PG&E'S WILDFIRE DISTRIBUTION RISK MODEL (WDRM)

OFFICE OF ENERGY INFRASTRUCTURE SAFETY WORKSHOP

OCTOBER 5, 2021

Agenda

- Our Understanding
- Evolution of Risk Assessment and Modeling
- Models and Their Applications
- 2021 WDRM (version 2)
- Third Party Validation
- 2022 WDRM (version 3)
- Future Model Schedule
- PSPS Circuit Consequence Model
- Collaboration Between California IOUs
- Appendix

Our Understanding

We were asked to address the following topics:

- An **overview of your current ignition, consequence, and PSPS risk models**, including any **subsequent models** and how each model is utilized
- Details of **the components of each model, such as the inputs and data used, modeling assumptions and algorithms, and outputs including confidences and uncertainties**
- **Changes being implemented and / or considered to your risk models for the 2022 WMP Update**, along with an explanation

Evolution of Risk Assessment and Modeling

2017 RAMP/ 2020 GRC

- First Generation RAMP Model using Probabilistic Modeling and Monte Carlo Simulation
- Multi Attribute Risk Score (MARS) & Risk Spend Efficiency (RSE)
- High Fire Threat Districts Definition

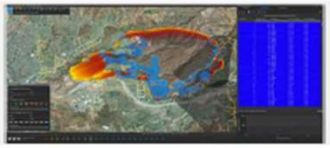
2019 WMP

- Community Wildfire Safety Program
- Enhanced Wildfire Safety Inspection Program
- Ignition Analysis for Distribution & Transmission Voltage Classes

- Initial Fire Propagation Modeling (Reax)
- First-of-a-Kind Circuit Prioritization Models for System Hardening & Enhanced Vegetation Management Programs

2020 WMP

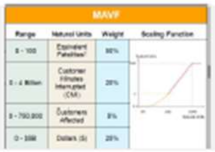
- Enhanced VM & SH
- Asset Inspection and Repair
- System Automation
- PSPS Improvements



- Improved Meteorology
- Inclusion of initial Egress methodology
- Fire Risk Model interaction between Outage Producing Winds (OPW) & Fire Potential Index (FPI)

2020 RAMP

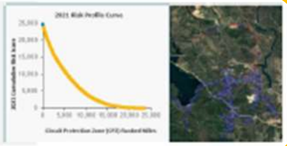
- Second Generation RAMP Model using Python
- Enhanced Multi Attribute Value Function (MAVF) in accordance with SMAP Settlement Agreement



- Enhanced Bowtie with Sub-drivers and Outcomes
- Exposure and Tranching performed various levels of granularity

2021 WMP

- Enhanced Risk Assessment and Prioritization Models for System Hardening and Enhanced Vegetation Management using:
  - Probability of Ignition
  - Fire Propagation & Consequence
- Risk Assessed at 100m grid-squares and aggregated to Circuit Segments



2022 WMP

- **Model extends beyond HFTD to entire distribution system**
- **Developed sub-models to composite or add probabilities and risks**
- **Added models for support structures and transformers**
- **Updated training data sets with 2020 outages, ignitions and PSPS damages**
- **Risk reduction for mitigation options at a granular level**

PG&E has developed a suite of risk models for various use cases, including:

Enterprise Risk Model using the bow tie methodology to assess risks at an enterprise level and mitigation program effectiveness at program level for GRC, RAMP and Investment Planning purposes evaluating Drivers, Exposure, Outcomes, Consequences, Tranches

Wildfire Risk Models for specific voltage classes (i.e. Distribution and Transmission) comprising Probability of Ignition Models, and Wildfire Consequence Model used to assess risk at a more granular level (e.g. circuit segment) for the purposes of mitigation work planning and prioritization

PSPS Operational Model comprised of the Ignition Probability Weather (IPW) and Fire Potential Index (FPI) models used to inform PSPS de-energizations during elevated fire weather conditions

PSPS Circuit Consequence Model to assess customer impacts from a PSPS de-energization event

The Wildfire Distribution Risk Model is one of many efforts that inform PG&E's Wildfire Mitigation Plan

2021 WILDFIRE DISTRIBUTION RISK MODEL (VERSION 2)

Modeling Objectives and Framework

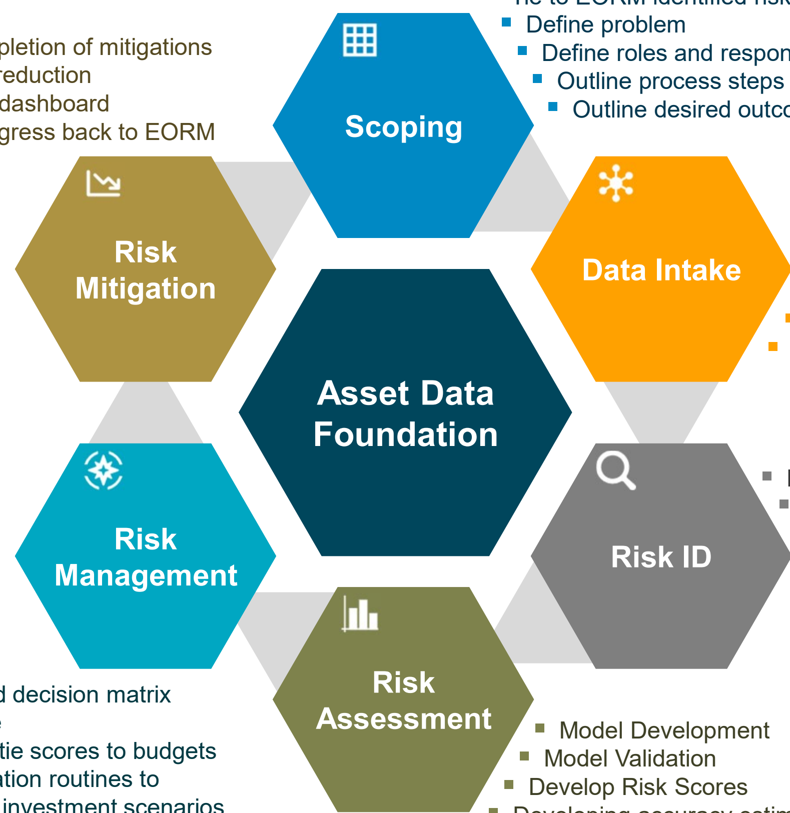
Risk and Data Analytics Team Objectives:

(1) Provide situational awareness of risk

(2) Enable risk-informed decisions making, and

(3) Enable PG&E to develop line-of-sight on risk reductions from wildfire risk mitigation initiatives

2021 established the baseline and foundation for future development of the WDRM to progress PG&E risk modeling and capability maturity



Scoping
- Tie to EORM identified risks
- Define problem
- Define roles and responsibilities
- Outline process steps
- Outline desired outcomes

Data Intake
- Document data sources
- Define data accuracy
- Data Conditioning

Risk ID
- Exploratory Data Analysis (EDA)
- Root Cause – FMEA
- Documentation of FMEA results

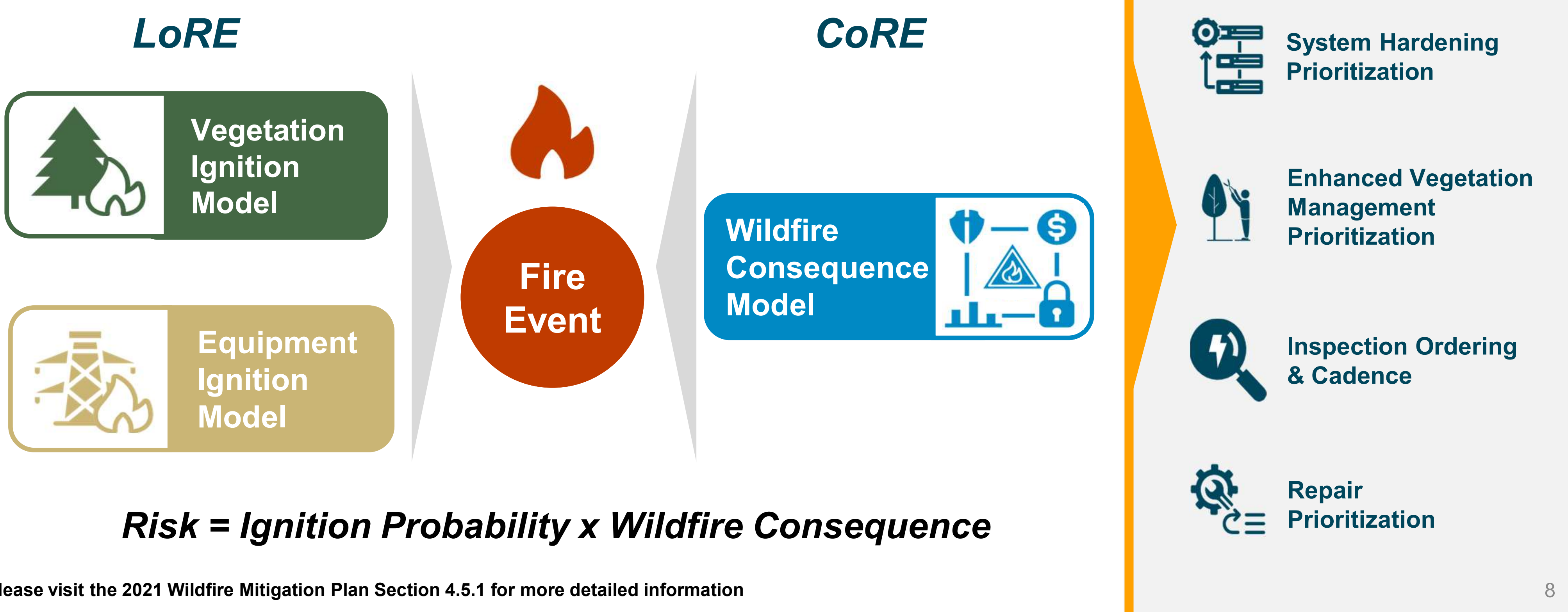
Risk Assessment
- Model Development
- Model Validation
- Develop Risk Scores
- Developing accuracy estimates
- Developing reduction scores for mitigation options
- Developing risk spend efficiency scores for mitigation options

Risk Management
- Standard decision matrix template
- Tools to tie scores to budgets
- Optimization routines to produce investment scenarios

Risk Mitigation
- Verify completion of mitigations
- Track risk reduction
- Daily Risk dashboard
- Report progress back to EORM CPUC

2021 Wildfire Risk Modeling Approach

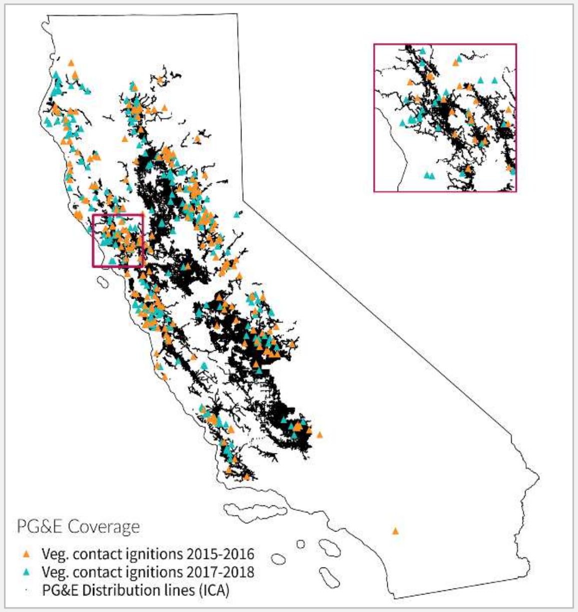
PG&E's wildfire risk modeling framework is aligned with our wildfire risk bowtie defined in the 2020 RAMP, and is used to assess Probability of Ignition or Likelihood of Risk Event (LoRE) and the Consequence of Risk Event (CoRE)



Risk = Ignition Probability x Wildfire Consequence

Please visit the 2021 Wildfire Mitigation Plan Section 4.5.1 for more detailed information

Maximum Entropy (MaxEnt) Approach



Locations and characteristics of areas where ignitions occur are collected and compiled

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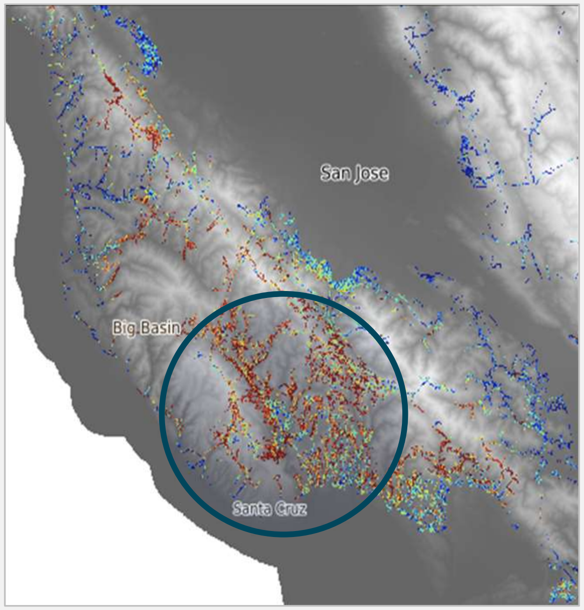

Similarities between the conditions at ignition points are identified, and evaluated for commonality

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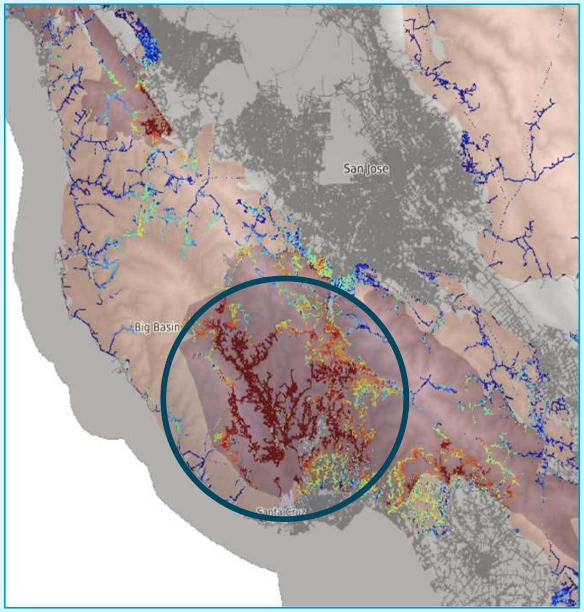
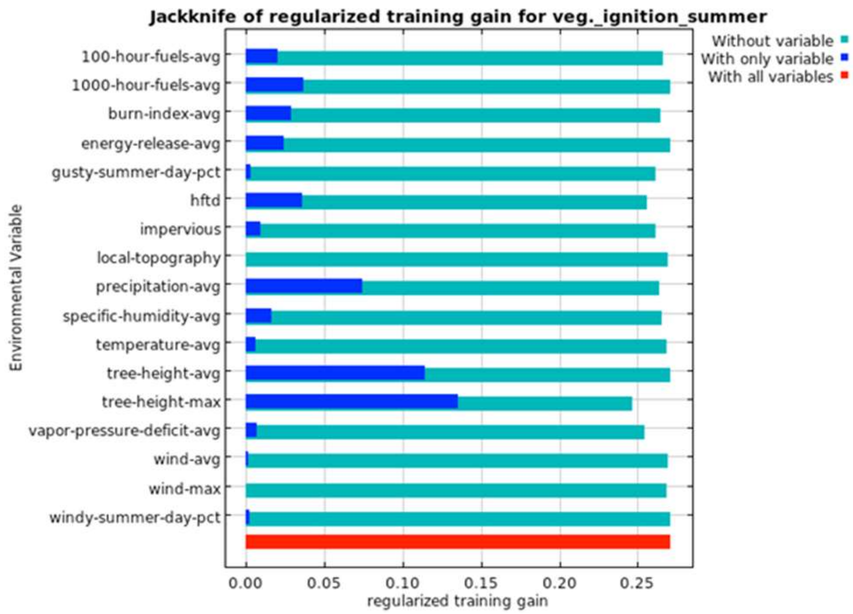


Places where there are similar conditions across the examined area are given a probability of the event occurring based on similarity to other ignition locations and a level of uncertainty

Please visit the 2021 Wildfire Mitigation Plan Section 4.3 for more detailed discussion on MaxEnt

Vegetation Probability of Ignition – Covariates

Rank	Model Feature	Feature description	Units	Permutation Importance (%)
1	tree-height-max	Satellite derived tree height estimates – highest tree per-raster pixel	m	26.1
2	100-hour-fuels-avg	standard fire modeling metric of fuel dryness for fuels about 1-3" in diameter, mean over season	%	24.1
3	vapor-pressure-deficit-avg	vapor pressure deficit, mean over season	kPa	21.6
4	gusty-summer-day-pct	The percentage of days with sustained hourly wind speeds over 20 mph	%	6
5	HFTD	High Fire Threat District (2 or 3)		4.2
6	precipitation-avg	Seasonal daily average precipitation	mm	3.1
7	Impervious	NLCD imperviousness product - represent urban impervious surfaces as a percentage of developed surface	%	2.8
8	specific-humidity-avg	Seasonal average specific humidity	kg/kg	2.4
9	burn-index-avg	National Fire Danger Rating System (USNFDRS) Burning Index (BI)		2.3
10	wind-max	Annual 99th percentile hourly wind speed at 10m	m/s	1.9
11	temperature-avg	Average of daily maximum temperature in Kelvin	K	1.6
12	windy-summer-day-pct	The percentage of days with sustained hourly wind speeds over 15 mph	%	1
13	local-topography	The topographic position index (TPI) extracted from the USGS national elevation dataset		0.8
14	tree-height-avg	Satellite derived tree height estimates – average per-raster pixel	m	0.8
15	1000-hour-fuels-avg	standard fire modeling metric of fuel dryness for fuels about 3-8" in diameter, mean over season		0.6
16	energy-release-avg	USNFDRS Energy Release Component (ERC)		0.4



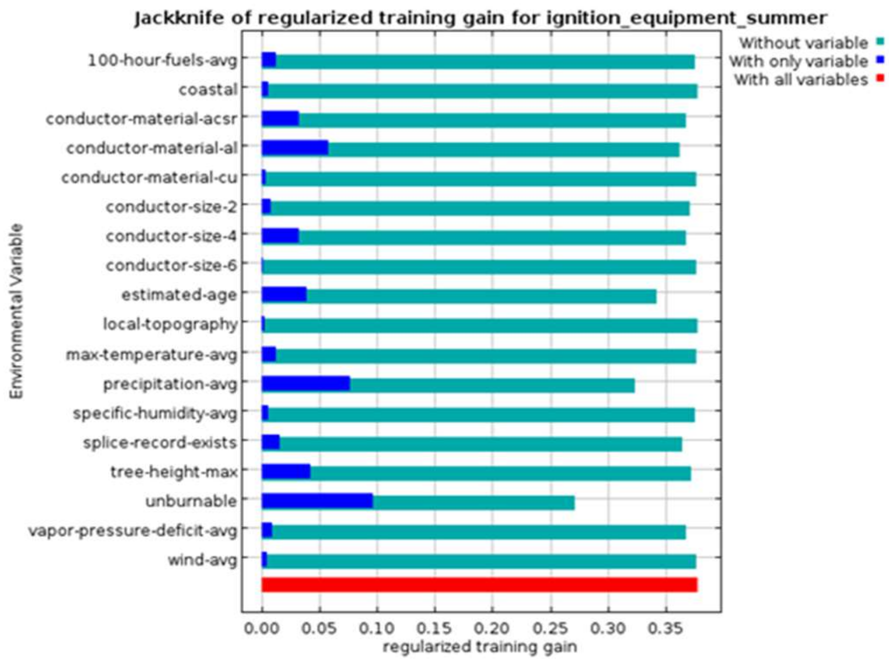
Predicted annual HFTD ignitions (average): **100**
Observed total HFTD ignitions (2015-2018): 401

Model Performance

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

Equipment Probability of Ignition – Covariates

Rank	Model Feature	Feature Description	Units	Permutation Importance
1	Unburnable	non-burnable area	%	30.8
2	precipitation_ave	daily precipitation, mean	mm	29.8
3	conductor_material_acsr	conductor material: ACSR	%	9.7
4	estimated_age	estimated conductor age	years	8.9
5	tree_height_max	max tree height	m	4.3
6	splice_record_exists	Reliability Program splice	%	4.3
7	vapor_pressure deficit_ave	vapor pressure deficit, mean	kPa	4.0
8	conductor_size_2	conductor size: 2	%	3.4
9	conductor_size_4	conductor size: 4	%	1.6
10	100_hour_fuels_ave	100-hour fuel moisture, mean	%	1.1
11	max_temperature_ave	max temperature, mean	K	1.0
12	wind_ave	wind speed, mean	m/s	0.9
13	local_topography	TPI	%	0.2
14	conductor_size_6	conductor size: 6	%	0.1
15	conductor_material_al	conductor material: Al	%	~0
16	conductor_material_cu	conductor material: Cu	%	~0
17	coastal	coastal	%	~0
18	specific_humidity_ave	specific humidity, mean	%	~0



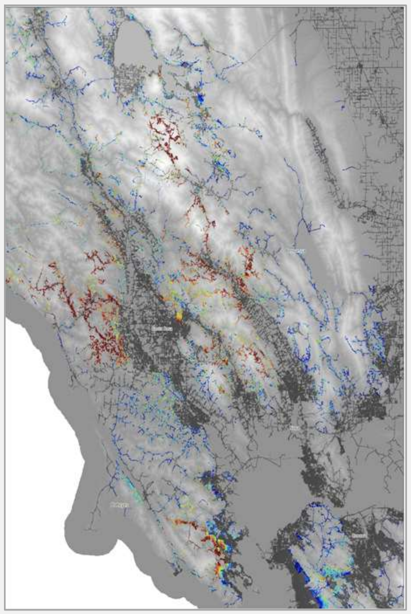
Predicted annual HFTD ignitions (average): **60**
Observed total HFTD ignitions (2015-2018): 242

Model Performance

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

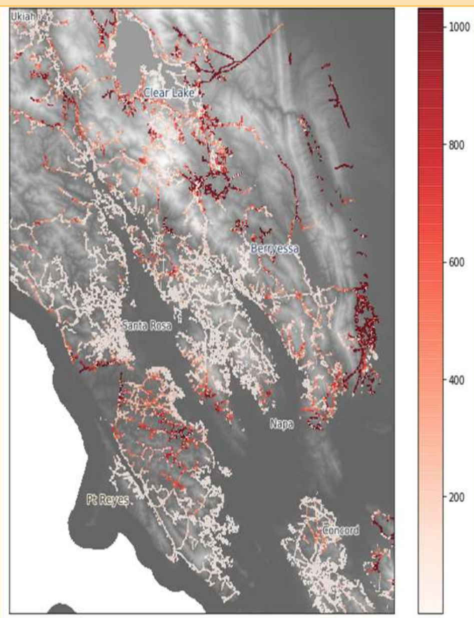
Probability and Consequence Visualization

Ignition Probability

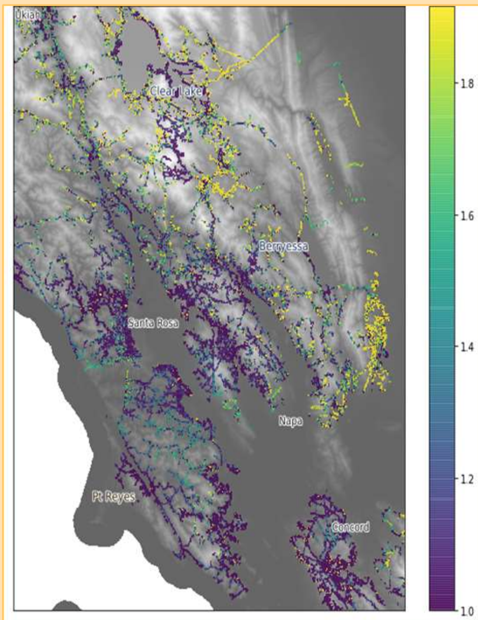


Probability of Ignition (Red High, Blue is Low)

Wildfire Consequence

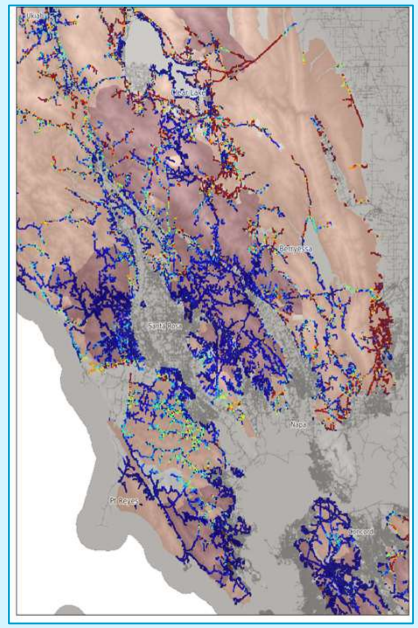


Technosylva Burn Area Consequence



Technosylva Fire Behavior Index

Risk Score



Risk Units (MAVF) (Red High, Blue Low)

Risk = Ignition Probability x Wildfire Consequence

Please visit the 2021 Wildfire Mitigation Plan Section 4.5.1 for more detailed information

Operationalizing the Model

Risk Model

2021 Wildfire Distribution Risk Model

Additional Considerations

- *Updated 2020 LiDAR data on strike potential trees across the 25,000 miles of HFTDs*
- *Public Safety Specialist expertise regarding fire history by area and the details on specific locations in terms of terrain and egress routes*
- *System hardening projects and fire rebuilds underway and completed*
- *Frequency and number of customers impacted by PSPS events in 2019 and 2020*

Workplans & Metrics

- *Enhanced Vegetation Management*
- *System Hardening*
- *PG&E Public Safety Metrics*

Additional Steps to Develop 2021 EVM Scope of Work

2021 Wildfire Distribution Risk Model (October 2020)

→

Modifications

Re-aggregation from 100m x 100m pixels to 1km x 0.7km grid areas (Unified Grid Maps)

×

Estimation of tree count per grid area using 2019/2020 LiDAR Survey Data and VM Inspection Results

×

Estimation of Remaining Tree Work in the Grid Map Grouping from EVM execution records

→

EVM Tree-Weighted Risk Prioritization (April 2021)

→

Work performed on 99 CPZs in risk ranked order

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2021 EVM Scope of Work (April 2021)

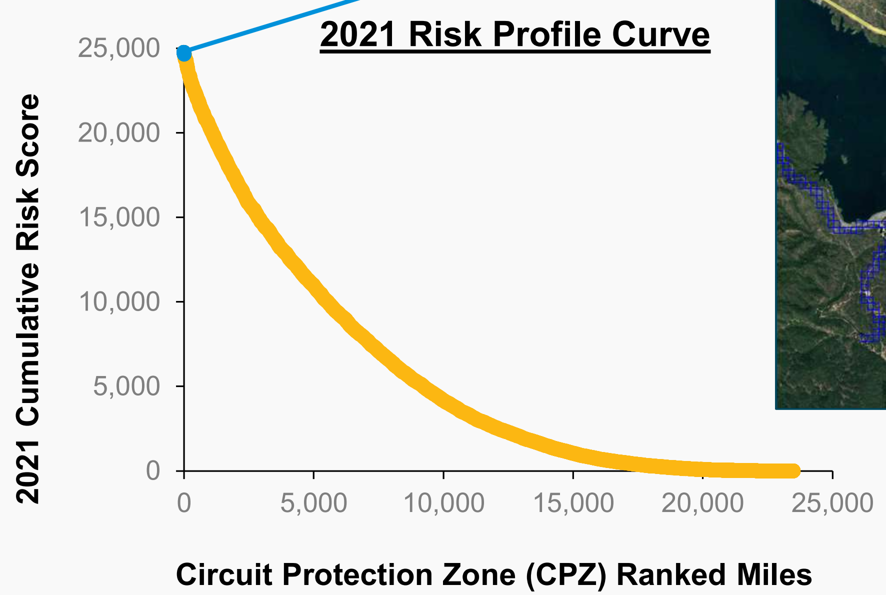
↑ Wildfire Risk Governance Steering Committee (WRGSC) must approve any changes

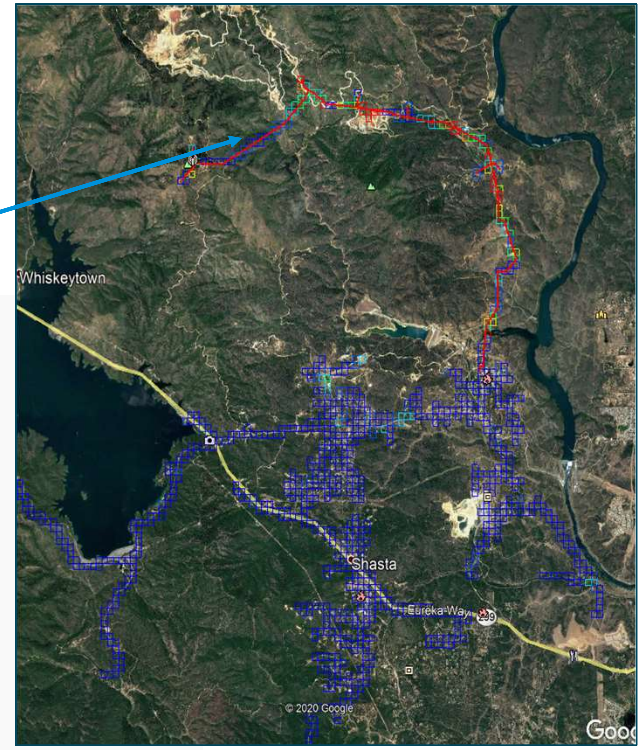
↓ Communicated to our EVM personnel

System Hardening Example

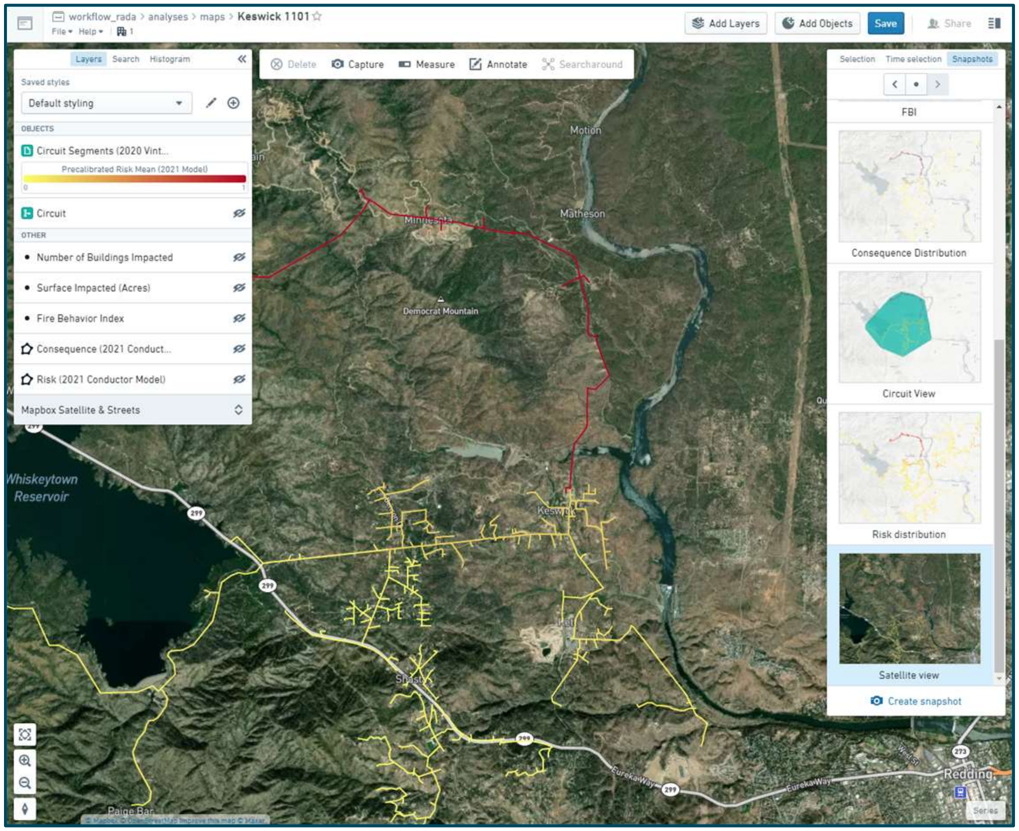
Keswick 1101 Circuit Protection Zone (CPZ)

- This circuit segment is in the top 50 miles in the risk profile curve
- 6.6 miles in total length
- The 100m X 100m squares (blue, yellow and red) on the picture each have a risk score
- Total CPZ risk score is 48.84 MAVF units (sum of all the 100m grid squares along the circuit)
- Average risk score of all the grid points results in the CPZ mean risk score of 1.25 units
- Circuit segment was evaluated for OH and UG solutions

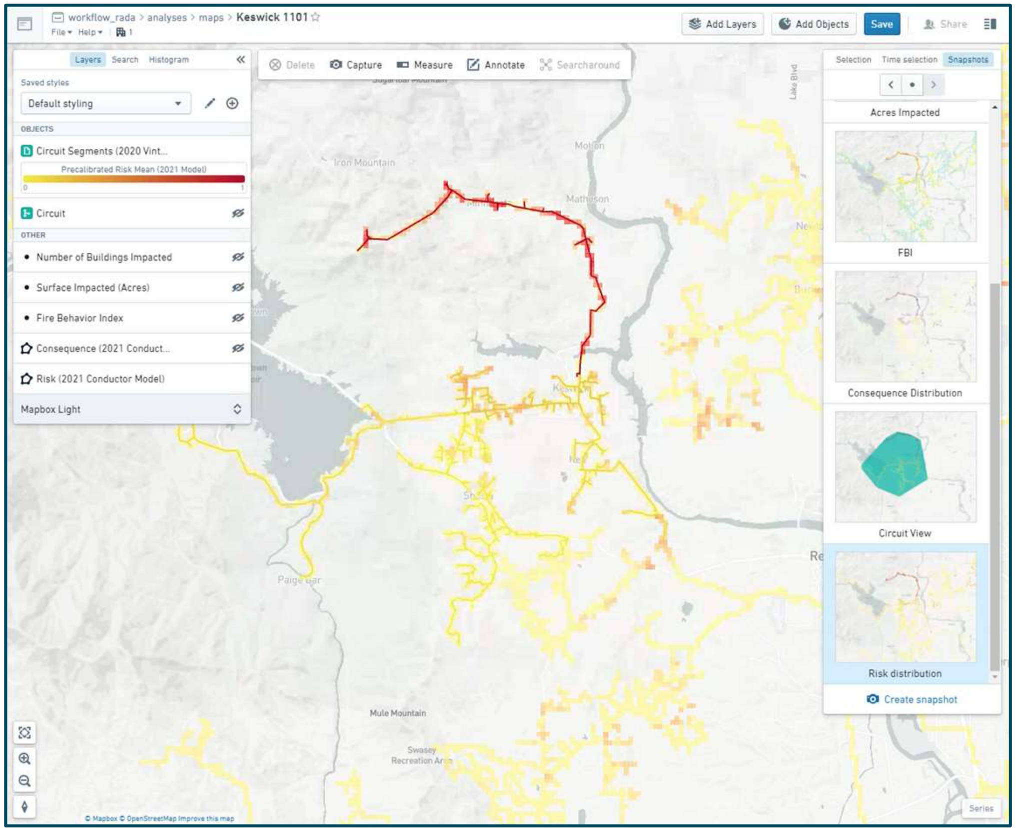




Model Visualization and Application



Circuit Segment View

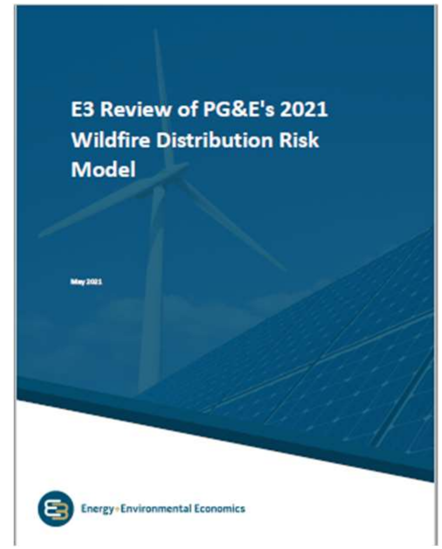


Risk Pixel View

Third Party Evaluation by Energy Environmental Economics

E3 have demonstrated expertise in:

- Energy and risk modeling methods and data analytics
- Machine learning
- California's energy landscape and the critical need and value of risk models



E3 performed an independent review of the 2021 WDRM focused on two main objectives:

1. Is the model and documentation "fit for purpose"?
2. Does the model produce reasonable results

E3 found that the 2021 Distribution Risk Model:

- Is **appropriately designed for its stated goals** including PG&E's goal to develop a model that provides estimates of risk from ignitions caused by its own equipment.
- Provides a **better predictor of where ignitions could occur and what damages could be expected from those ignitions that its older 2018-2019 model**. The improvements are primarily due to the use of more accurate consequence data and a more suitable modeling (MaxEnt) approach.
- PG&E's approach **represents a meaningful step above the industry standard approach used for planning and assessing where to target more traditional grid hardening measures.**

Suggested Areas for Improvement

E3 highlighted areas for improvement which were captured as commitments in the 2021 WMP:

- Strengthen the critical link that is often required between experts and models to effectively mitigate risk
- Strengthen and clarify the relationship between the Wildfire Distribution Risk Model and the PSPS model
- Improve documentation how the family of PG&E's fire risk mitigation models/data work together to address key questions
- Better balance model parsimony in using fewer parameters by including parameters that provide a direct line of sight to the impact of risk mitigation measures
- Explore more modeling algorithms in order to determine the best approach

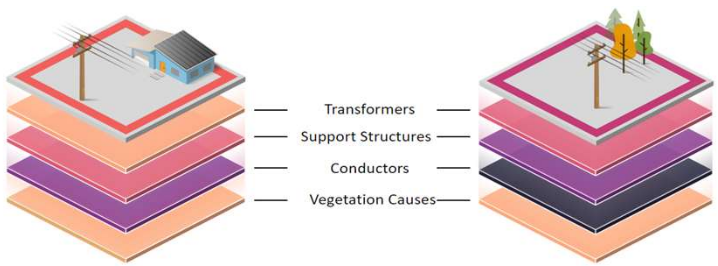
2022 WILDFIRE DISTRIBUTION RISK MODEL (VERSION 3)

2022 WDRM (version 3) Overview

Based on E3 feedback and risk model vision and schedule described in the 2021 WMP the v3 WDRM adds 8 new groups of features

2022 WMP

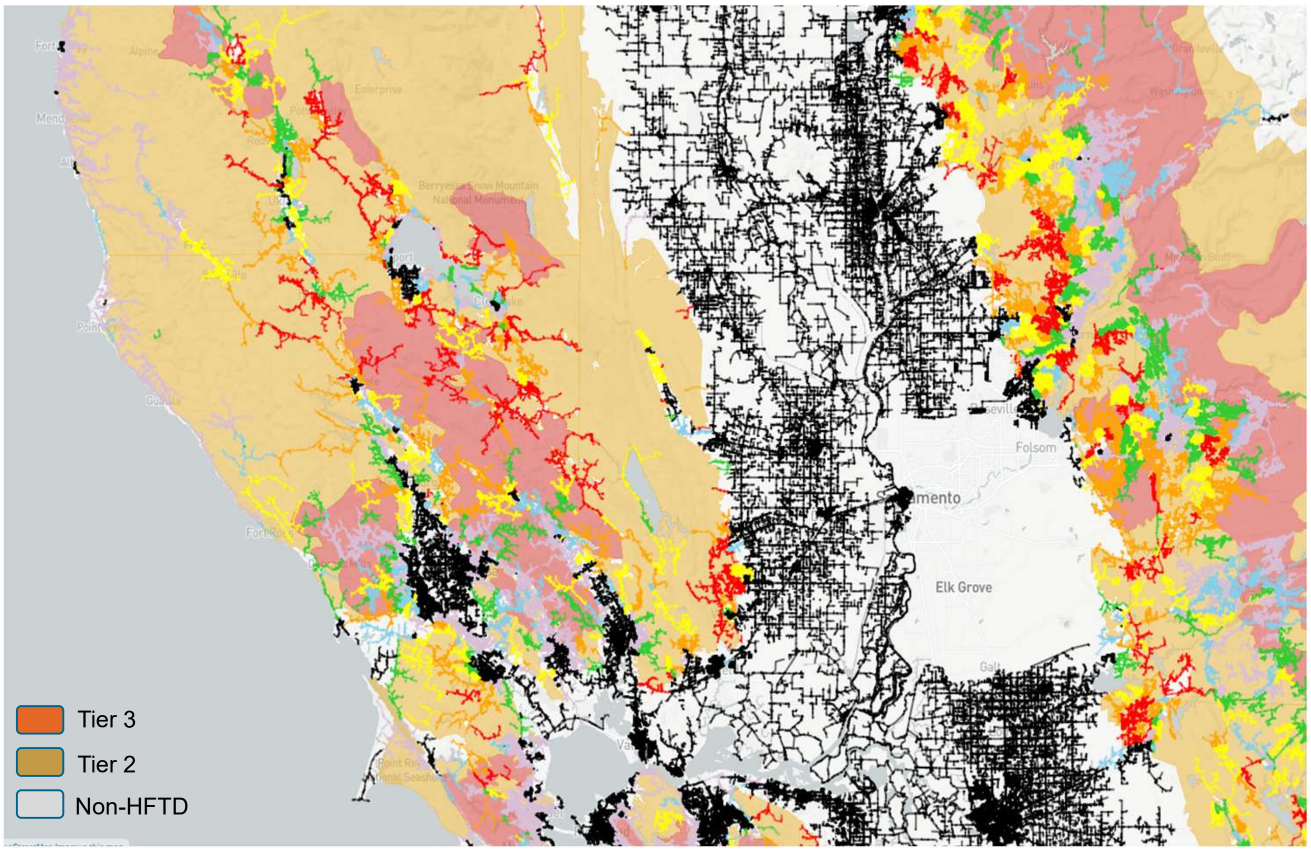
1. Model extends beyond HFTD to entire distribution system
2. Added models for support structures and transformers



3. Develop and evaluate wider range of model algorithms
4. Updated training data sets with 2020 outages, ignitions and PSPS damages
5. Improve coordination between PSPS and WDRM
6. Automation of composite model framework
7. Developed sub-models to composite or add probabilities and risks
8. Risk reduction for mitigation options at a granular level

WDRM v3 models the entire PG&E Overhead Distribution System

1



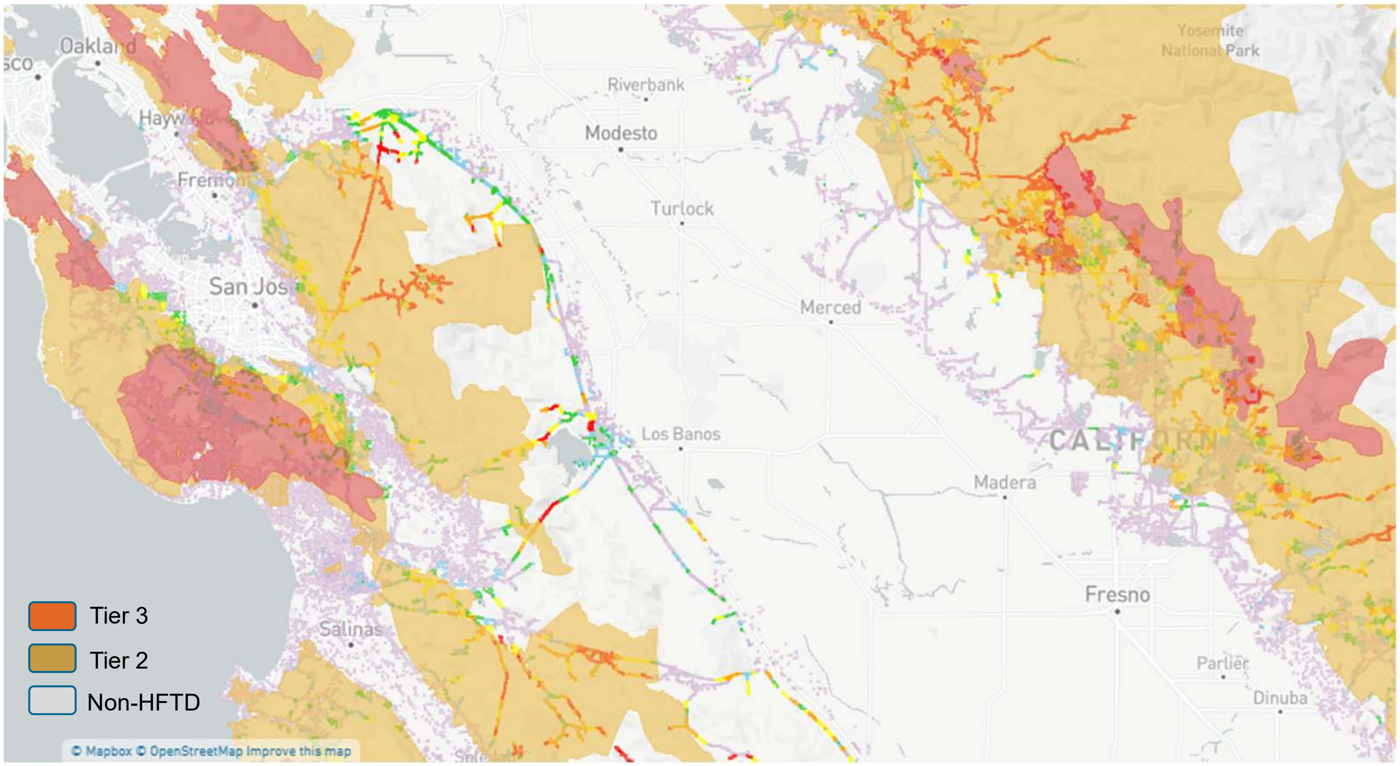
Model Geographic Expansion

Model extended to entire Overhead PG&E Distribution System including Primary and Secondary (added all black circuits)

Wildfire Consequence model extended to all 'burnable' areas including HFRA and Tier 1

Expansion of Wildfire Consequence beyond HFTD Tiers 2 & 3

1



Model Geographic Expansion

As climate change is not static, Technosylva fire simulations were modeled beyond HFTD to consider all 'burnable' areas within PG&E's Service Territory

In 'non-burnable' locations the probability of outage and ignition is available, but the wildfire consequence is not calculated

Modeling more detailed sub-models to represent risk drivers requires modeling outages and then outages to ignitions for Likelihood of Risk Event (LoRE)

PG&E

2

Likelihood of Risk Event (LoRE)

Vegetation Outage Model

Conductor Outage Model

Support Structure Outage Model

Transformer Outage Model

Probability of an Ignition Given an Outage

Fire Event

Consequence of Risk Event (CoRE)

Wildfire Consequence Model

Risk = Outage Probability x Ignition Probability Given Outage x Wildfire Consequence

WDRM v3 Models and Algorithms

3

MaxEnt
- Vegetation Outage Model
- Conductor Outage Model

Random Forest Classifier
- Support Structure Outage Model
- Transformer Outage Model

Logistic Regression
- Probability of an Ignition Given an Outage

Technosylva
- Wildfire Consequence Model

Probability models employ a range of model algorithms best suited to the problem

WDRM v3 Models Input and Training Data

4

Added/Improved Covariates

Tree
- LiDAR
- Species

Asset
- Asset Age
- Height
- Pole Test & Treat
- Pole Material
- Pole Treatment
- Soil
- Maintenance tags
- Electric Loading

Meteorology
- Average Wind
- Precipitation Max.
- Gusty Wind Pct.
- Windy Summer Pct.
- Vapor Pressure
- Humidity

MaxEnt
- Vegetation Outage Model
- Conductor Outage Model

Random Forest Classifier
- Support Structure Outage Model
- Transformer Outage Model

Train/Test Sets

Outages

PSPS Damages

Added curated data sets have resulted in additional models and improvements in predictive performance

P(Ignition) Models Overview – OPW/IPW vs. WDRM

5 **Improved alignment between the PSPS and WDRM as both models calculate p(outage) * p(ignition | outage) for a given cause, and sum over causes**

OPW
Probability Outage by Cause
Outputs:2x2km, Hourly

Outage Cause
P(Vegetation)
P(Equipment-Structural)
P(Animal-3rd Party)
P(Equipment-Electrical)
P(Unknown Cause)

Ignition Rate Depends Only On Cause
Vegetation: 8.7%
Equipment-Structural: 5.3%
Animal – 3rd Party: 5.2%
Equipment-Electrical: 1.5%
Unknown: 3.6%

IPW
Probability of Ignition by Cause
Outputs: 2x2km, Hourly

WDRM
Probability Outage by Cause
Outputs:100m x 100m, Fire Season & Rest of Year

Outage Cause
P(Tree trunk into conductor)
P(Tree trunk into pole)
P(Tree branch into conductor)
P(Tree branch into pole)
P(Animal)
P(Other)

Ignition Rate
Depends on cause, land use category, typical fuel moisture, impervious surface.

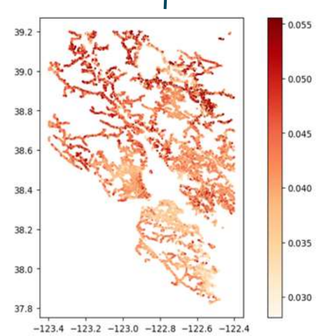
WDRM
Probability of Ignition by Cause
Outputs: 100m x 100m, Fire Season & Rest of Year

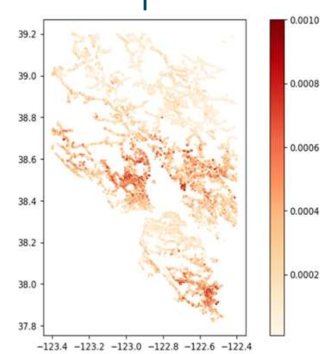
OPW: Very high temporal resolution, moderate spatial resolution*. This is what you want for PSPS decisions.*

WDRM outage model: Very low temporal resolution, high spatial resolution*. This is what you want for system hardening, EVM, and other mitigation work planning decisions.*

Both models use similar (but not identical) breakdown by cause.

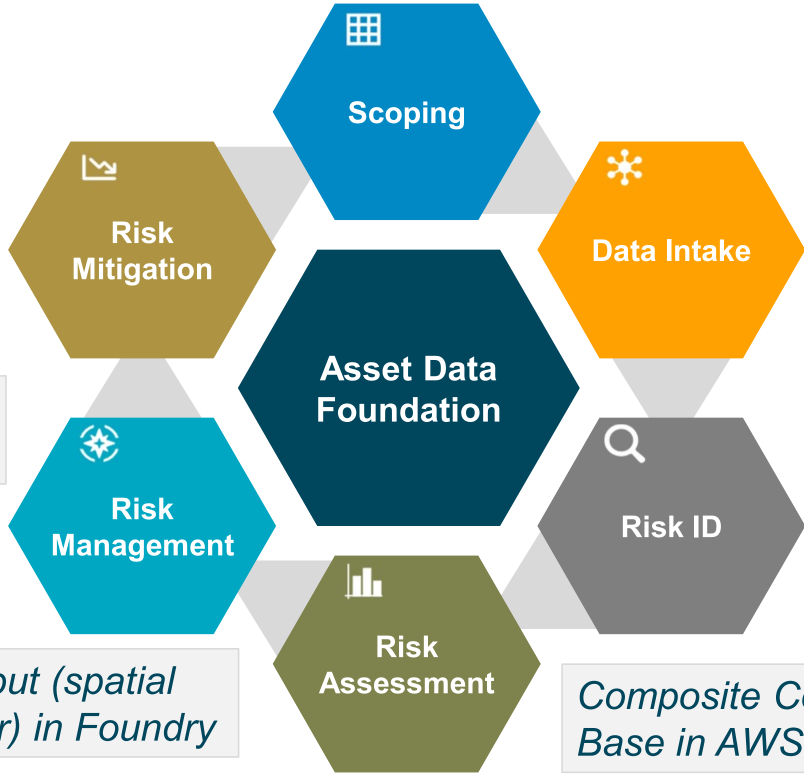
Candidate for future unification.





Composite Model Framework Automation

6 **Across the Risk Model Framework Methodology, automation improvements have been developed resulting in a more reproducible and transparent process, with emphasis on data visualization.**



Curate data (train/test sets and covariates) in the Palantir Foundry ontology

Workplan prioritization

Post model steps documented in Foundry

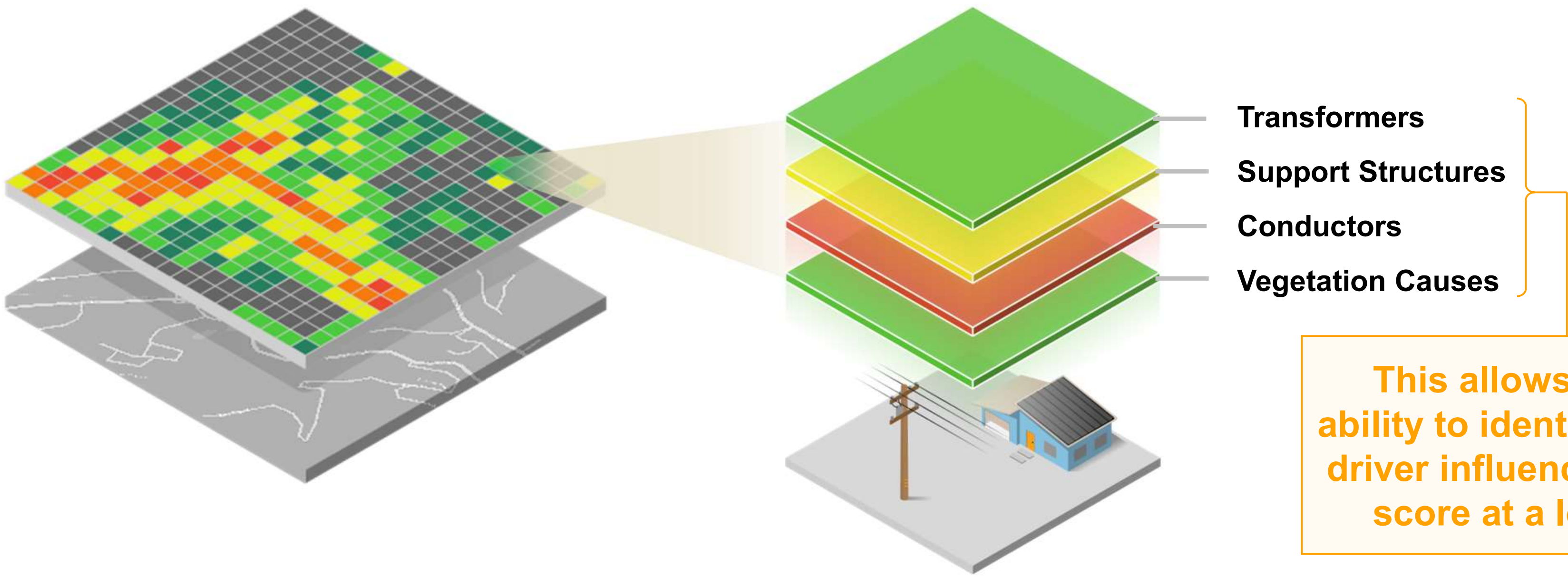
Model output (spatial and tabular) in Foundry

Composite Code Base in AWS

Palantir Foundry has been leveraged as a key enabler for automation

Composite Risk Model Values at a Location

7 **The total risk or probability at a specific location is provided by the sum of the LoRE sub-models**



This allows for the ability to identify the risk driver influencing a risk score at a location

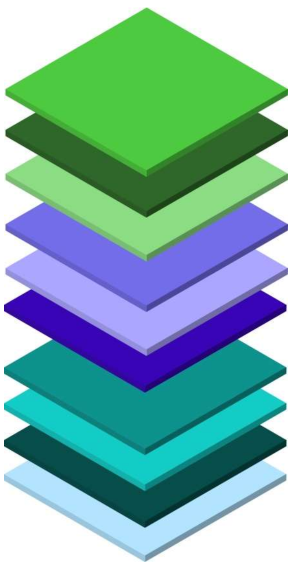
Full Territory Risk Pixels

Single Pixel Breakdown of Total Wildfire Risk

Compositing per Use Case

7 **A large set of models predicting individual outage causes can be modularly combined to give a risk score relevant to the strategic use case**

Total Overhead Distribution System Wildfire Risk



Relevant Models For Hardening

Relevant Models For Veg Management

Composite Risk Model Values at a Location – Vegetation Example

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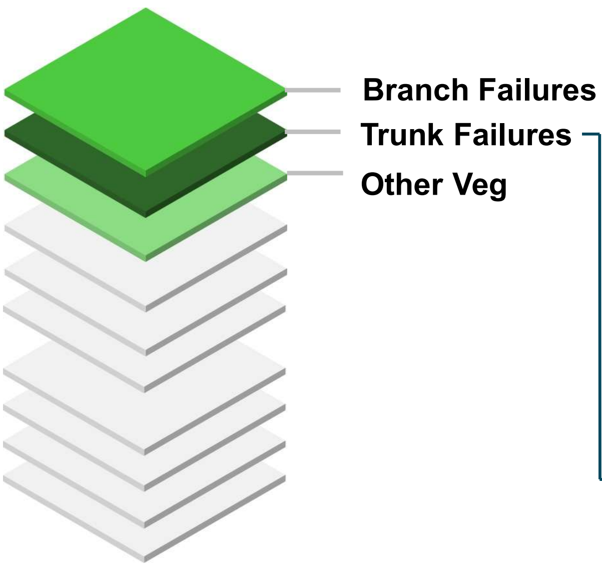
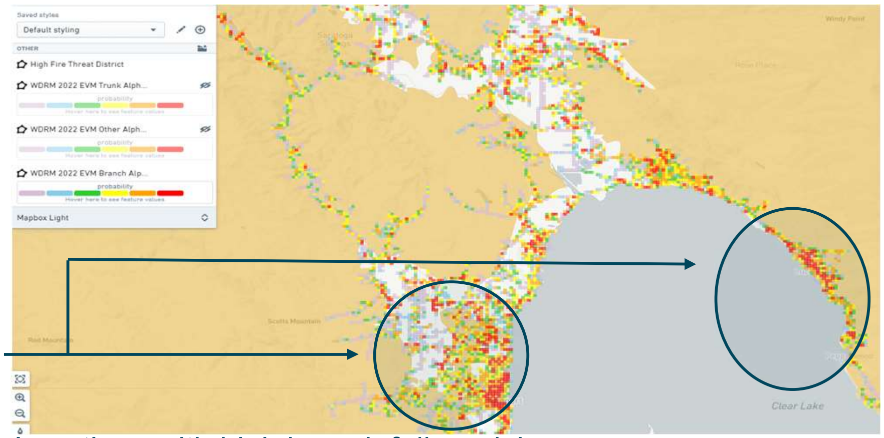
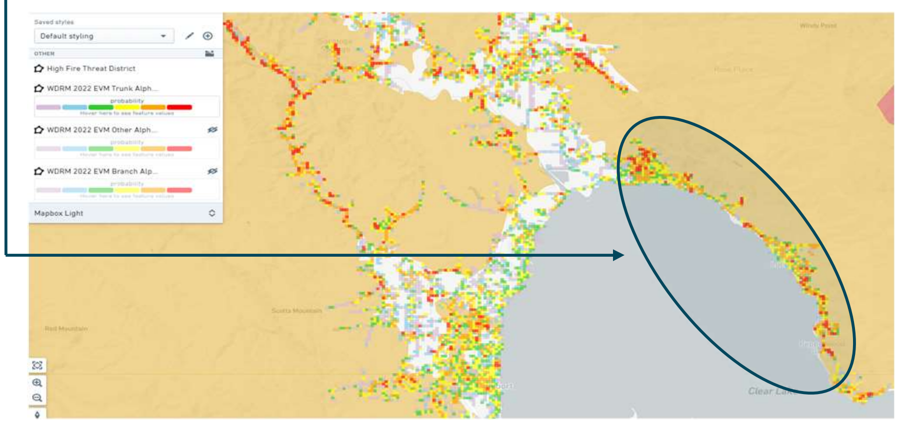
Relevant Models For Veg Management





Locations with high branch failure risk



Locations with high trunk failure risk

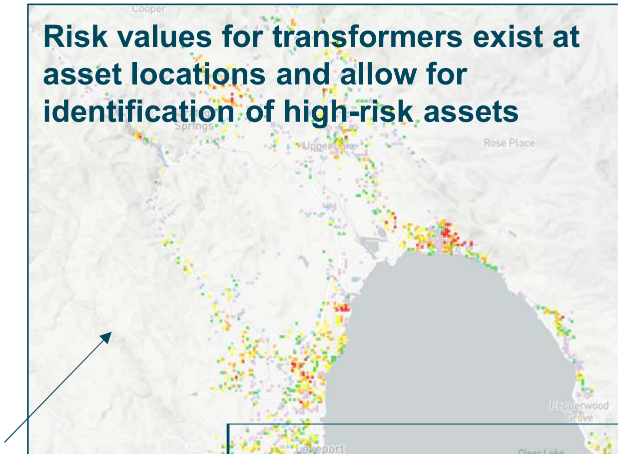
Sub-model details can allow for more targeted mitigations to locations more prone to branch or trunk failures

Composite Risk Model Values at a Location – System Hardening Example

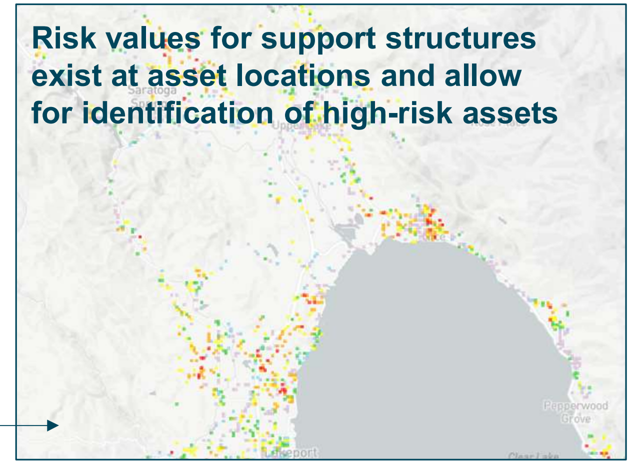
7

Relevant Models For Hardening

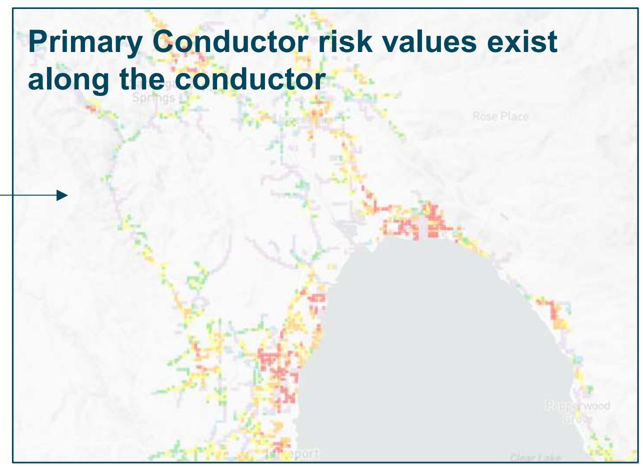
- Branch Failures
- Trunk Failures
- Transformer Electrical
- Support Structure
- Primary Conductor



Risk values for transformers exist at asset locations and allow for identification of high-risk assets



Risk values for support structures exist at asset locations and allow for identification of high-risk assets



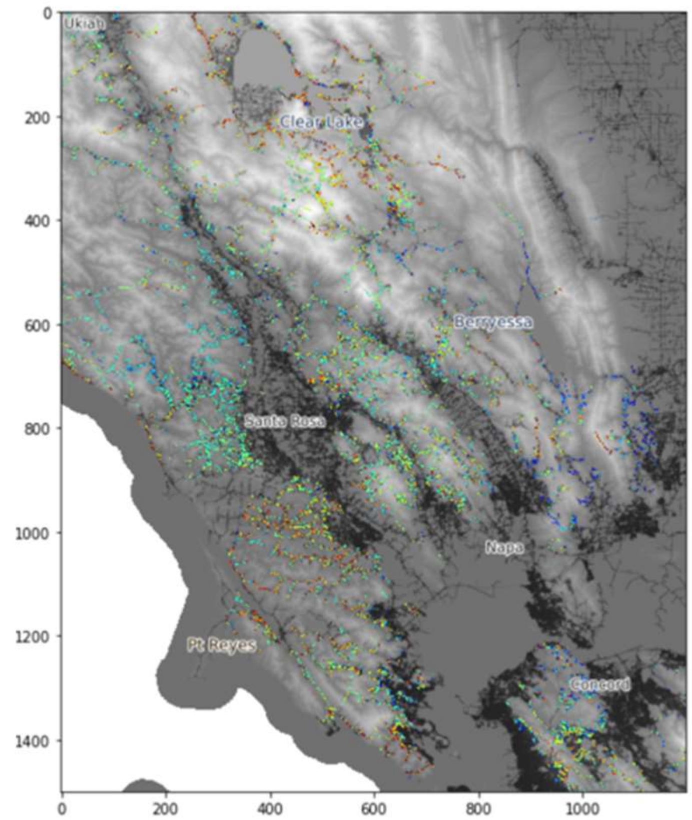
Primary Conductor risk values exist along the conductor

System Hardening type can be targeted to the sub-models by risk characteristic

Mitigation Effectiveness Factors

8

With granular sub-models, SME informed effectiveness factors can be applied resulting in a pixel level effectiveness estimate for mitigation identification

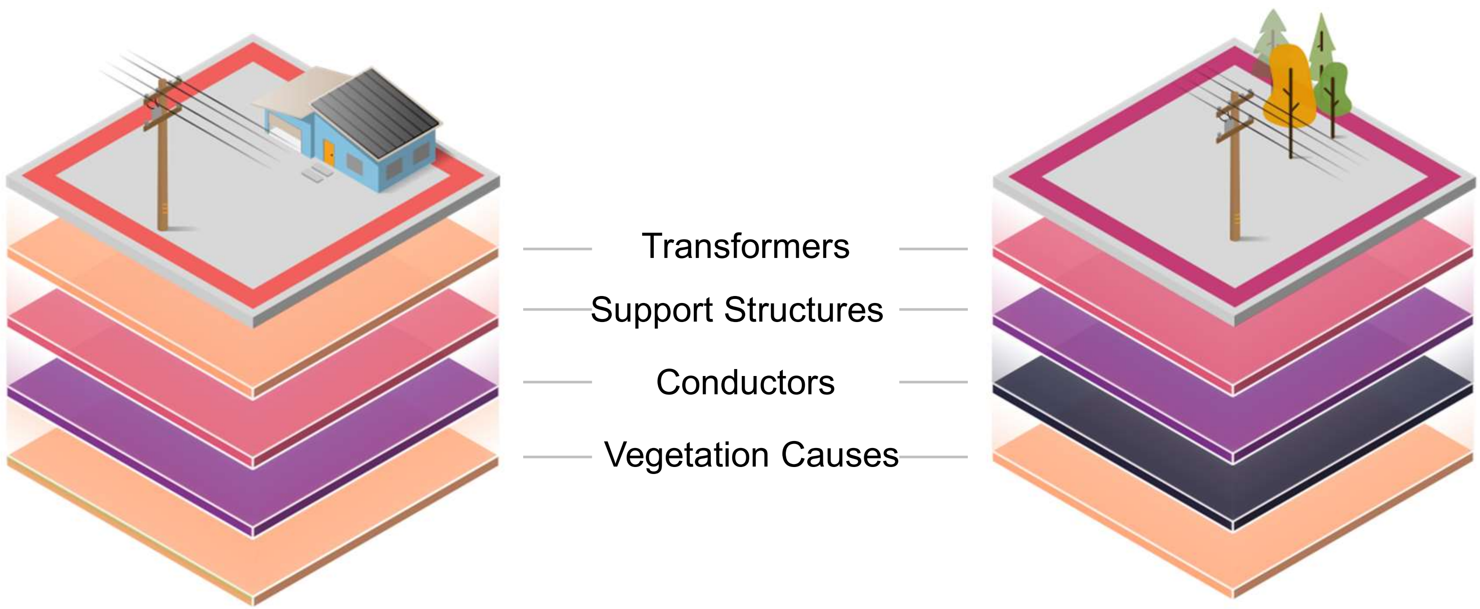


SH effectiveness identifying locations with the highest potential for risk reduction due to SH mitigation

Evaluating Risk Reduction due to Effectiveness of Mitigations Options

8

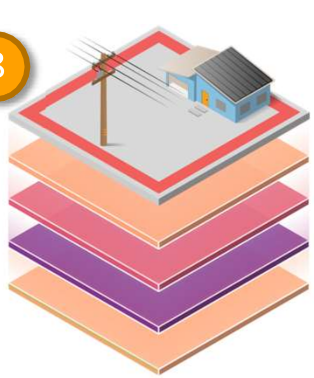
Wildfire Risk may be the same at two locations but, due to the risk of the individual sub-models the **most effective mitigation may differ**



The following examples highlight how the sub-model details in the composite model architecture enable improved identification of the most effective risk mitigations

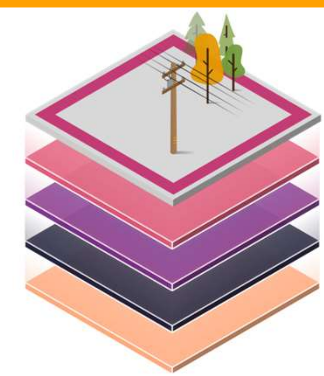
Estimate Risk by Location and Prioritize

8



Team identifies locations when looking at only one type of risk:

- Location B has a **higher risk of transformer caused wildfire**
- A **new transformer is 80% effective** in reducing the probability of failure
- **Location B is the higher priority** location for **a transformer replacement project** even though the wildfire consequence at Location A is higher



		Probability of ignition	Consequence of the ignition	Risk Score
	Location A	0.0010%	6000	0.06
Stacked Bar of Risk (A)	All assets – any vegetation causes	0.0000%		0.00
	Transformers - electrical/mechanical causes	**0.0033%**	**(consequence at A is constant, 6000)**	**0.02**
	Support Structures - mechanical causes	0.0033%		0.02
	Conductors etc. - electrical/mechanical causes	0.0033%		0.02
	Location B	0.0885%	2000	1.77
	Location C	0.0500%	6000	3

		Probability of ignition	Consequence of the ignition	Risk Score
	Location A	0.0010%	6000	0.06
	Location B	0.0885%	2000	1.77
Stacked Bar of Risk (B)	All assets – any vegetation causes	0.0600%		1.20
	Transformers - electrical/mechanical causes	**0.0225%**	**(consequence at B is constant, 2000)**	**0.45**
	Support Structures - mechanical causes	0.0010%		0.02
	Conductors etc. - electrical/mechanical causes	0.0025%		0.05
	Location C	0.0500%	6000	3

Estimate Risk by Location and Prioritize

8

Location A

Risk lower, largest reduction in risk from system hardening

One area (A) may have **lower chance of ignition of 0.0015%**, with very little of that due to vegetation because of the **lack of trees in the area**

However, there are a **large number of buildings or structures in the area**, leading to **higher wildfire consequence** (6000)

Mitigation$_{\text{system hard.}}$ → Hardening system (if 50% effective) **could reduce the risk score** to 0.03 – **BUT system hardening at Location B is more effective**

	Probability of ignition	Consequence of the ignition	Risk Score
Location A	0.0010%	6000	0.06
All assets – any vegetation causes	0.0000%	(consequence at A is constant, 6000)	0.00
Transformers - electrical/mechanical causes	0.0033%		0.02
Support Structures - mechanical causes	0.0033%		0.02
Conductors etc. - electrical/mechanical causes	0.0033%		0.02
Location B	0.0885%	2000	1.77
Location C	0.0500%	6000	3

Location B

Risk higher, largest reduction in risk from tree trimming

Another area (B) with high winds may have a **higher chance of ignition of 0.0885%, primarily due to vegetation**

However, due to a **less dense population center**, the consequence and thus the **risk score is much lower** (2000 compared to 6000)

Mitigation$_{\text{vegetation}}$ → **Cutting back vegetation** (if 50% effective) **reduces the risk** score to 1.12 **because vegetation is a primary driver** of ignition

Mitigation$_{\text{system hard.}}$ → **Hardening system** (if 50% effective) **could reduce the risk** score to 1.25 because **equipment is also a large driver**

	Probability of ignition	Consequence of the ignition	Risk Score
Location A	0.0010%	6000	0.06
Location B	0.0885%	2000	1.77
All assets – any vegetation causes	0.0600%	(consequence at B is constant, 2000)	1.20
Transformers - electrical/mechanical causes	0.0225%		0.45
Support Structures - mechanical causes	0.0010%		0.02
Conductors etc. - electrical/mechanical causes	0.0025%		0.05
Location C	0.0010%	6000	3

Transition Plan from v2 WDRM to v3 WDRM

In order to provide continuity for workplan execution, the **application of the V3 WDRM will be follow a phased approach over the next year**

Workplans with **shorter implementation cycles will be adjusted first in 2022**, followed by **emergent work during 2022,** and then for **longer term work for 2023 and beyond**

Further details will be provided in the 2022 WMP

Near Term Component Replacement Workplans

e.g. Fuses

e.g. Switches

Emergent Work

Tags

Future Workplans

System Hardening

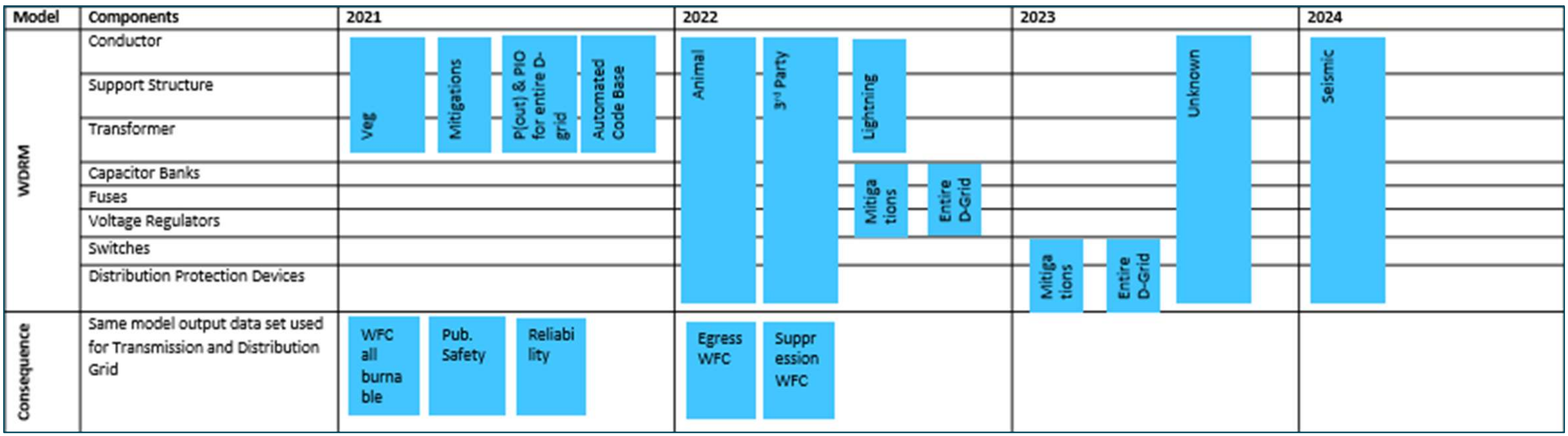
Undergrounding

WDRM Multi-Year Schedule

2021 WDRM established the framework or baseline for subsequent model evolution

Future iterations will **add additional components and ignition drivers** to our composite framework

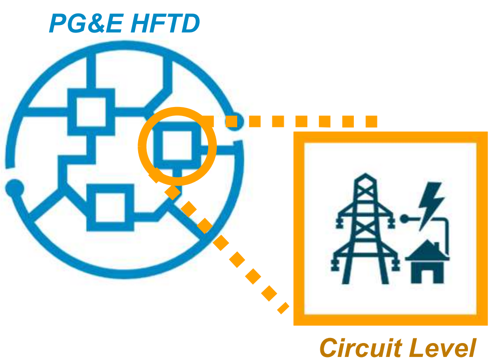
Full details will be provided in the 2022 WMP



PSPS CIRCUIT CONSEQUENCE MODEL

Need to Move to a More Granular Level

Commitment Language	*"PG&E has also modeled PSPS consequences to customers at a program level in terms of MAVF as discussed in Section 4.1(e); and is currently developing a more granular, circuit level model, to assess the impacts of PSPS de-energizations. PG&E currently plans to complete this analysis in collaboration with the WSD and the other California utilities by September 30, 2021."*



Determine the probability of PSPS circuit de-energization using historical look back analysis

Determining the consequences on each circuit based on frequency, customer scope, and duration, including customer type

Improvements since 2021 WMP submission, based on collaboration with other IOUs:

1) Moving from using actual 2019/2020 PSPS data into a historical lookback analysis
2) Updating the PSPS consequences to include safety and financial consequences, expanding on the reliability only consequence of PSPS

PSPS Circuit Level Framework

Goal	To develop a 2021 PSPS circuit risk model, to evaluate the spatial/circuit variation in risk, to help inform PSPS mitigation efforts to prioritize high risk locations and customers.
Objective	• *Enable risk assessment and mitigation quantification at a more precise, granular level* • *Allow mitigation quantification at that level of granularity* • *Create a framework for Risk Scores using MAVF values, allowing comparability between PSPS and Wildfire* • *Ultimately, consistent measure on the level of consequence for customers experiencing PSPS*

Baseline PSPS Circuit Consequence Model

- Utilize best available representation of meteorological impacts on PG&E system; currently, 10-Year Lookback for Potential PSPS
- Normalize the data to an average impact per year based on:
  1) number of events (frequency) per circuit
  2) number of customers (customer scope) per circuit
  3) average de-energization time (duration) per circuit
- Based on the combination of frequency, customer scope and duration, we can estimate the average customer minutes interrupted (CMI) on each circuit
- Based on total CMI across all circuits, the overall enterprise PSPS risk score is allocated across to each circuit to represent the risk score on each circuit

Ongoing Development

Mitigated PSPS Consequence

- Identify existing mitigation programs that provide customer reduction (by circuit)
- Identify mitigation programs focused on duration reduction (weather, restoration, switching)
- Estimate the PSPS Consequence mitigated from mitigation activities

Wildfire + PSPS Combined View

- Since both Wildfire and PSPS models are represented as MAVF scores, the results of the models can be combined to understand the Wildfire + PSPS risk per circuit

Modeling Framework – Baseline Consequence

Align Risk Modeling of PSPS customer impact at the circuit level based on MAVF risk scoring

Developed framework using the 10-year lookback for potential PSPS consequence at the Circuit Level

Risk per circuit driven meteorology scope, customers affected from Distribution impact, Transmission impact, or both Transmission & Distribution impact

Incorporating weighting for critical customer types to consider elevated risk impacts to these communities

Feeder Name	Cust. Count	Customer Events	Dx Risk %	Tx Risk %	Total Risk Score	Dx Risk Score	Tx Risk Score	Total Risk Rank	Total Dx Rank	Total Tx Rank
Circuit #1	4,555	122,655	59%	41%	30	18	12	1	4	18
Circuit #2	4,489	107,233	41%	59%	26	11	15	2	14	8
Circuit #3	5,152	118,916	52%	48%	26	14	12	3	8	17
Circuit #4	4,932	59,184	0%	100%	25	-	25	4	523	1
Circuit #5	4,223	107,070	53%	47%	23	12	11	5	11	25
Circuit #6	4,365	103,702	54%	46%	23	12	11	6	10	28
Circuit #7	3,668	87,169	41%	59%	21	9	13	7	19	15
Circuit #8	3,418	51,270	0%	100%	21	-	21	8	523	2
Circuit #9	2,823	83,288	59%	41%	21	12	8	9	12	43
Circuit #10	4,882	48,871	100%	0%	20	20	-	10	1	345
Circuit #11	4,022	48,264	0%	100%	20	-	20	11	523	3

Visuals shown are for demonstration purposes and may not reflect latest developments

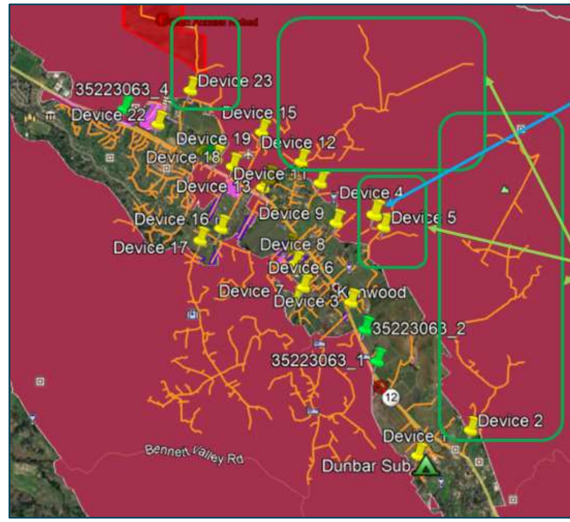
Modeling Framework – Mitigating Consequence

Identify top circuits based on PSPS risk ranking

Select mitigations over the planning horizon

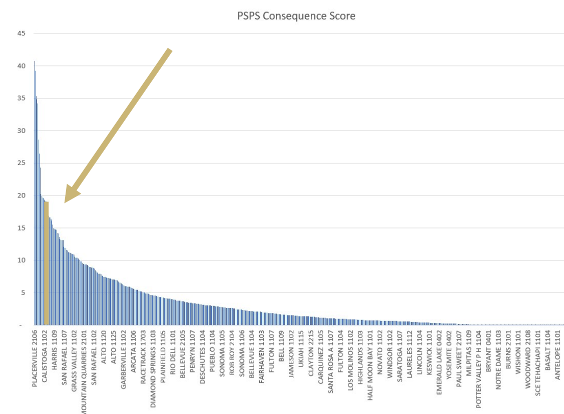
Account for mitigation effectiveness based on upstream impacts

For each circuit, identify mitigation solutions focused on risk reduction & risk spend efficiencies



Priority[1]	Projects
1	Sectionalizing Within HFTD
2	Line Removal
3	Undergrounding From Nearby Existing Source
4A	Temporary Distribution Microgrids Paired With Targeted Undergrounding
4B	Remote Grid

PSPS Location	Scope #	Scope Cost	Total Cust Saved	Regular Customer	Critical Customer	Cost/ Customer	Grid Solution PSPS RSE	Grid Solution PSPS+WF Grid RSE	BTM RSE
10*	Alternative	$385,000	67	55	12	$5,746	12.75	13.57	
2	PIH (A)	$789,000	7	7	0	$12,457	2.25	2.44	
1*	Alternative	$131,000	5	5	0	$26,200	1.07	1.80	
13*	Alternative	$1,724,000	32	30	2	$53,875	0.81	1.39	0.45
3	Preferred	$22,000	1	1	0	$22,000	1.28	1.28	
18*	Alternative	$1,610,300	22	20	2	$73,195	0.70	1.23	0.52
14*	Alternative	$726,300	8	8	0	$90,787	0.31	1.02	0.29
12	Preferred	$6,961,000	67	62	5	$103,895	0.45	1.02	0.48
23	Preferred	$4,372,000	22	22	0	$198,727	0.14	0.80	0.29



Visuals shown are for demonstration purposes and may not reflect latest developments

Future Enhancements

Process Development for PSPS Planning for 2022

- Utilizing PSPS model to point teams to plan on high consequence circuits
- Testing out impacts of prioritization and RSE at the project level

Integration of lookback data based on 2021 PSPS Protocols

- Due to the ongoing adjustments of the 2021 PSPS protocols, the same model framework will be updated based on latest available data

PSPS Circuit Segment Consequence Model

- WMP Remedy PG&E 21-05
- Alignment to the Wildfire Distribution Risk Model circuit segments

CALIFORNIA IOU COLLABORATION

Collaboration Between California IOUs

Since the 2019 WMP process, SCE, PG&E and SDG&E have conducted wildfire-related benchmarking sessions on various topics, including risk modeling, mitigation effectiveness, vegetation management activities, and PSPS operations:

- PG&E, SCE and SDG&E collaborated on at least 10 occasions in 2021 on risk assessment and modeling alignment opportunities
- IOUs have evaluated elements of risk modeling where near-term alignment could be achieved
- Currently developing a common vision (end-state) for long-term alignment on risk modeling, while recognizing differences

APPENDIX

Probability of Ignition Modeling Approach using MaxEnt

MODEL DETAIL

Methodology

- Divide Ignition Events into distinct categories of Vegetative or Conductor Caused
- Make vegetative or conductor ignition predictions with MaxEnt model 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: LoRE x CoRE

Approach

- Use MaxEnt model technique due to its ability to predict rare and unique events in a given region and their probability of occurrring both geospatially and under aggregated weather conditions
- Ignition probabilities calculated every 100m along conductor lines and then assigned to a pixel along Dx grid
- Ignition probabilities are combined with consequence (CoRE) to determine overall risk

Ignition Probability

Likelihood: via ignition prediction (MaxEnt)

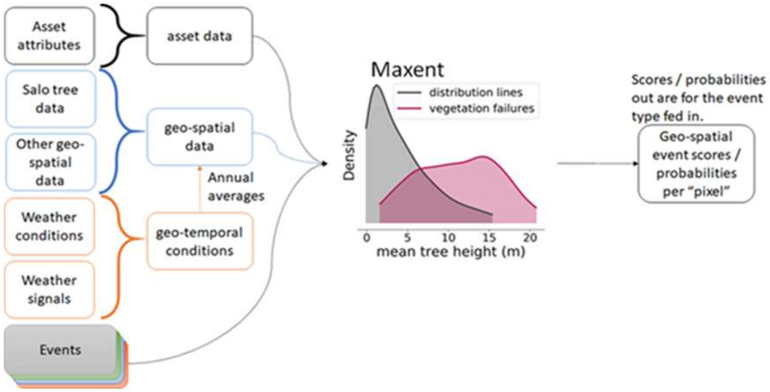
Effect: via:
(1) Ignition spread (Technosylva FireSim)
(2) Ignition consequence (Technosylva FireSim)

MAXENT MODEL

Training: On California Public Utilities Commission (CPUC) Reportable Ignition Events and related geospatial and temporal weather data

Vegetation/equipment Ignition Model: Two models were developed based on two specific risk mitigation priorities and their associated, relevant risk drivers – EVM and SH

Ignition likelihood: The likelihood of ignition in 100m x 100m pixels determined by either Vegetation or Equipment



Consequence Modeling Approach using Technosylva

MODEL DETAIL

Methodology

- Understand how a fire spreads in varying weather conditions and environments along PG&E resources
- Results tied back to RAMP model with MAVF scores
- Predict fire spread along all HFTD assets with an ignition event

Approach

- Fire spread simulations conducted at regular intervals along assets in HFTD
- Utilize Technosylva Firesim, an industry standard for fire burn simulations, taking into account environment and weather effects
- Consult with Fire Experts to review results

Consequence Components

Spread: via 8 hour burn simulation (Technosylva Firesim)

Effect: via:
(1) Ignition spread (Technosylva FireSim Acres Burned)
(2) Rate of Spread (Technosylva Firesim FBI)
(3) Burn Intensity (Technosylva Firesim FBI)
(4) Buildings Impacted (Technosylva Firesim Structures Impacted)

TECHNOSYLVA BURN SIMULATION

- Technosylva simulation of 8-hour burn every 200m along HFTD lines
- Simulations conducted with weather data from 452 worst historical fire weather days
- Outputs key consequence metrics: acres burned, population and structures impacted, and fire behavior index (FBI)
- FBI score based on flame length (burn intensity metric) and rate of spread (ROS)

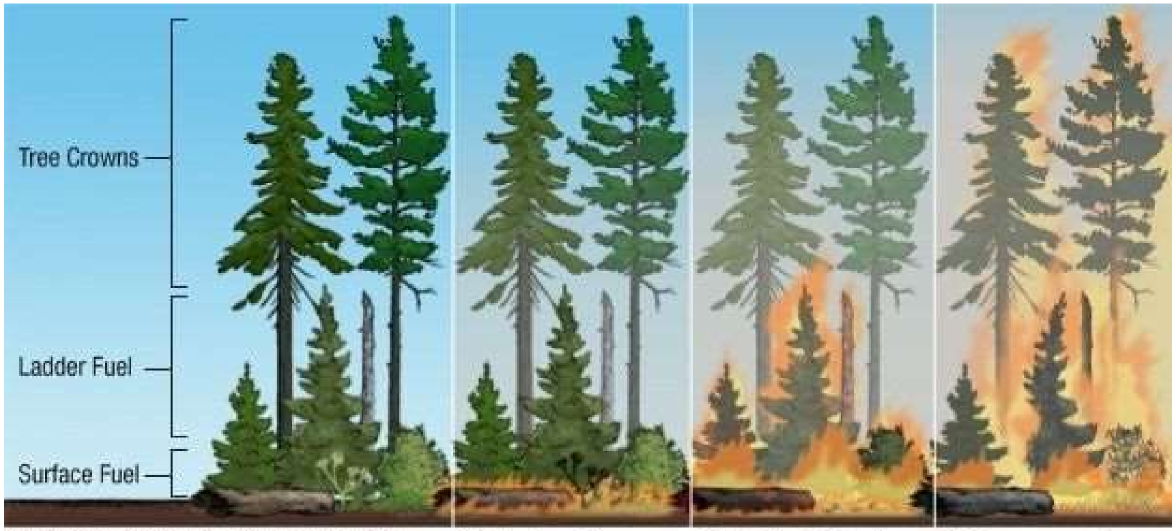
	FBI Class	Description
1	LOW	Fire will burn and will spread however it presents very little resistance to control and direct attack with firefighters is possible
2	MODERATE	Fire spreads rapidly presenting moderate resistance to control but can be countered with direct attack by firefighters
3	ACTIVE	Fire spreads very rapidly presenting substantial resistance to control. Direct attack with firefighters must be supplemented with equipment and/or air support.
4	VERY ACTIVE	Fire spreads very rapidly presenting extreme resistance to control. Indirect attack may be effective. Safety of firefighters in the area becomes a concern
5	EXTREME	Fire spreads very rapidly presenting extreme resistance to control. Any form of attack will probably not be effective. Safety of firefighters in the area is of critical concern.

Ladder Effect

Ladder effect in wildland fires create the conditions for low **lying fast burning fuels to intensify** as they move from up the canopy and into more energy dense fuel sources. Accounting for this effect in wildfire modeling **de-emphasizes areas of dense fuels** as high risk for ignition, due to lack of potential surface fuels.

Additionally, locations that have large amounts of surface fuels that can **sustain high temperatures** are rated more highly as these are more likely to ladder into difficult to contain crown fires.

Progression of Wildland Fire Ladder Effect



In a forest where fires rarely happen, fuel builds up: There's **surface fuel** (grass, logs, woody debris, brush); **ladder fuel** (shrubs, small trees, snags); and **tree crowns**.

1. Surface fires spread quickly through brush and woody debris.
2. Ladder fuels allow the fire to move up toward the forest canopy.
3. Tree crown fires are so intense, they're difficult to control.

Sourece: Idyllwild Fire https://idyllwildfire.com/defensible-space.html

LiDAR data preparation for the Vegetation Probability Model

LiDAR data, specifically tree heights and distances from lines, **has powered a ~10% improvement in predictive performance**

LiDAR data is only **recorded for distribution segments in the HFTD**

Salo Sciences has developed a model to ingest Satellite data and predict LiDAR **level tree height and distances estimates for the rest of the OH distribution locations.**