Network Asset Criticality Framework

CONTROLLED DOCUMENT

Summary					
The Network Asset Criticality Framework outlines the manner in which consequences associated with network asset failures are assessed and quantified.					
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1. Purpose

The purpose of the Network Asset Criticality Framework is to outline the manner in which consequences for network asset failures are consistently assessed and quantified across the business. This document supports:

- Prudent risk based investment decision making
- Achievement of the asset management objectives.

2. Scope

The scope of the Network Asset Criticality Framework (NACF) is network assets including:

- Substation assets
- Transmission line and cable assets
- Digital infrastructure assets.

The NACF provides details to support the principles set out in the Network Asset Risk Assessment Methodology.

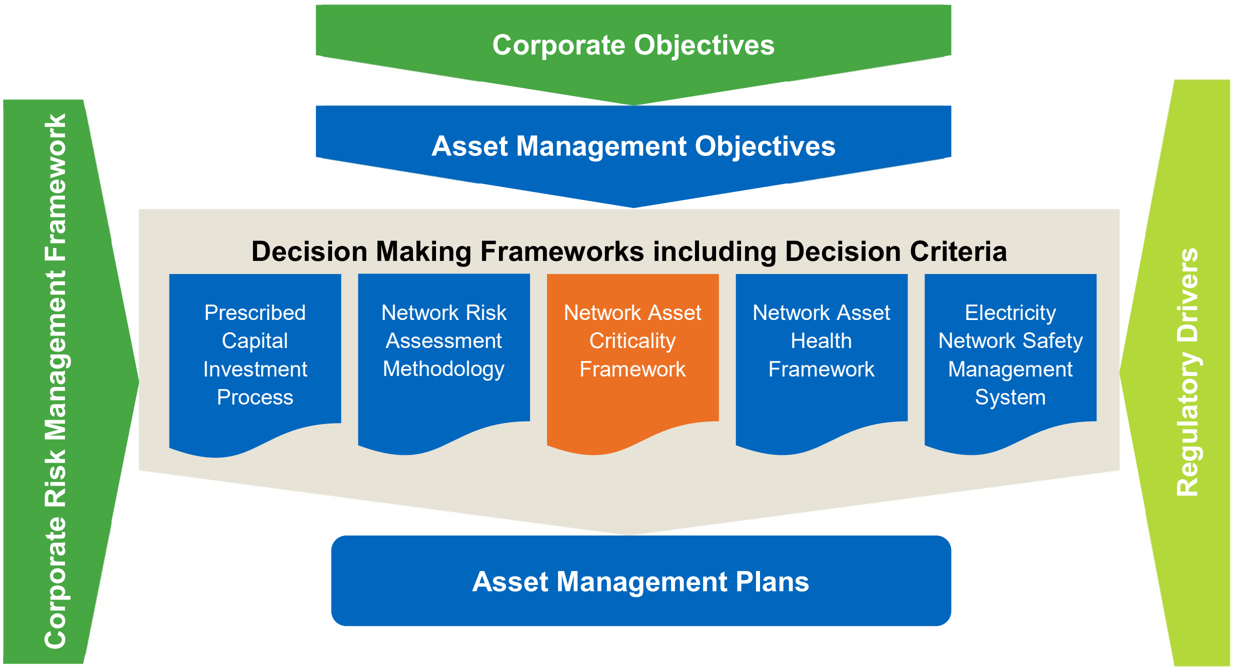
3. Definitions

Term	Definition
Consequence of Failure (CoF)	The consequence that could eventuate due to the failure of an asset. The consequence is moderated by the Likelihood of Consequence (LOC) to determine the Risk Consequence.
Failure Mode	The way in which an asset failure occurs e.g. conductor drop, tap changer failure, protection relay failure.
Hazardous Event / Threat	An event that poses a potential threat to cause harm or damage to the assets, property, the environment, our workforce, the general public and/or the viability of the business.
Likelihood of Consequence (LoC)	The likelihood that the full value of the consequence event eventuates given the hazardous event has actually occurred. The Likelihood of Consequence is based on the credible consequence used for Consequence of Failure (CoF) after mitigating controls are in place.
Probability of Failure (PoF)	Annual probability of failure occurring.
Risk Assessment	A systematic process of risk analysis and evaluation.
Risk Consequence	The outcome of an event expressed qualitatively or quantitatively, affecting Transgrid's objectives. There may be a range of possible outcomes associated with an event; these could have a positive or negative impact on objectives. The outcomes are categorised as environmental (including bushfire), reputational, safety (worker and public), compliance, and financial.

4. Background

This document (Network Asset Criticality Framework), along with Network Asset Health Framework (NAHF), support the Network Asset Risk Management Framework. Figure 1 shows the overall framework of documents related to risk based decision making and the position of the NACF.

Figure 1 – Decision Framework and Criteria



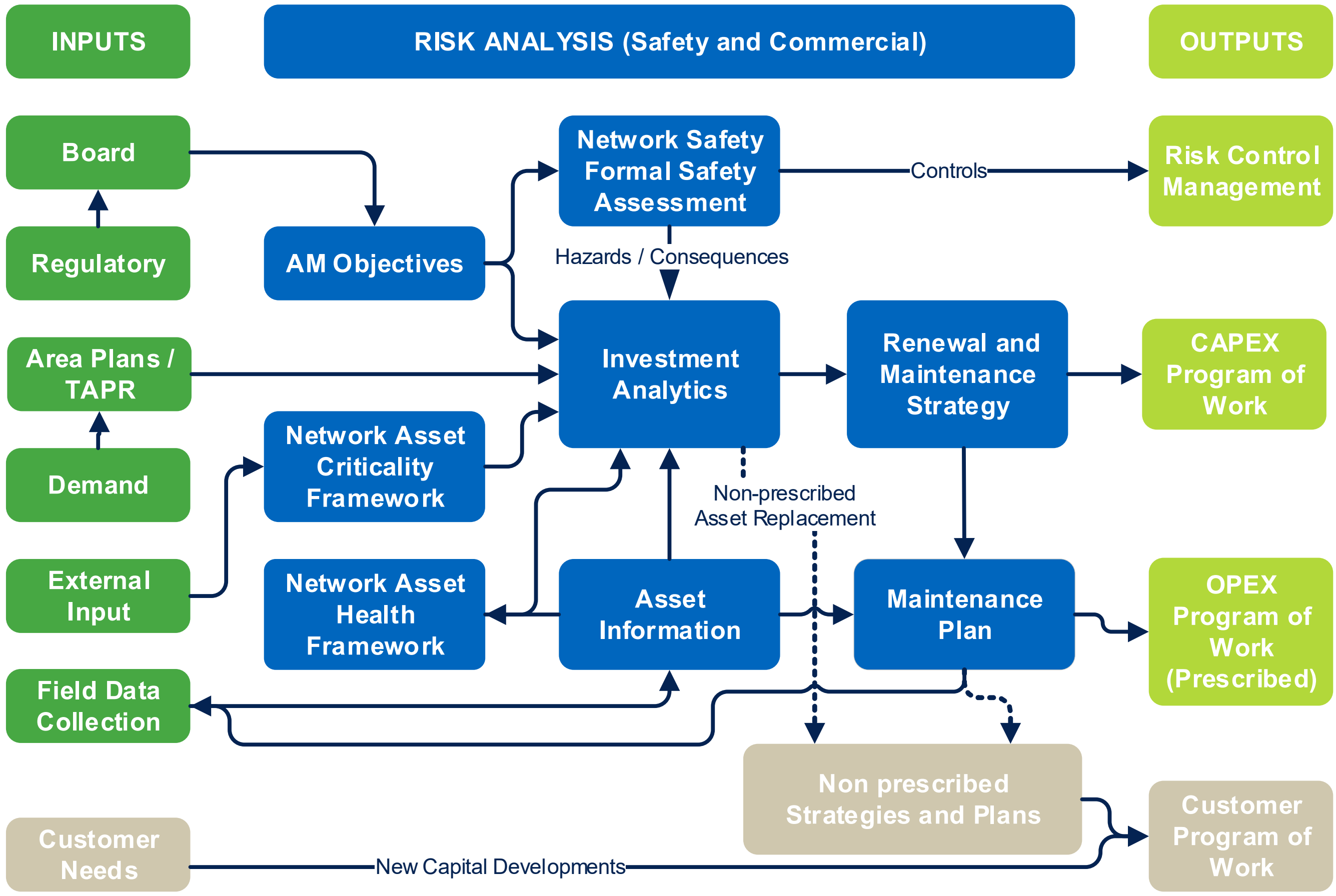
5. Framework

The NACF defines the principles and criteria for determining the criticality of network assets based on insights derived from detailed technical analysis of asset data and information gathered from the field. The NACF details the expected risk consequence in monetary terms of network asset failures.

The outcomes from the NACF are used to support risk assessments completed at all stages of the asset lifecycle.

The location of the NACF within the Network Risk Assessment Framework is shown Figure 2.

Figure 2 – Risk Quantification Process



Asset criticality is the relative risk of the consequences of an undesired outcome. Asset criticality considers the severity of the consequences of the asset failure occurring and the likelihood the consequence will eventuate. The analysis leverages data from past events, relevant research/publications and technical insights, to determine an economic value of the impact. Asset Criticality is used as an input to the consequence input to the risk assessment.

The analysis of the severity of the consequence assigns an economic value to the likely worst case impact in respect of the areas of consequence the organisation is concerned about, including safety, environment, network reliability and financial. The analysis of the likelihood of the consequence is used to determine the probability of the impact eventuating for the safety, environment, and system impact areas of consequence. This is to account for the fact that the combination of and economic value of consequences varies with and is dependent on the nature of the undesired outcome.

5.1. Corporate Risk Framework Consequence Areas

Below is a description of the scope of each of the broad areas of consequence as defined by the corporate Risk Management Framework (RMF):

- **Health and Safety**

  This refers to the safety consequence to staff, contractors and/or members of the public of an asset failure. The monetary value takes into account the cost associated with damage to the environment including compensation associated with loss assets including property and land use productivity, any associated loss of life, clean-up costs, litigation fees, fines and any other related costs.

- **Environment**

  This refers to the environmental consequence (including bushfire risk) to the surrounding community, ecology, flora and fauna of an asset failure. The monetary value takes into account the cost associated with damage to the environment including compensation, clean-up costs, litigation fees, fines and any other related costs.

- **Network Reliability**

  This refers to the system reliability and security consequence to the network of an asset failure. The monetary value takes into account the amount of load at risk and duration of loss of supply (MWh) due to the failure and any subsequent actions, and a value per MWh of lost load for the customer type. The value per MWh of lost load is dependent on the economic impact to customers, and also takes into consideration the safety implications of the loss of supply, including those associated with the loss of supply to critical services such as hospitals and other essential infrastructure (traffic lights, communications, water, etc.).

- **Financial Performance**

  This refers to the financial consequence of an asset failure. The monetary value takes into account the cost associated with the financial impact not covered in any of the other areas of consequence such as disruption to business operations, any third party liability, and the cost of replacement or repair of the asset, including any temporary measures. The financial consequence includes the market impact, which considers the monetary impact associated with generator/interconnector constraints due to an asset failure.

- **Compliance**

  This refers to the regulatory/legislative (jurisdictional, federal and market) compliance (or non-compliance more specifically) consequence of an asset failure. The monetary value takes into account the cost associated with non-compliance including litigation fees, fines, the cost necessary to achieve compliance, and any other related costs.

- **Social Licence**

  This refers to the reputational consequence of an asset failure. The monetary value takes into account the cost associated with liaison and engagement with media, the community and other stakeholders.

- **People**

  This refers to the business consequence of an asset failure. Disruption and impact which restricts the Transgrid business from operating effectively.

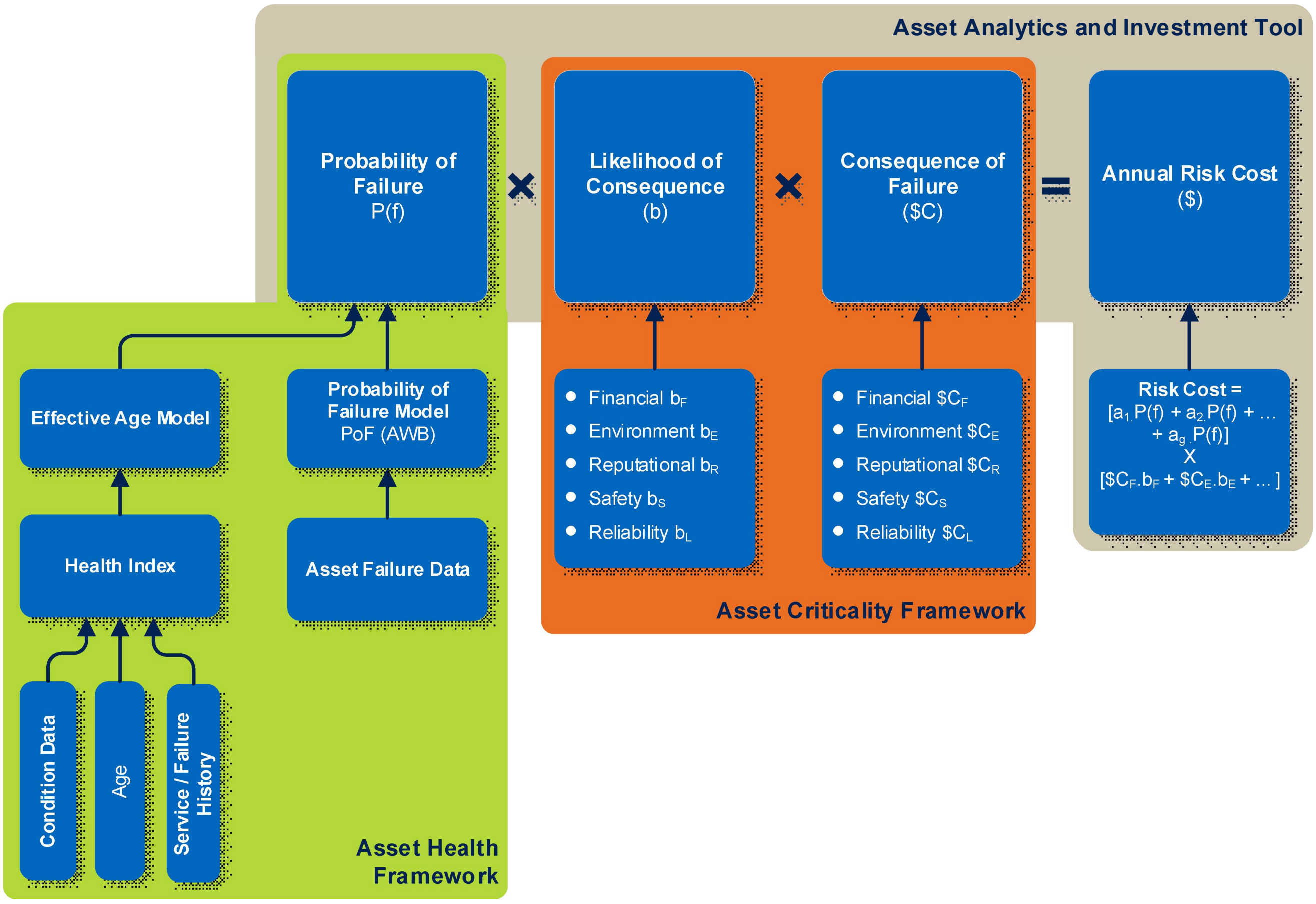
6. Process

6.1. Criticality Calculation

The key elements of the NACF are:

- A definition of the applicable areas of criticality for each asset type
- Consistent quantification values for asset failure consequences based on the asset or site level as appropriate
- Where necessary, a likelihood based on the range of possible consequences occurring
- Detailed information regarding the methodology and values used for consequences are listed in Appendix A.

Figure 3 – Illustrates a generic high level view of the Criticality Module



6.2. Risk Criticality Factors

The following factors are considered when determining the likelihood of a consequence occurring:

- For safety (worker) consequences:
  - Frequency of workers at site or structure
  - Duration of maintenance tasks at site or structure
  - Duration of capital works at site
  - Probability that the equipment will fail, and fail explosively
  - The area of effect of the explosive failure.
- For safety (public) consequences:
  - Frequency of person in near vicinity (on an annual basis as a percentage of time)
  - Effectiveness of preventative controls
  - Vicinity of a substation asset to publically accessible area.
  - The area of effect of the explosive failure.
- For environment consequences:
  - Location of site, structure or line route and the sensitivity of the area around the site
  - Volume of contaminant
  - Type of contaminant
  - Effectiveness of control mechanisms
  - For bushfire consequences the bushfire proneness of the land, the likelihood of a flashover causing a major bushfire event, and the extent of asset damage based on land use and associated potential loss of life based on the burn area of the bushfire event
  - Mass of SF6 contained in the equipment.
- For reliability consequences:
  - Anticipated load restoration time
  - Demand probability
  - Contingent unplanned outage likelihood
  - Contingent planned outage likelihood.
- For financial (market) consequences:
  - Effect on National Electricity Market (NEM) pool prices for consumers.
- For financial (other) consequences:
  - Compliance and regulatory consequences
    - Potential licence breach
    - Effects on financing or capital
    - Penalties

Table 1 maps the RMF consequence areas to the NACF area of criticality.

Table 1 – NACF consequence mapping to corporate risk framework

NACF - Area of Criticality	RMF Consequences						
	Health and Safety	Environment	Social Licence	Compliance	Network Reliability	Financial Performance	People
Safety (Worker)	✓						
Safety (Public)	✓						
Environment		✓					
Reliability					✓		
Financial (Market)						✓	
Financial (Other)				✓		✓	
Reputation			✓				

Bushfire is specifically identified in the Corporate Strategic Risk Register. By its nature, bushfire consequences includes work, health and safety, environment and financial. The NACF considers bushfire risk consequence based on:

- Safety impact on community
- Financial impact to the community through property loss.

For consistency with the RMF, these are mapped to the Environment consequence of RMF as the primary bushfire effect is Environmental.

The People consequence in the Risk Management Framework refers to disruptions to business continuity and Transgrid's ability to operate as a business. These are not directly asset related and so are not explicitly costed in the Criticality Framework.

7. Accountability

Role	Responsibilities and Accountabilities
Executive Manager Network Planning and Operations	• Implement the controls to manage asset risks in accordance with the corporate Risk Management Framework and Network Asset Risk Assessment Methodology • Oversight of the processes for the identification and management of asset risks, including the Network Asset Risk Assessment Methodology and Prescribed Capital Investment Procedure
Asset Management Committee	• Review and endorse the Network Asset Criticality Framework
Head of Asset Management	• Approve and ensure the Network Asset Criticality Framework is fit for purpose • Ensure consistent, effective and efficient implementation of the Network Asset Criticality Framework • Monitor the development of Need Statements and investment options
Asset Analytics and Insights Manager	• Maintain the Asset Analytics and Investment Tool to allow risk assessments with consequence values consistent with those defined in this document

	• Develop and refine the Network Asset Criticality Framework
Asset Managers	• Identify key asset hazardous events and risks • Apply the Network Asset Risk Management Framework to assess and evaluate asset risk • Develop Need Statements • Develop and evaluate investment options to address the asset risks

8. Implementation

The NACF will be implemented through:

- Discussions with business managers during the various asset management committee and working group meetings
- Development of Needs Statements and Option Evaluation Reports (OERs) including risk assessments consistent with this framework
- Consideration, analysis and evaluation of investment options through the Network Investment Process
- Development of the asset management strategies and plans
- Prioritisation and optimisation of capital expenditure at a portfolio level
- Calculations within the Asset Analytics and Investment Tool.

9. Monitoring and review

The NACF is reviewed by the Asset Management Committee three yearly or when material updates are performed.

Asset criticality is monitored and reviewed by the relevant Asset Manager in response to an emerging issue, incident, or improved methodology, or three yearly if no review has occurred.

10. Changes from previous version

Revision no.	Approved by	Amendment
0	Gerard Reiter, EGM/Asset Management	
1	Lance Wee, M/Asset Strategy	Issued 2016
2	Lance Wee, Head of Asset Management	Issued 2017
3	Andrew McAlpine, A / Head of Asset Management	Major rewrite of document to update criticality models. New format.

11. References

- Corporate Risk Management Framework
- Prescribed Network Capital Investment Process
- Network Asset Strategy
- Network Asset Health Framework
- Network Asset Risk Assessment Methodology

Appendix A Consequence Determination

A.1 Safety (Worker) Consequence

The following section describes the methodology used in determining Safety (Worker) consequence dollars for Substation and Digital Infrastructure assets.

It results in a dollar per event ($/event) consequence value based on an assessment of the likelihood of people being in the vicinity when the hazardous event occurs. A standard consequence values for a fatality/injury is used in the calculation.

Transformer, Reactive Plant and Substation Switchbay Equipment

The Safety (Worker) Consequence for transformer, reactive plant and substation switchbay equipment was determined by using an average of all Transgrid hours worked within each substation, based on a five year extract from Ellipse. This accounts for internal capital work, routine maintenance, breakdown, condition based maintenance and any other works (such as switching). From this average figure, the probability of a worker being on site can be determined. External contractor hours are not included in this calculation.

Background / Historical Failures

Within the last 10 years, asset failures within the Transgrid network have resulted in debris ranging from 45m to over 100m away from the failed asset. Publicly available documentation from transmission and distribution companies indicate that a 50m radius from the point of failure is a commonly adopted area of effect. Where debris has been found, the vast majority is found within 35m of the point of explosion (approximately 90%), and of the remaining debris, most is found within 50m. This aligns with Transgrid's experience.

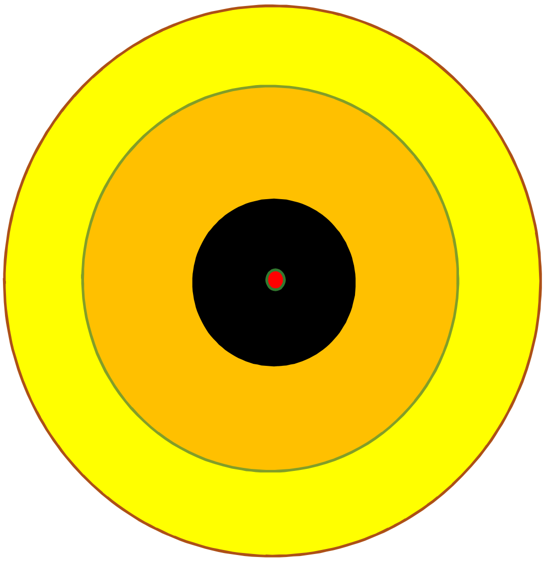
The probability of being injured is directly related to how close a person is to the point of the explosion. Transgrid has used a selection of zones around the equipment, assigning both a probability of being injured, and the probability on the types of injury within that zone.

Areas of Effect

The impact area is modelled as three zones as shown in Figure 4.

- Zone 1 is in black, and is 0-15m from the point of explosion. In this area, there will be an expanding ball of heat and compressed air, as well as flying debris. Injury is certain and fatality is the likely outcome.
- Zone 2, shown in orange, is from 15-35m. In this zone the heat and compressed air has dispersed sufficiently that the predominant injury mechanism will be through flying debris. Injury is not certain, and the most likely injuries are moderate in nature. Fatalities and major injuries are still considered probable.
- Zone 3, shown in yellow, is from 35-50m. Again, the predominant injury mechanism is through flying debris. Moderate injuries are considered more likely than in Zone 2.

Figure 4 - Zones of effect for an explosive failure



Probability of Injury

The range of injuries which may eventuate have been estimated for each of the impact zones as shown in Table 2

Table 2 – Probability of type of injury by zone

Injury distribution by area	Probability of type of injury (%)		
	Black Zone	Orange Zone	Yellow Zone
Fatality	97	20	10
Major	2	25	20
Moderate	1	45	50
Minor	0	10	20

Using a weighted average of the respective areas, this leads to an overall probability of types of injuries as shown in Table 3.

Table 3 – Average Probabilities of Different Injury Types

Injury Type	Average Probabilities (%) (weighted by respective area of each zone)
Fatality	22
Major	20
Moderate	45
Minor	14

For any given asset, the area of effect within the switchyard is determined by how close the asset is to the fence. Using the values from Appendix B.9, which puts a monetary value on the different injury types, a weighted calculation based on the total area of effect within switchyard, as well as the areas of the three zones is used to determine the risk cost per asset.

Risk of Injury

Assuming a person is somewhere in the modelled area of the failed device, the chances of being injured are as shown in Table 4.

Table 4 – Probability of Injury based on Zone

Injury Area	Probability of Injury (%)
Black Zone	100
Orange Zone	30
Yellow Zone	15
Weighted Average	29

With the exception of the black zone, where probability of injury is guaranteed (due to the nature of the failure), the probability of being hit in the outer zones is calculated as follows:

- Assumption of 50 fragments with sufficient energy to cause injury.
- A person's torso is assumed to be 40cm wide.
- A fragment does not need be a 'direct' hit to cause injury, in that a fragment has a width, and a person's arms could be the point of impact. The distribution of outcomes is considered as set out in Table 1.

Based on the circumference of each ring, and using 50 projectiles, you get a probability of being hit of:

- 50 x width of person x 2 / circumference.

This gives a probability at each boundary and the average probability is taken for the zone. Thus at 15m, the probability is 42%, and at 35m it is 18%, with the average for the 'orange zone' of 30.3%.

The method of averaging consequences across the impact area is expected to result in a misallocation in the safety risk calculation if the public occupancy is different to the internal switchyard occupancy (since the higher consequence areas are always internal to the switchyard, but the consequence is averaged over the full area). This is expected in most cases, assuming the internal occupancy rate is higher than the external occupancy. In order to increase the accuracy between the public and worker safety risk values, the ratio of the internal impact area to the external impact area will be used to moderate the consequence values accordingly.

Digital Infrastructure

The Safety (Worker) Consequence for Digital Infrastructure equipment was determined through the inheritance of associated primary plant consequences as listed above.

Protection Equipment

The Safety (Worker) Consequence further applies the statistical expected probability of several parameters to determine the likelihood of an incident occurring. Available data is utilised for all Transgrid protected assets, with an average taken and applied to third party protected assets where applicable such as for protection equipment. This is applied by the following equation:

$$\text{Safety (Worker) Consequence \$/event} = Primary\ Plant\ Safety(Worker) Consequence\ \frac{\$}{event} \times Primary\ Plant\ Fault\ Rate \times Watchdog\ Failure \times Duplicated\ System\ Failure$$

Where:

- $Primary\ Plant\ Safety(Worker)Consequence\ \$/event$ is direct allocation of consequence calculated from the protected primary plant
- $Primary\ Plant\ Fault\ Rate$ is the average of faults associated with the type of plant protected per annum
- $Watchdog\ Failure$ is the probability of failure of protection equipment without an alarm being raised
- $Duplicated\ System\ Failure$ is the probability of failure of the duplicated protection system

Control Equipment

The Safety (Worker) Consequence is deemed negligible and so $0 is applied.

Metering Equipment

The Safety (Worker) Consequence is deemed negligible and so $0 is applied.

SCADA Equipment

The Safety (Worker) Consequence is deemed negligible and so $0 is applied.

Telecommunications Equipment

The Safety (Worker) Consequence is deemed negligible and so $0 is applied.

A.2 Safety (Public) Consequence

The following section describes the methodology used in determining Safety (Public) consequence dollars for Transmission Line, Substation and Digital Infrastructure assets.

It results in a dollar per event ($/event) consequence value based on an assessment of the likelihood of people being in the vicinity when the hazardous event occurs, and subsequently the likelihood of these people being injured. A distribution across a range of potential injury consequences from minor injury to a fatality is used, based on relevant proportions of the standard consequence value for statistical life.

Transmission Line

The methodology considers four key hazards associated with overhead transmission lines:

- Conductor drop (for both structure and component failure that will result in a conductor contacting the ground)
- Earthing system failure
- Unauthorised access
- Low spans

Conductor Drop

This hazardous event covers the public safety consequence of injury to person(s) resulting from a conductor drop, including the likelihood that the event will lead to an injury and the type of injury incurred. It can occur as a result of failure of the relevant transmission line components, such as a structure or a conductor attachment.

Human movement data was used to identify the expected number of exposed people hours within the easement area of each transmission line span in the network. The calculation for the number of people hours is as follows:

$$\text{Total Monthly People Hours in Corridor} = \left[\frac{Australian\ Population}{Australian\ Total\ No.of\ Mobile\ Devices} \cdot \frac{Australian\ Total\ No.of\ Mobile\ Devices}{Total\ No.of\ Source\ Mobile\ Mobile\ Devices}\right] \times \left[(Device\_NOT\_in\_Dwell\_Calc\ \times 5min) + (Total\_Periods\_NOT\_in\_Dwell\_Calc\ \times 5min)\right]$$

Where it is assumed a unique non-dwelling device spends 5 min in the corridor. For unique dwelling devices, the actual dwell exposure times were calculated and averaged for each corridor.

In regions where there is no mobile reception, the number of people present will most likely be low and has been assumed to be non-material. Where relevant to spans with road and rail crossings, review of the human movement data to determine and allocate a minimum exposure level based on the relevant road/rail classification was implemented.

The conductor drop public safety consequence is calculated at each individual span location. The likelihood of consequence (LoC) is calculated in consideration of the following:

- Potential Impact Zone: Defined as the span length x easement width. Standard Transgrid easement widths have been applied, varying by voltage. The human movement data corridor used in the calculation corresponds to this area.
- Impact Zone: Defined as the span length x potential injury width. The potential injury width varies by voltage and is based on the approach distances in Table 2 of the *NSW SafeWork Work Near Overhead Power Lines Code of Practice*, as shown in Table 5.

- Injury likelihood factor: To denote that an exposed person may escape an injury, a likelihood of injury of 50% was applied.

Table 5 – Potential Injury Width Varying with Voltage

Voltage	Easement Width	Potential Injury Width[1]
33kV	45m – as per Transgrid 132kV	2.4m
66kV	45m – as per Transgrid 132kV	2.8m
132kV	45m	3.6m
220kV	50m	4.8m
330kV	60m	7.2m
500kV	70m	9.2m

The LoC at each span is calculated as follows:

$$\text{Conductor Drop LoC} = \frac{0.5 \times \text{Total People Hours in Corridor} \times \text{Impact Zone}}{\text{Potential Impact Zone} \times 8760}$$

The probability distribution of the injury consequence has been assessed based on the impact zone area. With a conductor on the ground, it is likely that a person located within this area who is injured receives a major injury, with fatality a probable outcome. The injury distribution is shown in the Table 6.

Table 6 – Conductor Drop Injury Distribution

Injury Distribution	Probability of Outcome
Fatality	40%
Major	40%
Moderate	10%
Minor	10%

Structure Earthing

This hazardous event covers the public safety consequence of injury from electric shock to person(s) in the vicinity of a transmission line structure in the event of a coincident fault. It can occur when a fault at the structure results in an earth potential rise through the structure earthing system. Failure of the earthing system, defined to be an out of specification condition when assessed against earthing requirements as specified by proper design, can contribute to the occurrence of the hazardous event.

The methodology applied combined the principles of ENA EG-0 and available human movement data to more accurately assess the likely exposure scenario at each structure. The human movement data was again used to identify the expected number of exposed people hours within the relevant structure exposure radius, taken to be half the easement width as per the relevant structure voltage. The calculation for the number of people hours is similar to the conductor drop equation. Because the human movement data was assessed per span easement corridor, the people exposure hours calculated was a ratio of the

[1] To determine the potential injury width the approach distances in Table 2 of the NSW SafeWork Work Near Overhead Power Lines Code of Practice have been multiplied by 2 to consider that the impacts can occur on either side of the impacted location.

structure exposure radius area against both the span easement area across both the ahead and back spans of the structure.

Where human movement data was not available, spatial information was used to estimate the expected exposure scenario at each structure. The Australian Land Use and Management (ALUM) Classification at each structure location was identified, and mapped to one of the three EG-0 selected contact scenarios:

- Backyard
- Urban
- Remote
- Note MEN was not included, as the risk of a Transgrid fault transferring into the MEN network is considered negligible with the application of Transgrid's easement design and management standards. The category can be used if specific field issues are identified.

The mapping is shown in Appendix A.1.

The adopted approach has considered the EG-0 categories and used the potential number of contacts to calibrate the exposure scenario categories to the human movement data, which is considered to be representative of real people movements. At structures where there is no human movement data, the calibration has been used to estimate the number of contact hours based on the locational ALUM categories. This is shown in Table 7.

Table 7 – Calibration of ALUM Categories

Exposure Category	EG-0 Contact Scenario Calibration	HMD Hrs/Yr within 30m Radius[2]	Included ALUM Categories if No HMD	Min HMD Allocated
Extreme	Not in EG-0. Proposed no. of contacts exceed EG-0 scenarios.	> 845.55	N/A	N/A
Very High	Not in EG-0. Proposed no. of contacts exceed EG-0 scenarios.	> 84.55	N/A	N/A
High	Not in EG-0. Proposed no. of contacts exceed EG-0 scenarios.	> 13.227	5.4.1	13.228
Medium	Backyard: Regular contact (4s) of up to 8 times per week – 416 contacts per year	> 3.179	5.4.2 / 5.4.3 / 5.4.4 / 5.4.5 / 5.3 / 5.5	3.18
Low	Urban: Occasional contact (4s) of up to 100 times per year	> 0.3179	5.1 / 5.2 / 5.6 / 5.7 / 5.8 / 5.9	0.318
Very Low	Remote: 10 contacts (4s) per year	> 0	2 / 3 / 4	0.1
Negligible	Not in EG-0.	0	N/A	0
MEN	Not currently used – reserved for future field reported MEN issues.			

The consequence is evaluated in consideration of the following:

- Injury likelihood factor: Assumes 100% conversion for people within the exposure radius receives an injury. Even a 'tingle' is assumed to represent a minor injury.
- An injury probability distribution across the exposure radius, based on the expected voltage at a distance r from the earth grid.

[2] Varies by voltage and exposure area to span ratio. Table values presented based on average span corridor length of 304m with a radius of 30m.

The LoC at each structure is calculated as follows:

$$\text{Tower Earthing Failure LoC} = \frac{\text{Total People Hours in Exposure Radius}}{8760}$$

The probability distribution of the injury consequence has been estimated based on the distance from the structure, where the structure earthing is predominantly located. The voltage at a distance r_x from the structure earthing is given by the equation:

$$V_r = \frac{\rho I}{2\pi r_x}$$

Where:

- r_x is a point from the centre of the earth grid (in m)
- Vr is the voltage at distance r_x from the earth grid (in volts)
- ρ is the resistivity of the earth in (Ω.m)
- I is the earth fault current (in amperes)

From the equation, the voltage decreases as the distance from the structure earthing increases, and accordingly the likelihood of fatality is extreme at the structure location reducing to minor injury at the edges of the exposure area. Based on this, the injury distribution is shown in Table 8.

Table 8 – Structure Earthing Injury Distribution

Injury Distribution	Probability of Outcome
Fatality	8%
Major	12%
Moderate	40%
Minor	40%

Unauthorised Access

This hazardous event covers the public safety consequence of injury as a result of a structure climbing event from unauthorised persons. It does not consider the attractiveness (i.e. ability) of the structure to be climbed which is considered as part of the probability of failure. This is only considered applicable to tower structures; poles are not considered attractive for climbing due to the position of the pole steps. Accordingly, the consequence considers the likelihood a selected tower will lead to an injury based on its exposure to the relevant vulnerability factors, and the expected injury distribution.

Unauthorised tower climbers have been categorised into:

- Self-Harmers: Persons with intention to climb and cause self-injury. Intentions may vary, such as those caused by an external trigger or persons of unstable mind.
- Fun-Seekers: Persons with intention to climb for thrill or fun.

The methodology applied considers a review of the vulnerability factors identified in Section 6 *ENA 015-2006 – National Guidelines for Prevention of Unauthorised Access to Electricity Infrastructure*, based on the applicability of transmission line structures and historical Transgrid incident information.

Table 9 – Unauthorised Access Factors Assessed for Consequence Methodology

Factor Description		Assumed Factor Value for Transmission Lines	Assessment of Applicability to Likelihood of Consequence Methodology
P1	Site Access	1 – Consistent. Climbing deterrent at each structure.	Different types of climbing deterrent, and their effectiveness to be assessed under the probability of failure category as these influence the attractiveness to climb. It is noted all reported tower climb incidents have evaded the climbing deterrent.
P2	Conductor Exposure	2 – Consistent for each.	N/A
S1	Locality	Varies by structure	Based on assessment of known incident locations, proximity to road and urban area is a key indicator. As described, the categorisation will vary between self-harmers and fun-seekers.
S2	Local criminal, anti-social activity and site activity	Varies by structure	N/A – based on assessment of known incident locations, little correlation has been found for this factor. Proximity to road and urban area appears to be a better indicator.
S3	Site activeness and housekeeping	3 – Consistent for each	N/A – Consistent for each.
S4	Natural Surveillance	Varies by structure	N/A – based on assessment of known and suspected incident locations, little correlation has been found and are a mix of both hidden and exposed.
S5	Education, Awareness and Signage	3 – Consistent for each	N/A – Consistent for each.
S6	Electronic surveillance	5 – Consistent for each	N/A – No towers have electronic surveillance.

From Table 11, it was identified that in relation to hazard exposure:

- Self-Harmers: Appears to be opportunistic so any tower in close proximity to an urban area or road would be a candidate.
- Fun-Seekers: Young people are major contributors so transport to the location is a key consideration. Any tower within 5-10km of an urban area would be a candidate.

The LoC's for Self-Harmers and Fun-Seekers are shown in Table 10 and Table 11.

Table 10 – Self-Harmers LoC

Category	Tower Criteria	LoC Conversion (including Data Review)	LoC / Tower
High	Within 100m of urban (based on ALUM categories 5.3, 5.4 and 5.5) population & within 50m of a road	1 death every 5 years i.e. 2 death / Year / 10,000 structures	0.0002 injuries / Tower / Year
Medium	Within 500m of urban (based on ALUM categories 5.3, 5.4 and 5.5) population and within 300m of a road	No injuries – likely to be higher. Assume: 0.5 Injury / Year / 10,000 structures	0.00005 Injuries / Tower / Year
Low	Any with HMD not included in above	No injuries – likely to be higher. Assume: 0.25 Injury / Year / 10,000 structures	0.000025 Injuries / Tower / Year
Very Low	All others	No injuries	0 Injuries / Tower / Year

Table 11 – Fun-Seekers LoC

Category	Tower Criteria	LoC Conversion (including Data Review)	LoC / Tower
High	Within 1.5km of urban (based on ALUM categories 5.3, 5.4 and 5.5) population and within 400m of a road	No injuries – likely to be higher. Assume: 1 Injury / Year / 10,000 structures	0.0001 injuries / Tower / Year
Medium	Within 5km of urban (based on ALUM categories 5.3, 5.4 and 5.5) population and within 1km of a road	No injuries – likely to be higher. Assume: 0.5 Injury / Year / 10,000 structures	0.00005 Injuries / Tower / Year
Low	Any with HMD not included in above	No injuries – likely to be higher. Assume: 0.1 Injury / Year / 10,000 structures	0.00001 Injuries / Tower / Year
Very Low	All others	No injuries	0 Injuries / Tower / Year

The probability distribution of the injury consequence, based on the review of Transgrid incidents, appears to indicate that intention is connected with the chance of injury. All Transgrid deaths appear to be from self-harmers, at locations in close proximity to an urban area and nearby road. Whilst Transgrid has not experienced injuries in known climbing incidents from fun-seekers, these incidents are unlikely to be reported and therefore remain unknown to Transgrid. The distributions have been proposed as follows in Table 12.

Table 12 – Unauthorised Access Injury Distribution for Self-Harmer and Fun-Seeker

Injury Distribution	Probability of Outcome (Self-Harmer)	Probability of Outcome (Fun-Seeker)
Fatality	90%	1%
Major	10%	4%
Moderate	0%	5%
Minor	0%	90%

Low Spans Risk

This hazardous event covers the public safety consequence of injury as a result of electric shock from exposure to a low span with a clearance breaching the standard requirements. It does not consider the probability that there is a low span, and the variability of this due to line loading, topography and climate.

Both human movement data, using the same calculation method as that used for conductor drop, and the span land use categories were used to estimate the number of people present at the span locations. People need to be present to be exposed and the more people (density) present for longer period of time (time of exposure) increases the risk of injury. Further, people engaged in the following applicable high risk activities were assessed to have a greater chance of being exposed:

- Farming and Construction Activities (linked to land use)
- Boating and air travel – linked to points of interest.

The LoC's are presented in Table 13.

Table 13 – Low Spans LoC

Category	HMD (Hours/Year) in Corridor	Land Use ALUM Category	Activity	LoC / Tower
High	Greater than 1,000 hours	3.3, 3.4, 4.3, 4.4, 4.5, 5.2	Within 500m of High Risk Activity based on POI: - Airport - Boat Ramp - Landing Ramp - Launching Ramp - Marina	0.001 Injuries / Structure / Year
Medium	Between 100 and 1,000 hours	3.5, 4.2, 5.3, 5.5, 5.7, 5.8, 6.4	Within 50m of Major Road Class 1, 2 and 3	0.0005 Injuries / Structure / Year
Low	Less than 100 hours	2.2, 3.1, 3.2, 4.1, 5.1, 5.4, 5.6, 5.9, 6.1, 6.2, 6.3, 6.6	N/A	0 Injuries / Structure / Year
Very Low	0 hours	1.1, 1.2, 1.3, 2.1, 3.6, 4.6, 6.5	N/A	0 Injuries / Structure / Year

The probability distribution of the injury consequence, should a person come into contact with a live conductor, is likely to result in a major injury, with fatality a probable outcome. The injury distribution is shown in Table 14.

Table 14 – Low Spans Injury Distribution

Injury Distribution	Probability of Outcome
Fatality	40%
Major	40%
Moderate	10%
Minor	10%

Transformer, Reactive Plant and Substation Switchbay Equipment

The methodology considers two key hazards associated with substations:

- Equipment explosive failure
- Unauthorised access

Explosive Failure

The equipment explosive failure consequence methodology is detailed in A.1 Safety (Worker) Consequence. For public safety exposures, the relevant corridor areas within the blast radius that are accessible to the general public were mapped. Human movement data, using the same equation as that for conductor drop, was evaluated to determine the level of people exposure expected within each corridor, which is then input into the consequence calculation method in A.1.

Unauthorised Access

This hazardous event covers the public safety consequence of injury as a result of a break-in to Transgrid's substations sites. It does not consider the attractiveness (i.e. ability) of the site to be accessed, which is considered as part of the probability of failure. This is only considered applicable to outdoor substations; indoor GIS sites such as Haymarket have not been considered due to the additional security. Accordingly, the consequence considers the likelihood a selected substation will lead to an injury based on its exposure to the relevant vulnerability factors, and the expected injury distribution.

Review of Transgrid substation unauthorised access events have identified that:

- All events had evaded security fences, which were not identified to have had condition issues
- All break-ins occurred within 7km of a crime hot spot as identified by the NSW Bureau of Crime Statistics and Research, with correlation also identified for proximity to urban areas and roads
- Only one minor injury has been reported from the incidents

The methodology applied considers a review of the vulnerability factors identified in Section 6 *ENA 015-2006 – National Guidelines for Prevention of Unauthorised Access to Electricity Infrastructure*, based on the applicability to transmission substation sites and historical Transgrid incident information above.

Table 15 – Unauthorised Access Factors Assessed for Consequence Methodology

Factor Description		Assumed Factor Value for Substations	Assessment of Applicability to Likelihood of Consequence Methodology
P1	Site Access	2 – Consistent for each	N/A
P2	Conductor Exposure	3 – Consistent for each	N/A
S1	Locality	Varies by location	N/A – based on assessment of proximity to urban areas, crime hotspots considered the best indicator. Noted these areas also show correlation.
S2	Local criminal, anti-social activity and site activity	Varies by location	Proximity to crime hotspots.
S3	Site activeness and housekeeping.	3 – Consistent for each	N/A – Consistent for each.
S4	Natural Surveillance	Varies by location	N/A – Data not conclusive.
S5	Education, Awareness and Signage	3 – Consistent for each	N/A – Consistent for each.
S6	Electronic surveillance	2 – Consistent for each	N/A – Consistent for each.

The LoC's are presented in Table 16.

Table 16 – Unauthorised Access LoC

Category	Crime Zone Criteria	Break in Events	Conversion Rate	LoC
High	Within 1km of crime hot spot	0.044	5% likelihood of injury	0.0022
Medium	Within 2.5km of crime hot spot	0.032	5% likelihood of injury	0.0016
Low	Within 10km of crime hot spot	0.004	5% likelihood of injury	0.0002
Very Low	All other sites	0	5% likelihood of injury	0

The probability distribution of the injury consequence is expected to be connected to the intention behind break-ins. The distribution have been proposed as shown in Table 17.

Table 17 – Unauthorised Access Injury Distribution

Injury Distribution	Probability of Outcome
Fatality	1%
Major	3%
Moderate	7%
Minor	90%

Digital Infrastructure - Communications Sites

The methodology considers two key hazards associated with communications sites:

- Communications tower failure
- Unauthorised access

Tower Failure

This hazardous event covers the public safety consequence of injury to person(s) resulting from a catastrophic failure of a communications tower, including the likelihood that the event will lead to an injury, and the type of injury incurred.

The public safety consequence for is calculated at each individual tower location. The likelihood of consequence (LoC) is calculated in consideration of the following:

- Potential Impact Zone: As the towers vary in height, this is defined as the circle with a radius of the tower height plus 10%. For example, if a tower was 80m in height, the potential impact zone will be a circle area with a radius of 88m.
- Impact Zone: Defined as the fall area of the tower within the potential impact zone. Based on typical tower designs, the tower width is circa 10% of its height. The impact zone is defined as the (tower width) x (tower height plus 10%).
- Exclusion areas: Where areas of the potential impact zone are located within a Transgrid substation boundary and therefore not accessible to the general public, these areas are not included in the potential impact zone and impact zone.
- Injury likelihood factor: To denote that an exposed person may escape an injury, a likelihood of injury of 50% was applied.

Human movement data was used to identify the expected number of exposed people hours within the communication tower corridor zones, using the same calculation equation as that for conductor drop.

The LoC at each structure is calculated as follows:

$$Tower\ Failure\ LoC\ = \frac{0.5 \times Total\ People\ Hours\ in\ Corridor \times Impact\ Zone}{Potential\ Impact\ Zone \times 8760}$$

The probability distribution of the injury consequence has been estimated based on the impact zone area. The main cause of injury is expected to be the result of physical impact with persons, with the likelihood of more severe injury increasing if impacted by tower components from a greater height. The injury distribution applied is shown in the Table 18.

Table 18 – Tower Failure Injury Distribution

Injury Distribution	Probability of Outcome
Fatality	20%
Major	20%
Moderate	20%
Minor	40%

Unauthorised Access

This hazardous event covers the public safety consequence of injury as a result of a communications structure climbing event from unauthorised persons. It does not consider the attractiveness (i.e. ability) of the structure to be climbed which is considered as part of the probability of failure. Accordingly, the consequence considers the likelihood a selected tower will lead to an injury based on its exposure to the relevant vulnerability factors, and the expected injury distribution.

Unauthorised communications tower climbers, like transmission line climbers, have been categorised into self-harmers and fun-seekers as per the abovementioned description.

The methodology applied considers a review of the vulnerability factors identified in Section 6 *ENA 015-2006 – National Guidelines for Prevention of Unauthorised Access to Electricity Infrastructure*, based on the applicability of transmission line structures and historical Transgrid incident information.

Table 19 – Unauthorised Access Factors Assessed for Consequence Methodology

Factor Description		Assumed Factor Value for Transmission Lines	Assessment of Applicability to Likelihood of Consequence Methodology
P1	Site Access	2 – Consistent. Climbing deterrent at each structure.	N/A
P2	Conductor Exposure	2 – Consistent for each.	N/A
S1	Locality	Varies by structure	Based on assessment of known incident locations, proximity to road and urban area is a key indicator. As described, the categorisation will vary between self-harmers and fun-seekers.
S2	Local criminal, anti-social activity and site activity	Varies by structure	N/A – based on assessment of known incident locations, little correlation has been found for this factor. Proximity to road and urban area appears to be a better indicator.
S3	Site activeness and housekeeping.	3 – Consistent for each	N/A – Consistent for each.
S4	Natural Surveillance	Varies by structure	N/A – based on assessment of known and suspected incident locations, little correlation has been found and are a mix of both hidden and exposed.
S5	Education, Awareness and Signage	3 – Consistent for each	N/A – Consistent for each.
S6	Electronic surveillance	5 – Consistent for each	N/A – Consistent for each.

From the above, it was identified that in relation to hazard exposure:

- Self-Harmers: Appears to be opportunistic so any tower in close proximity to an identified point of interest, urban area or road would be a candidate.
- Fun-Seekers: Young people are major contributors so transport to the location is a key consideration. Any tower within 5-10km of an urban area would be a candidate.

The LoC's for Self-Harmers and Fun-Seekers are shown in Table 20 and Table 21.

Table 20 – Self-Harmers LoC

Category	Tower Criteria – Within Substation	Tower Criteria – Outside Substation	Towers Exposed	LoC Conversion	LoC / Tower
High	N/A	Within 100m of urban (based on ALUM categories 5.3, 5.4 and 5.5 and relevant POIs) population and within 50m of a road	23	0.2 injury / year / 1,000 towers	0.0002 injuries / Tower / Year
Medium	Within 500m of urban (based on ALUM categories 5.3, 5.4 and 5.5 and relevant POIs) population and within 300m of a road		90	No injuries – likely to be higher. Assume: 0.5 injury / year / 1,000 towers	0.00005 Injuries / Tower / Year
Low	Any tower locations with HMD not included in the above		48	No injuries – likely to be higher. Assume: 0.25 injury / year / 1,000 towers	0.000025 Injuries / Tower / Year
Very Low	All Others		50	No injuries	0 Injuries / Tower / Year

Table 21 – Fun-Seekers LoC

Category	Tower Criteria – All Sites	Towers Exposed	LoC Conversion	LoC / Tower
High	Within 1.5km of urban (based on ALUM categories 5.3, 5.4 and 5.5 and relevant POIs) population & within 400m of a road	134	No injuries – likely to be higher. Assume: 1 injury / year / 1,000 towers	0.0001 injuries / Tower / Year
Medium	Within 5km of urban (based on ALUM categories 5.3, 5.4 and 5.5 and relevant POIs) population and within 1km of a road	41	No injuries – likely to be higher. Assume: 0.5 injury / year / 1,000 towers	0.00005 Injuries / Tower / Year
Low	Any tower locations with HMD not included in the above		No injuries – likely to be higher. Assume: 0.1 injury / year / 1,000 towers	0.00001 Injuries / Tower / Year
Very Low	All Others	36	No injuries	0 Injuries / Tower / Year

The probability distribution of the injury consequence follows that of the transmission line towers where intention is connected with the chance of injury. The distributions have been proposed as follows in Table 22.

Table 22 – Unauthorised Access Injury Distribution for Self-Harmer and Fun-Seeker

Injury Distribution	Probability of Outcome – Self-Harmer	Probability of Outcome – Fun-Seeker
Fatality	90%	1%
Major	10%	4%
Moderate	0%	5%
Minor	0%	90%

Digital Infrastructure – Transmission Line and Cable Assets

The Safety (Public) Consequence for Digital Infrastructure equipment was determined through the inheritance of associated primary plant consequences as listed above. This parameter is only applied to Transmission Line assets.

The Safety (Public) Consequence further applies the statistical expected probability of several parameters to determine the likelihood of an incident occurring. Available data is utilised for all Transgrid protected assets, with an average taken and applied to third party protected assets where applicable such as for protection equipment. This is applied by the following equation:

$$\text{Safety (Public) Consequence \$/event} = Primary\ Plant\ Safety(Public)Consequence\ \$/event\ \times Primary\ Plant\ Fault\ Rate \times Watchdog\ Failure \times Duplicated\ System\ Failure$$

Where:

- $Primary\ Plant\ Safety(Safety)Consequence\ \$/event$ is direct allocation of consequence calculated from the protected primary plant
- $Primary\ Plant\ Fault\ Rate$ is the average of faults associated with the type of plant protected per annum
- $Watchdog\ Failure$ is the probability of a failure of protection equipment without an alarm being raised
- $Duplicated\ System\ Failure$ is the probability of failure of the duplicated protection system

A.3 Reliability Consequence

The following section describes the methodology used in determining Reliability consequence dollars across a range of asset types. It results in a dollar per hour ($/hour) consequence based on an assessment of the combinations of unplanned and planned outages which may result in an Energy Not Served (ENS) event during the duration of the hazardous event.

General

The Reliability Consequence ($/hour) for the catastrophic failure of an asset has been assessed through evaluating its level of redundancy within the NSW High Voltage (HV) network and an estimate of the potential load at risk. A network load flow model of NSW with various levels of demands was analysed to determine the probabilistic load at risk at the different levels of demand. The network load flow studies examined up to two contingencies after the catastrophic failure of the asset, to determine the load shedding required to maintain power system security, operate within network limits or due to network topology.

The Reliability Consequence is calculated by the following equation:

$$Reliability\ Consequence\ \$/hour =$$

$$\sum_{k=1}^{n} Outage\ Unavailability_x \times\ Outage\ Unavailability_y\ \times Load\ at\ Risk\ \times Demand\ Probability \times Value\ of\ Customer\ Reliability$$

Where:

- $Outage\ Unavailability_x$ is the unavailability of the first network element contingency
- $Outage\ Unavailability_y$ is the unavailability of the second network element contingency, where relevant
- $Load\ at\ Risk$ is the load (MW) required to be shed to maintain power system security, operate within network limits or due to network topology
- $Demand\ Probability$ is the probability that the NSW demand will be at the chosen network load flow model
- $Value\ of\ Customer\ Reliability$ (VCR) ($/MWh) is the value customers place on a reliability supply of electricity.

The analysis was performed for the catastrophic failure of each network asset at ten different levels of NSW demand. Each simulated demand scenario was analysed for various combinations of contingencies to determine the potential load shedding required. The result of each demand scenario was scaled by the demand probability and summed for the total reliability consequence.

The analysis considered potential remediation activities, in line with standard operating practices, to ensure the load shedding quantity was minimal. In load shedding scenarios, mixed (residential and business) customers were prioritised continuity of supply over direct connected customers. The different types of VCR values used in the analysis are listed in Appendix B.8.

Other external parameters such as the interconnector flows and generators were monitored and adjusted to simulate the operations of the NEM.

This general methodology of Reliability Consequence applies for transmission line and cable, transformer, reactive plant and substation switchbay equipment assets.

Digital Infrastructure

Protection Assets

Unit protection is an industry standard whereby protection schemes are limited in their range of cover to only those protected assets. This approach to protection design maximises system security by mitigating the risk of false trips due to adjacent equipment conditions.

The deployment of unit protection results in the inability of adjacent protection schemes to detect faults outside their protection zone. Reliable protection operation is achieved through the duplication of protection schemes.

The impact of the failure of duplicated unit protections is that the faulted plant would continue to fail catastrophically placing a burden on the connected bus. This would effectively turn the connected bus and nearby transformers and transmission lines into a fuse, as the failure of the surrounding assets would become the only feasible way that an active protection scheme can be initiated. This would effectively become a race between surrounding assets failing and generators tripping.

The quantification of the reliability consequence of an uncleared fault on the NSW 500 kV and 330 kV network has been undertaken by the Digital Infrastructure Assets team in collaboration with the Asset Analytics and Insights. The impact of an uncleared or slow-to-clear fault is one of the main risks presented by Transgrid's protection systems to the primary transmission 500 kV and 330 kV network. The consequence of this risk can vary dramatically depending on a complex array of variables; the extreme result being a 'Black Start' – that is, the de-energisation of the entire NSW transmission grid.

In order to quantify the reliability risk associated with the failure of a protection system on the NSW 500 kV and 330 kV network, the following approach has been adopted:

- The concurrent failure of both independent protection systems was the only asset related scenario considered with the potential for causing an uncleared fault. It is of note that there is currently no record of this ever occurring on Transgrid's network.
- The potential for an uncleared fault to affect the wider network has been considered to be only present on protections systems of 500 kV and 330 kV assets.
- To simplify the analysis, the consequence cost presented by this reliability risk has been treated equally throughout the 500 kV and 330 kV network.
- The reliability consequence was modelled as a single value for load interruption over a single length of time.

The potential load loss (ENS event) for an uncleared fault on the 500 kV and 330 kV network was modelled as an average of NEM incidents resulting in significant network outages (brown events):

- 25 August 2019 - Queensland/South Australia Separation
- 2 July 2009 - Multiple Generator Disconnection and Under Frequency Load Shedding
- 13 August 2004 – Current Transformer Explosion Bayswater Substation

The outcome of this analysis is an ENS of 938 MWh to be applied to all 500 kV and 330 kV network elements.

The Digital Infrastructure Assets team has carried out an analysis for the performance of protection schemes at voltage levels of 220kV and below with assistance from the Protection Design team. The analysis has determined that an uncleared fault would result in the associated busbar effectively becoming a fuse to assist in a consistent analysis, the reliability consequence for these assets is calculated as the loss of load of the site associated with the failed protection element. These values are as derived from the Asset Analytics and Insights team.

The protection asset criticality for reliability is calculated as:

$$\text{Reliability Consequence } \$/\text{event } = $$
$$ENS \times VCR\ (mixed\ load) \times Restoration\ Time \times Primary\ Plant\ Fault\ Rate \times Watchdog\ Failure \times Duplicated\ System\ Failure$$

Where:

- ENS is either 938 MWh for 330 kV and 500 kV protected elements and the substation reliability consequence for all other protected elements.
- VCR is applied for mixed loads, this has been selected to account for the nature of the transmission network and its span across different load profiles.
- $Restoration\ Time$ is applied as 1 hour for 500 kV and 330 kV voltage levels as this is incorporated in the MWh ENS value, for 220 kV and below a restoration time of 8 hours is applied across the board, this time has been established as the time to respond and coordinated with third parties to establish alternate network configurations for restoration.
- $Primary\ Plant\ Fault\ Rate$ is the average of faults associated with the type of plant protected per annum.
- $Watchdog\ Failure$ is the probability of a failure of protection equipment without an alarm being raised.
- $Duplicated\ System\ Failure$ is the probability of failure of the duplicated protection system.

Control Assets

The key hazards faced by our control systems can be summarised into two components:

- Loss of visibility and control of an asset
- Inadvertent operation of an asset

While the risk of inadvertent operation of an asset is a feasible risk, it has not been identified as occurring frequently enough to be a statistical consideration during normal operation and the risk has generally been linked to situations where the Controllers are upgraded with new databases and re-energised.

Transgrid currently implements two types of controller installations, dedicated controller per HV plant and a single controller for an entire site. Calculation of reliability criticality for controllers is based on the following equation:

$$\text{Reliability Consequence } \$/\text{event } = $$
$$ENS \times VCR\ (mixed\ load) \times Restoration\ Time \times Primary\ Plant\ Fault\ Rate \times Watchdog\ Failure$$

Where:

- ENS is either the weighted averaged of independent HV network elements for single site controllers and the HV network element reliability consequence for independent controllers.
- VCR is applied for mixed loads, this has been selected to account for the nature of the transmission network and its span across different load profiles.
- $Restoration\ Time$ is applied as the travel time from the closest Transgrid depot to the site assessed. This has been applied as the time for an authorised switcher to attend site and manually operate the affected plant.

- $Primary\ Plant\ Fault\ Rate$ is the average of faults associated with the type of plant protected per annum. This is applied as the weighted average of fault rates for single controller installations and directly applied for dedicated controllers.
- $Watchdog\ Failure$ is the probability of a failure of the control equipment without an alarm being raised.

SCADA Assets

The key hazard faced by our Data Concentrator (DCON) installations can be summarised into the following:

- Loss substation visibility to SCADA (Network Control Room)
- Loss of substation remote control capability from SCADA

The two categories are intertwined and result in significant operational and financial consequences for our business.

SCADA asset reliability criticality is calculated as

$$Reliability\ Consequence\ \$/event\ = ENS\ \times VCR\ (mixed\ load) \times Restoration\ Time \times Primary\ Plant\ Fault\ Rate \times Watchdog\ Failure \times Duplicated\ System\ Failure$$

Where:

- ENS is the weighted averaged of independent HV network elements at the assessed site.
- VCR is applied for mixed loads, this has been selected to account for the nature of the transmission network and its span across different load profiles.
- $Restoration\ Time$ is applied as the travel time from the closest Transgrid depot to the site assessed. This has been applied as the time for an authorised switcher to attend site and manually operate the affected plant.
- $Primary\ Plant\ Fault\ Rate$ is the average of faults associated with the type of plant protected per annum. This is applied as the weighted average of fault rates for all installations.
- $Watchdog\ Failure$ is the probability of a failure of the control equipment without an alarm being raised.
- $Duplicated\ System\ Failure$ is the probability of failure of the duplicated protection system.

Telecommunications Assets

The key hazards faced by our telecommunications assets can be broken down into three scenarios:

- Failure to Clear a Fault in accelerated timing
- Failure to function as an intervening facility (AEMO PSDCS)
- Faure to provide visibility and control to SCADA

The assets associated with this are generally duplicated (with some rare exceptions). Additionally, Transgrid does not deploy a “self-healing” network topology and so it can be safely assumed that the loss of an asset cannot be automatically rectified.

Telecommunications asset reliability criticality is calculated as:

$$\text{Reliability Consequence \$/event} = ENS\ \times VCR\ (mixed\ load)\ \times Restoration\ Time \times Primary\ Plant\ Fault\ Rate \times Watchdog\ Failure \times Duplicated\ System\ Failure$$

Where:

- ENS is the weighted averaged of independent HV network elements at the assessed site.
- VCR is applied for mixed loads, this has been selected to account for the nature of the transmission network and its span across different load profiles.
- $Restoration\ Time$ is applied as the travel time from the closest Transgrid depot to the site assessed. This has been applied as the time for an authorised switcher to attend site and manually operate the affected plant.
- $Primary\ Plant\ Fault\ Rate$ is the average of faults associated with the type of plant protected per annum. This is applied as the weighted average of fault rates for all installations.
- $Watchdog\ Failure$ is the probability of a failure of the control equipment without an alarm being raised.
- $Duplicated\ System\ Failure$ is the probability of failure of the duplicated protection system.

Market Metering Systems

Market Metering System failures do not result in any identifiable reliability consequences to the network.

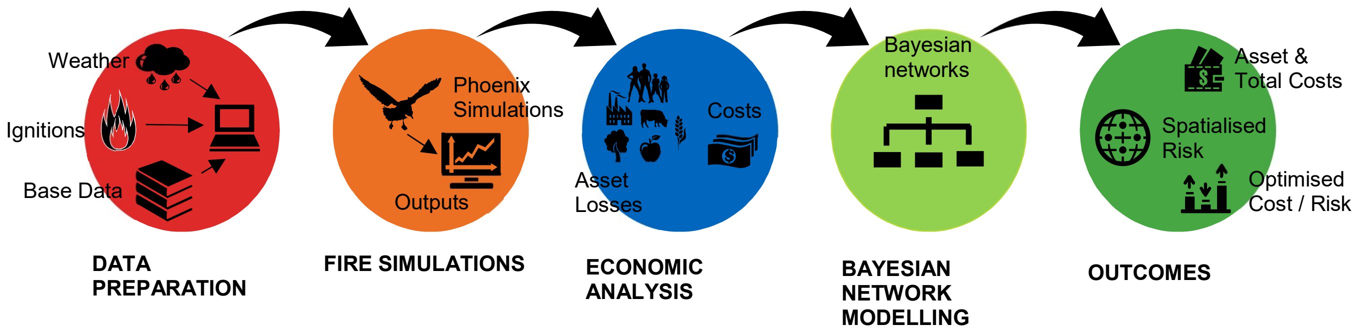
A.4 Environment Consequence

The following section describes the methodology used in determining Environment consequence dollars for Transmission Line, Substation and Digital Infrastructure assets. These include bushfires, oil leaks and SF6 gas escaping into the environment.

A.5 Transmission Line

The consequence of asset failure causing bushfire is analysed in depth in the University of Melbourne Report. The methodology is based upon that developed under the IGNIS Project[3] with some alterations such as fuel loads, value of statistical life, risks to Transgrid's asset for an externally caused fire and bushfire intensity at each asset. The conceptual diagram used in this project is described in Figure 5.

Figure 5 – Environment Consequence Conceptual Diagram



Phase one included the collection and preparation of data including weather data, location of ignitions and range of base date inputs. Phase two involves fire simulations using *Phoenix Rapidfire*, to determine area burnt and assets impacted under a range of weather scenarios. Phase three involves the economic analysis with cost assigned to each asset. Phase four brings it all together by combining weather and ignitions, fire simulation data and estimated costs per asset in a Bayesian network. The Bayesian network generates a series of outputs, including cost of damage per asset and total costs, and associated probability of the potential outcomes. Finally, using these outputs, the dollar consequence at each structure can be calculated.

Phoenix RapidFire Simulator models fires starting from each structure across Transgrid's Network, with various scenarios, weather conditions and Forest Fire Danger Index (FFDI) which are derived from historical data. These scenarios represent the distribution of fire intensity and burn areas at each structure location. The factors that can influence the fire intensity and burn area are topography, series of weather days from Automatic Weather station, FFDI, ignition location and fuel loads.

The final values are derived using a Bayesian Network to calculate the probable consequence from the range of burn areas and fire intensities which are representative of the various combinations of FFDI and ambient weather conditions modelled. Land use data, number of dwellings and other spatial information is used to model the quantity and type of asset impact within the boundary of the burn area to calculate the dollar value consequence per structure.

[3] The IGNIS Project was a collaboration been the Energy Networks Australian and the Bushfire and Natural Hazards CRC to develop a consistent methodology to derive bushfire consequences within electrical networks.

The approach was consistent with procedures currently used by the NSW Rural Fire Service (RFS) but includes a greater diversity of weather and asset loss models.

The consequence methodology considers an economic value for the tangible assets expected to be impacted by the modelled bushfire. It does not consider a wider economic impact value that also considers intangible factors, due to the complexity in expressing them in monetary terms.

Accordingly, the dollar value consequence per structure of a transmission line is determined by the following:

$$(Lif_{Lss} \times Lif_{Cst} + Hos_{Lss} \times Hos_{Cst} + Crp_{Lss} \times Crp_{Cst} + Plntt_{Lss} \times Plntt_{Cst} + Vnyrd_{Lss} \times Vnyrd_{Cst}) \times v_1 \times v_2$$

Where:

- Lif_{Lss} is number of potential lives lost within the modelled burn area.
- Lif_{Cst} is the economic cost of a life.
- Hos_{Lss} is the number of private properties within the modelled burn area.
- Hos_{Cst} is the economic cost of the properties impacted within the modelled burn area.
- Crp_{Lss} is the area of crops and/or orchards within the modelled burn area.
- Crp_{Cst} is the economic cost of crops and/or orchards impacted within the modelled burn area.
- $Plntt_{Lss}$ is the area forest plantation within the modelled burn area.
- $Pltnn_{Cst}$ is the economic cost of forest plantation impacted within the modelled burn area.
- $Vnyrd_{Lss}$ is the area of vineyards within the modelled burn area.
- $Vnyrd_{Cst}$ is the economic cost of vineyards impacted within the modelled burn area.
- v_1 is the likelihood of ignition for bushfire from asset failure. The value of the variable is 0.21. It is assumed that not every transmission line asset failure will generate an ignition that will cause a bushfire. The likelihood is derived by taking a ratio of the number of ignition events recorded against the number of potential ignition events (asset failure events) over a period of twelve years (2008 – 2020).
- v_2 is the emergency services response factor. This moderates the final consequence value in line with normalised number of properties impacted, Hos_{Lss} figure, within the modelled burn area and ranges from 0.1, the largest reduction factor, and 1.0, no reduction factor. The emergency services response factor is in line with the finding from the NSW Bushfire Inquiry July 2020 Final Report, that stated *"Generally, urban areas and their surrounds area better monitored because there are more people, so that new ignitions are detected early. Fire and Rescue NSW resources are available throughout the cities to respond quickly, and resources from other agencies are more concentrated in and around urban area."*(p.41). This variable is dependent on the location of the structure.

The dollar value of consequence at each structure is available in Ellipse and Asset Analytics and Investment Tool.

Underground Cables

Environmental consequence for underground cables applies to Self-Contained Fluid Filled (SCFF) cables only. Factors considered for the nomination of consequence level for each cable oil section included surrounding land use, distance to waterways and waterway crossings and PCB oil contamination of cable insulating oil. The consequence cost of an oil spill event is derived from the relevant costs associated with post incident geo-technical investigation, soil remediation and ground water remediation works. Work undertaken by the Property and Environment Asset Group and Substations Asset Group for transformer oil release has provided the basis for this analysis.

Transformer and Reactive Plant

- LoC value based on the chance of oil containment at the site failing to contain a major oil spill event.
- A consequence value taking into account the environmental sensitivity of the site.

Factors considered for nomination of the LoC for each substation included the existence and condition of containment bunds, the existence and capacity of spill oil tanks and the existence of containment dams.

Factors considered for nomination of the consequence level for each substation included the surrounding land use, environmental sensitivity, the distance from the last line of containment to closest receiving water/waterway, the site slope and the slope of surrounding land. The consequence cost of an oil spill event is derived from the relevant costs associated with post incident geo-technical investigation, soil remediation and ground water remediation works. Work undertaken by the Property and Environment Asset Group and Substations Asset Groups has provided the basis for this analysis.

Substation Switchbay Equipment

SF6 filled switchgear is expected to release all gas when an explosive failure occurs.

Substation Asset Bushfire Risk

A bushfire may be ignited by the explosive failure of a substation asset. The likelihood of a bushfire is determined by the proximity of the fuel to the explosion. Using similar methodology outlined for safety of workers in substations, and for that associated with public safety, a weighted probability of generating an ignition potential per asset can be determined.

There is an inherent risk associated with the explosive failure of equipment in switchyards. This risk has derived through analysis of previous failures of equipment, whilst accounting for the proximity of the equipment to material that could catch fire.

Background / Historical Failures

The history of distances for debris to travel from an explosive asset failure is outlined in the worker safety methodology in Appendix A.1. The bushfire risk methodology aligns with these distances.

One of these historic failures relates to the failure of a 330kV CVT where debris landed outside of the switchyard and an area of adjacent vegetation was burnt before being extinguished by emergency services. This example shows credibility of debris to retain heat and lead to ignition of vegetation outside of the switchyard.

Calculation Methodology

The probability of an explosive failure initiating a fire is directly related to how close fuel is to the point of the explosion. Transgrid has used a selection of zones around the equipment, assigning a probability of an item having sufficient energy to ignite fuel, were the conditions correct for a fire to start.

Areas of Effect

Figure 4 in Appendix A.1 shows three zones.

- Zone 1 is in black, and is 0-15m from the point of explosion. In this area, there will be an expanding ball of heat and compressed air, as well as flying debris. Ignition is highly likely.

- Zone 2, shown in orange, is from 15-35m. In this zone the heat and compressed air has dispersed sufficiently that the predominant ignition mechanism will be through flying debris. Ignition is not certain, as the debris may be fast, and hot, but whether it is hot enough to trigger a fire is another question.
- Zone 3, shown in yellow, is from 35m-50m. Again, the predominant ignition mechanism is through flying debris. As the debris will have travelled further, and thus had more chance to extinguish or cool, the probability of ignition is less than Zone 2.

Switchyard Ignition

Assuming a there is fuel somewhere in the vicinity of the failed device, the chances of having sufficient energy to start a fire are as follows in Table 23.

Table 23 – Substation Asset Fire Start Probability

Injury Area	Probability of fire start
Black Zone	90%
Orange Zone	30%
Yellow Zone	15%

With the exception of the black zone, where probability of having sufficient energy to start a fire is nearly guaranteed (due to the nature of the failure), the probability of having sufficient energy is assessed as follows:

- Assumption that only 30% of the fragments will be hot enough / still alight within Zone 1
- Assumption that only 15% of the fragments will be hot enough / still alight within Zone 2

Considerations:

- The probabilities have been estimated, but it is noted that they are assessing the likelihood of at least one ignition which could lead to fire under enabling conditions.
- Debris may not make it over the fence.

External ignition

The probability of igniting vegetation outside of the switchyard is assessed as a weighted average of the areas of the three rings outside the substation, with the weighting based on the area of each ring.

Risk of Internal Switchyard Ignition

For substations with grass switchyard surfacing, an additional risk exists of ignition of the switchyard surface spreading externally to the substation. This risk of this occurring is taken as 10% of the internal switchyard ignition risk and added to the external switchyard risk.

This probability inside the substation is significantly lower than external ignition due to accounting for topography (such as roads) and that Transgrid actively manages the fuel load.

The risk in a gravel switchyard of an internal switchyard ignition leading to external ignition is assumed to be negligible.

Fire Spread from Ignition

Bushfire consequence modelling has determined how many days per annum the conditions are correct for a fire start and the likely outcome of that fire. The work documented here determines the probability of substation equipment resulting in an ignition (burning / hot piece debris) which may result in in a fire. The consequences following ignition are as per the transmission lines and cables bushfire consequence modelling.

Calculation methodology

During the work on determining the risk to workers from explosive failure, the radii of each and every piece of equipment that could explode were determined. Those were mapped as shape files for use in applications like Google Earth. Similarly, the area within the switchyard, within the property boundary, outside the switchyard and outside the property boundary were determined. With those figures, and using the probabilities listed above, it is possible to assign a probability of an explosive failure having sufficient energy to start a fire, as a weighted average of the various areas (inner, zone 1, zone 2, and whether or not there is Transgrid managed vegetation within those zones).

In determining the overall bushfire environment consequence of an equipment failure, the equation is as follows:

$$Environmental\ (Bushfire)\ Consequence = \text{Probability of Equipment Failure} \times \text{Probability of Explosive Failure} \times (\text{External ignition: weighted average area of the 3 zones outside the substation} + \text{Grass site internal ignition: 10\% x weighted average area of the 3 zones inside the substation}) \times \text{Bushfire Spread LoC} \times \text{Bushfire Consequence}$$

Digital Infrastructure

The Environmental Consequence for Digital Infrastructure equipment was determined through the inheritance of associated primary plant consequences as listed above.

The Environmental Consequence further applies the statistical expected probability of several parameters to determine the likelihood of an incident occurring. Available data is utilised for all Transgrid protected assets, with an average taken and applied to third party protected assets where applicable such as for protection equipment. This is applied by the following equation:

$$Environmental\ Consequence\ \$/event = Primary\ Plant\ Environmental\ Consequence\ \$/event \times Primary\ Plant\ Fault\ Rate \times Watchdog\ Failure \times Duplicated\ System\ Failure$$

Where:

- $Primary\ Plant\ Environmental\ Consequence\ \$/event$ is direct allocation of consequence calculated from the protected primary plant.
- $Primary\ Plant\ Fault\ Rate$ is the average of faults associated with the type of plant protected per annum.
- $Watchdog\ Failure$ is the probability of a failure of protection equipment without an alarm being raised.
- $Duplicated\ System\ Failure$ is the probability of failure of the duplicated protection system.

A.6 Financial (Market) Consequence

The following section describes the methodology used in determining Financial (Market) consequence dollars. It results in a dollar per hour ($/hour) consequence based on an assessment of National Electricity Market data to determine the impact to consumers.

The quantification of Financial (Market) Consequence for an element has been based on information within the relevant Operating Manuals and historical data contained in the Australian Energy Market Operator (AEMO) Market Management System (MMS) database and/or Supervisory Control and Data Acquisition (SCADA) data. Approximately two years of historical data has been used for calculation of the Financial (Market) Consequence $/hour.

The general form of the equation to compute the Financial (Market) Consequence $/hour of an element is given by:

$$\begin{aligned} Financial\ (Market)\ Consequence\ \$/hour = \\ \text{Interconnector Region 1 to 2 Power Displaced} \times \text{Max}(0, \text{Region 2 RRP} - \text{Region 1 RRP}) + \\ \text{Interconnector Region 2 to 1 Power Displaced} \times \text{Max}(0, \text{Region 1 RRP} - \text{Region 2 RRP}) + \\ \text{Required Region FCAS Raise Dispatch} \times \text{Required Region FCAS Raise RRP} + \\ \text{Required Region FCAS Lower Dispatch} \times \text{Required Region FCAS Lower RRP} \end{aligned}$$

Where:

- RRP is Regional Reference Price and $FCAS$ is Frequency Control Ancillary Services.

An average Financial (Market) Consequence $/hour has been calculated using five-minute dispatch data from the sample period.

Appendix B Generic Consequence Values

The Asset Analytics and Insights Tool (AAIT) is configured with standard drop-down lists for consequence values, likelihood of consequence and other moderating factors. These values allow a consistent approach to determining the consequence of failure associated with individual assets.

Where specific values have been calculated in the manner described in the appendices above, the specific values should be used in preference.

An overview of the generic consequence values and guidance on their selection is presented in the following tables.

B.1 Asset Repair Duration

Relevant Consequence Areas:

- Reliability
- Financial

Table 24 – Asset Repair Duration - standard values

Failure Event	Typical Repair Duration
Instrument Transformer	2 days
Disconnector	2 days
Transmission Line Structure	4 days
Transmission Line Fitting / Insulator / Conductor	4 days
Circuit Breaker	5 days
Gas Insulated Switchgear (GIS)	7 days
Transformer Catastrophic*	1 month
Cable Accessory	2 months
Significant Gantry	3 months
Capacitor Bank	6 months
Oil or Air Cored Reactor	12 months

* An alternate repair time may be used based the NSW Electricity Transmission Reliability and Performance Standard 2017.

B.2 Legislation Breach

Relevant Consequence Areas:

- Financial

The value is set in dollars per event.

Table 25 – Legislation Breach - standard values

Level	Value
Minor Breach	$20,000
Moderate Breach	$50,000
Major Breach	$500,000
Extreme Breach	$5,000,000

B.3 Litigation Type

Relevant Consequence Areas:

- Financial

The values are set in dollars.

Table 26 – Litigation Type - standard values

Level	Value	Typical Event
Minor – Magistrates Court	$20,000	• Minor injury or property damage
Moderate – District / Magistrates	$50,000	• Serious Injury
Major – Large financial consequences	$500,000	• Fatality
Extreme – Supreme Court	$5,000,000	• Catastrophic Bushfire Event • Multiple Fatality due to negligence • Major system disturbance

The values nominated in the table above are based on the outcomes of consultation with Transgrid's Legal Counsel and Workplace Health and Safety (WHS) consultant.

Following a fatality, it is likely that there will be the following three court cases:

1. Coronial Inquest in the fatality
2. A potential WHS prosecution by WorkCover NSW
3. Civil proceedings by relatives of the deceased.

Estimating the time, cost and resources required for litigation cases in the event of a fatality is a difficult task. The value of $5,000,000 for the Extreme – Supreme Court Level of Consequence is based on the following indicative costs for Transgrid's legal representation in such proceedings and the associated assumptions:

- Senior Counsel: approximately $8,000 - $10,000 per day
- Junior Counsel: approximately $5,000 per day
- Solicitor: approximately $3,000 - $4,000 per day
- Significant amount of time invested by Transgrid senior management and personnel
- The combined duration of the legal cases will likely cover a six to eight year period.

B.4 Investigation Cost

Relevant Consequence Areas:

- Financial

The values are set in dollars and are an estimate of the cost of labour and management review time towards investigation of the incident.

Table 27 – Investigation Cost - standard values

Level	Value	Typical Event
Small Investigation	$10,000	• Small ENS • Local Fire Start
Medium Investigation	$50,000	• Major Fire Event • Large scale customer impact • Major Environmental spill
Large Investigation	$250,000	• Catastrophic Bushfire Event • Multiple Fatality due to negligence • Major system disturbance

B.5 Media Coverage

Relevant Consequence Areas:

- Reputation

The values are set in dollars and are an estimate of the direct media coverage costs of managing the incident.

Table 28 – Media Coverage - standard values

Level	Value	Typical Event
Board Request	$10,000	• Fire event • > 0.25 system minute event
Local Media	$30,000	• Fatality or Local fire event
State Media	$75,000	• Fatality or Large and obvious fire event
National Media	$150,000	• Catastrophic Bushfire Event • Multiple Fatality due to negligence • Major system shutdown

The Transgrid Corporate and Regional Emergency Management Plan (CREMP) and supporting Power Systems Emergency Response Plan (PSERP), which aims to assist in managing emergencies which impact safety, reliability, the environment or Transgrid's business, has provided a guide to the possible level of media coverage which could result from an incident.

The following Incident Levels defined in the CREMP/PSERP relate to the levels of media coverage listed in the table above:

- Level 1 - Board Request, involving management by the Corporate Communications team

- Level 2 - Local Media, involving management by the Corporate Communications team, the Executive and the Board
- Level 3 - State Media, involving management by the Corporate Communications team, the Executive, the Board and the Asset Monitoring Centre
- Level 4 and Level 5 - National Media, involving management by the Corporate Communications team, the Executive, the Board and the Asset Monitoring Centre.

B.6 Customer Consultation

Relevant Consequence Areas:

- Reputation

The values are set in dollars.

Table 29 – Customer Consultation - standard values

Level	Value	Typical Event
Minimal e.g. media briefing / website	$3,000	< 0.25 system minute event
Moderate consultation e.g. letter drops	$30,000	Major customer impact
Major consultation e.g. door knocks	$75,000	Widespread area reliability event
Extensive Consultation	$100,000	Major system shutdown

B.7 Customer Contacts

Relevant Consequence Areas:

- Reputation

The values are set in dollars.

Table 30 – Customer Contacts - standard values

Level	Value	Typical Event
20 to 50% increase	$3,500	< 0.25 system minute event
50 to 100% increase	$7,500	Major customer impact
100 to 250% increase	$15,000	Widespread area reliability event
> 250% increase	$25,000	Major system shutdown

B.8 Value of Customer Reliability

Relevant Consequence Areas:

- Reliability

The values are set in dollars[4] and are in accordance with AER (2019)[5].

Table 31 – Customer Type - standard values

Level	Value ($/ MWhr)
Mixed / Unknown	$45,060
Directly Connected Customer	$26,440

In the majority of cases mixed/unknown is used apart from directly connected customers.

B.9 Injury

Relevant Consequence Areas:

- Safety

The concept of value of statistical life evaluates trade-offs between money and fatality risks. The estimation of the value of a statistical life is generally based on econometric modelling approaches. Estimates of the value of a statistical life vary, based on context, the explanatory variables of the developed econometric model and the data set being investigated. Therefore, the value of a statistical life cannot be considered as a single estimate with universal application[6]. Empirical studies relevant to Australia referenced by an Australian Government paper[7] estimates the value of a statistical life to range from $3,000,000 to $15,000,000. Estimates of the value of statistical life from studies reviewed by the Australian Safety and Compensation Council[8] (currently Safe Work Australia) ranged from $2,870,000 to $28,400,000.

A value of $5,000,000 has been adopted for the standard consequence value for a fatality. This value aligns with the Best Practice Regulation Guidance Note[8].

Table 32 – Injury - standard values[9]

Level	Value
Minor Injuries	$50,000
Moderate Injuries	$500,000
Extensive or Severe (Major) Injuries	$1,500,000
Fatalities	$5,000,000

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4 Dollar values provided are in FY19.
5 AER (2019). *Values of Customer Reliability: Final report on VCR values.* Australian Energy Regulator.
6 Viscusi, W.K. and Aldy, J.E. (2003). *The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. Working Paper 9487.* National Bureau of Economic Research Working Paper Series. National Bureau of Economic Research.
7 Department of the Prime Minister and Cabinet, Office of Best Practice Regulation (2014). *Best Practice Regulation Guidance Note: Value of statistical life*. Australian Government, Canberra.
8 Department of the Prime Minister and Cabinet, Office of Best Practice Regulation (Aug 2020). *Best Practice Regulation Guidance Note: Value of statistical life*. Australian Government, Canberra.
9 All Dollar values provided in FY20

B.10 Air Impact Costs

Relevant Consequence Areas:

- Environment

A value of $1000/kg is used for the release of SF6.

B.11 Land or Water Clean Up

Relevant Consequence Areas:

- Environment

The values are set using a consequence value and a scaling factor.

Table 33 – Land or Water Clean Up - Oil Volume Scale Factors

Volume of Oil	Scale Factor
0- 30,000L	0.6
30,000 – 50,000L	0.8
50,000 – 100,000L	1.0
100,000L	1.2

Table 34 – Land or Water Clean Up - Impact Region Size Scale Factors

Impact Region Size	Scale Factor
Site Only	1
Localised Off Site impacts (this factor is applicable for underground self-contained fluid filled cable)	5

Table 35 – Land or Water Clean Up – Site Sensitivity standard values

Site Sensitivity	Value
Low	$50,000
Medium	$150,000
High	$300,000

Appendix C ALUM Classification Mapped to Land Use Categorisation

Figure 6 – ALUM Classification Mapped to Land use Categorisation