PACIFIC GAS AND ELECTRIC COMPANY

ELECTRICAL UNDERGROUNDING PLAN

ATTACHMENT B

WP018

EUP EPSS RISK MODEL V1 DOCUMENTATION

EUP EPSS Risk Model

v1 Documentation



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Revision History

Rev	Date	Comment
1		Initial Release
1.3	2026-03-03	Updates to address minor methodology changes

Table of Contents

1 Executive Summary 4
2 Introduction 5
2.1 EPSS Risk Model Overview 5
2.2 Document Suite 6
3 EPSS Risk Model Derivation 7
3.1 Data Inputs 7
3.2 EPSS Risk and Assumptions 7
3.3 EPSS Likelihood 9
3.3.1 WDRM: Probability of Failure 10
3.3.2 Circuit Segment Probability of Failure 10
3.4 EPSS Consequence 12
3.4.1 Impacted Customer Count 13
3.4.2 Reliability Consequence Model: Outage Duration 13
3.5 Likelihood and Derived Consequence for EUP 15
3.6 Customer-Experienced vs Circuit-Based Risk 16
4 Model Usage 17
4.1 Usage 17
4.2 Shelf Life 17
Appendices 18
Appendix A: Baseline Outage Risk 18
Appendix B: Mapping WDRM Subsets to IGP Asset Types 19

1 Executive Summary

The Enhanced Powerline Safety Settings (EPSS) Risk Model provides the dollarized risk of outages on circuit segments that occur during periods in which EPSS is enabled. It is used as a component of the overall Outage Risk Model, which is used by the Electrical Undergrounding Plan (EUP) project for prioritizing high risk circuit segments for undergrounding. The EPSS Risk Model is a deterministic mathematical model and calculates EPSS likelihood, which estimates the expected number of outages (in minutes per year) when EPSS is enabled, and EPSS consequence, which quantifies the expected cost (in dollars per minute of interruption) of an outage on a circuit segment that is calculated by the number of affected customers and value of service.

The EPSS Risk Model was developed to meet the requirements of SB884, which governs the regulation of the EUP filing, the guidelines for which were developed by the Office of Energy Infrastructure and Safety (OEIS). It also serves as a component of PG&E's broader strategy to mitigate wildfire risk while maintaining continuous and reliable electrical service to its customers.

2 Introduction

The EPSS Risk Model estimates the dollarized risk of outages on circuit segments during periods in which EPSS is enabled, including the risk associated with downstream outages. It is used as a component of the Outage Risk Model to support wildfire season planning and regulatory reporting, helping assess the tradeoff between wildfire mitigation and customer reliability impacts. While the model is deterministic and does not incorporate machine learning techniques, it provides a structured framework for evaluating outage risk on circuit segments, including downstream impacts. This document outlines the modeling approach, source data, and resulting probability predictions used in the EPSS Risk Model. It is intended to provide a high-level overview for a general audience, emphasizing conceptual understanding rather than detailed mathematical or scientific exposition.

Along with the PSPS Risk Model, the EPSS Risk Model is one of two models that feed into the Outage Risk Model. These models evaluate the risk associated with circuit segments using a circuit-based approach quantifying the dollar value of risk that could be avoided if a circuit segment was undergrounded and thereby excluded from exposure to the two preventative service outage programs.

2.1 EPSS Risk Model Overview

The EPSS program is a wildfire mitigation strategy in which EPSS device settings are enabled during elevated weather conditions. When active, the system automatically de-energizes power lines within one-tenth of a second when a fault is detected, reducing the risk of ignition. The EPSS Risk Model estimates the reliability risk, quantified in dollars, associated with sustained outages that occur under these conditions. The EPSS Risk Model is a deterministic mathematical model that leverages outputs from the Wildfire Distribution Risk Model (WDRM), developed by the Wildfire Data Science team, and the Distribution Reliability Value Model, developed by the Integrated Grid Planning team. The model calculates EPSS likelihood, which estimates the expected number of outages (in minutes/year) when EPSS is enabled, and EPSS consequence, which quantifies the expected cost (in dollars per minutes of interruption) of an outage on a circuit segment that is calculated by the number of affected customers and value of service.

This document describes version 1 of the EPSS Risk Model. Future versions will be developed around the Wildfire Mitigation Plan (WMP) reporting cycle and will be released in conjunction with the WDRM.

2.2 Document Suite

This documentation is part of the documentation suite for the Outage Risk Model developed in support of the EUP project:

- Outage Risk Model v1.1 Documentation
- EPSS Risk Model v1.3 Documentation (this document)
- PSPS Risk Model v1.3 Documentation

3 EPSS Risk Model Derivation

3.1 Data Inputs

The EPSS Risk Model relies on several data sources, described below. The specific applications of these sources are explained throughout the document.

The WDRM v4 provides circuit segments mapping (based on the January 1st, 2023 vintage) and probability of failure for each WDRM subset. In addition, WDRM subsets are also used to estimate the effectiveness of undergrounding power lines and alternative mitigations. Further details on WDRM v4, including methodology and subset models are available in the supporting document titled WDRM v4 Documentation.

The Distribution Reliability Value Model assesses the societal cost of service disruptions caused by asset failures. It produces a quantitative output called Distribution Reliability Consequence that determines the consequence based on both customer and grid-level costs. The model also provides outage duration estimates by equipment categories, which are used as inputs into the EPSS Risk Model.

The Interruption Cost Estimate (ICE) Calculator, developed by Lawrence Berkeley National Laboratory (LBNL) and Resource Innovations, Inc, is a reliability planning tool designed for estimating interruption costs and/or the benefits associated with reliability improvements. The EPSS Risk Model leverages customer power interruption costs from version 2.0 of the ICE Calculator.

3.2 EPSS Risk and Assumptions

The general framework of risk assessment is defined as:

$$Risk = Likelihood \times Consequence$$

For EPSS, this represents the incremental outage (or reliability) risk, quantified in dollars, associated with sustained outages that occur when EPSS is enabled during wildfire season. At the circuit segment level, this is calculated as the difference between the outage risk with EPSS enabled and the outage risk with EPSS disabled:

$$EPSS_Risk_{cs} = risk_with_epss_enabled_{cs} - risk_with_epss_disabled_{cs}$$

In this context, likelihood reflects the probability of a sustained outage when EPSS is enabled or disabled during wildfire season, while consequence represents the duration and monetary impact of those outages. The resulting risk when EPSS is enabled is:

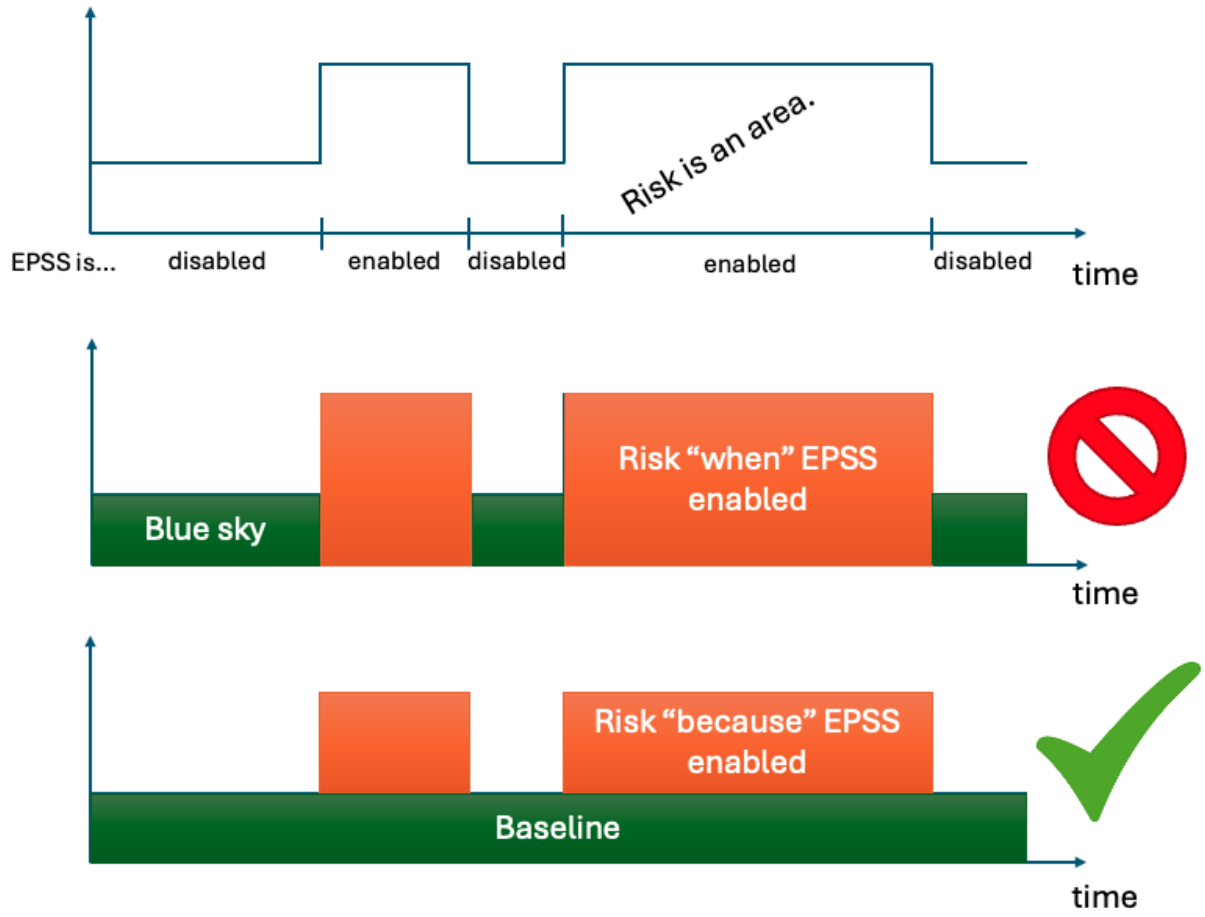
$$risk_with_epss_enabled_{cs} = \sum_{m \in asset_types} N^{EPSS_enabled}_{sustained\ outages,m(s),cs} * C^{EPSS_enabled}_{sustained\ outages,m,cs}$$

Where $N^{EPSS_enabled}_{sustained\ outages,m(s),cs}$ is the number of expected sustained outages $N_{sustained\ outages}$ (excluding momentary, forced, transformer and switch outages) on circuit segments, cs, during the portions of wildfire season when EPSS is enabled, $EPSS_enabled$. These outages are grouped according to the WDRM subsets s, which each subset is mapped to an asset type m (additional context is provided in Appendix B). Since this value represents a count over time, it is technically a rate and is also referred to as *likelihood* or *frequency*.

$C^{EPSS_enabled}_{sustained\ outage,m,cs}$ is the consequence of a sustained outage $C_{sustained\ outage}$ (excluding momentary, forced, transformer and switch outages) should it occur on the circuit segment cs, from each of the IGP asset types m.

The risk, if EPSS were disabled, is similar to when EPSS is enabled, except for one vital nuance. The term $N^{EPSS_disabled}_{sustained\ outages,m(s),cs}$ does *not* refer to outages expected during periods when EPSS was actually *disabled*. Instead, it estimates the number of outages that would have occurred during EPSS *enabled* periods if EPSS had *not* been enabled. For example, if EPSS is enabled on a circuit segment for 80% of wildfire season, $N^{EPSS_enabled}$ reflects the expected outage count during that time, and $N^{EPSS_disabled}$ reflects the expected outage count during that same time, assuming *EPSS had been disabled.* The remaining 20% of the season, when EPSS was disabled, is excluded from this analysis. This approach isolates the incremental outage risk attributable to EPSS enablement. As illustrated in Figure 1: Incremental Risk from EPSS Enablement, the model decomposes total EPSS outage risk into two components: the annual baseline risk that would exist if EPSS were disabled (the green horizontal rectangle), and the incremental risk introduced by enabling EPSS (the orange boxes stacked above). The full height of the stacked boxes reflects the total risk when EPSS is enabled. The portion overlapping the horizontal rectangle represents risk that would have occurred regardless. The difference between the “risk *because* EPSS is enabled” boxes, is the focus of this model.

Figure 1: Incremental Risk from EPSS Enablement



3.3 EPSS Likelihood

The EPSS likelihood represents the likelihood of a sustained outage occurring on a circuit segment when EPSS is enabled. It is derived from the probability of failures in the WDRM, and mapped to asset types, such as conductors and support structures. The calculation also incorporates historical EPSS enablement data, filtered for High Fire Threat Districts (HFTD) and/or High Fire Risk Areas (HFRA). This produces a likelihood value that reflects the expected number of sustained outages per year during EPSS-enabled periods.

As of the Oct 2025 methodology update, transformer and switch-related WDRM subset probabilities are set to zero for EPSS outage risk estimation because these failure modes are considered independent of EPSS operations.

3.3.1 WDRM: Probability of Failure

The EPSS likelihood calculation aggregates probability of failure from all WDRM subsets. While the WDRM shows that outages don't always cause ignitions and failures don't always cause outages, the EPSS Risk Model assumes every failure results in an outage. Therefore, in this analysis, the probability of failure is used interchangeably for outage rate. For asset-based models in the WDRM, this probability is mapped to the support structure. For pixel-based models, the probability of failure for each driver is divided by the number of structures per pixel to estimate per-structure risk. Assets and pixels are filtered to include only those located within HFTD/HFRA. This produces a per-structure probability of failure, which is then aggregated across all structures within a circuit segment to estimate EPSS likelihood at the circuit segment level.

$$L_{CS} = \sum_{CS,asset} L_{asset} + \sum_{CS,pixel} \frac{L_{pixel}}{N_{structures}}$$

3.3.2 Circuit Segment Probability of Failure

To estimate EPSS outage risk, two key probabilities are calculated for each circuit segment:

The first is the probability of a sustained outage when EPSS is enabled. This is derived from multiplying the expected number of outages during wildfire season, based on the WDRM, by the fraction of time during which EPSS is enabled (on each circuit). No adjustment is made for sustained versus momentary outages, as nearly all outages occurring during EPSS activation are sustained. Mathematically, this is expressed as:

$$N^{EPSS_enabled}_{sustained\ outages,s,cs} = f_{EPSS_{enabled},cs} * N_{outages,s,cs}$$

Where:

- $N_{outages,s,cs}$ is the annual expected outage count from each subset s on the circuit segment cs.
- $f_{EPSS_{enabled},cs}$ is the fraction of wildfire season during which EPSS is enabled on the circuit segment cs.

The second is a counterfactual (unrealized) probability, an estimate of the number of sustained outages that would have occurred during EPSS-enabled periods if EPSS had

not been active. This probability is calculated by multiplying the expected outage count during wildfire season by the fraction of time that EPSS is enabled on each circuit and by the proportion of outages that are historically sustained during wildfire season had EPSS been disabled. The expression is:

$$N^{EPSS_disabled}_{sustained\ outages,s,cs} = f_{EPSS_enabled,cs} * N_{outages,s,cs} * f_{sustained,s}$$

Where, the additional term, $f_{sustained,s}$ represents the ratio of sustained outages to total outages for subset s, based on historical data.

To complete the risk estimation, a baseline probability of sustained failure is calculated for the entire year, representing conditions as though EPSS were not in place. This annual probability, expressed in outages per year and potentially exceeding 1, is intended to reflect sustained outage risk across all seasons. Since the WDRM provides failure probability models only for the wildfire season (June through November), assumptions are required to extend the analysis to the winter season (December through May).

To estimate the annual probability of sustained outages, the wildfire season failure probability from the WDRM is multiplied by 2.5 (further explained in Appendix A), then adjusted by the historical proportion of sustained outages, and finally, normalized into outages/circuit-mile.

3.3.2.1 EPSS Historical Enablement

EPSS enablement is determined daily on elevated weather conditions and is primarily enabled during the wildfire season. Although EPSS may be enabled at any time of year, the system is most frequently activated between June and November, what is considered as wildfire season. Enablement occurs at the circuit level, meaning an entire circuit is either enabled or disabled.

For the years 2017-2020, the analysis uses EPSS lookback data developed by the Enterprise Operations Risk Management (EORM) team, which retrospectively estimates EPSS enablement based on current criteria. The year 2021 is excluded from the analysis, as it was a pilot year and does not reflect current EPSS settings or enablement (operational practices).

For 2022 through 2024, actual historical enablement data is used, filtered to include only wildfire season months. While EPSS may have been enabled outside of wildfire season, those instances are excluded to maintain consistency in seasonal risk assessment.

Based on the enablement data described above, the fraction of EPSS enablement for each circuit is calculated as the ratio of total enabled days to total wildfire season days.

$$f_{EPSS_{enabled}} = \frac{total\ enabled\ days_{2017-2024}}{total\ wildfire\ season\ days_{2017-2024}}$$

3.3.2.2 Sustained Outages

Momentary outages occur frequently and are inherent to automatic reclosing operations (particularly when EPSS is not enabled), therefore, the EPSS program primarily impacts sustained outages, defined as those lasting longer than five minutes. These events are tracked and reflected in reliability metrics such as System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI). To isolate sustained outages from total outages, the analysis applies a sustained outage fraction that excludes momentary events. When EPSS is *disabled*, reclosers frequently reestablish current for minor events, such as a small branch falling on the conductor, which creates a momentary outage. When EPSS is *enabled*, the same event will result in a sustained outage due to the disabling of automatic reclosing. As a result, the fraction of sustained outages when EPSS is *enabled* is assumed to be approximately 1, while the fraction of sustained outages when EPSS is *disabled* is based on WDRM subset. This calculation uses historical non-EPSS regular and forced outages during wildfire season in HFTD/HFRA. The sustained outage fraction for each WDRM subset is calculated by dividing the number of sustained outages over the total number of outages.

3.4 EPSS Consequence

EPSS consequence represents the financial impact of a sustained outage occurring on a circuit segment when EPSS is enabled, measured in dollars per minute of interruption. This value is determined by evaluating the number of customers affected by an EPSS outage, in addition to those who would have experienced a normal outage. The calculation also incorporates outage duration data from the IGP Distribution Reliability Value Model and customer interruption costs per minute, also referred to as value of service, sourced from the ICE 2.0 Calculator. Together, these components produce a consequence value that reflects the expected impact of sustained outages during EPSS-enabled periods. The final value is calculated using the following expression:

$$C^{EPSS_enabled}_{sustained\ outages,m,cs} = D_{sustained\ outage,m,cs} * N^{EPSS_enabled}_{customers,m,cs} * VOS_{cs}$$

Where m refers to two asset groups: conductor and support structure, represented as $m \in \{conductor, support\ structure\}$.

3.4.1 Impacted Customer Count

To determine the number of customers affected by an EPSS outage, the model evaluates the primary overhead conductor or support structure associated with each EPSS-enabled protective device. This analysis includes both the downstream customer count during EPSS-enabled outages and the customer count associated with conductors and support structures during outages that occur when EPSS is not enabled. This distinction allows the model to compare customer impact resulting from damage to conductor or support structures during EPSS-enabled outages versus non-EPSS outages, thereby identifying the incremental customer count attributable to EPSS activation.

The model then applies a standardized average value of service per EPSS device. This value is based on the mix of customers connected to that device and is calculated using the ICE 2.0 Calculator.

3.4.2 Reliability Consequence Model: Outage Duration

The expected duration of an outage on a circuit segment, $D_{sustained\ outage,m,cs}$ is derived from the IGP Outage Duration model. This model estimates the expected outage duration for each asset based on its type and the kind of protective device located upstream of it. The duration is represented as $d_{a(m,p)}$, where a is the asset, m indicates the asset type (such as conductor or support structure), and p identifies the upstream protective device (including fuse, switch, DPD [dynamic protective device], or breaker).

To calculate the expected outage duration for a specific asset type on a circuit segment, the model applies the following formulation:

$$D_{sustained\ outage,m,cs} = \frac{1}{N_{m,cs}} \sum_{\substack{a \in cs \\ of\ type\ m}} d_a$$

In this equation, $N_{m,cs}$ represents the number of individual assets of type m on circuit segment cs. For example, if the asset type is support structures, the model sums the estimated outage durations for all support structures within the circuit segment and

divides by the total number of support structures present on that segment. Each support structure's outage duration is determined by the type of upstream protective device, resulting in one of four possible values measured in minutes.

The model also estimates the number of customers impacted by an outage under two scenarios: when EPSS is enabled and when it is not. The expected number of customers affected when EPSS is enabled is denoted as:

$$N_{customers,m,cs}^{EPSS_enabled}$$

In this scenario, the outage is attributed to the nearest EPSS-enabled device, which may be located upstream of the nearest protective device that would normally isolate the fault. This results in a broader set of customers being impacted, as the outage is traced to a higher-level device in the system.

When EPSS is not enabled, the outage is contained by the nearest protective device. The number of customers impacted in this case reflects those downstream of that device and is represented as:

$$N_{customers,m,cs}^{EPSS_disabled}$$

In HFTD/HFRA, the average ratio of customers impacted under EPSS-enabled versus EPSS-disabled conditions varies significantly across circuit segments. This ratio is approximately 2.15 and is represented as:

$$N_{customers,m,cs}^{EPSS_enabled} \,/\, N_{customers,m,cs}^{EPSS_disabled}$$

The final component is VOS_{cs}, the value of service for customers in a given circuit segment. This value is calculated as the weighted average of the value of service across customer classes, based on the number of customers in each class:

$$VOS_{cs} = \sum_{c \in \{RES, NON-RES\}} VOS_c * \frac{N_{c,cs}}{N_{cs}}$$

As stated in previous sections, the EPSS Risk Model version 1 leverages value of service from the ICE 2.0 Calculator, which categorizes customers into two classes, Residential and Non-Residential for both HFTD/HFRA and Non-HFTD/Non-HFRA. For Residential customers, the value of service, VOS_c is $0.08 per customer-minute of interruption while for Non-Residential customers, it is $23.11 per customer-minute of interruption. In this equation, $N_{c,cs}$ refers to the number of customers of class c on the circuit segment cs, and N_{cs} is the number of customers on that circuit segment.

3.5 Likelihood and Derived Consequence for EUP

For EUP reporting, we define likelihood as total outage-minutes during EPSS-enabled periods (i.e., probability × duration), and we derive consequence as dollarized risk divided by likelihood.

The EPSS risk is defined as the incremental risk of outages that exceed the standard outage risk when EPSS is not enabled. This includes outages that were mitigated due to EPSS being active, by considering the likelihood of those outages occurring if EPSS had not been enabled during the same time. In contrast, the EPSS likelihood reported for the EUP reflects the full likelihood of an EPSS outage, encompassing all outages that would have occurred during that time regardless of EPSS activation. This approach ensures a comprehensive representation of outage likelihood, though it introduces a potential mismatch in risk and likelihood reporting.

Given that OEIS defines likelihood to include outage duration, the EUP framework removes outage duration from the consequence calculation. At the circuit segment level, this adjustment is implemented by multiplying the previously defined likelihood by outage duration, while consequence is calculated by dividing risk by likelihood.

It is important to note that consequence is calculated at the circuit segment level but cannot be aggregated to higher levels using a simple summation. Instead, consequence must be derived at the portfolio or system levels by dividing the aggregated risk across all relevant circuit segments by the aggregated likelihood across those same segments. This method accounts for the varying number of event probability results associated with each segment. Attempting to sum individual consequence values and the total likelihood directly would not yield an accurate representation of total risk. To resolve this mathematical inconsistency, the effective consequence for an aggregated composite is back-calculated as a likelihood-weighted value by dividing the total risk for the portfolio or system by the total likelihood for that same group of segments.

3.6 Customer-Experienced vs Circuit-Based Risk

“Circuit-Experienced” Risk refers to the risk attributed to the entire circuit resulting from failures that occur on a specific circuit segment. Whereas “Customer-Experienced” Risk captures the risk experienced by customers located on a circuit segment due to failures occurring anywhere along the full circuit. The EPSS Risk Model inherently produces circuit-experienced risk values. This is because EPSS devices are not mapped one-to-one with circuit segments; instead, an EPSS zone, the area protected by a single EPSS device, may span multiple circuit segments. When an EPSS outage occurs on a given circuit segment, it may affect customers located outside of that circuit segment but still within the same EPSS zone. In such cases, the risk is attributed to the circuit segment where the outage originated, which aligns with the definition of circuit-experienced risk.

4 Model Usage

Per circuit segment, reported outputs include: dollarized risk, annual CMI, likelihood (outage-minutes), consequence ($/minute), and expected outage count (sustained outages).

4.1 Usage

The EPSS Risk Model is applied at the circuit segment level. It is used as a component of the Outage Risk Model during wildfire season planning and regulatory reporting to assess the tradeoff between wildfire mitigation and customer reliability impacts.

4.2 Shelf Life

The EPSS Risk Model is structured around the Wildfire Mitigation Plan (WMP) reporting cycle and is refreshed in conjunction with new releases of the WDRM. With each Outage Program Risk Model version, the inputs will be updated accordingly with the WDRM and input data.

Appendices

Appendix A: Baseline Outage Risk

A baseline probability of sustained failure for the entire year must be calculated to get baseline outage risk, representing conditions as though EPSS were not in place. This annual probability, expressed in outages per year and potentially exceeding 1, is intended to reflect sustained outage risk across all seasons. Since the WDRM provides failure probability models only for the wildfire season (June through November), assumptions are required to extend the analysis to the winter season (December through May).

An initial approach to estimating annual outage risk involved comparing WDRM wildfire season models with prototype full-year models available for a limited number of subsets. However, this method was ultimately discarded due to significant compatibility issues between the two model types. In several instances, the winter outage probabilities derived from the full-year models were negative, an outcome that is clearly infeasible and indicative of underlying model misalignment.

As an alternative, the analysis shifted to examining counts at the circuit level, independent of subset distinctions. The objective was to determine whether a correlation existed between winter and wildfire season outages. While the drivers of outages in these two seasons differ substantially, making it plausible for a circuit to be highly vulnerable in winter but not during wildfire season, a moderate correlation of approximately 65% was observed. Based on this relationship, a multiplier of 1.5 was derived, indicating that circuits experience roughly 1.5 times more outages in winter than during wildfire season. To estimate the annual probability of sustained outages, the wildfire season failure probability from the WDRM is multiplied by 2.5 (accounting for both seasons), and then further adjusted by the historical proportion of sustained outages (~83%), thereby excluding momentary outages from the final estimate. Outages are then normalized by total circuit mileage to calculate outage density (outages per mile) for each.

Appendix B: Mapping WDRM Subsets to IGP Asset Types

Twenty-two WDRM subsets are categorized according to their association with either conductor or support structure failures. These groupings are used to calculate outage duration using the IGP model. Table 1: Example Mapping of WDRM Subsets to Asset Types illustrates this mapping using the example circuit segment ORO FINO 11012022. In the figure, the first ten subsets (highlighted in yellow) are mapped to conductors, while the remaining twelve subsets (highlighted in blue) are mapped to support structures.

Table 1: Example Mapping of WDRM Subsets to Asset Types

cs_name	ORO FINO 11012022
primary_conductor_line_slap_cause_prob_failure_cs_ss_split_sum	0.016805456
primary_conductor_wire_down_cause_prob_failure_cs_ss_split_sum	0.069652447
primary_conductor_other_cause_prob_failure_cs_ss_split_sum	0.045507094
cs_split_third_party_balloon_probability_outage_sum	0.002913768
cs_split_third_party_other_probability_outage_sum	0.101219326
cs_split_vegetation_branch_probability_outage_sum	0.558569741
cs_split_vegetation_trunk_probability_outage_sum	0.685249781
cs_split_vegetation_other_probability_outage_sum	0.135380507
cs_split_other_equipment_type_probability_outage_sum	1.42377945
cs_split_secondary_conductor_probability_outage_sum	0.070908471
capacitor_bank_equipment_cause_prob_failure_sum	0.006228554
fuse_equipment_cause_prob_failure_sum	0.041683587
support_structure_equipment_cause_prob_failure_cs_ss_split_sum	0.198224595
support_structure_electrical_cause_prob_failure_cs_ss_split_sum	0.054776475
switch_equipment_cause_prob_failure_sum	0.00571443
transformer_equipment_cause_prob_failure_sum	0.654647632
transformer_equipment_leaking_prob_failure_sum	0.043604699
voltage_regulator_equipment_cause_prob_failure_sum	0.004826526
cs_split_animal_bird_probability_outage_sum	0.025201331
cs_split_animal_squirrel_probability_outage_sum	0.710703967
cs_split_animal_other_probability_outage_sum	0.005710891
cs_split_third_party_vehicle_probability_outage_sum	0.16098247