline values established earlier due to consistently higher wind speeds in these areas.

Table 5. Average number of de-energization threshold exceedances per year (independent of ERC) based on analysis of ~3 years of archived HRRR data.

PSPS zone	FFWI threshold (-)	Wind gust threshold (mph)	80%	90%	100%
111_line	50	40	2.4	0.0	0.0
132_line	50	40	0.0	0.0	0.0
609_and_underbuild	50	40	0.0	0.0	0.0
625_line	50	40	0.0	0.0	0.0
629_line	50	40	0.0	0.0	0.0
640_tier_2	50	40	0.0	0.0	0.0
650_line	50	40	0.0	0.0	0.0
alpine_backside	50	40	0.0	0.0	0.0
alpine_meadows_and_629	50	40	0.0	0.0	0.0
angora_ridge_and_lily_lake	50	40	0.0	0.0	0.0
beacon_tap	50	40	0.0	0.0	0.0
bky_5100_to_nve	50	40	0.0	0.0	0.0
bky_5200	50	40	0.0	0.0	0.0
canterbury_and_commonwealth	50	40	0.0	0.0	0.0
cathedral_spring_creek_emerald_bay	50	40	0.0	0.0	0.0
fir_crags	50	40	0.0	0.0	0.0
glenshire_and_608	50	40	0.0	0.0	0.0
heavenly_lateral	50	40	0.0	0.0	0.0
hobart	50	40	0.0	0.0	0.0
mey_3400_angora_creek	50	40	0.0	0.0	0.0
mey3300_r1	50	40	0.0	0.0	0.0
mey3300_r3	50	40	0.0	0.0	0.0
mul_1296_r4	50	40	1.5	0.0	0.0
mul1296_r3	60	45	1.2	0.0	0.0
old_country_road	50	40	0.0	0.0	0.0
portola	50	40	0.0	0.0	0.0
russel_valley	50	40	0.0	0.0	0.0
sagehen_tap	50	40	0.0	0.0	0.0
sierra_brooks	50	40	0.0	0.0	0.0
sorensons_tap	50	40	0.0	0.0	0.0
squaw_valley	50	40	0.0	0.0	0.0
stampede	50	40	0.0	0.0	0.0
sunnyside	50	40	0.0	0.0	0.0
tah_52-68	50	40	0.0	0.0	0.0
tah_73-17	50	40	0.0	0.0	0.0
tah_73-36	50	40	0.0	0.0	0.0
tah_73-45	50	40	0.0	0.0	0.0
tah_73-60	50	40	0.0	0.0	0.0
tah_73-74	50	40	0.0	0.0	0.0
tah_7300_r1	50	40	0.0	0.0	0.0
tahoe_park_heights	50	40	0.0	0.0	0.0
the_grid	50	40	0.0	0.0	0.0
tier_3	50	40	0.0	0.0	0.0
topaz	60	45	2.1	0.9	0.0
ward_canyon_east	50	40	0.0	0.0	0.0
ward_canyon_west	50	40	0.0	0.0	0.0

5.0 Fire Weather Conditions associated with Fires of Historical Significance

As a check on the proposed de-energization thresholds, we have analyzed ERC and fire weather conditions associated with fires having historical significance (due to structure losses, near misses, or large fire acreage) in and around Liberty Utilities' PSPS zones.

5.1 Fires of historical significance

Five fires in the Greater Lake Tahoe region were identified as being of interest, with their locations relative to Liberty Utilities PSPS Zones shown in Figure 27:

1.) 1960 Donner Ridge Fire (43,000 acres, burned through parts of what is now Truckee's Tahoe Donner neighborhood)
2.) 2001 Martis Fire (consumed over 10,000 acres in one day)
3.) 2002 Gondola Fire (started at Heavenly Ski Area and was a "near hit" for structures along Kingsbury Grade)
4.) 2007 Angora Fire (Destroyed over 250 structures near South Lake Tahoe)
5.) 2016 Little Valley Fire (Escaped prescribed burn that destroyed 23 homes East of Lake Tahoe)

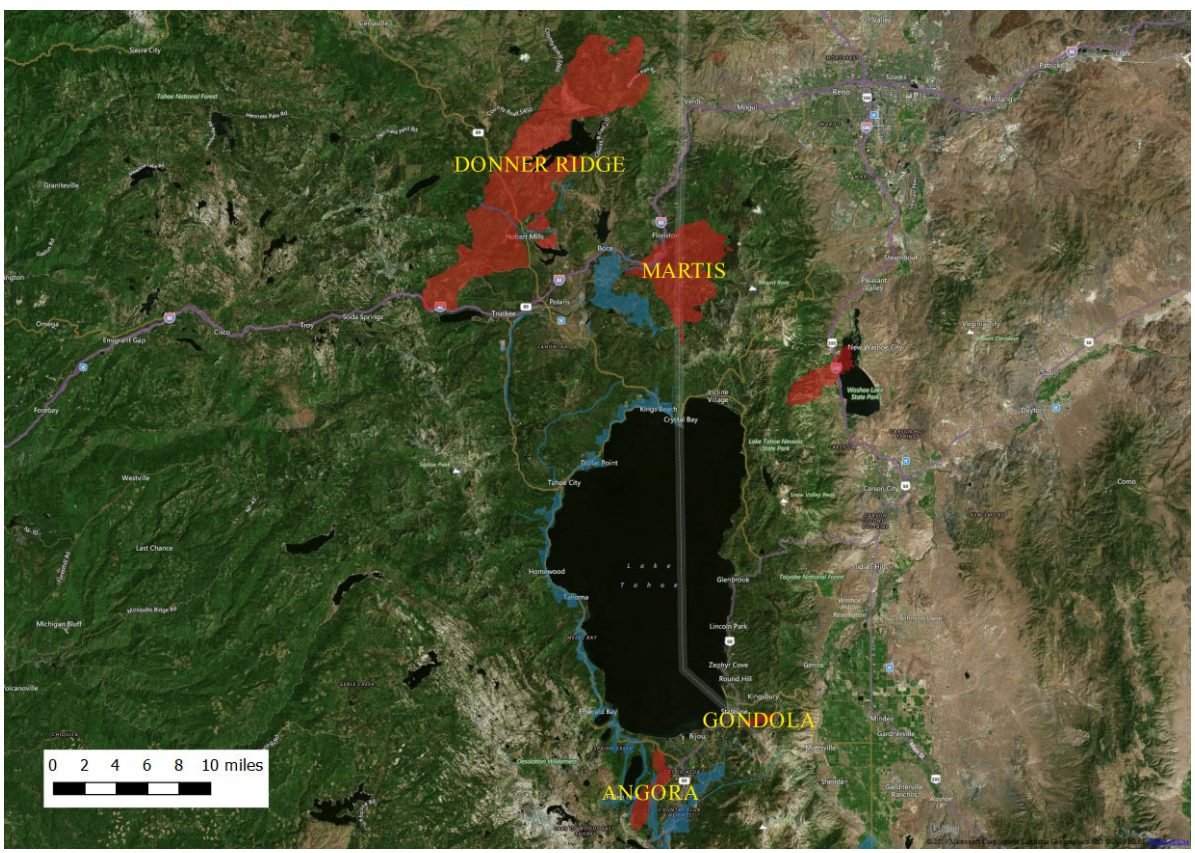


Figure 27. Greater Lake Tahoe region fires of historical significance.

5.2 Fire weather conditions

5.2.1 1960 Donner Ridge Fire

The Donner Ridge Fire began on August 25th, 1960. Although no weather station observations are available from conventional sources, it has been reported that winds were in the 60-70 mph range [13], which would have simultaneously exceeded wind gust and FFWI de-energization thresholds.

5.2.2 2001 Martis Fire

The Martis Fire was ignited on June 16, 2001. It consumed over 10,000 acres in its first seven hours and ultimately destroyed a cabin, a mobile home, and 3 vehicles [14]. Conditions at lower elevations were such that the initial rate of spread was rapid, but fuel moistures at higher elevations reduced spread rates. No representative weather station observations are available due to missing or bad data from surrounding stations. Without representative meteorological observations it is inconclusive as to whether de-energization thresholds were exceeded but they most likely were not.

5.2.3 2002 Gondola Fire

The Gondola Fire was ignited around 12:30 PM on July 3, 2002 near the gondola at Heavenly Ski Resort. It ultimately consumed approximately 700 acres and threatened over 500 structures although no structures were destroyed. The fire initially grew relatively slowly, reaching 25 acres several hours after ignition. Observations from the nearby Cave Rock station (Table 6) show relatively mild fire weather conditions. Peak wind gust was 13 mph with FFWI of 8. This is not close to exceeding de-energization thresholds.

Table 6. Weather observations at Cave Rock on the afternoon of the Gondola Fire.

Date PDT	T F	RH %	WS mph	WG mph	FFWI -
2002-07-03_12:00	69.2	47	1.6	4.5	3.4
2002-07-03_12:15	70.4	24	1.8	3.8	4.8
2002-07-03_12:30	68.6	46	2.2	4.7	4.3
2002-07-03_12:45	68.6	47	1.6	3.8	3.4
2002-07-03_13:00	70.2	46	1.8	3.8	3.7
2002-07-03_13:15	68.8	48	2	4	3.9
2002-07-03_13:30	70.2	39	2.5	4.7	5.3
2002-07-03_13:45	71	32	2	3.6	4.8
2002-07-03_14:00	72.4	30	3.1	7.6	7.1
2002-07-03_14:15	73.3	28	3.6	9.6	8.4
2002-07-03_14:30	73.8	32	3.4	12.5	7.6
2002-07-03_14:45	74	36	2.7	7.2	5.9
2002-07-03_15:00	73.8	33	3.1	7.8	6.9
2002-07-03_15:15	73.8	35	2.7	7.6	6.0
2002-07-03_16:00	73.8	35	2.2	5.6	5.0
2002-07-03_16:15	74.7	32	2.7	5.1	6.2
2002-07-03_16:30	74.4	34	3.6	13	7.8
2002-07-03_17:00	75.1	35	3.4	10.1	7.3
2002-07-03_17:30	75.3	34	2.9	5.8	6.4
2002-07-03_17:45	74.5	38	3.1	11.4	6.5
2002-07-03_18:00	74	33	4.5	12.3	9.8
2002-07-03_18:15	74	31	3.6	8.3	8.1
2002-07-03_18:30	74	32	3.6	10.7	8.0

5.2.4 2007 Angora Fire

The 2007 Angora Fire destroyed over 250 structures near South Lake Tahoe. It was ignited at approximately 2 PM on June 24, 2007. Steady winds of 20-30 mph gusting to 50 mph were reported, but observations at local weather stations showed lower wind speeds.

Table 7 shows observations from the US-50 Kahle Drive station on the afternoon of the first day of the Angora Fire (when most structures were destroyed). The highest wind gust was approximately 29 mph which occurred when FFWI was approximately 26. Although measured wind gusts approached de-energization thresholds, FFWI did not. Given reports of steady winds up to 30 mph with gusts to 50 mph, if a denser network of weather stations was available at the time of the fire, it is likely that weather conditions at more representative stations closer to the fire exceeded de-energization thresholds.

Table 7. Observations at US-50 Kahle Dr. on the first day of the Angora Fire.

Date PDT	T F	RH %	WS mph	WG mph	FFWI -
2007-06-24_13:00	66.9	14	8.3	21	21.9
2007-06-24_13:15	67.5	13	9	19.7	24
2007-06-24_13:30	68.7	13	7.4	22.8	19.8
2007-06-24_14:00	67.6	14	9.8	28.9	25.9
2007-06-24_14:30	69.1	13	9	23.7	24.1
2007-06-24_14:45	68.5	14	9.4	20.6	24.8
2007-06-24_15:45	65.7	14	9.8	25.3	25.8
2007-06-24_16:15	64.6	18	9	24.4	22.6
2007-06-24_17:15	63.7	21	7.8	18.3	19
2007-06-24_17:30	63	25	6.9	19.5	16.1
2007-06-24_18:00	63	23	9.4	23.7	22.3
2007-06-24_19:00	62.1	28	4.7	11.9	10.7
2007-06-24_19:30	61	30	4.5	11	10
2007-06-24_20:00	59.5	31	5.1	11.9	11.1
2007-06-24_21:15	54.5	40	2.7	6	5.5
2007-06-24_21:30	53.2	42	2.2	7.8	4.5
2007-06-24_21:45	53.2	43	2	8.7	4.1
2007-06-24_22:00	51.6	45	1.6	4.7	3.4
2007-06-24_22:15	51.3	45	1.3	3.6	2.9
2007-06-24_22:30	48.7	49	1.8	3.8	3.5
2007-06-24_23:00	47.7	51	1.3	3.8	2.6

5.2.5 2016 Little Valley Fire

The October 2016 Little Valley Fire was a holdover fire from an earlier prescribed burn. It rekindled and escaped on October 14, 2016 at approximately 12:30 am, ultimately destroying 23 homes East of Lake Tahoe. Little Valley RAWS (see Table 8) reported a wind gust of 87 mph at 12:38 AM on October 14, 2016, although the veracity of this observation is questionable. Several wind gust readings that morning exceeded 50 mph. However, FFWI remained below 45 because temperatures were low (52 °F), relative humidities were moderate (30% - 50%), and sustained wind speeds did not exceed 20 mph.

In summary, observations at Little Valley RAWS showed wind gusts well in excess of de-energization thresholds. However, peak FFWI reached approximately 87% of the de-energization threshold due to low temperatures, relatively high humidities, and moderate sustained wind speeds. If a denser network of weather stations was available at the time of the fire, it is likely that weather conditions at more representative stations closer to the fire exceeded de-energization thresholds.

Table 8. Observations at Little Valley RAWS data on first day of the Little Valley Fire.

Date PDT	T F	RH %	WS mph	WG mph	FFWI -
2016-10-13_14:38	62	25	12	31	27.7
2016-10-13_15:38	57	26	16	45	36.2
2016-10-13_16:38	57	31	16	39	34.1
2016-10-13_17:38	55	37	16	36	31.7
2016-10-13_18:38	53	39	16	35	30.8
2016-10-13_19:38	52	42	15	30	27.8
2016-10-13_20:38	51	38	14	33	27.3
2016-10-13_21:38	52	32	15	45	31.4
2016-10-13_22:38	52	32	13	44	27.3
2016-10-13_23:38	52	29	20	54	43.4
2016-10-14_00:38	52	32	16	87	33.5
2016-10-14_01:38	52	35	19	56	38.4
2016-10-14_02:38	51	38	15	55	29.2
2016-10-14_03:38	51	42	13	48	24.1
2016-10-14_04:38	51	44	9	39	16.3
2016-10-14_05:38	50	49	12	37	20.4
2016-10-14_06:38	49	53	9	35	14.3
2016-10-14_07:38	47	60	18	47	26.4
2016-10-14_08:38	49	55	16	52	24.9
2016-10-14_09:38	50	57	9	41	13.8
2016-10-14_10:38	46	71	8	33	9.5
2016-10-14_11:38	46	77	7	32	6.9
2016-10-14_12:38	44	84	9	33	6.7
2016-10-14_13:38	43	80	14	38	12.3

6.0 PSPS ZONE-SPECIFIC DE-ENERGIZATION THRESHOLDS AND DECISION TREES

6.1 Topaz and Mul 1296 r3 PSPS Zones

Based on the preceding discussion and analyses, the recommended protocol for de-energization in the Topaz and Mul 1296 r3 PSPS zones involves simultaneously testing whether the following criteria are exceeded:

1. Observed Energy Release Component (ERC) > 92nd percentile
2. Observed wind gust > 45 mph
3. Observed Fosberg Fire Weather Index (FFWI) > 60

This is presented as a decision tree in Figure 28:

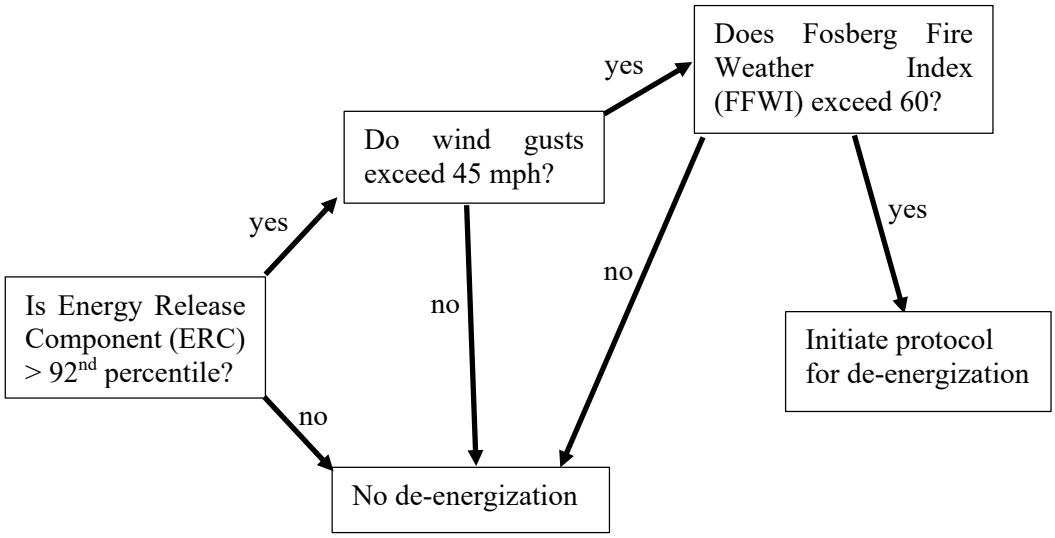


Figure 28. De-energization decision tree for Topaz and Mul 1296 r3 PSPS zones.

6.2 All PSPS zones except Topaz and Mul 1296 r3

Based on the preceding discussion and analyses, the recommended protocol for de-energization in the PSPS zones except Topaz and Mul 1296 r3 PSPS involves simultaneously testing whether the following criteria are exceeded:

1. Observed Energy Release Component (ERC) > 92nd percentile
2. Observed wind gust > 40 mph
3. Observed Fosberg Fire Weather Index (FFWI) > 50

This is presented as a decision tree in Figure 29:

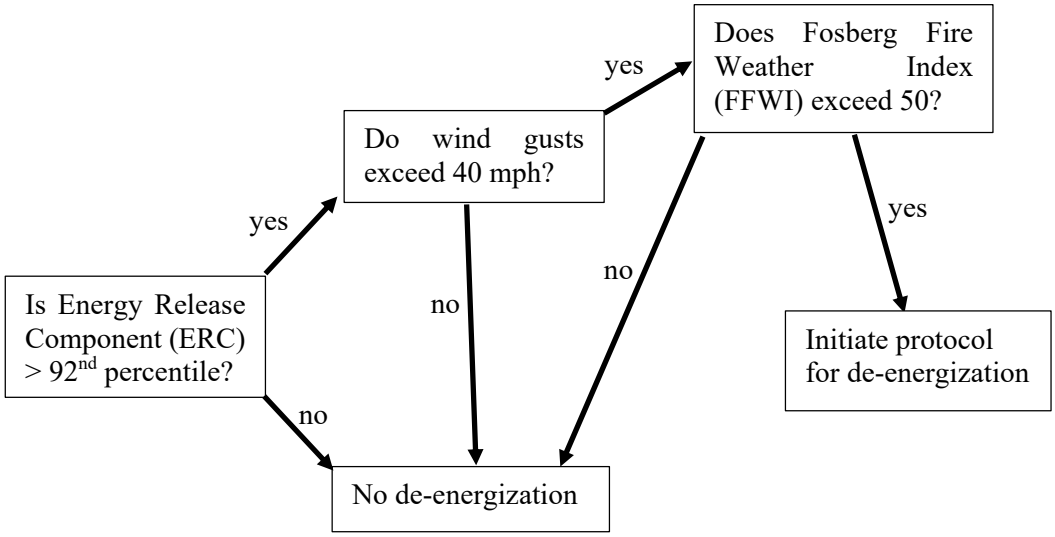


Figure 29. De-energization decision tree for PSPS zones except Topaz and Mul 1296 r3.

7.0 SUMMARY AND CONCLUDING REMARKS

This report recommends de-energization thresholds based primarily on fire weather considerations within PSPS zones that have been designated by others. This inherently assumes that each PSPS Zone presents equal risk from utility-associated fires to structures, people, and improved property. Factors such as Firewise practices (defensible space, construction techniques, etc.), ingress/egress, first responder response time and capabilities, wind direction relative to assets at risk, *etc*. were not considered here when establishing these de-energization thresholds. Empirically, vegetation failures are more likely to occur under countervailing winds (meaning winds from a direction dissimilar to the predominant wind decision).

Operationally, the forecast-based screening criteria described in Section 4.1.1 are used to screen for times in the future at which weather conditions may exceed de-energization thresholds. The weather analytics system used by Liberty Utilities provides notification when conditions are forecast to exceed 80%, 90%, and 100% of the screening criteria in each PSPS zone. If ERC exceeds 92nd percentile and these forecast-based screening criteria are forecast to be exceeded, then weather station observations are monitored in real time to assess whether forecasted conditions materialize and observed fire weather conditions are trending toward de-energization thresholds. The decision to de-energize is ultimately made manually upon consideration of weather station observations and data from field observers.

8.0 REFERENCES

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[2] Mitchell, J.W., "Power Lines and Catastrophic Wildland Fire in Southern California," Fire and Materials 2009.

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[5] Riley, K.L., Abatzoglou, J.T., Grenfell, I.C., Klene, A.E., and Heinsch, F.A., "The relationship of large fire occurrence with drought and fire danger indices in the western USA, 1984–2008: the role of temporal scale," *International Journal of Wildland Fire* **22**: 894–909 (2013).

[6] https://www.wfas.net/images/firedanger/fdr_obs.txt

[7] https://www.wfas.net/images/firedanger/fdr_fcst.txt

[8] https://wfas.net

[9] Durst, C.S., "Wind Speed Over Short Periods of Time," *Meteorological Magazine* **89**: 181-187 (1960).

[10] Fosberg, M.A, "Weather in Wildland Fire Management: The Fire Weather Index," *Conference on Sierra Nevada Meteorology*, American Meteorological Society, pp 1-4 (1978).

[11] Taylor, S.J., Bright, R., Carbin, G., Bothwell, P., and Naden, R., "Using short range ensemble model data in national fire weather outlooks," *Fifth Symposium on Fire and Forest Meteorology* (2003).

[12] https://gacc.nifc.gov/gbcc/predictive/docs/WGBEOY/EOY13.pdf

[13] https://www.tahoedailytribune.com/news/50-years-later-truckees-biggest-fire/

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APPENDIX A – FUEL MOISTURE SAMPLING PLAN

Field sampling of wildland fuels will be conducted in specific areas to quantify current fuel moisture conditions. These data provide insight into potential fire behavior and facilitate calculation of National Fire Danger Rating System (NFDRS) indices – specifically Energy Release Component (ERC) – based on actual field observations. This sampling also elucidates whether automated ERC values calculated from weather station observations and disseminated via the Wildland Fire Assessment System (WFAS) comport with field conditions.

Personnel

During the 2019 "fire season," field sampling will be conducted by Reax Engineering (Chris Lautenberger, Delaney Seeburger, J. Ronnie Thomas) and Spatial Informatics Group (Shane Romsos, Gary Roller, and Jarrett Barbuto).

Timeline and sampling frequency

Fuel moistures are commonly sampled bi-weekly. Therefore, a sampling interval of approximately 10 – 14 days will be implemented. This interval will be reassessed after initial measurements are obtained. Sampling will also be conducted after significant rain events.

Fuels to be sampled

ERC for fuel model G is extremely sensitive to 1000-hour fuel moisture so 1000-hour fuels will be sampled. Although ERC(G) is insensitive to live fuel moistures (due to lower live fuel loadings) live fuels will be sampled at each site because this provides additional insight into potential fire behavior. In Greater Lake Tahoe, Greenleaf Manzanita and Snowbrush Ceanothus will be targeted with Sagebrush at sites that do not have Manzanita or Snowbrush.

Sampling locations

Fuel moisture samples will be collected from the following locations in Greater Lake Tahoe (See Figure A-1):

1. Alder Creek (NV Energy Truckee PDZ)
2. Knox 2 RAWS (NV Energy Incline PDZ)
3. Spooner Summit (NV Energy Glenbrook PDZ)
4. Kingsbury / Tahoe Rim Trail North (NV Energy Roundhill PDZ)
5. Meyers / Baron RAWS (Liberty Utilities south shore PSPS zones)
6. Ward Creek (Liberty Utilities west & north shore PSPS zones)
7. Burton Creek State Park (Liberty Utilities west & north shore PSPS zones)

Sampling protocol

To the extent possible, sampling will follow recommendations in the US Forest Service fuel moisture collection and equipment guide[1].

Drying, reporting, and calculations

Samples will be weighed in the field, dried in a lab oven at 100 °C for 24-hours, and then weighed again to facilitate calculate of moisture content. The resulting moisture content values will then be used to calculate ERC using Fuel Model G. Since this gives values with units of Btu/ft^2, a Fire Family Plus climatology analysis of the nearest NFDRS weather station will be used to convert ERC values in Btu/ft^2 to percentiles.

[1] Zahn, S. and Henson, C., "A Synthesis of Fuel Moisture Collection Methods and Equipment – A Desk Guide," US Department of Agriculture Forest Service, National Technology & Development Program, May 2011.

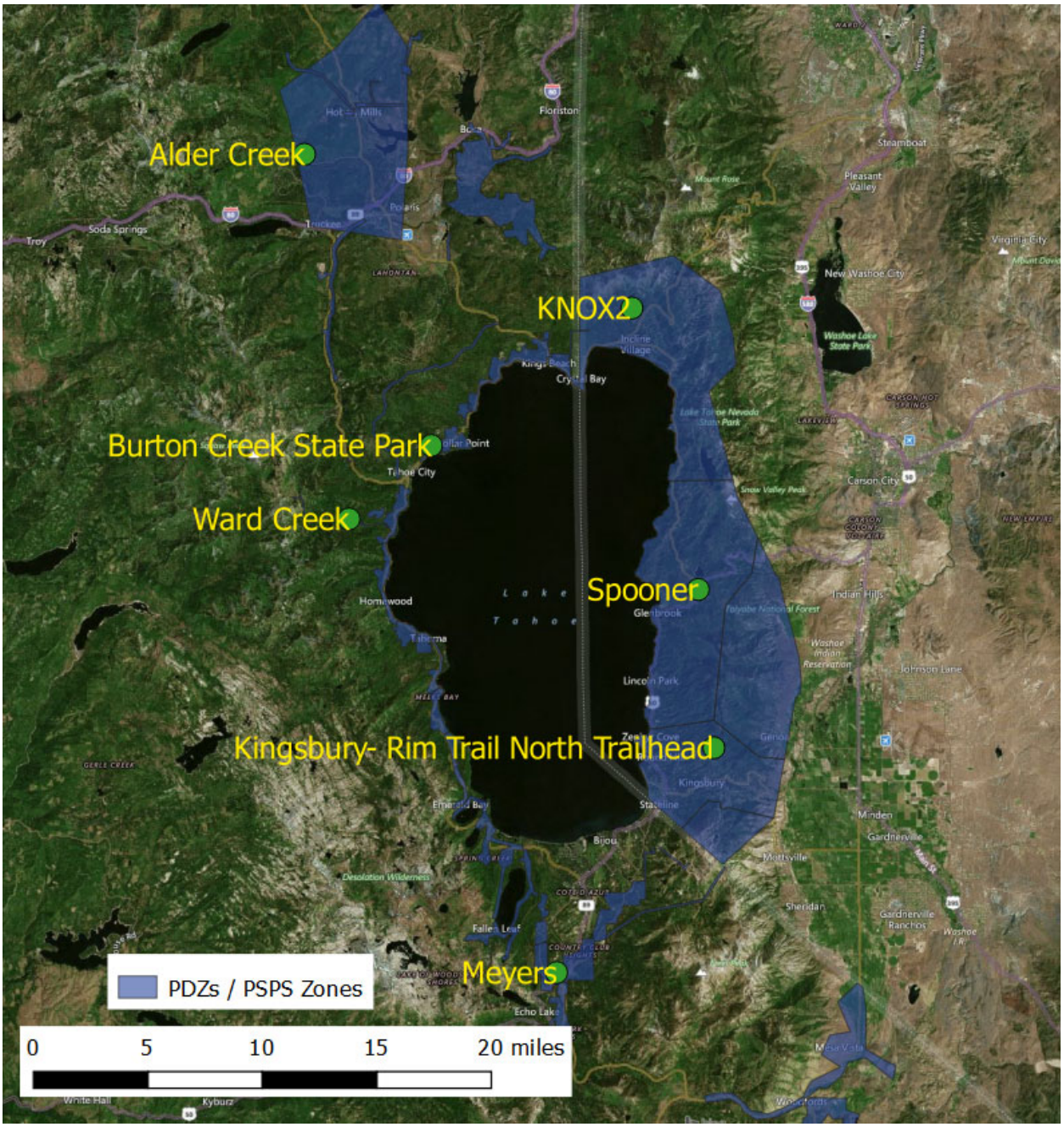

Figure A-1. Fuel moisture sampling locations in Greater Lake Tahoe area.