Resiliency of Power Systems
Earthquake, Wind, Ice, Fire

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What will be the duration of Power Outage?

- Where are we today?
- Earthquake: 1 Day in M 6.0 (good seismic design); 3 Days (no seismic design). 14+ Days in CSZ M 9.0; 60+ Days in Rural areas
- Wind: Weeks in Cities, Months in Rural
- Ice: Days in Cities, Months in Rural
- Fire: Months in Rural

These outages are based on ~1,000 year events, that happen “someplace” every couple of decades

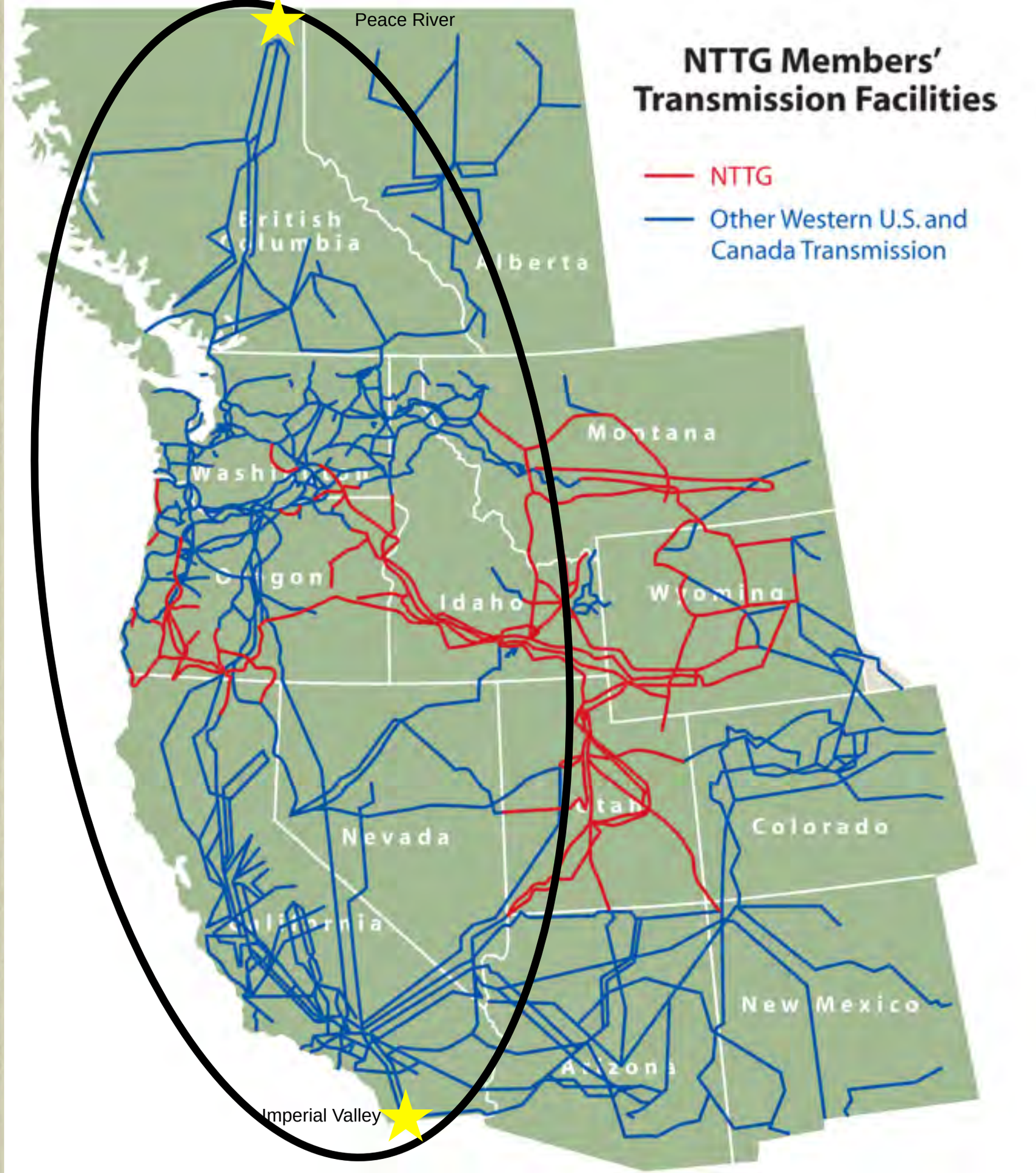
These outage durations apply to many of the areas within the black oval, from the Mexico Border in the South to the Peace River in the North

SERA

System
Earthquake (Wind, Ice, Fire)
Risk
Assessment

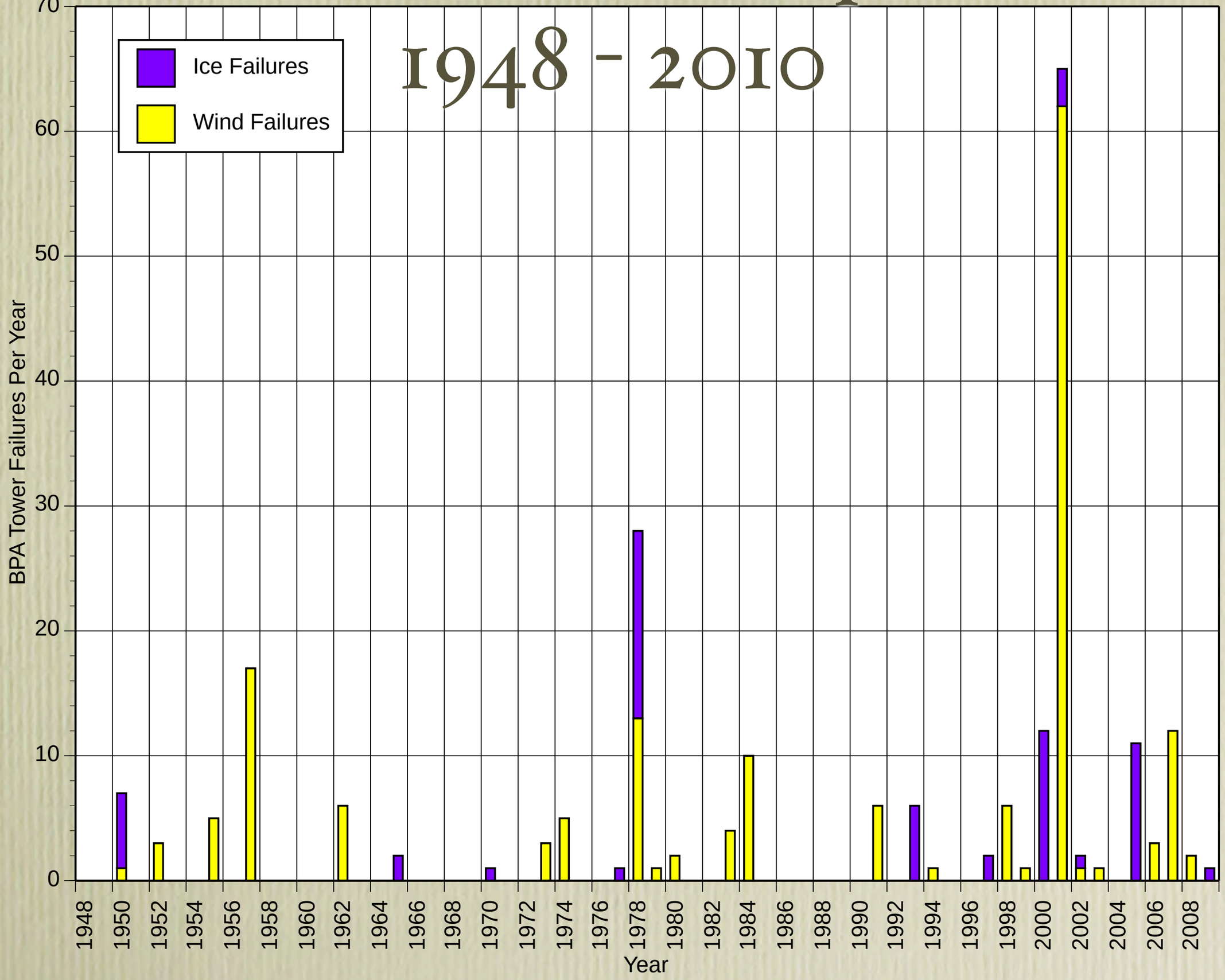
Nearly every 500 kV and most 230 kV substations, from
British Columbia to the Mexico Border

More than 100,000 high voltage components



BPA Tower Failures per Year,

1948 - 2010



Failure

Both tension legs had square shaped pullout holes

Leg 1 Bent by dragging of tower during failure

RESILIENCY

- Dictionary Definition: Restore to the way it was before
- Power Company Action: Fix it as fast as you can. No mitigation done during the restoration process.
- BUT, to get shorter outage times for future events, we need to UPGRADE and not just "fix it the way it was"

Besides disrupting transportation, heavy ice and snow can damage utilities. Power and telephone lines sagging after heavy ice storm.

Image ID: wea00955, NOAA's National Weather Service (NWS) Collection

Hydro Quebec, Montreal, Canada,
January 5-9, 1998

1,000 steel towers
collapsed.

Most are 735 kV

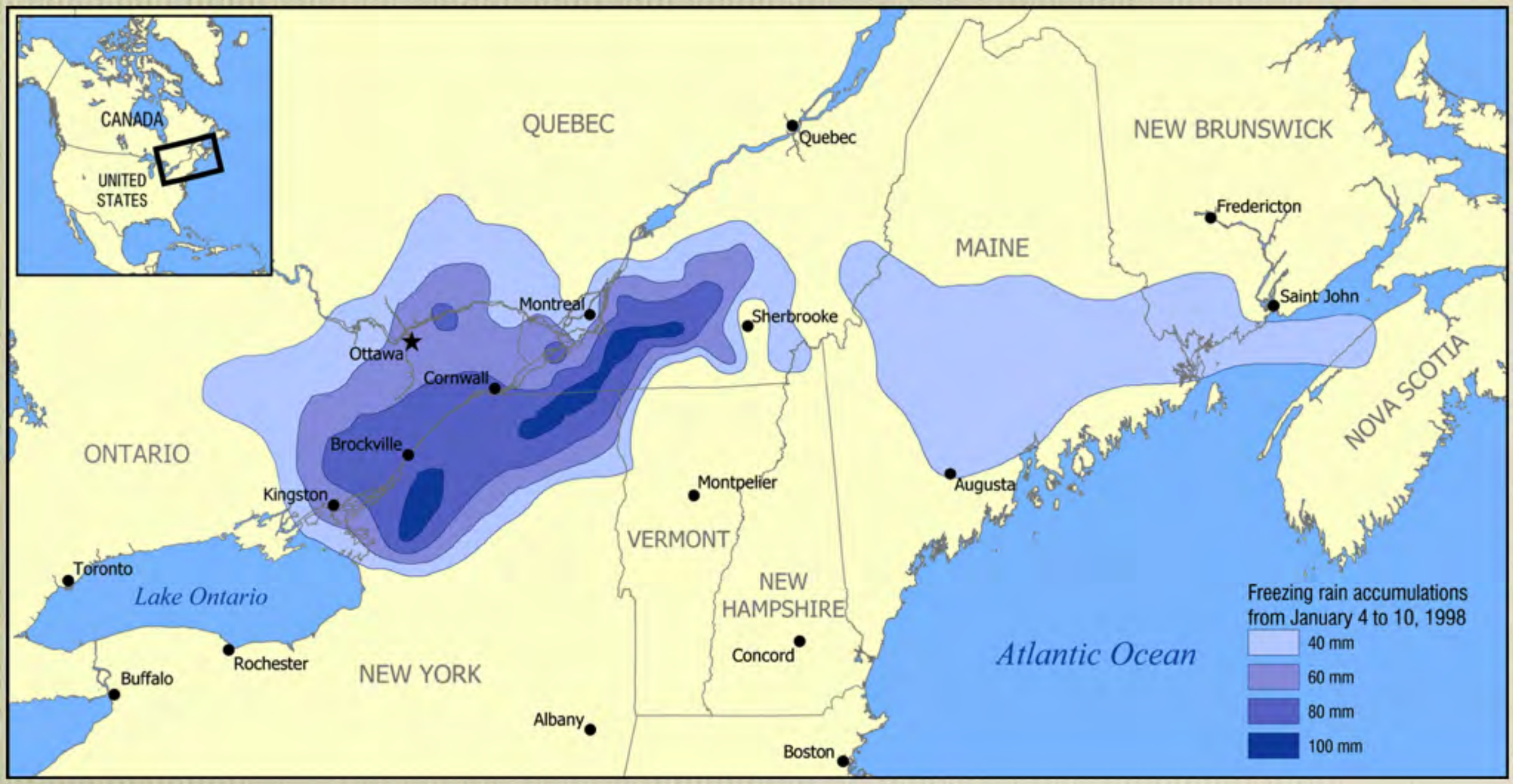
Why?

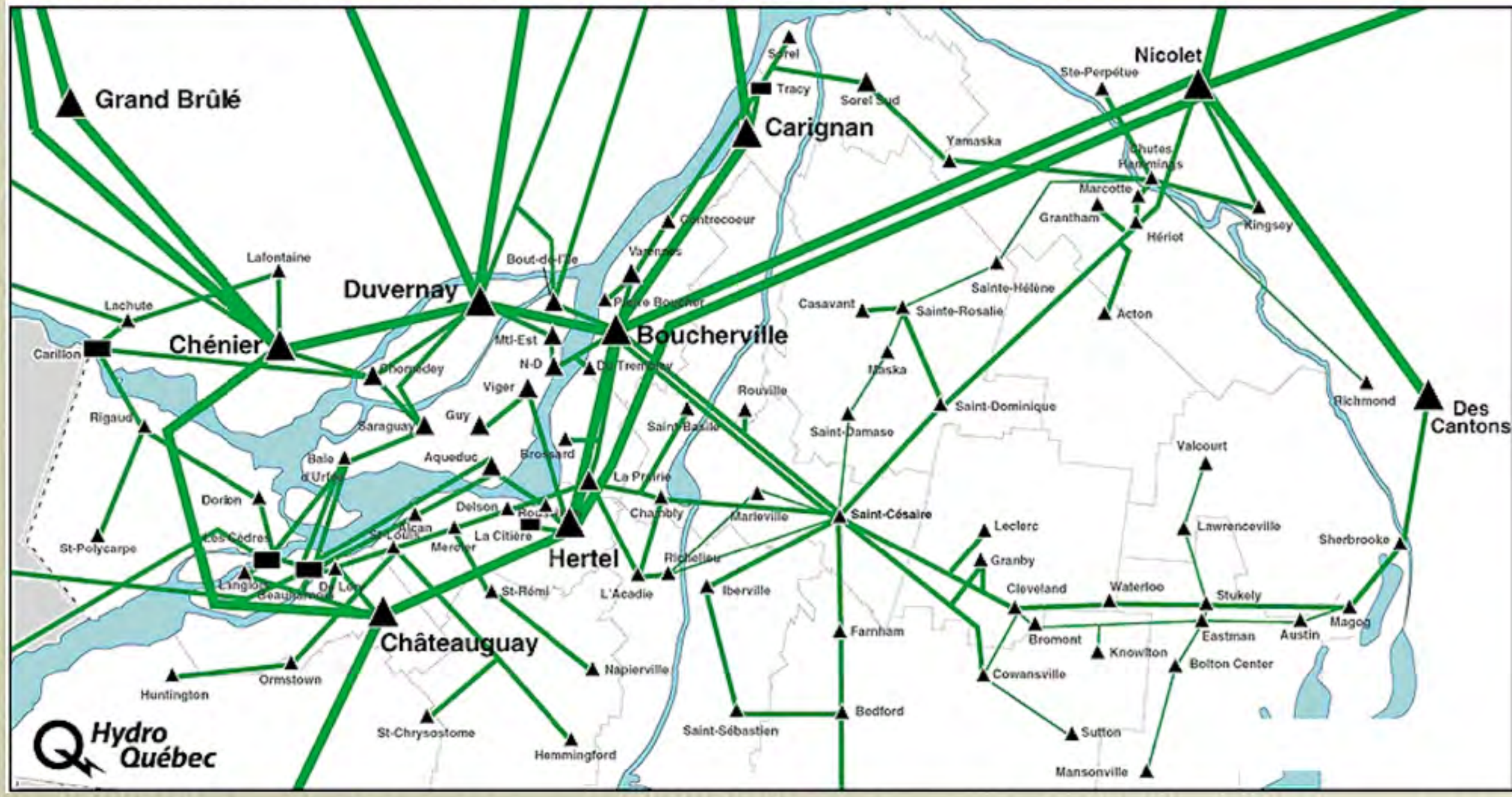
PLUS

30,000 distribution wood pole failures

EQUALS

6 month outage in some rural areas


CANADA
UNITED STATES
QUEBEC
Quebec
NEW BRUNSWICK
Fredericton
MAINE
Saint John
Montreal
Sherbrooke
Ottawa
Cornwall
Brockville
ONTARIO
Kingston
Montpelier
Augusta
VERMONT
NOVA SCOTIA
Toronto
Lake Ontario
NEW HAMPSHIRE
Concord
Rochester
Buffalo
NEW YORK
Albany
Boston
Atlantic Ocean
Freezing rain accumulations
from January 4 to 10, 1998
40 mm
60 mm
80 mm
100 mm

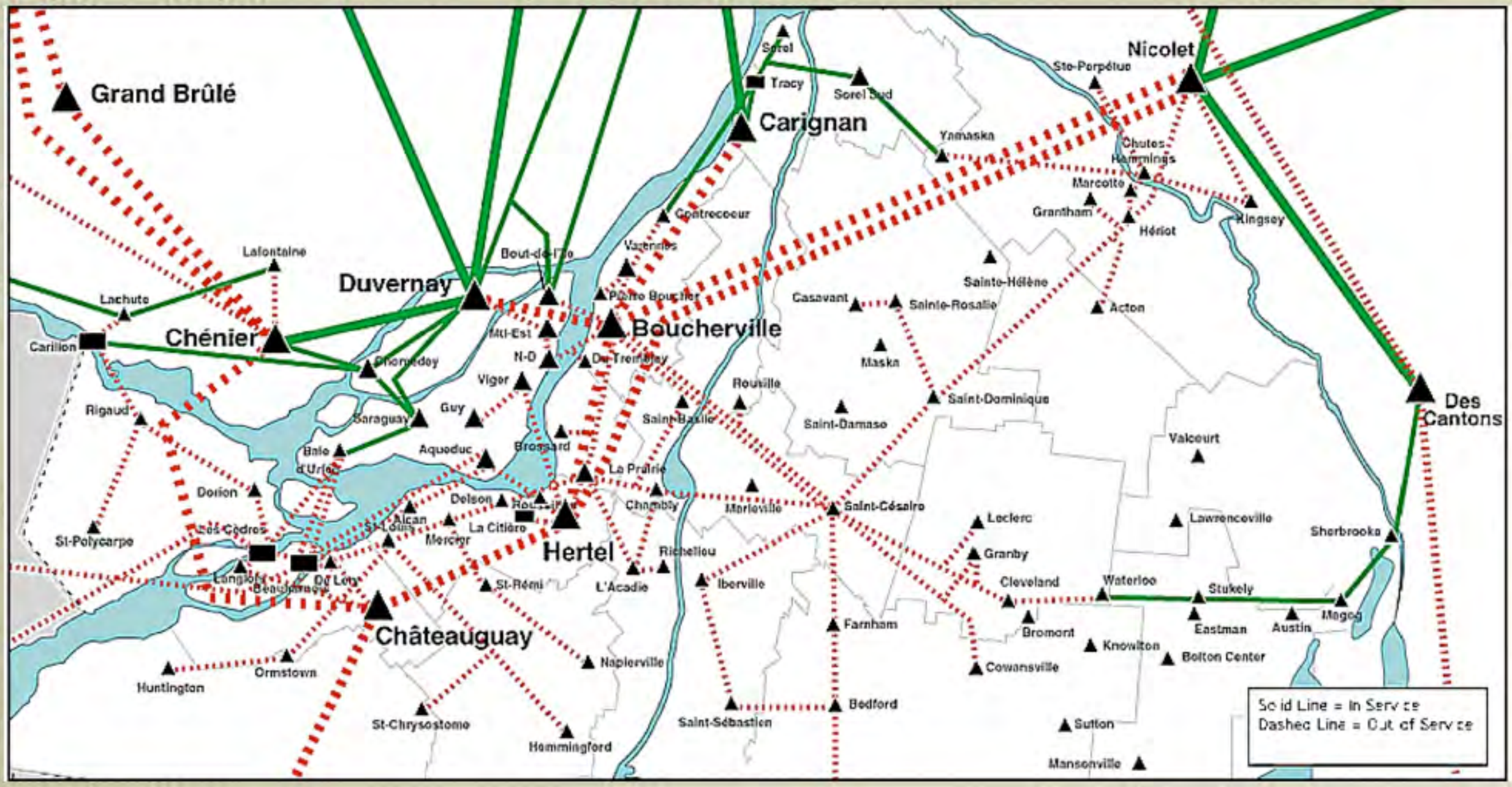


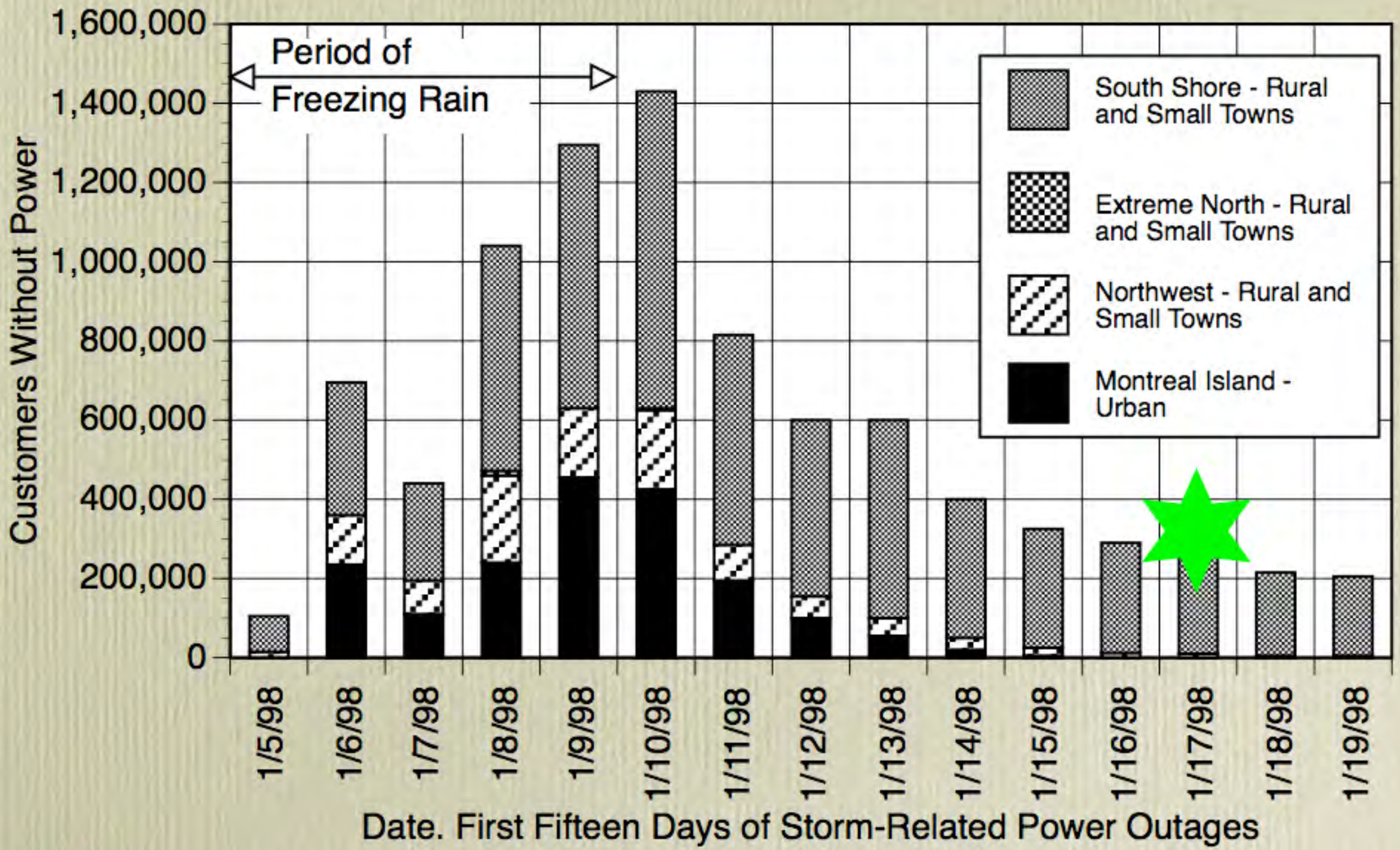
▲ 735 kV Substation

▬ Generation

▲ 230-315 kV Substation

Green: energized circuits
Dashed: out-of-service circuits





Power restored to Hydro Quebec Research Facility

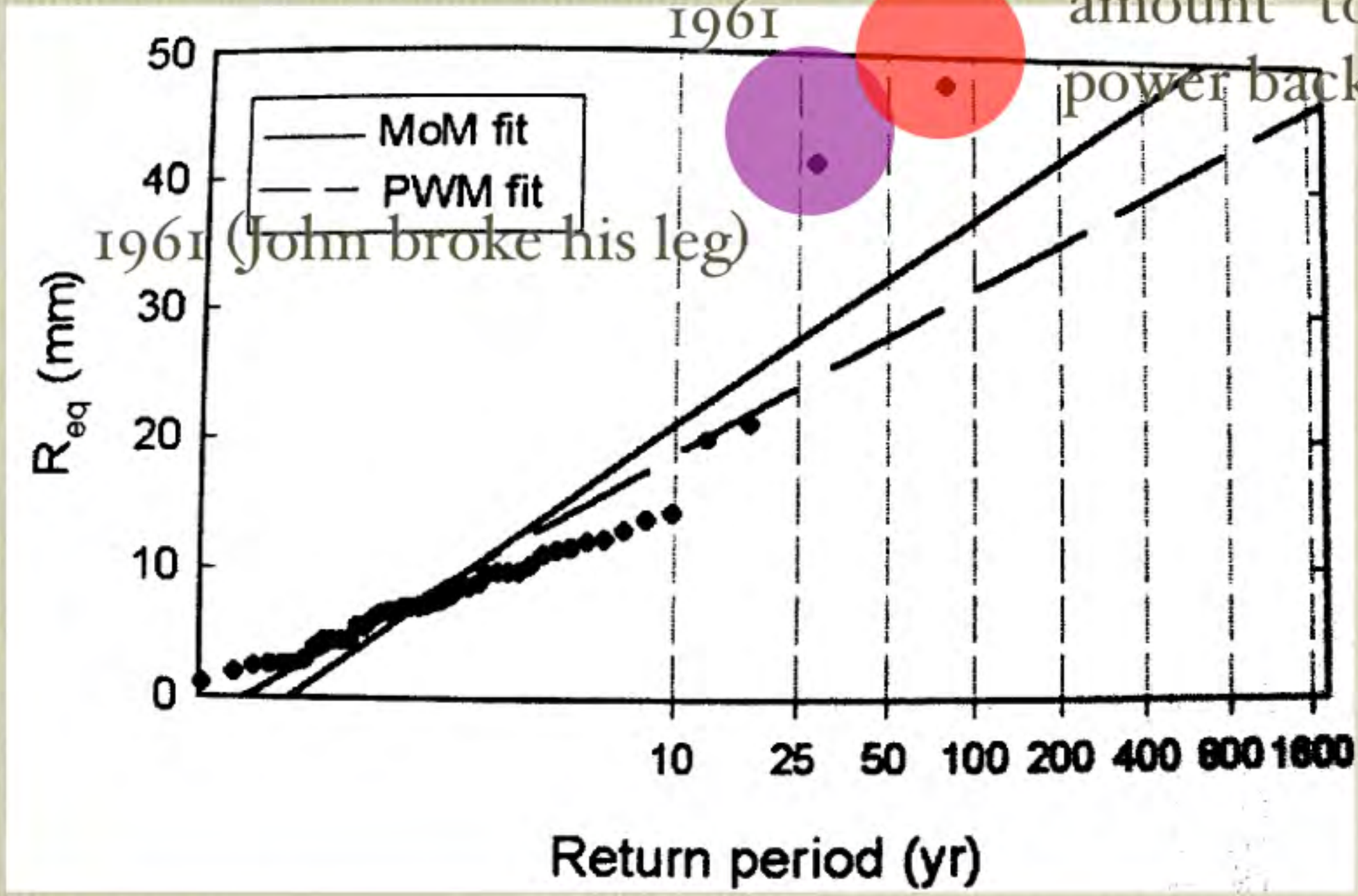
Return Periods

1998 (John's Dad says he will pay "any amount" to get power back on)

1998

1961

1961 (John broke his leg)



Maximum accumulated ice measured at Dorval airport (Montreal) in single storm, over one year

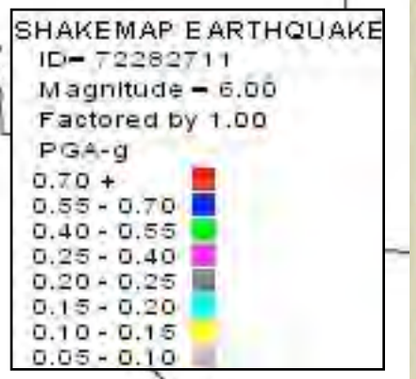
Why did the towers fail?

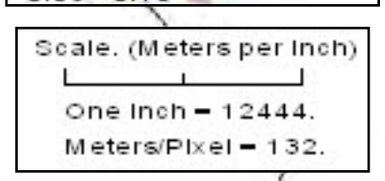
- Type II Gumbel, Lognormal, etc. are all fiction. But, we use them all the time. Worse, we use 50 years of real data to project to 1,000 to 10,000 year time frames. Superstations cannot be used to reliably predict rare events.

Place Names and Populations

Urban Areas (est. population as of June 2014, or latest data)

SERA 8.4.3.3 Third Shakemap, PGA (g), Max of NS, EW





Sonoma County (491,829)

Napa County (139,045)

St Helena (5,814)

Santa Rosa (170,685)

Yountville (2,933)

Vacaville (94,275)

Sonoma Valley (42,296)

Rohnert Park (41,232)

Napa (76,915)

Fairfield (109,320)

Petaluma (57,941)

Vallejo (118,837)

San Rafael (57,713)

Martinez (36,673)

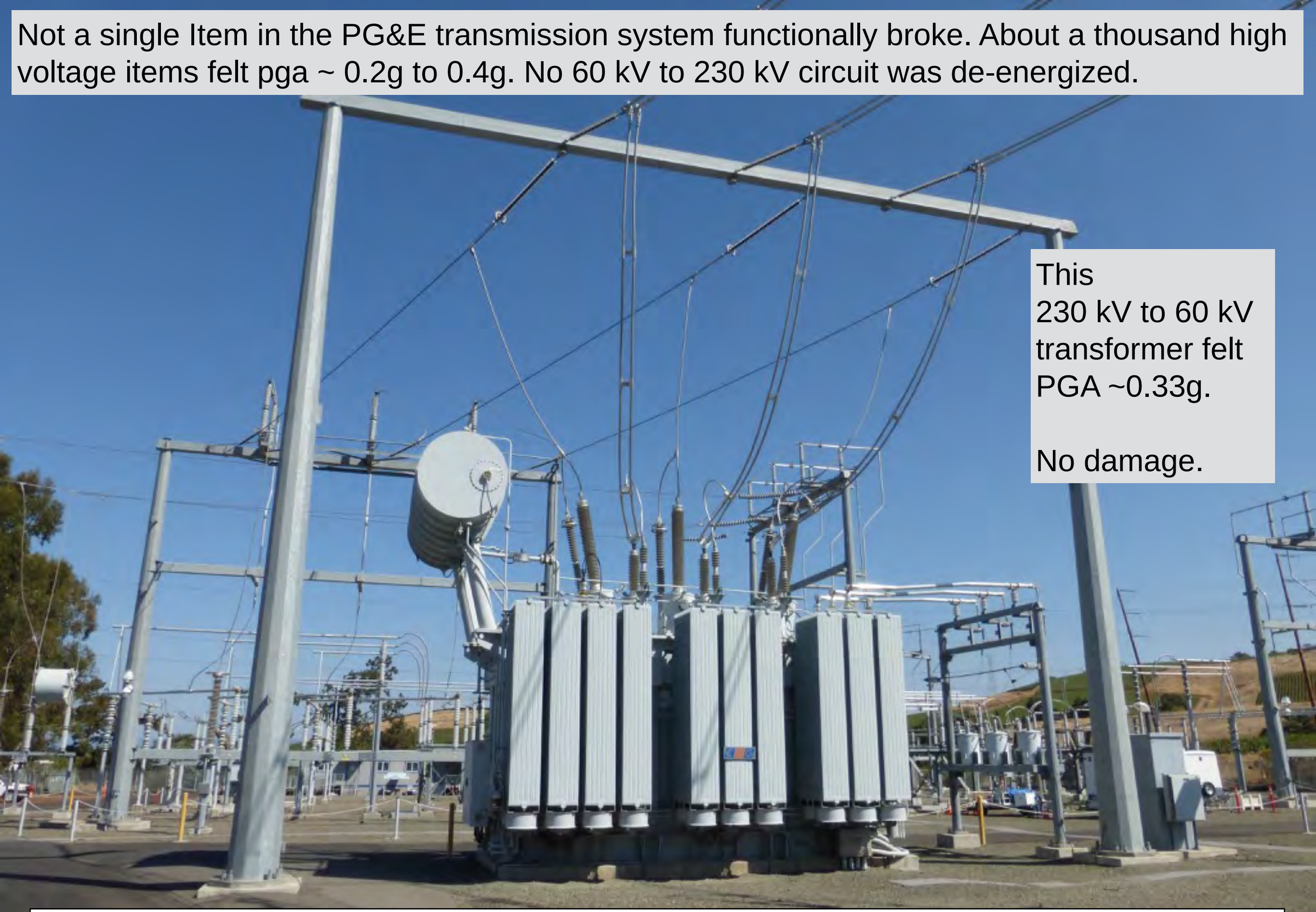
Richmond (106,516)

Berkeley (116,768)

San Francisco (825,863)

Oakland (400,740)

Not a single Item in the PG&E transmission system functionally broke. About a thousand high voltage items felt pga ~ 0.2g to 0.4g. No 60 kV to 230 kV circuit was de-energized.

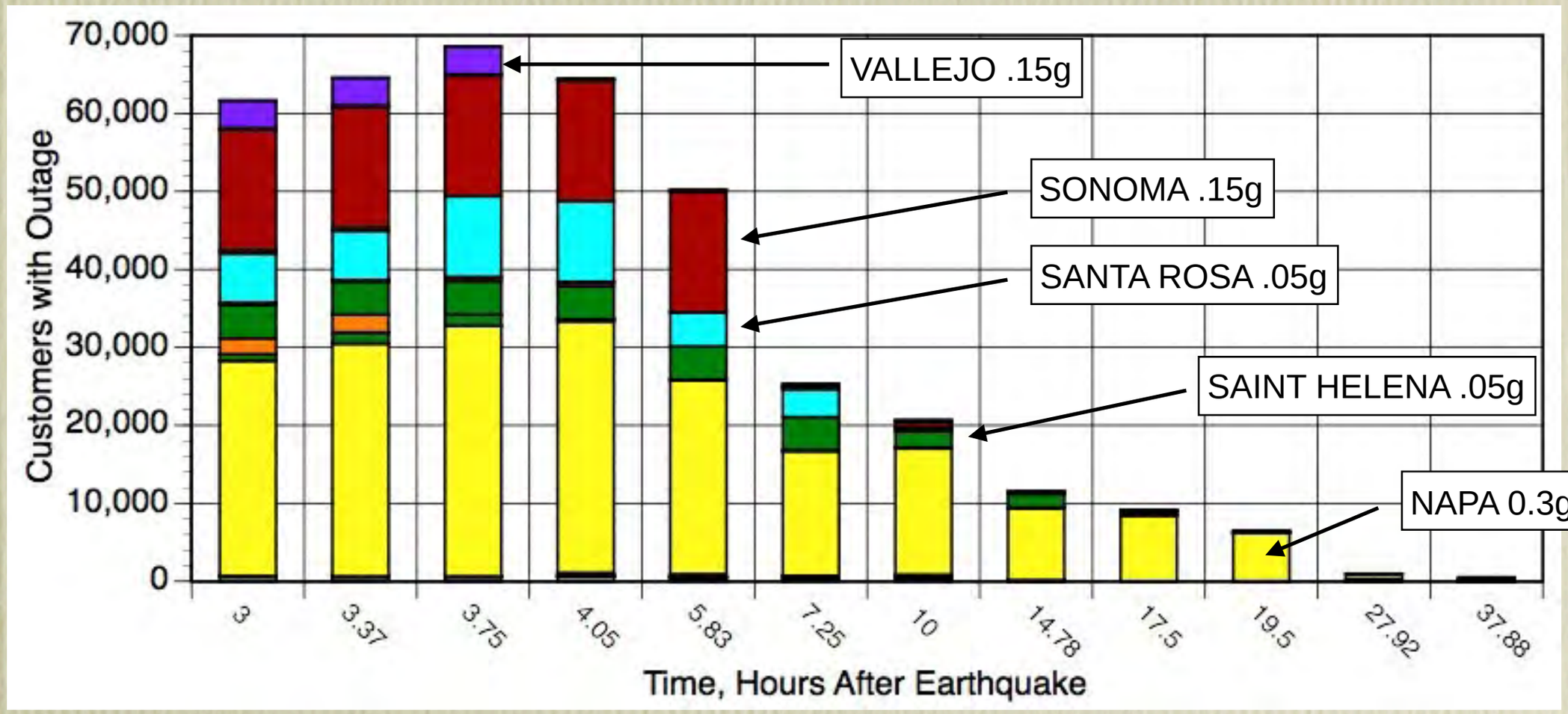


This
230 kV to 60 kV transformer felt PGA ~0.33g.

No damage.

Bank 3. 230 - 60 kV. Anchorage capacity is low (V=0.3W), but PGA small enough to not overcome sliding / rocking, so no damage.

Power Outages - M 6.0 Napa Earthquake Aug 23 2014



NAPA PGA = .3g

VALLEJO PGA = 0.15g

SONOMA PGA = 0.15g

SANTA ROSA PGA < 0.05g

SAINT HELENA PGA < 0.05g

Key Findings

- PG&E has ZERO damage to high voltage equipment
- Still, 70,000 customers lost power. Why?
  - Distribution system. Mostly overhead. Damage is correlated to SA (T = 3.0 seconds), NOT PGA. Why? Wire slapping causes “easy to fix” short circuits.
  - CAVEAT: No liquefaction in this event. Buried cables will have a different story.


Photo taken September 25, 2014

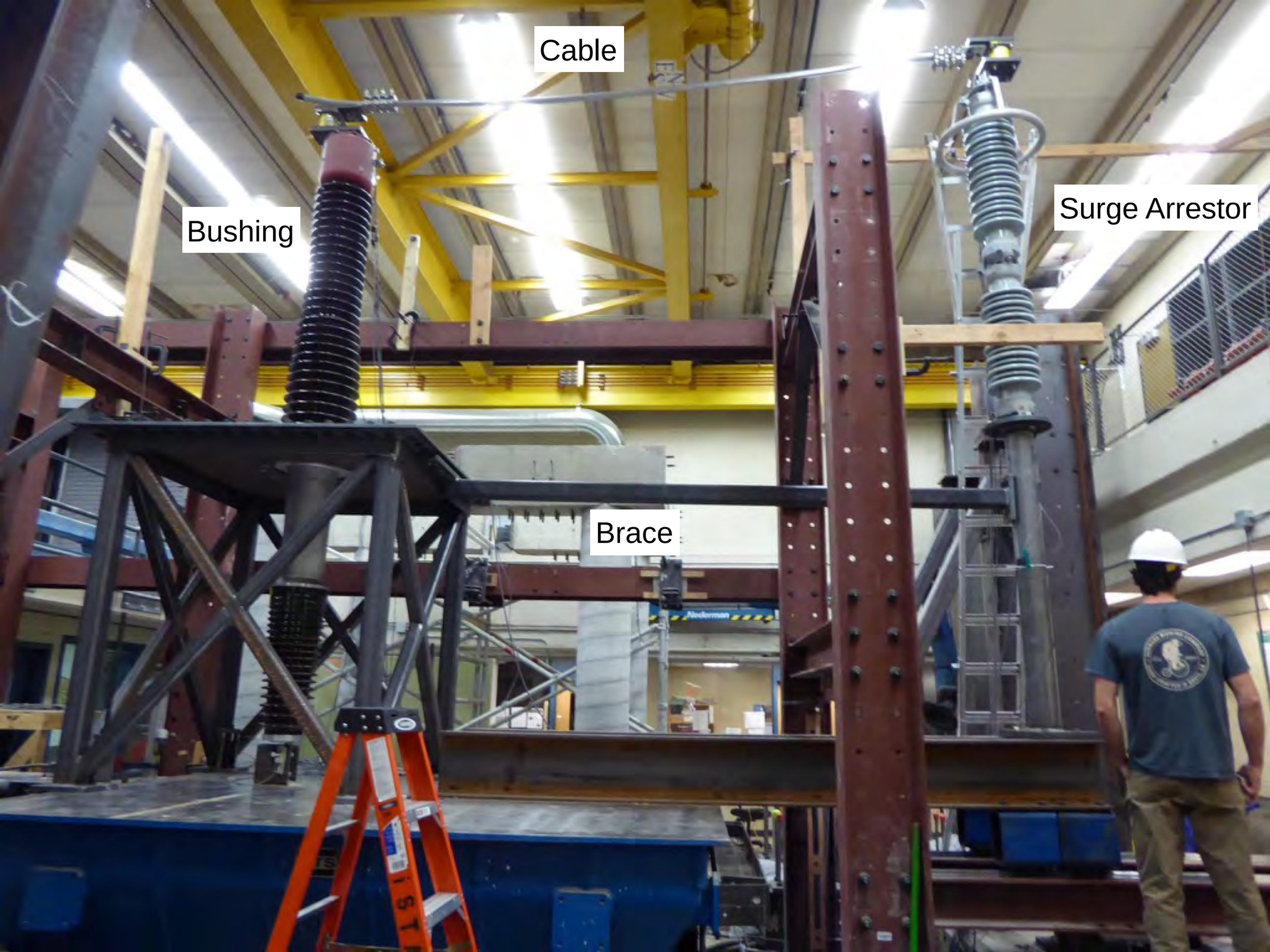
Prof Anshel Schiff

He has spearheaded power system seismic issues for 40 years.

Today, every power company in the world uses his insights

IEEE 693
Ed Matsuda
Dennis Ostrom
Ron Tognazini
Leon Kempner

2014: more than 50 engineers from dozens of companies are involved


Cable
Bushing
Surge Arrestor
Brace

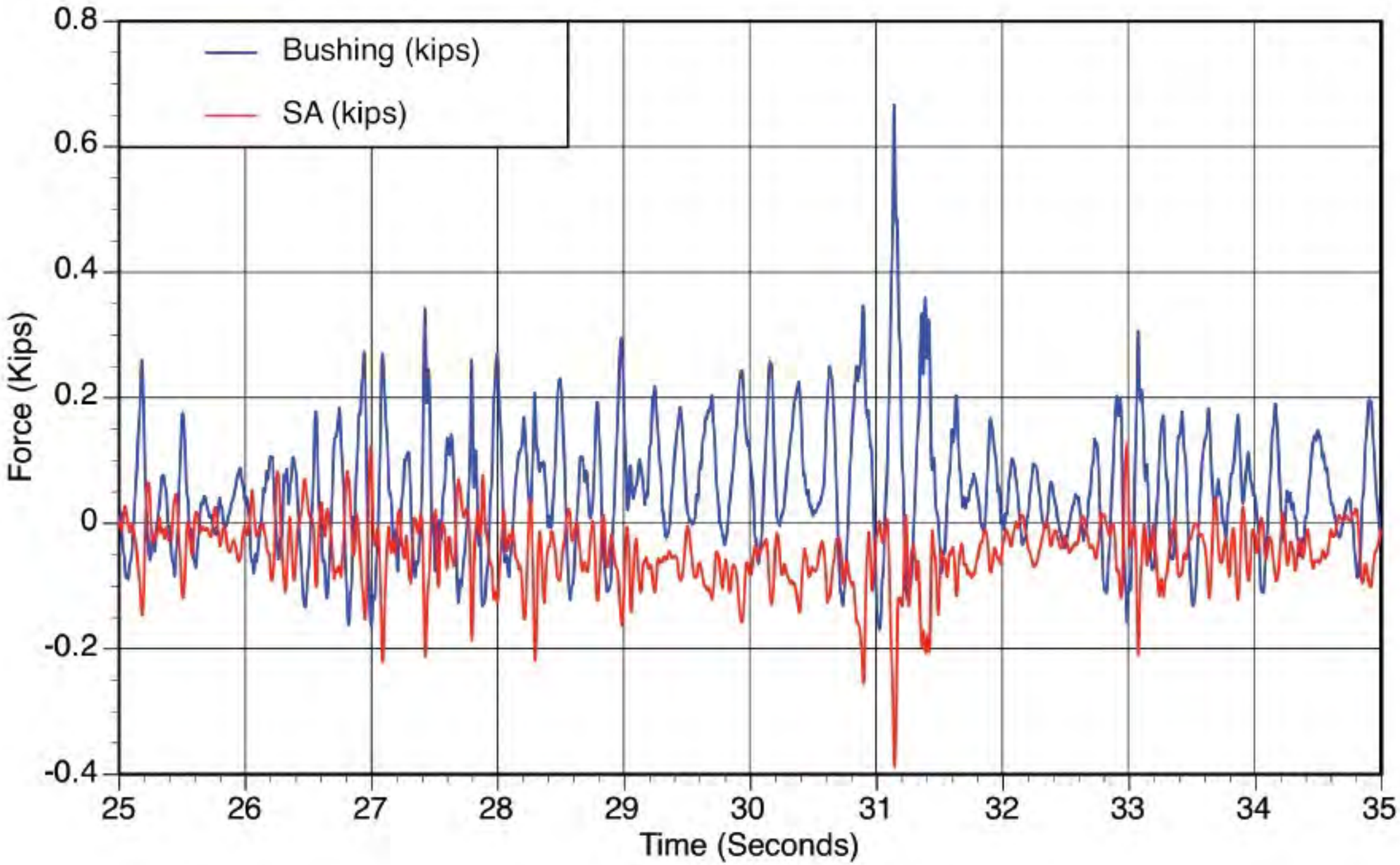
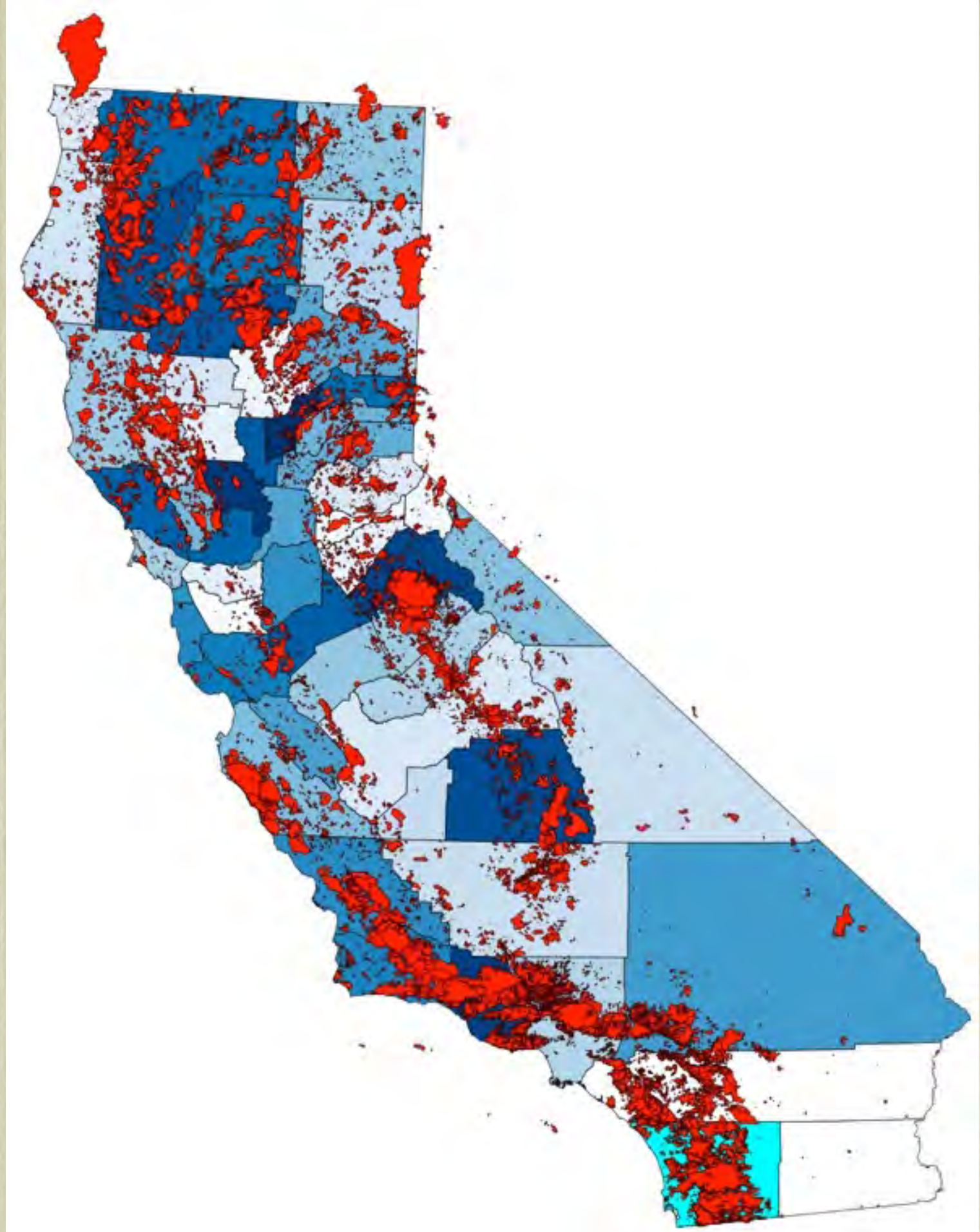


Figure 3-4. Cable Forces (RRS = 1.0g, 0% Slack, No Brace, Narcissus)

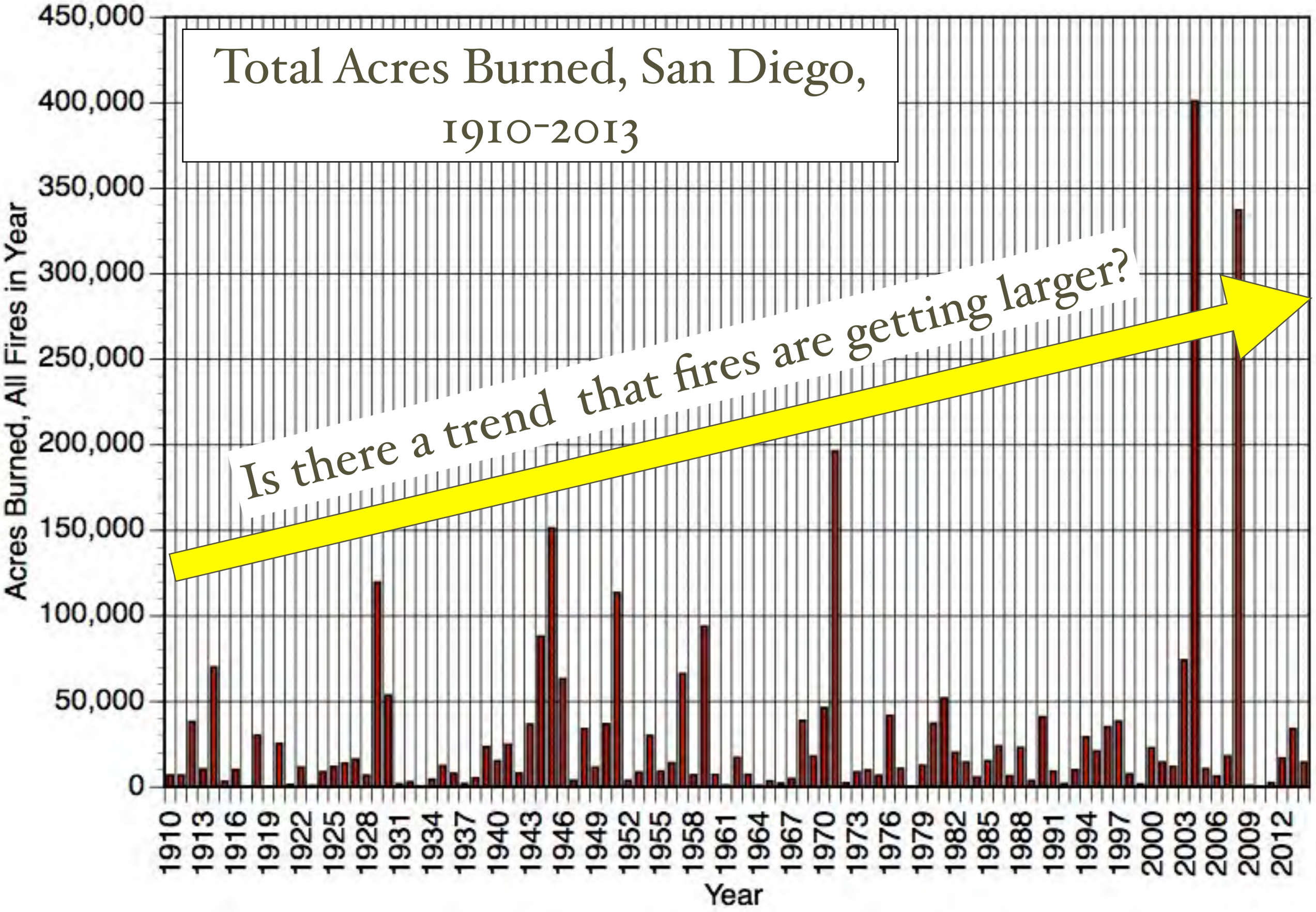
Map of Wildland Fires, California, 10 Acres or More 1878 - 2013

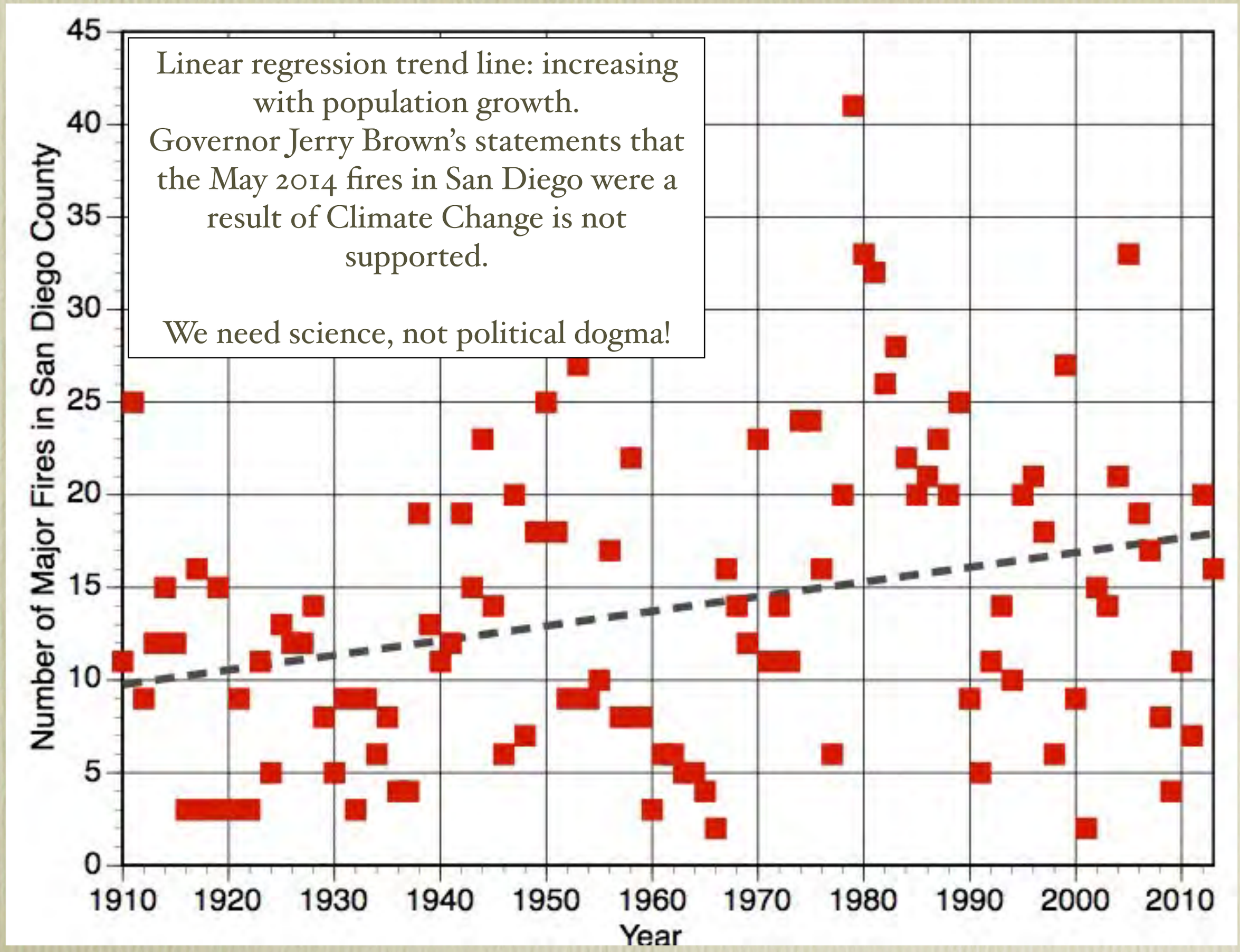
18,712 Fires

Excludes
Urban Fires
Unreported Fires
Small Fires



Total Acres Burned, San Diego, 1910-2013





Trend in Number of Fires per Year, SD County

Ignition Cause	Countywide	California Statewide	Ratio, San Diego County / California
Lightning	72	2,989	2.4%
Equipment Use	49	995	4.9%
Smoking	9	326	2.8%
Campfire	54	319	16.9%
Debris	10	651	1.5%
Railroad	1	80	1.3%
Arson	49	805	6.1%
Playing with Fire	14	168	8.3%
Miscellaneous	665	3,125	21.3%
Vehicle	6	267	2.2%
Power line	9	279	3.2%
Firefighter training	0	5	0.0%
Non-firefighter training	0	11	0.0%
Unknown / unidentified	482	8,553	5.6%
Structure	1	14	7.1%
Aircraft	0	11	0.0%
Escaped prescribed burn	2	80	2.5%
Illegal Alien Campfire	15	21	71.4%
Total	1,438	18,699	7.7%

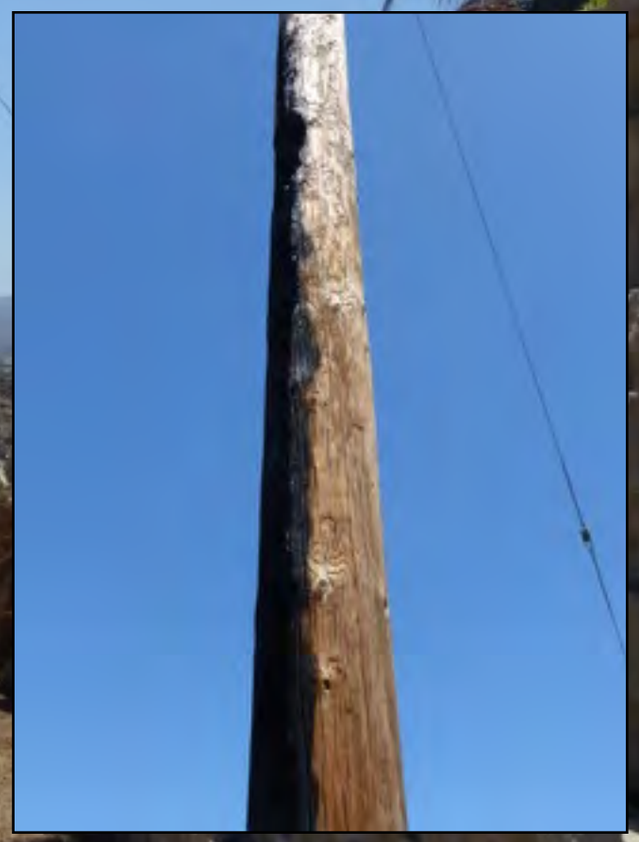
Table 2-8. Comparison Statistics, San Diego County and State of California

230 kV lattice towers. No damage.
Substantial burned fuel under and within ten feet.
No charring, no smoke on steel

Nearby 138 kV wood poles. More damage.

3 wood poles in fire.
1 no damage.
1 minor damage.
1 extensive damage.
Nearby house burned.

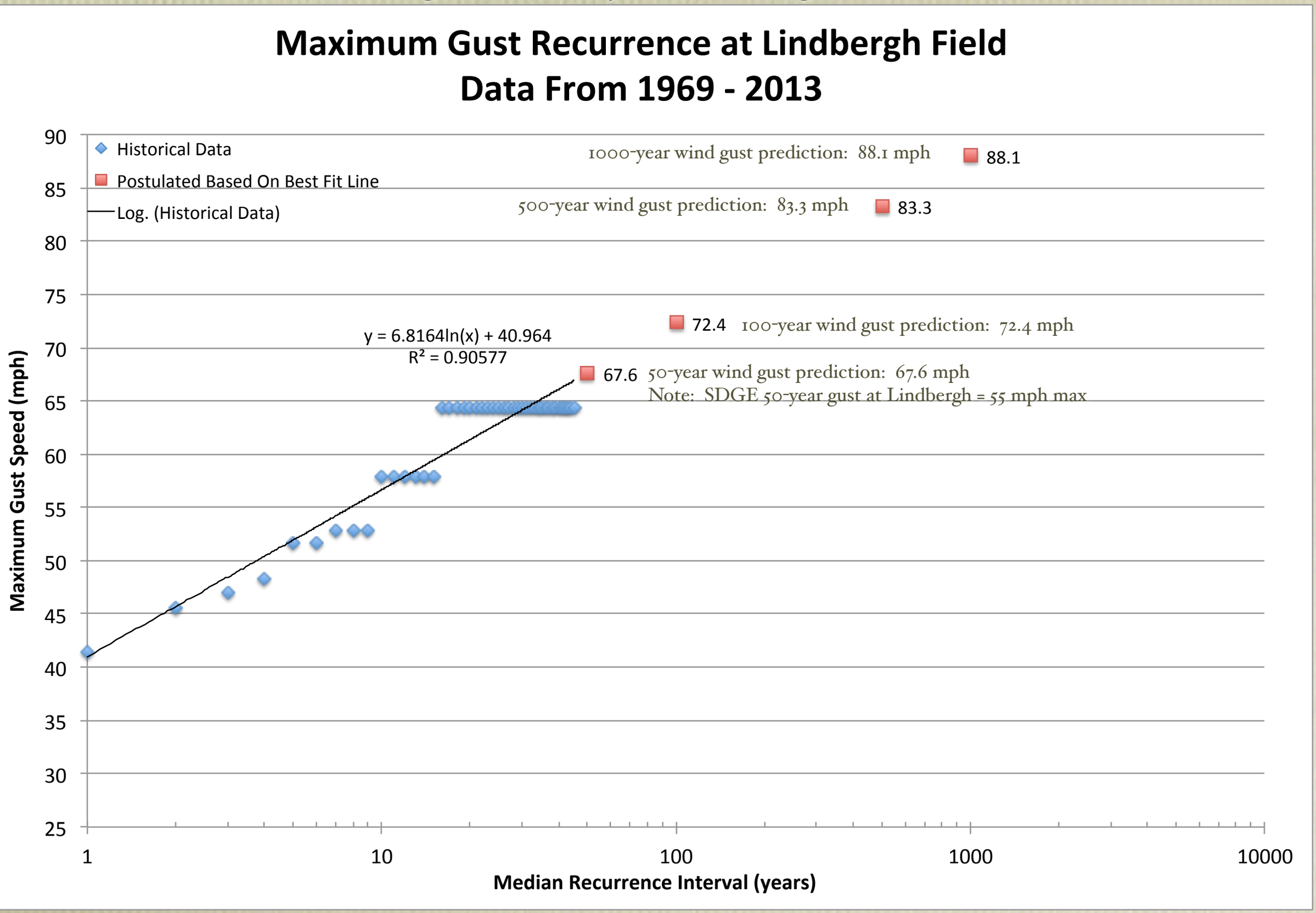
Extensive damage



Wood pole replaced

Wind Gust Data

Regression Analysis - Lindbergh Field

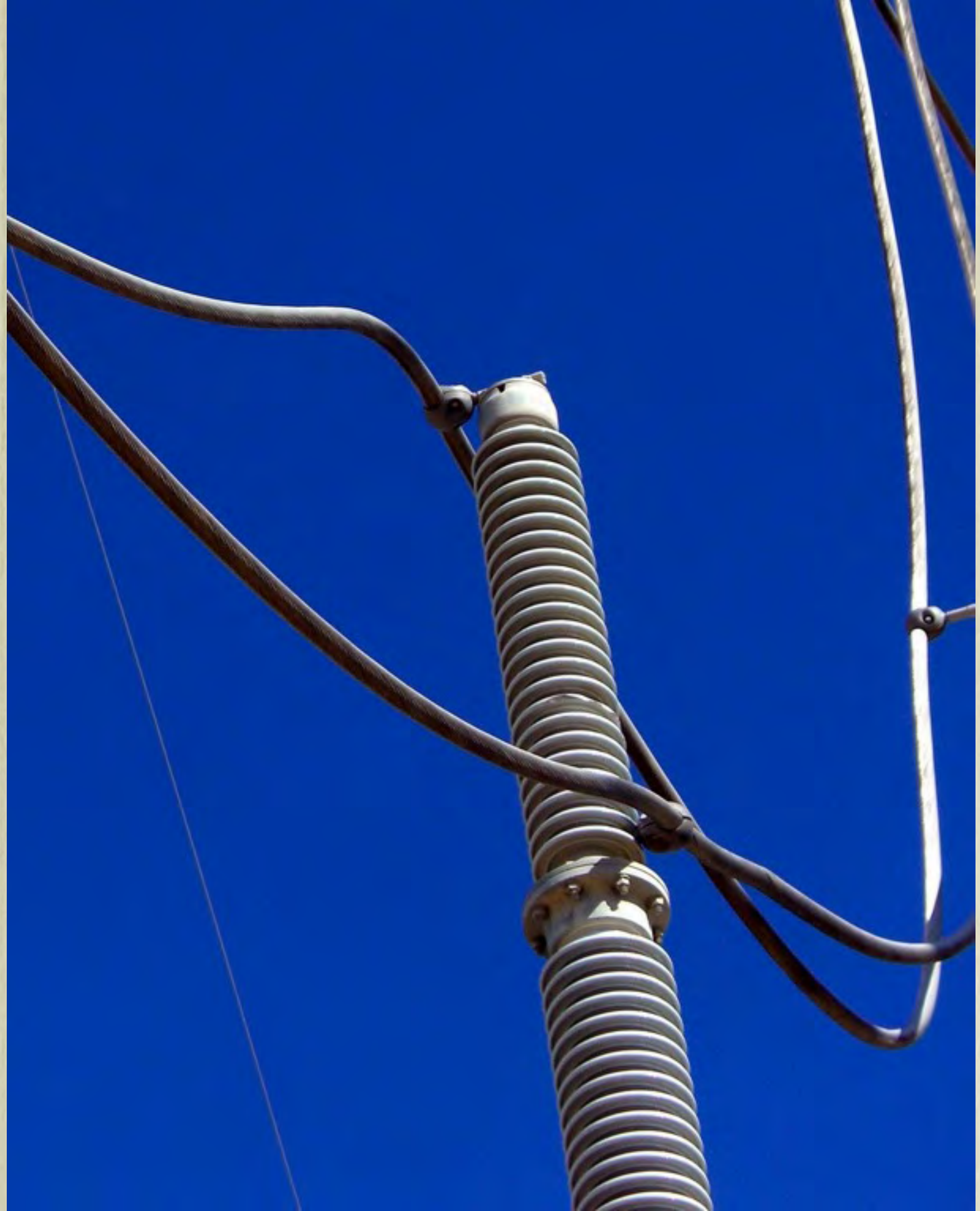


Bay 1 Looking south

In 2008, these surge arrestors were seismically qualified for PGA = 0.5g with a Factor of Safety of 3, by a world leading company, doing it “on the cheap”

In April 2010, with PGA = 0.30g, 4 of 4 broke.

Bay 1 Phase C



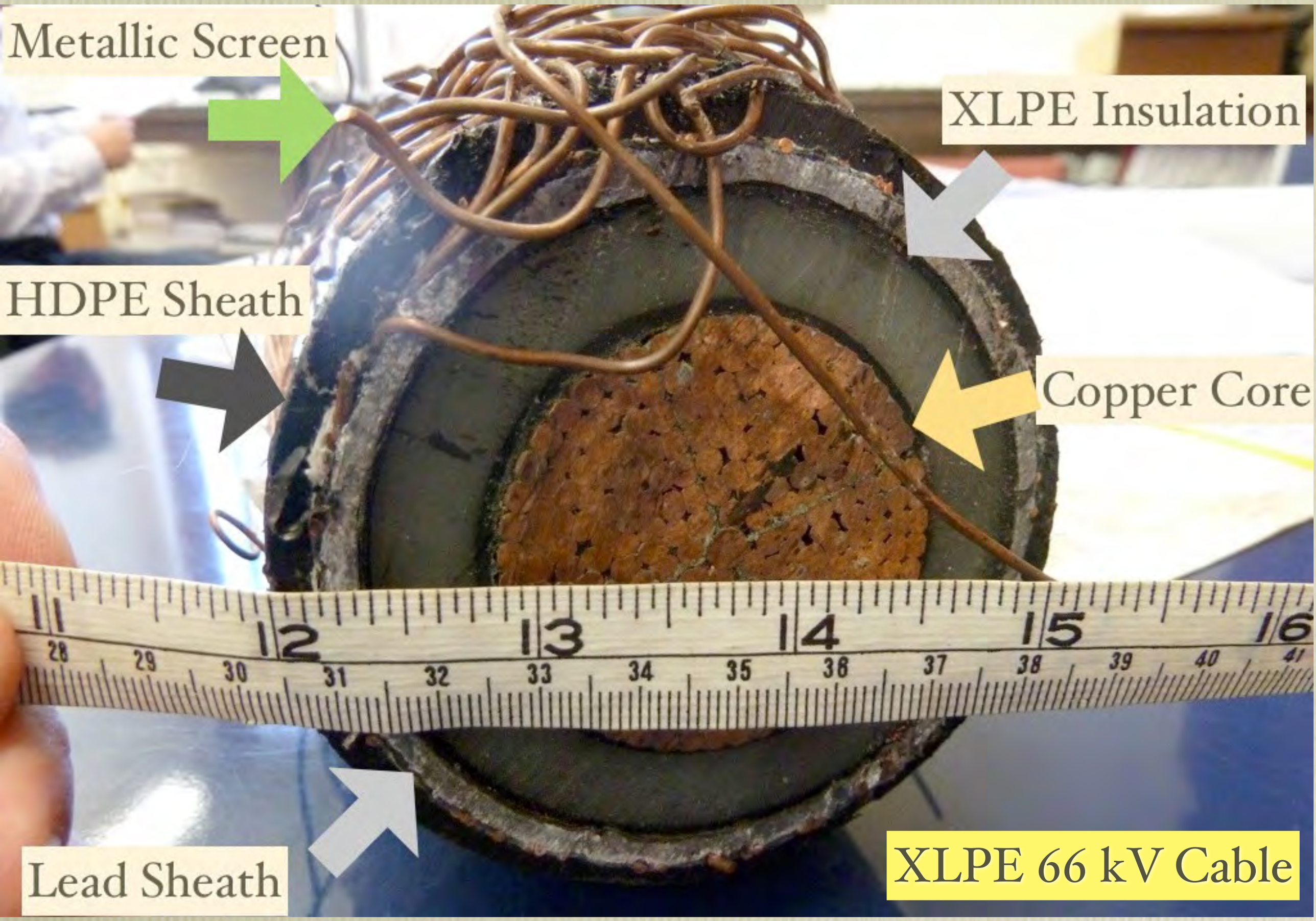
A note about Buried Cables in Liquefaction zones

New Zealand

Performance of XLPE Cables in Liquefaction Zones

New Zealand

Performance of XLPE Cables in Liquefaction Zones


Metallic Screen
XLPE Insulation
HDPE Sheath
Copper Core
Lead Sheath
XLPE 66 kV Cable

500 kV

Unanchored

What have we learned?

What Can We do to Shorten These Outages?

- Earthquake. IEEE 693. After 20 years, look what it got PG&E in NAPA. Still, nothing for distribution, buried cables. If we want 1+ day, the cost is about $4 per month increase in electric rates, forever.

- Wind: GO 95. V = 56 mph for design in California. If we want 1,000+ wind design, Add $2 per month

- Ice: Choice 1, like Hydro Quebec. Choice 2. Design for 3 inches of radial ice. Add $1 per month.

- Fire: Months in Rural. Underground? Add $20 per month for rural customers…. won't happen….

How can we pay to reduce power outages?

- Growing Economy. Rate Making. For $1 Billion per year to expand the network for increasing power demand, we can solve substations in <40 years.

- No Growth Economy. For long-lived items (towers, buried cables), there will be no mitigation.... unless....

- GUIDELINES are written by the industry, and the industry self-regulates, and we have 40 years. Example: IEEE 693.

- or.... the GOVERNMENT imposes requirements, and the GOVERNMENT allows 25% rate increases.

Thank you!

Courtesy NASA