

PACIFIC GAS AND ELECTRIC COMPANY
ENTERPRISE RISK MODEL DOCUMENTATION AND USER GUIDE
JUNE 30, 2021

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1 **PACIFIC GAS AND ELECTRIC COMPANY**
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4 **Introduction and Purpose**

5 PG&E’s Enterprise Risk Model User Guide (User Guide) contains a description
6 of the Python-based¹ analytical risk model (the Model) PG&E used to compute Risk
7 Scores and Risk Spend Efficiency (RSE) values for the risks and associated
8 mitigation and control programs presented in PG&E’s General Rate Case (GRC)
9 report filed June 30, 2020 (Application (A.) 21-06-021).

10 This document was originally produced as Chapter 3 in PG&E’s 2020 Risk
11 Assessment and Mitigation Phase (RAMP) Report (A. 20-06-12). It has been
12 updated to reflect changes to PG&E’s Enterprise Risk Model.

13 This document is organized in four sections.

- 14 1. The first details how PG&E built a methodology that reflects the
15 company’s risk management approach that meets the requirements of the
16 Safety Model Assessment Proceeding (S-MAP) Settlement Decision. This
17 includes defining a Multi Attribute Value Function (MAVF), using the
18 MAVF to compute Risk Scores and Risk Spend Efficiency (RSE) values.
- 19 2. A simple but complete numerical example of Risk Score and RSE
20 calculations to illustrate how the methods described in the first part of this
21 document are applied.
- 22 3. A User Guide which documents the details of using a Risk Model Input
23 File template to quantify a risk using methodology described in the first
24 part of this document. The User Guide includes screenshots from an
25 example Risk Model Input File.
- 26 4. Formulas and calculation details specific to the way the Model computes
27 various risk baselines/states for a risk event using the details from the
28 Risk Model Input File.

29 **1. Risk and Mitigation Analysis Methodology**

30 The objective of this section is to explain the methodology used to develop
31 models that assess the likelihood and probabilistic consequence of various risks

1 Python is the programming language upon which PG&E’s risk model is constructed.

1 events reported in PG&E’s 2021 GRC filing. Each of these models produces a 2023
2 Test Year Baseline Risk Score, which is calculated using the methodology
3 discussed below.

4 PG&E’s risk modeling, analysis and mitigation strategy is focused on reducing
5 the potential for catastrophic risk events and the consequences of those events. In
6 terms of risk modeling, this strategy entails paying special attention to tail risk—the
7 low frequency, high consequence events. We achieve this by using a non-linear
8 scaling function which gives a greater weight in the risk model to low frequency, high
9 consequence events than to high frequency, low consequence events.

10 **1.1. PG&E’s Risk Management Approach**

11 PG&E is risk averse in the sense that term is used in economics. Given a
12 choice between two mitigations that theoretically reduce the same expected
13 amount of loss, one of which is targeted at catastrophic (low frequency, high
14 consequence) risk events and another that is targeted at routine (high
15 frequency, low consequence) risk events, our preference is to select the
16 mitigation that targets the catastrophic events because of the uncertainty of their
17 frequency and consequence. Catastrophic events can have a more severe
18 impact than multiple routine events for numerous reasons, including:

- 19 • The maximum scope and consequences of certain catastrophic events, such
20 as a wildfire, are very hard to determine;
- 21 • The effects of catastrophic events have the potential to be concentrated in
22 one place and one time, disproportionately affecting communities;
- 23 • Catastrophic events can also overwhelm emergency facilities and
24 infrastructure; and
- 25 • Catastrophic events can have significant, unforeseen consequences that are
26 not factored into everyday operations and contingency planning, and
27 therefore have a greater potential to disrupt PG&E’s operations (compared to
28 multiple low consequence events).

29 We have learned through experience that the biggest risk events—those
30 that disrupt the lives of our customers, their communities and PG&E itself—are
31 the ones we need to avoid by clearly understanding what drives these events
32 and then taking the right steps to prevent them in the future.

33 This attitude is reflected in the design of the Multi-Attribute Value Function
34 (MAVF) explained in the following section.

1 **1.2. Multi-Attribute Value Function (MAVF)**

2 PG&E quantifies risk according to the Safety Model Assessment Proceeding
3 (S-MAP) Settlement Decision. Step 1A in that proceeding, D.18-12-014, requires
4 utilities to build a Multi-Attribute Value Function (MAVF) to evaluate and rank
5 alternative risk mitigation programs.² PG&E’s MAVF reflects our focus on
6 low-frequency/high-consequence risk events without neglecting operational risks
7 (high-probability/low-consequence events). Additional information on the
8 principles according to which the MAVF should be constructed can be found in
9 the reference.³

10 **1.2.1. MAVF Principle 1 – Attribute Hierarchy**

11 Principle 1 requires that Utilities identify Attributes that are combined in
12 a hierarchy such that the top-level Attributes are categories and the lower
13 level Attributes, or sub-Attributes, are observable and measurable.⁴

14 PG&E identified four Attributes: (1) Safety, (2) Electric Reliability,
15 (3) Gas Reliability, and (4) Financial, each with one lower-level Attribute.

- 16 1) “Safety” has one lower-level observable and measurable attribute:
17 Equivalent Fatalities (EF).
18 2) “Electric Reliability” has one lower-level observable and measurable
19 attribute: Customer Minutes Interrupted (CMI).
20 3) “Gas Reliability” has one lower-level observable and measurable
21 attribute: Number of Customers Affected.
22 4) “Financial” has one lower-level attribute: U.S. Dollars. Pursuant to
23 D.18-12-014 and D.16-08-018, shareholders’ financial interests are
24 excluded.⁵

25 **1.2.2. MAVF Principle 2 – Measured Observations**

26 MAVF Principle 2 requires that each lower-level Attribute have its own
27 minimum and maximum range expressed in natural units that are
28 observable during ordinary operations and as a Consequence of a Risk

2 D.18-12-014, p. 22.

3 D.18-12-014, Attachment A, pp. A-5 to A-6.

4 D.18-12-014, Attachment A, p. A-5, No. 2.

5 D.18-12-014, p. 29, and D.16-08-018, p. 193, Conclusion of Law (COL) 37.

1 Event (CoRE).⁶ Table 1-1 below summarizes PG&E's Attributes and
2 associated ranges.

TABLE 1-1
STEP 1A, PRINCIPLE 2 – MEASURED OBSERVATIONS

Line No.	Attribute	Natural Unit of Attribute	Range
1	Safety	Equivalent Fatalities (EF)	0 – 100
2	Electric Reliability	Customer Minutes Interrupted (CMI)	0 – 4 billion
3	Gas Reliability	Number of Customers Affected	0 – 750 thousand
4	Financial	Dollars	0 – 5 billion

3 The S-MAP Settlement Decision defines the low and high end of the
4 Range of the Natural Unit to be a smallest and largest observable value
5 from a risk event.⁷ PG&E uses the term Upper Bound to denote the highest
6 value in a Range. However, given the uncertainty in what the largest
7 observable outcome of a risk event might be, PG&E defines the Ranges
8 based on historical events and plausible high-consequence scenarios.

9 PG&E defines each of the natural units of the Attribute as follows:

- 10 • An Equivalent Fatality is defined as the sum of Fatalities and Serious
11 Injury Equivalents per event occurrence. Serious Injury is defined as an
12 injury that requires in-patient hospitalization of an individual pursuant to
13 existing Federal and State reporting guidelines.^{8,9} Fatalities and
14 Serious Injuries are converted to EFs using the factors shown in Table
15 1-2. The conversion rate from Serious Injury to EF is based on the
16 disutility factors for Serious Injuries relative to Fatality available from

6 D.18-12-014, Attachment A, p. A-5, No. 3.

7 D.18-12-014, Attachment A, p. A-3.

8 Pipeline and Hazardous Materials Safety Administration (PHMSA) § 191.3, Definitions: Incident. See also: <https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-facility-incident-report-criteria-history>, accessed June 25, 2020.

9 D.98-07-097, Appendix B, Accident Report Requirements, par. 3. See also, <https://www.cpuc.ca.gov/General.aspx?id=2090>, accessed June 22, 2020.

1 Federal sources.¹⁰ The Upper Bound of the Range for the Safety
2 Attribute is based on EFs resulting from the Camp Fire rounded up
3 to 100.

**TABLE 1-2
EQUIVALENT FATALITY CONVERSION FACTORS
SIMULATED FATALITY OR SERIOUS INJURY QUANTITIES**

Line No.	Type	Equivalent Factor
1	Fatality	1.00
2	Serious Injury	0.25

- 4
- 5 • The Electric Reliability Upper Bound is based on the October 26-29,
6 2019 Public Safety Power Shutoff event consequence of approximately
7 3.6 billion CMI rounded up to 4 billion.
 - 8 • The Gas Reliability Upper Bound is based on a scenario of an outage at
9 a critical gas facility.
 - 10 • The Upper Bound of the Financial Range represents a financial loss
11 commensurate with a 2000-2001 Energy Crisis-type event. Costs
12 related to recent wildfires were not used to set the Upper Bound
13 because, pursuant to D.18-12-014, utility shareholders' financial
interests are excluded from consideration.

14 **1.2.3. MAVF Principle 3 – Comparison**

15 MAVF Principle 3 directs Utilities to use a measurable proxy for any
16 Attribute that is logically necessary, but not directly measurable.¹¹ Since all
17 PG&E's Attributes are directly measurable, proxies are not used.

18 **1.2.4. MAVF Principle 4 – Risk Assessment**

19 MAVF Principle 4 states that when Attribute levels resulting from the
20 occurrence of a risk event are uncertain, the utility should assess the

¹⁰ See Federal Aviation Administration (FAA) Office of Aviation Policy and Plans, Treatment of the Values of Life and Injury in Economic Analysis, p. 2-3, Table 2-3, Updated September 2016, accessed June 19, 2020, at: https://www.faa.gov/regulations_policies/policy_guidance/benefit_cost/media/econ-value-section-2-tx-values.pdf.

¹¹ D.18-12-014, Attachment A, p. A-5, No. 4.

1 uncertainty in the Attribute levels using expected values or percentiles, or by
2 specifying well-defined probability distributions from which expected values
3 and tail values can be determined. Monte Carlo simulations may be used to
4 satisfy this principle.¹²

5 PG&E employs a probabilistic approach to modeling Attribute levels.
6 The Attributes are specified by well-defined conditional probability
7 distributions with parameters derived from data and/or calibrated subject
8 matter expert (SME) input. Monte Carlo methods are used to simulate
9 Attribute levels from these distributions. Details about PG&E's Risk
10 Assessment methodology and a numerical example are presented in
11 Section 2.

12 **1.2.5. MAVF Principle 5 – Scaled Units**

13 MAVF Principle 5 requires Utilities to construct a scale that converts the
14 range of natural units to scaled units to specify the relative value of changes
15 within the range.¹³

16 The S-MAP Settlement Decision defines the Scaled Unit of an Attribute
17 as a value that varies from 0 and 100. The Scaled unit is set to 0 for the
18 most desirable level, and 100 for least desirable level.¹⁴ Consistent with the
19 S-MAP Settlement Decision, PG&E's Scaled Units reflect a 0-to-100-point
20 scale, where zero reflects no adverse consequences (i.e., no EFs, no
21 reliability impact, or no financial loss) and 100 corresponds to the Upper
22 Bound of the Attribute Range. In cases when Attribute levels goes above the
23 Upper Bound, Scaled Units are set higher than 100.¹⁵

24 MAVF Principle 5 provides that the scale described above can be
25 constructed so as to “captur[e] aversion to extreme outcomes or indifference
26 over a range of outcomes”¹⁶ and that the “scaling function can be linear or
27 non-linear.”¹⁷ As described in Section 1.1, above, PG&E's risk

12 D.18-12-014, Attachment A, p. A-5, No. 5.

13 D.18-12-014, Attachment A, pp. A-5 to A-6, No. 6.

14 D.18-12-014, Attachment A, p. A-3.

15 This is a change in TY2023 GRC from 2020 RAMP. In 2020 RAMP, Scaled Units were set to 100 even if Attribute levels go beyond the Upper Bound.

16 D.18-12-014, Attachment A, p. A-5, No. 6.

17 D.18-12-014, Attachment A, p. A-6, No. 6.

1 management objective is to prioritize the mitigation of risks characterized as
2 low frequency/high consequence (LFHC) events, even though their
3 expected loss might be the same as multiple high frequency events with low
4 consequences. To reflect this objective, PG&E uses a non-linear scaling
5 function that captures aversion to extreme outcomes, rather than using a
6 linear Scaling Function that would yield indifference over a range of
7 outcomes.

8 The S-MAP Settlement Decision that sets forth the requirements for the
9 2020 RAMP does not give PG&E the opportunity to use the Tail Average as
10 a metric, which was one of two metrics used in the 2017 RAMP Report. The
11 S-MAP Settlement Decision adopted a single measure of risk—the Risk
12 Score— which is the product of the Likelihood of a Risk Event (LoRE) and
13 the Consequence of a Risk Event (CoRE). The S-MAP Settlement Decision
14 further defines CoRE to be the weighted sum of the scaled values of the
15 level of the individual Attributes using the MAVF.¹⁸

16 One effect of using the Expected Value of Attributes as the sole
17 measure for CoRE is that the tail risk of risk events may be obscured,
18 depending on what scaling function is used. A linear scaling function
19 essentially adopts the average of risk event outcomes as the measure of the
20 risk. It is indifferent to the distribution of those outcomes. Consider the
21 scenarios shown in Figure 1-1 and Figure 1-2 below, which represent the
22 potential safety consequence of two hypothetical risk events:

¹⁸ D.18-12-014, Attachment A, p. A-11, No. 13.

FIGURE 1-1
HIGH FREQUENCY, LOW CONSEQUENCE EVENT WITH MEAN LOSS OF \$150

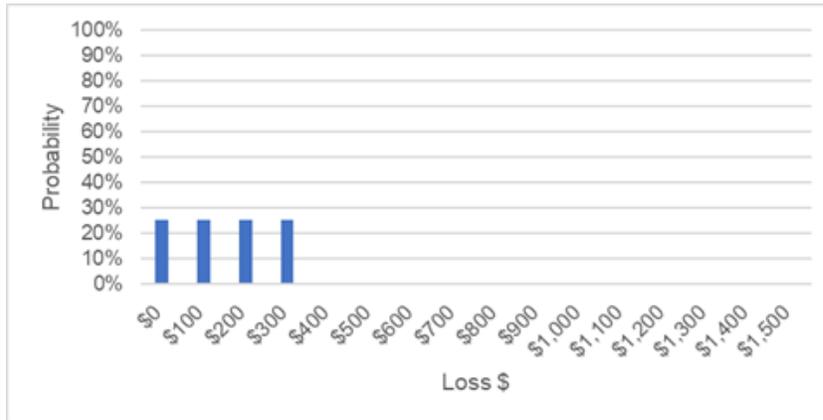


FIGURE 1-2
LOW FREQUENCY, HIGH CONSEQUENCE EVENT WITH MEAN LOSS OF \$150



1 Figure 1-1 represents a high frequency, low consequence event.
 2 75 percent of the risk events result in a loss, but the losses are small
 3 (\$100-300 in this example). Figure 1-2 represents a low frequency, high
 4 consequence (i.e. catastrophic) event. Only 10 percent of the risk events
 5 result in a loss, but that loss is large (\$1,500). In both cases, the mean loss
 6 for all the risk events considered together is the same—\$150.¹⁹ Because
 7 their mean loss is the same, a linear scaling function would treat these two
 8 risks similarly, despite the large difference in the distribution of risk

¹⁹ $(0.25 \times \$100) + (0.25 \times \$200) + (0.25 \times \$300) = \$150 = 0.10 \times \$1500.$

1 outcomes.²⁰ By contrast, as described below, a non-linear scaling function
2 assigns a greater weight to low frequency high, consequence risk events, so
3 that mitigations for the risk in Figure 1-2 would be prioritized over mitigations
4 for the risk shown in Figure 1-1. PG&E uses non-linear scaling function
5 because it allows us to better understand tail risk and prioritize mitigations
6 for low frequency, high consequence events, consistent with our risk
7 management objectives.

8 In academic settings, MAVFs are used in conjunction with a utility
9 function when extending standard, single-attribute utility theory to a
10 multi-attribute setting.²¹ The MAVF first establishes an ordering preference
11 for all the different combinations of attribute levels. The utility function,
12 either on its own or together with the MAVF, is then used to express risk
13 preference (i.e., risk-aversion, risk-seeking or risk-neutral). However, that
14 possibility does not exist in the framework of the S-MAP Settlement
15 Decision, which requires expected values to be used for the CoRE,²²
16 basically giving CoRE the role of the utility function. The S-MAP Settlement
17 Decision further requires that, “The CoRE is the weighted sum of the scaled
18 values of the levels of the individual Attributes using the utility’s full
19 MAVF.”²³ Mathematically, this implies $U(V(a)) = V(a)$, where U is the utility
20 function and V is the expected value of the multi-attribute value function.
21 The utility function is risk-neutral and, in the context of the S-MAP
22 Settlement Decision, cannot be used to express risk aversion. Therefore,
23 the only way to express aversion to catastrophic risk is through the Scaling
24 Function, consistent with MAVF Principle 5.

20 In Economics theory, Figure 3-2 is a Mean-Preserving Spread of Figure 3-1.
Risk-averse individuals will prefer Figure 3-1 to Figure 3-2.

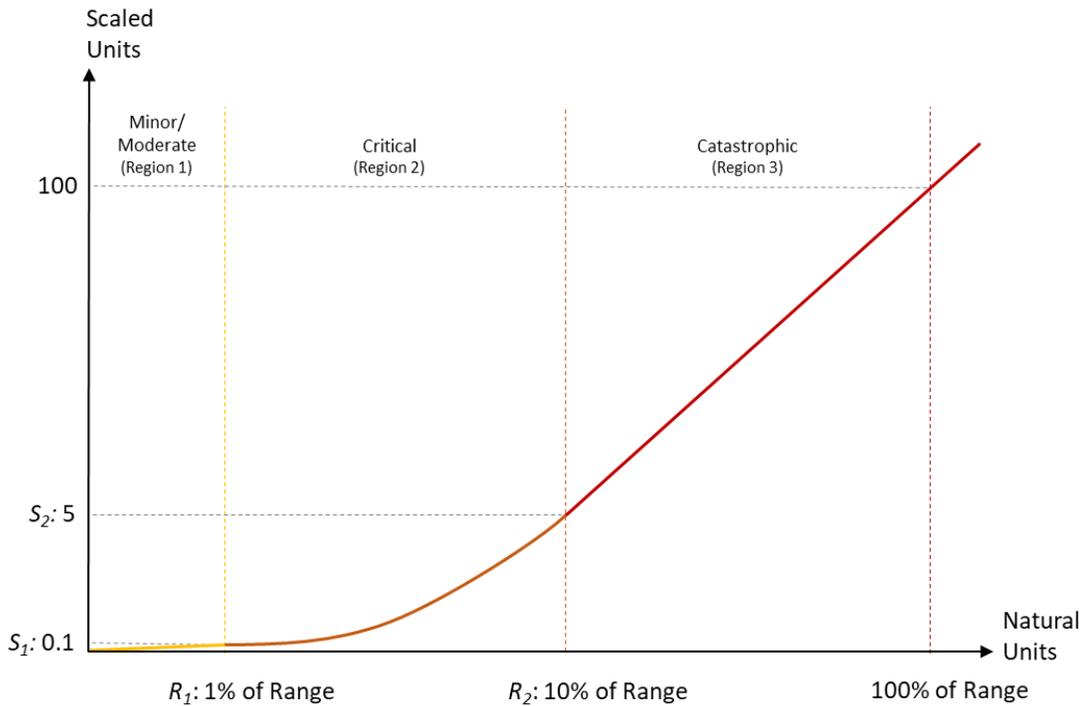
21 In decision analysis, a value function quantifies preferences concerning a set of
outcomes so that larger values reflect preferred outcome. Probabilistic outcomes can be
ranked according to the expected utility where a utility function includes information
about risk attitudes of the decision maker or stakeholder. Reference: Reichert et al, The
conceptual foundation of environmental decision support, Journal of Environmental
Management 154 (2015) 316-332.

22 D.18-12-014, Attachment A, pp. A-12 to A-13, No 24.

23 D.18-12-014, Attachment A, p. A-11, No 13.

1 The non-linear Scaling Function used by PG&E consists of three regions
 2 that define its overall shape, illustrated in Figure 1-3. Each of the regions is
 3 described below.

**FIGURE 1-3
 NON-LINEAR SCALING FUNCTION FOR PG&E'S MAVF**



- 4 a) Minor/Moderate Region: Linear for natural unit consequence from
 5 0 percent to 1 percent of the Range. Events whose consequence result
 6 in this region are assigned Scaled Units between 0 and 0.1.
- 7 b) Critical Region: Quadratic for natural unit consequence from 1 percent
 8 to 10 percent of the Range. Events whose consequence result in this
 9 region are assigned Scaled Units between 0.1 and 5.
- 10 c) Catastrophic Region: Linear for natural consequence from 10 percent to
 11 100 percent of the Range (catastrophic events). Events whose
 12 consequence results in this region and beyond 100 percent of the
 13 Range are assigned Scaled Units above 5. This region includes events
 14 whose consequences are greater than the Upper Bound of the Attribute
 15 Range (i.e., Scaled Unit above 100). There is no cap to the assignment
 16 of Scaled Units.

1 Mathematically, the Scaling Function, $S(r)$, used for all Attributes is defined
 2 below in Equation 1.

FIGURE 1-4
EQUATION 1: SCALING FUNCTION FOR ALL ATTRIBUTES

$$S(r) = \begin{cases} 10r, & \text{Region 1: } r \leq R_1 \\ 10r + \frac{1}{2} \cdot \frac{100(0.99 - 0.10)}{(R_2 - R_1)} (r - R_1)^2, & \text{Region 2: } R_1 < r \leq R_2 \\ \frac{100 - S_2}{(1.0 - R_2)} (r - R_2) + S_2, & \text{Region 3: } r > R_2 \end{cases}$$

where

a : Attribute Level (e.g. \$ loss)

R : Upper Range of Attribute (e.g. \$5billion for Financial)

$r = \frac{a}{R}$: Normalized Attribute Level

$R_1 = 1\%$ (Upper bound of Minor/Moderate Region)

$R_2 = 10\%$ (Upper bound of Critical Region)

$S_1 = 0.1$ (Maximum value in Minor/Moderate Region)

$S_2 = 5$ (Maximum value in Critical Region)

3 For consequences in the minor/moderate region (Region 1),
 4 representing high-frequency/low-consequence events, a linear function with
 5 a relatively small coefficient is adequate because the resulting low
 6 consequence value is multiplied by a relatively high frequency of occurrence
 7 when risk scores are calculated.

8 As the consequence from a risk event enters the critical level (defined
 9 as 1 percent of the Upper Bound), PG&E's Scaling Function reflects growing
 10 risk aversion through a quadratic function. In the Critical region (Region 2),
 11 PG&E assigns an incremental value of between approximately 1 to 10 times
 12 the value of an incremental loss in a minor/moderate situation. This
 13 increase in Scaled Units can be seen in the increasing slope of a scaling
 14 function:

- 15 • Going from an Attribute level of 2 percent to 2.1 percent is
- 16 approximately twice the increase in Scaled Units going from 0.0 percent
- 17 to 0.1 percent;

- The increase in Scaled Units going from an Attribute level of 5 percent to 5.1 percent is approximately five times the increase when going from 0.0 percent to 0.1 percent; and,
- The increase in Scaled Units going from an Attribute level of 9.9 percent to 10 percent is approximately 10 times the increase when going from 0.0 percent to 0.1 percent.

These increases were achieved by calibrating the quadratic coefficient.

Throughout the Catastrophic region (Region 3), incremental losses are assigned approximately 10 times the value of an incremental loss in a minor/moderate situation. The increase in Scaled Units (i.e. slope) going from an Attribute level of either 10 percent to 10.1 percent or 99.9 percent to 100 percent is about 10 times more than the increase going from 0.0 percent to 0.1 percent. This consistent increase is illustrated by the constant slope of the scaling function in the Catastrophic region in Figure 3.4. The linear coefficient for Region 3 was set to be approximately 105.6 to achieve this consistent increase.

1.2.6. MAVF Principle 6 – Relative Importance

MAVF Principle 6 states that each Attribute should be assigned a weight reflecting its importance relative to other Attributes defined in the MAVF.²⁴

PG&E uses the Attribute Weights shown in Table 1-4.

**TABLE 1-3
ATTRIBUTE WEIGHTS**

Line No.	Attribute	Weight
1	Safety	50%
2	Electric Reliability	20%
3	Gas Reliability	5%
4	Financial	25%

PG&E assigned the Attribute Weights to reflect the relative importance of moving each Attribute from its least desirable level (i.e., Upper Bound) to its most desirable level (i.e., zero). For example, the Attribute Weights

²⁴ D.18-12-014, Attachment A, p. A-6, No. 7.

1 reflect PG&E's view that it is twice as valuable to move the Safety Attribute
2 from 100 to 0 EFs as it is to move the Financial Attribute from \$5 billion to
3 \$0. Assigning 50 percent weight to the Safety Attribute is in line with
4 PG&E's emphasis on safety and is also consistent with the S-MAP
5 Settlement Decision's requirement for a minimum 40 percent weighting for
6 Safety.²⁵

8 **1.3. Bow Tie Methodology**

9 PG&E shows Bow Tie visuals for quantified risks to provide a consistent,
10 visual summary of the risk. In the center of the Bow Tie is the risk event, which
11 is a well-defined, single, observable, and measurable event. In the example
12 Bow Tie below, Figure 1-5, the Risk Event is a Loss of Containment (LOC) on a
13 Gas Transmission Pipeline.

14 In the following sections PG&E describes each of the Bow Tie elements:
15 drivers/frequency; outcomes/consequences; the risk score; and the cross-cutting
16 factors.²⁶

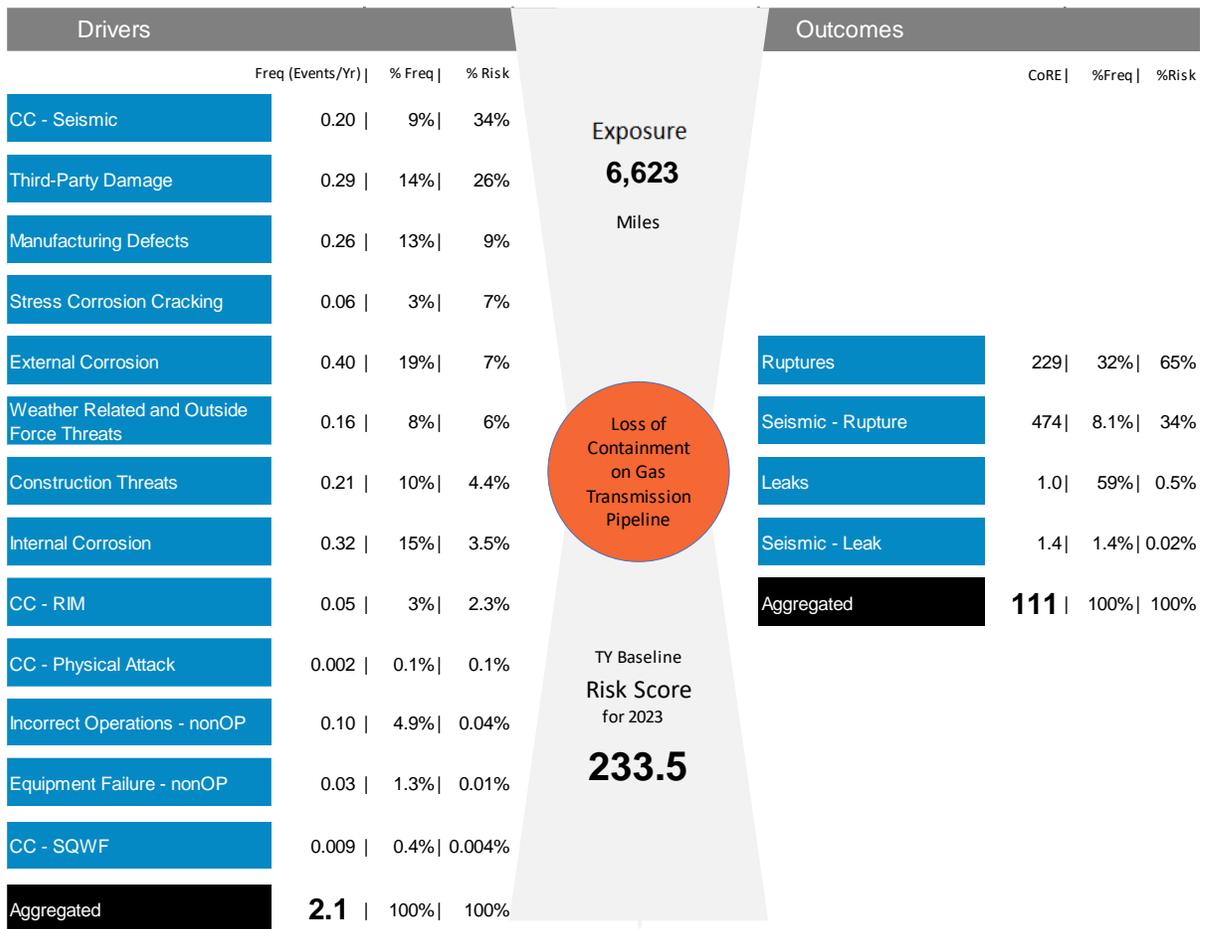
17 The risk score shown at the bottom of the Bow Tie, in the center, is
18 calculated as the frequency of the risk event multiplied by the consequence of
19 the risk event (Frequency x CoRE). Calculating the risk score is described in
20 more detail below.

21 Please note the CoRE shown in the Bow Tie includes a scaler of 1,000.

²⁵ D.18-12-014, p. 66, COL 5.

²⁶ Cross-cutting factors are not risk events themselves but rather they impact either the likelihood or consequence of other risk events. The cross-cutting factors are shown on the left side of the Bow Tie preceded by the letters "CC." On the right side of the Bow Tie they are shown in combination with other consequence events.

**FIGURE 1-5
RISK EVENT BOW TIE: LOSS OF CONTAINMENT ON A GAS TRANSMISSION PIPELINE**



1.3.1. Frequency of a Risk Event

On the left-hand side of the Bow Tie are the Risk Event drivers and their associated frequencies. The set of drivers includes the causes or threats identified for the Risk Event. Drivers are measurable events. The annual frequency of a risk driver leading to a Risk Event is informed by PG&E event data that is supplemented with industry data and/or SME input when necessary. Although not shown in the Bow Tie visual, certain drivers are further divided into multiple sub-drivers (components of a risk driver),²⁷ where the further division is useful and where data are available. Risk and mitigation analysis can also be done at a sub-driver level.

²⁷ For example, the risk driver “Animal” in the Failure of Electric Distribution Overhead Assets risk event includes two sub-drivers: animal contact; and, bird contact.

1 Drivers are expressed as the frequency of occurrence of a Risk
2 Event per exposure *per year*, the time unit for the analysis. For
3 example, Figure 1-5 shows a frequency of 0.29 for the Third-Party
4 Damage driver (top left side of the figure) which means that in 2023
5 PG&E expects to have 0.29 loss of containment events on a gas
6 transmission pipeline due to third-party damage events if no mitigations
7 are implemented starting in 2023. The frequency of a Risk Event
8 associated with each driver is summed to establish the risk-level
9 frequency. Without implementing any mitigations starting in 2023,
10 PG&E expects to have 2.1 loss of containment events—the aggregated
11 number of events shown in the lower left corner of the Bow Tie.

12 **1.3.2. Potential Consequence of a Risk Event**

13 On the right-hand side of the Bow Tie, PG&E introduces Outcomes
14 to differentiate manifestations of a risk event that have significantly
15 different consequences (changes in Attribute levels representing the
16 impact of the outcome). Each Outcome is characterized by different
17 probability distributions over the applicable Attributes, determined from
18 PG&E data, industry data, and/or SME input. The consequences of the
19 Risk Event are shown in more detail in the Consequence Table. Figure
20 1-6 below is the Consequence Table for the LOC on a Gas
21 Transmission Pipeline risk.

**FIGURE 1-6
CONSEQUENCE TABLE: LOSS OF CONTAINMENT ON A GAS TRANSMISSION PIPELINE**

					Natural Units Per Event			CoRE			Natural Units per Year			Attribute Risk Score		
	CoRE	%Freq	%Risk	Freq	Safety	Gas	Financial	Safety	Gas	Financial	Safety	Gas	Financial	Safety	Gas	Financial
					EF/event	#cust/event	\$M/event		Reliability		EF/yr	#cust/yr	\$M/yr		Reliability	
Ruptures	229	32%	65%	0.66	1	5,193	6.5	200	6.5	22	0.40	3,449	4.3	133	4.3	15
Seismic - Rupture	474	8%	34%	0.17	1	6,433	13	416	9.6	48	0.19	1,092	2.1	71	1.6	8.1
Leaks	0.96	59%	1%	1.2	0	24	0.47	0.71	0.016	0.23	0.016	29	0.58	0.88	0.019	0.29
Seismic - Leak	1.35	1.4%	0%	0.03	0	35	0.70	1.0	0.024	0.35	0.0005	1.02	0.020	0.028	0.0007	0.010
Aggregated	111	100%	100%	2.1	0.29	2,173	3.4	97	2.8	11.1	0.61	4,571	7.1	204	6.0	23

For reference, the attribute ranges are shown again below – Table 1-1 (above):

Line No.	Attribute	Natural Unit of Attribute	Range
1	Safety	EFs	0 – 100
2	Electric Reliability	Customer Minutes Interrupted	0 – 4 billion
3	Gas Reliability	Number of Customers Affected	0 – 750 thousand
4	Financial	Dollars	0 – 5 billion

In the LOC on a Gas Transmission Pipeline risk above, the consequences of a LOC event include the potential for serious injury or fatality (Safety), loss of gas service (Gas Reliability), and property damage (Financial). The manifestation of these consequences depends on the Outcome, or type of loss of containment. A leak is sufficiently different from a rupture that modelling them both with a single consequence attribute distribution does not fairly characterize either. Having different sets of Attribute distributions for each Outcome more precisely models the potential consequences of the Risk Event.

The probability distributions characterizing Safety, Financial and Gas Reliability Consequence for the leak outcome are lower in mean and variance across the attributes than the set of distributions for a rupture. Furthermore, some drivers are more or less likely to lead to lower or higher severity outcomes. For example, the Third-Party Damage driver leads only to the rupture outcome, not a leak. In contrast, External Corrosion, an important driver of LOC events, is more likely to lead to a leak than to a rupture. Through this analysis, PG&E can better identify and mitigate drivers strongly tied to the more severe outcomes when elements on the left- and the right-hand side of the Bow Ties are presented as specifically as possible, given the available information.

The Bow Tie available for each risk lists drivers and outcomes of the Risk Event, as well as the associated summary quantities such as frequency, consequence and contribution to risk score. Within PG&E’s enterprise risk model, those elements can vary by one or more of: time, tranche, sub-driver, outcome, and attribute as summarized in Table 1-4.

**TABLE 1-4
SUMMARY OF BOW TIE ELEMENT UNITS AND DIMENSIONALITY**

Line No.	Bow Tie Element	Quantification Unit	Can Vary By
1	Exposure	Depends on risk event (e.g., miles of pipe, number of high hazard dams, number of employees)	<ul style="list-style-type: none"> • Time • Tranche
2	Driver	Expected number of risk events per year (frequency)	<ul style="list-style-type: none"> • Time • Tranche • Sub-driver • Outcome
3	Outcomes	CoRE	<ul style="list-style-type: none"> • Time • Tranche • Attribute

1.3.3. Tranches

For each Risk Event, underlying the Bow Tie structure is a set of tranches over which driver frequencies and Outcome attribute distributions vary both in applicability and magnitude. Each tranche includes a group of assets, a geographic region or other grouping that is intended to have a similar risk profile. For example, the Employee Safety Incident Risk defines tranches to capture distinct groups of employees based on the work done: Office Employees are distinguished from Field Employees, and Field Employees tranches are further distinguished by Line of Business supported. The Bow Tie is essentially defined at a tranche level which provides a more granular view of risk and how mitigations will reduce risk.

1.3.4. Calculating the Risk Score

Each bow tie has an associated Risk Score that is a function of the LoRE and the CoRE.²⁸

$$Risk\ Score\ per\ Unit\ of\ Exposure = LoRE \times CoRE$$

CoRE is the weighted sum of Scaled Units representing the consequence from an occurrence of a Risk Event on each Attribute using the MAVF. To calculate CoRE using Attribute Weights and Attribute Scaled Units, PG&E applies a Scaler of 1000. Specifically,

²⁸ D.18-12-014, Attachment A, p. A-11, No. 13.

$CoRE = Safety\ CoRE + Electric\ Reliability\ CoRE + Gas\ Reliability\ CoRE + Financial\ CoRE$

Where:

- $Safety\ CoRE = Scaler\ (1,000) \times Safety\ Weight\ (50\%) \times Safety\ Scaled\ Unit$
- $Electric\ Reliability\ CoRE = Scaler\ (1,000) \times Electric\ Reliability\ Weight\ (25\%) \times Electric\ Reliability\ Scaled\ Unit$
- $Gas\ Reliability\ CoRE = Scaler\ (1,000) \times Gas\ Reliability\ Weight\ (5\%) \times Gas\ Reliability\ Scaled\ Unit$
- $Financial\ CoRE = Scaler\ (1,000) \times Financial\ Weight\ (20\%) \times Financial\ Scaled\ Unit$

PG&E treats LoRE as specified per unit of exposure and expresses Risk Scores equivalently as Frequency x CoRE at a Tranche or System level:

$$\begin{aligned}Tranche\ Risk\ Score &= Tranche\ Exposure \times LoRE \times CoRE \\ &= Tranche\ Frequency \times CoRE\end{aligned}$$

$Risk\ Score = Sum\ of\ Tranche\ Risk\ Scores\ over\ all\ Tranches\ for\ the\ Risk\ Event$

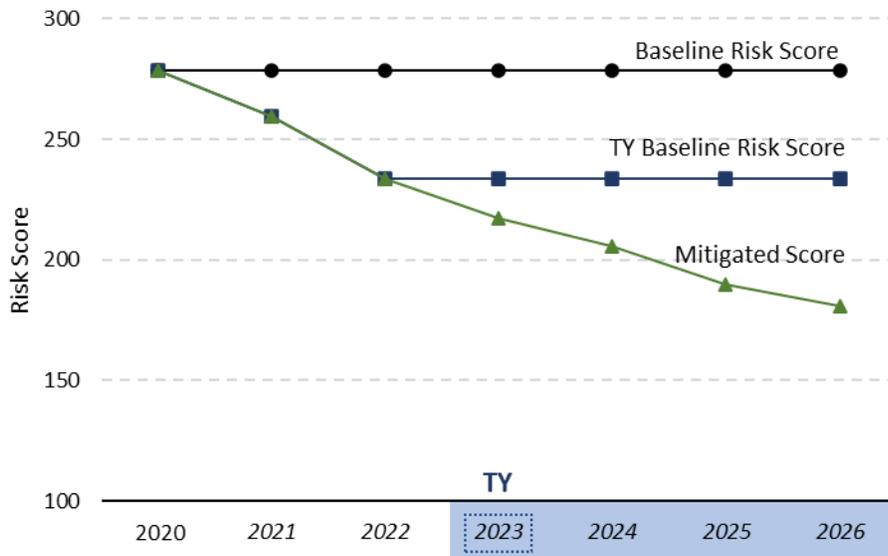
Frequency (the number of occurrences per year) is directly observable and easily understood. For events that are expected to happen less than once per year per unit of exposure, the likelihood of the risk event happening in a year for a Tranche and the frequency of the risk event happening are equivalent (e.g., a 100-year flood has an annual probability, or LoRE, of 0.01, and, the expected number of floods per year, Frequency, is 0.01). For risk events that are expected to happen more often than once per year per unit of exposure, the likelihood of the risk event is 1 though the frequency of the risk event is greater than 1. Frequency captures the difference between a risk event that happens twice per year and 1,000

times per year, whereas likelihood, as a metric, is unable to do so given a one-year time period for analysis.²⁹

1.3.5. Baseline used to Evaluate Risk Mitigation Programs

A "baseline" serves as a level of risk against which to evaluate proposed changes in the way that PG&E manages risk. Proposed changes may include applying new/additional mitigation efforts or reducing the scope/pace/type of current risk mitigation activities. In the Enterprise Risk Model taxonomy, there are two points in time against which we baseline in order to evaluate programmatic changes: the current calendar year and the upcoming GRC Test Year (TY). Baseline Risk Score and Test Year (TY) Baseline Risk Score are associated with those two time points for baseline, respectively. From these baselines, two other risk scores can be computed: Inherent and Mitigated Risk Scores.

**FIGURE 1-7
RISK SCORES FOR LOSS OF CONTAINMENT ON A GAS TRANSMISSION PIPELINE**



²⁹ A potential approach to this issue would be to vary the period for analysis (i.e., a month, a day) in order to compute a LoRE < 1. However, PG&E believes that varying the analysis period from a year would add complexity without substantial benefit, especially since PG&E’s enterprise risks have frequencies ranging in order of magnitude from 10⁻³ to 10⁴.

1.3.5.1. Baseline Risk Scores

The Baseline Risk Score is often calculated using available historical data for each Risk Event likelihood and consequences. The Baseline Risk Score, therefore, reflects the influence of risk management programs (measures) that are already in place, given the sources of information used to compute the Baseline Risk Score. Using a Baseline Risk Score informed by historical data to assess work in future years requires the assumption that that we continue to do historic levels. In the figure above, the Loss of Containment on Gas Transmission Pipeline Risk Score computed for 2020 reflects data available up to and including 2020. There are no exogenous factors which affect the level of risk going forward, so, the 2020 Baseline score is assumed constant in 2021 and beyond. As the historical data already includes the effect of the programs in place for the historical period, the Baseline Risk is independent of what and how much we intend or plan to do for risk mitigation in the current and future years.

1.3.5.2. Test Year (TY) Baseline Risk Score

The TY Baseline Risk Score is a specification of risk scores for the purpose of planning for the General Rate Case (GRC). As computed in the 2020 RAMP and TY 2023 GRC filings, the TY Baseline Risk is the baseline for each year assuming that we do the planned amount of work for current GRC period (i.e., 2021 and 2022) and that we do historical levels of work (i.e., controls) for the test year (2023) and later. In implementation, the TY Baseline risk score is derived from the Baseline Risk Score. Put another way, the Baseline Risk Score is adjusted according to work planned for the remainder of the current GRC period such that the baseline against which we measure risk reduction from proposed 2023 GRC programs accurately reflects the level of risk during the 2023 GRC period (2023 through 2026). In the figure above, the work done in 2021 and 2022 leads to a TY Baseline Risk Score that is lower than the Baseline Risk Score.

The Baseline Risk Score and the TY Baseline Risk Score may vary over time. Factors, such as increasing threat of natural hazards over time due to climate change or changing demographics in PG&E's service territory, independent of PG&E risk management activities can affect baseline risk in future years.

Some caveats when we compute Baselines solely using historical risk event data are:

1. PG&E implicitly assumes that the amount of control work done (e.g., asset replacement rate) changes in reaction to changes in the potential risk event frequency (e.g., potential asset failure rate). If historical level of some programs do not keep up with an increase in the number of assets reaching its useful service life, we would expect the baseline risk to increase over time.

2. The Baseline and TY Baseline assumptions do not account for the changing effectiveness of historical risk reduction programs in relation to climate change or impact of climate change on asset failure rate.

1.3.5.3. Mitigated (or Proposed) Risk Score

The Mitigated Risk Score, also referred to as the Proposed Risk Score in the risk models, is the post-mitigation risk score, i.e., the level of risk assuming the set of proposed mitigation programs are implemented at proposed levels at a specified level of effectiveness through the end of the GRC period (2026 in Figure 1-7). The set of programs are evaluated as a portfolio when calculating the Mitigated Risk Score; interaction between programs (e.g., two programs mitigate the same unit of risk exposure) means that the total risk reduced by each program in the set is less than or equal to the risk reduction of the program computed in isolation.

1.3.5.4. Inherent Risk Score

The Inherent Risk Score is defined in the Revised S-MAP Lexicon in D.18-12-014 as “the level of risk that exists without risk controls or mitigations.”³⁰ The Inherent Risk Score can be calculated by adding to the baseline risk score a risk reduction from a portfolio of risk controls and mitigations that are assumed to be embedded in the baseline.

1.4. Modeling the Cross-Cutting Factors

Cross-cutting factors are not risk events themselves but rather they impact either the likelihood or consequence of other items (risk events) on PG&E’s Corporate Risk Register (CRR).

³⁰ D.18-12-014, p. 17 (see 2018 S-MAP Revised Lexicon, pp. 16-19).

Beginning with the 2020 RAMP, PG&E integrates each applicable cross-cutting factor into the appropriate risk models as a driver, driver component or consequence of that specific risk.

There are four ways the cross-cutting factors are explicitly modelled in event-based risk models.

- a) Driver: Appears on the left-hand side of the Bow Tie as a driver and is modeled identically to other drivers. Frequency of a Risk Event associated with cross-cutting drivers is identified in the same manner as for the other drivers based on historical frequency of those events, or SME judgement if historical data is not available or sufficient.
- b) Consequence Multiplier: When a cross-cutting factor affects the consequence of an event for an Outcome regardless of drivers, it is modeled as a Consequence Multiplier to the Natural Unit of the simulated risk event outcome, affecting the CoRE.
- c) Outcome: Where the impact of a cross-cutting driver differs from the impact of the non-cross cutting drivers on the consequences of a Risk Event (e.g., the severe Seismic outcome is driven solely by the Seismic driver).
- d) Escalating Frequency: Is applied as a Frequency Multiplier over time to one or more applicable risk drivers (e.g., climate change).

1.5. Modeling the Mitigations and Control Programs

A mitigation is defined as a measure or activity proposed or in process that is designed to reduce the impact/consequences and/or the likelihood/probability of a risk event.³¹ The adequacy and effectiveness of a mitigation is assessed based on how much of the exposure is affected (i.e., scope of mitigation), the impact on specific driver/sub-driver frequencies (and how those frequencies may change over time), the impact on the consequence of specific attributes, and the associated cost.

A control is a currently established measure that modifies risk, such as standard operation/routine work that is undertaken as part of normal business operations and is not a new program, or an enhancement to an existing one.³² Controls have no end date.

³¹ D. 18-12-014, p. 17 (see 2018 S-MAP Revised Lexicon, pp. 16-19).

³² D.18-12-014, p. 16 (see, 2018 S-MAP Revised Lexicon, pp. 16-19).

The benefits of applying mitigations and controls are represented by percentage reductions in driver/sub-driver frequencies by tranche and outcome, and/or consequence magnitude (e.g., the number of customer minutes interrupted per risk event outcome as simulated) by tranche and outcome. Mitigations are further defined by the duration of risk reduction benefits once mitigation is complete, and effectiveness degradation with time.

1.6. Risk Spend Efficiency

Risk Spend Efficiency is a metric for representing the benefit to cost ratio of a mitigation and/or control, where benefit is described in terms of risk reduction. The S-MAP Settlement Decision states that RSE should be calculated by dividing the mitigation risk reduction benefit by the mitigation cost estimate. Further, the values in the numerator and denominator should be present values and, for capital programs, the mitigation costs in the denominator should include incremental expenses made necessary by the capital investment.³³

PG&E's RSE results show the risk reduction achieved per 1 million dollars (\$M) spent. For example, a risk event with Frequency of one event per year and Consequence of 40 million CMI has a risk score of 20.³⁴ If a mitigation that costs \$10 million reduces the Frequency of this risk event by 50 percent (from 1 event per year to 0.5 events per year), then the risk reduction (the difference between pre- and post-mitigation scores) is 10 and RSE is 1.³⁵

When the benefit of a mitigation lasts more than one year, risk reduction is aggregated by the present value of risk reduction over the benefit years and the cost is aggregated as the present value of the costs over the spend years.

Equation 2 shows the RSE calculation:

$$RSE = \frac{NPV(\text{Pre-mitigation Risk Scores}) - NPV(\text{post-mitigation Risk Scores})}{NPV(\text{Program Costs})}$$

Where:

- NPV (Risk Scores) and NPV (Program Costs) are the Net Present Value of the Risk Score and Program Costs.

³³ D.18-12-014, Attachment A, p. A-13, No. 25.

³⁴ Risk Score = Frequency x CoRE = Frequency (1) * Scaler (1000) * Attribute Weight (50%) * Scaled Unit (0.1) = 50.

³⁵ Risk Reduction = Pre-mitigation Risk Score (50) – Post-mitigation Risk Score (25) = 25.
RSE = Risk Reduction / Cost = 25/ 25M = 1 /\$M spend.

The following sections discuss how PG&E has implemented the S-MAP Settlement Decision requirements for calculating RSE.

1.6.1. Discounting

In compliance with the S-MAP Settlement Decision, PG&E shows the numerator and denominator of the RSE as present values.³⁶ PG&E uses a single discount rate, its After Tax Weighted Average Cost of Capital (ATWACC) to calculate the present value of all future costs and attributes. The base year for all discounting is 2021.

PG&E focused on two core principles when discounting:

- 1) Costs and benefits occurring over different time periods should be assessed on an equal basis. Principle 1 implies a non-zero discount rate for costs to account for the time value of money.
- 2) All else being equal, RSEs should not change if both costs and mitigations are offset by a period of time.³⁷

To achieve Principle 2, the discount rate for Attributes (i.e., in the numerator of the RSE) must not only be the same across all Attributes but also must be the same as the discount rate for costs (i.e., the denominator). The ATWACC was derived as follows:

³⁶ D.18-12-014, Attachment A, p. A-13, No. 25.

³⁷ As an example of why Principle 2 is necessary, consider a program that starts immediately and runs for a set number of years, with costs only incurred during that period. All else being equal, the program should have the same RSE if it started one year later, otherwise one could simply defer or expedite the work to increase the RSE score with no fundamental improvement in the program.

TABLE 1-5
2021 AFTER TAX WEIGHTED AVERAGE COST OF CAPITAL CALCULATION

Line No.	Component	Weight	Cost of Capital (%)	WACC		After Tax WACC
1	Debt	47.5%	4.17	1.98	x (1 - tax rate)	1.43
2	Preferred Stock	0.5%	5.52	0.03		0.03
3	Common Stock	52.0%	10.25	5.33		5.33
4						7
<p>Note: The ATWACC used in the risk model is based on PG&E's cost of capital as of the June 30, 2021 filing date for the GRC. This is rounded to the nearest 50bp (bp = basis points, or, 0.01%)</p>						

This discount rate was determined solely based on the Principles and considerations above. Therefore, it is only valid in the context of calculating RSEs and should not be extended to other applications without further consideration.

1.6.2. Treatment of Capital Costs

To account for all costs associated with capital investments subject to cost-of-service ratemaking (e.g., depreciation, income taxes, property tax, insurance, incremental expenses and return on investment over the life of an asset), PG&E uses an estimated Present Value of Revenue Requirement (PVRR) associated with capital investment in the denominator of the RSE. PVRR represents the present value of revenue that must be collected from customers to pay for all the costs (net of benefits) incurred on a project, including an approved rate of return on investment, over the life of that project. The discount rate used in the PVRR should be the after-tax, weighted-average cost of capital, which is the same as discount rate used for RSE calculations. The ratio of the PVRR to initial capital investment is referred to as the Present Value of Revenue Requirement (PVRR) multiplier. Using the PVRR for calculating NPV of Program Costs in RSE allows for a direct comparison between the RSEs for capital programs and the RSEs for expense programs by normalizing the risk reduction per dollar spent. Using an estimated revenue requirement leads to

lower RSEs for capital programs than an otherwise identical expense program because the revenue requirement costs will be included.

Details on the PVRR can be found in the RSE Lite Tool Documentation and User Guide³⁸.

1.6.3. Pre-Mitigation and Post-Mitigation Risk Scores

Pursuant to the S-MAP Settlement Decision, PG&E calculates pre- and post-mitigation risk scores for each year that proposed mitigations are in effect.³⁹

For the TY2023 GRC, PG&E defines the different periods as:

- Pre-mitigation: This corresponds to the TY Baseline Risk Score. For programs planned for the upcoming GRC period (2023-2026) PG&E calculates a pre-mitigation program score that accounts for the benefits from any mitigations that are planned for 2020–2022.
- Post-Mitigation: This corresponds to the Mitigated (or Proposed) score. The benefits from proposed mitigations for the 2023-2026 GRC period are accounted for in the Post-mitigation Risk Scores.

1.6.4. Risk Reduction

The Risk Reduction value captures all the program's benefits and is not limited by the GRC time period. For example, gas pipeline replacement assumes a capital life of 80 years so the benefits are assumed to accrue over all 80 years.

Certain programs PG&E implements benefit multiple risks. For example: (1) PG&E proposes mitigations (e.g., Enhanced Vegetation Management) that will reduce the risk of both a Wildfire and a Failure of Electric Distribution Overhead Assets (DOVHD) risk event; and (2) PG&E proposes a mitigation (3A and 4C Line Reclosers) that will reduce risk of both an Failure of Electric Distribution Overhead Assets and a Third-Party Safety Incident (TPTSI).

For programs that benefit multiple risks, PG&E includes the impact of the program in the calculation of the Risk Reduction score for each risk that benefits from the program.

³⁸ Risk Modeling WP-2.

³⁹ D.18-12-014, Attachment A, p. A-11, No. 13.

Many of the cross-cutting mitigations (mitigations aligned to the cross-cutting factors) address multiple risk events. The Risk Reduction for these mitigations is calculated at the risk level and then summed across each risk to present at the cross-cutting factor level (e.g., a Risk Reduction score is provided for all Records and Information Management mitigations combined).

The S-MAP Settlement Decision states that utilities should provide the pre- and post-mitigation values for the effects of a mitigation at the tranche level.⁴⁰ PG&E characterizes programs at the tranche level and calculates risk reduction values for each risk at the tranche level.

1.6.5. Tranche-Level RSE

The S-MAP Settlement Decision states that Utilities should provide RSEs at the tranche level. PG&E provides RSEs at the tranche within the RSE Input File workpapers, in the RSE Results tab.

To calculate tranche-level RSEs, the risk model requires a tranche-level cost estimate for each mitigation and control. Tranche-level Risk Reduction and cost is used to compute the tranche-level RSEs.

When calculating RSEs, in instances where a program benefits more than one risk, there are two methods to handle program cost at the risk level:

1. The program forecast in its entirety is associated with the program for each affected risk. For example, the HPR Replacement Program affects both the Large Overpressure Event Downstream of Gas Measurement and Control Facility risk and the Loss of Containment at Gas Measurement and Control or Compression and Processing Facility risk, so there are two risk-level RSEs and a program-level RSE. Since the same cost is used to calculate the risk-level RSEs, the program-level RSE is the sum of the two risk-level RSEs.
2. The forecast is divided between risk events. In this case, the RSEs at the risk level reflects the fraction of the spend specifically targeted for reducing that risk. For example, the Independent Oversight and Training Program affects both the Nuclear Extended Shutdown risk (NSHUT) and the Nuclear Core Damaging Event risk (NCORE). Since the cost of the program is allocated into the two risks when calculating the risk-level RSEs, the

⁴⁰ D.18-12-014, Attachment A, p. A-12, No. 16.

program-level RSE is the sum of risk-level risk reductions divided by the sum of allocated costs.

Many of the cross-cutting mitigations address multiple RAMP risk events, but the costs cannot be meaningfully separated or allocated. Therefore, the first method is used for cross-cutting mitigations, and the RSEs for the cross-cutting mitigations are provided at the risk-level with the total cost of the program, and at the program level by summing risk-level RSEs across all affected risks. .

1.6.6. Foundational Programs

PG&E defines foundational programs as those that support multiple mitigations/controls that reduce risk, but do not reduce the risk themselves. PG&E does not allocate the costs of foundational mitigations among the mitigations they support because the costs cannot be allocated in a meaningful way.

Foundational mitigations and foundational controls are, by definition, assigned an RSE of 0 and marked as such in the analyses.

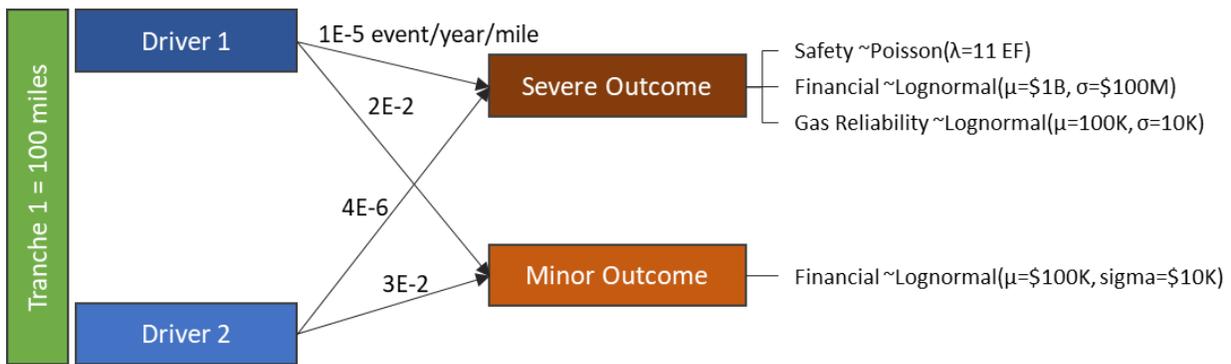
Certain actions that could be considered foundational mitigations are necessary to support a *single* mitigation program. PG&E includes the costs for these actions as part of the cost of the mitigation program they enable and does not consider them foundational mitigations.

2. Risk Analysis Example: MAVF, Risk Score, Risk Reduction, and RSE

This section walks through an example of how a simple Bow Tie model (shown in Figure 2-1 below) is used to compute RSE values for two proposed mitigations and addresses:

- a) LoRE;
- b) CoRE;
- c) Expected Value from simulated CoRE;
- d) Risk Score;
- e) Risk Reduction; and
- f) RSE.

**FIGURE 2-1
EXAMPLE BOW TIE INPUT ASSUMPTIONS**



Note: Poisson and Lognormal refer to the parametric probability distributions used to model the outcome of the risk event.

The example Bow Tie includes:

- Two drivers – Driver 1 and Driver 2;
- Two Outcomes – Minor and Severe;
- One tranche, Tranche 1, defined by an exposure of 100 miles of an asset;
- The risk event is characterized by potential Safety, Gas Reliability, and Financial consequences;
- The Minor outcome has only Financial consequences; and
- The Severe outcome has greater Financial consequences, as well as Safety and Reliability impacts.

The two distinct outcomes for this single risk event, allows the model to capture the low frequency high consequence outcome and the high frequency low consequence outcome, each of which have uncertainty regarding the magnitude of the consequences.

2.1.1. Likelihood of Risk Event

Likelihood of Risk Event is calculated per tranche-outcome-driver. The example Bow Tie in Figure 2-1, with one tranche, two drivers, and two Outcomes requires ($1 \times 2 \times 2 = 4$) four frequency values.

Where there is more than one tranche, PG&E calculates as many sets of tranche-driver-outcome frequencies and Outcome Attribute distributions as there are tranches. Risk Events that are presented in this RAMP report include tens or hundreds of frequency values per Risk Event.

For the sample Bow Tie, the LoRE occurring per year, per unit of exposure (LoRE) is the sum of the four frequencies shown in Table 2-1.

**TABLE 2-1
SAMPLE BOW TIE: SUMMARY OF LORE BY DRIVER, OUTCOME AND RISK EVENT**

Line No.	Calculation	Minor Outcome	Severe Outcome	LoRE by Driver	Percent of Frequency by Driver
1	LoRE for Driver 1	0.02	0.00001	0.02001	40%
2	LoRE for Driver 2	0.03	0.000004	0.030004	60%
3	LoRE (/yr/mile) =	0.05	1.4E-05		
4	Freq (#/year) =	5	0.0014		
5	% of Freq =	99.97%	0.03%		100%

- LoRE for each Driver = Minor Outcome + Severe Outcome;
- LoRE per year per mile = LoRE for Driver 1 + LoRE for Driver 2;
- Frequency (number of events per year) = LoRE per year per mile x 100 (exposure);⁴¹ and,
- Percent of Frequency = Frequency of Each Outcome / Total Frequency –
For example, $5/(5+0.0014) = 99.97\%$

Therefore, the model expects 0.050014 events per year per mile, which is equivalent to a probability of 0.050014 that the event will happen each year on a given mile of exposure.

Given 100 miles of exposure on the tranche, the risk event frequency is:

$$\text{Frequency} = \text{Exposure} \times \text{LoRE} = 100 \times 0.050014 = 5.0014 \text{ events per year}$$

Of these 5.0014 events:

- 99.97% of the time the outcome is Minor; and
- 0.03% of the time (1 in 714 years) the outcome is Severe.

2.1.2. Consequence of Risk Event (CoRE) for one Trial

Risk event consequences are calculated per tranche-outcome-attribute combination. The Severe Outcome is illustrated in this example given its complexity relative to the Minor Outcome.

The Severe Outcome has Safety, Reliability, and Financial attributes, each defined using a parametric probability distribution (two Lognormal, one Poisson). This example of the CoRE calculation using the MAVF assumes that these attributes are deterministic (the model does not include elements of

⁴¹ The value “100” is used here because the Tranche is defined as 100 miles and the LoRE is measured per mile.

randomness and the results will be the same every time you run the model) to simplify the application of the MAVF. A description of the probabilistic case (i.e., a model that includes elements of randomness and presents results that vary each time you run the model) follows in Section 2.1.3, CoRE as Expected Value.

The Consequences of a Risk Event in Natural Units for the Severe Outcome are listed in Column A of Table 2-2. The step-by-step calculation below computes all quantities for the Safety Attribute to illustrate the Safety CoRE calculation. Identical steps are performed for each of the other Attributes.

**TABLE 2-2
SAMPLE BOW TIE: MAVF DATA FOR SEVERE OUTCOME
ASSUMING DETERMINISTIC CONSEQUENCE**

Line No.	Attribute	Column			
		A	B	C	D
		Consequence of Risk Event in Natural Unit	Normalized Natural Unit (0-1)	Scaled Unit	Attribute CoRE
1	Safety	11 EF	0.11	6.1	3,027
2	Gas Reliability	100K Customers	0.133	8.5	426
3	Financial	\$1B	0.2	15.6	3,889

Column A has values in Natural Units for each Attributes. The expected values of the distributions are assumed to be a deterministic consequence. The Safety consequence is 11 EFs.

Column B is an intermediate step applying the scaling function characterized in Equation 1 (Figure 1-3), specifically calculating parameter *r*. It results from normalizing the Natural Unit values in Column A using the Attribute Ranges in Table 1-1. This step determines which scaling function Region the Natural Units fall within.

$$\begin{aligned} \text{Normalized Unit (Safety)} &= \text{Natural Unit (Safety)} / (\text{Upper Bound} - \text{Lower Bound}) \\ &= 11 / (100 - 0) = 0.11 \end{aligned}$$

Column C shows the results of applying the scaling function to the Natural Unit. Given Normalized Natural Units, r , the scaling function returns Scaled Units.⁴² The Safety outcome is “catastrophic”, $r = 0.11 > R_2$, so the equation corresponding to Region 3 from Equation 1 and Figure 1-3 is used ($S_2 = 5$, $R_2 = 0.1$).

$$\begin{aligned} \text{Scaled Unit (Safety)} &= \frac{100 - S_2}{1.0 - R_2} (\text{Normalized Unit} - R_2) + S_2 \\ &= \frac{100 - 5}{1.0 - 0.1} (0.11 - 0.1) + 5 = 6.1 \end{aligned}$$

Column D is the Attribute CoRE, calculated as scaled units multiplied by the appropriate weight \times a Scaler of 1000. The Attribute weights are as defined in Table 3-4. The Safety CoRE is calculated as:

$$\begin{aligned} \text{Safety CoRE} &= \text{Scaler} \times \text{Safety Weight} \times \text{Scaled Unit (Safety)} \\ &= 1000 \times 0.5 \times 6.1 = 3,027 \end{aligned}$$

Finally, all Attribute-level CoREs (Column D) are summed to compute the CoRE at the risk level:

$$\begin{aligned} \text{CoRE} &= \text{Safety CoRE} + \text{Gas Reliability CoRE} + \text{Financial CoRE} \\ &= 3027 + 426 + 3889 = 7,343 \end{aligned}$$

Following the same steps, the CoRE of the Minor Outcome is 0.05.

2.1.3. CoRE as Expected Value

When needed, PG&E’s risk model simulates the Natural Units for relevant tranche-outcome-attribute combinations, so this example illustrates that method for all outcomes⁴³. Table 2-3 below shows the simulated natural unit values for all Severe Outcome attributes for 10 trials⁴⁴.

⁴² If a linear scaling function had been used, Column C would simply be 100*Column B.

⁴³ Circumstances where PG&E instead applies an analytical solution are explained in Section 4.1.2.

⁴⁴ PG&E’s model runs 10,000 trials per distribution.

**TABLE 2-3
SAMPLE BOW TIE: SIMULATED SEVERE OUTCOMES VALUES IN NATURAL UNITS AND
ATTRIBUTE CoRE CALCULATIONS^(a)**

Trial	Safety				Reliability				Financial			
	Sim Natural Unit (EF)	Normalized	Scaled	Total CoRE	Sim Natural Unit (1k Cust)	Normalized	Scaled	Total CoRE	Sim Natural Unit (\$M)	Normalized	Scaled	Total CoRE
1	5	0.05	1.3	646	84	0.11	6.3	315	871	0.17	12.8	3,207
2	8	0,08	3.2	1,611	86	0.12	6,6	330	871	0.17	12.8	3,209
3	8	0.08	3.2	1,611	91	0.12	7.2	362	982	0.20	15.2	3,791
4	10	0.10	5.0	2,503	96	0.13	8.0	400	987	0.20	15.3	3,819
5	12	0.12	7.1	3,556	97	0.13	8.0	401	1,006	0.20	15.7	3,923
6	12	0.12	7.1	3,556	104	0.13	8.1	406	1,028	0.21	16.2	4,039
7	13	0.13	8.2	4,083	104	0.14	9.1	453	1,031	0.21	16.2	4,053
8	14	0.14	9.2	4,611	108	0.14	9.1	456	1,051	0.21	16.6	4,158
9	14	0.14	9.2	4,611	108	0.14	9.6	481	1,119	0.22	18.1	4,517
10	15	0.15	10.3	5,139	109	0.14	9.7	486	1,134	0.23	18.4	4,594
	Safety CoRE 3,193				Reliability CoRE 409				Financial CoRE 3,931			
Sum of Attribute Values: 7,533												
<hr/> <p>(a) The Attribute CoRE is the average of the CoRE per trial for that Attribute.</p>												

The additional step required to compute the Attribute CoRE (compared to the steps required to calculate the CoRE for one trial described in Section 2.1.2) is to take the average of all Trial CoRE values.

Therefore, the CoRE for the Severe Outcome is the average sum of the three Attribute CoRE values: $3,193 + 409 + 3,931 = 7,533$.

The CoRE using the probabilistic values is greater than the CoRE computed using deterministic values because of the non-linear scaling function, which places greater weight on those trials having the least favorable outcomes (e.g., Row 10 in Table 2-3).

Following the identical process, PG&E calculated the CoRE for the Minor Outcome (based only on the Financial Attribute because it is the only outcome of a minor event). The Minor Outcome CoRE is 0.054.

TABLE 2-4
SAMPLE BOW TIE: CORE PER OUTCOME

Line No.	Outcome	CoRE
1	Severe	7,533
2	Minor	0.054

Using these outcome-based CoRE values, the CoRE at the risk-level is calculated as a weighted sum of CoRE based on the frequency percentage of each outcome.

$$\text{CoRE} = \% \text{ Freq (Minor Outcome)} \times \text{CoRE (Minor Outcome)} \\ + \% \text{ Freq (Severe Outcome)} \times \text{CoRE (Severe Outcome)}$$

$$\text{CoRE} = 0.03\% \text{ (Table 2-1)} \times 7,533 \text{ (Table 2-4)} + 99.97\% \text{ (Table 2-1)} \times 0.054 \text{ (Table 2-4)} = 2.2$$

2.1.4. Risk Score

The Risk Score is computed at the tranche-outcome level. Given a single tranche for this example risk, the risk scores per outcome are:

$$\text{Risk Score (Minor Outcome)} = \text{Frequency (Minor Outcome)} \times \text{CoRE (Minor Outcome)} \\ = 5 \text{ (Table 2-1)} \times 0.054 \text{ (Table 2-4)} = 0.27$$

$$\text{Risk Score (Severe Outcome)} = \text{Frequency (Severe Outcome)} \times \text{CoRE (Severe Outcome)} \\ = 0.0014 \text{ (Table 2-1)} \times 7,533 \text{ (Table 2-4)} = 10.55$$

$$\text{Risk Score} = \text{Risk Score (Minor Outcome)} + \text{Risk Score (Severe Outcome)} \\ = 0.27 + 10.55 = 10.82$$

The sample risk Bow Tie, Figure 2-2 below, shows that the Severe Outcome contributes 97 percent of the total risk though it represents only 0.03 percent of the frequency of a risk event.

**FIGURE 2-2
SAMPLE BOW TIE: EXAMPLE RISK EVENT SUMMARY**



2.1.5. Risk Reduction Score

To calculate the Risk Reduction score PG&E uses data supplied by the RAMP risk teams that outline the effectiveness of the proposed mitigation and the duration of the mitigation benefit.

Table 2-5 is information for two mitigations used in the example calculation.

**TABLE 2-5
SAMPLE BOW TIE: CHARACTERISTICS FOR MITIGATION 1 AND MITIGATION 2**

Line No.	Target	Effectiveness Percentage	Scope	Benefit Duration	Effectiveness Degradation
1	Frequency of Drivers 1 and 2	20%	17 miles in Year 1	4 Years	20% annually
2	Safety Consequences of Severe Outcome	10%	100 miles each year from Year 1 to Year 4	1 Year	0%

2.1.5.1. Mitigation 1 – Program Frequency

Proposed mitigation M1 targets all risk drivers for the risk event and is 20 percent effective at reducing event frequency. Effectiveness of M1 is provided per unit of exposure to which the mitigation is applied. Using the scope and effectiveness of the mitigations, the model calculates the average effectiveness at the tranche level:

$$\begin{aligned} \text{Average effectiveness} &= \text{Effectiveness} \times \text{Scope} / \text{Tranche Exposure} \\ &= 20\% \times 17 \text{ miles} / 100 \text{ miles} = 3.4\% \end{aligned}$$

Because M1 affects all risk drivers equally applied to the single risk tranche, Risk Reduction is equal to 3.4% of the Risk Score (10.82 x 0.034 = 0.37). Risk Reduction can also be calculated as:

$$\begin{aligned} \text{Pre-Mitigation Risk Score} &= 10.82 \text{ (Section 2.1.4)} \\ \text{Post-Mitigation Risk Score} &= (1 - 3.4\%) \times 10.82 = 10.45 \\ \text{Risk Reduction Score (M1)} &= \text{Pre-Mitigation Risk Score} - \text{Post-Mitigation Risk Score} \\ &= 10.82 - 10.45 = 0.37 \end{aligned}$$

2.1.5.2. Mitigation 2 – Consequence Mitigation

Proposed mitigation M2 reduces the magnitude of the Safety consequence by 10 percent, but only for the Severe Outcome. The mitigation effectiveness is applied to the entire project scope, so the average effectiveness at a tranche level is the same as the effectiveness at a program exposure level:

$$\begin{aligned} \text{Average effectiveness} &= \text{Effectiveness} \times \text{Scope} / \text{Tranche Exposure} \\ &= 10\% \times 100 \text{ miles} / 100 \text{ miles} = 10\% \end{aligned}$$

The average effectiveness is applied to the simulated Natural Units (Table 2-3) to determine the post-mitigation consequence as shown in Table 2-6 below.

**TABLE 2-6
SAMPLE BOW TIE: SIMULATED SEVERE OUTCOME VALUES IN MITIGATED NATURAL UNITS
AND ATTRIBUTE CORE CALCULATIONS**

Trial	Pre-Mitigation Consequence in Natural Units (EF) ^(a)	Post-Mitigation Consequence in Natural Units (EF) ^(b)	Normalized	Scaled	Trial CoRE
1	5	4.5	0.045	1.1	528
2	8	7.2	0.072	2.6	1,310
3	8	7.2	0.072	2.6	1,310
4	10	9.0	0.090	4.1	2,032
5	12	10.8	0.108	5.8	2,922
6	12	10.8	0.108	5.8	2,922
7	13	11.7	0.117	6.8	3,397
8	14	12.6	0.126	7.7	3,872
9	14	12.6	0.126	7.7	3,872
10	15	13.5	0.135	8.7	4,347
				Safety CoRE	2,651

- (a) Values from Table 3-9, Severe Outcomes Values in Natural Units.
 (b) Reflects value after 10 percent effectiveness applied to the Pre-Mitigation Consequence in Natural Units.

Mitigation M2 reduces Safety consequence by 10 percent but the Safety CoRE is reduced by 17 percent—from 3,193 (Table 2-3) to 2,651—as a result of the non-linear scaling function. Risk Reduction is calculated as follows:

$$\text{Pre-Mitigation Risk Score} = 10.82 \text{ (Section 2.1.4)}$$

$$\begin{aligned} &\text{Post-Mitigation CoRE (Severe Outcome)} \\ &= 2,651 \text{ (Table 2-6)} + 409 \text{ (Table 2-3)} + 3,931 \text{ (Table 2-3)} = 6,991 \end{aligned}$$

$$\begin{aligned} &\text{Post-Mitigation Risk Score (Severe Outcome)} \\ &= \text{Frequency (Severe Outcome)} \times \text{Post-Mitigation CoRE (Severe Outcome)} \\ &= 0.0014 \text{ (Table 2-1)} \times 6,991 = 9.78 \end{aligned}$$

$$\begin{aligned} &\text{Post-Mitigation Risk Score} \\ &= \text{Post-Mitigation Risk Score (Severe Outcome)} + \text{(Post-Mitigation) Risk Score} \\ &\text{(Minor Outcome)} \\ &= 9.78 + 0.27 = 10.05 \end{aligned}$$

$$\text{Risk Reduction Score (M2)} = \text{Pre-Mitigation Risk Score} - \text{Post-Mitigation Risk Score}$$

$$= 10.82 \text{ (Section 2.1.4)} - 10.05 = 0.77$$

**TABLE 2-7
SAMPLE BOW TIE: RISK REDUCTION SCORE BY MITIGATION**

Line No.	Mitigation	Risk Reduction Score	Post-Mitigation Risk Score
1	M1	0.37	10.45
2	M2	0.77	10.05

2.1.6. Risk Spend Efficiency

Risk Spend Efficiency is the risk reduction per dollar spent:

$$RSE = \frac{NPV(\text{Pre-mitigation Risk Scores}) - NPV(\text{post-mitigation Risk Scores})}{NPV(\text{Program Costs})}$$

PG&E calculated the RSEs shown in Table 2-8 for the two sample mitigations using: the risk reduction scores in Table 2-7; the discounting factor discussed in Section 1.6.1 to calculate the NPV; and sample program costs

**TABLE 2-8
SAMPLE BOW TIE: RISK REDUCTION SCORE BY MITIGATION BY YEAR**

Line No.	Risk Reduction Score and Cost by Mitigation	Year 1	Year 2	Year 3	Year 4	NPV
1	Risk Reduction Score (M1)	0.37	0.30	0.24	0.19	1.01
2	Risk Reduction Score (M2)	0.77	0.77	0.77	0.77	2.79
3	M1 Program Cost (\$M – Capital)	\$2.00	–	–	–	2.00
4	M2 Program Cost (\$M – Expense)	\$0.50	\$0.50	\$0.50	\$0.50	1.81

$$\begin{aligned} RSE (M1) &= NPV \text{ of Risk Reduction Score (M1)} / NPV \text{ of Program Costs (M1)} \\ &= 1.01 / 2.00 = 0.50 \end{aligned}$$

$$\begin{aligned} RSE (M2) &= NPV \text{ of Risk Reduction Score (M2)} / NPV \text{ of Program Costs (M2)} \\ &= 2.79 / 1.81 = 1.54 \end{aligned}$$

3. Enterprise Risk Model (ERM) Overview

This section of the document presents in detail how the methodology described in the previous Risk Assessment section has been implemented, and serves as a User Guide for anyone interested in reviewing/understanding, or building out, a quantified bow tie model of a risk event using PG&E's ERM to calculate Risk Scores. The ERM generates necessary data for the RSE Lite Tool to generate Risk Spend Efficiency (RSE) values.

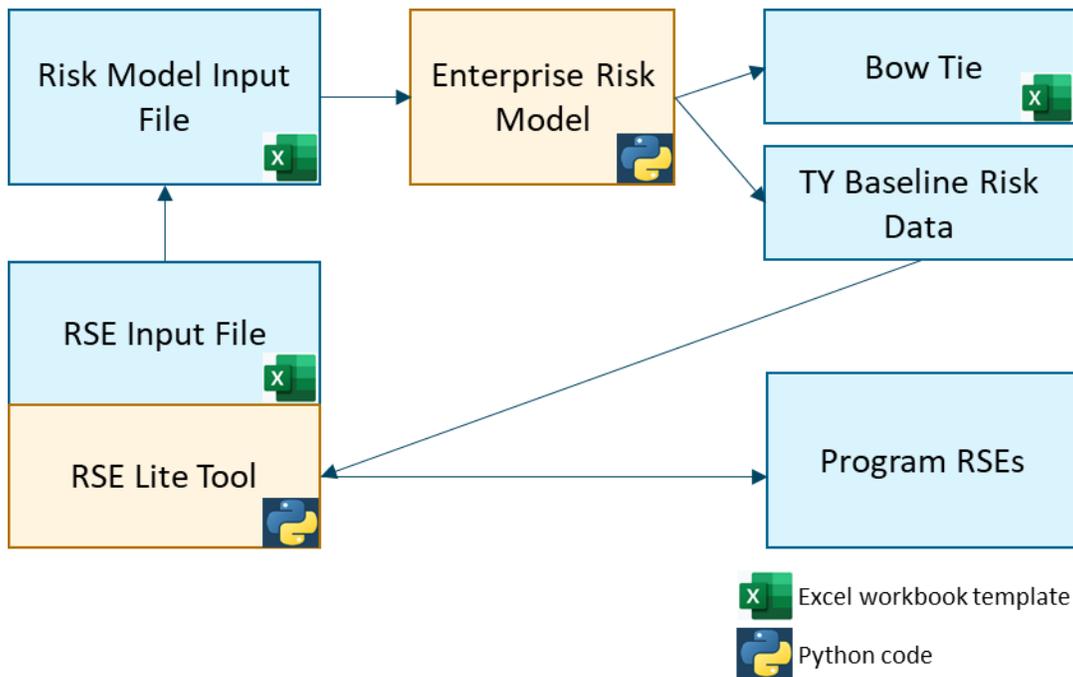
3.1. Model Architecture

Each risk event is defined in an Excel workbook, the Risk Model Input File⁴⁵, which includes all of the necessary elements for calculating Baseline, TY Baseline, and Mitigated risk: risk exposures, risk event likelihood; risk event consequence; and mitigation program scope, effectiveness and cost. Additionally, the Risk Model Input File includes modeling parameters specifying the Model run characteristics such as the number of iterations for a Monte Carlo Simulation and span of years to be simulated (analysis horizon).

All control and mitigation programs are defined in the RSE Input File. Program definition includes specifications around scope, cost, and effectiveness for relevant bow tie elements (e.g., tranche, sub-drivers, consequence attributes). Mitigation program specifications are imported to the Risk Model Input File so that the TY Baseline and Mitigated risk score can be calculated within the ERM Model.

⁴⁵ The risk modeling workpapers for each risk event and cross-cutting factor include a Risk Model Input File, RSE Input File (described in the following paragraph), Bow Tie File (described below), supporting data and an index listing all of the files used in developing the risk model.

**FIGURE 3-1
ENTERPRISE RISK MODEL ARCHITECTURE**



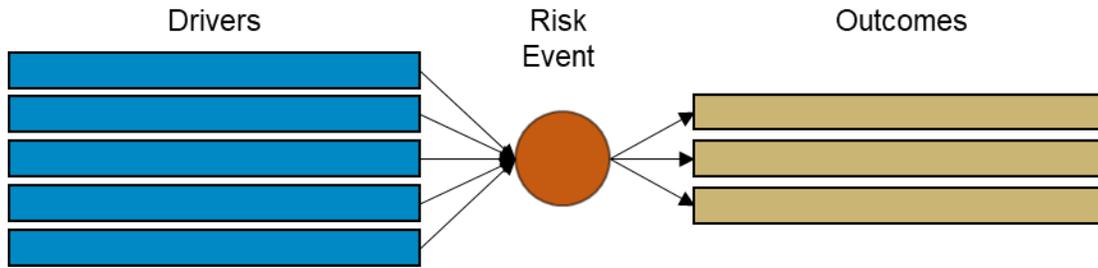
Note: The Risk Model Input File, the Bow Tie file, TY Baseline Risk Data and the RSE Input File are documents following the same template across all risk events.

The ERM Model and the RSE Lite Tool were developed using Python. The ERM Model reads exposure, frequency, consequence, and mitigation programs information defined in the Risk Model Input File to compute Baseline, TY Baseline, and Mitigated Risk Score. The Mitigated Risk Score is calculated from baseline risk scores and the set of mitigations evaluated as a portfolio. This set of mitigations (and a set of controls) for each risk for which RSEs are calculated are defined in the RSE Input File. TY Baseline Risk Score data is fed to the RSE Lite Tool to calculate individual RSEs for each mitigation and control program. See RSE Lite Tool Model Documentation and User Guide for further details on the RSE Input File and RSE calculations.

3.2. Bow Tie Framework

The Model is built on a Bow Tie framework, where the center of the Bow Tie represents a Risk Event, the left-hand side represents risk drivers, and the right-hand side represents risk outcomes. This is illustrated in Figure 3-2.

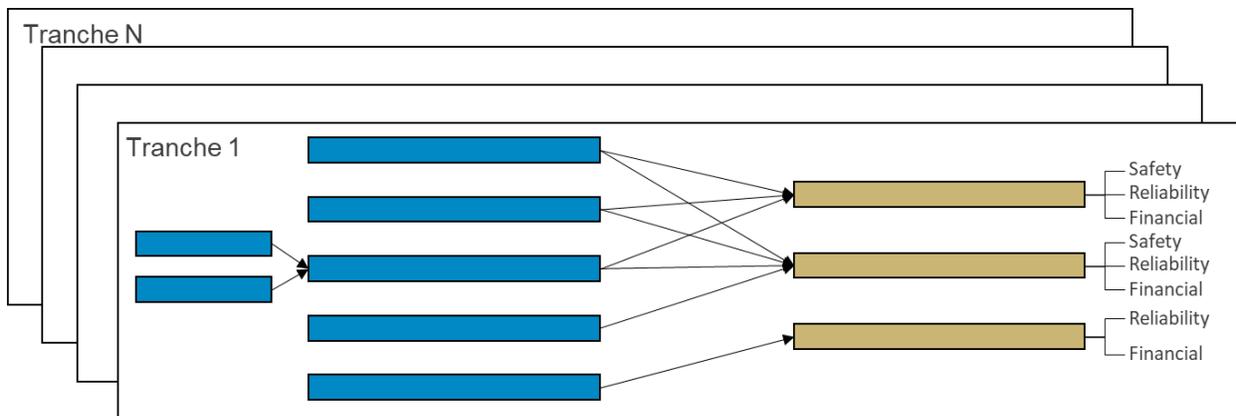
FIGURE 3-2
CONCEPTUAL MODEL OF THE BOW TIE FRAMEWORK, WITH DRIVERS ON THE LEFT, THE RISK
EVENT IN THE CENTER, AND OUTCOMES ON THE RIGHT



Note: The left-hand side of the Bow Tie is quantified using likelihood of a risk event; and the right-hand side of the Bow Tie is quantified using an outcome consequence of a risk event.

The quantification is calculated at the Tranche level. A Tranche represents a logical disaggregation of a group of assets (physical or human) or systems into subgroups with similar risk profiles for the purpose of risk quantification. Thus, the final risk event Bow Tie is constructed from a series of tranche-level Bow Ties that are ultimately combined and presented as a single Bow Tie. Figure 3-3 shows the individual tranche-level Bow Ties.

FIGURE 3-3
ILLUSTRATION OF RELATIONSHIP BETWEEN DRIVERS (LEFT) AND OUTCOMES (RIGHT) WITH
CONSEQUENCE ATTRIBUTES PER TRANCHE



Note: Even though bow tie graphics shows an arrow from drivers (five blue boxes) to outcomes for visualization purposes, Bow Tie implemented in the Risk Model Input File and Enterprise Risk Model is more correctly represented by having arrows to come from sub-drivers (two blue boxes on the left) to outcome directly without being aggregated into drivers.

Risk drivers, which can be further broken down into sub-drivers, are factors that contribute to the occurrence of a risk event.⁴⁶ Sub-driver inputs represent the expected likelihood of a risk event (LoRE) per unit of exposure. Sub-driver likelihood values (the probability of a risk outcome per unit of exposure per year from that sub-driver) are characterized at the Tranche x Sub-Driver x Outcome level.

For a risk event with five tranches, six sub-drivers, and three outcomes, the number of likelihoods that are required by the Model as an input is $5 \times 6 \times 3 = 90$ (with 0 being an acceptable value).

The event frequency is the product of the exposure and expected annual likelihood of a risk event per unit exposure. The LoRE and event frequency are aggregated across sub-drivers, drivers, outcomes and/or tranches to show different levels of aggregated LoRE and event frequency. Note that the number of risk events is not simulated.

Outcomes are characterized by statistical distributions of the potential levels of impact from a risk event across four different attributes, which are listed in Table 3-1. Consequences are sampled from their respective distributions for each set of tranche, outcome, and attribute and for each year of the analysis period.

**TABLE 3-1
CONSEQUENCE ATTRIBUTES AND THEIR NATURAL UNITS**

ATTRIBUTE	NATURAL UNIT
Safety	Equivalent Fatality
Electric Reliability	Customer-Minutes Interrupted
Gas Reliability	Customers Affected
Financial	Dollars

⁴⁶ For example, the risk driver “D-Line Equipment Failure” in the Failure of Electric Distribution Overhead Assets risk event includes sub-drivers such as Conductor, Pole, Recloser/Sectionalizer, Cross-arm, Switch, Cutout/Fuse, etc.

Each set of consequence outputs are represented in their natural units. Using PG&E's MAVF,⁴⁷ these natural-unit consequences are then represented as consequence of risk event (CoRE) values.

$$\text{Attribute Risk Score} = \text{Exposure} \times \text{LoRE} \times \text{Attribute CoRE} = \text{Frequency} \times \text{Attribute CoRE}$$

Attribute Risk Scores can be aggregated across consequence attributes, outcomes, and/or tranches to show different levels of aggregated risk scores.

Risk, as measured by the Risk Scores, can be reduced by implementing mitigation and/or control projects or programs. Details on project/program effectiveness calculations and allocations are provided in Section 4.2 of this document.

Listed below are the steps used to fully characterize a Bow Tie risk model. Walking through these steps mirrors moving through the worksheets in the Risk Model Input File workbook, each of which is discussed in detail beginning in Section 3.6.

- 1) Define risk event, drivers/sub-drivers, and outcomes.
- 2) Define tranches and tranche-level exposure over time.
- 3) Define sub-driver LoRE for all relevant Tranche-Sub-Driver-Outcome combinations (unit: events/year/unit exposure):
 - a) Escalation factors can be defined for sub-drivers where expected LoRE is anticipated to change over time; and
 - b) Multipliers can be applied to account for cross-cutting factors, which may or may not vary with time.
- 4) Define conditional consequence distributions for all relevant Tranche-Outcome-Attribute combinations, which have the following elements:
 - a) Distribution probability, which captures the probability of the Attribute consequence given the Outcome;
 - b) A probability distribution and its parameters defining each Attribute consequence in Natural Units;
 - c) Optional operator(s) (sum, prod) if the Attribute consequence is characterized by multiple distributions;
 - d) Escalation factors for parameters that are anticipated to change with time; and

⁴⁷ Recall, the Multi-Attribute Value Function is a tool for combining all potential consequences of the occurrence of a risk event, and for creating a single measurement value. D.18-12-014, p. 17.

- e) Multipliers to the Attribute consequence to account for cross-cutting factors, which may or may not vary with time.

The Baseline Risk Scores for each year included in the analysis can be computed for the risk event given these model inputs. The TY Baseline Risk Scores and Mitigated (alternatively described as a Proposed Risk Score) ⁴⁸ require Mitigation programs to be defined.

3.3. Mitigation Analysis Methodology

Mitigation programs impact some portion(s) of the quantified Bow Tie. Depending on the type of program, the mitigation can either reduce the event likelihood or the consequence magnitude of a risk event when it occurs, or both. The adjusted, or mitigated, event frequency and/or risk event consequence are used to compute a Mitigated Risk Score (aka Post-Mitigation Risk Score).

$$\text{Mitigated Risk Score} = \text{Exposure} \times \text{LoRE}_{\text{mit}} \times \text{CoRE}_{\text{mit}} = \text{Frequency}_{\text{mit}} \times \text{CoRE}_{\text{mit}}$$

For each model year, the Mitigated Risk Score is compared to the Baseline Risk Score to compute a Risk Reduction score.

The steps to build out the Mitigation programs within the model are as follows. These programs are defined within the RSE Input File and imported into the Risk Model Input File. These steps align with the four input worksheets described in the RSE Lite Tool Documentation and User Guide.

- 1) Define mitigation or control program(s), specifying whether they mitigate event likelihood, consequence magnitude, or both.
- 2) Characterize program exposure (scope) and estimated program costs over the appropriate time period.
- 3) Define mitigation program effectiveness (percent of frequency or natural unit consequence reduced), duration of benefits, and the degradation of benefits for relevant Tranche-Sub-Driver-Outcome (frequency mitigation) or relevant Tranche-Outcome-Attribute (consequence mitigation).⁴⁹

⁴⁸ The TY Baseline Risk Score accounts for the risk reduction impacts from the planned mitigations implemented prior to the TY. The Mitigated Risk Score accounts for the risk reduction impacts of all planned mitigations.

⁴⁹ PG&E developed an RSE Input File for each risk event and Cross-Cutting Factors for which RSEs are calculated.

3.4. Risk Model Input File Metadata

This section broadly describes the organization of the Risk Model Input File.

3.4.1. Table of Contents (TOC)

The TOC lists the tabs in the Risk Model Input File and includes a description of what each tab contains.

**FIGURE 3-4
RISK MODEL INPUT FILE TABLE OF CONTENTS**

Tab #	Tab	Description
0	0-Global Parameters	Global Parameters for Model Run
1	1-Risk	Define Risk
2	2-BowTie	Define Drivers, Sub-Drivers, Outcome and Consequences Attributes
3	3-Tranche	Define Tranches for the Risk
4	4-Freq	Specify Likelihood and Frequency of Risk Event inputs
5	5-FreqMult	Specify Multipliers for Likelihood/Frequency of Risk Event inputs
6	6-Conseq	Specify Consequence Distributions
7	7-ConseqMult	Specify multipliers for Consequence values simulated
8	8-Program	Define Programs and association with other programs
9	9-ProgramExposureSpend	Define Program units and spend
10	10-ProgramFreqEff	Specify Program Effectivenesses on Frequency
11	11-ProgramConseqEff	Specify Program Effectivenesses on Consequences
12	12-esc_method	Define custom case for escalation methods
13	13-DistributionParameters	Distribution Parameter Characteristics
14	REF_Tranche	Reference data for Tranches
15	REF_CC	Reference data for cross-cutting factors
16	REF_Freq	Reference data for Frequencies
17	REF_Conseq	Reference data for Consequences
18	REF_ProgramExposureSpend	Reference data for program exposure and cost
19	REF_FreqEff	Reference data for effectiveness of programs that impact Frequency

- Input Sheet 0 includes the global parameter used in the Model for the specific risk event;
- Input Sheets 1 through 7 are the tabs used for the Bow Tie inputs;
- Input Sheets 8 through 11 are the tabs used for mitigation inputs;
- Input Sheets 12 and 13 are auxiliary tabs that are used to define parameters or functions used in other tabs;
- The names of certain Input Sheets in the Risk Model Input Files start with “REF” (for reference) which indicates that the sheet contains reference data used by the other sheets to perform various calculations (in the example TOC above, the Risk Model Input File includes reference data for Tranche, Cross-Cutting Factors, Frequencies and Consequences, program exposures, cost and effectiveness).

3.4.2. Risk Model Parameters

The Model includes three tabs wherein the user defines fundamental information needed to model the risk event.

3.4.2.1. Tab 0-Global Parameters

The 0-GlobalParameters tab is the first tab in the Risk Model Input File with fields that directly impact the analytical model processing. This tab includes:

- Number of Simulations:⁵⁰ the number of values that should be sampled from each statistical distribution specified for each year as part of the Monte Carlo simulation.
- Baseline/Proposed/Inherent Case: a Boolean flag, TRUE or FALSE, that determines whether or not the model should process the specified case. The cases can be defined as:
 - Baseline Case: This represents the model scenario where risk controls are implemented, but the impact of proposed mitigations are not taken into account for calculation;
 - Inherent Case: This represents the model scenario where specified risk controls (defined on the #8, #9, #10, and #11 tabs of the Risk Model Input File) are no longer being implemented, simulating what risk scores would be without specified risk controls;
 - Mitigated Case: This represents the model scenario where proposed and/or alternative mitigations (defined on the #8, #9, #10, and #11 tabs of the Risk Model Input File), are implemented, providing a reduction in risk score.
- Diagnostic Run: This Boolean flag, when TRUE, sets the specified Number of Simulations and Number of Batches to 1, in order to test that the Risk Model Input File is valid for model processing, without running unnecessary iterations of the distribution sampling functions;
- Archive Run: This Boolean flag allows the model to store the values sampled for *all* iterations rather than only retaining the mean value of simulated Consequence of Risk Event values in natural units; and
- Number of Batches: If greater than 1, the simulation is run in batches. Multiple batches should be run when the Number of Simulations necessary to achieve a desired level of convergence would lead to memory issues. These memory issues are driven by the size of the data/arrays required in the computation.

⁵⁰ Technically this indicates the number of iterations of Monte Carlo Simulations to perform.

**FIGURE 3-5
0-GLOBALPARAMETERS TABLE**

Number of Simulation	Baseline Case	Mitigated Case	Inherent Case	Diagnostic Run	Archive Run	Number of Batches
50000	TRUE	TRUE	FALSE	FALSE	FALSE	50

3.4.2.2. Tab 12-esc_method

Tab 12-esc_method describes different escalation methods that can be specified by the user throughout the Risk Model Input File for specifying how to adjust base year values to derive the values for each future year in the analysis horizon, without having to specify the values for every year.

Escalation methods are used to extrapolate the base input parameters for frequencies, consequences, exposures, frequency or consequence multipliers, and mitigation effectiveness across the entire timeframe of the analysis horizon.

There are five available escalation methods implemented in the Model, each of which is listed and defined on Tab 12:

Method 1: esc

Input Parameter: escFactor

Description: growth rate increase

Formula:

$$active\ year\ value = prior\ year\ value \times (1 + escFactor)$$

This method requires at least one year of input data for the parameters and uses the escFactor parameter as the growth rate to escalate the parameters across all years in the simulation.

Method 2: inc

Input Parameter: escFactor

Description: arithmetic increase

Formula:

$$active\ year\ value = prior\ year\ value + (prior\ year\ value - value\ from\ two\ years\ prior) \times (1 + escFactor)$$

This method requires at least two years of input data for the parameters and uses the `escFactor` parameter as the arithmetic growth rate to escalate the parameters across all years in the simulation.

Method 3: cagr

Input Parameter: n

Description: compound annual growth at rate n

Formula:

$$active\ year\ value = \left(\frac{x[-1]}{x[-1-n]} \right)^{1/n} - 1$$

where `x[-1]` is the last yearly value provided.

This method requires at least n years of input data for the parameters, where n is the number of years for which the compound annual growth is applied.

Method 4: avg

Input Parameter: n

Description: mean of last n years

Formula:

$$active\ year\ value = \frac{\sum_{y-n}^y x}{n}$$

where `y` is the index of the last yearly value provided, and `x` is the value in each year used for the average calculation.

This method requires at least n years of input data for the parameters, where n is the number of years for which the formula is applied. This calculated value is then applied to all remaining values.

Method 5: match

When a user chooses the “match” escalation method, the user can define a custom escalation methodology on the 12-`esc_method` tab by using the table shown in Figure 3-6.

**FIGURE 3-6
CUSTOM ESCALATION METHODS FOR THE 'MATCH' ESCALATION METHOD**

x_match	Description	2019	2020	2021	2022	2023
case1		1	1	1	1	1
ClimateCase1		0.01	0.01	0.01	0.01	0.01
linear_0_30_5		1	1	1	1	1

The user specifies which set of escalation values should be used for matching. The value in the “x_match” column denotes the escalation parameter that must be entered alongside the “match” escalation method.

Input Parameter: x_match

Description: match the values from another series

Formula:

$$Active\ Year\ Value = Prior\ Year\ Value \times \frac{Active\ Year\ Match\ Table\ Value}{Prior\ Year\ Match\ Table\ Value}$$

This method requires at least one year of input data for the parameters and of the input file to provide the match table values.

3.4.2.3. Tab 13-DistributionParameters

Sheet 13 contains the distribution types with the associated parameters.

**FIGURE 3-7
DISTRIBUTION PARAMETER TABLE FROM TAB 13**

Distribution Type	_param1	_param2	_param3	_param4	_param5	_param6
Poisson	Mean					
Ztpoisson	Mean					
Discrete	Discrete_params_1	Discrete_params_2	Discrete_params_3	Discrete_probs_1	Discrete_probs_2	Discrete_probs_3
Triangular	Tri_left	Tri_mode	Tri_right			
Binomial	N_Trials	Probability				
Ztbinomial	N_Trials	Probability				
Ztbinomial	N_Successes	Probability				
Normal	Mean	Standard_Dev				
Truncnormal	Mean	Standard_Dev	Trunc_left	Trunc_right		
Lognormal	Mean	Standard_Dev				
Rtlognormal	Mean	Standard_Dev	Trunc_right			
Exponential	Beta					
Deterministic	D_Value					
Uniform	Min	Max				
Ztpoisson_bernoulli_ef	Mean	Probability				
Rtlognorm_bernoulli_ef	Mean	Standard_Dev	Trunc_right	Probability		
Binomial_ef	N_Trials	Probability				
Truncpareto1	s	loc	scale	ineq	trunc	
Truncpareto2	s	loc	scale	ineq	trunc	
Truncpareto3	s	loc	scale	ineq	trunc	
Truncpareto4	s	loc	scale	ineq	trunc	

The choice of distribution is driven by available data to characterize the outcome consequence. It is often the case that insufficient data are available to fit a parametric distribution, especially for rare events. As such, the user must choose which distribution best represents the data that is often supplemented by Subject Matter Expert (SME) judgement regarding key distribution characteristics (e.g., mean or median, 95th percentile, skewed or not skewed).

All available distributions are described in the following section. The order provided is roughly by the most commonly used distributions to the least used.

3.4.2.4. Standard Distributions

Poisson

The Poisson distribution is a discrete probability distribution that expresses the probability of a given number of events occurring in a fixed interval of time or space if these events occur with a known constant mean rate and independent of the time since the last event.

A Poisson-distributed random variable, X , can take the values $k=0, 1, 2, \dots$ with probability $P(X = k) = \lambda^k e^{-\lambda} / k!$, where parameter λ is the positive real number equal to the expected value of X and to its variance.

The Poisson distribution is useful for random variables of discrete outcomes like total serious injuries or fatalities given a safety incident, and only requires one parameter, the mean. It is a common choice when describing a discrete random variable and there is not much data to fit additional parameters. One drawback with using this distribution is that Poisson random variables have equal mean and variance, so plausible scenarios with very high consequences may not be captured with the simulation of Poisson distribution when the true distribution has a larger variance than Poisson distribution.

Parameter Specification: Use sample average as Mean.

Zero-Truncated Poisson (Ztpoisson)

The Zero-Truncated Poisson (ZTP) distribution is the conditional probability distribution of a Poisson-distributed random variable, given that the value of the random variable is not zero. Thus, it is impossible for a ZTP random variable to take the value zero.

Parameter Specification: Use the average of the sample excluding zeroes as Mean.

The choice between a Poisson and a zero-truncated Poisson depends on how sample data were used to represent the consequence of a risk event. The following example illustrates how to define a zero-truncated Poisson distribution.

Here is a vector with observed serious injuries or fatalities (SIF) in a dataset of 10 risk events:

[0 0 0 0 19 0 0 0 25 0]

Eight events have zero SIFs, two have non-zero SIFs. The expected number of SIFs per event given these 10 observations is $(19 + 25)/10 = 4.4$. However, the expected number of SIFs given a risk event with non-zero SIF is $(19 + 25)/2 = 22$.

To check whether to use a Poisson distribution for the number of SIFs per event represented by this dataset, compute the probability of having zero SIF from an event as:

$$P(k=0) = e^{-\lambda} = \exp(-4.4) = 0.012$$

Compare that to the fraction of samples which are 0

$$8/10 = 0.8$$

These are an order of magnitude different, suggesting a ZTP is the preferred distribution compared to the Poisson distribution which will overestimate the probability of events with non-zero SIF consequence. The ZTP distribution is parametrize as follows:

Distribution probability: $2/10 = 0.2$

ZTP sample mean: 22

Normal

A normal distribution is a symmetrical, continuous distribution, useful when skewness can be assumed to be zero.

Parameter Specification: Use the sample average and standard deviation as Mean and Standard_Dev, respectively.

Truncated Normal (Truncnormal)

Truncated normal distribution is the probability distribution derived from that of a normally distributed random variable by bounding the random variable from either below or above (or both).

Parameter Specification: Use the mean and standard deviation of Normal distribution before truncation.

Lognormal

The Lognormal distribution is a continuous, non-zero distribution, useful for characterizing Financial or Reliability outcomes believed to have a long tail. If Monte Carlo Simulation is used, the model will automatically truncate the lognormal distribution at 5 times the specified standard deviation to ensure mean convergence.

Parameter Specification: Specify the mean and standard deviation in linear space (i.e., ones of lognormal distribution, not of the logarithm of the random variable).

Truncated Lognormal (Rtlognormal)

If the upper bound of a lognormally distributed random variable is known or reasonable to be enforced, then the Truncated Lognormal distribution can be used.

Parameter Specification: Specify the mean, standard deviation, and upper bound in linear space. Note that the mean and standard deviation are those before truncation.

Deterministic

A point estimate used when no reasonable information is available to inform a range of possible values, or the value is known not to vary.

Discrete

The Discrete distribution allows the user to specify up to three discrete values each with a certain probability.

Parameter Specification: Each discrete value of param1, param2, and param3 with the associated probabilities prob1, prob2, prob3.

Uniform

The Uniform distribution is used for continuous random variables. It is useful when a range of values can be assumed to be equally likely (i.e., very little is known about the probability distribution of the values within the range).

Parameter Specification: The range [Min, Max] of values that the variable can take

Triangular

The Triangular distribution is used for continuous random variables. It is useful when a range of values is known, and the most commonly occurring value (the mode) can be estimated.

Parameter Specification: The range (Tri_left, Tri_right) of values that the variable can take, and the most commonly occurring value, Tri_mode.

Binomial

The Binomial distribution is used to model a discrete number of adverse outcomes with a certain Probability given the N_Trials number of times an incident occurs.

Parameter Specification: Specify N_Trials and the Probability of an adverse outcome, between 0 and 1.

Zero-Truncated Binomial (Ztbinomial)

The Zero-Truncated Binomial distribution is used when, given N_Trials number of times an incident occurs, one expects at least one adverse outcome with a certain Probability of occurrence.

Parameter Specification: Specify N_Trials and the Probability of an adverse outcome between 0 and 1.

Zero-Truncated Negative Binomial (Ztnbinomial)

The Zero-Truncated Negative Binomial distribution models the number of non-adverse outcomes (where *Probability* = probability of an adverse outcome) up to an *N_Success* number of adverse outcomes. “Zero-Truncated” means that at least one non-adverse outcome is expected. This distribution is used when the Poisson distribution does not provide enough variance for describing the variable (i.e., when one believes the variance is greater than the mean).

Parameter Specification: Specify N_Success as the number of adverse outcomes, where the probability of an adverse outcome is specified by Probability.

Exponential

The Exponential distribution is typically used to model the time between events in a Poisson process where the average rate of occurrence of the event is known.

Parameter Specification: Specify Beta = 1/rate of occurrence of the event.

Truncated Pareto Distributions (Truncpareto1 to Truncpareto4)

The Pareto family of distributions are often used to model random variables which demonstrate variations of power law relationship between frequency of occurrence and magnitude. There are four types of Pareto distributions available to use in the ERM. Formulations of Type 1 and Type 2 can be found in Section 4.1.2.1.

Parameter Specification: Specify s as the shape parameter, loc as the location, $scale$ as scale, $ineq$ as the inequality parameter. The final parameter ($_param5$) represents the upper truncation point for the distribution, which functions similarly to the truncating point specified for the truncated lognormal distribution.⁵¹

3.4.2.5. Safety Attribute Distributions

Adapted Zero-Truncated Poisson and Bernoulli Compound Distribution (Ztpoisson_bernoulli_ef)

The equivalent fatalities Y following this distribution is constructed as follows:

$$Y = \sum_{i=1}^N (X_i(p) + (1 - X_i(p)) * EFfactor)$$

Where N is Zero-Truncated Poisson distributed, X_i 's are i.i.d. Bernoulli random variables with the probability p where p is the probability of fatality for each SIF, and $EFfactor$ is the equivalent fatality per serious injury.

The rationale for this method is to assume that: (1) the total number of SIFs in a safety incident follows a Zero-Truncated Poisson; and (2) each SIF follow a Bernoulli distribution, with one as fatality and zero as injury with a fixed probability. Because one serious injury is deemed as equivalent to $EFfactor$ fatalities, the count of serious injuries (i.e., zeros) is multiplied by $EFfactor$ and then added to count of fatalities (i.e., ones) to get the total count of EF in the equation for Y .

Note: The correlation between injury and fatality counts turns from negative to positive when the expected value of N increases.

⁵¹ The script *Trunc_pareto.py* implements the Truncated Pareto class. It includes a data fitting algorithm which outputs goodness of fit statistics for a given sets of inputs and outputs the set of parameters (listed above) needed to characterize Pareto distributions for the Risk Model Input File.

Parameter Specification: Mean is that of the Poisson after truncation, and Probability is the likelihood of fatality for each SIF.

Example:

Using $EF = \frac{1}{4}$ from the PG&E's MAVF, Table 3-2 shows four random draws from this distribution.

**TABLE 3-2
EXAMPLE OF RANDOM DRAWS FROM PG&E'S MAVF ZERO-TRUNCATED POISSON AND
BERNOULLI COMPOUND DISTRIBUTION ADAPTED FOR EQUIVALENT FATALITY DISTRIBUTION**

No. of SIFs Given a Risk Event, N	No. of Fatalities, $\sum_{i=1}^N X_i$	No. of Serious Injuries, $\sum_{i=1}^N (1 - X_i)$	No. of EF, Y
5	4	1	$4 + 1/4 = 4.25$
4	2	2	$2 + 2/4 = 2.50$
3	1	2	$1 + 2/4 = 1.50$
2	0	2	$0 + 2/4 = 0.50$

Right-Truncated Lognormal and Bernoulli Compound Distribution Adapted for Equivalent Fatality (Rtlognorm_bernoulli_ef)

This distribution is set up similarly to Ztpoisson_bernoulli_ef. The only difference is N now follows a rounded Right-Truncated Lognormal distribution instead of the Zero-Truncated Poisson distribution.

Parameter Specification: Mean and Standard_Dev are those of Lognormal distribution before truncation, Trunc_right is the right truncation point of lognormal, and Probability is the likelihood of fatality for each party involved.

Binomial Distribution Adapted for Equivalent Fatality (Binomial_ef)

This distribution assumes the total number of SIFs per risk event is deterministic and then each fatality given a SIF follow a Bernoulli distribution. In this implementation, the ones of the simulated Bernoulli random variable represent fatalities, and the zeroes represent the serious injuries (0.25 EF). So, the count of zeros also contributes to the value of the random variable.

Parameter Specification: N_Trials is the deterministic total parties involved and Probability is the likelihood of fatality for each SIF.

3.4.3. Bow Tie Input Sheets

The Bow Tie Input Sheets are Tabs 1 through 7 in the Risk Model Input File and are used to describe the Bow Tie Inputs. These tabs contain the: risk; drivers and sub-drivers; cross-cutting factors; list of outcomes; applicable attribute; tranches; consequence definitions; the distributions and parameters associated with the inputs; information used to extrapolate the inputs over the a specified timeframe; and inputs that describe multipliers which are applied to the extrapolated sub-driver and consequence inputs.

Each Bow Tie sheet is described in detail in Section 0. The way the model uses information contained within these sheets is described in Section 1.

3.4.4. Mitigation Input Sheets

Mitigation Input sheets are Tabs 8 through 11 in the Risk Model Input File. They are used to describe the mitigation programs applicable to the risk event. These tabs contain program names, effectiveness values, project scope, estimated spend, and performance over time (i.e., degradation of effectiveness).

Each of the input sheets addressing the mitigation programs is described in detail in Sections 3.8 and 3.9. The way the model uses information contained within these sheets is described in 4.2. The values in these sheets are read in from the RSE Input File.

3.4.5. Reference (REF) Sheets

Each Risk Model Input File contains some number of tabs that begin with *REF*. These tabs are not parsed by the Python risk model. Rather, they serve as reference tabs within the Risk Model Input File and primarily include input data from the source data and other modeling workpapers. This information is used to implement calculations that assemble and organize data into a format that can be easily read from the tables in the numbered tabs that are parsed by the Python model.

Within the REF sheets, the following color conventions tend to be used to differentiate data pulled in from external source documents from calculations performed within the risk input sheet itself.

**FIGURE 3-8
COLOR CONVENTION FOR CELLS WITHIN THE REF_ SHEETS**

Format Guide

<u>Description</u>	<u>Format</u>
1 Input cell - user input required	
2 Error checking cell - formula that should not be touched	
3 Analysis cell - formula that should not be touched	

Within the REF sheets, the name of the source document from which the data were pulled are included beside the green-shaded input cells.

**FIGURE 3-9
EXAMPLE OF SOURCE NOTATION STRUCTURE**

<u>Source</u>	<u>Sheet</u>	<u>Notes</u>
GO-LOCT-6	pivot	<i>Filter for Significant, Excluded IO, EF from cause, OP-type event, and malfunction of relief device and ruptured or leaking seal pump from cause_details</i>

From Figure 3-9, Source refers to the document name within the Source Document Index for each risk. Some references include Sheet names and/or Notes where necessary.

3.5. Risk Model Outputs

Through the calculations and processes outlined in this document, the Model generates a series of outputs, which are then prepared for visualization in the Bow Tie File. The Model produces the Bow Tie file with the following sheets, shown in Table 3-3:

**TABLE 3-3
MODEL OUTPUTS WITH DESCRIPTIONS OF EACH WORKSHEET**

Sheet	Description
Bow Tie	Bow Tie graphic for Test Year Baseline values which includes: risk exposure; risk score; risk event frequency and percent frequency; percent total frequency and percent total risk by driver; aggregate CoRE, CoRE by outcome, frequency of outcome and percent of total risk per outcome
Conseq (Consequences)	Summary table for Test Year Baseline values including: outcome-level CoRE, percent frequency, percent risk, event frequency; natural units per event, CoRE, natural units per year, and attribute risk score over all relevant attributes for the risk event.
Drivers, Outcomes, Cases	Lists of drivers, outcomes, and cases (all risks include Baseline, risks for which RSEs were calculated include TY Baseline Proposed and Proposed)
Risk Scores	Baseline risk score in 2021, Test Year Baseline risk score (2023), Post-Mitigation Risk Score at the end of the evaluation period (2026) and sum Risk Scores over 2023-2026 for Test Year Baseline and Post-Mitigation cases
Freq_Driver (Frequency)	Frequency by Case, Tranche, Outcome, and Driver over model years
Input_Exposure	Exposure by Tranche over model years
RiskScore_Driver	Risk Score by Case, Tranche, Outcome, and Driver over model years
RiskScore_Subdriver	Risk Score, Frequency, and CoRE by Case, Tranche, Outcome, Driver, and Subdriver
RiskScore_Attribute	Risk Score by Case, Tranche, Outcome, and Attribute over model years
RiskScore_Outcome	Risk Score by Case and Outcome over model years
RiskScore_Tranche	Risk Score by Case and, Tranche over model years
RiskScore_NU (Natural Units)	Consequence in Natural Unit per year by Case, Tranche, Outcome and Attribute over model years
%DriverRiskScore	Percent contribution of a tranche-outcome pair to the driver risk score by Case and Driver over model years
%RiskScore_Driver	Percent contribution of a driver to total risk score by Case over model years
TYBaselineRS_By_Trache	Tranche Exposure, Percent Exposure, Attribute Risk Scores, Percent Risk Score by Case and Tranche for the Test Year (i.e., 2023)
TYBaseline2023_by_subdriver	TY Baseline Frequency, Risk Score and CoRE values by Tranche, Outcome, Driver and Subdriver for 2023
TYBaseline2023_Attribute	TY Baseline Frequency, Risk Score and CoRE values by Tranche, Outcome and Attribute.

3.6. Bow Tie Inputs

This section of the User Guide describes the process by which the Risk Model Input File is developed and how the individual sheets and model elements are processed by the Model when calculating risk scores.

The model steps are described in parallel with descriptions and visual representations of the Excel tabs on the Risk Model Input File that inform each step.

The Large Overpressure Event Downstream of M&C Facility from the 2020 RAMP Report is used as an example Risk Input Sheet, as that model illustrates many features of the Risk Model Input File.

3.6.1. Tab 1-Risk

The *1-Risk* tab describes the risk event modelled by the input file. In addition to describing the risk event itself, there is information regarding the years for which outputs are simulated by the Model.

**FIGURE 3-10
RISK TABLE**

Risk Event	Risk Code	Risk Description	Start Year	End Year	Exposure	Test Year
Large Overpressure Event Downstream of M&C Facility	OPDOWN	Loss of containment with or without ignition downstream of an M&C facility	2020	2121	Stations	2023

The Risk Event is used to identify the risk event across the set of output files.

The Start Year and End Year field describe the first and final year for which outputs are simulated. This span of years is referenced in this document as the “analysis horizon.”

The Exposure field defines the unit by which ‘Exposure’ is expressed. In this example, the risk depends on the number of Stations in each tranche.

The Test Year field is the initial year of the rate case. It is used to determine mitigation programs implemented in and after the Start Year but before the Test Year for the purpose of calculating Test Year Baseline Risk Scores. This value must be within the bounds of Start Year to End Year (inclusive).

3.6.2. Tab 2-BowTie

The *2-BowTie* tab lists the drivers and sub-drivers that comprise the left-hand side of the risk Bow Tie, the outcomes that define the right-hand side of the Bow Tie, and the consequence attributes used to define each outcome.

The information that needs to be completed on Tabs 4 to 7 (the frequency and consequence definition tabs) depends on the lists of drivers, sub-drivers and outcomes specified on this Bow Tie tab.

**FIGURE 3-11
BOW TIE DRIVER, SUB-DRIVER TABLE**

Row#	Sub-Driver#	Driver#	Driver	Sub-Driver	Active	Cross Cut
1	1	1	Incorrect Operations	Incorrect Operations	TRUE	
2	2	2	Equipment Related	Equipment Related	TRUE	
3	3	3	CC - SQWF	SQWF	TRUE	SQWF
4	4	4	CC - RIM	RIM	TRUE	RIM

The driver table lists the drivers, the associated sub-drivers, a Boolean flag for whether or not the sub-driver should be considered in the model processing and calculation, and the cross-cutting factor label to which the sub-driver rolls up (if applicable).

The 2-BowTie tab also features a list of Outcomes, which represent different manifestations of the risk event. Within the same tranche, model input parameters may differ between outcomes. Model outputs are generated for each outcome, as well as at an aggregate level across outcomes.

**FIGURE 3-12
OUTCOME TABLE**

Outcome#	Outcome
1	Benign
2	LOC
3	LOC and Cyber Attack
4	LOC and IT Asset Failure

The third table on this tab is the Consequence table. The only part of the Consequence Attribute table that needs to be adjusted based on the risk event is the Boolean flag in the Active column. Only those Attributes which are Active will require parameterization in the input sheets that follow. In the example below, there are no Electric Reliability consequences for the Large Overpressure risk event. The total number of active Attributes is 3 (maximum of the activerow# computed column). If an Attribute is not active, it will not show up in any of the downstream tabs (Tabs 6, 7, and 10).

**FIGURE 3-13
BOW TIE CONSEQUENCE ATTRIBUTE AND SUB-ATTRIBUTE TABLE**

Row#	Sub-Attribute#	Attribute	Sub-Attribute	Active	activerow#
1	1	1 Safety	Safety	TRUE	1
2	2	2 Electric Reliability	Electric Reliability	FALSE	1
3	3	3 Gas Reliability	Gas Reliability	TRUE	2
4	4	4 Financial	Financial	TRUE	3

3.6.3. Tab 3-Tranche

The population or system to which a risk event applies is segmented into different tranches. The definition and units of exposure for each tranche is defined in the *3-Tranche* tab of the input workbook. The number of tranches impact several Model inputs (e.g., frequency, consequence, mitigation definitions) as each input can be defined differently for each tranche. (As described earlier, the Bow Tie of a Risk Event can be conceived as having one Bow Tie per tranche).

Tranches are listed with identifiers and descriptors, a Boolean Active flag, and 7 'Year' fields (denoted Year1 through Year7). Note that Year1 corresponds to the Start Year specified in the *1-Risk* tab.

**FIGURE 3-14
LEFT SIDE OF A TRANCHE DEFINITION TABLE ON 3-TRANCHE.**

ID	Tranche#	Active	Tranche	Year1	Year2	Year3	Year4	Year5	Year6	Year7
OPDOWN_T1	1	TRUE	MCDS - Transmission Simple	252						
OPDOWN_T2	2	TRUE	MCDS - Distribution District Reg	1330						
OPDOWN_T3	3	TRUE	MCDS - Distribution HPR+FT	2608						
OPDOWN_T4	4	TRUE	MCDS - Transmission Complex	131						
OPDOWN_T5	5	TRUE	MCDS - Transmission LVCR	98						
OPDOWN_T6	6	TRUE	MCDS - Distribution LPR	205						

The values input into the Year fields, shown in Figure 3-14, describe the total units of exposure to which the risk may apply. These values are used with the sub-driver likelihood values (defined in 4-Freq) to compute the Tranche-Sub-Driver-Outcome frequency.

The exposure can vary from year to year, and the Escalation Method and Escalation Parameter fields describe the process by which the initial year's values should be extrapolated over the model's timeframe.

**FIGURE 3-15
RIGHT SIDE OF A TRANCHE DEFINITION TABLE ON 3-TRANCHE**

Escalation Method	Escalation Parameter	Tranche Description
esc	0%	Simple Stations on the Transmission System
esc	0%	District Regulators on the Distribution System
esc	0%	High Pressure Regulators on the Distribution System
esc	0%	Complex Stations on the Transmission System
esc	0%	LVCR Stations on the Transmission System
esc	0%	Low Pressure Distribution System

The Escalation Method describes what escalation function should be used (described in Section 2.4.2.2) and how the inputs are scaled year-to-year. The Escalation Method is applied in the first year without exposure values specified. If the exposure for each year is defined, and the analysis horizon is greater than six years, the Escalation Method begins to apply in Year 7.

The Escalation Parameter is the factor that determines by how much the Escalation Method should scale the inputs over the analysis horizon. When left blank, the default value for Escalation Method is “esc,” and the default value for Escalation Parameter is 0 percent.

In the example shown here, since there are no exposure values beyond Year 1 and the escalation rate is 0 percent, the exposure will remain constant over time.

3.6.4. Tab 4-Freq

The expected likelihood of a risk event (LoRE) for each sub-driver is defined on the 4-Freq tab. Sub-driver LoRE information is defined at a tranche and outcome level, potentially varying among tranches and/or outcomes.

**FIGURE 3-16
LEFT SIDE OF A FREQUENCY INPUT TABLE**

activerow#	Row#	Tranche#	Sub-Driver#	Outcome#	Tranche	Sub-Driver	Outcome	Active Sub-Driver	Active	Driver
1	1	1	1	1	MCDS - Transmission Simple	Incorrect Operations	Benign	TRUE	TRUE	Incorrect Operations
2	2	1	2	1	MCDS - Transmission Simple	Equipment Related	Benign	TRUE	TRUE	Equipment Related
3	3	1	3	1	MCDS - Transmission Simple	SQWF	Benign	TRUE	TRUE	CC - SQWF
4	4	1	4	1	MCDS - Transmission Simple	RIM	Benign	TRUE	TRUE	CC - RIM
5	5	1	1	2	MCDS - Transmission Simple	Incorrect Operations	LOC	TRUE	TRUE	Incorrect Operations
6	6	1	2	2	MCDS - Transmission Simple	Equipment Related	LOC	TRUE	TRUE	Equipment Related
7	7	1	3	2	MCDS - Transmission Simple	SQWF	LOC	TRUE	TRUE	CC - SQWF
8	8	1	4	2	MCDS - Transmission Simple	RIM	LOC	TRUE	TRUE	CC - RIM
9	9	1	1	3	MCDS - Transmission Simple	Incorrect Operations	LOC and Cyber Attack	TRUE	TRUE	Incorrect Operations
10	10	1	2	3	MCDS - Transmission Simple	Equipment Related	LOC and Cyber Attack	TRUE	TRUE	Equipment Related

Figure 3-16 shows the sub-driver identifying information, the tranche and outcome to which that set of distribution information applies, an “Active” Boolean flag, as well as the driver to which the sub-driver rolls up.

The columns on the left side of the worksheet include:

- Activerow# is defined in this table, based on the number of rows with the Active flag set to TRUE. This is referred to in subsequent sheets (5-FreqMult, 10-ProgramFreqEff).
- Row# is defined for this table, and the maximum row number is the product of the number of sub-drivers, tranches, and outcomes.
- Tranche# refers to the number assigned to the active Tranche from 3-Tranche, and drives the Tranche listed in the Tranche column.
- Sub-Driver# refers to the number assigned to the sub-driver from 2-BowTie, and drives the sub-driver listed in the Sub-Driver column.
- Outcome# refers to the number assigned to the sub-driver from 2-BowTie, and drives the sub-driver listed in the Outcome column.
- Driver is the name of the driver to which sub-drivers roll up, and which is displayed in the Bow Tie visual.

**FIGURE 3-17
RIGHT SIDE OF A FREQUENCY INPUT TABLE.**

Distribution1_p		Distribution1_pa		Distribution1_pa			
Distribution	Distribution1_pa	aram1_esc_met	Distribution1_param	Distribution1_pa	ram2_esc_meth	ram2_esc_para	
1	ram1	hod	1_esc_param	ram2	od	m	Note
Poisson	0.000660796						
Poisson	0.001044739						
Poisson	1.08217E-05						
Poisson	7.46242E-05						
Poisson	3.82541E-05	match	non_cyber_outcome				
Poisson	6.04809E-05	match	non_cyber_outcome				
Poisson	6.2648E-07	match	non_cyber_outcome				
Poisson	4.32006E-06	match	non_cyber_outcome				
Poisson	1.13989E-07	match	cyber_outcome				
Poisson	1.80221E-07	match	cyber_outcome				

Figure 3-17 displays how the distribution is defined.

- The Distribution1 field denotes the statistical distribution that should be used to model the sub-driver LoRE. The number of events for each year is not currently

simulated for the calculation of the risk scores, because the Risk Score requires expected value of LoRE.

- The Distribution1_param1 is the expected likelihood of risk event (LoRE), expressed per year and per unit of exposure.

An Escalation Method and Escalation Parameter can be applied to the LoRE values, informing the Model how to scale and shape the LoRE over the timeframe simulated by the Model. These are specified in the fields ending with _esc_method (Escalation Method) and _esc_param (Escalation Parameter). One of the five escalation methods described in Section 2.4.2.2 can be chosen. The escalation method chosen includes a numerical parameter which dictates by how much to escalate and extrapolate the data. For example, the values shown on Figure 3-17 for cyber-related frequencies are escalated using a *match*-type escalation with the parameter named *cyber_outcome* that is defined in in the 12-esc_method tab.

The sub-driver LoREs are read by the model and escalated over the model's analysis horizon according to the specified escalation methodology.

3.6.5. Tab 5-FreqMult

Some cross-cutting factors, such as Climate Change, may impact how the sub-driver LoREs change over time. These factors are modeled as “frequency multipliers,” factors that are applied to the specified sub-driver’s frequency.

The *5-FreqMult* tab specifies how multipliers impact sub-driver frequencies at the tranche and outcome level over time, after the multiplier-independent escalation/scaling (defined on the *4-Freq* tab) occurs.

FIGURE 3-18
FREQUENCY MULTIPLIER TABLE WITH ACTIVE COLUMN EMPTY

Row#_Sheet5	Row#	Tranche#	Sub-Driver#	Outcome#	Tranche	Sub-Driver	Outcome	Active	Escalation Method	Escalation Parameter	Year1	Year2
1	1	1	1	1	MCDS - Tran:Incorrect Operations		Benign					
2	2	1	2	1	MCDS - Tran:Equipment Related		Benign					
3	3	1	3	1	MCDS - Tran:SQWF		Benign					
4	4	1	4	1	MCDS - Tran:RIM		Benign					
5	5	1	1	2	MCDS - Tran:Incorrect Operations		LOC					
6	6	1	2	2	MCDS - Tran:Equipment Related		LOC					

The Frequency Multiplier table in Figure 3-18 lists the sub-drivers, tranches, and outcomes to which the multipliers are applied (along with other identifying information).

- The Row# identifier refers to this table (*5-FreqMult*);
- The Tranche#, Sub-Driver#, and Outcome# identifiers refer to numbers defined on *2-BowTie* and *3-Tranche*.

Each multiplier is defined by a yearly value, specified in ‘Year’ columns, which can be filled by an escalation method and escalation parameter. The escalation method is applied for the first year of undefined multiplier data over the analysis horizon.

Figure 3-18 shows an example where the Active column is empty, which indicates that the frequency multipliers are not needed. Within the model, Escalation Method is set to **esc** when empty and Escalation Parameter is set to 0 when empty within the Model as default values.

FIGURE 3-19
EXAMPLE INPUT FILE WITH ESCALATION PARAMETER ACROSS SEVERAL OUTCOMES

Active	Escalation Method	Escalation Parameter	Year1	Year2	Year3	Year4
TRUE	esc	0.014531316	1			
TRUE	esc	0.014531316	1			
TRUE	esc	0.014531316	1			
TRUE	esc	0.014531316	1			
TRUE	esc	0.014531316	1			
TRUE	esc	0.014531316	1			

A numerical example for a row with Active value TRUE is included in Figure 3-19. The Escalation Method and Escalation Parameter fields are defined as described in Section 2.4.2.2. This example shows that the frequency multipliers are 1 for the first year (Year1). Because there are no values in Year2, Year3 and Year4, the multiplier value of 1 in Year1 is used and is escalated using **esc** method at 1.4531316 percent rate. Therefore, the multipliers are 1.014531316 for Year 2, 1.0145316^2 for Year3, and 1.0145316^3 for Year4, etc.

For example, if a sub-driver LoRE in Year 1 is 0.000660796 (Figure 3-17), the sub-driver LoRE in Year 2 is now set as 0.00067031 ($0.000660796 \times 1.014531316 = 0.00067031$).

The escalated sub-driver data, with multipliers applied, represents the final set of sub-driver inputs that determine the LoREs at sub-driver, outcome, and tranche level.

3.6.6. Tab 6-Conseq

The consequences, expressed as potential results per driver frequency, are provided on Risk Model Input File tab *6-Conseq*. As with sub-drivers, consequences for each attribute are defined at the tranche and outcome level.

FIGURE 3-20
LEFT SIDE OF THE CONSEQUENCE DEFINITION TABLE FROM 6-CONSEQ

Row#	active row#	Tranche#	Outcome#	Sub-Attribute#	Tranche	Outcome	Sub-Attribute	Active	Note	Distribution1
1	0	1	1	1	MCDS - Transmission Simple	Benign	Safety	FALSE	MCDS - Transmissic	
2	0	1	1	2	MCDS - Transmission Simple	Benign	Gas Reliability	FALSE	MCDS - Transmissic	
3	1	1	1	3	MCDS - Transmission Simple	Benign	Financial	TRUE	MCDS - Transmissic Lognormal	
4	2	1	2	1	MCDS - Transmission Simple	LOC	Safety	TRUE	MCDS - Transmissic Ztpoisson_bernoulli_ef	
5	3	1	2	2	MCDS - Transmission Simple	LOC	Gas Reliability	TRUE	MCDS - Transmissic Lognormal	
6	4	1	2	3	MCDS - Transmission Simple	LOC	Financial	TRUE	MCDS - Transmissic Lognormal	
7	5	1	3	1	MCDS - Transmission Simple	LOC and Cyber Att Safety		TRUE	MCDS - Transmissic Ztpoisson_bernoulli_ef	
8	6	1	3	2	MCDS - Transmission Simple	LOC and Cyber Att Gas Reliability		TRUE	MCDS - Transmissic Lognormal	
9	7	1	3	3	MCDS - Transmission Simple	LOC and Cyber Att Financial		TRUE	MCDS - Transmissic Lognormal	
10	8	1	4	1	MCDS - Transmission Simple	LOC and IT Asset f Safety		TRUE	MCDS - Transmissic Ztpoisson_bernoulli_ef	

The Consequence table in Figure 3-20 lists the Active tranches, outcomes, and Attributes for which consequence distributions need to be defined, along with identifying information.

- The Row# identifier refers to the *6-Conseq* table;
- The activerow# number is defined in the *6-Conseq* table based on the number of active rows within the table; and
- The Tranche#, Sub-Attributer#, and Outcome# identifiers refer to numbers defined on *2-BowTie* and *3-Tranche*.

**FIGURE 3-21
RIGHT SIDE OF THE CONSEQUENCE DISTRIBUTION FROM 6-CONSEQ**

Distribution1	Prob	param1	method	aram	param2	method	aram	Operator	Note	Distribution2
Lognormal	1	50000			25000					
Ztpoisson_bernoulli_ef	0.019444444	10.42857143			0.123287671					
Lognormal	0.66	46147			88373					
Lognormal	1	787973.106			2186684.372					
Ztpoisson_bernoulli_ef	0.019444444	10.42857143			0.123287671					
Lognormal	0.66	46147			88373					
Lognormal	1	787973.106			2186684.372					
Ztpoisson_bernoulli_ef	0.019444444	10.42857143			0.123287671					

A distribution is selected for each consequence, along with the distribution's parameters, escalation method, and escalation parameter. The distributions that can be included in the distribution field are listed in Section 2.4.2.3.

In cases where the Active field is identified as FALSE, there is no consequence for that outcome and no consequence definition is needed.

The distribution probability (also called sampling probability) field is unique to the *6-Conseq* tab. This is shown in Figure 3-21 as Distribution1_Prob. The probability field denotes the probability that the consequence actually occurs given the risk event outcome. For example, with Distribution1_Prob of 0.4, the consequence described by Distribution1 is expected to materialize with 40 percent probability and not to materialize (i.e., zero consequence) with 60 percent probability.

The consequences can be described by a variety of distributions. Those distributions can have up to six parameters, which are shown on the *6-Conseq tab* and listed as Distribution1_param1, Distribution1_param2, Distribution1_param3, etc.

The final set of inputs to characterize the distributions are escalation parameters, which use one of the methods described in Section 2.4.2.2. Each of the input parameters for the distributions has an associated escalation method (e.g., Distribution1_param1_esc_method and Distribution1_param1_esc_param). DistributionN_paramN_esc_Method is set to **esc** when empty and DistributionN_paramN_esc_param is set to 0 when empty within the Model as default values.

The Risk Model Input File enables multiple distributions for defining the consequence for a single row on the *6-Conseq* table (the combination of tranche, outcome, and attribute). This is useful when the consequence is either the sum or the

product of two random variables. In this case, Distribution2 parameters can be specified as Distribution1 and the Model either sums or takes the product of those distributions to generate a final Natural Unit for each trial depending on the operator specified: “sum”, “prod”, or “efprod” under the Distributions Operator field. If more than two distributions are needed, parameters for Distribution3 and Distribution4 can be specified.

3.6.6.1. Safety Attribute Distributions

The remainder of this section presents two options for specifying distribution inputs for modeling the Safety consequence which uses Equivalent Fatality (EF) count as the Natural Unit. The Safety attribute consequence of a risk event has three required components, while the other attributes have two.

Safety consequences are characterized by:

- 1) Distribution probability (probability that outcome has a Safety consequence);
- 2) Distribution of total serious injuries and fatalities; and
- 3) Fraction of serious injuries and fatalities that are fatalities.

There are two different options to define the parameters in the Model with based on Items 1 through 3 above.

- 1) *Option 1:* Define a single Safety distribution to include the three safety consequences characteristics. The three distributions which end in _ef are tailored to expect an additional parameter (fraction of fatalities) beyond the standard set of required parameters (distribution probability and distribution parameters).

This option was implemented in Figure 3-20 and Figure 3-21 (see the Distribution1 field). These distributions are defined in Section 2.4.2.4.1.

- 2) *Option 2:* Use any parametric distribution for Distribution1, the ‘efprod’ Distributions Operator, and Distribution2 to specify the fraction of SIFs that are fatalities (which can either be deterministic or not). The random variables from the two distributions are as follows:

- a) The number of SIFs from a safety incident, N, is assumed to follow Distribution1, which can be any positive discrete distributions (e.g., Zero-Truncated Poisson, Discrete); and
- b) The percent of fatality, X, follows Distribution2, which can be any distributions with support in [0, 1] (e.g., Standard uniform distribution, Deterministic distribution with D_Value in [0,1], and Discrete distribution).

The final EF count, Y, is generated as follows:

$$Y = N \times (X + (1 - X) \times EFfactor)$$

Notes: The sampling probabilities for the Distribution1 and Distribution2 must be set the same when using *Option 2*.

Example:

Assuming *EFfactor* = ¼ (i.e., one serious injury is ¼ fatality), Table 3-4 shows four random draws using this option.

**TABLE 3-4
FOUR RANDOM DRAWS USING SAFETY MODEL OPTION 2**

No. of SIFs, N	Percent of Fatality X	No. of EF, Y
5	0.2	5*(0.2 + 0.8/4) = 2.00
4	0.4	4*(0.4 + 0.6/4) = 2.20
3	0.8	3*(0.8 + 0.2/4) = 2.55
2	0.6	2*(0.6 + 0.4/4) = 1.40

Figure 3-22 is an example of how the two options are presented in the *6-Conseq* tab.

**FIGURE 3-22
SUMMARY OF TWO OPTIONS TO CHARACTERIZE SAFETY CONSEQUENCE DISTRIBUTIONS**

	Dist1	Dist1_ Prob	Dist1_	Dist1_	Dist1_	Dist1_	Dists Operator	Dist2	Dist2_ Prob	Dist2_	Dist2_
			param 1	param 2	param 3	param 4				param 1	param 2
Option 1	Ztpoisson_bernoulli_ef	5%	2	46%					5%		
Option 1	Rtlognorm_bernoulli_ef	100%	26	50	300	50%			100%		
Option 2	Ztpoisson	85%	3				efprod	Uniform	85%	14%	34%
Option 2	Ztpoisson	100%	2				efprod	Deterministic	100%	90%	

3.6.7. Tab 7-ConseqMult

Consequence multipliers are applied to the Natural Units simulated for each trial from the consequence distribution of each tranche, outcome, attribute and year, based on the specification in *6-Conseq*.

**FIGURE 3-23
CONSEQUENCE MULTIPLIER TABLE**

Row#	Row#_Sheet#	Tranche#	Outcome#	Sub-Attribute#	Tranche	Outcome	Sub-Attribute	Active	Cross Cut	Note	Escalation Method	Escalation Parameter	Year1
1	3	1	1	3	MCDS - Transmission Simple	Benign	Financial	TRUE	RIM				101.90%
2	4	1	2	1	MCDS - Transmission Simple	LOC	Safety						
3	5	1	2	2	MCDS - Transmission Simple	LOC	Gas Reliability						
4	6	1	2	3	MCDS - Transmission Simple	LOC	Financial	TRUE	RIM				101.90%
5	7	1	3	1	MCDS - Transmission Simple	LOC and Cyber Attack	Safety	TRUE	CYB				102.25%
6	8	1	3	2	MCDS - Transmission Simple	LOC and Cyber Attack	Gas Reliability	TRUE	CYB				102.50%

Other than the variable to which the multipliers are applied, the fields shown in Figure 3-23 are functionally identical to those on *5-FreqMult*. A user can specify if the multiplier should be active by setting Active as TRUE and can specify an Escalation Method and Escalation Parameter by which to extrapolate the multiplier data over time.

In the example shown in Figure 3-23, the multipliers do not increase with time (implied by the empty Escalation Method and Escalation Parameter columns), so the same multiplier is applied across all simulated years.

3.7. Baseline Risk Score

Using the input data from the Risk Model Input File Sheets 1 through 7 (defining the drivers, sub-drivers, tranches, risk event frequencies, frequency multipliers, consequences and consequence multipliers) the Model calculates baseline Frequency, CoRE and risk scores.

An overview of the calculation process is provided in Section 4.1, and a numerical example of calculation for the Failure of Electric Distribution Network Assets used for the 2020 RAMP Report is included in workpapers.⁵²

3.8. Program Definition Inputs

Mitigation and Control projects and/or programs are the efforts enacted or proposed in order to reduce overall risk. Risk Controls are programs that are in place that reduce the risk from an Inherent case to the Baseline case. Mitigations represent work that would reduce Baseline risk to Mitigated risk levels. Risk Reduction is defined as the difference between the Inherent and Baseline risk scores, or the difference between the Baseline and Mitigated risk scores. Values in the Risk Model Input File, Tabs 2 through 7, represent the Baseline case, or the current state of risk.

⁵² See WP User Guide-1.

Mitigated cases can include the Proposed case or Alternative cases, depending on the group of mitigations considered.

To calculate risk scores for the Inherent and Mitigated cases, the risk Bow Tie inputs stored for each tranche and outcome are transformed to model the effectiveness of the programs. The scale by which the distributions are transformed are a function of the program effectiveness calculations, outlined in Section 4.2 of the User Guide.

3.8.1. Tab 8-Program

The programs listed on Tab *8-Program* are those which apply to the risk described in the Risk Model Input File and can include the proposed mitigations and alternative mitigations developed to address that risk as well as mitigations developed to impact the cross-cutting factors. Tab, *8-Program* shown in Figure 3-24, features descriptive program information. These specifications determines the numerical values needed in Tabs 9 to 11.

**FIGURE 3-24
MITIGATION AND CONTROL PROGRAM DEFINITION**

Row#	LOB/ Cross	Program#	Program			Scenario	Conseq		active# freq program	active# cons program	
			Cut	Program	Type		Program Description	Case			FreqMitig
1	GO	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	Mitigation	Additional SCADA infrastructure	Proposed	1	TRUE	1	0	
2	GO	2	M3-SCADA Visibility [Transmission] (2023 - 2026)	Mitigation	Additional SCADA infrastructure	Proposed	1	TRUE	2	0	
3	GO	3	M4-Station OPP Enhancements [Transmission] (2020 - 2022)	Mitigation	Station OPP	Proposed	1	TRUE	3	0	
4	GO	4	M4-Station OPP Enhancements [Transmission] (2023 - 2026)	Mitigation	Station OPP	Proposed	1	TRUE	4	0	
5	GO	5	M1-Critical Documents Program (2020 - 2022)	Mitigation	Revision and/or developing new criti	Proposed	1	TRUE	TRUE	5	1
6	GO	6	M1-Critical Documents Program (2023 - 2026)	Mitigation	Revision and/or developing new criti	Proposed	1	TRUE	TRUE	6	2
7	GO	7	M3-SCADA Visibility [RTU] (2020 - 2022)	Mitigation	Additional SCADA infrastructure	Proposed	1	TRUE	7	2	
8	GO	8	M3-SCADA Visibility [RTU] (2023 - 2026)	Mitigation	Additional SCADA infrastructure	Proposed	1	TRUE	8	2	
9	GO	9	M3-SCADA Visibility [ERX] (2020 - 2022)	Mitigation	Additional SCADA infrastructure	Proposed	1	TRUE	9	2	
10	GO	10	M3-SCADA Visibility [ERX] (2023 - 2026)	Mitigation	Additional SCADA infrastructure	Proposed	1	TRUE	10	2	

There are four computed data columns in *8-Program*:

- Row# refers to the row number in *8-Program* and serves as an identifier for Tabs 9-11.
- The Program# increases by one number each time a new program is listed in the Program column.
- The final two columns, active# freqprogram and active# conseqprogram increase by one number each time there is a new program which affects frequency or consequence, respectively, based on information entered into the FreqMitigation and ConseqMitigation columns. These two columns are referred to in Tabs 10 and 11 where mitigation effectiveness values are specified.

The remaining information is input by the user to describe the programs and includes the Line of Business (LOB) or cross-cutting factor to which the program applies, the program name, the program type (Mitigation or Control), and a description of the program.

The Case column is used to group programs together for portfolio-level RSE calculations. In the 2020 RAMP, cases included Proposed and Alternatives. This functionality is not used GRC. The two Boolean flag columns, indicating FreqMitigation or ConseqMitigation, determine which programs apply to the two program effectiveness definition tabs (*10-ProgramFreqEff* and *11-ProgramConseqEff*).

3.8.2. Tab 9-ProgramExposureSpend

The programs defined on the *8-Program* tab can be applied across the tranches. The units of exposure and tranches to which the programs apply are listed on *Tab 9-ProgramExposureSpend*.

**FIGURE 3-25
LEFT SIDE OF THE TABLE DEFINING PROGRAM EXPOSURE AND SPEND AT THE TRANCHE LEVEL**

Row#	Row#_Sheet8	active#	Tranche#	Program	Tranche	Index	Active	Spend Type	Scope%	Exposure Year1
1	1	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	M3-SCAD	TRUE	capital	9.52%	8
2	1	1	2	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Distribution District Reg	M3-SCAD	FALSE	expense	0.00%	0
3	1	1	3	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Distribution HPR+FT	M3-SCAD	FALSE	expense	0.00%	0
4	1	1	4	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Complex	M3-SCAD	FALSE	expense	0.00%	0
5	1	1	5	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission LVCR	M3-SCAD	FALSE	expense	0.00%	0
6	1	1	6	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Distribution LPR	M3-SCAD	FALSE	expense	0.00%	0
7	2	2	1	M3-SCADA Visibility [Transmission] (2023 - 2026)	MCDS - Transmission Simple	M3-SCAD	TRUE	capital	12.70%	0
8	2	2	2	M3-SCADA Visibility [Transmission] (2023 - 2026)	MCDS - Distribution District Reg	M3-SCAD	FALSE	expense	0.00%	0
9	2	2	3	M3-SCADA Visibility [Transmission] (2023 - 2026)	MCDS - Distribution HPR+FT	M3-SCAD	FALSE	expense	0.00%	0
10	2	2	4	M3-SCADA Visibility [Transmission] (2023 - 2026)	MCDS - Transmission Complex	M3-SCAD	FALSE	expense	0.00%	0

9-ProgramExposureSpend starts with four numerical identifier data columns:

- Row# refers to the row number within this table.
- The Row#_Sheet8 refers to the identifier from *8-Programs*.
- The active# is computed here and increases by one each time there is a new Active row.
- The Tranche# corresponds to the listed Tranche and is based on the table from *3-BowTie*.

These four columns determine which Programs and Tranches are listed.

**FIGURE 3-26
RIGHT SIDE OF THE PROGRAM EXPOSURE AND SPEND DEFINITION TABLE**

Scope%	Exposure Year1	Exposure Year2	Exposure Year3	Exposure Year4	Cap Spend USD Year1	Cap Spend USD Year2	Cap Spend USD Year3	Cap Spend USD Year4	O&M Spend USD Year1	O&M Spend USD Year2	O&M Spend USD Year3	O&M Spend USD Year4	Case	Program Short Name
9.52%	8	8	8	0	3750000	3840000	3936000	0	0	0	0	0	0	Proposed M3-SCADA'
0.00%	0	0	0	0	0	0	0	0	0	0	0	0	0	Proposed M3-SCADA'
0.00%	0	0	0	0	0	0	0	0	0	0	0	0	0	Proposed M3-SCADA'
0.00%	0	0	0	0	0	0	0	0	0	0	0	0	0	Proposed M3-SCADA'
0.00%	0	0	0	0	0	0	0	0	0	0	0	0	0	Proposed M3-SCADA'
0.00%	0	0	0	0	0	0	0	0	0	0	0	0	0	Proposed M3-SCADA'
12.70%	0	0	0	8	0	0	0	4034400	0	0	0	0	0	Proposed M3-SCADA'
0.00%	0	0	0	0	0	0	0	0	0	0	0	0	0	Proposed M3-SCADA'
0.00%	0	0	0	0	0	0	0	0	0	0	0	0	0	Proposed M3-SCADA'
0.00%	0	0	0	0	0	0	0	0	0	0	0	0	0	Proposed M3-SCADA'

Note: The number of years has been condensed in this graphic so the table can fit on this page.

As shown in Figure 3-26, the columns on the right side of the table include the program scope, amount of exposure and estimated program costs.

- The Scope % field is computed as a ratio of the total exposure of all years relative to the Tranche exposure; it may be greater than 100 percent.
- Exposure Year1, Exposure Year2, Exposure Year3, etc., fields, denotes the units of exposure per Program-Tranche combination per year. These values must be less than or equal to the total units of exposure for the tranche in the specified year.
- The Cap Spend USD Year1, etc., and O&M Spend USD Year1, etc., fields list the estimated cost for the amount of work done relative to those units of exposure in each tranche. The spend values entered on *9-ProgramExposureSpend* will be used to calculate a Risk Spend Efficiency (RSE) for each program.
- The Program Short Name is simply an abbreviation of the program without the duration (either 2020-2022 or 2023-2026).

3.9. Program Effectiveness Inputs

Tabs 10-ProgramFreqEff and *11-ProgramConseqEff* describe the mitigation effectiveness impact at the sub-driver and consequence distributions levels.

A mitigation or control program's effectiveness is a measure (described as a percentage) of how much the mitigation or control reduces the frequency or consequence of a risk event. Given that the program is applied only to a portion of the tranche in this input sheet, the effectiveness input is adjusted by the Model to determine the average effectiveness for the whole tranche by multiplying a ratio of program exposure to the tranche exposure. The Model also calculates the effectiveness for the

years beyond the program implementation year when the program's benefit lasts longer than one year. The average effectiveness of mitigations in a Portfolio is then aggregated into the overall Portfolio effectiveness.

The Proposed case shows the impact that implementing the Proposed mitigations has on the baseline risk score. As such, the Proposed risk score will be less than the baseline risk. The final mitigation effectiveness factor, is defined as $1 - [\text{overall mitigation effectiveness}]$, expressed as a percentage. For example: the effectiveness of a given portfolio of mitigations may be 20 percent. The expected baseline frequency of an outcome is 0.7 events per year. After the portfolio of mitigations is implemented, the mitigated frequency would be 0.56 ($= [1 - 0.2] \times 0.7$).

Controls represent risk mitigation programs that are already in place. The Inherent case represents the risk absent the Control program. The risk score for the Inherent case will be greater than the results from the baseline case. Whereas the scaling factor from the mitigations are represented as $[1 - \text{program effectiveness}]$ for mitigations, the scaling factor for controls is represented as $[1 + \text{program effectiveness}]$ where the effectiveness of a Control is defined as the percentage increase expected if the Control is removed.

Sections 3.9.1 and 0 outline how the program effectiveness values are derived and applied to sub-drivers and consequences.

3.9.1. Tab 10-ProgramFreqEff

At the tranche level and outcome level, programs are described by a series of identifier fields, fields describing the "Active" status of the program, and fields describing the effectiveness of program application. Shown in Figure 3-27, the set of identifier fields includes only the set of tranches, sub-drivers and outcomes that are Active in *4-Freq* (identified with Row#_Sheet4) and includes only Programs identified as applicable to Frequency mitigation (identified with Row#_Sheet8).

**FIGURE 3-27
PROGRAM DEFINITION SECTION (LEFT SIDE) OF THE PROGRAM EFFECTIVENESS TABLE**

Row#	Row#_Sheet4	Tranche#	Sub-Driver#	Outcome#	Row#_Sheet8	Program#	Program	Tranche	Sub-Driver	Outcome	Program Active On	Tranche	Category
1	1	1	1	1	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	Incorrect Operations	Benign	TRUE		Incorrect Operations
2	2	1	2	1	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	Equipment Related	Benign	TRUE		Equipment Related
3	3	1	3	1	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	SQWF	Benign	TRUE		CC - SQWF
4	4	1	4	1	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	RIM	Benign	TRUE		CC - RIM
5	5	1	1	2	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	Incorrect Operations	LOC	TRUE		Incorrect Operations
6	6	1	2	2	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	Equipment Related	LOC	TRUE		Equipment Related
7	7	1	3	2	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	SQWF	LOC	TRUE		CC - SQWF
8	8	1	4	2	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	RIM	LOC	TRUE		CC - RIM
9	9	1	1	3	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	Incorrect Operations	LOC and Cyber Attack	TRUE		Incorrect Operations
10	10	1	2	3	1	1	M3-SCADA Visibility [Transmission] (2020 - 2022)	MCDS - Transmission Simple	Equipment Related	LOC and Cyber Attack	TRUE		Equipment Related

- The program identification fields include the program, the tranche to which it applies, and the outcome to which it applies.
- The Category field includes the Driver to which Sub-drivers map.
- The Program Active on Tranche field denotes if the program should be applied and calculated for that tranche in the Model.
- The Active field denotes if the program should be applied and calculated for the specified sub-driver in the outcome.

**FIGURE 3-28
LEFT SIDE OF THE PROGRAM EFFECTIVENESS TABLE, INCLUDING NUMERICAL PROGRAM DEFINITIONS**

Effectiveness	Re-mitigation Impact on Effectiveness	Annual Degradation Rate During Period 1	Number of years for period 1	Escalation Method for Period 1	Program Short Name
50.00%		0.00%	15		M3-SCADA'
15.00%		0.00%	15		M3-SCADA'
50.00%		0.00%	15		M3-SCADA'
50.00%		0.00%	15		M3-SCADA'
50.00%		0.00%	15		M3-SCADA'
15.00%		0.00%	15		M3-SCADA'
50.00%		0.00%	15		M3-SCADA'
50.00%		0.00%	15		M3-SCADA'
50.00%		0.00%	15		M3-SCADA'
15.00%		0.00%	15		M3-SCADA'

The effectiveness of the mitigation or control program is described using the numerical fields in Figure 3-28. The Effectiveness field denotes the percentage reduction to the sub-driver parameter per unit of program exposure for the specified tranche and outcome, independent of historical program application to the same exposure. When blank, the “Effectiveness” field defaults to 0.

Programs can have a diminishing marginal effectiveness. If the same program is applied to the same exposure, the application of the program will not yield the same level of effectiveness.⁵³

The effectiveness of a mitigation can degrade over time. In the *10-ProgramFreqEff* input sheet, this degradation can be specified using one or two periods. The periods are defined as two sets of yearly degradation, where in the first period, the effectiveness may decrease by one set of values, and in the second period, a different set of degradation values apply.⁵⁴ A user can also specify a custom escalation curve using the “match” method in the *12-esc* input sheet. Effectiveness degradation for programs are defined using the following fields:

- Annual Degradation Rate During Period 1: Represents the yearly rate by which the effectiveness of the program degrades. When left blank, the default value is zero.
- Number of years for Period 1: Represents the number of years the degradation rate outlined for Period 1 should apply. When left blank, the default value is the full analysis horizon of the model.
- Escalation Method for Period 1: Using the escalation functions outlined for other variable escalation and extrapolation, this is the chosen method for the Period 1 degradation rate escalation. When left blank, the default value is “esc.”

The degradation rate is escalated and applied to the effectiveness value for the years specified in each period.

Interaction between programs for the same Tranche-Driver-Outcome are discussed in Section 4.2.1.1.

3.9.2. Tab 11-ProgramConseqEff

Functionally, the *11-ProgramConseqEff* tab is identical to the *10-ProgramFreqEff*. Effectiveness values are calculated the same way, except they applied to the simulated consequence in Natural Units, rather than the Drivers and Sub-Drivers.

⁵³ This re-mitigation impact capability was not utilized in the GRC risk models, but, is available for future use.

⁵⁴ None of the GRC risks use different degradation rates over two different periods of time.

4. Calculations: Baseline Risk Score and Mitigation Analysis

4.1. Baseline Risk Score Calculation

This section provides an overview of the process for calculating the Baseline Risk Score. A numerical example for the Electric Distribution Network Asset Failure risk calculation is included in workpapers.⁵⁵ The name of the tab from the sample calculation workpaper (WP) corresponding to each step described below is included at the end of each step.

Steps for using completed model to calculating Risk Scores and RSEs:

- 1) Exposure: Obtain annual exposure for each Tranche, apply escalation factors, as necessary, using inputs specified in *3-Tranche*. (WP Tab: Input_Exposure.)
- 2) LoRE: Given the likelihood of the risk event occurring at each Tranche-Sub-Driver-Outcome combination in year 1, apply escalation factors (as necessary) to those values to compute future-year LoRE values. Apply any frequency multipliers (cross-cutting factor impacts) to these annual LoRE values. LoRE has units of expected number of events/unit exposure/year, or can be interpreted as the probability of having an event per unit of exposure per year when the unit of exposure is small enough.⁵⁶ (WP Tab: Input_LoRE.)
- 3) Frequency: Compute as the product of tranche exposure and LoRE for each Tranche-Sub-Driver-Year combination. Frequency has units of expected number of events per year. (WP Tab: Frequency.)
- 4) CoRE: Using the conditional distributions of consequence specified for each Tranche-Outcome-Attribute, simulate Natural Units per Tranche-Outcome-Attribute. (WP Tab: ExpectedNaturalUnitPerEvent.)
 - a) Apply distribution parameter escalation methods. (Not relevant to this risk.)
 - b) Simulate sufficient number of iterations to ensure mean convergence within 2 percent for each conditional distribution for each analysis year. (WP Tab: Sim_Distribution.)
 - c. Apply Consequence multipliers to simulated Natural Unit values. (Not relevant to this risk.)

⁵⁵ See the workpaper Risk Modeling WP-3.

⁵⁶ Within the model, the number, or frequency, of risk events is not simulated. The mean of the Poisson distribution specified in Distribution1_param1 in 4-Freq tab is used as the expected number of events per unit exposure each year.

- d) For each consequence distribution for the Tranche-Outcome-Attribute with multiple distributions specified with operator for combining, simulate Bernoulli Random Variable with conditional sampling probability, which is sampling probability for the distribution divided by the maximum sampling probability across distributions for the same Tranche-Outcome-Attribute. The maximum of the conditional sampling probabilities for the consequence distributions of same Tranche-Outcome-Attribute would be equal to 1. If there is just one consequence distribution defined for a Tranche-Outcome-Attribute combination, the conditional sampling probability would be equal to 1, so there is no need to simulate Bernoulli random variables. (WP Tab: Sim_CondProbability.)
 - e) Multiply values from 4.c. to 4.d. element-wise so trials with realized outcome corresponds to conditional sampling probability, and then add them element-wise over the same Tranche-Outcome-Attribute. (WP Tab: Sim_DistMultiplyCondProb.)
 - f) Compute total natural units over all distributions for each event (defined at the Tranche-Outcome-Attribute level). (WP Tab: Sim_CondNaturalUnitPerEvent.)
 - g) Transform the simulated natural units per risk event for each Tranche-Outcome-Attribute using MAVF to get Trial CoRE conditional on the Attribute consequence occurring given the Risk Event. (WP Tab: Sim_CondCoRE.)
 - h) Compute CoRE per Tranche-Outcome-Attribute by taking the mean over all conditional Trial CoRE and multiplying it by the maximum sampling probability. (WP Tab: CoRE.)
- 5) Multiply Frequency at tranche/outcome by the corresponding (Multi-Attribute) CoRE to get Risk Score per tranche/outcome. (WP Tab: RiskScore.)
 - 6) Sum Baseline Risk Scores by tranche over all tranches to get Baseline Risk Score. (WP Tab: Summary.)

4.1.1. Frequency Calculation

The essential information on the left-hand side of the bow tie is the event frequency. Frequency is computed using the likelihood of risk event (LoRE) per unit of exposure and the units of risk exposure. LoRE values are defined by Tranche, Sub-Driver, and Outcome (see Section 1.3.1 for more, and Section 2.1.1 for a calculation example). The values used in the model are taken from *4-Freq* and are escalated, as needed, over the analysis horizon using the method specified in the input sheet and detailed in

12-esc_method. The frequency multipliers in *5-FreqMult* are also escalated, also using the method specified in *12-esc_method* and applied to the escalated LoRE. This is multiplied to the tranche exposure obtained from *3-Tranche* sheet, to derive Frequency by tranche and outcome for each year over the analysis horizon. Note that in the formulas below, the year dimension is not included in the subscripts since it applies to all variables.

$$Frequency_{tr,o} = Exposure_{tr} \times LoRE_{tr,o}$$

Where:

$Exposure_{tr}$ is the exposure for tranche tr.

$LoRE_{tr,o}$ is the LoRE of outcome o in tranche tr, and is obtained by summing over the sub-drivers leading to the outcome as shown below:

$$LoRE_{tr,o} = \sum_d LoRE_{tr,d,o}$$

4.1.2. CoRE Calculation

As discussed in Section 1.3.2, the Consequence of Risk Event (CoRE) is calculated at the Tranche, Outcome and Attribute level, and results from the application of the MAVF to the Natural Unit of the outcomes of a risk event. Consequence per event outcome is represented by the probability distributions in the input file. There are two methods used in ERM to compute Attribute CoRE values given probability distributions for each Tranche and Outcome:

1. Simulating trial CoRE values and computing an expected value, or
2. Computing an expected value using a closed-form solution derived using the scaling function. Closed-form solutions have been derived for six distribution types: Normal, Truncated Normal, Lognormal, Truncated Lognormal, Pareto Type 1, Pareto Type 2.

4.1.2.1. Closed-form Solution

PG&E has made significant improvements over the 2020 RAMP model in the way CoRE values are calculated. In the 2020 RAMP filing, all Tranche-Outcome-Attribute consequences were simulated to arrive at an Expected Value for each Attribute CoRE. The number of simulations required for convergence within our tolerance were not always computationally feasible for distributions with high variance. PG&E derived

closed-form solutions for a set of parametric distributions to address this shortcoming of the Monte Carlo Simulations.

The closed form solutions listed for each distribution type below were derived using the PG&E scaling function presented in Figure 1-4. Each function takes as input normalized units (see Section 1.2.2 for Attribute Ranges used to normalize), as well as the probability distribution parameters specified in *6-Conseq*.

Normal or Truncated Normal Distribution:

If the attribute level in normalized units, r , has a probability density function, $h(r)$, that is normal with mean μ and variance σ^2 ,⁵⁷ then the integration, I , of the PG&E's MAVF scaling function over $h(r)$ is

57 Note: μ and σ are the untruncated normal distribution's mean and standard deviation. When there is no truncation, the mean and standard deviation of the data can be used as estimates of μ and σ . When there is truncation, the mean and standard deviation of the data (which are truncated) can be used as estimates of the mean, μ_T , and standard deviation, σ_T , of the truncated normal distribution. μ and σ can then be estimated from these estimates of μ_T and σ_T , with the following two-step procedure.

First, iteratively solve the following equation for α and β ,

$$(1) \quad \beta - \alpha + \frac{r_L - r_U}{\left[\frac{\sigma_T^2}{g(\alpha, \beta)} \right]^{0.5}} = 0,$$

where $g(\alpha, \beta) = 1 + \frac{\alpha\varphi(\alpha) - \beta\varphi(\beta)}{N(\beta) - N(\alpha)} - \left(\frac{\varphi(\alpha) - \varphi(\beta)}{N(\beta) - N(\alpha)} \right)^2$, $\varphi(\cdot)$ is the probability density function of a standard normal variable, $\alpha = \frac{r_L - \mu}{\sigma}$, and $\beta = \frac{r_U - \mu}{\sigma}$.

Second, substitute these α and β values into (2) below to solve for σ and μ ,

$$(2) \quad \sigma = \left[\frac{\sigma_T^2}{g(\alpha, \beta)} \right]^{0.5} \quad \text{and} \quad \mu = \mu_T - \sigma \frac{\varphi(\alpha) - \varphi(\beta)}{N(\beta) - N(\alpha)}$$

Note, when there is only a lower truncation, (1) and (2) become

$$(3) \quad \alpha - f(\alpha) - \frac{r_L - \mu_T}{\left[\frac{\sigma_T^2}{g(\alpha)} \right]^{0.5}} = 0,$$

$$(4) \quad \sigma = \left[\frac{\sigma_T^2}{g(\alpha)} \right]^{0.5} \quad \text{and} \quad \mu = \mu_T - \sigma f(\alpha)$$

where $g(\alpha) = 1 + \alpha f(\alpha) - f(\alpha)^2$, $f(\alpha) = \frac{\varphi(\alpha)}{1 - N(\alpha)}$ and $\alpha = \frac{r_L - \mu}{\sigma}$.

Similarly, when there is only an upper truncation, (1) and (2) become

$$(5) \quad \beta + f(\beta) - \frac{r_U - \mu_T}{\left[\frac{\sigma_T^2}{g(\beta)} \right]^{0.5}} = 0,$$

$$(6) \quad \sigma = \left[\frac{\sigma_T^2}{g(\beta)} \right]^{0.5} \quad \text{and} \quad \mu = \mu_T + \sigma f(\beta),$$

$$\begin{aligned}
(1) \quad I = & \left(\frac{1}{\int_{z_0^*}^{z_{\infty}^{**}} \frac{1}{\sqrt{2\pi}} e^{-\frac{s^2}{2}} ds} \right) \{ \\
& 10 \left\{ \mu [N(z_{0.01}^{**}) - N(z_0^*)] + \frac{\sigma}{\sqrt{2\pi}} \left[e^{\left(\frac{-z_0^{*2}}{2}\right)} - e^{\left(\frac{-z_{0.01}^{**2}}{2}\right)} \right] \right\} \\
& + 0.049\bar{4} [N(z_{0.1}^{**}) - N(z_{0.01}^*)] \\
& + 0.\bar{1} \left\{ \mu [N(z_{0.1}^{**}) - N(z_{0.01}^*)] + \frac{\sigma}{\sqrt{2\pi}} \left[e^{\left(\frac{-z_{0.01}^{*2}}{2}\right)} - e^{\left(\frac{-z_{0.1}^{**2}}{2}\right)} \right] \right\} \\
& + 494.\bar{4} \left\{ \mu^2 [N(z_{0.1}^{**}) - N(z_{0.01}^*)] \right. \\
& \quad + \frac{2\mu\sigma}{\sqrt{2\pi}} \left[e^{\left(\frac{-z_{0.01}^{*2}}{2}\right)} - e^{\left(\frac{-z_{0.1}^{**2}}{2}\right)} \right] \\
& \quad + \frac{\sigma^2}{\sqrt{2\pi}} \left[z_{0.01}^* e^{-\frac{z_{0.01}^{*2}}{2}} - z_{0.1}^{**} e^{-\frac{z_{0.1}^{**2}}{2}} \right] \\
& \quad \left. + \sigma^2 [N(z_{0.1}^{**}) - N(z_{0.01}^*)] \right\} \\
& - 5.\bar{5} [N(z_{\infty}^{**}) - N(z_{0.1}^*)] \\
& + 105.\bar{5} \left\{ \mu [N(z_{\infty}^{**}) - N(z_{0.1}^*)] + \frac{\sigma}{\sqrt{2\pi}} \left[e^{\left(\frac{-z_{0.1}^{*2}}{2}\right)} - e^{\left(\frac{-z_{\infty}^{**2}}{2}\right)} \right] \right\} \\
& \left. \right\},
\end{aligned}$$

where $N(\cdot)$ is the cumulative distribution function for a standard normal variable, and $z_{0.01}^{**} = \max \left[\frac{\min(r_u, 0.01) - \mu}{\sigma}, \frac{r_L - \mu}{\sigma} \right]$, $z_0^* = \min \left[\frac{\max(r_L, 0) - \mu}{\sigma}, \frac{r_U - \mu}{\sigma} \right]$. Here, r_u is the upper truncation value, if any, and is $+\infty$ otherwise; and r_L is the lower truncation value, if any, and is 0 otherwise.

Lognormal or Truncated Lognormal Distribution

If the attribute level in normalized units, r , has a probability density function, $h(r)$, that is lognormal and the natural logarithm of r has a mean of μ and a variance of σ^2 ,⁵⁸ then the integration, I , of the PG&E's MAVF scaling function over $h(r)$ is

$$\begin{aligned}
(2) \quad I = & 10 E[r] [N(z_{0.01}^{**} - \sigma) - N(z_0^* - \sigma)] \\
& + 0.049\bar{4} [N(z_{0.1}^{**}) - N(z_{0.01}^*)] \\
& + 0.\bar{1} E[r] [N(z_{0.1}^{**} - \sigma) - N(z_{0.01}^* - \sigma)] \\
& + 494.\bar{4} E[r]^2 e^{\sigma^2} [N(z_{0.1}^{**} - 2\sigma) - N(z_{0.01}^* - 2\sigma)] \\
& - 5.\bar{5} [N(z_{\infty}^{**}) - N(z_{0.1}^*)] \\
& + 105.\bar{5} E[R] [N(z_{\infty}^{**}) - N(z_{0.1}^* - \sigma)].
\end{aligned}$$

where $g(\beta) = 1 - \beta f(\beta) - f(\beta)^2$, $f(\beta) = \frac{\varphi(\beta)}{N(\beta)}$ and $\beta = \frac{r_U - \mu}{\sigma}$.

⁵⁸ Ibid

where, $N(\cdot)$ is the cumulative distribution function for a standard normal variable, $E[R] = e^{\mu + \sigma^2/2}$, and, for example, $z_{0.01^{**}} = \frac{\ln\left(\max\left[\frac{\min(r_U, 0.01) - \mu}{\sigma}, \frac{r_L - \mu}{\sigma}\right]/E[r]\right) + \sigma^2/2}{\sigma}$, $z_{0^*} = \frac{\ln\left(\min\left[\frac{\max(r_L, 0) - \mu}{\sigma}, \frac{r_U - \mu}{\sigma}\right]/E[r]\right) + \sigma^2/2}{\sigma}$. Here, r_U is the upper truncation value, if any, and is $+\infty$ otherwise; and r_L is the lower truncation value if any and is 0 otherwise.

Pareto Type 1 Distribution

If the attribute level in normalized units, r , has a Pareto Type 1 distribution, then its probability density function $h(r)$ is

$$(3) \quad h(r) = C \cdot r^{-(\alpha+1)} \quad \text{for } 0 < r_L \leq r \leq r_U \text{ and } 0 < \alpha,$$

$$= 0 \quad \text{otherwise,}$$

where $C = \frac{\alpha}{r_L^{-\alpha} - r_U^{-\alpha}}$, α is called the shaping parameter, r_L is the necessary lower bound, r_U is the upper bound, if there is one, and is $+\infty$ otherwise. The integration of the PG&E's MAVF scaling function over $h(r)$ is

$$(4) \quad I = 10 \left(\frac{C}{\alpha_2}\right) [r^{\alpha_2}]_{0^*}^{0.01^{**}} \\ + 0.049\bar{4} \left(\frac{C}{\alpha_1}\right) [r^{\alpha_1}]_{0.01^*}^{0.1^{**}} \\ + 0.\bar{1} \left(\frac{C}{\alpha_2}\right) [r^{\alpha_2}]_{0.01^*}^{0.1^{**}} \\ + 494.\bar{4} \left(\frac{C}{\alpha_3}\right) [r^{\alpha_3}]_{0.01^*}^{0.1^{**}} \\ - 5.\bar{5} \left(\frac{C}{\alpha_1}\right) [r^{\alpha_1}]_{0.1^*}^{\infty^{**}} \\ + 105.\bar{5} \left(\frac{C}{\alpha_2}\right) [r^{\alpha_2}]_{0.1^*}^{\infty^{**}},$$

where α_1 , α_2 , and α_3 are, respectively, $-\alpha$, $-\alpha + 1$, and $-\alpha + 2$, and, for example, $0.01^{**} = \max(\min(0.01, r_U), r_L)$ and $0^* = \min(\max(0, r_L), r_U)$.

Pareto Type 2 Distribution

If the attribute level in normalized units, r , has a Pareto Type 2 distribution, then its probability density function $h(r)$ is

$$(5) \quad h(r) = C \cdot \left[1 + \frac{r-\mu}{\sigma}\right]^{-(\alpha+1)} \quad \text{for } \sigma > 0, \alpha > 0, r \geq \mu \text{ and } r_L \leq r \leq r_U,$$

$$= 0 \quad \text{otherwise,}$$

where $C = \frac{\alpha'_1}{\xi(r_U)^{\alpha_1} - \xi(r_L)^{\alpha_1}}$, μ , σ , and α are constants and are commonly referred to as, respectively, location, scale, and shape, $\xi(r) = 1 + \frac{r-\mu}{\sigma}$, $\alpha'_1 = \frac{\alpha_1}{\sigma}$, $\alpha'_2 = \frac{\alpha_2}{\sigma}$, $\alpha'_3 = \frac{\alpha_3}{\sigma}$, $\alpha_1 = -\alpha$, $\alpha_2 = -\alpha + 1$, and $\alpha_3 = -\alpha + 2$.

The integration of the PG&E's MAVF scaling function over $h(r)$ is

$$(6) \quad I = 10 \left(\frac{C}{\alpha'_1}\right) \left\{ [r\xi(r)^{\alpha_1}]_{0^*}^{0.01^{**}} - \left(\frac{1}{\alpha'_2}\right) [\xi(r)^{\alpha_2}]_{0^*}^{0.01^{**}} \right\} \\ + 0.049\bar{4} \left(\frac{C}{\alpha'_1}\right) [\xi(r)^{\alpha_1}]_{0.01^*}^{0.1^{**}}$$

$$\begin{aligned}
& +0.1 \bar{1} \left(\frac{C}{\alpha'_1} \right) \left\{ [r\xi(r)^{\alpha_1}]_{0.01^*}^{0.1^{**}} - \left(\frac{1}{\alpha'_2} \right) [\xi(r)^{\alpha_2}]_{0.01^*}^{0.1^{**}} \right\} \\
& +494.4 \bar{4} \left\{ C \left(\frac{1}{\alpha'_1} \right) [r^2 \xi(r)^{\alpha_1}]_{0.01^*}^{0.1^{**}} \right. \\
& \quad -2C \left(\frac{1}{\alpha'_1} \right) \left(\frac{1}{\alpha'_2} \right) [r\xi(r)^{\alpha_2}]_{0.01^*}^{0.1^{**}} \\
& \quad \left. +2C \left(\frac{1}{\alpha'_1} \right) \left(\frac{1}{\alpha'_2} \right) \left(\frac{1}{\alpha'_3} \right) [\xi(r)^{\alpha_3}]_{0.01^*}^{0.1^{**}} \right\} \\
& -5.5 \bar{5} \left(\frac{C}{\alpha'_1} \right) [\xi(r)^{\alpha_1}]_{0.1^*}^{+\infty^{**}} \\
& +105.5 \bar{5} \left(\frac{C}{\alpha'_1} \right) \left\{ [r\xi(r)^{\alpha_1}]_{0.1^*}^{+\infty^{**}} - \left(\frac{1}{\alpha'_2} \right) [\xi(r)^{\alpha_2}]_{0.1^*}^{+\infty^{**}} \right\}.
\end{aligned}$$

4.1.2.2. Monte Carlo Simulation

ERM performs Monte Carlo Simulation to get trial CoRE values for an Outcome if:

1. The closed-form solution is not available for the consequence distribution specified
2. The consequence is defined as the sum or product of two distributions (e.g., Rtlognormal multiplied by Normal) (see Section 3.6.6 for list of operators).

The Attribute CoRE for tranche tr, outcome o, and attribute a is calculated as follows:

$$\text{Attribute } CoRE_{tr,o,a} = \frac{1}{\# \text{ trials}} \times \sum_{n=1}^{\# \text{ trials}} \text{Trial } CoRE_{tr,o,a,n}$$

Where:

$$\text{Trial } CoRE_{tr,o,a,n} = \text{scaler} \times w_a \times p_{tr,o,a}^{\max} \times f \left(\sum_{m=1}^{\# \text{ dists}} I_{n,m,a,tr,o} \times NU_{n,m,a,tr,o} \right)$$

$NU_{n,m,a,tr,o}$ is Natural Unit simulated in trial n for distribution m of attribute a of outcome o for tranche tr, conditional on distribution m of attribute a materializes given risk event.

$I_{n,m,a,tr,o}$ is Bernoulli variate based on conditional sampling probability for distribution m simulated in trial n of attribute a of outcome o for tranche tr. $I_{n,m,a,tr,o}$ is only applicable when there are multiple distributions needed to characterize the given attribute.

$f(\cdot)$ is the scaling function for converting natural units into scaled unit (see Section 1.2.5).

$p_{tr,o,a}^{max}$ is the maximum sampling probability across distributions for attribute a of outcome o for tranche tr (explanation below)

w_a is the MAVF weight of attribute a.

scaler is an MAVF scaler of 1,000.

If an attribute has more than one distribution and not all the distribution (or sampling) probabilities are the same, the distribution's sampling probability conditional on at least one of the distributions occurs is obtained as its sampling probability divided by the largest sampling probability of all distributions. The distribution's conditional sampling probability is used to simulate Bernoulli random variates to determine whether the part of consequence following that distribution occurs given the consequence materializes.

$$p_{tr,o,a}^{max} = \text{Max}\{p_{1,a,tr,o}, \dots, p_{M,a,tr,o}\}$$

$$P_{m,a,tr,o}^{cond} = \frac{p_{m,a,tr,o}}{p_{tr,o,a}^{max}}, \quad \forall m = 1, \dots, M$$

Where:

M is the number of distributions that characterize consequence of a given tranche, outcome and attribute.

$p_{m,a,tr,o}$ is the sampling probability of the m th distribution for the given tranche, outcome and attribute.

$p_{tr,o,a}^{max}$ is the maximum sampling probability across all $p_{m,a,tr,o}$, with $m = 1 \dots M$.

Regardless of which of the two methods used to obtain the Attribute CoRE, the overall Tranche-Outcome CoRE is the weighted sum of Scaled Units of four Attributes (Safety, Financial, Electric Reliability, Gas Reliability), multiplied by 1,000. The Scaled Unit of each Attribute varies is the output of applying the MAVF's Range and Scaling Function to the Attribute Levels.

$$CORE_{tr,o} = \sum_a CORE_{tr,o,a}$$

For an example of this calculation, see Section 2.1.3

4.1.3. Baseline Risk Score Formula

Risk Score by Tranche and Outcome is calculated as the product of Exposure, Likelihood of Risk Event (LoRE) and Consequence of Risk Event (CoRE), and can be expressed formulaically as follows:

$$Risk\ Score_{tr,o} = Exposure_{tr} \times LoRE_{tr,o} \times CoRE_{tr,o} = Frequency_{tr,o} \times CoRE_{tr,o}$$

Where:

Risk Score by Tranche, Sub-Driver and Outcome is proportioned by the frequency as follows:

$$Risk\ Score_{tr,d,o} = Risk\ Score_{tr,o} \times \frac{LoRE_{tr,d,o}}{LoRE_{tr,o}}$$

Total Risk Score is the sum of the Risk Scores over all tranches and outcomes

$$Risk\ Score = \sum_{tr,o} Risk\ Score_{tr,o}$$

4.2. Mitigation Analysis

The risk score for the Mitigated/Inherent case is obtained by applying control/mitigation effectiveness to specified sub-driver-outcome-tranche frequencies or outcome-tranche-Attribute simulated natural unit values.

- 1) For mitigated risk scores:
 - a) Apply mitigation effectiveness to specified sub-driver-outcome-tranche frequencies or outcome-tranche simulated natural unit values.
 - b) Recalculate Risk Score given mitigated exposure for each year.
 - c) Compute risk reduction allocation factor.
- 2) Compute program cost NPV.
- 3) Compute risk reduction NPV.
- 4) Compute RSE.

These program related inputs are defined in Tabs *8-Program*, *9-ProgramExposureSpend*, *10-ProgramFreqEff*, and *11-ProgramConseqEff* in the Risk Model Input File.

The following sections include numerical examples as to how these calculations are performed.

For a simple example of these calculations, see Section 2.1.5.

4.2.1. Portfolio-level Analysis

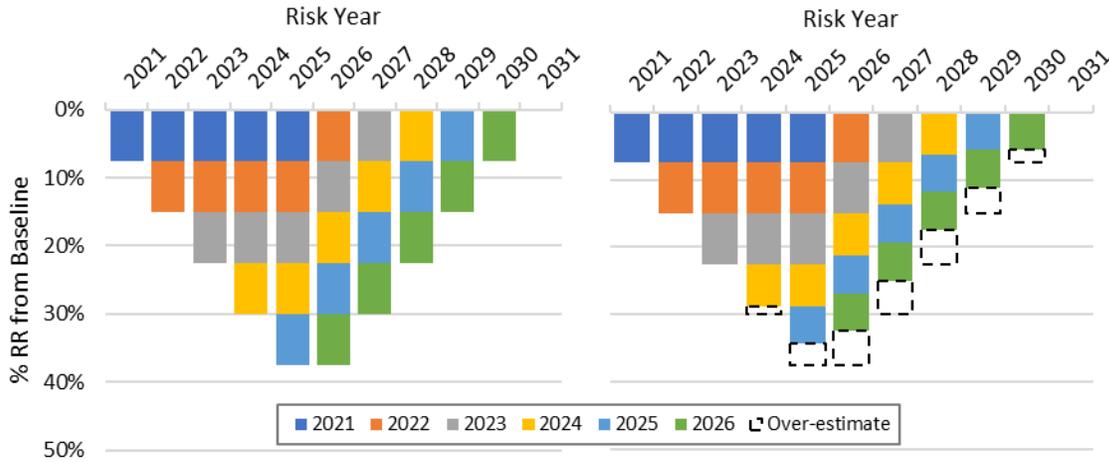
As mentioned in Section 1.3.5.3, the Enterprise Risk Model (ERM) computes risk reduction given mitigation programs for the purposes of calculating the TY Baseline Risk Score. The TY Baseline Risk Score is used to determine potential risk reduction from proposed mitigations, a calculation undertaken by the RSE Lite Tool. Given the different primary use cases, the methodology to calculate risk reduction is different in the ERM than in the RSE Lite Tool. ERM assesses risk reduction from a portfolio, or set, of mitigation programs, to compute the TY Baseline Risk Score (as well as the Post-Mitigation Risk Score in 2026). ERM allocates portfolio-level risk reduction to individual mitigations to compute RSEs, though those RSEs reflect the full lifetime of a program (not limited to 2023-2026) and are computed against the Baseline Risk Score. The RSE Lite Tool assesses risk reduction relative to the TY Baseline Risk Score for each mitigation independently.

While a more complex calculation (detailed in the section below), computing portfolio risk reduction when estimating TY Baseline Risk Scores addresses two areas where risk reduction may be overestimated if the interactions between mitigations are not considered. When evaluating proposed programs, In ERM, portfolio risk reduction considers interactions two ways:

1. Scope overlap within a program: this may happen if a program revisits exposure within its scope of work which is still receiving benefit from the previous set of work. The figure below shows the Risk Reduction (RR) of a program which is 25% effective at reducing event frequency over 30% of risk exposure, so, the percent RR from Baseline is $30\% * 25\% = 7.5\%$. The benefits of the program last for 5 years, so, work done in 2021 offers benefits until 2025. Work is executed in 2021-2026, with each year represented by a series in the figure. Given the scope of the program, 30% of exposure per year, by the fourth year of execution (2024) the program revisits exposure from year one (2021). Since program benefits last 5 years, risk reduction from 2021 remains in 2024. The overall effectiveness of work done in 2024 is less than that of 2021 because work in 2024 only mitigates the remaining fraction of risk. The chart on the left illustrates % RR from Baseline if the work was 7.5% effective over all work efforts, an over-estimate, while the right-hand chart illustrates the interaction of the program

over the same risk exposure; the only series that are affected are 2025 and 2026.

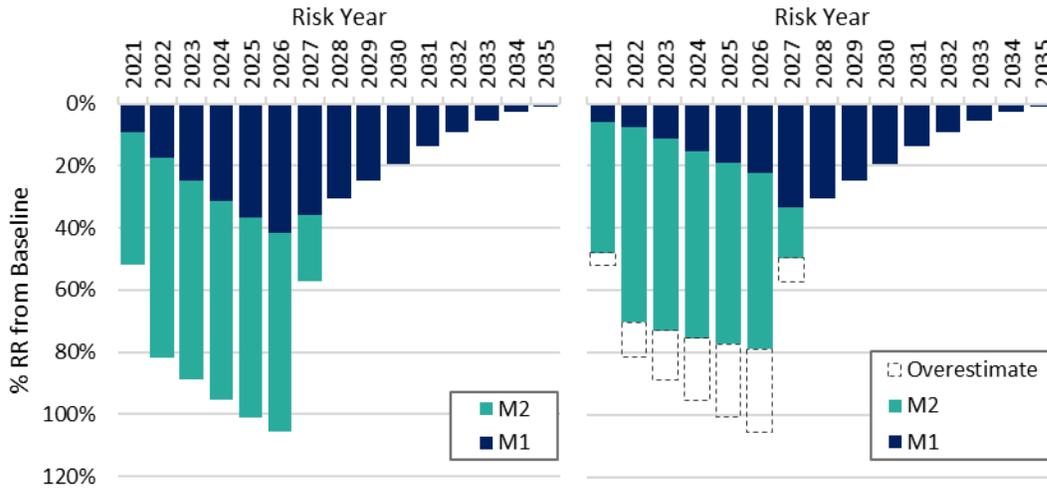
**FIGURE 4-1
SINGLE MITIGATION PROGRAM WITH SCOPE OVERLAP**



2. Scope overlap between programs: this may happen when the same unit of exposure is affected by multiple mitigations in a year. The figure below shows the % RR from Baseline for two highly effective programs:
 - a. M1 is 92% effective at reducing event frequency over 10% of the risk exposure, benefits last 10 years but degrade annually.
 - b. M2 is 95% effective at reducing event frequency over 45% of the risk exposure, benefits last 2 years but degrade annually.

If the risk reduction from these two programs are added, the risk reduction exceeds 100% by 2025 (shown in the left-hand chart below). If the marginal contribution of M1 and M2 to overall risk reduction is considered instead, risk reduction cannot exceed 100%; peak risk reduction is 79% in 2026.

**FIGURE 4-2
TWO MITIGATION PROGRAMS WITH SCOPE OVERAP**



The ERM reflects both potential types of overlap when determining portfolio-level risk reduction via an Overall Effectiveness Calculation.

4.2.1.1. Overall Effectiveness

There are two overall effectiveness calculations: Overall Effectiveness on Frequency and Overall Effectiveness on Consequence.

Overall Effectiveness on Frequency:

Overall Mitigation Factor by Tranche, Sub-Driver and Outcome is the percentage risk remaining after all mitigation programs are implemented.

$$\text{Overall Mitigation Factor}_{tr,d,o} = 1 - \text{Overall Effectiveness Factor}_{tr,d,o}$$

Where the Overall Effectiveness Factor is the overall percentage reduction of frequency due to all mitigation programs (subscript m) proposed.

$$\begin{aligned} \text{Overall Effectiveness Factor}_{tr,d,o} &= 1 - \prod_m \text{Mitigation Factor}_{tr,d,o,m} \\ &= 1 - \prod_m (1 - \text{Effectiveness Factor}_{tr,d,o,m}) \end{aligned}$$

Mitigation Factor_{tr,d,o,m} is the percentage remaining risk post mitigation program m, which is one minus the percentage risk reduction due to program m, Effectiveness Factor_{tr,d,o,m}, as derived below:

$$\text{Effectiveness Factor}_{tr,d,o,m} = \text{Scope}_{tr,m} \times \text{Effectiveness}_{tr,d,o,m}$$

$Scope_{tr,m}$ is the percentage exposure of tranche tr to mitigation program m.

$Effectiveness_{tr,d,o,m}$ is the percentage reduction of frequency for applicable scope from mitigation program m.

From the #1. Scope overlap within a program, above, the overall effectiveness of work in 2024 is $10\% * 25\% + 20\% * 25\% * (1 - 25\%) = 6.25\%$, where 20% is the exposure overlapped and $(1-25\%)$ represents the risk remaining after that first pass. Overall effectiveness of work in 2025 is $30\% * 25\% * (1-25\%) = 5.63\%$. If this program were applied over the same risk exposure as another program, effectiveness values of 6.25% and 5.63% would be used as the program effectiveness in years 2024 and 2025 when calculating the Overall Effectiveness Factor for the portfolio.

From the #2. Scope overlap between programs, the allocation of risk reduction attributable to each mitigation is done based on the marginal effectiveness of each mitigation to the portfolio of mitigations for a given Tranche, Outcome, and Sub-Driver/Attribute. Assuming both affect the same Tranche, Outcome, and Sub-Driver/Attribute, the calculations are as follows:

- Overall program effectiveness for the Tranche-Outcome-Sub-Driver/Attribute is 99.60 percent ($= 1 - (1 - 0.92) \times (1 - 0.95)$).
- If we remove M1 from the portfolio, then the overall effectiveness is 95 percent (from M2). Thus, marginal effectiveness of M1 is 4.6% percent ($= 99.6\% - 95\%$).
- If we remove M2 from the portfolio, then the overall effectiveness is 92 percent (from M1). Thus, marginal effectiveness of M2 is 7.6 percent ($= 99.6\% - 92\%$).
- Risk Reduction Allocation factor for M1 is set to $4.6\% / (4.6\% + 7.6\%) = 37.7\%$
- Risk Reduction Allocation factor for M2 is set to $7.6\% / (4.6\% + 7.6\%) = 62.3\%$

After the risk reduction attributable to consequence reduction and attributable to frequency reduction have been allocated to each program, the risk reduction can be aggregated at the mitigation program level. Mitigation program risk reduction allocation is calculated at the yearly level for each tranche in the Model.

Overall Effectiveness on Consequence:

The formulas for the overall mitigation factor for Attribute a are developed by simply replacing the subscript d with a.

Caveats

There are several important caveats to the current implementation of the Portfolio Mitigation Effectiveness calculations and Risk Reduction Allocation currently implemented in ERM:

- The model assumes that all programs which affect risk exposure for the same Tranche-Sub-Driver-Outcome/Attribute will overlap. This will lead to underestimated risk reduction in cases where programs target non-overlapping fractions of the total exposure in that tranche by design.
- When programs with significantly different effectiveness values are part of the portfolio, the allocation methodology weights the highly effective programs such that effectiveness is adjusted to a lesser degree. For example, if one program is 60% effective and the other 30% (Overall Effectiveness of 0.72), 78% of the risk reduction is the 60% effective program, 22% the 30% effective program.

4.2.2. Test Year Baseline Risk Scores

The nature of the Baseline and TY Baseline Risk Scores are discussed in Section 1.3.5. The Test Year Baseline risk score is the product of the Test Year Baseline Frequency and Test Year Baseline CoRE over the set of modeled years.

4.2.2.1. Test Year Baseline Frequency

The Test Year Baseline Frequency is the product of the Baseline frequency and the overall mitigation effectiveness factor for all Frequency mitigation programs implemented before the Test Year.

4.2.2.2. Test Year Baseline CoRE

The Test Year Baseline CoRE is the product of the Baseline CoRE and the overall mitigation effectiveness factor for all Consequence mitigation programs implemented before the Test Year.

4.2.1. Risk Reduction Scores

Total Risk Reduction is the reduction in the overall Risk Score due to the mitigation programs over the full period the program is active (starting as early as 2021 and going through potentially 2026, given the PG&E's upcoming GRC timeframe). The two possible formulations are follows, with the first applying to a mitigation portfolio and the second to a control portfolio:

$$\begin{aligned} \textit{Total Risk Reduction} &= \textit{Baseline Risk Score} - \textit{Mitigated Risk Score} \\ \textit{Total Risk Reduction} &= \textit{Inherent Risk Score} - \textit{Baseline Risk Score} \end{aligned}$$

Baseline Risk Score is the pre-mitigation risk score.

Mitigated Risk Score is the post-mitigation risk score.

The above expression is also applicable at specific tranche and outcome levels.

4.2.2. Mitigated Risk Scores⁵⁹

Mitigation programs which act to reduce the Frequency but have no impact on CoRE are simply a function of the difference in the Baseline and Mitigated Risk Scores in LoRE and hence Frequency.

$$\begin{aligned} \text{Baseline Risk Score}_{tr,d,o} &= \text{Exposure}_{tr} \times \text{Baseline LoRE}_{tr,d,o} \times \text{Baseline CoRE}_{tr,o} \\ &= \text{Baseline Frequency}_{tr,d,o} \times \text{Baseline CoRE}_{tr,o} \end{aligned}$$

$$\begin{aligned} \text{Mitigated Risk Score}_{tr,d,o} &= \text{Exposure}_{tr} \times \text{Mitigated LoRE}_{tr,d,o} \times \text{Mitigated CoRE}_{tr,o} \\ &= \text{Mitigated Frequency}_{tr,d,o} \times \text{Mitigated CoRE}_{tr,o} \end{aligned}$$

The mitigated LoRE for a specific tranche, sub-driver and outcome combination is expressed as follows:

$$\text{Mitigated LoRE}_{tr,d,o} = \text{Baseline LoRE}_{tr,d,o} \times \text{Overall Mitigation Factor}_{tr,d,o}$$

The mitigated CoRE for a specific tranche, sub-driver and outcome is expressed as follows:⁶⁰

$$\text{Mitigated Trial CoRE}_{tr,o,a,n} = \text{Scaler} \times w_a \times f(\text{Overall Mit Factor}_{a,tr,o} \times NU_{n,a,tr,o})$$

The Mitigated Trial CoRE is used to compute the Mitigated CoRE as follows:

$$\text{Mitigated CoRE}_{tr,o} = \sum_a \frac{1}{\# \text{ trials}} \sum_{n=1}^{\# \text{ trials}} \text{Mitigated Trial CoRE}_{tr,o,a,n}$$

⁵⁹ Mitigated Risk Scores mean the post-Mitigation Risk Scores.

⁶⁰ This formula assumed the case where the sampling probability equal to one and there is one distribution specified for tranche-outcome-attribute. Otherwise, the same adjustments are made in the formula similarly as described in Section 4.2.