Risk Models
&
2021 Workplans

November 17, 2020

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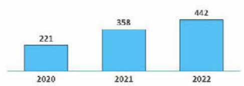
Evolution from units of work completed to risk reduced

2020 Plan

System Hardening

- **Risk Exposure -** Count of circuit miles system hardening in High Fire Threat Districts (HFTD) and High Fire Risk Areas (HFRA). Goal was ~1,021 circuit miles over 3 years; 235 miles hardened YTD in 2020



Enhanced Vegetation Management (EVM)

- **Risk Exposure -** 18Count of EVM miles worked in HFTD and HFRA areas, 1800 miles per year

2021 Plan

System Hardening

- **Risk Exposure –** Count of circuit miles system hardened in the HFTD and HFRA areas
- **Risk Profile** – 80% of system hardening miles have to be high-risk miles; High risk miles include – 1) Top 20 % of the risk buydown curve, 2) Fire rebuild and, 3) PSPS mitigation miles
- **Risk Effectiveness -** Prioritizes higher risk reduction mitigation options (Undergrounding and Line removals)

Enhanced Vegetation Management (EVM)

- **Risk Exposure –** Count of EVM miles worked in the HFTD and HFRA areas
- **Risk Profile** - 80% of EVM miles worked in the top 20% of the HFTD's includes Fire impacted areas
- **Risk Effectiveness –** Execute work consistent with defined EVM scope

Risk Model and Risk Quantification

Wildfire Risk Models calculates risk units in CPUC framework

LoRE

- The likelihood of a risk event (LoRE) is the relative frequency of a specific risk event occurring.
- In the case of **wildfire risk**, this is the relative **likelihood of an ignition occurring**.

CoRE

- The consequence of a risk event (CoRE) is the average impact of the risk should it materialize across key outcomes (Safety, Reliability, Financial).
- In the case of wildfire risk, **consequence contains serious injuries, fatalities , property damage**, and impacts to reliability.

Risk = LoRE X CoRE

- Risk is the product of the likelihood and consequence of a risk event.
- This method produces an expected value of impact across the consequence outcomes, and when combined results in a multi-attribute score that can inform risk-based decision making

Methodology

Ignition Model

Likelihood of Ignition

Ignition likelihood was determined based on 2021 modeling predicting ignitions at the circuit protection zone (CPZ)

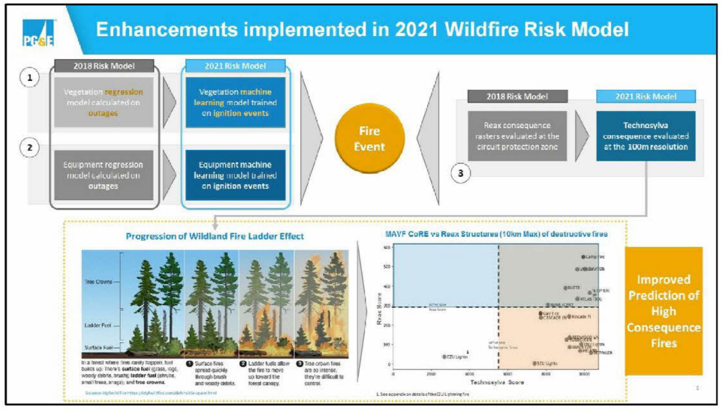
✖

Fire Spread Model

Likelihood of Spread ✖ **Consequence**

Spread likelihood was determined based on a study conducted by PG&E and Technosylva

Consequence considerations focused on the potential impact of a wildfire



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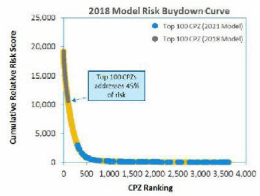
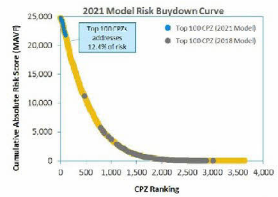
Risk models provide risk buydown curves to guide workplan

The risk buydown curve shows ***the amount of risk that can be addressed*** with every subsequent mile or CPZ that is mitigated. This view shows the relative magnitude of potential projects and can compare impacts of programs with varied effectiveness. The visualization helps to highlight the consolidation of risk by mile as you move down the prioritization list.





System Hardening Risk Buydown curves highlight the significant shift of where the top 100 CPZ's are between the two models

System Hardening

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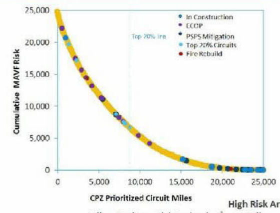
The team proposes a "No Regrets" plan for approaching initial wildfire scope

Included Scope

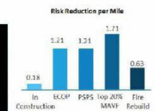
- All projects in the top 20% CPZ
- Any ECOP projects in the top 20% CPZs
- All PSPS Mitigation Projects
- All Fire Rebuild Projects



The "No Regrets" plan is an initial scope of work for the 2021 wildfire season that rests in the highest risk locations for either experienced or predicated fire risk. This scope of work will allow for the system hardening execution teams to remain fully utilized while confirmation of the remaining workplan is underway.

The system hardening team is requesting approval to move forward with this initial scope of work from the wildfire governance team.

	Miles	Projects	Risk Reduction[1]	High Risk Area Miles	Expected Case
In Construction	41.17	27	7.62	5.11	[redacted]
ECOP (In Estimating)	55.94	17	68.03	49.04	
PSPS Mitigation	14.47	12	17.45	14.47	
Top 20% MAVF CPZ	41.32	8	70.58	41.42	
Fire Rebuild	12.7	2	8.12	12.7	Unknown



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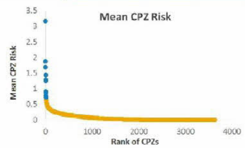
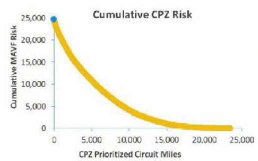
The top 50 miles of CPZs will be targeted for 25 miles of system hardening in 2021





Protection Zone Name	Miles	Cumulative Miles	Mean MAVF Score	Total CPZ Mavf	% total risk reduced (62%)
OREGON TRAIL 1103CUS391	0.02	0.02	3.16	3.16	0.01%
CALPINE 1144276-G	0.01	0.03	1.88	1.88	0.01%
MARIPOSA 210190130	0.08	0.12	1.69	1.69	0.02%
SHEPHERD 2111688294	0.01	0.13	1.44	1.44	0.02%
MIDDLETOWN 1103CB	0.05	0.18	1.30	5.20	0.03%
UPPER LAKE 1101CB	1.00	1.17	1.26	3.77	0.04%
KESWICK 11011586	6.66	7.83	1.25	48.84	0.17%
MIDDLETOWN 1102302610	4.21	12.04	0.92	48.56	0.29%
KONOCTI 1102965078	5.61	17.65	0.88	51.70	0.42%
MARIPOSA 2102241564	0.64	18.29	0.77	10.81	0.44%
BUCKS CREEK 1101CB	4.29	22.58	0.73	9.55	0.47%
DEL MAR 2109378446	0.09	22.67	0.73	2.19	0.47%
MIDDLETOWN 1102CB	0.42	23.08	0.72	8.70	0.49%
MIDDLETOWN 1103830	24.80	47.88	0.72	151.83	0.87%

Key Takeaways

- Mitigating 25 of the 50 riskiest miles within PG&E's service territory would reduce ~0.5% of PG&E's total wildfire risk.
- Some of these segments are relatively small and may be the result of edge effects. However trends in the data, such as the Middletown circuit, highlight areas of high risk were more extensive remediation can occur
- The team recommends creating a strike team to assess the most effective way to address and mitigate the wildfire risk across these circuits and locations to complete these in 2021 as a stretch target

Enhanced Vegetation Management

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The VM Wildfire Risk Model, which forms the basis of EVM risk calculations, has been modified to obtain a tree-weighted risk scoring

VM Wildfire Risk Model

1 Highlights

- Looks at the overall wildfire risk caused by vegetation that exists in each area
- Does not take into account tree count within the vicinity of the grid
- The analysis does not take into account the completed miles that were captured in 2019 to 2020.

2 Data

- Trained on historic ignition data (wildfire season 2015-2018)
- Includes Technosylva simulation outputs into the MAVF consequence data
- While preserving the Technosylva outcomes at the 100m pixel level, MAVF scores are then scaled to the Risk Scores generated in regulatory fillings such as RAMP and WMP.

3 Methodology

- Risk per-pixel is spread across all trees in the VM database within each pixel
- Modelling and EVM work are constrained to pixels within HFTDs
- Pixel-level results are rolled up to higher level CPZ results

VM Wildfire Risk Model with Tree-Weighted Scoring Adjustments

1 Re-Aggregation of Risk

- The 100m x 100m risk pixels are re-aggregated into ~1 km x 1 km grid areas (utilizing the unified grid (PlatMap))
- An entire grid area is assigned to a single CPZ
- All risks in the grid area that are assigned to the same CPZ are aggregated to obtain a risk score for the CPZ

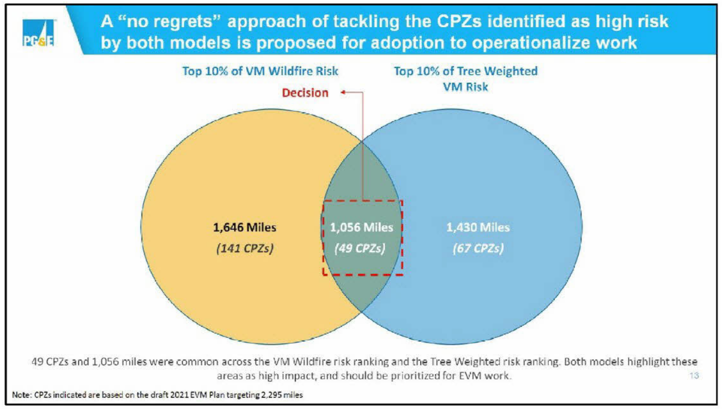
2 Estimation of Existing Tree Work

- LiDAR data spanning 25K miles of HFTD distribution circuits was used to estimate existing tree work
- The estimates were prepared based on inspectors visiting ~5K miles of conductor segments to validate LiDAR information
- On the basis of LIDAR and ground inspection data, regression models were built to predict estimated tree work

3 CPZ Risk Weighting

- The predicted tree work was combined with the number of trees already worked to determine remaining CPZ tree work
- The number of remaining trees were then used to weigh the CPZ risk
- Tree-Weighted Adjusted Grid Risk = Average MAVF core risk x percent of tree work complete x number of trees in the CPZ

Tree Weighted Risk = (VM Wildfire Risk) X (% CPZ Completed) X (Trees in CPZ)


A “no regrets” approach of tackling the CPZs identified as high risk by both models is proposed for adoption to operationalize work
Top 10% of VM Wildfire Risk
Top 10% of Tree Weighted VM Risk
Decision
1,646 Miles
(141 CPZs)
1,056 Miles
(49 CPZs)
1,430 Miles
(67 CPZs)
49 CPZs and 1,056 miles were common across the VM Wildfire risk ranking and the Tree Weighted risk ranking. Both models highlight these areas as high impact, and should be prioritized for EVM work.
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Note: CPZs indicated are based on the draft 2021 EVM Plan targeting 2,295 miles

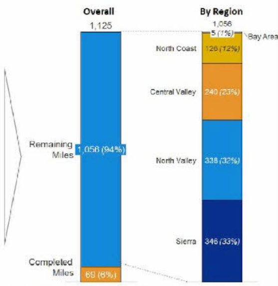
EVM is requesting approval to commence work on ~1,056 'no regret' miles involving a total of 49 Circuit Protection Zones (CPZs)

Circuit Protection Zones with 'No Regret' Remaining Miles

Risk Tier: <=10%

CPZ Name	Completed Miles	Total Remaining Miles	Estimated Remaining Tree work
Higgins 110950072	-	51	1,849
Deschutes 11011580	-	45	2,321
Shingle Springs 210913322	-	40	1,632
Red Bluff 11011334	-	40	506
Auberry 1101R2578	9	40	1,260
Mariposa 210210880	-	39	676
Auberry 1102 Circuit Breaker	1	33	380
Bell 11082202	2	30	886
Cedar Creek 11011664	-	29	2,143
Higgins 1109 Circuit Breaker	-	28	1,217
Remaining 39 CPZs	58	680	29,879
Total	69	1,056	42,749

Remaining Miles (Top 10% of Risk)



While the full EVM 2021 work plan is being discussed, the EVM team seeks an approved scope for work starting in December that includes 1,056 miles prior to the approval of the full 2021 work plan

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High Level Timeline

11/20/2020

- Final Decision on System Hardening Plan (If feasible)
- Initial Review into Inspections 2021 Plan
- Initial Review into Repairs 2021 Plan
- Close out Completed Action Items

12/01/2020

- Final Decision on EVM 2021 Plan (If feasible)
- Decision Items needed for Inspections 2021 Work Plan
- Close out Completed Action Items

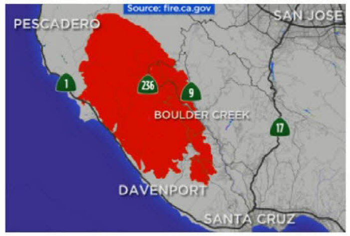
12/08/2020

- Decision needed on Inspection. Initial views of 2021 Work Plan
- Decisions needed on Repairs 2021 Work Plan
- Tier 1 – Overhead Conductor Replacement Discussion

Appendix

CZU Lightning Fire had at least 5 different points of ignition

CZU Lightning Complex Fire Map



Source: CALFIRE

Damage Overview

- 86,509 acres burned
- Active for 37 days
- 1,490 structures destroyed
- 140 structures damaged
- 1 injury
- 1 fatality

Fire Description and Observations

- The wildfires started at 6:41 AM on August 16, 2020 and were the result of a thunderstorm that produced close to **11,000 bolts of lightning** and started **hundreds of fires** throughout California
- The lightning strikes initially **started fires separately** known as the Warnella Fire near Davenport and the Waddell Fire, near Waddell Creek, as **well** as three fires on what would become the northern edge of the CZU Complex fire.
- Two days after the fires began, **a change in wind conditions** caused these three **northern fires to rapidly expand and merge**, growing quickly to over 40,000 acres
- The modeling complexity of this wildfire is such that it would **require taking into account the hundreds of fires** that were started rather than treating this as a single wildfire

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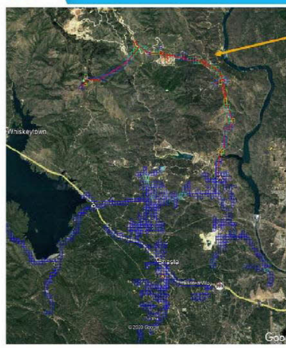
Project Example: Keswick 11011586 Circuit Protection Zone



Keswick 11011586 Circuit Protection Zone

- 6.6 Miles in total, the 100m X 100m squares are the absolute risk values for each section of that protection zone
- The total protection zone absolute risk score is 48.84 risk units (sum of all the 100m squares along the circuit)
- Average risk score of all the squares gives the CPZ mean risk score of 1.25

Keswick (6.6 Miles)	No System Hardening	Overhead Hardening	Under-grounding	50-50 OH / UG
Total CPZ Risk Score After Mitigation	48.84	30.28	48.35	39.32
Total CPZ Residual Risk Value	**48.84**	**18.56**	**0.49**	**9.52**

Overall Miles	6.6	6.6	6.6	6.6
OH System Hardening [redacted]/mile)	$ -	[redacted]		
UG System Hardening [redacted]/mile)	$ -			
Total Capital Cost	$ -			
NPV @ 7% discount rate				
$ NPV per unit of risk (RSE)				

Assumptions:

- Discount Rate: 7%, Cost Escalation / Inflation: 3%
- Benefit Duration: 30 years for OH and 60 for UG
- Routine Veg Tree Count / Mile: 50.76
- PSPS Cost of Reenergizing [redacted]/ mile
- Patrols and Inspections [redacted]/ mile for OH and [redacted]/ mile for UG

The top 50 riskiest miles represent 4.9% of the system risk.

Protection Zone Name	Miles	Cumulative Miles	Mean MAVF Score	Total CPZ Mavf	% total risk reduced (62%)
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Key Takeaways

- Mitigating 25 of the 50 riskiest miles within PG&E's service territory would reduce ~0.5% of PG&E's total wildfire risk.
- Reason it is only 0.5% is because this is across all circuits in HFTD's (~25000 miles)
- On each project a more granular risk spend efficiency calculation can and will be performed on an NPV basis once the project is fully scoped similar to what is shown on the Keswick 11011586 circuit protection zone

2021 Dx Model

In the effort to prioritize circuits, 2021 Dx Model continues advancement of risk model capabilities compared to earlier models

PRIORITIZATION DETAILS

Methodology

- Make ignition predictions at a scale of 100m x 100m "pixels" along the Dx grid
- Rolls-up pixels to Circuit Protection Zones
- For each pixel, assign risk score based upon the product of:

(1) **Likelihood** of ignition
(2) **Effect** of a potential ignition

Scope

- ✓ Tier 3
- ✓ Tier 2

Risk Components

- ✓ **Likelihood**: via ignition prediction (Max Entropy)
- ✓ **Effect**: via :
  (1) Ignition spread (Technolylva)
  (2) Ignition consequence (Technolylva)

RISK EQUATION

Wildfire risk=

LoRe **X** CoRe (Ignition Spread **X** Consequence)

Ignition likelihood:
The likelihood of ignition in 100m x 100m pixels

Ignition spread:
The likelihood of ignition spread in 100m x 100m pixels

Consequence:
The Consequence score is the effect on structures and natural resources in 100m x 100m pixels

2021 Dx Model (EVM Model)
LoRE Ignition likelihood calculation

IGNITION LIKELIHOOD

Wildfire Risk = LoRE * CoRE (Ignition Spread * Consequence)

Scoring methodology

Ignition likelihood (LoRE) was determined based on a probability analysis predicting ignitions in 100m pixels. The model was trained on ignitions limited to fires season evens and CPUC reportable ignitions from 2015 to 2018:

1. **Variables importance ranking**

Variable	Permutation Importance
tree-height-max	26.1
100-hour-fuels-avg	24.1
vapor-pressure-deficit-avg	21.8
gusty-summer-day-pct	6
hftd	4.2
precipitation-avg	3.1
impervious	2.8
specific-humidity-avg	2.4
burn-index-avg	2.3
wind-max	1.9
temperature-avg	1.6
windy-summer-day-pct	1
local-topography	0.8
tree-height-avg	0.8
1000-hour-fuels-avg	0.6
energy-release-avg	0.4

2. **Model Type**

Maximum Entropy: The principle of maximum entropy states that the probability distribution which best represents the current state of knowledge is the one with the largest entropy, in the context of precisely stated prior data

Model Results

Top 10 feeders with the highest predicted count of vegetation caused ignitions:

Feeder name	Predicted count
GARBERVILLE 1103	0.000336
FRUITLAND 1142	0.00033
FRUITLAND 1141	0.000274
GARBERVILLE 1102	0.000265
BEN LOMOND 0401	0.000245
BEN LOMOND 1101	0.00024
GARBERVILLE 1101	0.000216
HOOPA 1101	0.000216
FELTON 0401	0.000215
PARADISE 1106	0.000204

Model Statistics and Performance

- Predicted annual HFTD ignitions (average): **100**
- Observed total HFTD ignitions (2015-2018): 401

Model Performance

- ROC-AUC - 0.737 (in-sample)
- ROC-AUC - 0.716 (out-of-sample)

2021 Dx Model (Conductor Model)
LoRE Ignition likelihood calculation

IGNITION LIKELIHOOD

Wildfire Risk = LoRE * CoRE (Ignition Spread * Consequence)

Scoring methodology

Ignition likelihood (LoRe) is calculated using classification model that identifies the likelihood of at least one ignition per year at a given 100m by 100m pixel location. More specifically, the Conductor Failure models the conditional probability that a reportable ignition will occur within a given pixel location :

1. **Variables importance ranking**

Variable	Permutation Importance
Non burnable area	30.8
Daily precipitation, mean	29.8
Conductor material: ACSR	9.7
Estimated conductor age	8.9
Max tree height	4.3
Reliability Program splice	4.3
Vapor pressure deficit, mean	4.0
Conductor size: 2	3.4
Conductor size: 4	1.6
100-hour fuels, mean	1.1
Max temperature, mean	1.0
Wind speed, mean	0.9
Local topography	0.2
Conductor size: 6	0.1
Conductor material: Al	~0
Conductor material: Cu	~0

Model Results

Top 10 feeders with the highest probability of ignition led by asset failure :

Feeder name	Mean Ignition Probability
CRESTA 1101	.001
PARADISE 1105	0.00098
BIG BASIN 1101	0.000911
APPLE HILL 1104	0.00086
CAMP EVERS 2104	0.00079
PARADISE 1103	0.00072
CURTIS 1705	0.00070
PARADISE 1104	0.00067
CEDAR CREEK 1101	0.00065
PARADISE 1106	0.00064

Model Statistics and Performance

- Predicted annual HFTD ignitions (average): 60
- Observed total HFTD ignitions (2015-2018): 242

Model Performance

- ROC-AUC - 0.76 (in-sample)
- ROC-AUC - 0.74 (out-of-sample)

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2021 Dx Model – Technosylva Modeling and CoRE Calculation

IGNITION SPREAD

Wildfire Risk = LoRE * CoRE (Ignition Spread * Consequence)

Ignition Spread Calculation Concept

- Ignition points were selected within a 200m buffer around PG&E's assets, creating a grid of 100m squares. (~254,000)
- For each point on the grid pick a date from the worst weather dates (452)
- Simulate a fire and let it burn for 8 hours using underlying fuel and weather conditions.
- Simulation results were aggregated including acres burned, flame length, rate of spread, buildings destroyed, and fire volume.
- Pixels were then averaged across CPZs to create consequence scores for CPZs

Destructive fire probability

A destructive fire probability is calculated at each of the 255k HFTD locations by taking a ratio of number of simulations that met the following criteria

1) Acres burnt* >= 300
2) Building destroyed* >= 50 Or 1) FBI >= 3
3) Fire behavior index (FBI)>= 2

* Acres burnt and building destroyed are at the end of the 8 hrs simulation

CONSEQUENCES

Wildfire Risk = LoRE * CoRE (Ignition Spread * Consequence)

Scoring methodology

Within PG&E, the Meteorology team is working with Technosylva to create fire spread simulation for every 100 x 100m pixel within HFTD regions. By leveraging the Technosylva fire spread modeling outputs and historical Red Flag Warning shapefiles, consequence model are developed to distinguish the consequence within the HFTD tranche at 100m x 100m grid level. The steps implemented included:

1. **Calculate RFW and Fire Size Probabilities**
   Technosylva and (Red Flag Warning) RFW shape files from National Weather Service to re used to calculate the Probability of the fire size given an ignition, and the probability of RFW at 100m pixel level
2. **Calculate pre-calibrated MAVF CoRE**
   Combining the fire size probabilities and RFW probabilities calculated in Step1 with MAVF CoRE values at tranche, the MAVF CoRE values at 100m Tranche Level are calculated.
3. **Calibrate MAVF CoRE w.r.t Ignition Driver**
   Calibrate the CoRE by matching uncalibrated Risk per event to the weighted average CoRE from the wildfire bowtie model. By applying uniform calibration factor across all pixels, this method preserves the relative consequence difference between 100m pixels

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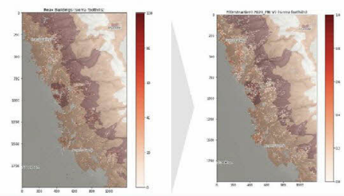
Evaluating Wildfire Consequence (REAX vs. Technosylva)

REAX identifies highest risk in tree dense areas based on fuels



Technosylva score (MAVF) identifies locations in the foothills based on ability of ignitions to 'ladder' from grass to Chaparral to trees more readily

Key Insights

- While densely forested areas have the fuels to support a catastrophic fire, it is **more difficult for an ignition to propagate** to the tree-tops where the fuel resides.
- Foothill regions have an even higher wildfire consequence due to the more readily available fuel ladder to tree-tops.
- **Wildfire risk and vegetation ignitions are not highly correlated.**
- In many areas of highest wildfire risk the probability of ignition is low. Therefore, **mitigations to reduce the probability of an ignition may have a marginal impact on reducing overall wildfire risk.**
- Vegetation ignitions are still highly correlated with trees and fuels.
- Conductor ignitions are correlated with conductor type and age.

Risk Model Action Items

Workstream	Action Item	Description	Responsible party	Resolution	Date
Risk Models	Risk model contributors	Provide a detailed description of the top model contributors	Jon Eric Thalman	**Complete –** Targeted for inclusion in deep dive sessions	11/12/2020

Vegetation Model – Contributors Description

Variable	Description
Tree-height-max	Maximum tree height, in meters, for each 100m x 100m pixel area along the distribution grid
100-hour-fuels-avg	The dead fuel moisture data from GRIDMET
Vapor-pressure-deficit-avg	The average vapor pressure deficit from the GRIDMET dataset
Gusty-summer-day-pct	Percentage of days that have high frequency of gusts.
Hftd	High fire threat district
Precipitation-avg	The average daily precipitation from the GRIDMET dataset
Impervious	Impervious ground cover (i.e. non-flammable)
Specific-humidity-avg	The average specific humidity from the GRIDMET dataset
Burn-index-avg	An derived variable based off of the geographical and topographical aspects of a location
Wind-max	The maximum wind velocity at a height of 10-meters from the Real-Time Mesoscale Analysis (RTMA) dataset at a resolution of 2.5-km
Temperature-avg	The average temperature from the GRIDMET dataset
Windy-summer-day-pct	Percentage of days that have a high percentage of days with high average wind speed
Local-topography	The topographic position index (TPI) was extracted from a USGS digital elevation model (DEM) at 100-meter resolution
1000-hour-fuels-avg	The dead fuel moisture data from GRIDMET
Energy-release-avg	Average release of energy from fuels

Conductor Model – Contributors Description

Variable	Description
Non-burnable area	Land surface descriptor similar to imperviousness that includes surfaces that typically don't ignite when a spark occurs
Daily precipitation, mean	The average daily precipitation from the GRIDMET dataset
Conductor material: ACSR	Aluminum conductor steel-reinforced
Estimated conductor age	Number of years since the installation year
Max tree height	Maximum tree height, in meters, for each 100m x 100m pixel area along the distribution grid
Reliability Program splice	Spans with more than three splice per phase
Vapor pressure deficit, mean	The average vapor pressure deficit from the GRIDMET dataset
Conductor size: 2	Conductor-size-2
Conductor size: 4	Conductor-size-4
100-hour fuels, mean	The dead fuel moisture data from GRIDMET
Max temperature, mean	The average maximum temperature from the GRIDMET dataset.
Wind speed, mean	The average wind velocity at a height of 10-meters from the Real-Time Mesoscale Analysis (RTMA) dataset at a resolution of 2.5-km
Local topography	The topographic position index (TPI) was extracted from a USGS digital elevation model (DEM) at 100-meter resolution