Multi Hazard Evaluation of a High Voltage Transmission Network

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ABSTRACT

The Bonneville Power Administration (BPA) operates one of the nation's largest high voltage transmission networks spanning four states, with more than 250 substations, 80,000 transmission towers, and 15,000 transmission circuit miles.

The BPA system is exposed to a variety of natural hazards, including earthquake and severe winter storms. Earthquakes can trigger ground shaking, landslides, and liquefaction at BPA's substations. Winter storms can cause high winds, ice accumulation, intense rainfall-triggered landslides and flooding at BPA's substations and transmission towers.

BPA is conducting a multi-hazard evaluation of its inventory for all these hazards. The objective is to examine the effects of each hazard, and then determine what type of mitigation, if any, is cost effective.

INVENTORY

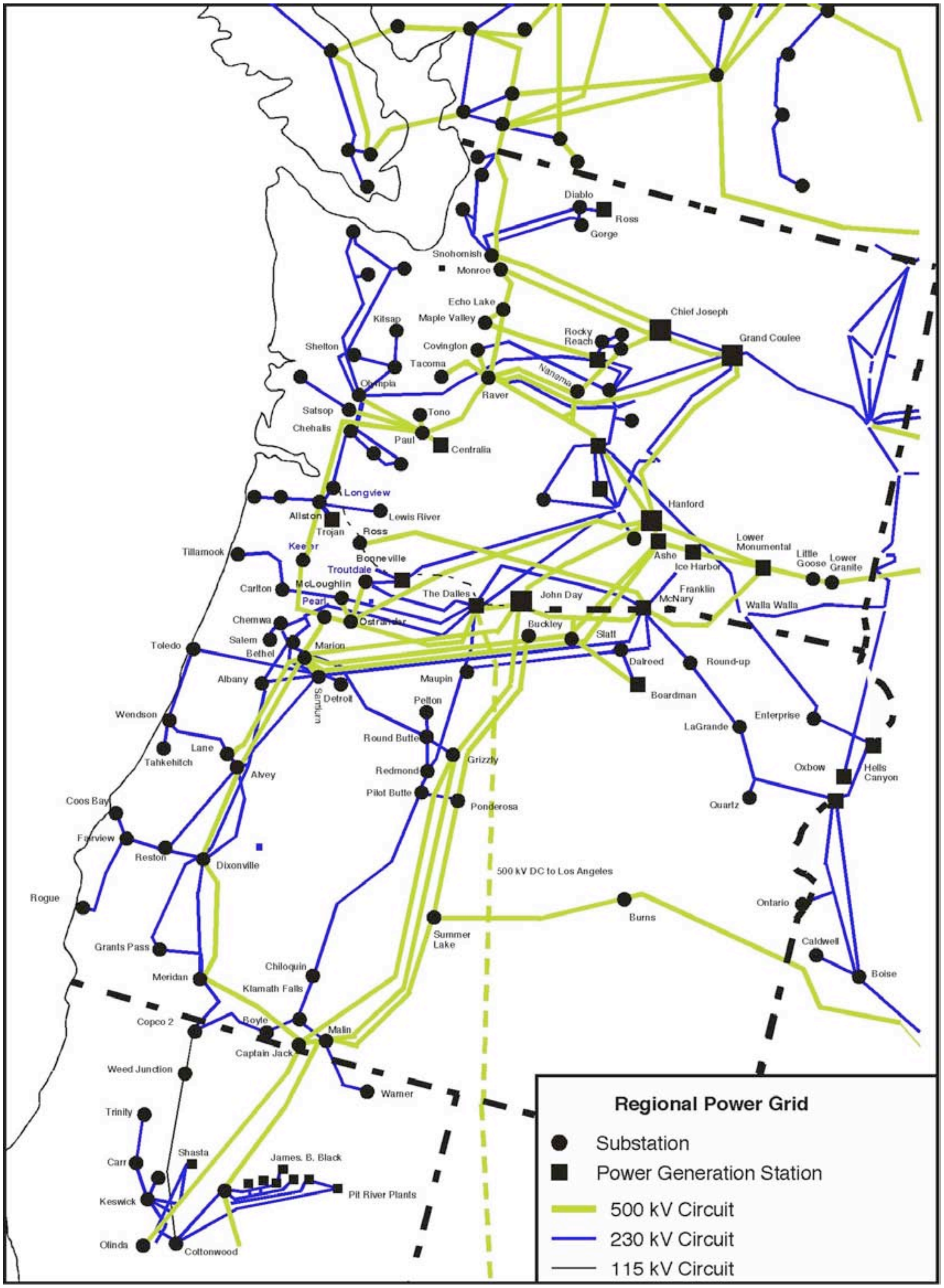

Figure 1. Map of Regional Power Transmission System

ICE AND WIND STORMS

The west coasts of Oregon and Washington states are exposed to high wind storm events. The "Columbus Day" storm of October 12, 1962 was one such event. Storms with similar occurred in 1981, 1995 and 2008 (see Figure 2). The 1962 Columbus Day storm led to damage of various BPA transmission towers, including some rather large ones adjacent to the Columbia River.

BPA's design criteria for transmission towers includes design for wind and ice. Depending on location of the tower, and vintage of the design, the design wind and ice loads varies. For practical reasons, site-specific design of individual towers is not normally done, and the design for the tower is often based on the highest wind/ice combination, although the same tower might be installed at locations with lower ice and wind load specifications. This means that individual towers at specific locations have differing reliabilities.

A challenge is that even for towers that have been designed to remain elastic for 100 mph winds, it is not unheard of having collapses in wind storms that "nominally" produces peak gusts (as recorded) under 90 mph. This implies that the true wind speed at a specific tower is greater than the design speed; or the tower was under designed (or had defects in construction, accumulated corrosion, etc.); or some combination.

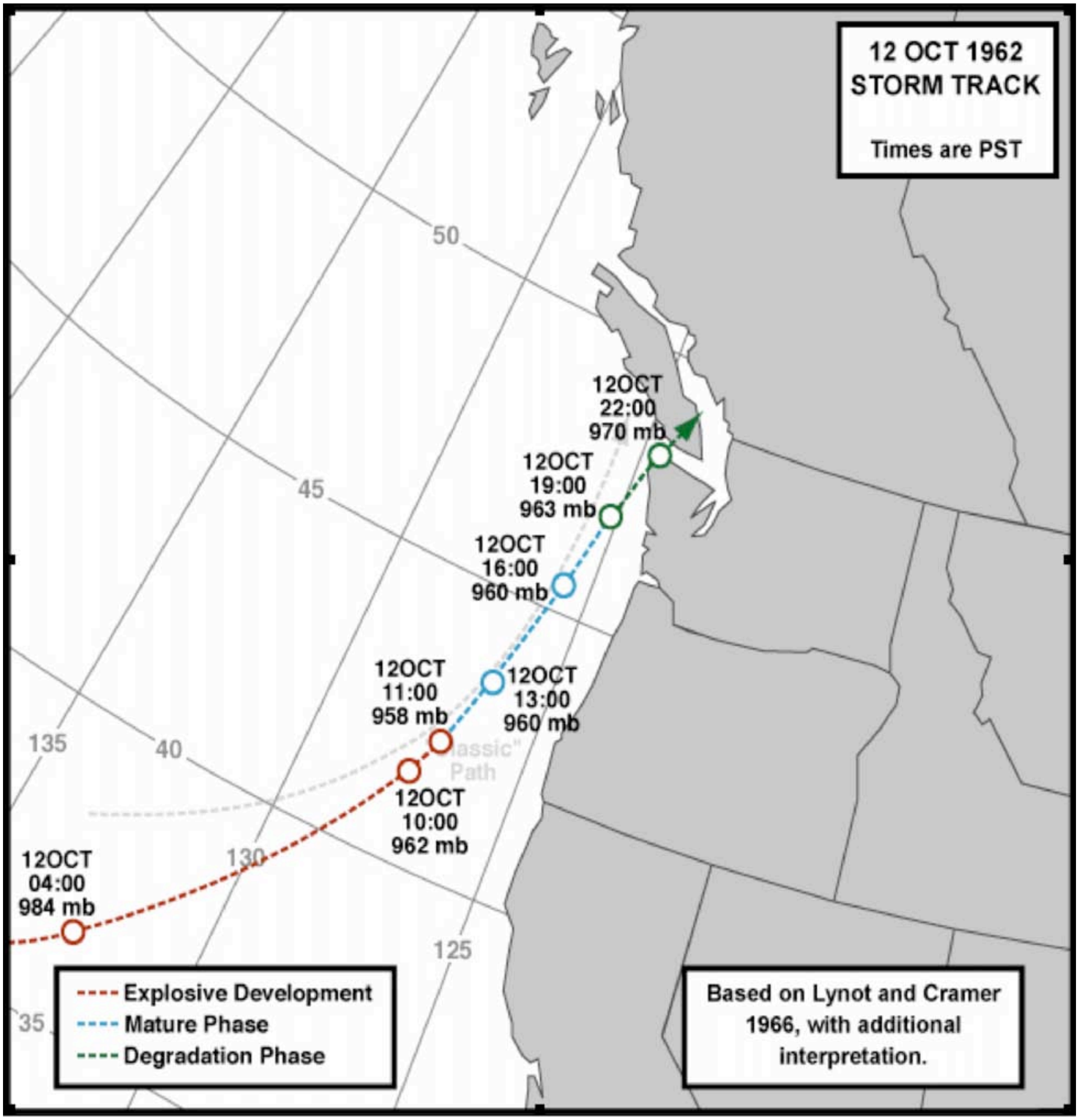

Figure 2. Track of Columbus Day Storm, 1962

Based on historical data, we develop a "scenario wind storm", Figure 3. This map shows wind speeds for 5 second gusts over open terrain at 33 feet above ground level.

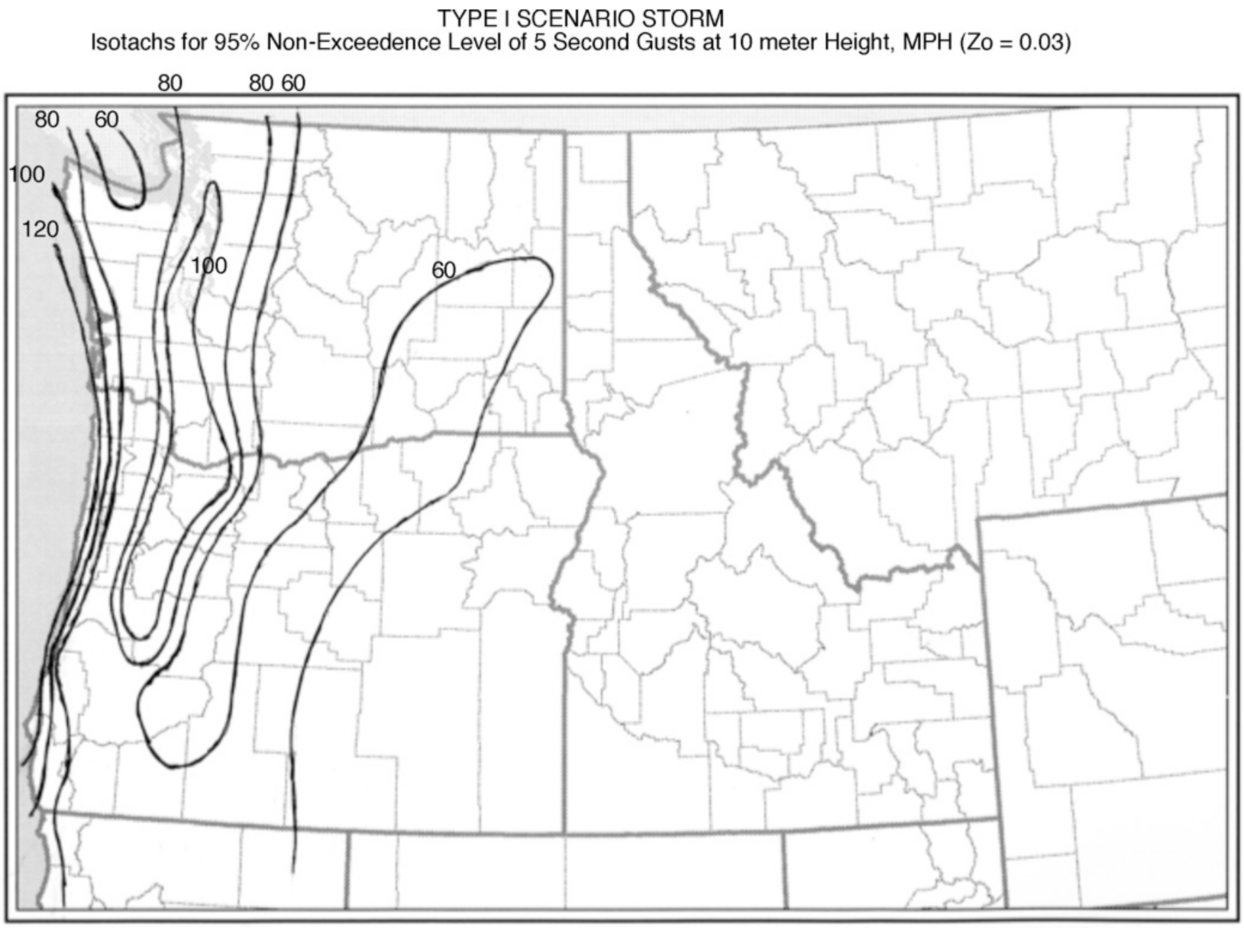

Figure 3. Hypothetical Scenario Wind Storm

Ice storms have occurred in the BPA service area as follows: 1997, 1996, 1995, 1991, 1986, 1984, 1983, 1982, 1980, 1978, 1970, 1963, 1957, 1955, 1950, 1948. Figure 4 shows the footprint of ice storms that affected the BPA service area during the 1950s. On average, the BPA system is exposed to an ice storm about one every three years.

Reflecting that concurrent wind and ice storms can be extremely damaging to transmission towers, BPA has help sponsor the development of probabilistic ice-loading maps.

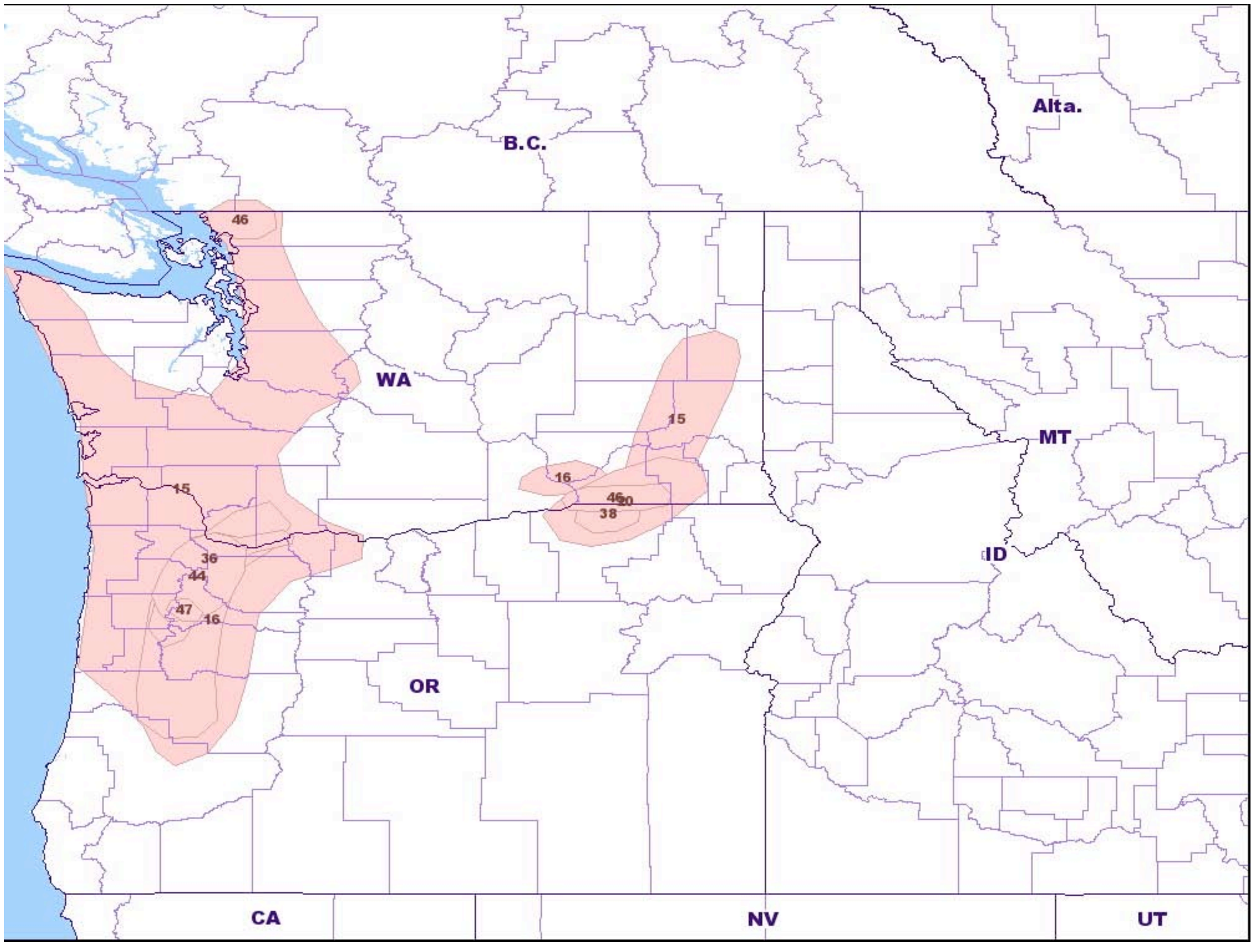

Figure 4. Footprint of Ice Storms (shaded areas) in BPA Service Area, 1950 – 1959

In Figure 5, the thick red lines denote either 80 mph wind speeds (along coastal Oregon and the eastern portion of the Columbia River Gorge), or 1.25 inches of equivalent radial glaze ice (Columbia River just east of Portland, Oregon).

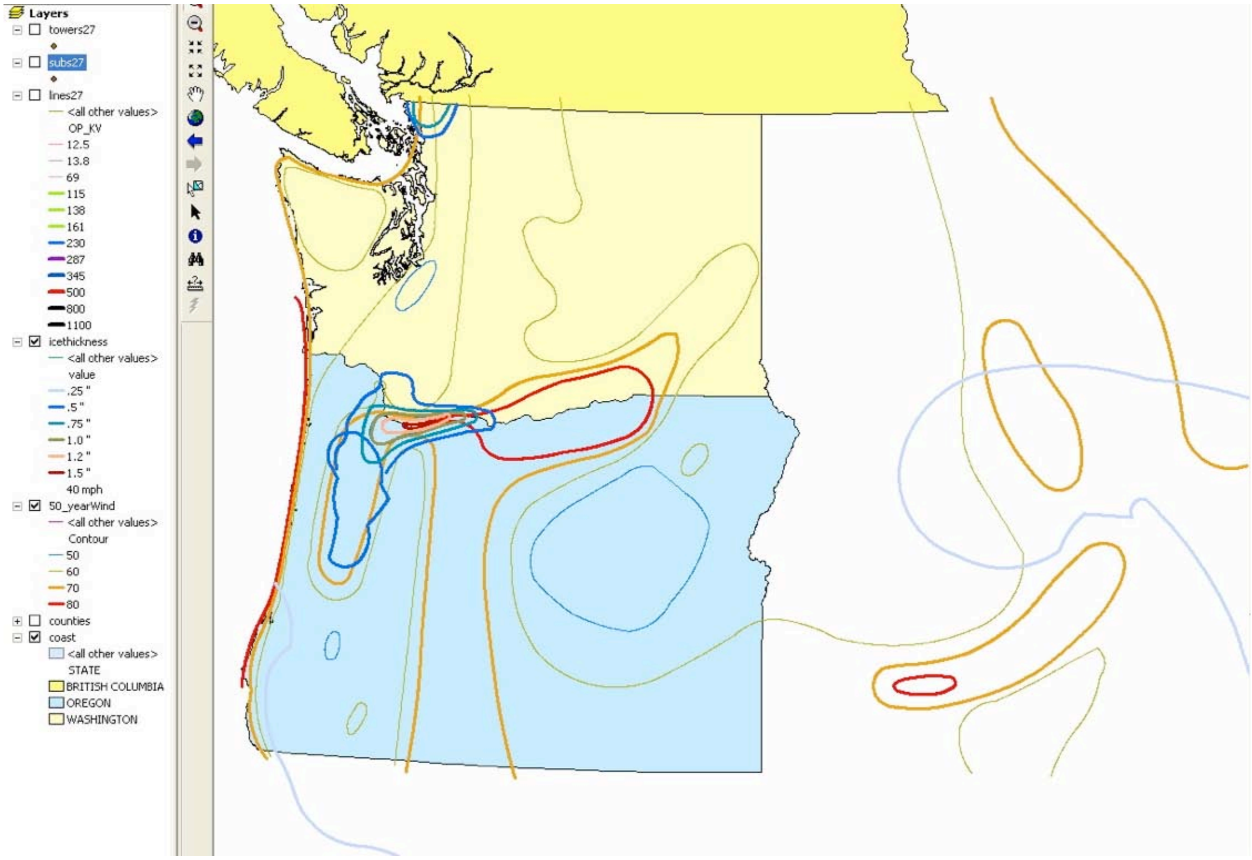

Figure 5. Map for Ice and Wind Loads, 50 Year Return Period

LANDSLIDES

Winter storms have caused deep-seated landslides in the BPA system. Historically, these landslides damage on the order to tens of towers per decade. BPA has also experienced intermittent damage due to slow moving slides. About 25% of BPA's transmission towers are located in mountainous regions. To help quantity the magnitude of the risk, an earthquake-induced landslide model was developed.

The model factors in site morphology, geologic reconnaissance, historical landslides, local triggers (road or creek cuts) and variations for the geology in the Coastal and Cascade ranges. Figure 6 shows a site along one BPA transmission line, highlighting a location where a 230 kV tower failed in a landslide (buried under the soil mass), along with the replacement tower. Table 1 show the forecast results for two transmission lines, one that goes through the Coastal range, and the other through the Cascades.

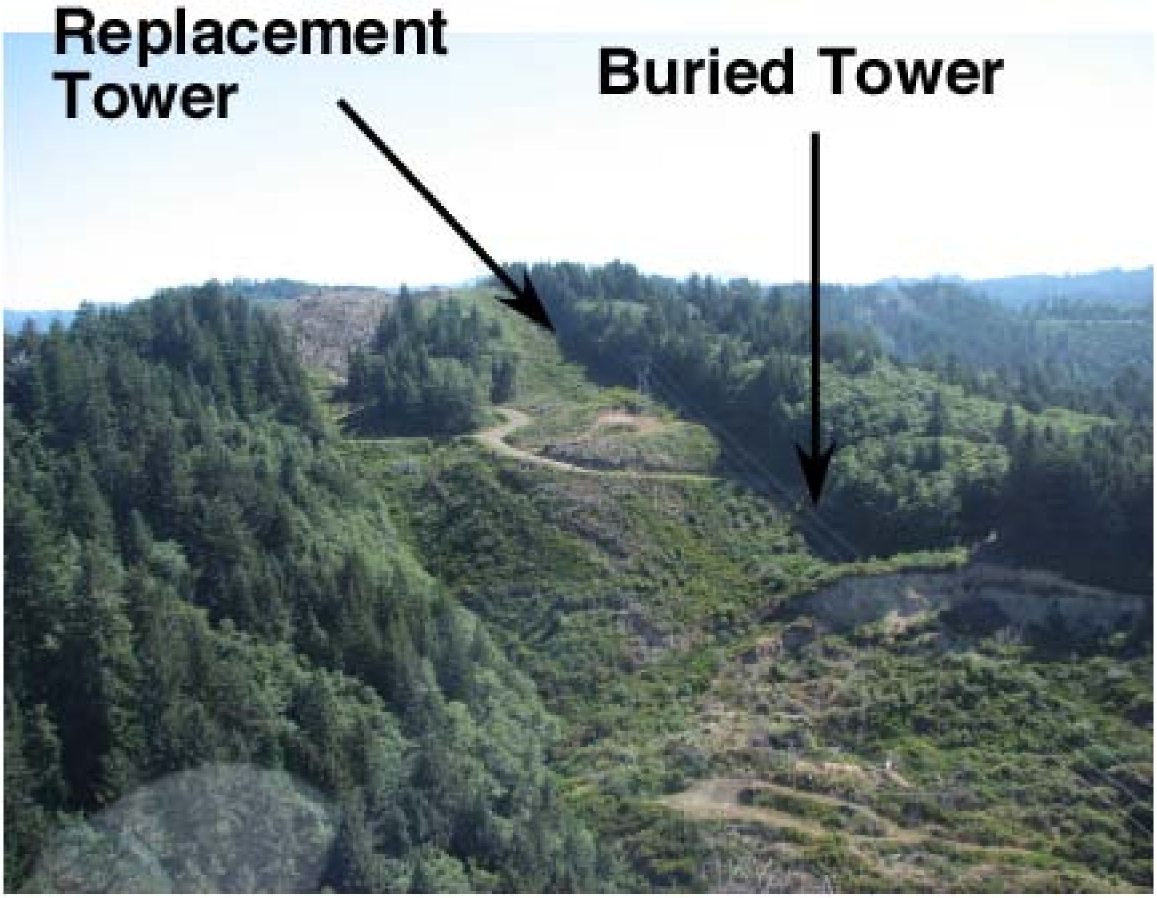

Figure 6. Transmission Tower Buried by Landslide

Item	Line 1 – 230 kV, Coastal Range	Line 2 – 500 kV, Cascade Range	Both Circuits
Number of Towers Analyzed	173	575	748
PGA minimum, g (median motions)	0.36g	0.13g	0.13g
PGA maximum, g (median motions)	0.43g	0.28g	0.43g
PGA average, g (median motions)	0.41g	0.18g	0.24g
Towers within block landslide initiations, winter	11.19	1.51	12.70
Towers within block landslide initiations, summer	5.60	0.75	6.35
Towers with >25% chance of a block slide initiation, winter	14	3	17
Towers within debris flow initiations, winter	8.50	7.38	15.88
Towers with >25% chance of being within a debris flow initiation, winter	16	0	16

Table 1. Landslide Initiations at Towers, Given CSZ M9 Earthquake

EARTHQUAKE

The performance of substations by major utilities (SCE, PG&E, BPA) in earthquakes has been documented in prior reports (Matsuda et al, 1994, Kempner et al, 2006).

CONCLUSIONS

There is potential for damage to components of a high voltage transmission network from multiple hazards. Depending on the extent and location of the damage, the impacts could range from nearly zero (undamaged redundant parts of the network pick up the load), to slight (short outages until critical links are repaired) to severe (cumulative damage overwhelms the network and restoration capability).

By examining all the major hazards (wind, ice, rain, earthquake), utilities like BPA can assess the potential for adverse impacts. It is intended that through this research that BPA can make informed decisions as to whether to mitigate existing vulnerabilities, or alter design criteria for construction of new components in the future.

REFERENCES

Matsuda, E. N., Savage, W. U., Williams, K.K., Laguens, G.C., "Earthquake Evaluation of a Substation Network," in Lifeline Earthquake Engineering, Proceedings, Third U.S. Conference, Technical Council on Lifeline Earthquake Engineering, Monograph No. 4, August, 1991.

Kempner, L., Eidinger, J., Perez, J, Schiff, A., Seismic Risk of a High Voltage Transmission Network, EERI 8th National Conference on Earthquake Engineering, San Francisco, April, 2006.