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Quantifying and managing the bushfire-related risks posed by powerlines

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Synopsis

1. Powerlines cause wildfires
2. Powerline-initiated wildfires are more likely to be large and lead to fatalities
3. Mitigations exist: these reduce the likelihood (i.e., the number of fires per year)
4. What is the effect of these mitigations? (i.e., how much risk is eliminated?)
5. How to prioritize investment in mitigation?
6. What did we do in Victoria, Australia?

1. Powerlines cause wildfires

Electrically-initiated wildfires happen

- Vegetation strike (asset damage)
- Vegetation contact (embers on ground)
- Bird and animal contact
- Conductor clash
- Conductor break
- Transformer malfunction
- Lightning strike and arrestor mal-operation
- Fuse mal-operation
- Insulator tracking and pole-top fire
- Loose and failed connections
- Cross-arm and pole failures
- Vehicle and agricultural machinery strikes

Increasing fire likelihood

Wind speed
Wind gust
Vegetation dryness
Humidity
Ambient temperature

Higher fire danger

Electrically-initiated wildfire rates internationally

Chile (in territory of major forestry company):

- 5% electrical
- 90% human (arson and negligence)

Victoria, Australia:

- 2.7% electrical
- Up to 8.9% electrical fires under *total fire ban* conditions

Perth, Western Australia:

- 1.6% electrical
- 55.3% deliberate

2. Powerline-initiated wildfires are more likely to be large and fatal

- Victoria and South Australia:
  - **Over 80% of bushfire fatalities in Australia since 1950 have been due to fires initiated on high-voltage (HV) distribution powerlines**
  - Wimmera 1977: 5 fatalities, all due powerline fires (conductor clash) – *led to installation of spreaders*
  - Ash Wednesday 1983: 75 fatalities (47 in Vic, 28 in SA), 180 fires, $400M losses. Major SA fires due to powerlines – *led to 1200km covered conductor, asset hardening, and right to de-energize lines*
  - Black Saturday 2009: 173 fatalities (159 in powerline fires), $4B damage – *led to more than $750M in interventions in undergrounding, asset hardening, REFCL*
- Chile:
  - January 2017 – more than 500,000 Ha impacted (90,000 Ha forest plantation, $500M USD)
  - 11 lives lost, 1100 homes destroyed
  - Several alleged powerline fire starts – court trials for power company executives
- California:
  - Multiple major fires in 2010s
  - Powerlines implicated disproportionately

Why is this?

- **We do not know**
- Some evidence from data analysis in Victoria

2015 catastrophic fires study

- Hypothesis #1 – *electrical fires occur in difficult locations* – not supported
- Hypothesis #2 – *electrical fires have more rapid escalation* – partly supported

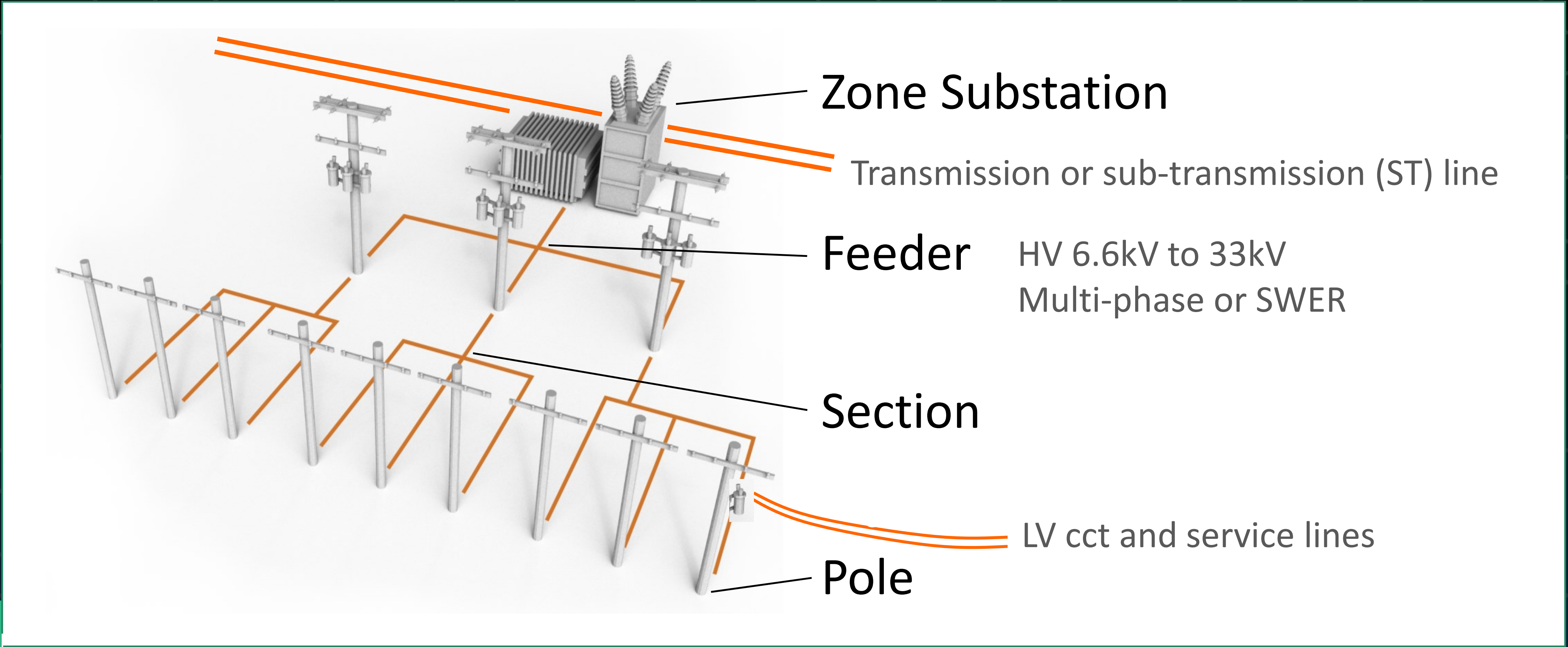
There was no single infrastructure, meteorologic, or ground situation conditions that could be attributed as causing these six fires… occurring:

- *in flat grassland areas;*
- *with SWER lines potentially being over-represented relative to their prevalence on networks;*
- *potentially near wooden poles;*
- *multiple faults recorded in nearby space and time;*
- *when there were sustained winds above 30km/hr;*
- *when drought index and drought factor were relatively high; and*
- *across a relatively wide range of temperatures and humidities.*

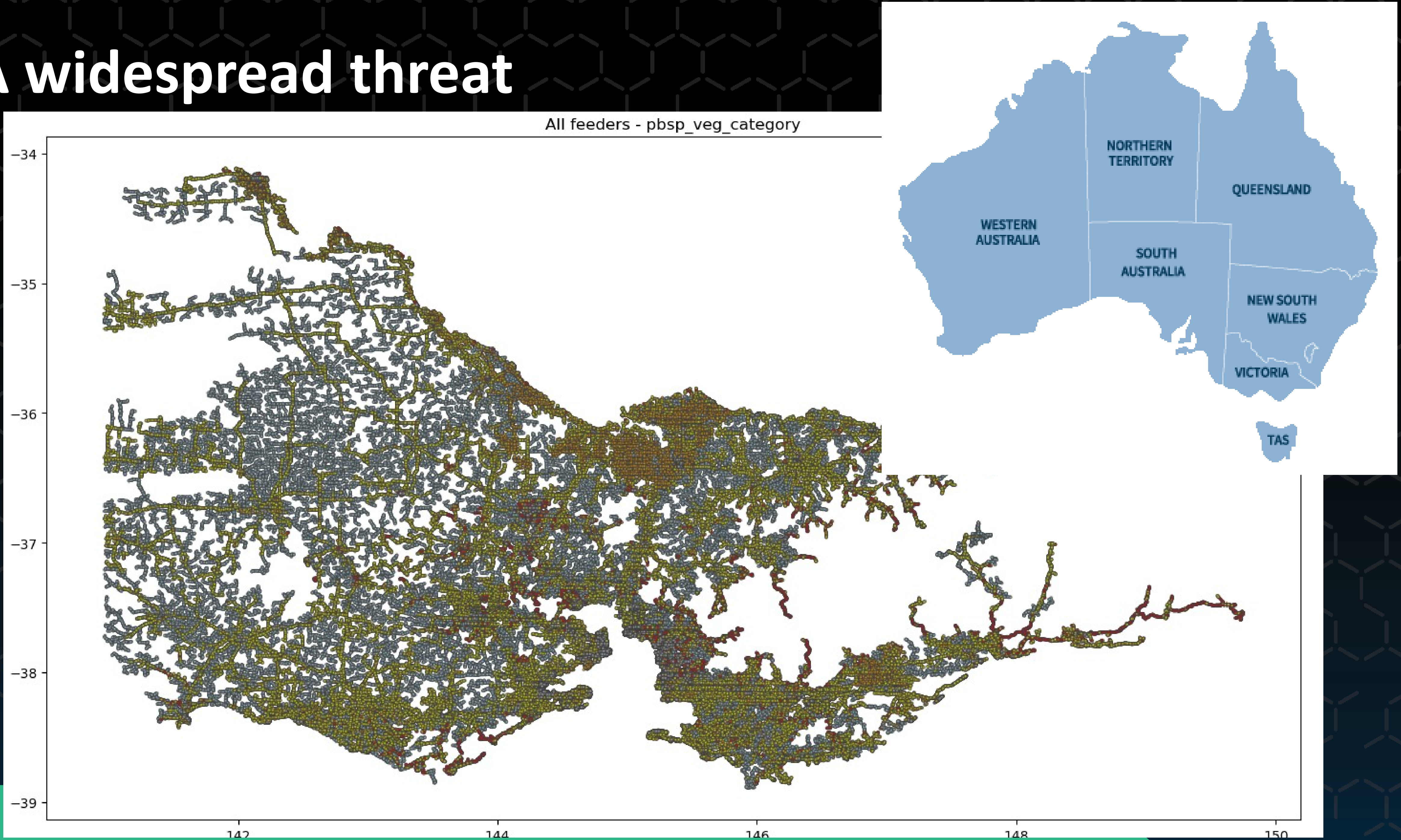
… many of the ignitions occurred near to wooden poles, possibly some with wooden cross-arms … up to 100% possibly occurred near or on lines with wooden poles … there were multiple faults occurring on lines near to where the fires ignited … in up to 5/6 of the fires considered … all of the fires of interest occurred in areas that primarily have grassland vegetation. Most had a few trees interspersed, but the amount, and amount they would interact with powerlines was variable. With the exception of one fire, the fires ignited on flat landscapes.

Electrical distribution

- High Voltage electrical distribution lines (VIC Au: mainly 22kV 3ϕ and 12.7kV 1ϕ)
- Sub-transmission and transmission built and maintained to different standard



A widespread threat



3. Mitigations

- Reducing the **likelihood** of a fire ignition

Threat management

Vulnerability management

Electrical Protection

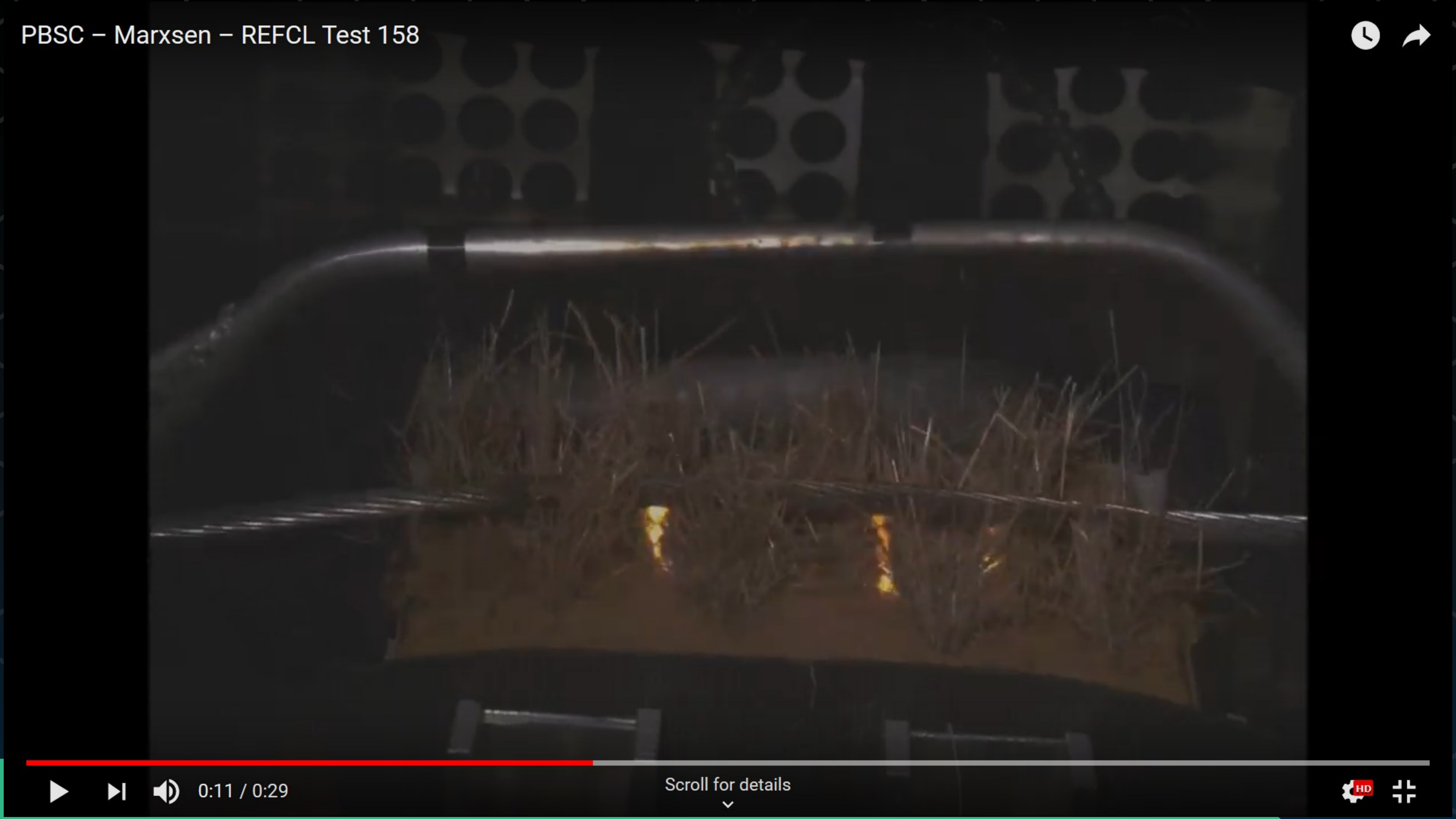
Vegetation clearance	Pole
Bird covers and other bare metal insulation	Pole
Crash barriers, visibility aids, bark catchers	Pole
Spreaders, dampeners, armour rods	Pole
Asset condition	Pole
Covered conductor	Section
Undergrounding	Section
Fuse and arrestor replacement	Section
Automatic Circuit Reclosers (ACR)	Section
Rapid Earth Fault Current Limiters (REFCL)	Feeder
Early Fault Detection (EFD)	Section

https://www.youtube.com/watch?v=JCFQJFrVkSQ

Ignition reduction effect of REFCL

https://www.youtube.com/watch?v=Q1MNBV48x0Q

Ignition reduction effect of REFCL



4. Quantifying the effect of these mitigations

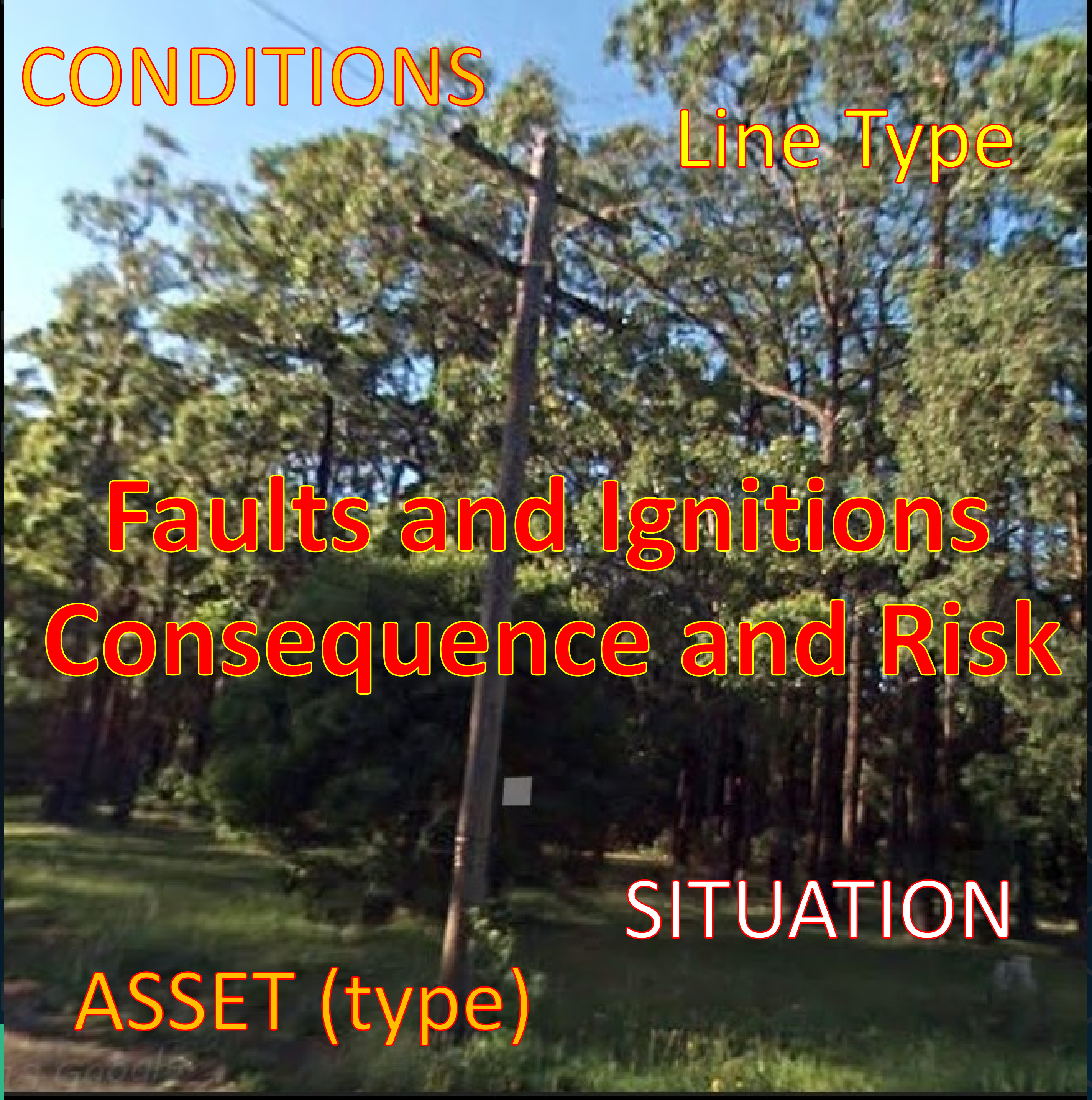
- **Quantified Risk** as **[Consequence × Likelihood]**
- Likelihood and consequence vary pole-to-pole
- Escalation: threat >> fault >> asset ignition >> ground ignition >> small fire >> large fire
- Some threats operate on a poles basis, others on a spans basis
- Quantify likelihood for old and new types of asset
- **Risk Reduction Model**
  A. FAULTS MODEL. Estimating (pre-ignition) electrical fault rates using historical data on faults on bare wire assets.
  B. FAULT TO IGNITION MODEL. Converting pre-ignition electrical fault rates into fire ignition rates.
  C. FUTURE ASSETS MODEL (FAM). Estimating electrical fault rates and ignition rates for alternative asset types.
  D. RISK CALCULATION. Using the other model components and pre-computed **bushfire consequence data** to create estimates of current and future bushfire powerline risk.

(A) Fault rates

Quantify the rate of faults* as a function of

- ASSET CONSTRUCTION AND ELECTRICAL PROTECTION (incorporates mitigations)
- METEOROLOGICAL CONDITIONS
- SITUATION
- FAULT CAUSE
- FAULT IMPACT

(* ignitions per million pole days or per million km.days)



HV fault rates in cleaned data

- Analysis of around 45,000 electrical faults

Class	Description	Proportion of Faults 2007-2013	Fault Reduction 22kV Insul OH
A	Animal/Bird	49%	100%
C	Public Tree	8%	83%
D	Deterioration	7%	58%
E	Private Tree	1%	89%
F	Malfunction	6%	31%
H	Human	1%	83%
N	No fault *	<1%	
U	Unclassified *	1%	
W	Weather	26%	74%

Electrical equipment damage

The damage to the equipment is important from a wildfire point of view because it gives insight into ignition mechanisms

	Damage	No Damage
A (Animals and Birds)	3%	46%
C (Public Tree)	3%	3%
D (Deterioration)	6%	1%
E (Private Tree)	0%	0%
F (Malfunction)	4%	2%
H (Human Activity)	2%	4%
W (Weather)	4%	22%
Grand Total	22%	78%

Damage	Count
BF (Broken flex)	234
CB (Conductor Breakage)	919
CL (Connection Loose)	118
CT (Cable Tie Failure)	80
DB (Broken or Burnt D)	67
EF (Transformer Earth failure)	26
FE (Fuse EDO tube damaged)	381
IF (Insulator Failure)	73
LA (Surge Diverter Failure)	504
OT (Other (Detail in comments))	4321
PB (Pole Broken)	130
SW (Switch or Isolator Failure)	101
TE (Transformer Electrical Failure)	1705
UC (Underground cable failure)	135
XB (X-arm Broken)	566

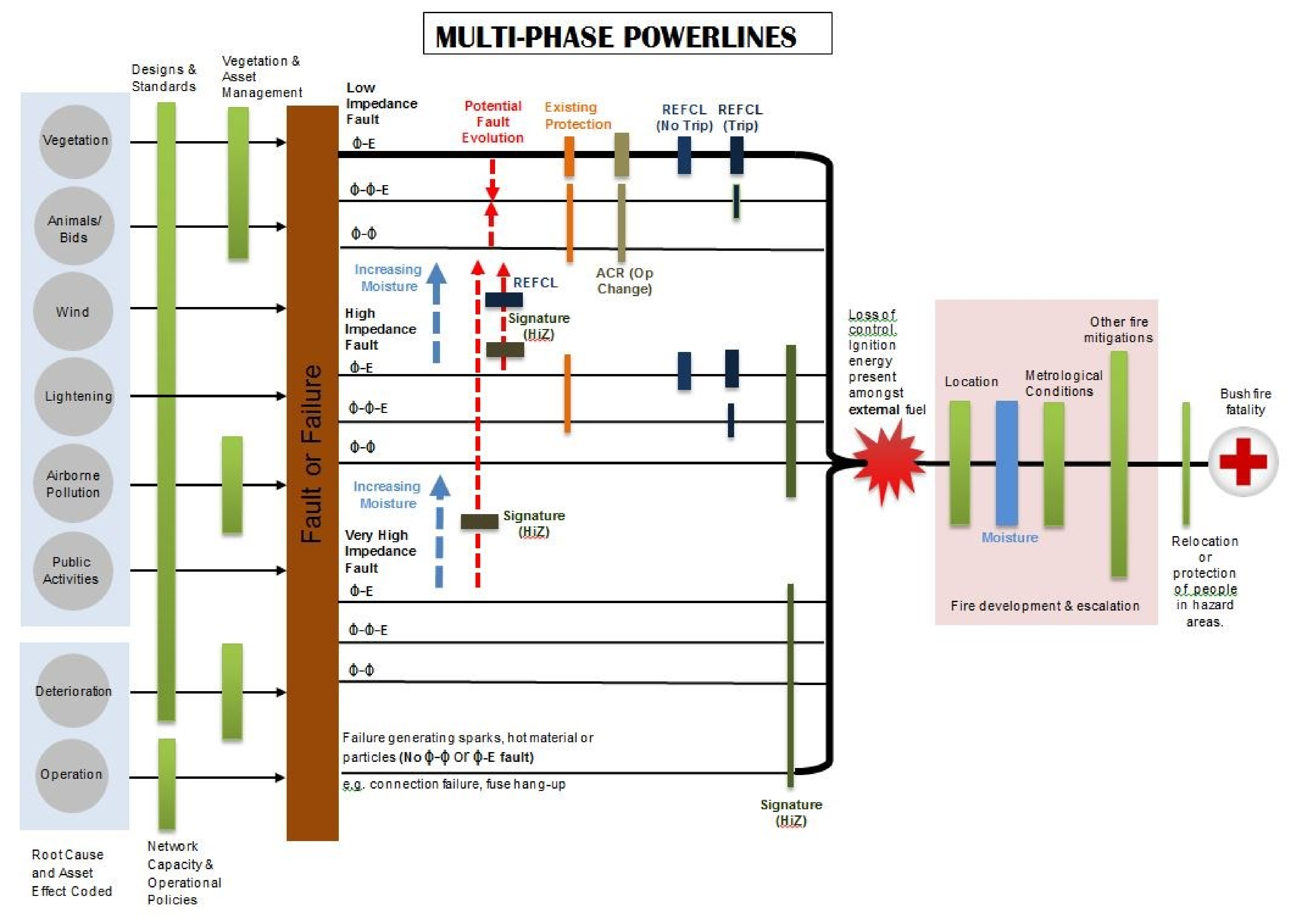
(B) Faults to ignitions

- Analysis of 772 ignitions in Victoria between 2006 and 2013
- Linked meteo, fault and fire data

Line Type	Cause Class	Fire Danger Rating						
		Not Forecast	Low-Moderate	High	Very High	Severe	Extreme	Code Red
22kV	Animals & Birds (A)	0.42%	0.93%	1.26%	1.07%	1.07%	1.07%	1.07%
	Deterioration (D)	2.11%	5.76%	12.59%	12.75%	5.33%	5.33%	5.33%
	Malfunction (F)	3.64%	5.48%	5.14%	5.32%	5.32%	5.32%	5.32%
	Human Activity (H)	0.21%	1.27%	2.61%	2.61%	2.61%	2.61%	2.61%
	Network (N)	0.21%	1.07%	1.07%	1.07%	1.07%	1.07%	1.07%
	Vegetation (T)	0.67%	1.88%	3.12%	4.57%	4.57%	4.57%	4.57%
	Unclassified (U)	0.21%	0.42%	0.32%	0.32%	0.32%	0.32%	0.32%
	Weather (W)	0.45%	1.28%	0.95%	1.22%	1.22%	1.22%	1.22%
SWER	Animals & Birds (A)	0.23%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
	Deterioration (D)	3.73%	3.67%	5.99%	5.99%	5.99%	5.99%	5.99%
	Malfunction (F)	3.25%	4.92%	6.47%	6.47%	6.47%	6.47%	6.47%
	Human Activity (H)	0.23%	12.50%	12.50%	12.50%	12.50%	12.50%	12.50%
	Network (N)	0.23%	5.88%	5.88%	5.88%	5.88%	5.88%	5.88%
	Vegetation (T)	0.23%	7.02%	7.02%	7.02%	7.02%	7.02%	7.02%
	Unclassified (U)	0.23%	0.17%	0.17%	0.17%	0.17%	0.17%	0.17%
	Weather (W)	1.00%	0.72%	1.39%	1.39%	1.39%	1.39%	1.39%

(C) Future Assets Model

- Quantify a threat barrier diagram
- Estimate relative likelihood reduction due to mitigations
- Assimilate field data, math model and lab experimental data



Average likelihood reduction in flat-terrain grassland, under worst-case conditions

Reduction varies spatially and with fire weather conditions

The percentage reductions are sensitive to local conditions, asset condition and model parameters and so **these values are indicative only**

REFCL ignition reduction effectiveness estimated to be in 50% to 60% range

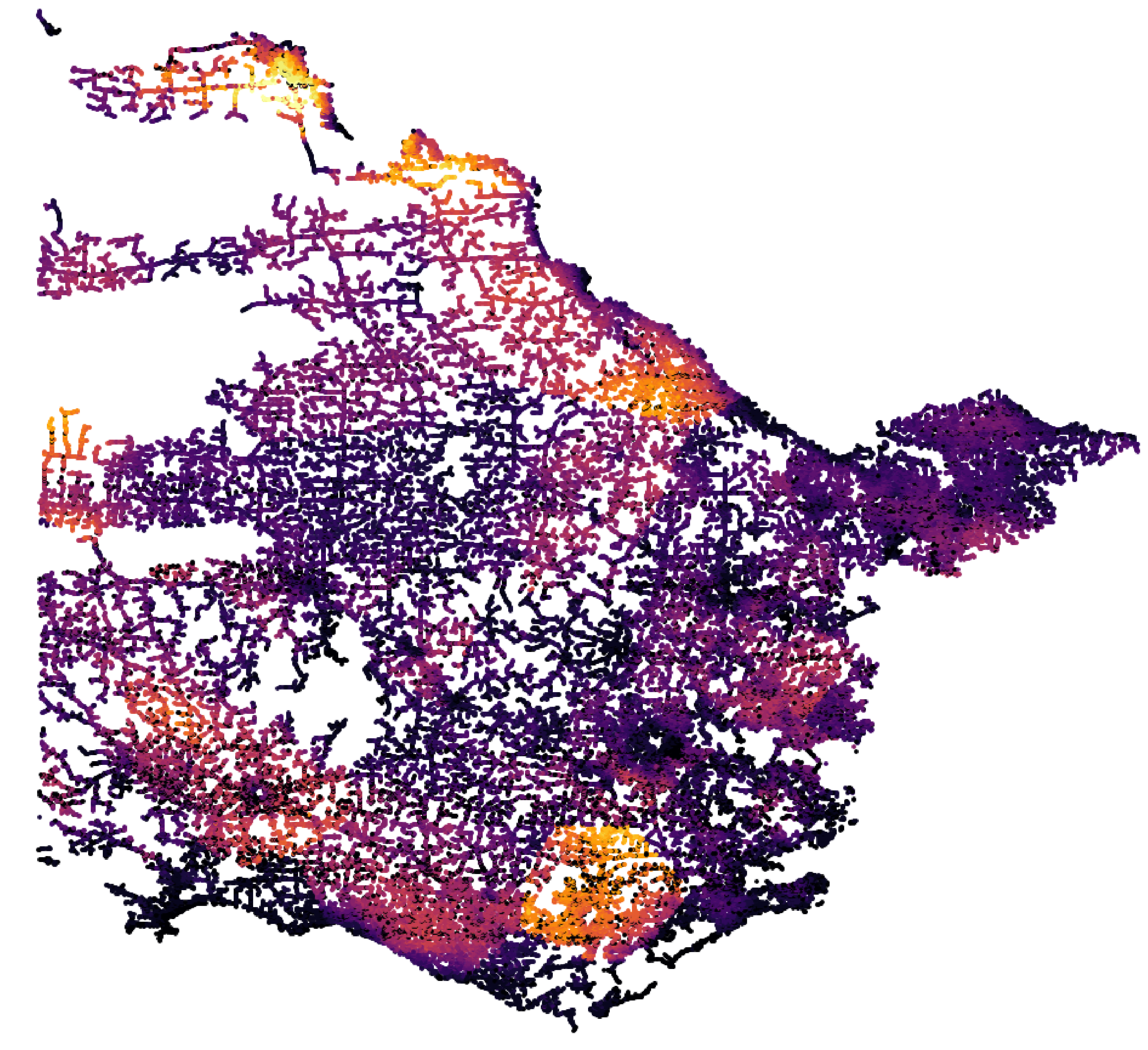
Covered conductor and undergrounding effectiveness estimated to be in 97.5% to 99.8% range

Asset construction	Ignitions Reduction	Ground Fires Reduction
22kV Bare	**0.0%**	**0.0%**
22kV Bare & ACR Op Change	**8.0%**	**7.3%**
22kV Bare & REFCL	**58.7%**	**60.1%**
22kV Bare, REFCL & ACR	60.7%	61.7%
22kV Insulated OH Bare Eqpt w ACR	98.8%	98.7%
22kV U/G Bare Eqpt w ACR	98.8%	98.7%
22kV Insulated OH Insul Eqpt w ACR	99.4%	99.1%
22kV U/G Insul Eqpt w ACR	**99.5%**	**99.3%**
22kV Insulated OH Bare Eqpt w ACR & REFCL	99.6%	99.5%
22kV U/G Bare Eqpt w ACR & REFCL	99.6%	99.5%
22kV Insulated OH Insul Eqpt w ACR & REFCL	99.8%	99.7%
22kV U/G Insul Eqpt w ACR & REFCL	99.9%	99.8%

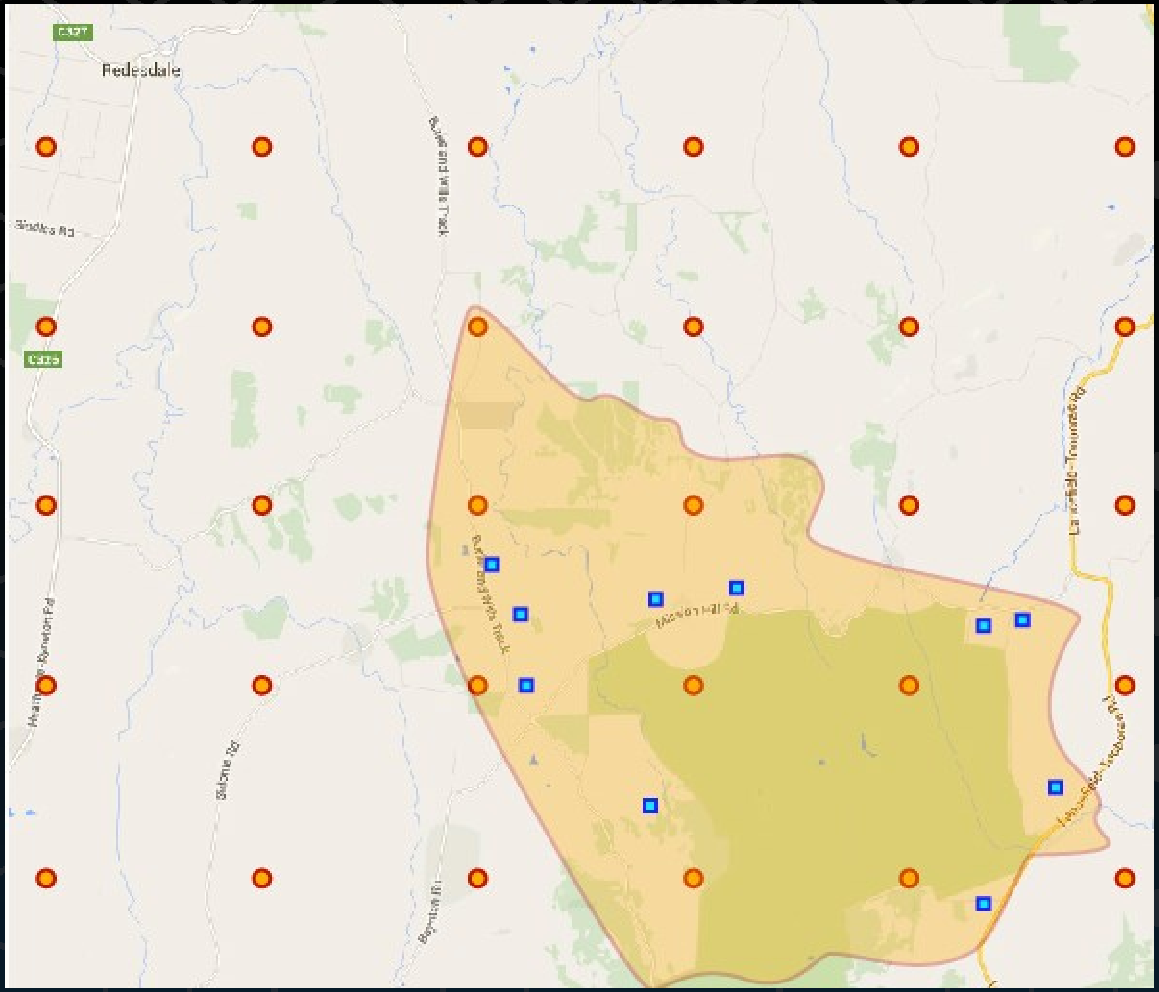
5. Where to prioritize investment in mitigation?

Bare wire and mitigated risk:

- 2.1M fire simulations
- 20M ignition rate data points at (pole, option) level
- Estimation of initial attack success probabilities



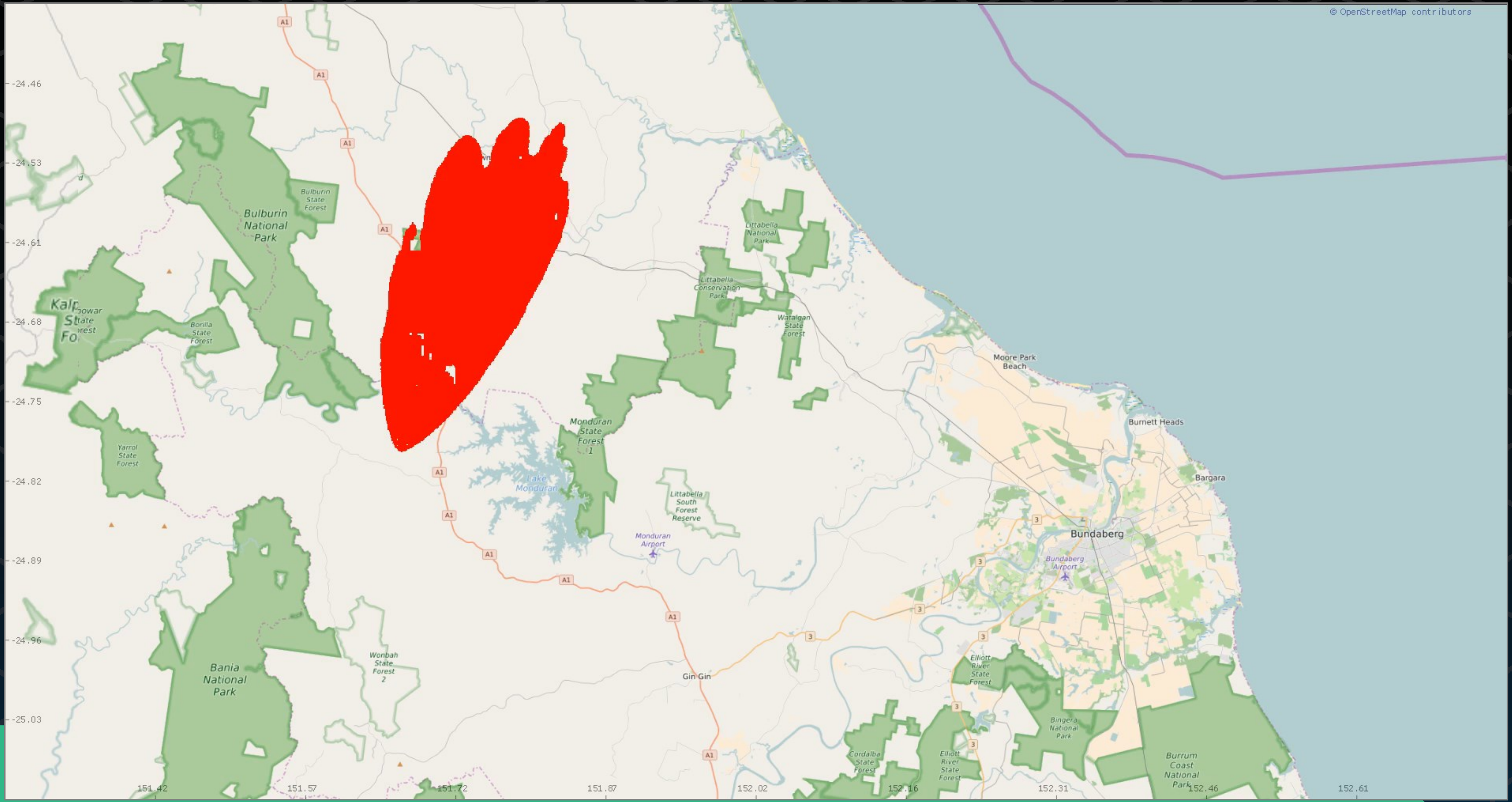
Consequence estimation



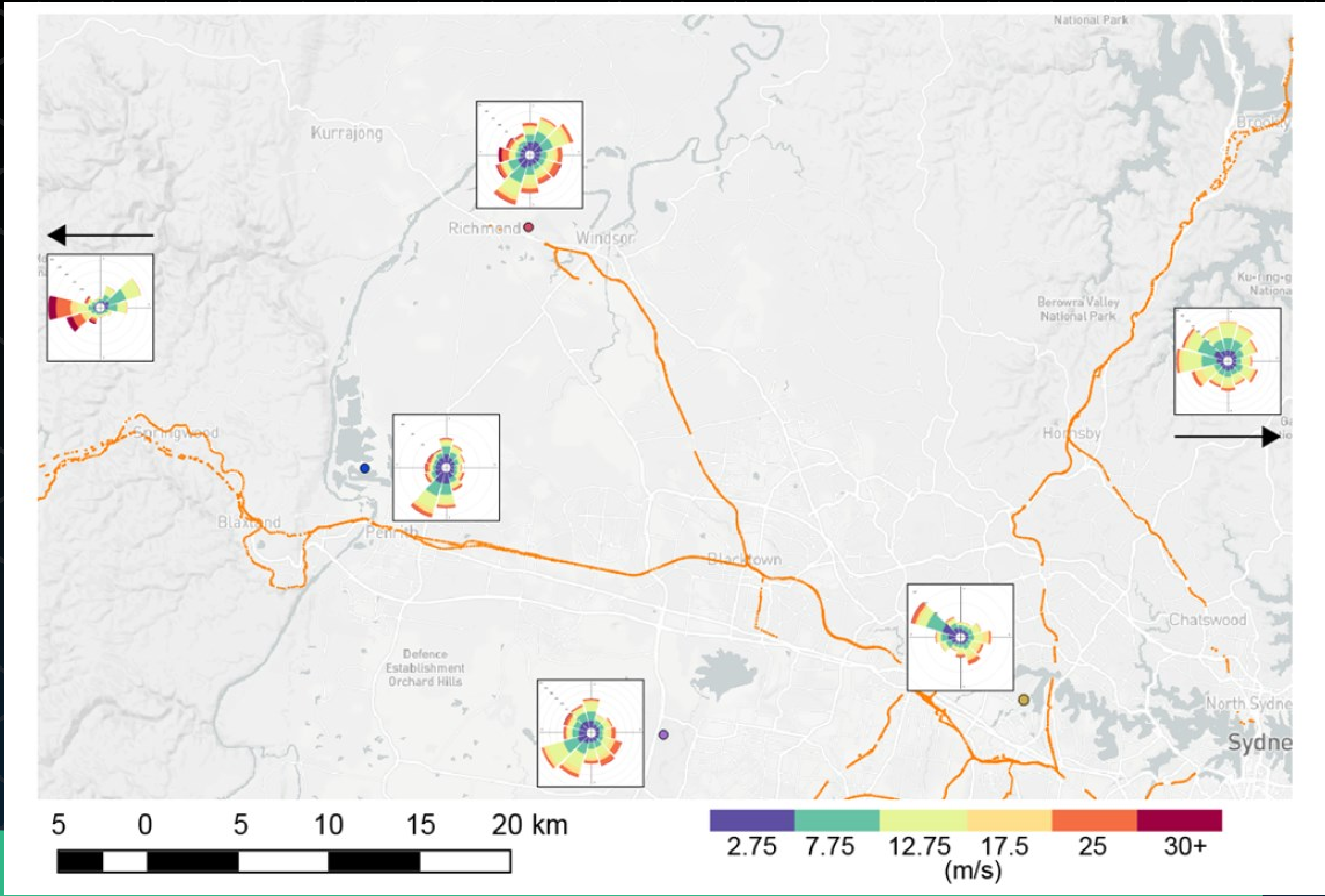
- For explanatory and illustrative purposes only. This diagram is not based on real data.

Probabilistic impact area (due wind variation)

Probability of fire reaching particular location
Colour scale shows probability (red = high)



Meteorological spatial variation



Fire intensity probability mapping

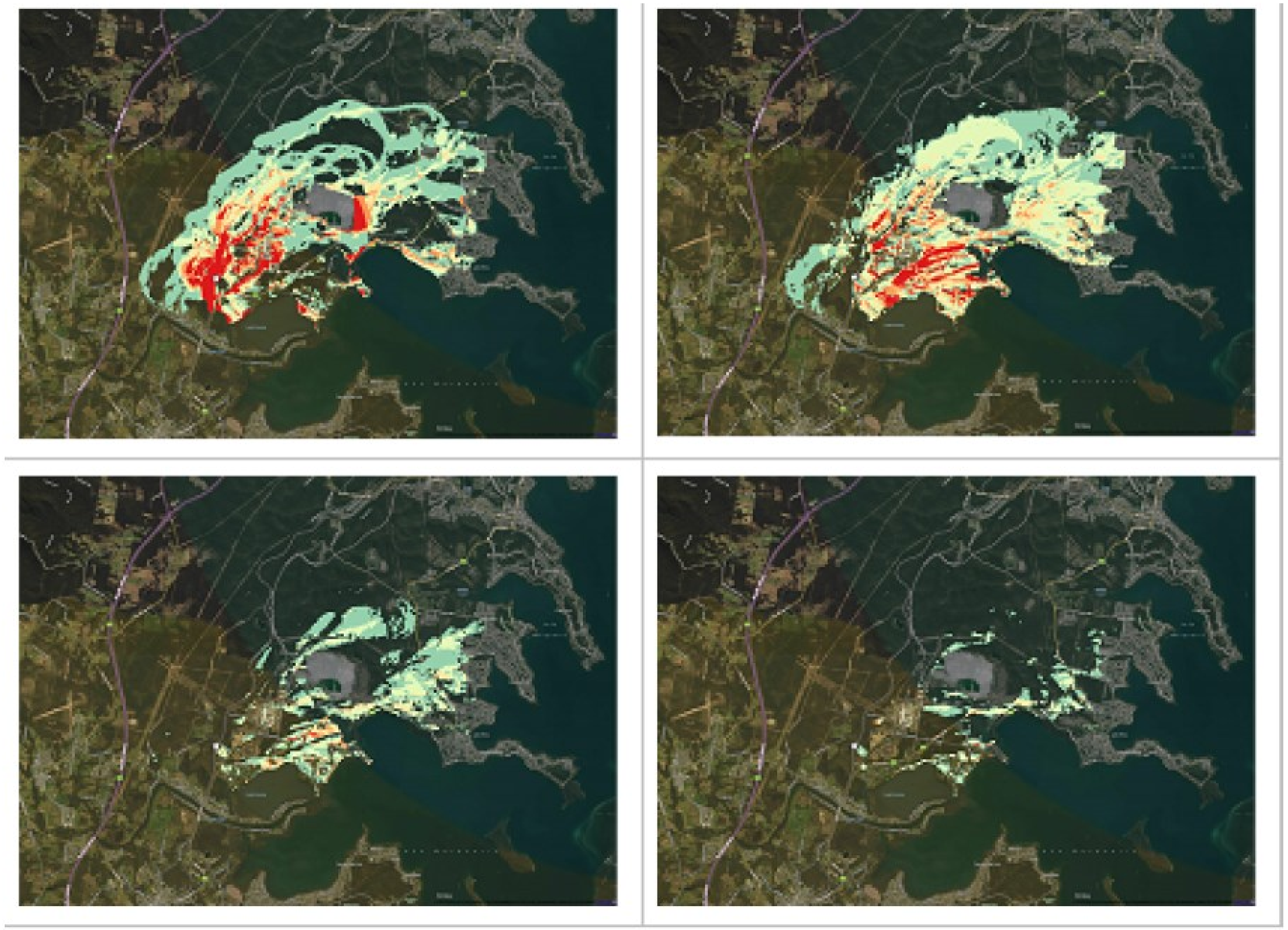
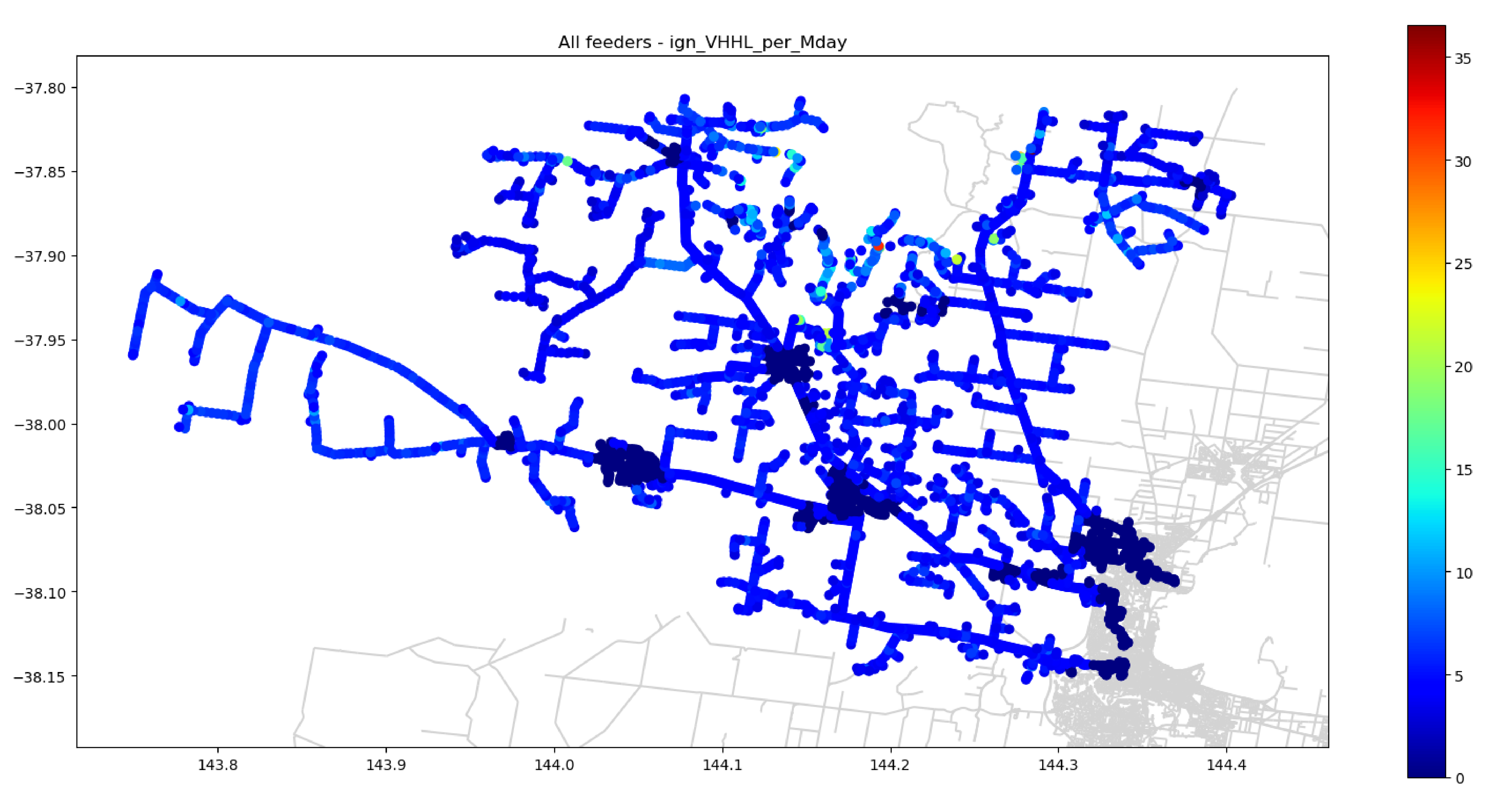
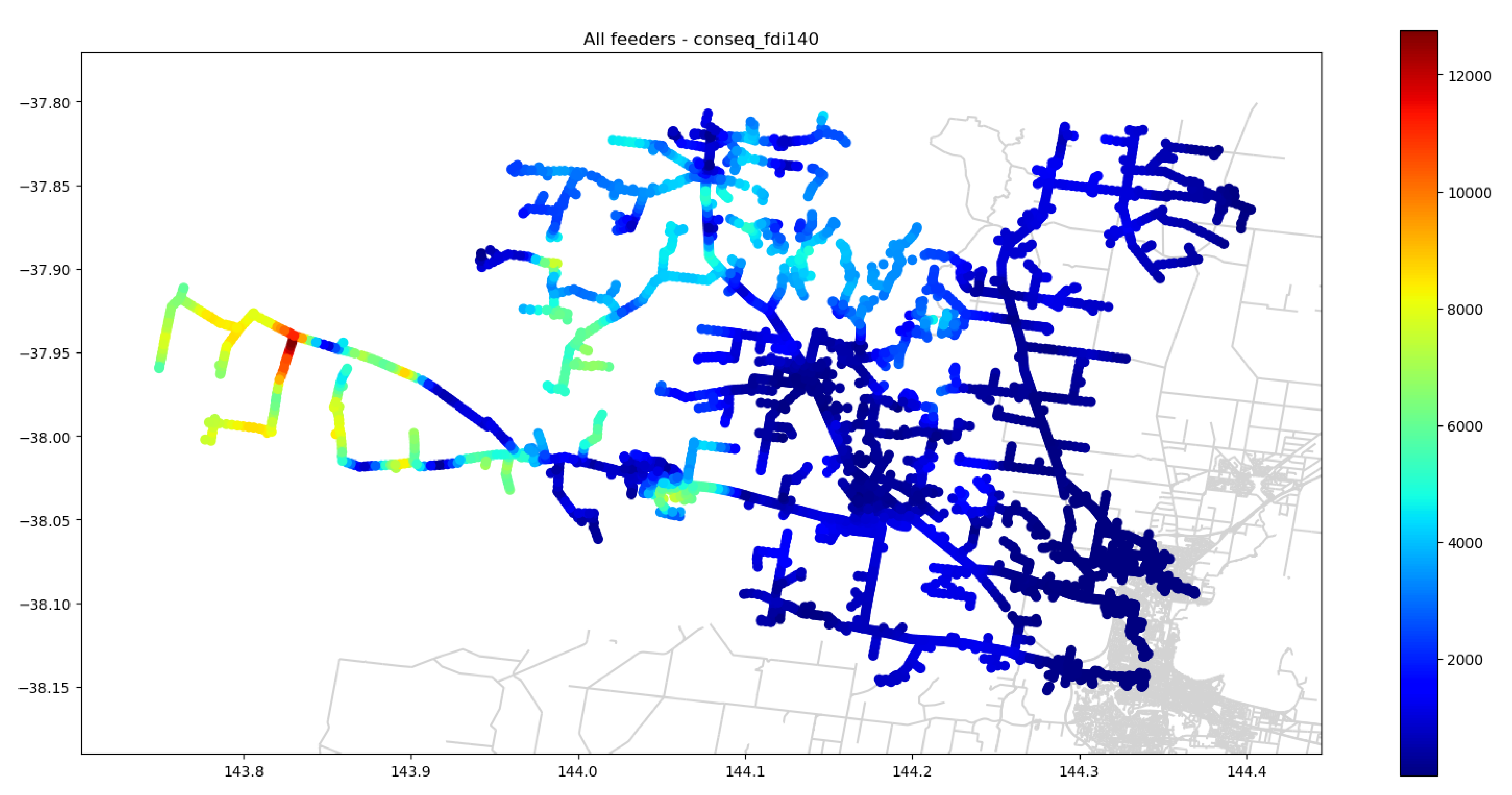


Figure 4.4: Fireline intensity histogram for run 1000 (Pole ID 477114923), FFDI band 4 (worst case). Upper left show probability of impact at low intensity, upper right at medium intensity, lower left at high intensity and lower right at very high intensity. Red is high probability, green is low. Small white star shows ignition location.

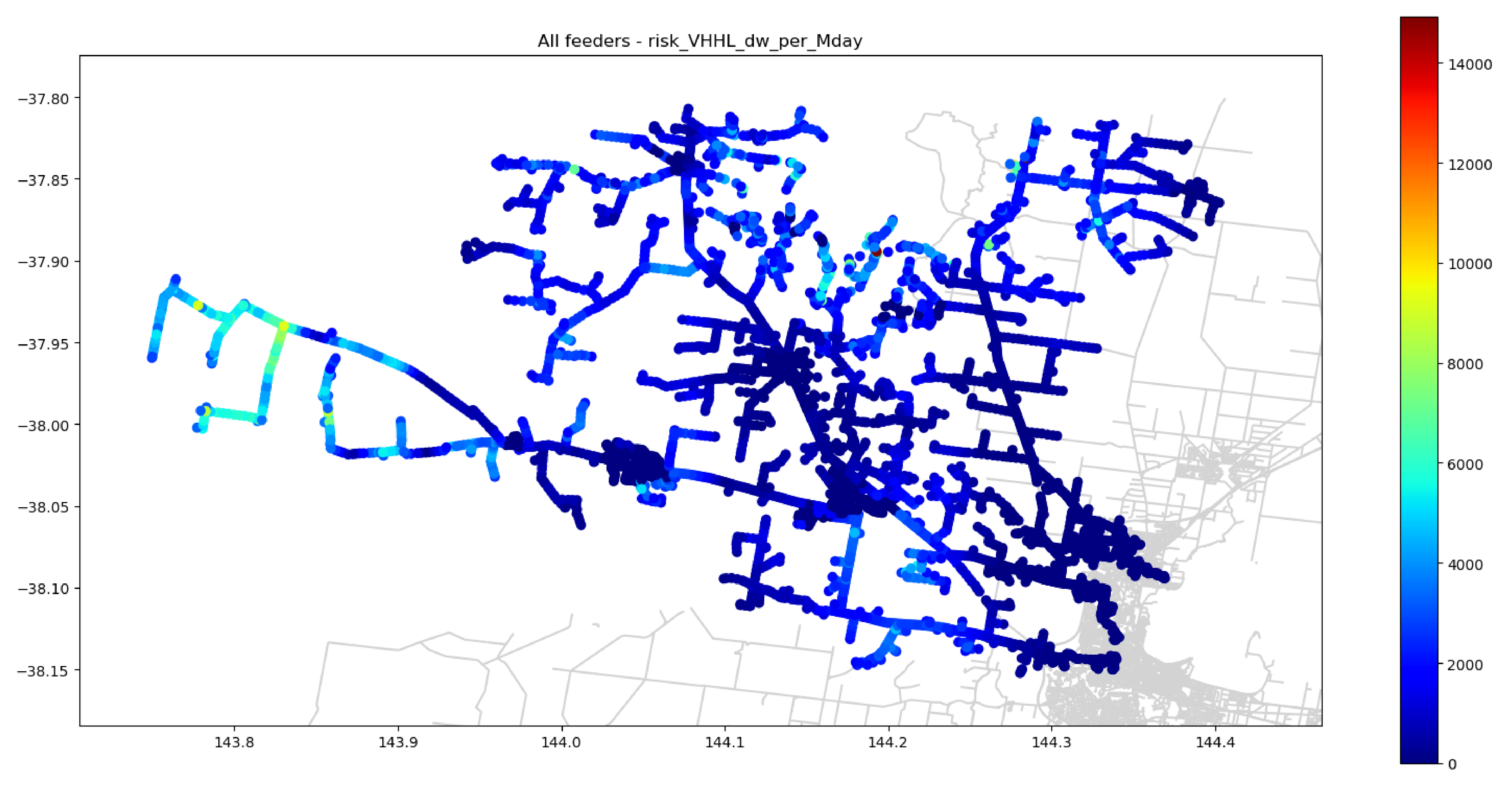
Bare-wire likelihood spatial variation



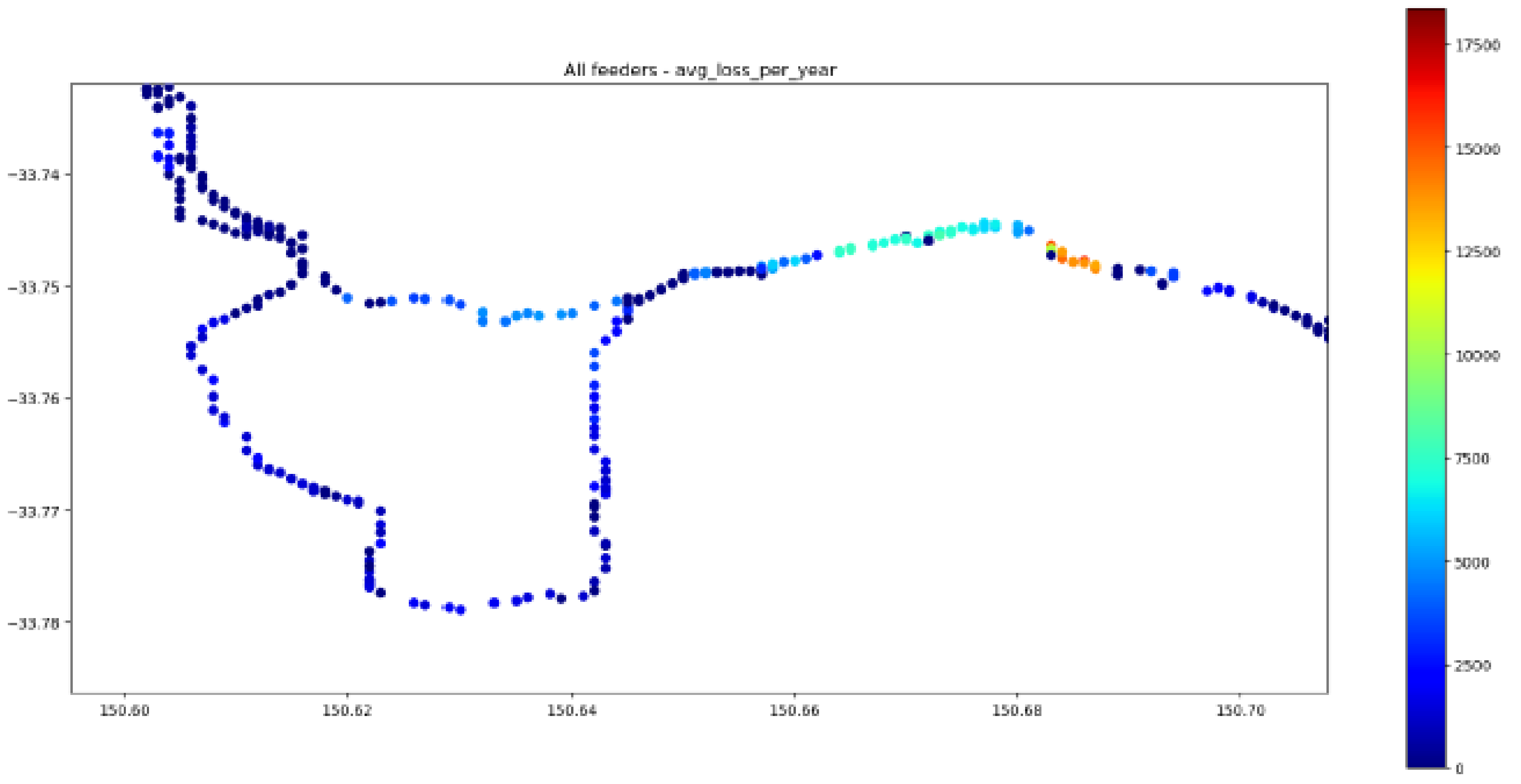
Consequence spatial variation



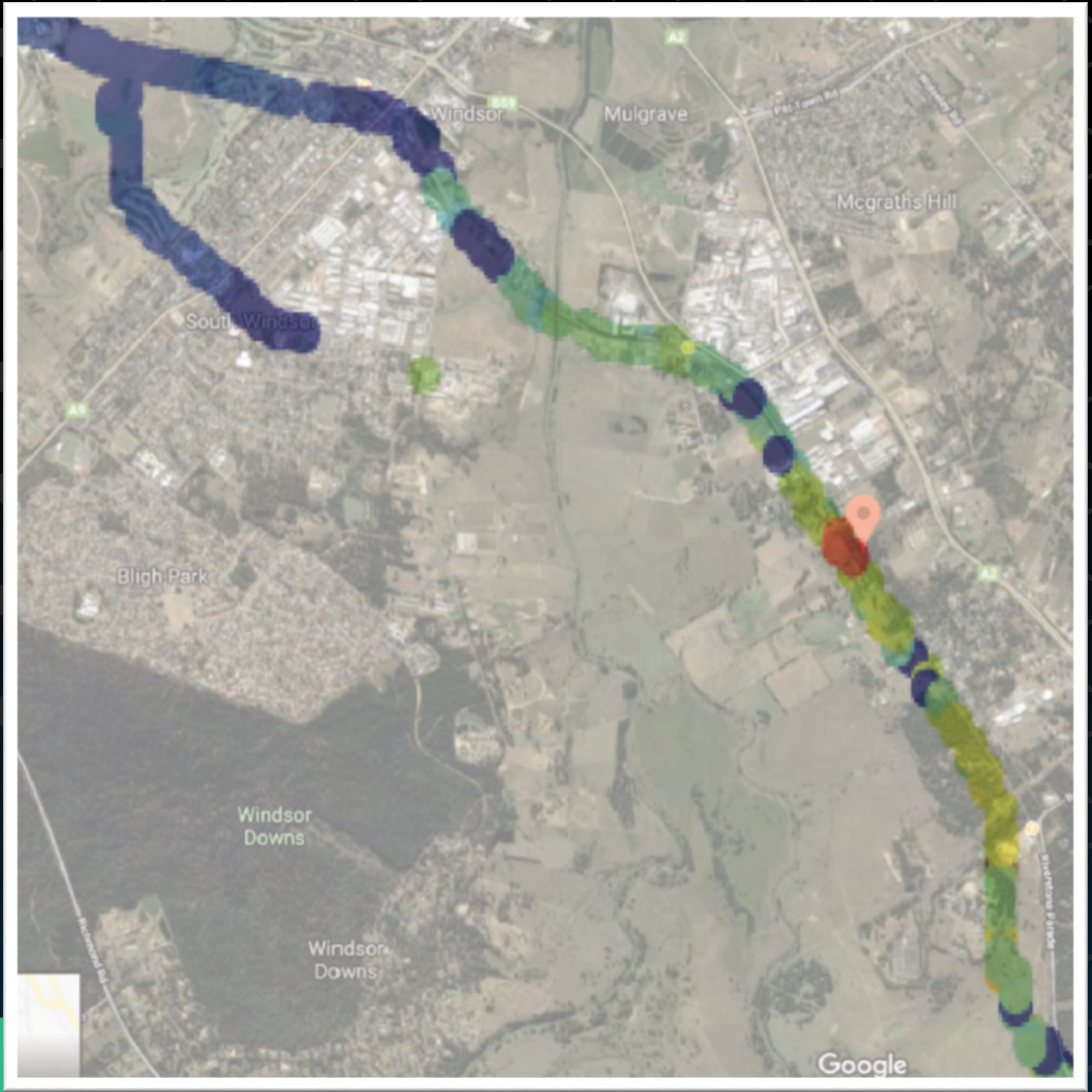
Bare-wire risk spatial variation (structures)



Bare-wire risk spatial variation (value)



Understand and verify risk hotspots



6. What did we do in Victoria?

- Black Saturday, 7 February 2009 (60+ km/h winds, 47°C, 5% RH, almost no fuel moisture)
- Victorian Bushfires Royal Commission (VBRC) chaired by Bernard Teague
- Socio-economic study: consumers would pay around $200 per year for fire reduction
- Powerline Bushfire Safety Taskforce (2011-2012)
- Powerline Bushfire Safety Program (2012-2019)
- Post-PBSP rollout and risk-reduction fine-tuning (2018-)
- Integration with prescribed burning (2019-)

PBSP: policy and regulatory change

- Overall policy position oriented around facilitating data-driven optimized investment profiles, enabled by regulations which communicate technical requirements but moreover ***state the community's risk tolerance and accepted trade-offs***.
- Regulatory change leading to investment in partnership between the state and electricity companies. ***Quantitative risk analytics as a guiding principle***.
- A$200M in targeted powerline undergrounding
  - Locations selected based on quantitative risk assessment
- A$300M+ in staged REFCL rollout across codified areas
  - According to new electrical safety regulations, with sequence based on quantitative risk assessments
  - Final A$100M+ funded from processes overseen by Australian Energy Regulator (AER)
- A$350M on local reliability solutions, private OH lines, consumer subsidy, R&D
- Likelihood and consequence datasets
  - "Official" estimates of fire likelihood reduction due to HV powerlines
  - Used for targeting and in justifying risk-reducing exemptions to regulations
- Financial penalty scheme for electrical fire starts
  - Risk reduction estimates used in "tapering" fire counts over time
  - Expected annual cost and cost variability analysis, for fairness and acceptability
- Emerging national standard in the concepts, approach and data

Spatial targeting

- Quantitative risk data plus the insight of the Emergency Services
  - Additional consideration of population vulnerability
  - Critical assets for protection and escape
  - Resident, daytime and transient populations
- Powerline Replacement Fund and Electric Line Construction Areas
  - Immediate direct investment in undergrounding
  - Upgrading mandatory at life expiry
  - Large penalties for future fire starts in these areas (up to $1M per ignition)
- Low Bushfire Risk Areas (LBRA) and High Bushfire Risk Areas (HBRA)
  - Telemetry-fitted ACRs required throughout HBRA
  - Private Overhead Electric Line replacement in HBRA


Powerline Bushfire
Safety Program
delivering safety
GETTING ON WITH IT!
Project Powerline Replacement Fund – 112km Otway Ranges Works
Contribution $31 million
Completion March 2016
Information www.energyandresources.vic.gov.au/powerlines


Powerline Bushfire Safety Program - working to make communities safer
https://youtu.be/JZVYTkYY2u4
First phase of staged works across Victoria
MORE VIDEOS
Data SIO, NOAA, U.S. Navy, NGA GEBCO
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Data LDEO - Columbia, NSF, NOAA
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Google earth
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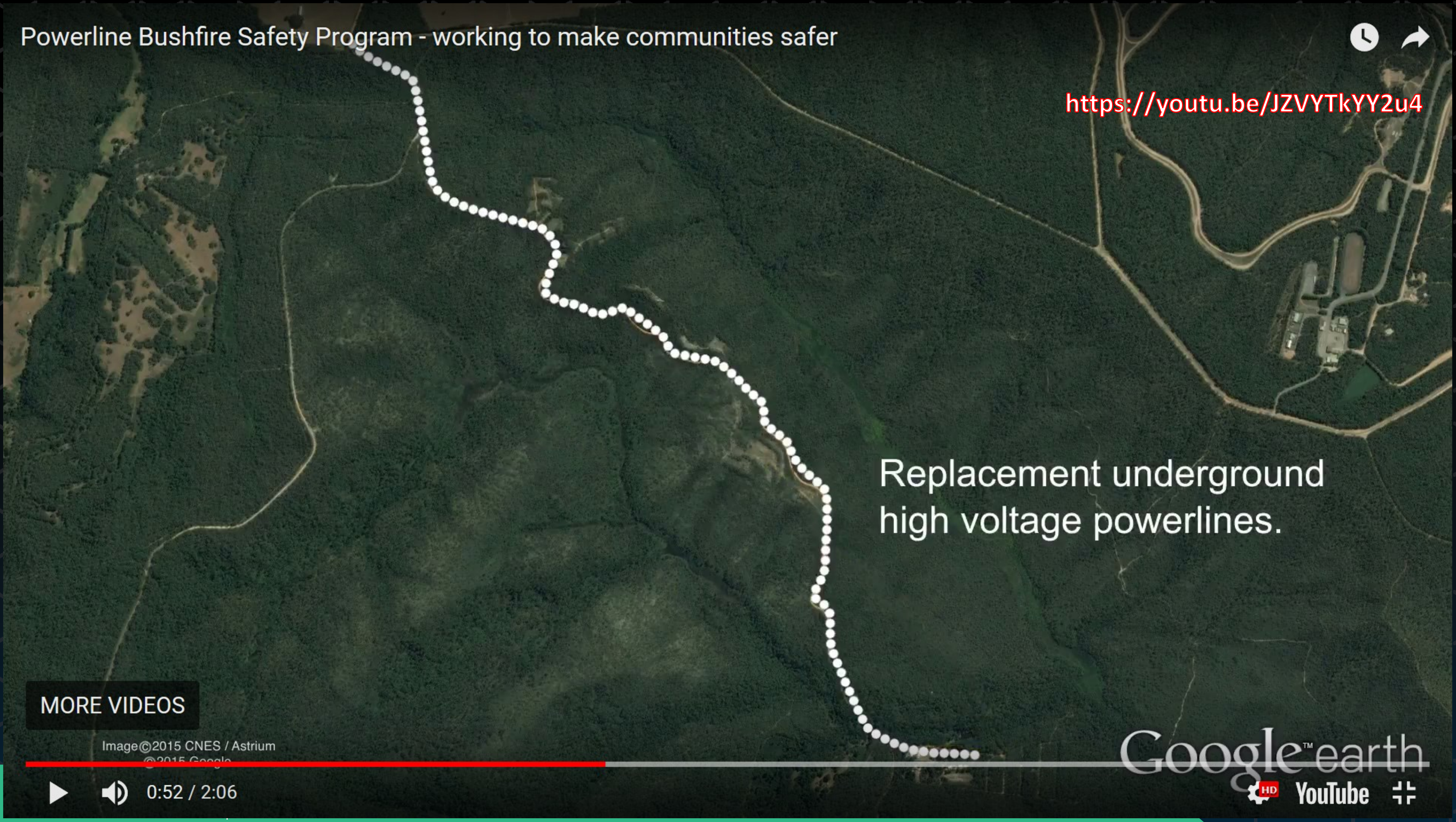
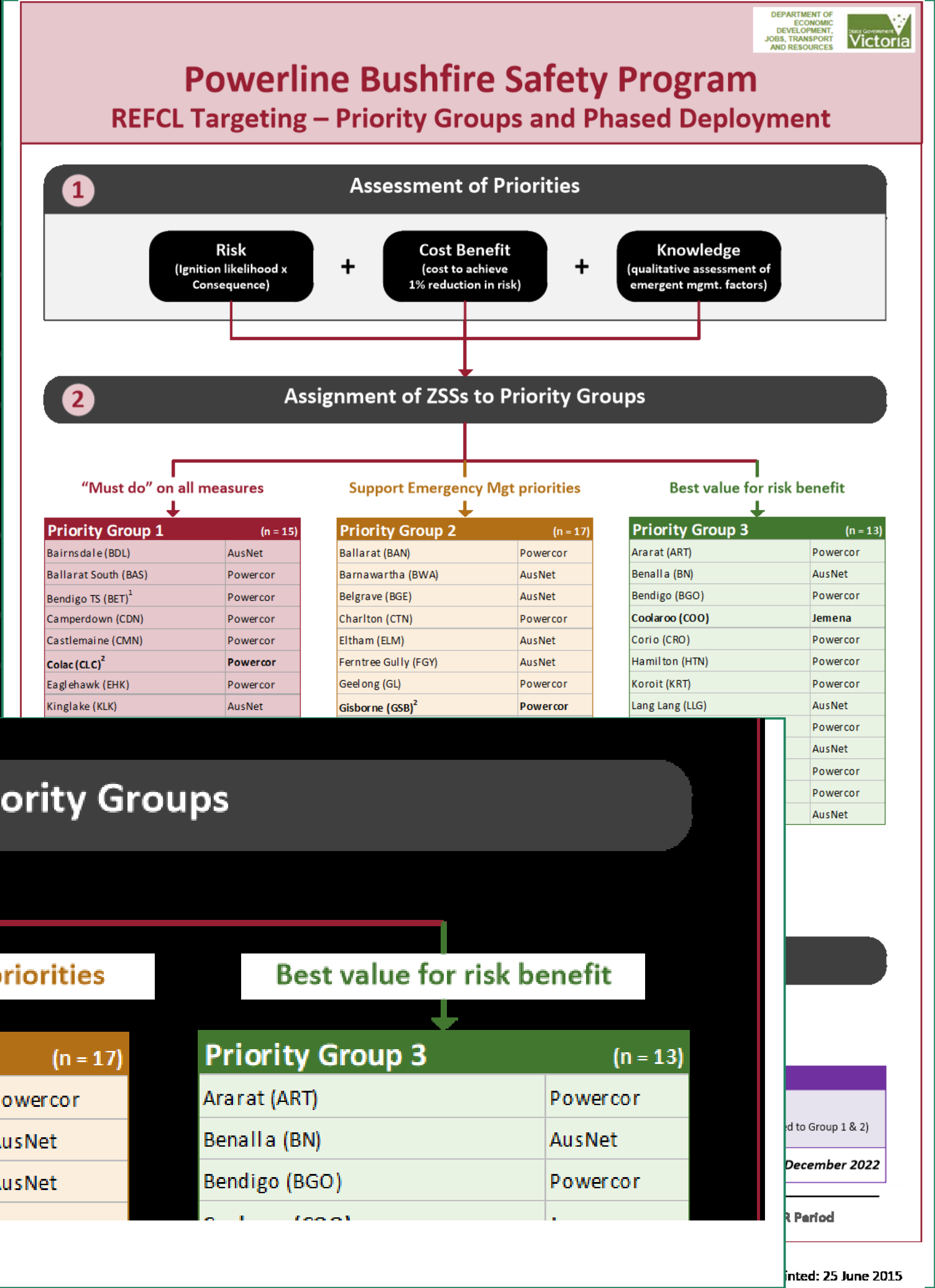
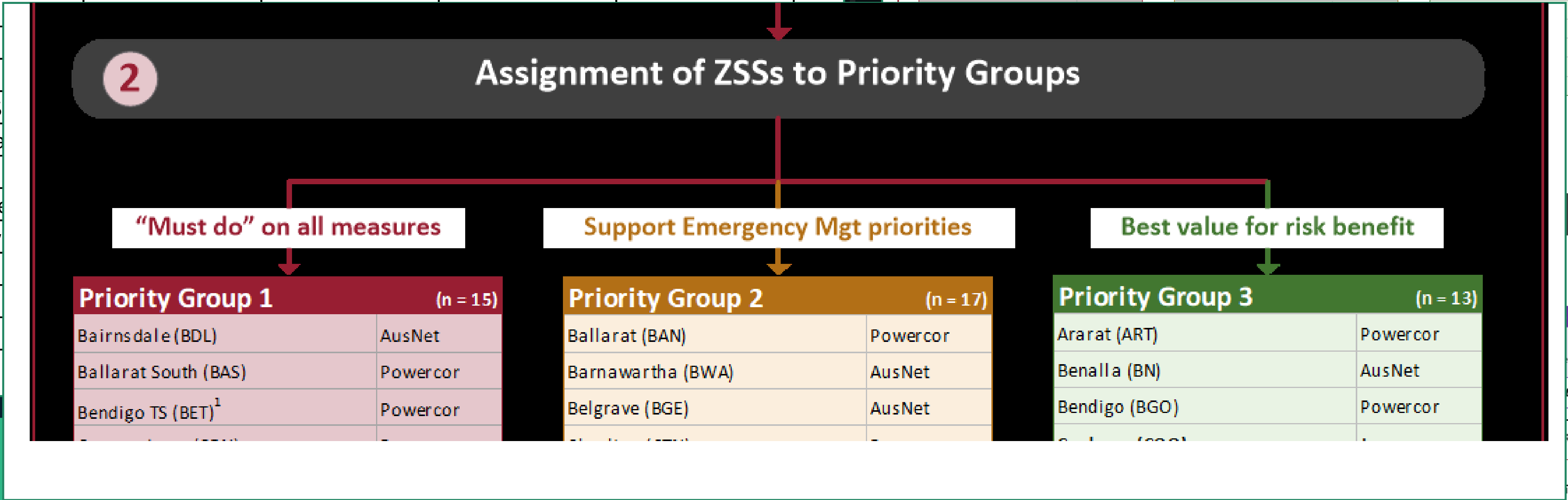

Powerline Bushfire Safety Program - working to make communities safer
https://youtu.be/JZVYTkYY2u4
Replacement underground high voltage powerlines.
MORE VIDEOS
Image©2015 CNES / Astrium
Google earth
0:52 / 2:06
YouTube


Powerline Bushfire Safety Program - working to make communities safer
https://youtu.be/JZVYTkYY2u4
MORE VIDEOS
1:40 / 2:06
HD
YouTube

REFCL zone-substation and feeder ranking

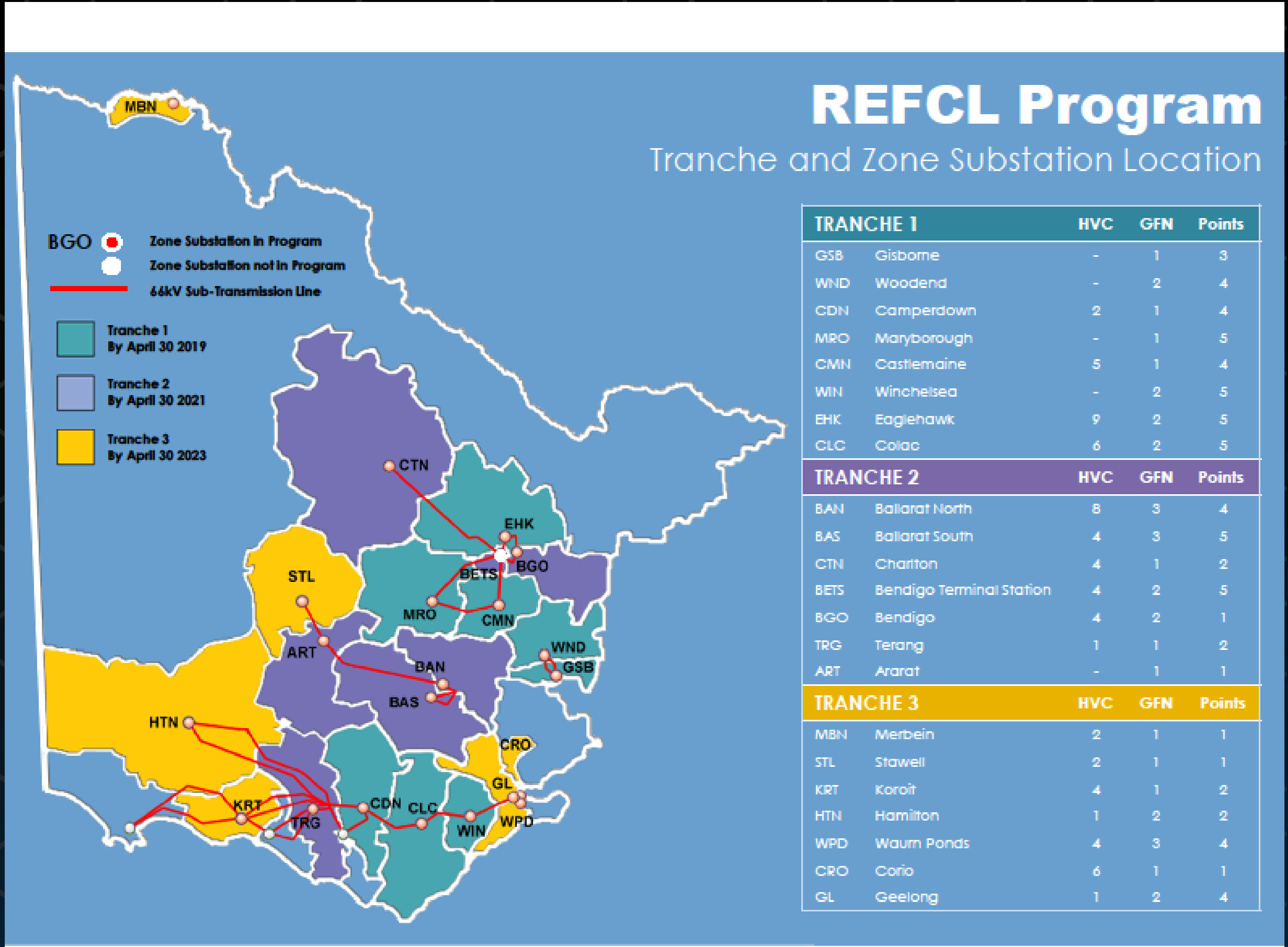
	WITHOUT REFCL	WITH REFCL	REDUCTION	REDUCTION
Zone Substation	*Structures per day*	*Structures per day*	*Structures per day*	*%*
Colac	0.78	0.43	0.35	44.7%
Winchelsea	0.71	0.41	0.31	43.2%
Eaglehawk	0.46	0.25	0.21	45.2%
Maryborough	0.42	0.25	0.18	41.8%
Ballarat South	0.39	0.24	0.15	39.4%
Geelong				
Ballarat				
Seymour				
Bendigo TS				
Wangaratta				
Benalla				
Castlemaine				
Camperdown				
Woodend				
Kinglake				
Hamilton				
Koroit				





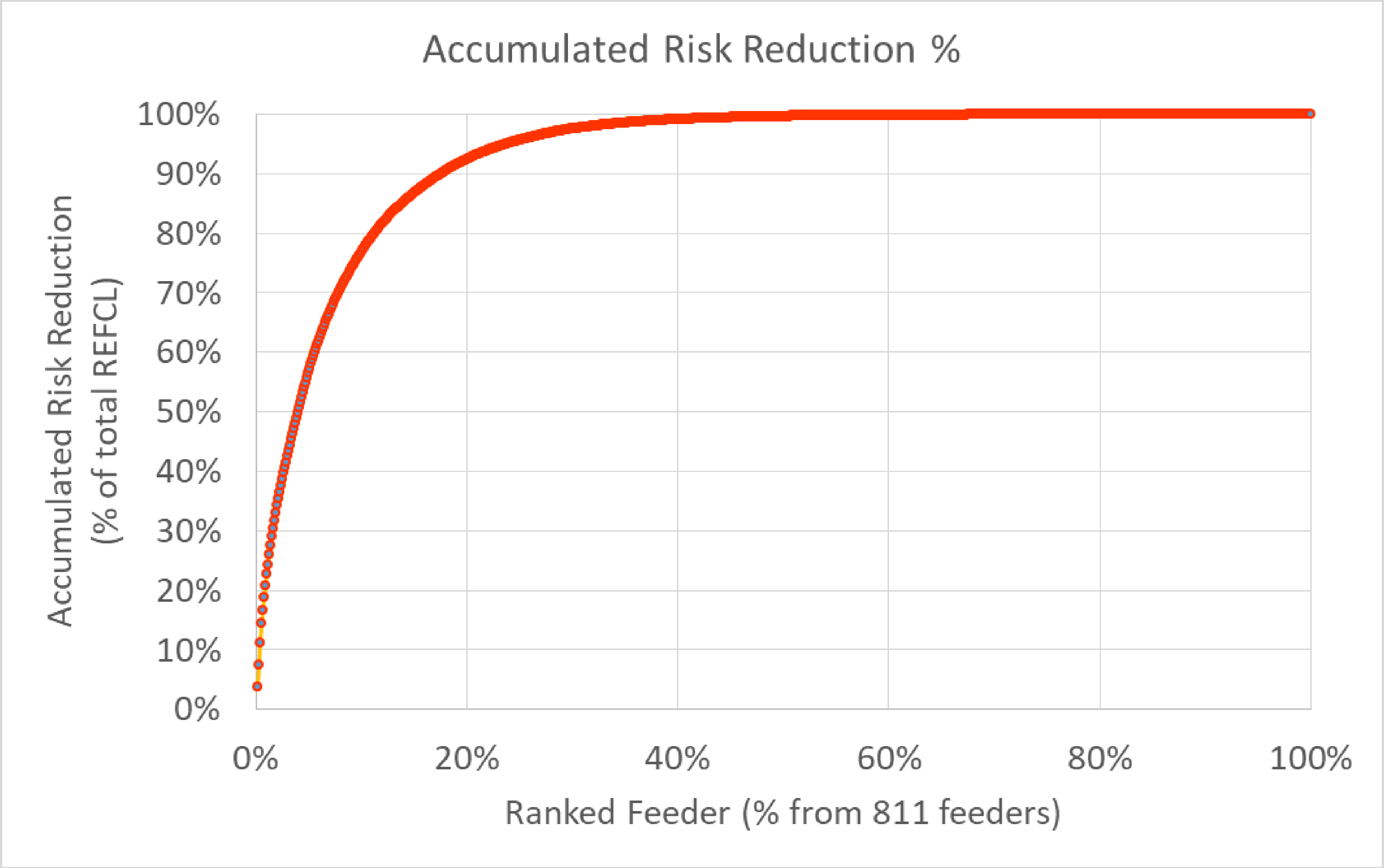
REFCL rollout

- Three tranches: April 2019, 2021 and 2023
- First two tranches are PBSP-funded
- Highest risk zone substations done first
- Cost is in the equipment and in feeder “balancing”
- HV customers’ equipment as sticking point
- REFCL performance needs to be validated



Courtesy *Citipower-Powercor*, 2018

Spatial variation drives action bias to Top 10%



Expected result

60% risk reduction

compared to non-ACR bare-wire performance, by April 2023

for 2% of the cost

compared to undergrounding all powerlines at a cost of A$40B

Conclusions

- Powerline-initiated wildfires are disproportionately dangerous
- Multiple mitigations are available
- Risk is very spatially dependent, this making targeted risk reduction an economic proposition
- Government and industry can and must act cooperatively and in a data-driven manner
- This is a “digital transformation” that matters

Acknowledgements

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- *Arauco Forestal* (Chile)
- Sydney Trains
- Energy Safe Victoria
- Ausnet Services
- Anthony Wilson and *Mondo* (previously *Geomatic Technologies*)
- Country Fire Authority, Victoria
- Rural Fire Service, NSW
- Dept. Environment, Water and Natural Resources (South Australia)
- Dept. Environment, Lands, Water and Planning (Victoria)
- Dept. Premier and Cabinet (Victoria)