Wildfire Distribution Risk Model Version 4
(WDRM v4)
Documentation

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Revision History

Rev	Date	Comment
0	08/27/2024	Initial Release
1	03/11/2025	Added new cover page

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Executive Summary

The Wildfire Distribution Risk Model (WDRM) is used by PG&E to quantify and categorize wildfire risk from overhead distribution network assets. The model predicts the relative risk of a wildfire occurring during an annual fire season as the result of an ignition related to distribution grid assets. The relative wildfire risk results produced by the WDRM informs the PG&E Wildfire Mitigation Plan (WMP) as well as specific mitigation program work plans to help realize the company stand, *“Catastrophic wildfires will stop”*.

This document describes WDRM version 4 (v4) development by the Risk and Data Analytics (RaDA) team and highlights improvements implemented over its predecessor, WDRM v3.

WDRM v4 Risk Prediction

Wildfire risk is the combination of two modeled values, the probability, or likelihood, of an ignition event and the likely consequence of an ignition event at a geographical location. Each of these models apply machine learning techniques to historical events, asset attributes, and meteorological information to predict what will occur for a future fire season.

The probability of ignition model represents the likelihood of an ignition event occurring during a single fire season. The probability of ignition is predicted in two steps. First, the probability of outage (or failure) for a fire season is estimated for a variety of asset types and failure modes. These are often referred to as subset models. Second, the probability of an ignition given an outage is determined for each asset type and failure model combination. The final probability of ignition result is the multiplication of the probability of outage and probability of ignition given outage model results.

The consequence model projects the severity of fires that are ignited at geographic locations associated with distribution grid assets. The model is trained using historical fire records, fire simulation data from Technosylva, Fire Potential Index (FPI) information from PG&E meteorology, terrain topology, and other attribute data.

Often, wildfire mitigation programs are concerned with addressing the wildfire risk from multiple distribution assets and failure modes, which often require different remedial actions. The WDRM assembles the risk predicted for individual assets and failure modes into composite risk models to support more comprehensive mitigation planning such as system hardening and vegetation management.

WDRM v4 Improvements

WDRM v4 features several significant improvements to the modeling of distribution wildfire risk:

- Improved quality of training and covariate datasets, resulting in a direct impact on model quality.
- Transition of several WDRM v3 equipment asset event probability models from spatial, pixel-based to asset-based.
- Introduction of four new equipment asset-based event probability models.
- Vegetation event probability models were improved with data for tree health and wind direction.
- Wildfire Consequence v4 received several significant upgrades, including 24-hour fire simulations, Technosylva’s Terrain Difficult Index, Dry Wind Conditions, and corrections for public Egress and fire Suppression impacts. Wildfire Consequence v4 performance prediction for historical fires improved significantly over Wildfire Consequence v3.4.
- Circuit segment risk rankings are based on risk per primary overhead conductor mile for v4, replacing the mean risk based rankings issued for v3. This change made in response to System Hardening and Undergrounding mitigation team requests.

WDRM v4 Wildfire Risk Insights

WDRM v4 benefited from significant improvements to both the Event Probability Models for outages and ignitions and the Wildfire Consequence Model. As a result of the many contributing model improvements, WDRM v4 produces risk values that show a general flattening of the risk profile for the service territory. The most critical insight is that the WDRM v4 System Hardening composite risk buydown curve requires considerably more primary overhead conductor miles to account for 80% of the HFTD risk, increasing from 10,000 miles for WDRM v3 to 14,600 miles for WDRM v4.

While there are many contributing factors for the flattened risk buydown curve, a principal cause has been changes to the wildfire consequence model driven by improved historical fire datasets, 24-hour fire simulations, Technosylva's Terrain Difficulty Index, the introduction of public Egress and fire Suppression impacts, and the implementation of a revised consequence Multi-Attribute Value function (MAVf). While the new Wildfire Consequence v4 features have improved performance when compared with v3.4, it has also redistributed consequence, and therefore risk, across the service territory, resulting in a much flatter risk buydown curve.

Future Development Plans

The RaDA team has a 3-year risk model product plan targeted at the delivery of the next WDRM version release. While RaDA has historically produced the WDRM on an annual cycle, in the future WDRM version releases will be aligned with the WMP filing schedule. Therefore, this version of the WDRM is planned in support of the 2026 WMP.

WDRM v4 delivered several features planned for 2024 and 2025 development and additional features will be delivered during the remainder of 2024 and 2025. Several new features are planned for delivery in support of the 2026 WMP filing. Substantial efforts are expected to further improve the capture, detail, maintenance, and curation of data sets used for risk models. Future risk modeling will progress beyond informing mitigation work plan development and will provide risk and risk reduction values in support of data driven portfolio level decisions for the Integrated Grid Planning process.

1 Introduction

The Wildfire Distribution Risk Model (WDRM) is used by PG&E to quantify and categorize wildfire risk from overhead distribution network assets. The model predicts the relative risk of a wildfire occurring during an annual fire season as the result of an ignition initiated at the location of a distribution grid asset. The relative wildfire risk results produced by the WDRM supports the PG&E Wildfire Mitigation Plan (WMP) as well as specific mitigation program work plans to help realize the objective, *"Catastrophic wildfires will stop"*.

This document describes WDRM version 4 (v4) development by the Risk and Data Analytics (RaDA) team and highlights improvements implemented over its predecessor, WDRM v3.

1.1 Wildfire Risk Management Ecosystem

PG&E uses several planning and operational risk models for wildfire risk management within its wildfire risk management ecosystem:

- Planning models
  - Enterprise Risk Model
  - Wildfire Transmission Risk Model (WTRM)
  - Wildfire Distribution Risk Model (WDRM)
- Operational models for Public Safety Power Shut-off (PSPS) and Enhanced Power System Settings (EPSS)
  - Distribution OPW and IPW models
  - Transmission Operability Assessment

The outputs of the planning and operational models, along with input from Public Safety Specialists (PSS) and other Subject Matter Experts (SME), are used to form PG&E's Wildfire Mitigation Plan (WMP).

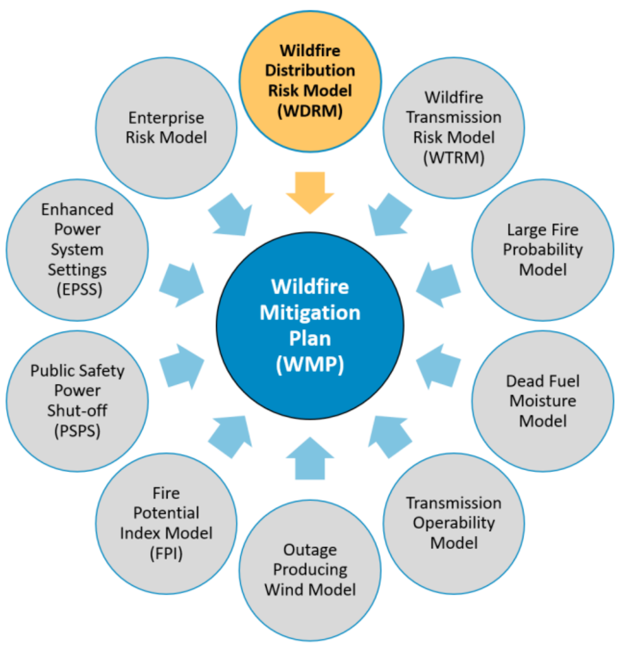

Figure 1 - PG&E Risk Management Ecosystem

The WDRM is the primary risk model that PG&E uses to provide insights to prioritize mitigation work to reduce wildfires initiated by the distribution grid. The WDRM produces predictions of wildfire risk and estimates of risk reduction for potential mitigation activities. Mitigation program work planners use the WDRM results, along with subject matter expertise and additional information potentially not included in the risk models, as part of their mitigation program work planning tools to develop work plans that systematically reduce wildfire risk while considering constraints such as budget allocation, human and equipment resource capacity, and regulatory commitments.

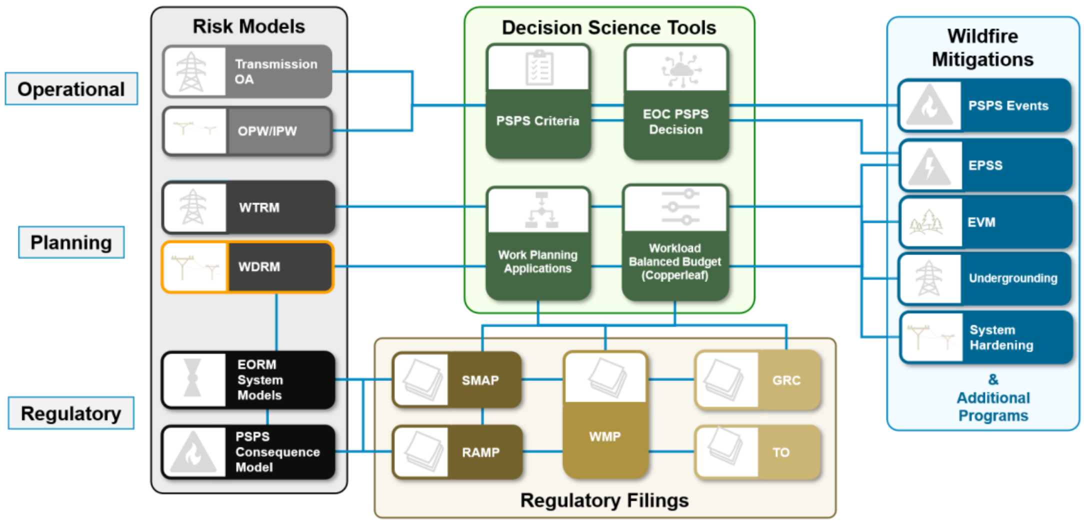

Figure 2 - WDRM Role in Risk Management

Wildfire risk modeling, mitigation work planning, and mitigation work execution occur on overlapping time cycles. *Figure 2* illustrates the expected coordination of the development and execution workflows.

1.2 Wildfire Distribution Risk Model (WDRM)

The WDRM was developed by the PG&E Risk and Data Analytics (RaDA) team to quantify the risk related to PG&E's overhead distribution equipment assets, which consist of overhead transformers, poles and other parts of support structures, conductor lines, and line-related equipment such as interrupters.

The WDRM provides predictions of the where, why, and how much wildfire risk occurs during a wildfire season of June 1st through November 30th.

It is important to understand that since the WDRM is built as a support model for wildfire mitigation planning, the model therefore predicts risk as an aggregate value for an annual fire season. The model does not predict specific risk for shorter time intervals within a fire season such as on a daily or monthly basis. The WDRM model results are relevant

WDRM	• **Provides predictions of wildfire risk**
Where is the risk?	• Risk is predicted at geographic and specific asset locations along PG&E's overhead distribution network
Why does the risk exist?	• Risk is dependent on asset attributes, environmental conditions, and other factors
How much risk is there?	• Risk scores are determined as a function of probability of ignition and wildfire consequence
When does the risk apply?	• Risk is predicted in aggregate for a fire season (June to November)

Figure 3 - WDRM Objectives

only for annual and multi-year planning programs. There are other models in the PG&E wildfire risk management ecosystem, such as the PSPS model, which are intended to inform operational risk mitigation using near-term data and forecasts.

Through modeled relationships between wildfire risk and an array of environmental and asset attributes, the WDRM helps mitigation program work planners understand why risk exists at a location or asset, and, therefore, which action(s) may be most effective for reducing the wildfire risk.

The WDRM estimates risk at geographic locations along the distribution network and for individual assets. Wildfire risk for the distribution network is determined from the results of two component models: the Probability of Ignition Model and the Wildfire Consequence Model.

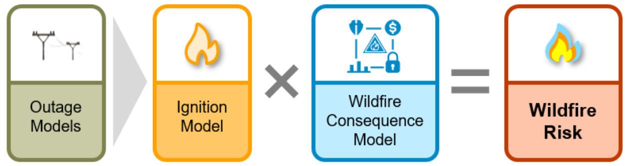

Figure 4 - Wildfire Risk Calculation

The Probability of Ignition, or p(i), Model uses two steps to predict the likelihood of an ignition for distribution grid assets and locations. First, a series of Probability of Outage, or p(o), models predict the likelihood of equipment asset outages that could be caused by various equipment and contact from object failure modes. Second, depending on an asset failure type and its failure mode, the likelihood that a failure will result in an ignition event is determined. The Probability of Ignition Model and the contributing Outage models are described in more detail in the *Distribution Network Event Probability Models v4 Documentation*.

The Wildfire Consequence (WFC) Model predicts the impact of an ignition event in terms of the potential hazard posed to life, property, and land. Consequence values are determined for the service territory based on simulated fire outcomes that use detailed fuels, weather, and topography data. Consequence values are generally higher at locations that are typically dry, windy, and have an abundance of burnable fuel. The WFC is described in more detail in the *Wildfire Fire Consequence Model v4 Documentation*.

The predictions from the Probability of Ignition Model and the Wildfire Consequence Model are combined to determine the Wildfire Risk for a distribution grid asset or location.

1.3 Mitigation Program Planning

The WDRM primary purpose is to inform various PG&E wildfire risk mitigation plans, also known as Work Plans. Work plans are produced, then executed, by various programs, including:

- *System Hardening* – replaces existing assets with more resilient equipment such as covered conductors or stronger poles or relocates assets to lower-risk locations.
- *Undergrounding* – moves existing assets underground to eliminate wildfire risk.
- *Vegetation Management* – performs expanded vegetation trimming and removal in selected locations.
- *Pole Replacement* – replaces old and worn wood distribution poles.
- *Transformer Replacement* – replaces old and overloaded distribution transformers.

The WDRM output is a relational dataset that can be viewed on spatial map with layered representation of risk, consequence, and probability values – each characterizing risk from different causes or assets. These layers of risk can be examined and compared individually, or they can be composited together to understand the full risk from all applicable distribution grid assets.

1.4 System Inspections and Electric Corrective Tags Programs

The WDRM, in addition to PG&E's long-term wildfire risk mitigation work plans, also inform the prioritization of annual work plans for both the System Inspections and Electric Corrective (EC) Tags Programs.

- *System Inspections* – develops a plan which emphasizing risk to determine assets to be inspected in the upcoming year and whether those assets will receive a ground or aerial inspection.
- *EC Tags Program* –addresses the Wildfire Mitigation Plan (WMP) annual commitment to meet annual risk reduction targets associated with the existing number of HFTD/HFRA tags.

1.5 Documentation Suite

This document is part of the documentation suite for the Wildfire Distribution Risk Model (WDRM) v4:

- WDRM v4 Documentation (this document)
- Wildfire Consequence Model v4 Documentation
- Distribution Network Event Probability Models v4 Documentation
- RaDA Algorithms and Methodologies

The intent of this document is to present the development, performance, and use of the Wildfire Distribution Risk Model. This document describes the calculation of distribution asset wildfire risk, aggregation of risk to System Hardening circuit segments, and the creation of risk composites in support of wildfire mitigation program planning.

Note that the calculation of wildfire risk is dependent on prediction results from the Distribution Event Probability and Wildfire Consequence models. These models are only generally described in this document. Detailed documentation for the Distribution Event Probability and Wildfire Consequence models can be found following the links provided above.

This document seeks to provide the lay reader with a broad understanding of WDRM v4. It is not intended to provide comprehensive detailed mathematical or scientific descriptions of all methods used to produce the risk model.

2 WDRM v4 Highlights and Evolution

The WDRM is continuously improved and expanded to incorporate refreshed data and new data sources, explore new event probability models that provide new causal path insights, and absorb advancements in wildfire simulation. The continuous improvement effort is reflected in the evolution of the WDRM version releases. While each new model has advanced the science of wildfire risk models they are each statistical approaches to characterizing and quantifying wildfire risk in support of PG&E's stand that catastrophic wildfire will stop. As statistical predictions the predictive power of the models or their subparts can have similar effectiveness while subsequent models can provide improvements in singling out specific risk drivers. For this reason, workplans developed with one version of the risk models do not become outdated or incorrect with the release of a new model.

2.1 WDRM v4 Highlights

WDRM v4 features several significant improvements to the modeling of wildfire risk.

- Concentrated effort to improve the quality of training and covariate datasets, which had a direct impact on the quality of model predictions.
- Migration of several equipment asset event probability models from spatial, pixel-based to asset-based, including:
  - Primary Conductors
  - Support Structures
  - Transformers
  - Voltage Regulators
- Development of new equipment asset-based event probability models, including:
  - Capacitor Banks
  - Dynamic Protective Devices
  - Fuses
  - Switches
- Vegetation event probability models were improved with data for:
  - Tree Canopy Density
  - Tree Health
  - Wind Direction
- Wildfire Consequence received several significant upgrades:
  - Technosylva's wildfire simulations were increased from 8-hour to 24-hour duration.
  - Technosylva's Terrain Difficulty Index (TDI) was incorporated into the Consequence model.
  - Dry Wind conditions were added to the Consequence model.
  - Egress and Suppression impacts are used to modify Consequence predictions.
- In response to System Hardening and Undergrounding mitigation work planning team requests, circuit segment aggregated risk rankings are produced based on wildfire risk per primary overhead conductor mile.

2.2 WDRM Version Evolution

Mitigating wildfire risk posed by utility assets is a rapidly evolving area of practice where improvements are achieved through the adoption of new data and methods. As such, PG&E's WDRM has evolved – and improved – over time.

Figure 5 provides an overview of the evolution and improvement of the Event Probability Models that contribute probability of failures and ignitions to the WDRM.

Distribution Event Probability Model Evolution				
Feature	**v1 (2019)**	**v2 (2021)**	**v3 (2022)**	**v4 (2023)**
Service Scope	HFTD Tier 2/3	HFTD Tier 2/3	Service Territory	Service Territory
GIS Vintage	2018	2018v/2020c	January 2022	January 2023
Ignitions Event Domain	2015 – 2018	2015 – 2019	2015 – 2020	2015 – 2022
Failures Event Domain	n/a	n/a	2015 – 2021	2015 – 2022
Circuit Segment Aggregation	x	x	Mean Pixel	Risk per Line Mile
Model Compositing	x	x	✓	✓
Asset Models				
Primary Conductor	Pixel-based	Pixel-based	Pixel-based	Asset-based
Secondary Conductor	x	x	Pixel-based	Pixel-based
Support Structure	x	x	Pixel-based	Asset-based
Transformer	x	x	Pixel-based	Asset-based
Voltage Control	x	x	Pixel-based	Asset-based
Capacitor Bank	x	x	x	Asset-based
Switch	x	x	x	Asset-based
DPD	x	x	x	Asset-based
Fuse	x	x	x	Asset-based
Vegetation Models	Pixel-based	Pixel-based	Pixel-based	Pixel-based
LiDAR Data	x	x	✓	✓
with Tree Canopy Density	x	x	x	✓
Tree Health	x	x	x	✓
Wind Direction	x	x	x	✓
Animal Models	x	x	Pixel-based	Pixel-based
Third Party Models	x	x	Pixel-based	Pixel-based

Figure 5 - Event Probability Model Evolution

Figure 6 provides an overview of the evolution and improvement of the Wildfire Consequence Model that contributes potential ignition consequences to the WDRM.

Wildfire Consequence Model Evolution				
Feature	**v1 (2019)**	**v2 (2021)**	**v3.4 (2022)**	**v4 (2023)**
Service Scope	HFTD Tier 2/3	HFTD Tier 2/3	Service Territory	Service Territory
GIS Vintage	July 2016	April 2019	January 2022	January 2023
Fuels	2012 LANDFIRE	2020 Fuels Snapshot	2030 Forecast Growth	2030 Forecast Growth
Fire Simulation	6 hours	8 hours	8 hours	24 hours
Historical Fire Locations	No	No	Nearest Asset	At Ignition Location
Model Formulation				
REAX, Vol. & Struct.	✓	x	x	x
Fire Burn Index (FBI)	x	✓	x	x
Acres Burned	x	✓	x	x
Fire Potential Index (FPI)	x	x	✓	✓
Flame Length	x	x	✓	✓
Rate of Spread	x	x	✓	✓
Dry Wind Conditions	x	x	x	✓
Egress Impact	x	x	x	✓
Suppression Impact	x	x	x	✓

Figure 6 - Wildfire Consequence Model Evolution

2.3 Legacy WDRM Models

Legacy WDRM version release data remain available for historical and audit purposes. WDRM v2 and v3 results are directly available to self-service users through the WDRM Landing Page in Foundry.

2.3.1 WDRM v1

WDRM v1 was generated for the 2017 initial RAMP filing under the S-MAP agreement. The first-generation RAMP model for Enterprise Risk Management used probabilistic modeling. It was built in an Excel format (with an add-in feature called @Risk) and relied on Monte Carlo simulation to produce a baseline and mitigated Multi Attribute Risk Score (MARS) and Risk Spend Efficiency (RSE). The first version of the model used in the 2019 WMP predicted wildfire risk on a per-circuit basis and circuit segment basis, for High Fire Threat District (HFTD) only.

In 2019, PG&E started to prioritize circuits and circuit segments for wildfire risk mitigation using a probability of ignition from this v1 model, and wildfire consequence predictions from fire modeling software vendor REAX. Mitigation work planned with the benefit of the v1 WDRM was performed during 2019, 2020, and 2021.

2.3.2 WDRM v2

WDRM v2 was generated for the 2020-2021 second RAMP filing in accordance with the S-MAP Settlement Agreement (Dec 2018). WDRM v2 took a meaningful step forward by using more advanced modeling. WDRM v2 featured more specific event models for predicting ignitions and used PG&E's version of the CPUC's multi-attribute value function (MAVf) to estimate wildfire consequences as required by the S-MAP Settlement Agreement. During the second year of the filing, the v2 model was improved to use more advanced algorithms and machine learning.

PG&E also improved the v2 modeling to be more granular spatially and by risk driver. The spatial resolution of the model was improved from circuits for v1 to 100m x 100m geographic areas, or pixels, within HFTD for v2. In addition, vegetation-caused ignitions were modeled separately from other ignitions along conductor lines to understand the differences between these two risk drivers. This resulted in two related but separate models, vegetation-caused and conductor-involved, which were subsequently used by the EVM and System Hardening wildfire risk mitigation programs, respectively.

WDRM v2 also featured upgraded wildfire consequence mapped into MAVF fire size/severity tranches based upon physics-based fire simulations provided by outside vendor Technosylva.

2.3.3 WDRM v3

WDRM v3 was released in support of the 2023 WMP. The third generation of WDRM development was guided by internal reviews, public safety specialist feedback, technology partner feedback, third-party intervener comments, and an independent third-party model review.

WDRM v3 greatly expanded the scope of the model and included more-advanced machine-learning modeling techniques, incorporated newly available data, and significantly expanded its understanding of potential ignition sources from distribution assets.

WDRM v3 modeled several new causal pathways to ignitions. While WDRM v2 provided ignition event modeling for primary conductors and vegetation, WDRM v3 offered asset event models for secondary conductors, support structures, transformers, and voltage controls. New contact from object event models were added for animal and third-party contacts with distribution assets.

WDRM v3 incorporated Wildfire Consequence v3.4, which included updates to consider 2030 forecasted growth for fuels, Fire Potential Index, simulated flame length, and simulated flame rate-of-spread to predict ignition consequences.

3 WDRM v4 Risk Prediction

3.1 Risk Model Overview

There are two main component models for determining risk in the WDRM, an event probability of ignition and the consequence of ignition at a geographic location. However, both the event probability of ignition and the consequence models are composed of supporting models that contribute causal knowledge to the WDRM. *Figure 7* provides an overview of all model components that contribute to the estimation of wildfire risk.

Probability of ignition, or p(i), sometimes referred to as Likelihood of a Risk Event (LoRE), represents the expected count of ignition events for an annual wildfire season of June 1st through November 30th. The probability of ignition is determined from a suite of distribution event probability models. All but one of the event probability models are probability of outage (or failure) models. These models predict the expected number of outages or failures for a fire season for a specific type of asset found in the distribution network. The outcomes for the outage event models are in turn processed through a single probability of ignition given outage (p(i|o)) model that yields the probability of ignition values for all event models. Full documentation on the probability of ignition model and the associated set probability of outage models is available in a separate document, *Distribution Network Event Probability Models (DEPM) v4 Documentation*.

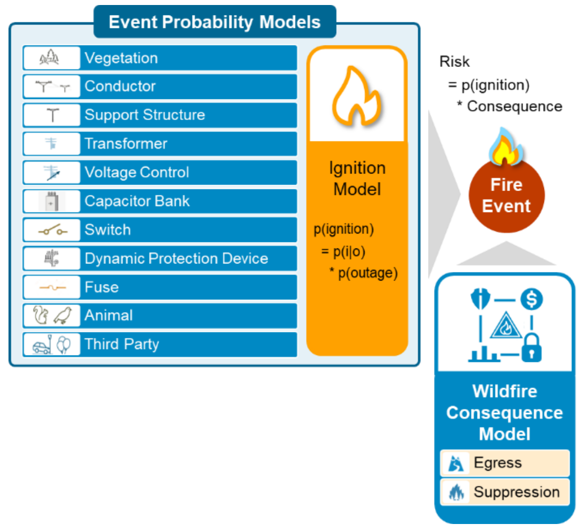

Figure 7 – WDRM Risk Components

Consequence of an ignition event, sometimes referred to as Consequence of a Risk Event (CoRE), provides the expected severity of wildfire outcome for a specific geographical location within the distribution network. Full documentation on the Consequence model is available in a separate document, *Wildfire Fire Consequence Model (WFC) v4 Documentation*.

The combination of probability of ignition and its consequence results in a relative wildfire risk value that can be used to inform wildfire mitigation planning. This document explains how wildfire risk is determined from combining probability of ignition and consequence values for assets, locations, and circuit segments, and mitigation program composites.

3.1.1 Risk Value Calculation

Wildfire Risk for a given asset or asset location is simply the product of an event probability of an ignition and the expected consequence of an ignition event. The event probability of ignition has two modeling components, an event probability of outage and the probability of ignition given outage. *Figure 8* illustrates the wildfire risk calculation form its components.

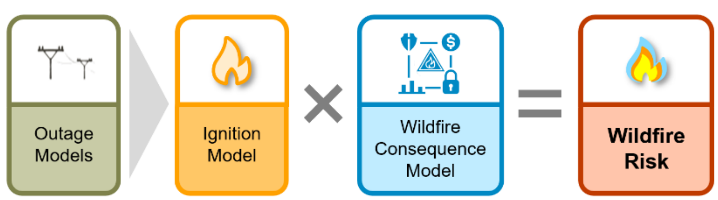

Figure 8 - Wildfire Risk Calculation

In its simplest form, wildfire risk is the product of an event probability of ignition and its potential consequence:

$$Risk = p(i) * Consequence$$

The probability of ignition, however, is itself the product of an event model probability of outage and the estimated probability of ignition given an outage, and the risk calculation can be expanded to:

$$Risk = p(o) * p(i|o) * \ Consequence$$

Where:

Variable	Description
Risk	Seasonal wildfire risk for an asset or asset location
p(i)	Seasonal probability of ignition for an asset or asset location
p(o)	Seasonal probability of outage (or failure) for an asset or asset location
p(i|o)	Seasonal probability of ignition given probability of outage
Consequence	Expected wildfire consequence for an ignition location

In theory, the WDRM calculates a wildfire risk value for every asset and every location containing an asset for the entire distribution network. Unfortunately, data quality issues and the asynchronous nature of many of the underlying data sources will result in some WDRM assets and locations having insufficient information to generate an event probability of ignition, an ignition consequence value, or both. As a result, the WDRM is always missing some wildfire risk values for a small number of assets and locations.

3.1.2 Key Modeling Constructs

There are several important modeling constructs for delivering the WDRM risk data. WDRM risk is the result of combining probability of ignition predictions from the Event Probability Models with the probable wildfire outcome from the Wildfire Consequence Model. However, the supporting models provide their data at the granularity of either an individual asset or an individual geospatial grid pixel. For the risk data to be useful for mitigation work planning, the risk data must be adapted to match how the work is planned. This is accomplished through two methods of processing: results aggregation and multi-model compositing. Results aggregation organizes and sums multiple pixel and asset risks to the work planning context of circuit segments used by several mitigation programs. Multi-model compositing combines the risk from several different event models to create a total risk value for work plan prioritization.

3.1.2.1 Modeling Components

A persistent goal for each new WDRM version release is to improve its predictive power over its predecessor. One way this has been achieved is to increase causal specificity of the Event Probability and Wildfire Consequence Models.

For the Event Probability Models, WDRM v2 only delivered separate event probability models for System Hardening and Vegetation Management mitigation work planning. For WDRM v3, 17 unique causal event probability models were developed. WDRM v4, via DEPM v4, delivers 23 causal event models.

There are two types of Event Probability model, Equipment Asset Models and Contact From Object Models. Asset Models provide event probability values for specific equipment assets, while Contact From Object Models are geo-spatial, delivering probability values associated with 100m by 100m grid of pixels that overlay the distribution assets.

DEPM v4 delivers fourteen Equipment Asset and nine Contact From Object models for WDRM v4 risk calculations.

The Wildfire Consequence Model v4 that supports WDRM v4 has also grown in capability and now includes two impact adjustments for Egress response and fire Suppression.

3.1.2.2 Results Aggregation

Several use cases for the WDRM results require understanding the total or average risk for a set of assets. This is accomplished through the aggregation of contributing causal risks. The WDRM supports the aggregation of risk to circuit segments, which break up distribution circuits into small sections which are more appropriate for planning by mitigation programs such as System Hardening, Undergrounding, and Vegetation Management. For each circuit segment, the risk for any given event probability model can be summed to determine the aggregated risk contribution. In the case of an Asset model, the risk for each asset assigned to a circuit segment is summed. For a Contact From Object model, the risk value for each pixel touched by the circuit segment is summed. Risk aggregation is explained in more detail in Section *4.1*.

3.1.2.3 Model Compositing

Some mitigation programs need to consider the combined risks from multiple causal Event Probability Models. The WDRM provides this capability through the compositing of risk. WDRM v4 provides several model composites for assets that have multiple causal models and for specific mitigation work plans.

Asset model composites sum the constituent causal models to provide a summed risk. For instance, the Primary Conductor Line Slap, Wire Down, and Other causal model risk are combined to produce a total Primary Conductor risk.

Mitigation program composites sum risks from the suite of causal models that can influence the selection of risk mitigation methods. WDRM v4 provides composite risk values in support of System Hardening, Undergrounding, and Vegetation Management mitigation work planning.

Model compositing is explained in more detail in Section *4.2*.

3.2 Model Development Process

All WDRM models are developed following an iterative process. A high-level view of the development process is shown in *Figure 9*.

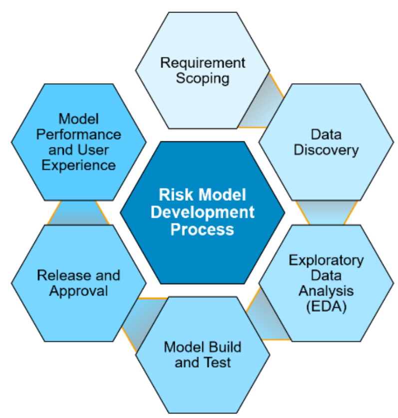

Figure 9 - Model Development Process

Requirement Scoping – Encompasses user feedback, new user requirements, potential performance improvements, and new or desired causal information to set model development goals.

Data Discovery – Researching new data sources, obtaining updates to refresh existing data sources, and cleaning and validating data for potential model use.

Exploratory Data Analysis (EDA) – Data analysis and investigation to determine fitness for modeling.

Model Build and Test – Successive builds of proposed models verified for performance against independent testing data.

Release and Approval – Candidate release models are published to the user community for critique. Viable release candidates are presented through a governance process to gain approval for general release in support of wildfire mitigation work planning.

Model Performance and User Experience – The approved model is monitored for performance against actual events and user feedback is collected to inform the next iteration of model development.

This is a very simplified description of the risk modeling process. At any step in development, knowledge gained can require an iteration back to an earlier process step or even to a reevaluation of model development scope.

3.3 Event Probability Models Contribution

The Event Probability Models support the WDRM by predicting where distribution assets are most likely to experience an abnormal operating event that results in an outage or ignition event and include:

- Probability of Outage Models
  - Equipment Asset Models
  - Contact From Object Models
- Probability of Ignition (given Outage) Model

Equipment Asset Models consider event history and contributing factors to predict failure of specific types of electrical equipment. Each asset model uses a unique set of inputs (covariates) from a pool of asset attributes and environmental conditions. For some assets, unique models (sub-sets), are produced for specific types of failures.

The following Equipment Asset models were produced in support of WDRM v4:

- Capacitor Bank
- Dynamic Protection Device (DPD)
- Fuse
- Primary Conductor
  - Line Slap
  - Wire Down
  - Other
- Secondary Conductor
- Support Structure
  - Electrical Failure
  - Structural Failure
- Switch
- Transformer
  - Leaking
  - Failure
- Voltage Regulator
- Other Equipment

Contact from Object Models consider event history and contributing factors to predict failure caused by contact from foreign objects with electrical assets. Each contact model uses a unique set of inputs (covariates) from a pool of object attributes and environmental conditions. All contact models provide unique models (sub-sets) for specific types of contact failures.

The following Contact from Object models were developed in support of WDRM v4:

- Animal
  - Bird
  - Squirrel
  - Other
- Third Party
  - Balloon
  - Vehicle
  - Other
- Vegetation
  - Branch
  - Trunk
  - Other

The Probability of Ignition is the likelihood that an asset-based ignition will occur during a fire season. Probability of Ignition is predicted by the Probability of Ignition Given Outage Model using the probability of outage predictions from all of the Asset Equipment and Contact From Object Models along with other attributes such as environmental conditions. Fire season probabilities of ignitions are individually predicted for each specific Asset Equipment and Contact From Object Model.

3.4 Wildfire Consequence Model Contribution

The Wildfire Consequence Model supports the WDRM by estimating the likely outcome of an ignition originating at the geographical location of any electrical asset. The consequence model is trained to historical fires while considering Technosylva fire simulations, PG&E Meteorology's FPI index, dry wind conditions, and other fuel and weather conditions. In addition, the consequence estimates are adjusted for population Egress and fire-fighting Suppression impacts.

The consequence model produces estimates outcomes for acres burned, buildings damaged, and probable fatalities. The model outcomes are transformed through a Multi-Attribute Value function (MAVf) provided by Enterprise Risk Management to determine the final consequence value used for calculating wildfire risk.

The Wildfire Consequence Model v4 that supports WDRM v4 risk has also grown in capability when compared with Wildfire Consequence Model v3.4, and now includes two impact adjustments for Egress response and fire Suppression as shown in *Figure 10*.

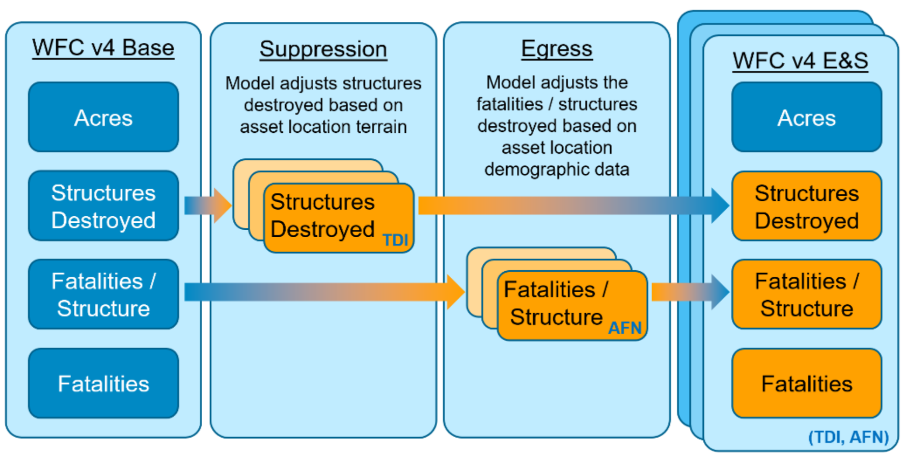

Figure 10 - Wildfire Consequence Model v4

4 Compositing and Aggregation

An important objective for the WDRM is to provide wildfire risk analysis in support of wildfire risk mitigation program planning, including System Hardening, Undergrounding, and Vegetation Management. Mitigation program planners need to understand model results in a larger context than the direct model outputs. Providing contextual values requires that the asset and spatial model results be composited and aggregated to the desired planning context. The WDRM, based on requirements originally provided by the System Hardening program, provides risk results that composite several of the event probability model risk results and aggregate these risks to circuit segments.

Detailed descriptions on circuit segment definitions, risk compositing, and risk aggregation can be found in the RaDA Algorithms and Methodologies documentation.

4.1 Model Results Aggregation

The WDRM is supported by Event Probability models that produce both equipment asset and geospatial results. Equipment Asset models produce results that estimate event probabilities or risk for individual assets at point locations. Spatial, or grid pixel, models, product results that estimate event probabilities or risk within 100m by 100m square pixels that form a grid over the distribution and transmission service territories. The Wildfire Consequence model also produces geospatial results assigned to the same 100m by 100m pixel grid. Assigning risk to a circuit segment context requires the aggregation of multiple grid pixel and equipment asset risk results.

4.1.1 Aggregation Methodology

Simply, circuit segment aggregation sums up all the potential risk that modeled along the length of a segment. *Figure 11* shows an example of two circuit segments that intersect multiple grid pixels and have multiple assigned equipment assets ( ). For geospatial models, this pixel risk for any pixel that is intersected by a circuit segment is summed to determine the aggregated pixel risk. For asset models, the risk for each asset belonging to the circuit segment is summed to determine the aggregated asset risk. Finally, the summed pixel and asset risks can in turn be summed to calculate the total aggregated circuit segment risk.

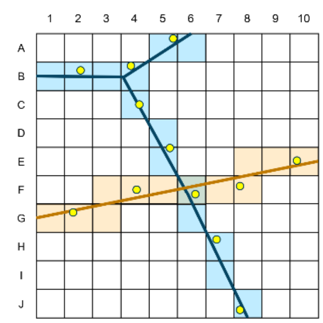

Figure 11 - Circuit Segment Aggregation

Shared pixels and assets complicate circuit segment aggregation of risk. In *Figure 11* the two circuit segments share a common pixel, F6, and a support structure (pole) asset also located in pixel F6. To keep the total sum of risk on the network constant, these shared risk results must be partially distributed to each of the circuit segments. The aggregation methodology, in this case, would assign half of the F6 pixel risk and half of the support structure risk to each of the circuit segments.

Aggregation methodology is described in more detail in RaDA Algorithms and Methodologies documentation.

4.2 Compositing Event Models

Ultimately, the purpose for the WDRM is to inform the prioritization of wildfire risk mitigation programs. The WDRM event probability model risk results can be flexibly composited to provide risk values and priority rankings for specific mitigation programs. Using composited results, programs can prioritize mitigation of the highest total risks while using the contributing event probability models to understand the best mediation approach to handle the specific components of risk.

Risk can be composited for any combination event probability models. Mitigation planners and Subject Matter Experts can focus on the drivers of risk for which they are responsible with confidence that their composited view is relevant to their work planning needs.

4.2.1 Compositing Methodology

An event probability model produces, by asset or pixel, a probability of ignition. Combining a probability of ignition with its consequence produces the wildfire risk. Probability of ignition and risk results can be composited to create total probability of ignition and total risk. As visualized in *Figure 12*, individual model results are summed to determine total composite results.

Compositing methodology is described in more detail in RaDA Algorithms and Methodologies documentation.

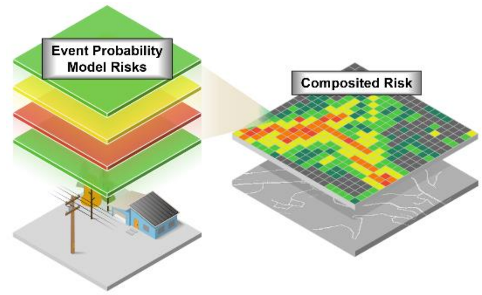

Figure 12 - Model Compositing

4.2.2 Mitigation Composites

Mitigation program work planners are often interested in a partial set of event probability model risk results. Custom composites are configured so that the total risk for only the applicable event models gets considered as part of the work prioritization process. *Figure 13* illustrates how model selection can be used to configure a composite for a specific work plan.

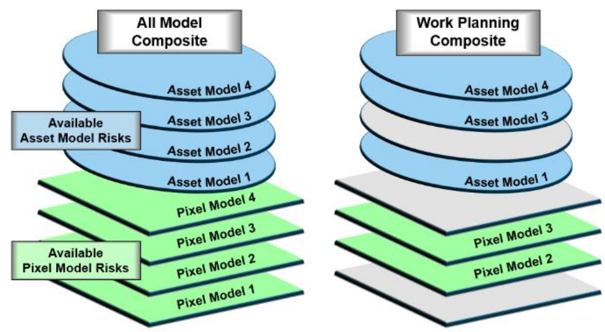

Figure 13 - Mitigation Composite Membership

WDRM v4 delivers the following mitigation composites, composed from the 23 available event probability models:

Table 1 – WDRM v4 Mitigation Composites

Event Probability Model	All Composite	System Hardening	Vegetation Management
Animal – Bird	✓	✓	×
Animal – Squirrel	✓	✓	×
Animal – Other	✓	✓	×
Capacitor Bank	✓	✓	×
Dynamic Protection Device (DPD)	✓	✓	×
Fuse	✓	✓	×
Primary Conductor – Line Slap	✓	✓	×
Primary Conductor – Wire Down	✓	✓	×
Primary Conductor – Other	✓	✓	×
Secondary Conductor	✓	✓	×
Support Structure – Electrical	✓	×	×
Support Structure – Equipment	✓	✓	×
Switch	✓	✓	×
Third Party – Balloon	✓	✓	×
Third Party – Vehicle	✓	✓	×
Third Party – Other	✓	✓	×
Transformer – Failure	✓	✓	×
Transformer – Leaking	✓	×	×
Vegetation – Branch	✓	✓	✓
Vegetation – Trunk	✓	✓	✓
Vegetation – Other	✓	✓	✓
Voltage Regulator	✓	✓	×
Other Equipment	✓	✓	×

4.3 Composite Aggregation

Composites are defined in support of a specific mitigation program. As mentioned previously, many mitigation programs are aggregates of risk results, most commonly the context of circuit segments. Aggregating composite results require a specific calculation procedure.

4.3.1 Aggregated Composite Probability of Ignition and Risk

The aggregation of event probability of ignition and risk composites is relatively straightforward as they are simply sums of all component results. *Figure 14* provides a simple example where a circuit segment is comprised of several assets located in two consequence pixels. The composited results for the assets (○) are shown beneath the consequence grid pixels. The aggregation of the composited values for probability of ignition and wildfire risk are shown in the blue-shaded boxes to the lower right.

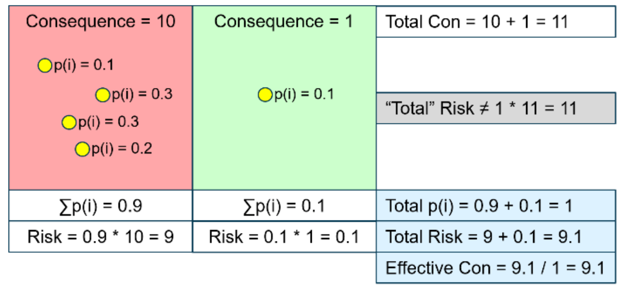

Figure 14 - Composite Aggregation Example

4.3.2 Aggregated Composite Ignition-Weighted Consequence

Unfortunately, consequence values cannot be directly composited like probability of ignition and wildfire risk when aggregating contextually to circuit segments. This is because the process of compositing and circuit segment aggregation will combine each consequence pixel result with a varying number of event probability of ignition results. Referring again to *Figure 14*, we can see in the gray-shaded box that using a simple sum of the consequence values and the total probability of ignition will not yield the correct total risk.

The resolution to this mathematical inconsistency is to back-calculate the effective, or ignition-weighted, consequence for an aggregated composite by dividing the total aggregated risk by the total aggregated probability of ignition. This calculation is shown in the blue-shaded box at the lower right-hand corner of the example.

5 Results and Model Performance

WDRM v4 benefited from improvements to both the Event Probability Models for outages and ignitions and the Wildfire Consequence Model. As a result of the many contributing model improvements, WDRM v4 produces risk values that show a general flattening of the risk profile for the service territory.

5.1 WDRM v4 Performance

WDRM wildfire risk is calculated using predicted values from the supporting Event Probability and Wildfire Consequence models. Therefore, WDRM performance is dependent on the performance of the supporting models. Significant performance improvements were realized for WDRM v4 from both supporting models.

A focused effort was made to improve the quality of the event probability datasets. Historical event records were reviewed to correctly attribute failures and ignitions to their correct cause and equipment asset relationships were improved so that risk could be determined and aggregated appropriately. In addition, both the failures and ignitions datasets were corrected for probable impacts of EPSS activation.

Several new event probability models were introduced for v4, including Fuses, Switches, and Voltage Regulators as well as introducing three Primary Conductor causal models for Line Slap, Wire Down, and Other. Also introduced for v4 were Asset-based models. New models were developed as Asset-based, while v3 pixel-based spatial models for Capacitor Banks, DPD, Primary Conductors, Support Structures, and Transformers were transitions to Asset-based. These changes contributed to improved model performance for both probability of outage and probability of ignition predictions.

Figure 15 provides an overview of Event Probability Model v4 performance. Performance values shaded in green show strong performance, in tan demonstrate adequate performance, and a few, shown in gray, exhibit poor performance.

Event Model	p(o) AUC	p(i) AUC	p(o) Conc. Factor	p(i) Conc. Factor
Animal – Bird	0.651	0.683	1.79	2.16
Animal – Squirrel	0.839	0.852	3.70	3.91
Animal - Other	0.741	0.756	2.53	2.93
Capacitor Bank	0.558	0.549	1.40	1.40
DPD	0.625	0.475	1.00	1.50
Fuse	0.669	0.681	2.00	2.10
Primary Conductor – Line Slap	0.770	0.757	3.33	3.33
Primary Conductor – Wire Down	0.628	0.639	1.91	1.78
Primary Conductor - Other	0.694	0.706	2.75	2.50
Secondary Conductor	0.718	0.728	2.49	2.59
Support Structure - Electrical	0.854	0.848	3.90	3.70
Support Structure - Equipment	0.602	0.654	1.63	2.02
Switch	0.637	0.608	1.67	1.67
Third Party - Balloon	0.801	0.817	3.25	3.42
Third Party - Vehicle	0.681	0.712	1.85	2.23
Third Party - Other	0.613	0.672	1.78	2.05
Transformer – Equipment	0.725	0.748	2.94	3.53
Transformer – Leaking	0.865	0.845	5.00	5.00
Vegetation - Branch	0.804	0.824	3.20	3.43
Vegetation - Trunk	0.825	0.832	3.40	3.45
Vegetation - Other	0.760	0.771	2.57	2.74
Voltage Regulator	0.739	0.720	2.00	2.00
Other Equipment	0.640	0.650	1.82	2.05

Figure 15 - Event Probability v4 Model Performance

More details on Event Probability Model v4 performance can be found in Distribution Network Event Probability Models v4 Documentation.

The Wildfire Consequence Model v4 achieved performance improvements from several initiatives. Fire simulation times were increased from 8 to 24-hours, historical fire datasets were reviewed and cleaned to increase number of fires used of model calibration, a Dry Wind Conditions index was developed, Technosylva's Terrain Difficulty Index was incorporated, and public Egress and fire Suppression impacts adjustments were added to the v4 model.

The many model updates contributed to better performance for all three model outputs as shown in *Figure 16*. In each case the v4 model high consequence areas account better for historical fires.

More details on Event Probability Model v4 performance can be found in Wildfire Consequence Model v4 Documentation.

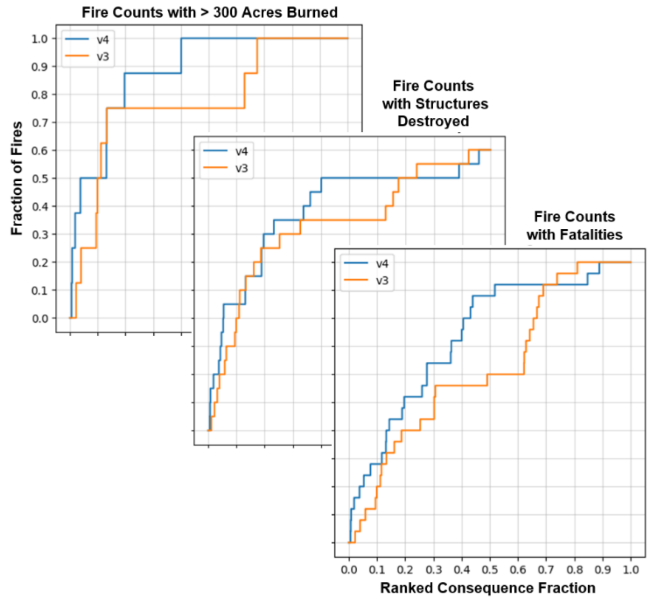

Figure 16 - Wildfire Consequence v4 Performance

5.2 WDRM v3/v4 Comparison

The most significant discovery when comparing WDRM v4 with its predecessor v3 is that wildfire risk is more widely distributed across the distribution grid than previously thought. This is most easily understood from a comparison of the v3 and v4 risk buydown curve as shown in *Figure 17*.

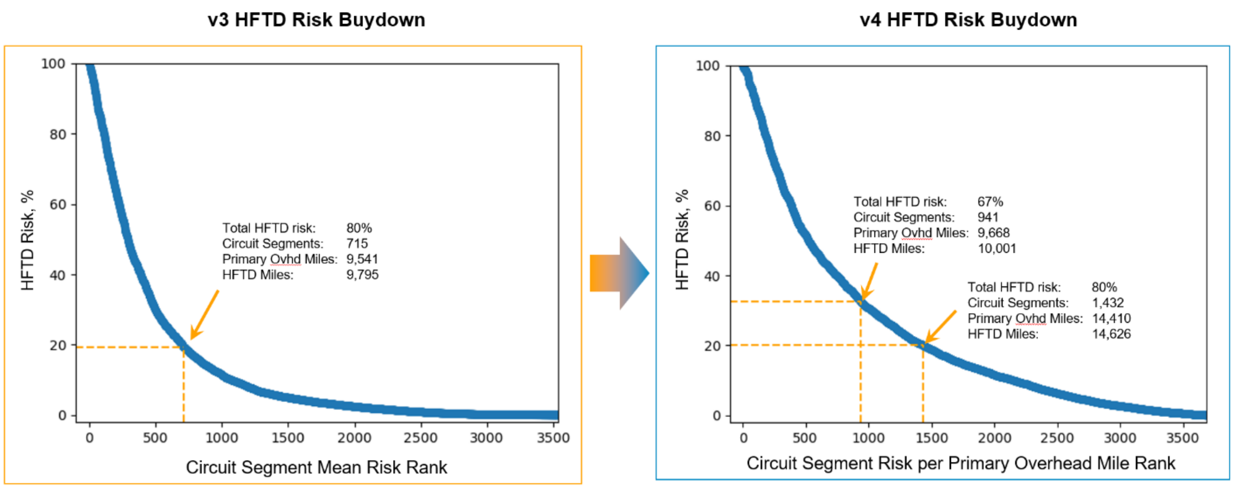

Figure 17- WDRM v3/v4 Risk Buydown Curves

The WDRM v4 risk buydown curve is noticeably flatter, and critically, increases the amount of primary overhead conductor length that represents 80% of the HFTD wildfire risk from 10,000 to 14,400 miles. While the flattened v4 risk buydown curve has multiple sources in the updated models, the most pronounced effect from is the Wildfire Consequence Model. Consequence results were likewise flattened when comparing v4 with v3.4, in large part due to the addition of public Egress and fire Suppression impacts.

Another way to visualize the redistribution of wildfire risk in WDRM v4 is to look at relative county risk aggregations as shown in *Figure 18*. For WDRM v3, El Dorado County dominated the concentration of risk for the distribution grid. WDRM v4 shows a more even distribution of risk. While El Dorado County still has the highest concentration of risk for v4, several other counties are similar in risk. Particularly notable is the increase in relative percent of aggregated risk for Sonoma and Fresno counties as detailed in *Figure 19*.

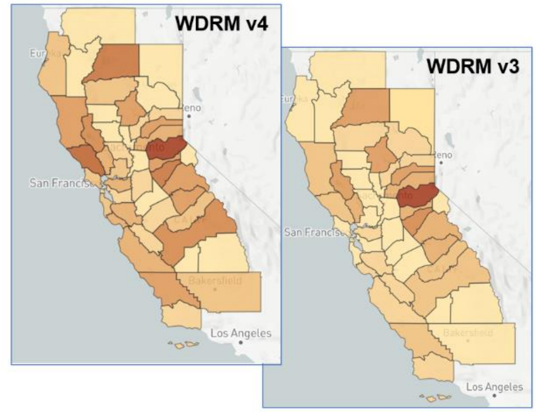

Figure 18 - WDRM v3/v4 Relative County Risk Aggregations

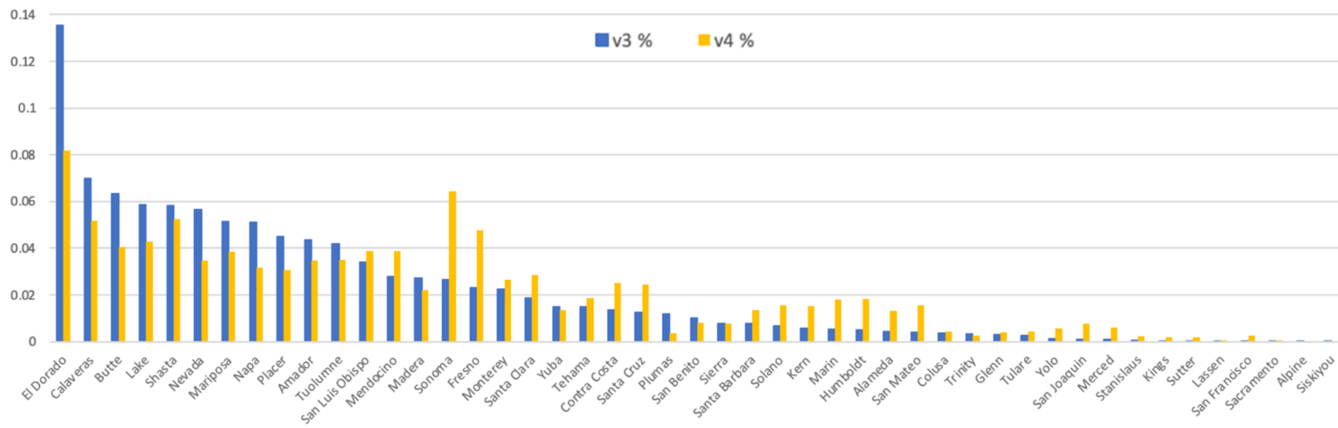

Figure 19- WDRM v3/v4 Relative County Risk Distribution

Finally, the System Hardening maps implemented in Foundry provide a more detailed look at how circuit segment relative risk values have changed from WDRM v3 to v4.

Figure 20 is the relative risk map for WDRM v3 emphasizing the circuit segments that are in the top 30% in terms of risk rank, with the top 1% of ranked circuit segments shown in red. Circuit segments outside the top 30% of risk rank are shown in a dark blue.

For WDRM v3, the western Sierras had a very high concentration of top 1% risk.

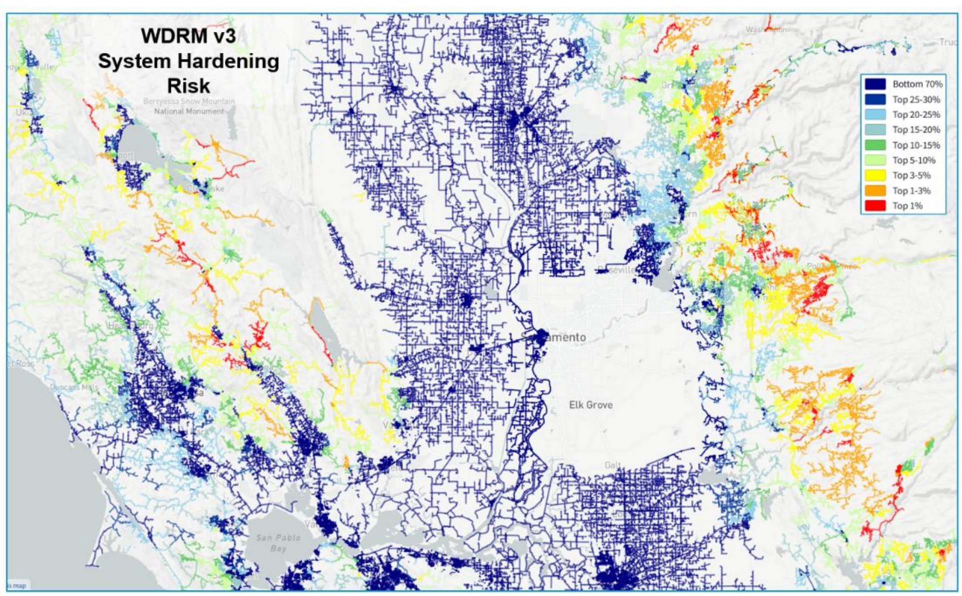

Figure 20 - WDRM v3 System Hardening Risk Map

As described previously, WDRM v4 produces a flatter risk curve and shifts relative areas of risk when compared with v3. *Figure 21* is a heat map of relative risk change between WDRM v3 and v4 where dark red indicates the relative risk increased and dark blue highlights where the relative risk decreased for the transition from WDRM v3 to v4.

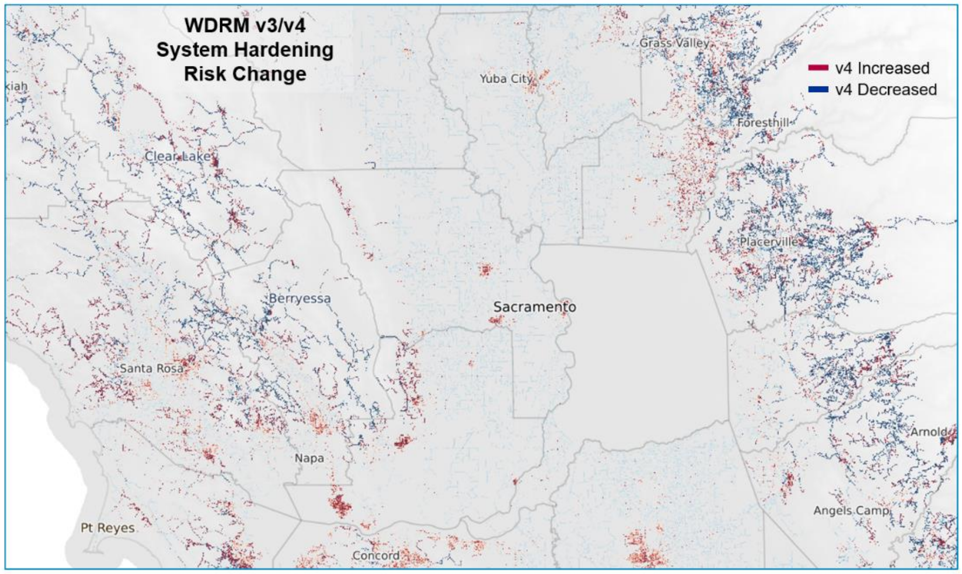

Figure 21 - WDRM v3/v4 Relative Risk Change Map

Figure 22 presents the WDRM v4 relative risk map, again emphasizing the top 30% of circuit segments by relative risk rank.

A visual comparison with the WDRM v3 map confirms that WDRM v4 projects lower relative risk for the western Sierras while elevating relative risk for the coastal mountains. The shift in relative risk between WDRM v3 and v4 contributes to the general flattening of the risk buydown curve.

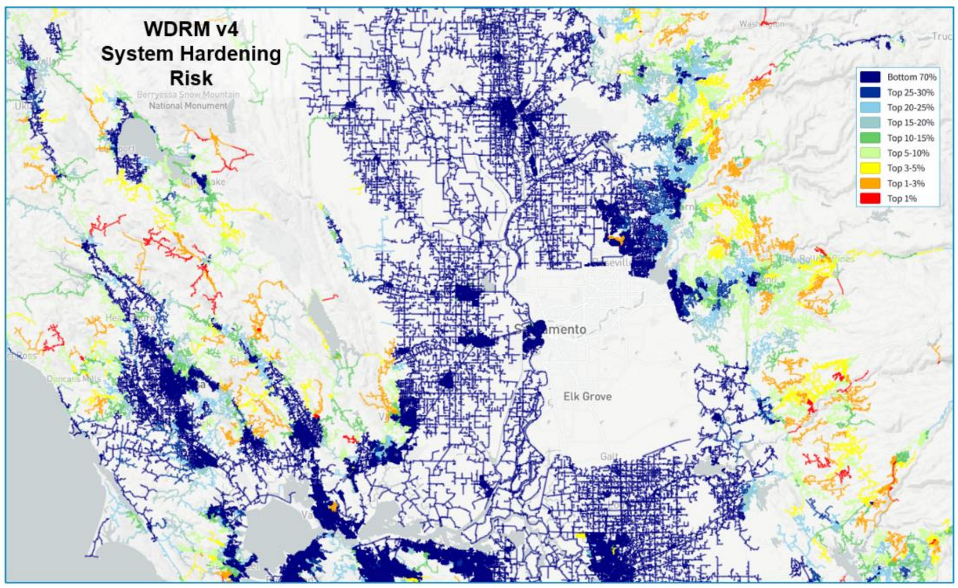

Figure 22 - WDRM v4 System Hardening Risk Map

5.3 Validation Reviews

WDRM v4 went through several formal and informal reviews during development. The critical model reviews were with PG&E's Wildfire Risk Governance Steering Committee and an external review performed by third-party Energy and Environmental Economics, Inc. (E3).

5.3.1 Wildfire Risk Governance Steering Committee Review

Several review meetings were held with the Wildfire Risk Governance Steering Committee during the development of WDRM v4. Three specific areas of WDRM v4 development were in response to action items from the 2023 Wildfire Mitigation Plan (WMP). Each WMP action item was reviewed with the committee to inform and obtain agreement to implement planned development in WDRM v4. Inform review meetings were also held for the Wildfire Consequence Model v4 and WDRM v4 Release Candidate 3 (RC3). Finally, WDRM v4 RC4 was approved as WDRM v4 at an approval meeting held on January 11th, 2024.

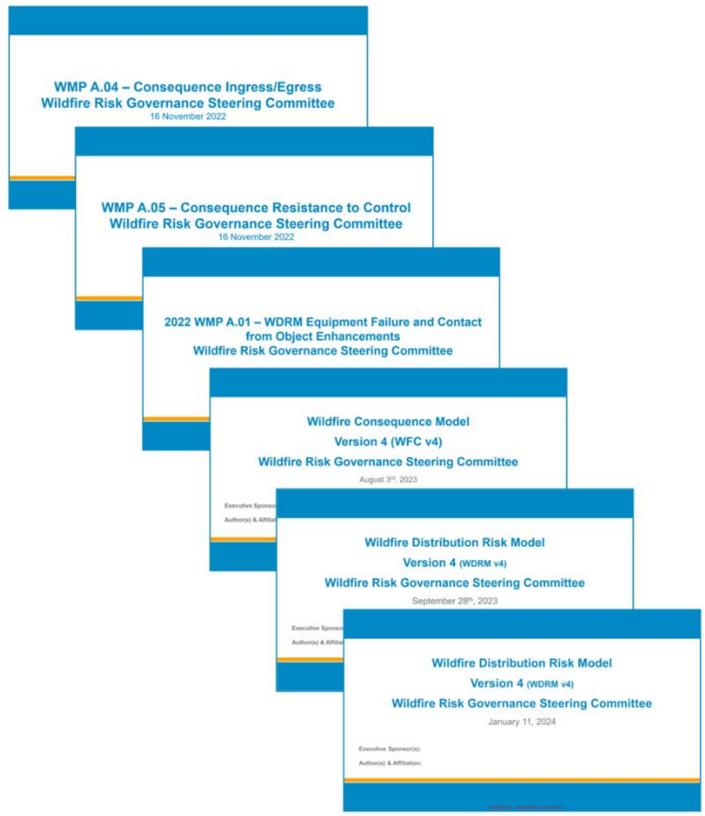

Figure 23 - WRGSC Review Meetings

5.3.2 Energy and Environmental Economics, Inc. (E3) Review

An independent, third-party review of the WDRM v4 was conducted by E3 to evaluate the following objectives:

- Review the suitability and applications of consequence data in the modelling framework.
- Review the specific use of the risk model information in each of its operations areas.
- Describe potential future uses of v4 and longer-term multi-year wildfire planning models.

A few comments from the E3 review:

"As with in our previous reviews, overall we have seen considerable improvement between versions of the PG&E wildfire risk modeling effort."

"Over the last several years, PG&E has continued to improve upon their wildfire risk modeling framework and has built a suite of models that is capable of systematically quantifying the wildfire risk across their system, frequently going above and beyond requirements."

"PG&E should continue development of the model to inform the entire risk planning decision space, building on v4 to produce transparent and justifiable company-wide mitigation budgets for short- and long-term planning. While we continue to believe that the combination of informed risk modeling and experienced SME's provides a robust risk management framework, we also believe that the models, as they become more informative, should have an increasing role in the decision-making process."

E3 identified several potential improvements for future versions of the WDRM:

"*Our findings from this review are based on documentation provided by PG&E on their v4 model, interviews with PG&E's risk modeling team, and interviews with experts comprising the external technical advisory committee assembled by E3. The following bullets re-state the most pertinent recommendations stemming from our present review:*

- *PG&E should focus on using its model to develop transparent and justifiable company-wide mitigation budgets.*
- *Given the unique nature of wildfire risk and mitigations, consideration should be given to cost recovery mechanisms outside of the traditional general rate case.*
- *Development efforts should be right-sized based on impact.*
- *PG&E should seek to improve and justify simplifications made in the consequence model.*
- *Uncertainty should be incorporated into modeling outputs to stabilize results.*
- *PG&E should consider incorporating air quality and health impacts."*

6 WDRM Future Plans

PG&E has historically produced the WDRM on an annual cycle. In the future, WDRM releases will be aligned with the WMP filing schedule. Therefore, this version of the WDRM is planned in support of the 2026 WMP. The RaDA team 3-year risk modeling product plan is shown in *Figure 24* with WDRM plans highlighted in blue font.

WDRM v4 delivered several features planned for 2024/2025 development. Additional features will be delivered during the remainder of 2024 and 2025. Substantial efforts are also expected to further improve the capture, detail, maintenance, and curation of data sets used for risk models. Future risk modeling will progress beyond informing mitigation work plan development and expects to provide risk and risk reduction values in support of data driven portfolio level decisions for the Integrated Grid Planning process.

Products	2026 WMP	Future WMP

Event Probability Models	• Data Quality Improvement
	• Model Refresh / Calibration
	• Asset Models – Distribution
	  • Switches
	  • Fuses
	  • Capacitor Banks
	  • Voltage Regulators
	• Asset Health – Tags
	• Work Plan Model Causality
	• Animal/Third Party – Distribution
	• Vegetation
	  • Tree Mortality
	  • Time Series Update
	• Insulator Contamination Update
		• Data Quality Improvements
		• Model Refresh / Calibration
		• Full Year Models
		• Asset Model – Distribution
		  • Secondary Conductor
		• Underground Assets
		• Lightning
		• Seismic – Distribution
		• Third Party – Transmission

Risk Models	• WDRM v4 • WTRM v2 • Public Safety Risk Model v2 • Reliability Risk Model v1 • Integrated Grid Planning	• WDRM Update • WTRM Update • Risk Mitigation Automation • Risk Reduction Reporting
Consequence Models	• Wildfire Consequence v4 • Wildfire Egress Impact • Wildfire Suppression Impact • Public Safety Consequence v2 • Reliability Consequence v1	• Wildfire Consequence Update • Conflagration • Vulnerable Communities • WUI Population Growth

Figure 24 - RaDA Product Plan - WDRM

The product plan for the Event Probability Models that contribute to the WDRM calls for the development of new risk driver causal models to improve predictive performance and provide more selectivity for mitigation work plans. In response to our user community needs to compare and balance investments across multiple risks, the Event Probability Models will be expanded beyond its current annual fire season focus to predict failures, outages, and ignitions for the full calendar year.

The Wildfire Consequence Model will continue to evolve, refining the Egress and Suppression impacts delivered for v4 and developing new impact features for vulnerable communities, conflagration, and fire consequence in the Wildland Urban Interface (WUI).