EXHIBIT NO. ___(BAV-8)
DOCKET NO. UE-09___/UG-09___
2009 PSE GENERAL RATE CASE
WITNESS: BERTRAND A. VALDMAN

BEFORE THE
WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, **Complainant,** **v.** **PUGET SOUND ENERGY, INC.,** **Respondent.**	**Docket No. UE-09____** **Docket No. UG-09____**

SEVENTH EXHIBIT (NONCONFIDENTIAL) TO THE PREFILED DIRECT TESTIMONY OF BERTRAND A. VALDMAN ON BEHALF OF PUGET SOUND ENERGY, INC.

MAY 8, 2009

Storm Hardening the Electric Transmission System

Performed for:

Puget Sound Energy

By

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Ecological Solutions Inc.
March 2009

Proprietary Notice

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Executive Summary

The Puget Sound Energy (PSE) service area experienced winds ranging from gale force to the equivalent of a category two hurricane over December 14-15, 2006. With soils saturated from previous heavy rains, tens of thousands of trees uprooted, falling onto power lines and substations. More than 40% of PSE's transmission lines were knocked out of service.

In the aftermath of the storm, PSE began a review to identify what additional measures could be taken to prepare for severe storms, minimize or prevent storm damage and improve the response when outages occur. As trees played a dominant role in the extent of system damage incurred, any successful avoidance or minimization of future storm damage will necessarily entail new, altered or increased vegetation management activities.

Ecological Solutions Inc. of Sherwood Park, Alberta was contracted to audit PSE's vegetation management program and to assess and quantify conditions that impact tree-caused service interruptions.

This report describes:

- the investigation process,
- data collection and analysis,
- resulting conclusions, and
- recommendations of means and options for transmission system hardening.

This section of the report provides a synopsis of the project, its twenty-seven findings and six recommendations.

Vegetation Management Program Audit

The first element of the project was an audit of PSE's distribution and transmission vegetation management program. Documentation of VM standards, specifications, procedures and guidelines were reviewed. Field inspections were undertaken to establish whether the work as applied and delivered in the field is consistent with the standards, specifications, etc. Field inspections were the source of information used to assess the adequacy and suitability of the chosen maintenance cycles.

Key findings of the audit include:

- The VM work delivered in the field is consistent with the expressed standards and specifications
- PSE's current VM program is well organized with the potential for only a minor improvement in cost effectiveness

- The maintenance cycles are appropriate for the local tree growth rates
- PSE's rate of tree-caused service interruptions are not due to a sub-standard VM program

Outage Statistics and Tree-caused Outage Investigations

Outage statistics and data from the tree-caused outage investigations were reviewed and analyzed. As the motivation for this work is to learn what might be done to avoid such extensive storm damage as was experienced in late 2006, the outage statistics used include the un-audited major storm statistics. The outage data from 1998 through 2007 contains over 34,000 records for tree-caused outages. Outage data provides insight into the extent and characteristics of tree-caused outage events. The following is a list of the key observations.

- PSE's service interruption experience is driven by trees (*Exhibit 0-1*)
- Vegetation Management funding needs to be increased to arrest the trend of increasing outages from outside the right of way
- About 80% of tree-caused outages arise from the in-fall of off right of way trees
- Off right of way trees are increasingly contributing to outages
- From 1998 through 2007 the transmission system experienced 265 tree-caused outages
- A more frequent inspection cycle for hazard trees and a focus on problem tree species may reduce tree-caused interruptions as much as 20%
- Limb failures account for 35% of all tree-caused outages
- Shortening the pruning cycle will not improve reliability

Exhibit 0-1
Percent of Outages That Are Tree-caused

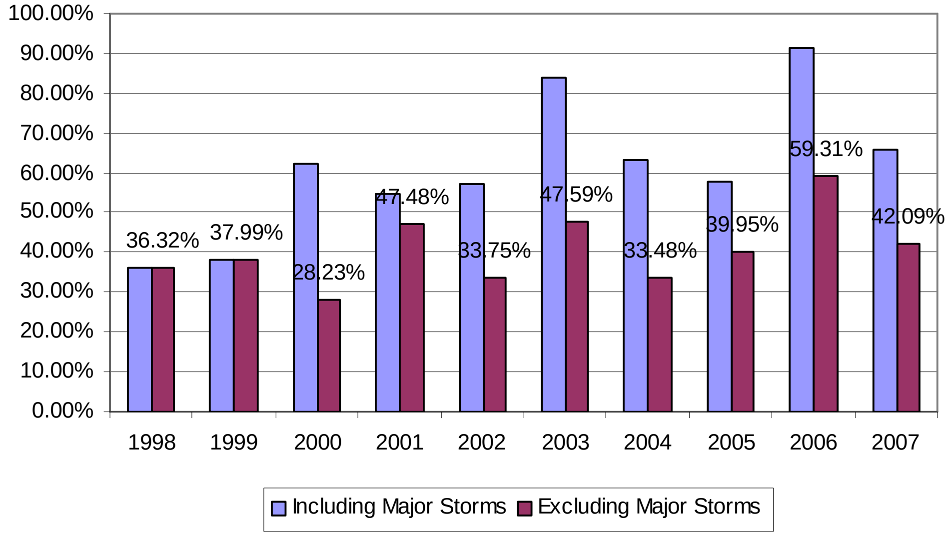


Exhibit 0-2
Tree Limb Caused Outages 1998-2007

Limb Origin	Clear Width (ft)
On ROW	10
Off ROW	24

PSE's outage experience indicates that a better understanding of the transmission system tree exposure is required.

While PSE refers to 55 and 115 kV lines as high voltage distribution, for the purposes of this report, transmission will refer to 230 kV, 115 kV and 55 kV lines. Voltages below 55 kV are referred to as distribution.

Since 2005 in-growth trees have comprised less than 5% of all tree-related outages. Outages arise predominantly from trees that appear healthy, the attendant risk of which are not addressed by the vegetation management program. Storm hardening the electric system will necessitate either limiting the potential for the in-fall of trees, particularly trees located beyond the right of way or their effects.

The location of trees giving rise to outages caused by limb failures (*Exhibit 0-2*) suggests a path to reducing these interruptions. It is seen that on average, trees giving rise to limb failure outages are located in close proximity to conductors (*Exhibit 0-2*). Such close proximity suggests branches are overhanging conductors. For transmission lines overhangs are removed. On the distribution system, overhangs are tolerated. Therefore, a more intense focus on assessing tree health and strength of limbs of particular problem tree species may yield a reliability benefit. Further reliability gains can be achieved by eliminating, if not all overhangs, as a minimum, overhangs of Douglas fir, big-leaf maple, black cottonwood and red alder, between the substation and the first protective device.

Transmission System Tree Exposure

To determine the extent of transmission tree exposure 400 randomly selected points along the system were assessed for the percent of forested edge. It was found that 74.94% ± 2.14 of PSE's system is exposed to forested edge (95% confidence level). Field measurements at 218 edges of the random sample points, determined line height, tree height, clear width, tree density and tree species adjacent to the right of way. From these measurements it was calculated that PSE's utility forest supports an average of 272 ± 13 trees per acre. Based on field measured variable means and Pythagorean calculations there are 4,219,053 trees located outside the transmission right of way, which on failure could strike a transmission line (danger trees[1]). The tree exposure can also be stated as 1,995 danger trees per line mile.

The utility forest, like any forest, is in a constant state of renewal. Some portion of the population becomes decadent and dies, opening up areas for seedlings to become established and prosper. Based on the estimated annual tree mortality rate of 1.7% for PSE's service territory, about 72,000 trees of the utility forest along side transmission lines become decadent each year. In trees, death does not occur at a specific moment in time but is a process, which occurs over a period of months or even years. Consequently, trees early in the mortality process may or may not be perceived and labeled as hazard trees. Over time, however, unless the total tree exposure has been changed, there will be an ongoing population of 72,000 hazard trees. As the trees become more decadent, there may be indicators of where failure is most likely to occur and in some cases the likely direction of fall. Based on the available data, it is estimated that 23-33% of the hazard trees will need to be removed to protect the transmission system. These percentages equate to 16,500 to 23,700 trees that will need to be removed annually to prevent the build up of unhealthy trees, which become increasingly vulnerable to stress loading.

The over 11,000 tree data records collected in field sampling provide information on the species composition of the utility forest. Comparing the species composition (*Exhibit 0-3*) with the problem species identified in the tree-caused outage investigations (*Exhibit 0-4*) permits a hazard ranking (*Exhibit 0-5*) to guide the field identification of hazard trees. The hazard ranking shows attention needs to be focused on minor species in landscaped settings and the deciduous species, particularly, big-leaf

[1] Danger trees are trees, which on failure could strike electrical equipment interrupting service. Hazard trees are a subset of danger trees, which in addition to having the capacity to interrupt service on failure, have a visible fault.

maple, black cottonwood and red alder. The main coniferous species requiring careful hazard evaluations is Douglas fir.

Exhibit 0-3
PSE Utility Forest Species Composition

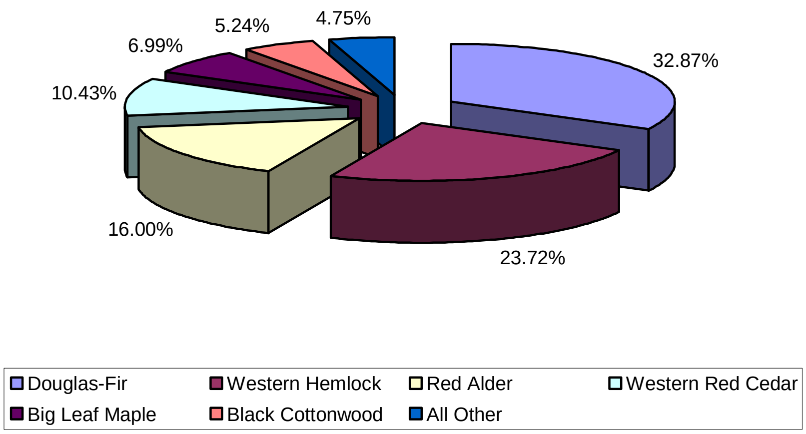


Exhibit 0-4
Major Contributing Species to Tree-caused Interruptions

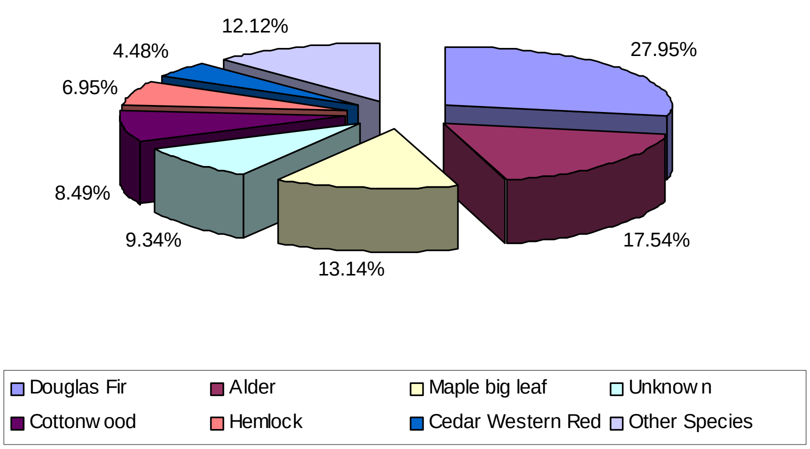


Exhibit 0-5
Failure/Hazard Ranking

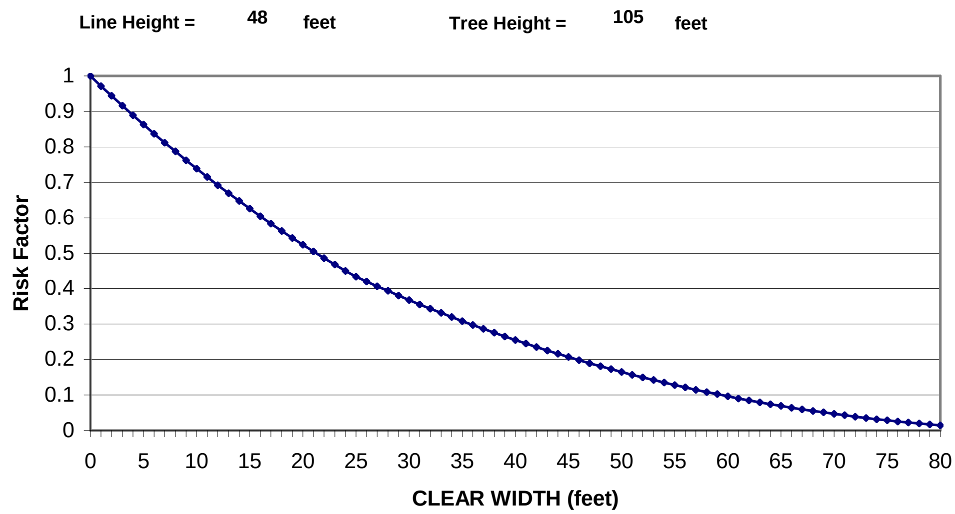
Species	Composition Rank	Failure/Hazard Rating	Failure/Hazard Rank
Douglas-Fir	1	0.85	5
Western Hemlock	2	0.29	7
Red Alder	3	1.10	4
Western Red Cedar	4	0.43	6
Big Leaf Maple	5	1.88	2
Black Cottonwood	6	1.62	3
All Other	7	2.55	1

Tree Exposure Risk

Tree exposure risk is comprised of two factors: the number of trees capable of striking the line on failure; and, the average arc of line exposure to a falling tree. To quantify tree risk, Ecological Solutions has developed the Optimal Clear Width Calculator. Using the field variables line height, tree height, clear width and tree density, the proprietary Optimal Clear Width Calculator, produces a measure of the tree exposure risk. It is expressed as the Risk Factor.

To illustrate the Risk Factor (RF), the mean variables, line height 48 feet, dominant tree height 105 feet, tree density 252 trees/Ac, for 230 kV lines were used to generate *Exhibit 0-6*. The mean clear width is 52 feet, which produces a RF of 0.1497. *Exhibit 0-6* shows that a clear width of 0 feet will have a RF of 1 and a RF of 0 is reached when the clear width is so great that no tree on failure will strike the line (tree-free).

Exhibit 0-6
Line Strike Risk



The Risk Factor was calculated for each of the 218 right of way edges sampled using the measured variables. The RF's were then calculated for each voltage class. As a considerable amount of the 55 and 115 kV system is along roadsides, with one small and one quite large clear width, the mean clear width does not adequately reflect the tree risk. The 55 and 115 kV voltage classes were further segregated into Street side and ROW side. The RF ratings are provided in *Exhibit 0-7*. Due to the influence of weather and tree failure rates, PSE's tree risk cannot be directly compared to other utilities. Rather, the usefulness of the RF rating is in evaluating the impact of changes to one or more of the variables of clear width, line height or tree height.

Note generating the RF from mean variables (*Exhibit 0-6*) produces a somewhat different result from that derived by calculating the mean from the RF for each of the 230 kV right of way edges sampled (*Exhibit 0-7*).

Exhibit 0-7
Tree Exposure Risk

Voltage (kV)	Side	Risk Factor (%)
55	ROW	30.47
55	Street	7.86
55	Both	27.64
115	ROW	29.67
115	Street	5.18
115	Both	25.81
230	Both	13.55
System		**22.73**

Typically utilities use two variables, clear width and line height, at the point of line design and installation to limit the tree risk. The other variables studied that influence tree risk, tree height and tree density, are not variables that utilities control to any extent prior to line installation. Scatter diagrams were used to show that clear width and line height increase with voltage class and tree risk (RF) decreases with increasing voltage class (Section 8, Controllable Variables and their Relationship to Risk).

The field variables were statistically compared to determine whether clear width and line height had been used to make significant distinctions between voltage classes, a distinction that is desirable due to the number of customers affected with each interruption.

Line height between 55 and 115 kV is not significantly different (*Exhibit 0-8*). Nor is there a significant difference in clear width between 55 and 115 kV (*Exhibit 0-9*). Clear width and line height have not been used to the extent necessary to statistically distinguish the tree risk on 115 kV lines from that faced on 55 kV (*Exhibit 0-10*).

Exhibit 0-8
PSE Transmission Line Height

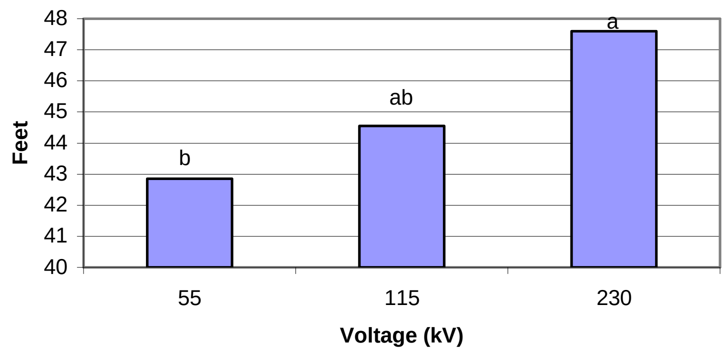


Exhibit 0-9
Transmission Clear Width

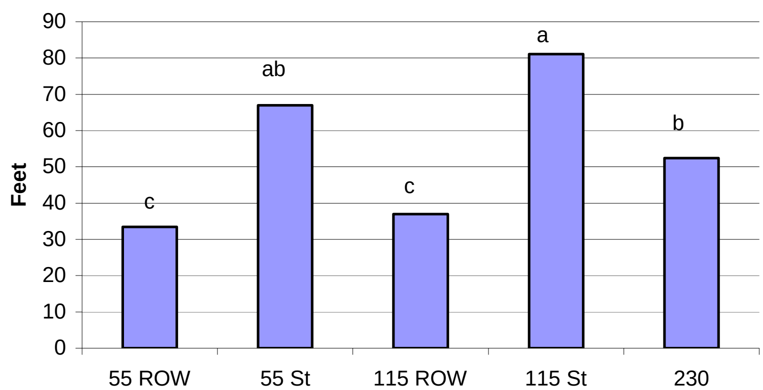
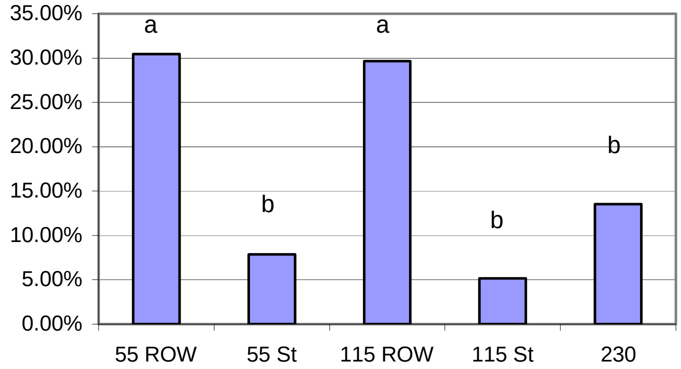


Exhibit 0-10
Transmission Tree Risk Factor



To study the relationship between variables and tree-caused outage incidents it is necessary to segregate the data by voltage class and to express outage incidents by an equal unit, regardless of system miles. The unit used is the average annual number of tree-caused outage events per 1,000 miles of line for each voltage class. It is reported as the annual incident frequency, F_{AI}. The mean variable values, RF rating, tree exposure, along with outage frequency from 1998 through 2007 are presented in *Exhibit 0-11*.

Exhibit 0-11
Key Variables for PSE Transmission
(At Found Sag)

Voltage (kV)	Clear Width	Line Height	Tree Height	Risk Factor	Tree Exposure	Trees mi^{-1} Edge	F_{AI} 1000 mi^{-1}
55 ROW	33	43	94	.3047	359,728	1,442	27.75
55 St	67	43	100	.0786	20,333	570	0.30
115 ROW	37	45	97	.2967	3,392,215	1,224	12.60
115 St	81	43	103	.0518	99,771	193	0.17
230	52	48	91	.1355	372,054	568	2.14

F_{AI} = annual incident frequency

In statistical testing field measured and calculated variables for correlation to outage frequency, only two variables, trees mi^{-1} edge and RF, were found to be significantly correlated (*Exhibit 0-12*). The lack of a significant correlation between F_{AI} and clear width and F_{AI} and line height indicates that any difference in outage experience between voltage classes cannot be positively attributed to the differences in right of way width or line height.

Exhibit 0-12
Variable Relation To Interruption Experience
(F_{AI} 1000 mi^{-1})

Variable (means)	Correlation Coefficient (r)	P(r=0)
Clear Width	-0.8238	0 .0864 ns
Line Height	-0.2760	0.6530 ns
Tree Height	-0.4114	0.4914 ns
Total Tree Exposure	0.2513	0.6835 ns
Trees mi^{-1} Edge	0.9172	0 .0282 *
Risk Factor	0.8878	0.0443 *

* significant - 95% level
** highly significant - 99% level
ns not significant

The annual tree incident frequency can be predicted from the extent of tree exposure per mile of right of way edge. There is a very strong, significant correlation between F_{AI} and the number of trees per mile of right of way edge. The correlation co-efficient (r) of 0.9172 indicates that over 91% of the annual tree-related outage events can be explained by transmission line exposure to trees. Hence, actions that reduce the amount of tree exposure will have a very positive effect on reliability.

To better understand the relationship between annual outage incidents and tree exposure a regression was sought for F_{AI} 1000 miles^{-1} and trees mi^{-1} edge. The smallest residuals (variance of calculated values from actuals) were yielded by the exponential regression:

F_{AI} 1000 mi^{-1} = 0.07722073493*e^(0.0041125167* Trees mi^{-1} edge) (*Equation 1*)

The regression has a coefficient of multiple determination of, $r^2 = 0.9012$ and P(0) = 0.0136. That is, 0.9012 of the variation in F_{AI} 1000 mi^{-1} is explained by the regression and the probability that the null hypothesis is valid is 0.0136. Another way of stating this is that the regression has a chance of error of only 1.36%. The equation will permit forecasts of the resulting annual outage frequency following actions that reduce the extent of tree exposure.

The annual tree incident frequency can be predicted from the Risk Factor. RF is the second variable that is significantly correlated to F_{AI} 1000 mi^{-1}. Given that trees mi^{-1} edge was found to have a significant correlation to F_{AI} 1000 mi^{-1}, this result is expected as the RF reflects both aspects of tree exposure, the number of trees and arc of exposure to line strikes. The correlation coefficient (r) is 0.8878 with 0.0443 chance of error. To better define the relationship between RF and F_{AI} 1000 mi^{-1} a regression was sought. Past work in this area[1] has established that the relationship is exponential in nature. The exponential regression is:

F_{AI} 1000 mi^{-1} = 0.08765294536*e^(18.2203153259*RF) (*Equation 2*)

The regression coefficient of multiple determination, $r^2 = 0.9559$ and P(0) = 0.0040. That is 0.9559 of the variation in F_{AI} 1000 mi^{-1} is explained by the regression and the probability that the null hypothesis is valid is 0.0040.

This highly significant result provides confidence in the use of this regression to predict the reliability impact of various management decisions. The RF is derived from field measurable variables of clear width, line height, tree height and tree density. The work undertaken in this project has established the average tree density to be 272 trees per acre. The clear width, line height and adjacent tree height are easily measured in the field.

Two regressions to predict expected outages have been derived. One requires the resulting trees mi^{-1} edge after an intervention and the other requires the resulting RF. At low incidence of tree-caused outages RF has a better fit to the data but at higher levels and overall, the regression using trees mi^{-1} edge has a better fit as indicated by the smaller residual values. It is logical that if initiatives were to be undertaken to reduce tree-caused interruptions the implementation would first focus on right of way segments, which currently have a high incidence of outages, and where the greatest reliability impact can be had. Consequently, generally, the regression using trees mi^{-1} edge is the recommended algorithm for predicting the outcome of the intervention. There is one exception. It is quite conceivable that PSE may choose to apply the findings of this work to the 230 kV system, where the outage incidence is already quite low. In that case the algorithm using the variable RF is a superior choice.

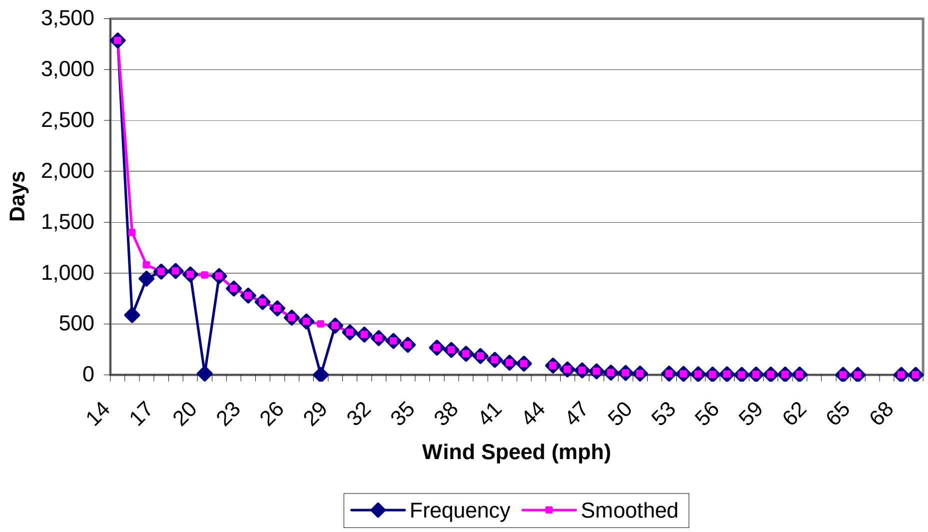
Wind Data

While some tree-caused interruptions may occur with little or no stress loading on trees, the majority will occur when there is wind, ice or snow loading on trees. For the purposes of this work only wind loading is examined.

The wind data used for analysis provides maximum wind speeds for all days between January 1, 1998 and December 31, 2007 with winds equal to or greater than 15 mph. The data is comprised of approximately 33,000 records. Data was obtained from nine airfields.

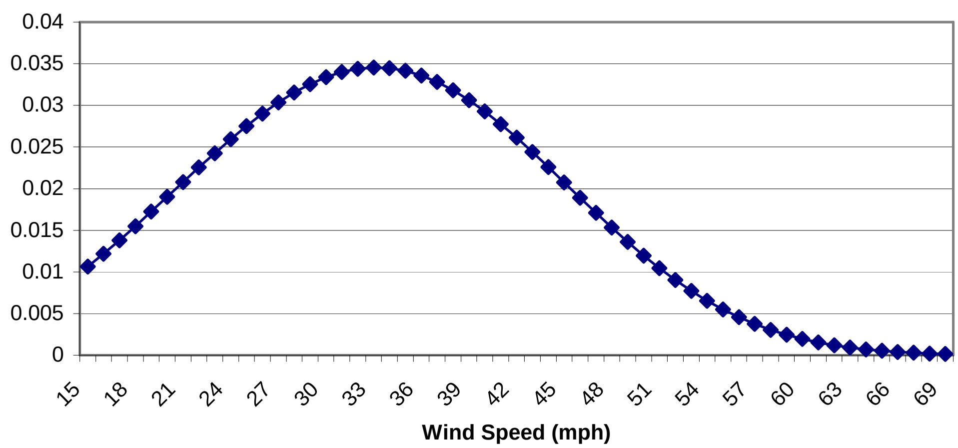
The frequency of wind days by wind speed is shown in *Exhibit 0-13*. The occurrence of transmission outages based on wind speeds creates a choppy graph, however, with a clear trend. The data was smoothed using a Weibull distribution, which produces *Exhibit 0-14*.

Exhibit 0-13
PSE Service Territory 10 Year Wind Frequency



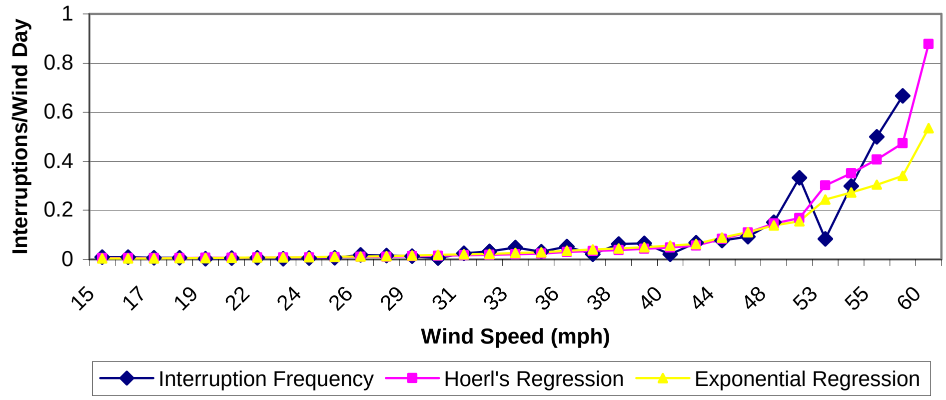
Note: Y-axis is number of days when winds of a specific speed were experienced

Exhibit 0-14
Weibull Distribution for Transmission Outages
1998-2007



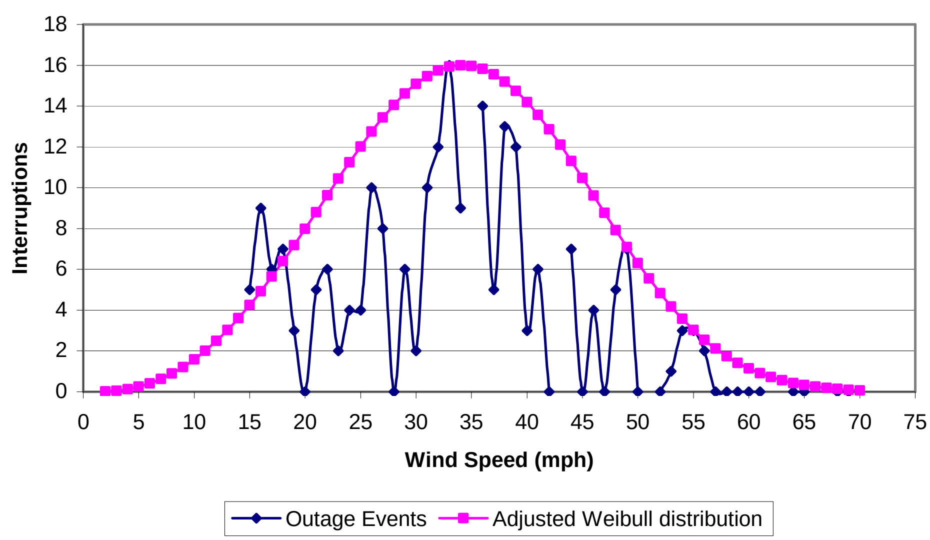
As would be anticipated, the number of outage events increases with increasing wind speed (*Exhibit 0-15*). The outage frequency is exponential to wind speed (*Exhibit 0-15*). The incidence of high wind intensities (>45 mph) is low but when they do occur the rate of tree failures is high.

Exhibit 0-15
Interruption Frequency



For the purposes of modeling outages, the Weibull distribution was adjusted to provide the number of interruptions on the y-axis. Considering the impact of transmission outage events, the distribution was intentionally set so as not to underestimate the number of outage events (*Exhibit 0-16*).

Exhibit 0-16
Modeling Transmission Interruptions Based On Wind Speed
1998-2007

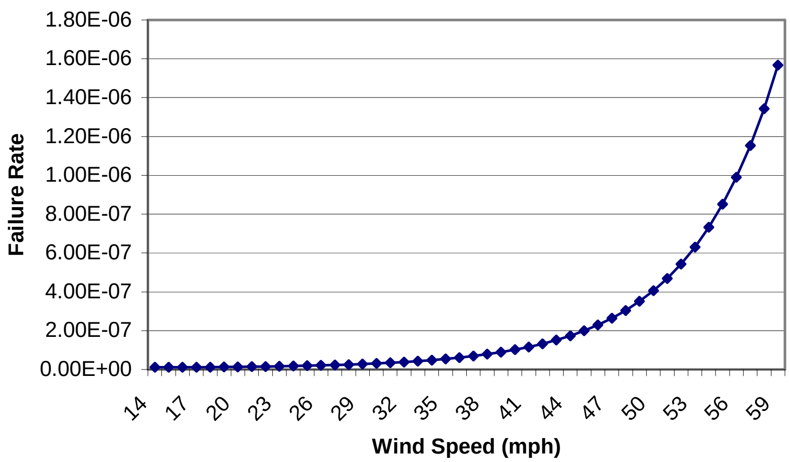


To be able to assess the reliability impact of different vegetation management standards it is necessary to build predictive models from the observed data and relationships. If standards impacting the size of the utility forest are to change, modeling that is responsive to this change is required. Ideally the model would have the capacity to forecast the long-term impact of changes in vegetation management standards and the interruption expectations for a single storm event. Both types of models were established by calculating tree failure rates from smoothed curves. The smoothed curve for 10-year tree-caused outages is shown in *Exhibit 0-16*. The smoothed curve derived from the Hoerl's regression shown in *Exhibit 0-15* is provided in *Exhibit 0-17*. The models will be supplied to PSE in MS Excel format. The two algorithms are:

Expected Interruptions = DT*10-year tree failure rate @ WS*0.5*mean RF; (*Equation 4*)
where DT is total exposure to danger trees, RF is Risk Factor, WS is wind speed, and

Expected Interruptions = DT*tree failure rate @ WS*0.5*mean RF; (*Equation 5*)
where DT is total exposure to danger trees, RF is Risk Factor, WS is wind speed.

Exhibit 0-17
PSE Transmission Tree Failure Rate



It has been found that over the last ten years the frequency of relatively low wind events is much higher than high wind events (*Exhibit 0-13*). It has also been established that most of the tree-caused outages occurred at mid-range wind intensities of 30-40 mph (*Exhibit 0-16*). The incidence of outages experienced increases on high wind intensity days (*Exhibit 0-15*). Accordingly, tree failure rates increase with wind intensity (*Exhibit 0-17*). The data suggests that the tree failure rate will top out at some wind intensity level but precisely where that point is, is unknown.

Operational Options to Reduce Tree-related Outages

There are three variables that affect the extent of tree exposure: line height, clear width and tree height. To manage tree-related outages one or more of these variables will need to be manipulated. As it is not realistic to think that the tree risk can be eliminated, the question becomes what amount of tree risk are the utility, the regulator and the public willing to accept? It is tempting to try to establish a standard line height or clear width for each voltage class. However, neither of these variables nor the tree height was significantly correlated to the outage experience. This informs us that one or more of the variables are so variable between sample locations as to thwart a significant correlation. The two identified in *Exhibit 0-12* are tree height and line height. That there is variability in tree height is readily understood. It also informs us that failing to assess tree risk on a local basis via measures of tree exposure will unnecessarily increase the cost of reliability improvement.

An essential element of this project is the identification of valid measures of tree risk and to quantify what the current level of risk is. Risk Factor and trees mi^{-1} edge have been found to be valid measures of tree risk due to their relationship to the outage experience (*Exhibit 0-12*). The baseline RF values for the voltage class and sides are presented in *Exhibit 0-11*. The status quo conditions for trees mi^{-1} edge are also found in *Exhibit 0-11*. The current outage experience as expressed by the found regressions for RF and trees mi^{-1} edge have been tabulated in a MS Excel file.

The elimination of all tree risk not being a feasible option due to costs, environmental and stakeholder concerns, PSE will need to determine what level of tree risk is tolerable. As previously intimated, this is a decision that PSE in conjunction with its stakeholders will need to make. *Exhibit 0-18* serves as a guide to RF ratings that will result in reliability improvements.

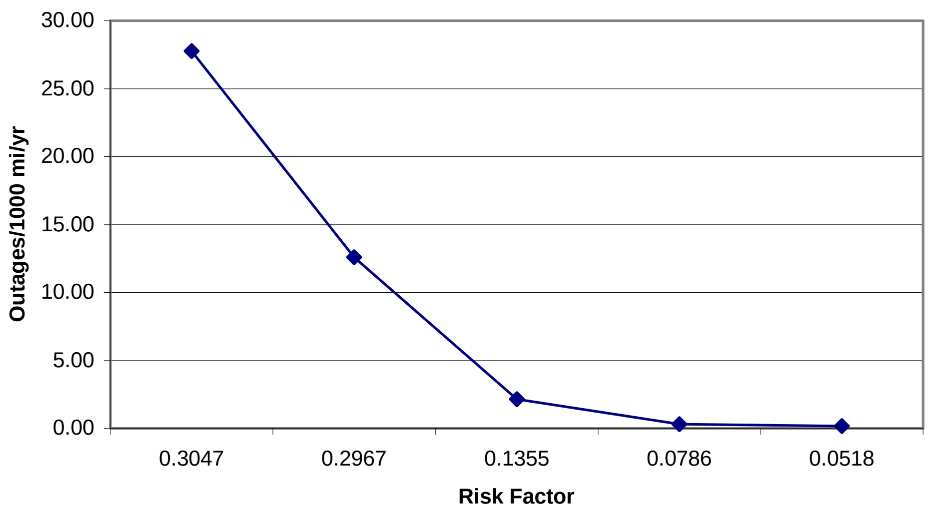
The quantification of the current tree risk presented in this work is new to PSE. As such, it is difficult for PSE to determine what constitutes a reasonable, tolerable risk. Further, some guidance regarding the sensitivity of measures of tree risk to changes in the variables would be useful. Given these considerations, in conjunction with the observation of line segments of anomalous high tree risk, we propose that PSE identify line segments where the tree exposure risk exceeds the mean tree exposure risk for the voltage class and undertake interventions that will reduce the site tree exposure risk to the voltage class mean tree exposure risk. At this point, neither the cost of such an undertaking nor the feasibility from a landowner and public relations perspective, are known. However, it establishes a beginning point for evaluation.

The variables involved in the measures of tree exposure are line height, clear width, tree height and tree density. These are used in the derivation of the RF. However, tree density is not a variable that can be controlled. Rather, it is a reflection of the species characteristics, soil types and fertility and climatic conditions. Line height, tree height and clear width can be modified and doing so changes tree exposure.

Decreasing tree exposure benefits reliability both during storm and non-storm conditions.

- Increasing the clear width entails the removal of trees. Provided that any re-emergent brush is controlled, it provides an enduring reliability benefit. The extent of the benefit will erode somewhat over time based on the increase in height of the adjacent danger trees.
- In using the tree height variable, trees undergo crown reduction through pruning. The response to the pruning will vary with the tree species pruned. However, where the crown reduction is severe and well into old wood, generally regrowth will be non-existent. Where crown reduction removes only a few years growth, regrowth is likely and the pruning will need to be repeated at intervals.
- The persistence of the reliability benefit derived from adjusting line height depends on the rate of change in the height of the adjacent danger trees.

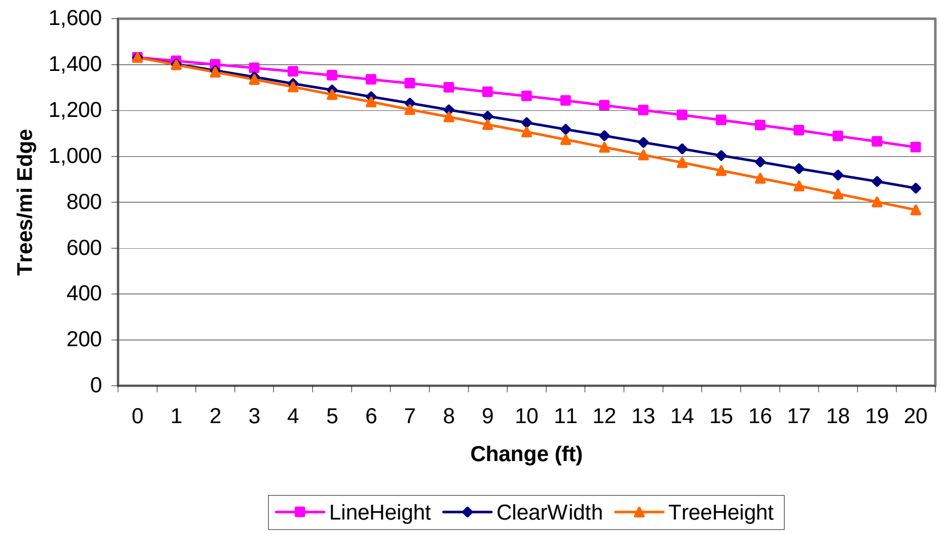
Exhibit 0-18
Relationship of Risk Factor to Outages



Is the change in tree exposure the same for each unit of change in the variable? *Exhibit 0-19* and *Exhibit 0-20* provide the answer as derived from 55 kV on the narrow or right of way side. Changes in line height produce the least change in tree exposure measured both as trees mi^{-1} and RF.

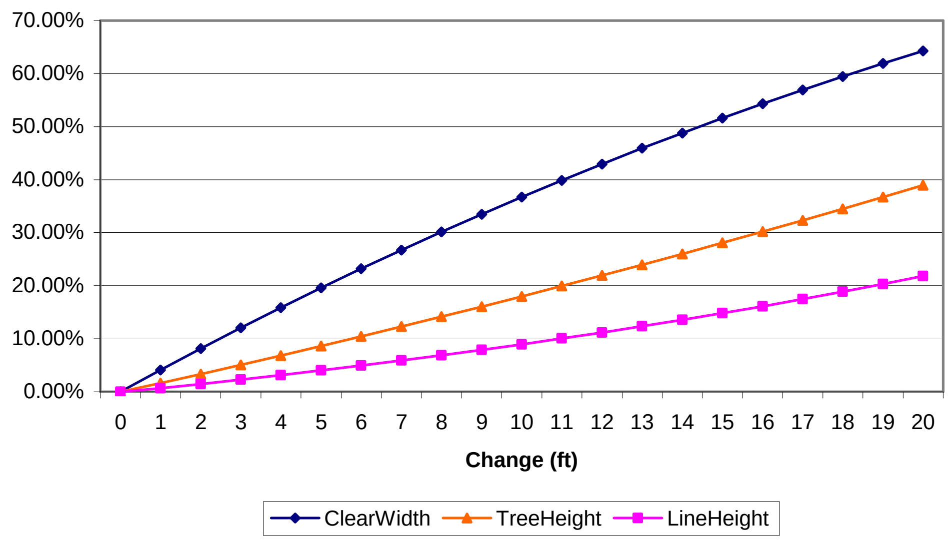
Generally, adjustments in clear width yield the largest change in tree risk. Consequently, in illustrating the potential for reliability improvement, it will be the clear width variable that is adjusted.

Exhibit 0-19
Sensitivity of Tree Exposure to Change in Variable



55 kV ROW side

Exhibit 0-20
RF Sensitivity to Variable Change



55 kV ROW side

Within the report three examples are provided to show how the algorithms developed in this work can be used to predict the reliability impact of changes in vegetation management. Through these algorithms and the spreadsheets provided, PSE will have the ability to calculate and predict:

- Tree-related transmission outages over a ten year period if the status quo is maintained
- Tree-related transmission outages to be expected for a specific wind speed event if the status quo is maintained
- Tree-related transmission outages over a ten year period for a new vegetation management standard
- Tree-related transmission outages to be expected for a specific wind speed event for a new vegetation management standard
- The impact of changes in vegetation management standards on the total danger tree exposure
- The impact of changes in vegetation management standards on the number of danger trees per mile of right of way edge
- The impact on SAIDI for a new vegetation management standard
- The field variable adjustments necessary to achieve a specified transmission tree-related outage frequency

For the purposes of this summary only one example is provided.

Example 1

Presume that PSE wishes to consider the system wide impact of identifying and addressing line segments of tree risk exceeding the voltage class mean risk.

For this example, the 55 and 115 kV lines have not been segmented into right of way and street-side. The benefit shown in *Exhibit 0-21* is an average 37% reliability improvement over the transmission system. This calculation has not included a factor for the influence of wind.

The total transmission tree exposure after intervention is calculated to be 3,900,168 trees. This is a reduction of 318,885 trees.

With the derivation of the new values for system RF and the amount of system tree exposure, or danger trees, the algorithms set out in *Equation 4* and *Equation 5* can be applied to a specific wind speed or to a range of wind values. By applying the algorithms to a range of wind values, the impact of the intervention on expected outages based on wind speed and the outages expected over ten years of mean wind values can be compared to the status quo.

Exhibit 0-21
Forecasting Reliability Improvement
For Reducing Site RF's to Voltage Class Mean RF

	Tree Risk		Tree Risk for Records with RF=<Mean RF		Tree Risk for Records with RF>Mean RF			Tree Risk After Work	
	No. of Records	Ave. Risk Factor (%)	No. of Records	Ave. Risk Factor (%)	No. of Records	Ave. Risk Factor (%)	Risk Factor After Work (%)	Ave. Risk Factor (%)	Improvement (Weighted Average)
55 kV	48	27.64	25	9.70	23	47.14	27.64%	18.30	33.80%
115 kV	108	25.81	60	8.84	48	47.02	25.81%	16.39	36.52%
230 kV	62	13.55	38	3.77	24	29.02	13.55%	7.55	44.23%
System	218	22.73						14.29	37.10%

Expected Interruptions = DT*10-year tree failure rate @ WS*0.5*mean RF (*Equation 4*)
produces *Exhibit 0-22*. It assumes a similar wind distribution as that experienced over the period of 1998 through 2007. The difference in expected interruptions between before and after intervention is a 42.5% reduction. The result varies slightly from improvement shown in *Exhibit 0-21*, which did not include a factor for wind.

Expected Interruptions = DT*tree failure rate @ WS*0.5*mean RF; (*Equation 5*)
produces *Exhibit 0-23*.

In *Exhibit 0-23* one observes that there is a substantial benefit to the proposed intervention at high wind speeds. The benefit is actually a uniform 42.5% reduction at all wind speeds. The benefit simply becomes more apparent at higher wind speeds, where the number of interruptions is greater. A further inference drawn from the observation that the reliability benefit is uniform across wind speeds is that while it is possible to reduce the F_{AI}, it is not possible to make the system absolutely tolerant of wind speeds up to some specified level i.e. 20 mph.

Applying PSE's unit costs to the number of trees to be removed begins the costing process. Any additional costs that are exclusively associated with the intervention should be included. For example, where clear width is adjusted, trees, which had previously grown within a more protected environment within the forest, will be exposed to greater wind loadings. It will be necessary to monitor for hazard trees on at least an annual basis for a period of three to five years. Should such monitoring represent an incremental cost, it is to be included in the cost of the intervention. Avoided costs such as the cost of service restoration can be subtracted to determine either the reliability gain available per dollar or conversely, the dollar cost for each percentage point improvement in reliability. The proposed intervention can then be compared to other vegetation management or engineering options.

Exhibit 0-22
10 Year Outage Expectations
Before and After Intervention

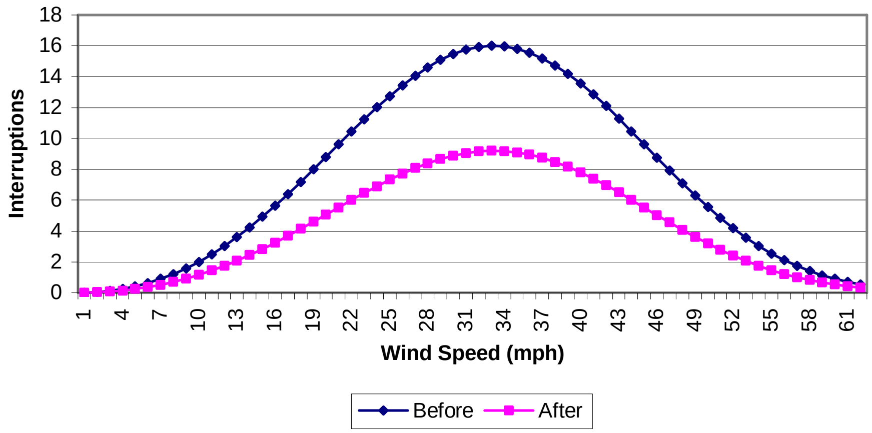
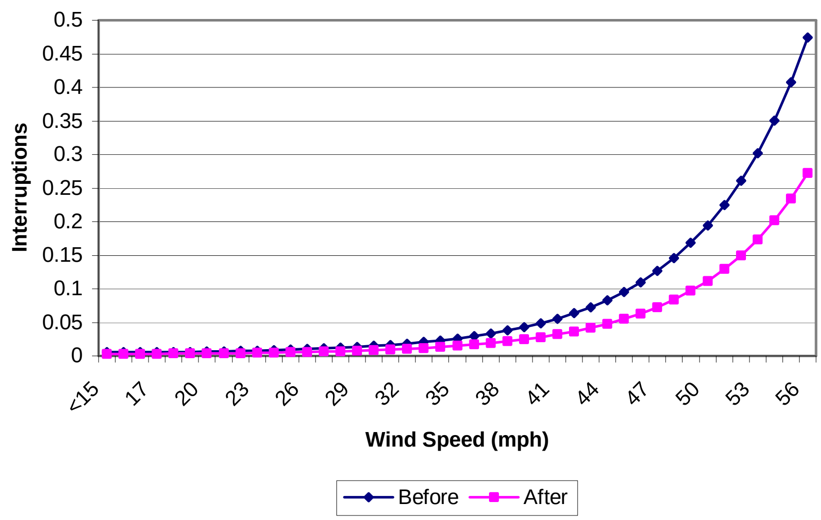


Exhibit 0-23
Outages per Wind Intensity Event
Before and After Intervention



Recommendations

With a view to reducing future tree-caused interruptions of the transmission system, six recommendations have been made. They are listed below. The detailed justification for the recommendations can be found in the Conclusions & Recommendations section.

In general, recommendations are drawn from the findings. Recommendations have been made where the findings point to the potential either for reducing tree-related interruptions or to better inform the selection of interventions in the future.

The recommendations are:

1. Increase the frequency of hazard tree patrols along transmission lines (*Finding 5-11*, *Finding 6-12*)
2. Remove all identified hazard trees located within 40 feet of a conductor (Refer to *Finding 5-11*, *Finding 6-12*, *Exhibit 6-20*)
3. Hazard tree patrols should place emphasis on evaluating the health of Douglas fir, red alder, big-leaf maple, black cottonwood and Western hemlock (Refer to *Exhibit 6-19*, *Exhibit 6-22*, *Exhibit 7-34*, *Finding 5-11*, *Finding 7-18*)
4. Dedicate uniform effort and resources to the tree-caused outage investigations (*Finding 6-12*, *Finding 6-13*, *Finding 6-14*)
5. Set tolerated tree exposure risk standards by voltage class and apply these on any new construction (*Finding 9-22*)
6. Use the found relationships and regressions to run "what if" scenarios to test the reliability impact of possible interventions (Refer to *Finding 9-23*, *Finding 9-24*, *Finding 9-25*, *Finding 10-26, Exhibit 10-61*, *Exhibit 11-71*, *Exhibit 11-72*)

Storm Hardening the Electric Transmission System

1. Background

The Puget Sound Energy (PSE) service area experienced winds ranging from gale force to the equivalent of a category two hurricane over December 14-15, 2006. With soils saturated from previous heavy rains, tens of thousands of trees uprooted falling onto power lines and substations. More than 40% of PSE's transmission lines were knocked out of service.

In the aftermath of the storm, PSE began a review to identify what additional measures could be taken to prepare for severe storms, minimize or prevent storm damage and improve the response when outages occur. As trees played a dominant role in the extent of system damage incurred, any successful avoidance or minimization of future storm damage will necessarily entail new, altered or increased vegetation management activities.

This report describes:

- the investigation process,
- data collection and analysis,
- resulting conclusions, and
- recommendations of means and options for transmission system hardening.

The work is divided into the following project elements.

1. Current Vegetation Management (VM) Review and Assessment
2. Review of Outage Statistics
3. Review of Failed Tree Investigations
4. Determine Outside ROW Tree Exposure
5. Quantify Outside ROW Tree Risk by Voltage Class
6. Obtain Historical Weather Data
7. Statistical Analysis
8. Recommendations & Operational Options

Generally, each project element is detailed in a section of the report. The project element Statistical Analysis is found in more than one report section. The section headings may differ somewhat from the stated project element.

While PSE refers to 55 and 115 kV lines as high voltage distribution, for the purposes of this report, transmission will refer to 230 kV, 115 kV and 55 kV lines. Voltages below 55 kV are referred to as distribution.

Background to Utility Vegetation Management

On many distribution systems, trees are the primary cause of unplanned service interruptions.[2 3] Even though greater conductor-to-tree clearances are maintained on transmission systems, these systems are not immune to tree-caused outage events. Within less than ten years, there were three major tree-caused cascading-outage events in the U.S. and one in Italy:

- July 2, 1996 on U.S. western grid; 2.2 million customers affected[4]
- August 10, 1996 on U.S. western grid; 7.5 million customers affected[5]
- August 14, 2003 on U.S. northeast grid; 50 million customers affected[6]
- September 28, 2003 intertie-line between Switzerland and Italy; 60 million customers affected[7]

In the context of very clear National Electric Safety Code, which should prevent such outages, this history suggests that how vegetation management is related to outage events is inadequately understood. A literature review will reveal few articles on establishing a mathematical link between vegetation management expenditures or maintenance cycles with the frequency of tree-caused outage events. Among the scant few that do exist, a number are flawed through the exclusion of critical variables. In the absence of appropriate, statistically derived regression algorithms linking the timing and scope of past maintenance activities with tree-caused outage events, a conceptual approach serves as a starting point and provides guidance.

The following section is included to provide the non-vegetation manager a context for understanding some of the key issues in vegetation management. Vegetation management concepts and principles are presented to make explicit key aspects of the relationship between vegetation management and tree-caused outage events. This information is general to utility vegetation management. None of the data used in the Vegetation Management Concepts and Principles section is derived from PSE. This introduction seeks to make distinctions between work types, their origins and provide mathematical representations for the change in vegetation management workload over time. More importantly, it should facilitate an understanding that tree-caused outages, while lagging work in the field, are a suitable proxy for assessing the adequacy or effectiveness of a vegetation management program. The vegetation management concepts and principles provide a conceptual template that will subsequently be used to make assessments regarding the adequacy of funding of PSE's vegetation management program.

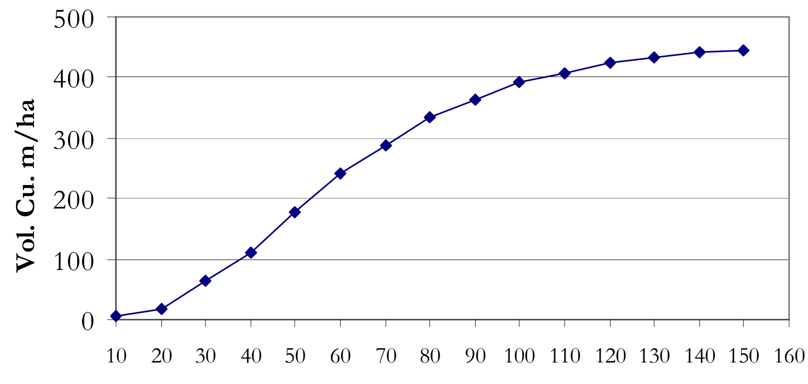
2. Vegetation Management Concepts and Principles

Trees that interrupt electric service can be categorized as in-growth trees and in-fall trees. The inventory of all trees that have the potential to either grow into a power line or, on failure (breakage), fall into and strike a conductor will be referred to as the utility forest. While we commonly think of forests in terms of more or less rectangular blocks, the utility forest amounts to ribbons or transects of the service area. Generally, the centerline of these transects is the power line. The utility forest has the same characteristics as any forest. In most cases the tree species composition is what is native to the area. The same patterns of biomass addition (tree growth) and tree mortality apply. Both of these patterns are significant factors in power line security and both can be mathematically represented by geometric progressions, as illustrated in *Exhibit 2-1* and *Exhibit 2-2*. Biomass additions result in trees that encroach on conductors, thereby necessitating tree pruning and either mechanical or chemical (herbicide) brush clearing. Failure to mitigate this encroachment leads to deteriorating safety and reliability. *Exhibit 2-1* shows an asymptotic curve that is typical of biological populations. Tree mortality produces decadent trees that are subject to breakage or tipping over (*Exhibit 2-2*). Tree mortality is not an event that occurs at a specific point in time. Rather, tree mortality occurs over a period of months and years.

Natural tree mortality is a process of losing vigor either due to the stress of competition for light, water and nutrients or an inability to sustain the attained mass. In the early stages of senescence or decline there may be no visible defect. However, as the tree becomes increasingly decadent and subject to failure under increasingly less stress loading, symptoms of the decline become apparent. Such senescent trees must be identified as faulty and prone to failure under weather stress and must be removed prior to the occurrence of stress. *Exhibit 2-2* shows both the forest stand density over time and the population of trees of concern to utility facilities, the Decadent Trees. While the South Carolina forest data (*Exhibit 2-2*) is restricted to sixty-two years, the line for Decadent Trees is seen to be approaching an asymptote. Further, because the capacity of the land-base to produce biomass is limited, the line for the evolution of decadent trees must be asymptotic. The nature of the expansion of the two sources of tree-caused interruptions, biomass addition (in-growth) and tree mortality (in-fall), is additive or constructive. This in conjunction with the process of tree mortality leads to insight into the consequences of failure to manage trees in proximity to power lines.

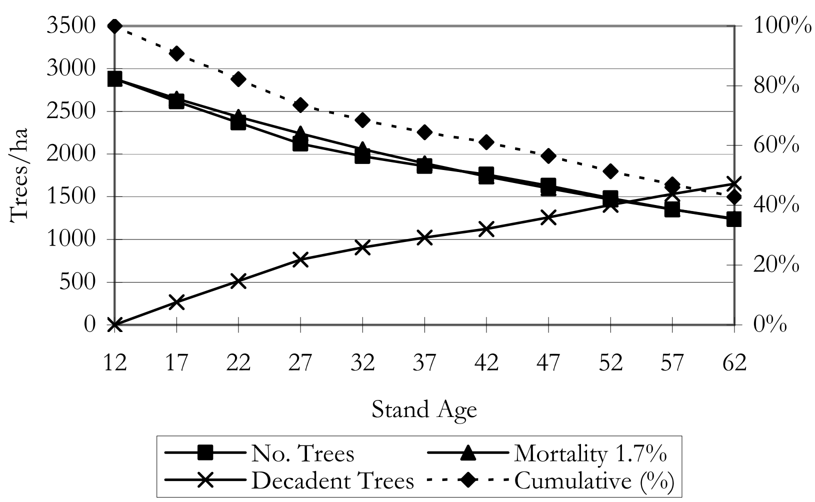
From a utility perspective, trees represent a liability in both the legal and financial sense. The fact that the utility forest changes by a geometric progression is significant. It means that the tree liability, if not managed, will grow exponentially.

Exhibit 2-1
Vegetation Management Concepts and Principles
Forest Biomass Addition
Timber Production
Spruce on Good Site



Source: Freedman, Bill and Todd Keith, 1995. Planting Trees for Carbon Credits. Tree Canada Foundation.

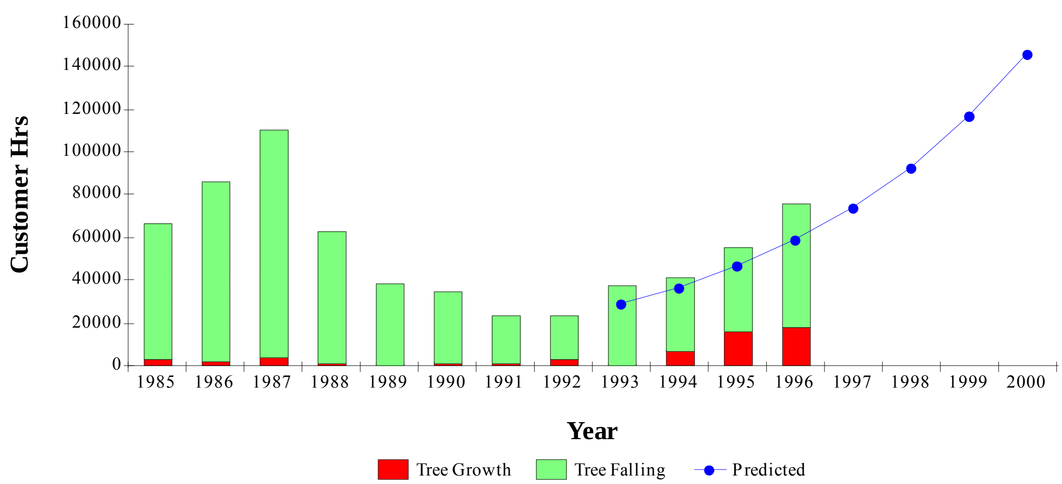
Exhibit 2-2
Vegetation Management Concepts and Principles
Stand Density
South Carolina
State Forest



Source: Crookston, Nicholas L. 1997. Suppose: An Interface to the Forest Vegetation Simulator.
Note: The graph shows the remaining live, viable trees. Of interest to utilities is the 60% of trees in the stand that die over 50 years because they hold the potential to disrupt electrical service.

Trees cause service interruptions by growing into energized conductors and establishing either a phase-to-phase or phase-to-ground fault. Trees also disrupt service when they or their branches fail, striking the line and causing phase-to-phase faults or phase-to-ground faults or breaking the continuity of the circuit. Because the two factors that are responsible for service interruptions, tree growth (biomass addition *Exhibit 2-1*) and tree mortality (*Exhibit 2-2*), change by geometric progressions, the progression of tree-related outages is, necessarily, also exponential (*Exhibit 2-3*) up to the approach of the asymptote. Failure to manage the tree liability leads to both exponentially expanding future costs and tree-related outages. Conversely, it is possible to simultaneously minimize vegetation management costs and tree-related outages (*Exhibit 2-4*).

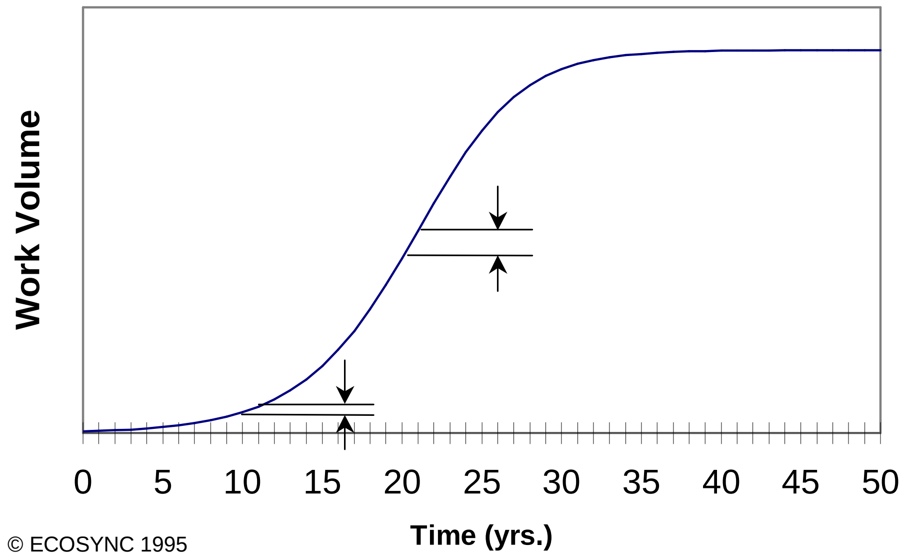
Exhibit 2-3
Vegetation Management Concepts and Principles
Tree-caused Distribution Outage Statistics



Source: Western Canadian utility
Note: This work and prediction for future tree-caused outages was performed in early 1997 to show the expected trend to 2000 based on funding below that required to remove the annual workload volume increment.

It is not possible to totally eliminate the tree liability because the ecological process of succession is a constant force for the re-establishment of trees from whence they were removed. The tree liability then is like a debt that can never be completely repaid. Under such circumstances, the best economy is found in maintaining the debt at the minimum level, thereby minimizing the annual accrued interest. However, irrespective of cost, minimizing the size of the tree liability or utility forest is rarely an option for utilities because there are multiple stakeholders with an interest in the trees. What can be achieved, however, is equilibrium. The tree liability can be held at a constant point by annually addressing the workload increment. To continue the debt analogy, a debt is stabilized when the annual payments equal the interest that accrues throughout the year. The interest equivalent in the utility forest is comprised of annual tree growth and mortality. Actions that parallel the reduction in the debt principal are actions that actually decrease the number of trees in the utility forest. Such actions include removal of trees and brush by cutting or through herbicide use.

Exhibit 2-4
Vegetation Management Concepts and Principles
Stabilizing Tree Workload
(Illustrative Model)



The graph shows the work volume that must be completed in a year to hold tree work inventory, costs and reliability steady. Performing less than the annual workload-volume increment shifts the total tree work inventory to the right, thus necessitating greater annual vegetation management expenditures to arrest the expansion of tree-related service interruptions.

When the pruning cycle removes the annual growth increment and the hazard tree program removes trees as they become decadent (*Exhibit 2-4*), tree-related outages are stabilized. The residual level of tree-related outages reflects the interaction of several characteristics, including the size of the utility forest, chosen maintenance standards (such as clear width), tree-conductor clearance, and tree-species characteristics (such as mode of failure and decay). An expression of a managed tree liability, one in which the annual workload volume increment is removed, is stable tree-related outages. Reducing tree-related outages below an achieved equilibrium necessitates actions that decrease the size of the utility forest. Actions are not limited to vegetation management. For example, increasing conductor height reduces the size of the utility forest as it reduces the number of trees that are capable of striking the line.

Funding

There are three possible outcomes determined by the level of investment made in vegetation management.

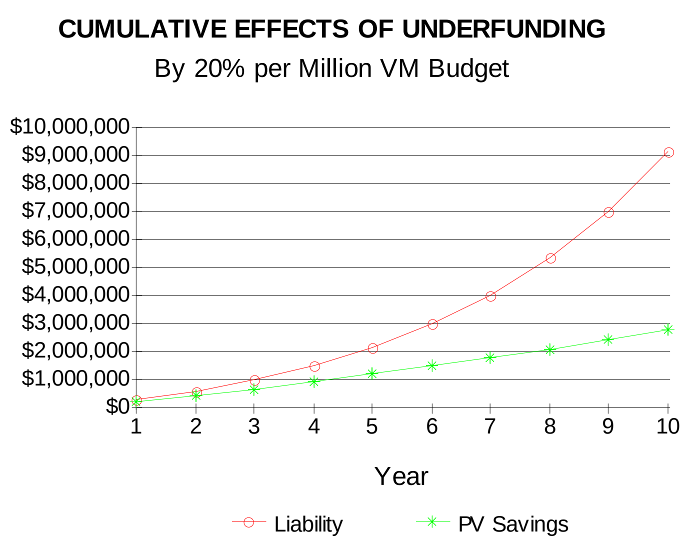
1. The annual workload volume increment is removed, thus keeping the size of the tree liability and next year's workload increment constant.
2. More than the annual workload volume increment is removed, thus decreasing the size of the tree liability and the subsequent year's workload increment.
3. Less than the annual workload volume increment is removed, thus increasing the size of the tree liability. That is because the work not done expands exponentially, thus increasing the workload increment for the following year.

Tree-related outages are an expression of the tree liability. Hence, changes in the tree liability result in proportional changes in tree-related outages (*Exhibit 2-3, Exhibit 2-5*). Actual outage experience may deviate from the trend based on variance from mean weather conditions.

When less than the annual workload volume increment is removed, the fact that tree liability increases by a geometric progression has two major implications for future costs and reliability. First, the impact of doing less vegetation management work than the annual workload volume increment, as expressed through tree-related outages, may be relatively imperceptible for a few years. Second, the point at which the impact of under-funding is readily observed in deteriorating reliability is where the effect of annual compounding in the workload, and thereby costs, is large (*Exhibit 2-5*). The lack of a significant negative reliability response to reduced vegetation management investment (see 1992 to 1995 *Exhibit 2-3*) may provoke further funding reductions, thereby exacerbating the size of the future re-investment required to contain tree-related outages.

Recognition that the tree workload expands by a geometric progression serves to explain some common utility experience. For many utilities, graphing customer hours lost on tree-caused interruptions over the last ten to twenty years reveals cyclical up and down trends (*Exhibit 2-3*). There are periods when trees are perceived as a problem and funding is increased. Increased funding permits a buying down of the tree liability, reducing tree risks and tree-related outages. Faced with these positive results, spending on vegetation management is reduced. While this tendency is perfectly logical, without the conceptual framework outlined, it is inevitable that funding will be reduced to the point where there is an observable response in tree-related outages. Unfortunately, by the time that tree-related outages are definitively observed to be on an increasing trend, for some years, vegetation management investment has been less than what is required to remove the annual workload volume increment. At this point, the power of compounding is well under way and only a very aggressive increase in funding will arrest the trend. The rate of change in the workload liability in *Exhibit 2-5* is approximately equal to a compounding rate of 27% per year. Warmer climates with a longer growing season support higher rates of change. In other words, for distribution systems, the rate of change in the tree workload is substantially higher than the discount rate (currently 3-11%) one would conceivably use to derive the present value benefit of deferred maintenance spending. Taking a short-term financial perspective, any deferred or diverted vegetation management funding that inhibits removal of the annual workload volume increment is poorly allocated unless it provides a better rate of return. The example provided in *Exhibit 2-5* shows that returning the work volume and reliability to the original levels after 10 years of under-funding by 20%, increases costs by 80% over maintenance, which annually removes the workload volume increment.

Exhibit 2-5
Vegetation Management Concepts and Principles
Impact of Under-Funding Vegetation Management Revealed Over Time



© ECOSYNC 1997

Notes: Rate of change in liability based on western Canadian utility with a 4-month growing season.
Interest/Discount rate = 6%

It has been shown, through *Exhibit 2-3* and *Exhibit 2-5*, that under-funding VM has a substantial impact on future reliability and costs to return to the level of reliability enjoyed before under-funding. The increase in workload due to deferred maintenance is not linear. Hence, the impacts of a dollar deferred this year cannot be erased with an investment of a dollar next year. Further, this section has provided the conceptual context that utilities have lacked, which lack has allowed the inefficient, repetitive cycles of under-funding followed by reactive catch-up periods.

Exhibit 2-5 illustrates that failing to make the necessary investment in vegetation management will, in most circumstances, prove imprudent. While utilities are expected to justify their intended vegetation management expenditures, regulators play a role in the effectiveness of the program. Failure to understand the nature of vegetation management workload expansion or skepticism that leads to decisions limiting the ability to remove the annual workload volume increment, will impose the inefficiencies illustrated in *Exhibit 2-5*. By focusing on cost containment, the regulatory process risks supporting such inefficiency. Utilities that are pressured to minimize costs must prove the harm that will result as a consequence of failure to fund and perform proposed work. This burden of proof proves very challenging for maintenance work, where it becomes necessary to prove that an event that did not occur would have occurred but for specific actions and expenditures. By insisting on demonstrable harm, the regulatory structure supports a reactive approach to maintenance with the attendant cyclical inefficiencies.

Managing the Tree Liability for Positive Returns

Trees need to be recognized as a liability in a utility context. While this puts utilities in conflict with community perceptions of trees as assets, the conflict does not change the fact that trees hold only the capacity to impair the safe, reliable operation of the electric system, not to augment it in any way. The recognition and quantification of the utility forest as a liability provides a measure of the potential for, or risk of, tree-conductor conflicts. Furthermore, it connects and clarifies the influence of design and operating decisions on maintenance costs and reliability risks.

Managing the tree liability necessitates an understanding of how and where tree risks arise, a quantification of the extent of tree exposure, the rate of change in the tree liability, and a commitment to funding that permits, at a minimum, the removal of the annual workload volume increment.

Appropriate investment in vegetation management is one of the best investments a utility can make. It serves to minimize tree-caused interruptions for the chosen clearance standard, thereby avoiding customer complaints, the need for regulator intervention, and in some cases performance penalties. It avoids the inefficiencies that are inherent in the cycle of allowing trees to become a major problem, getting trees under control by buying down the tree liability, and then losing the investment by failing to contain the tree liability. Investment based on the removal of the annual tree workload increment provides the conceptual approach that is needed to deliver a sustainable, least-cost vegetation management program. Simultaneously, such a program provides the lowest incidence of tree-caused service interruptions (*Exhibit 2-4*) for community-accepted clearance standards, thereby benefiting ratepayers and shareholders alike.

3. Vegetation Management Performance Audit

This section addresses PSE's vegetation management organization, processes and outcomes. Information on PSE's vegetation management program was garnered through data requests, interviews, and field tours.

Vegetation management is critical in providing reliable service to the customer. Tree-conductor contacts are the single largest cause of unplanned service interruptions on the PSE system. Based on a visual qualitative assessment, PSE's exposure to trees is very high. It is only in the most developed urban areas that tree exposure is low and typical of conditions found at other utilities. In rural and suburban areas PSE is exposed to more and larger trees than what would be considered the norm for utilities.

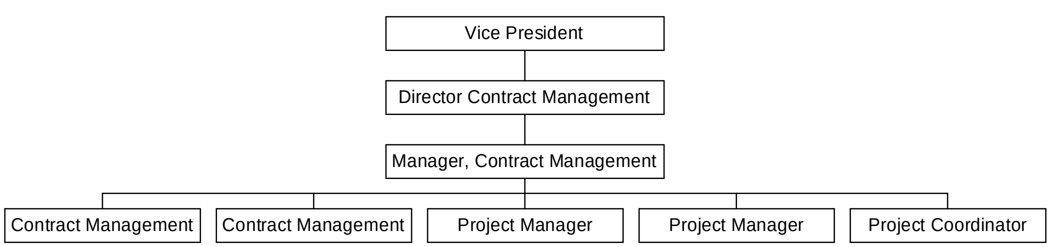
Organization

The PSE Manager, Contract Management has responsibility for PSE's vegetation management program and reports to the Director Contract Management.

Working under the direction of the PSE Manager, Contract Management is two Contract Managers, two Project Managers and the Project Coordinator. One of the key areas of responsibility of the Contract Manager is distribution vegetation management. Of the two Project Managers, one holds the responsibility for the vegetation management program delivered on transmission and the other is responsible for substations and landscaping. The Project Coordinator tends new construction and major projects.[8]

The organization chart[9] is presented in *Exhibit 3-6*.

Exhibit 3-6
PSE Vegetation Management Organization



Staffing [10]

PSE's staffing is as follows:

- Project Coordinator, major projects, new construction
- Project Manager, mostly transmission
- Project Manager, substation, landscaping
- Contract Manager, mostly distribution
- Manager, Contract Management
- 1 administrative assistant

Additionally, there are 6 contractor positions as consulting utility foresters, who are involved in the management of the VM program.

- 5 regions each with consulting utility foresters, project coordinator
- Transmission set up as if another region in terms of personnel available

Facilities [11]

Vegetation management work is performed on:

- ~ 10,800 miles of Distribution – 4.4 kV, 7.2 kV, 12.5 kV, 34.5 kV
- ~ 2,100 miles of Transmission – 55 kV, 115 kV, 230 kV
- Substations, substation perimeters and landscaping

Easements & Rights [12]

It was stated that there are standard easements for both transmission and distribution. What the easement is for a specific voltage class would not be apparent on field inspection, as there is considerable variability in the right of way width installed.

Easement rights are clear but variable between sites.

In performing VM work, PSE will generally try to clear the width that was previously cleared. Easement rights are not rigorously exercised if there is strenuous landowner/public objection.

Clearance Standards & Pruning Maintenance Cycles

Maintenance cycles are 4 and 6 years on distribution circuits. Transmission lines of 55 kV and 115 kV are on a 3-year cycle. The 230 kV system is currently on an annual cycle as it is being upgraded to meet the new NERC standards.[13]

On all voltage classes below 230 kV, PSE does not specify the clearance that is to be attained on pruning. Rather, the contractor must consider the target maintenance cycle, the growth rate for the tree species and the location to determine the necessary clearance to be installed.[14]

A summary of PSE's clearance standards is provided in *Exhibit 3-7*.[15]

Exhibit 3-7
PSE Clearing Standards
(As of October, 2007)

Voltage (kV)	Action	Zone A	Overhangs	Zone B	Zone C	Zone D
4, 12.5, 34.5		**0-4 feet**		**4-8 feet**	**8-12 feet**	**>12 feet**
	Remove	brush		brush	brush	brush
	Remove	mature height ≥ 25 ft	within 12 feet	≤ 15" dbh	deciduous ≤ 15" dbh, conifers ≤ 10" dbh	hazard trees
	Prune	to achieve cycle		> 15" dbh	deciduous > 15" dbh, conifers > 10" dbh	
55, 66, 115		**0-8 feet**		**8-14 feet**	**14-18 feet**	**>18 feet**
	Remove	brush		brush		
	Remove	mature height ≥ 25 ft	all	≤ 20" dbh	deciduous ≤ 15" dbh, conifers ≤ 10" dbh	hazard trees
	Prune	to achieve cycle		> 20" dbh	deciduous > 15" dbh, conifers > 10" dbh	
230		**Wire Zone**		**Border Zone**		**Outside ROW**
	Remove	mature height ≥ 15 ft	all			hazard trees
	Prune			side clearance	deciduous ≥ 20 ft, conifers ≥ 15 ft	

Confirmation that the clearance standards have been achieved is ascertained through a quality assurance procedure.[16]

Tree Workload & Budgeting

The tree workload has been established through the capture of historic costs per circuit. The historic costs form a baseline for budgeting. The historic costs are adjusted for inflation and other modifiers, such as productivity improvements, fuel escalators, etc..[17] The total budget has an upper limit based on vegetation management funding permitted via regulator-approved rates.[18]

Budgeting for the 230 kV lines is different in that the contractor patrols the planned work area and provides an estimate of the work. This estimate provides guidance in setting the budget.[19]

Without considering Tree Watch funding, the budget for distribution and transmission work has been relatively level over the last five years showing only a slight escalation. Tree Watch dollars have been increasingly assigned to transmission.[20] For 2008 there has been an increase for 230 kV work to meet NERC compliance.[21]

Exhibit 3-8
PSE Vegetation Management Budget (thousands $)

	2003	2004	2005	2006	2007
Distribution					
- Brush	$416	$200	$300	$310	$300
- Hot spot	$370	$225	$215	$237	$300
- 4-yr cycle	$2,657	$3,193	$2,320	$2,600	$2,400
- 6-yr cycle	$3,442	$3,307	$4,175	$4,091	$4,258
Total Distribution	$6,885	$6,925	$7,010	$7,239	$7,258
Transmission					
- Hot spot	$315	$225	$150	$164	$125
- Maintenance	$800	$850	$1,000	$1,029	$1,153
Total Transmission	$1,115	$1,075	$1,150	$1,193	$1,278
Tree Watch					
- distribution	$6,300	$2,400	$500	$500	$300
- transmission	$0	$0	$1,500	$1,500	$1,698
Total Tree Watch	$6,300	$2,400	$2,000	$2,000	$1,998
Substations	$50	$50	$50	$381	$347
Total	**$14,350**	**$10,450**	**$10,210**	**$10,813**	**$10,881**

The vegetation management budget for the last five years is shown in *Exhibit 3-8*. The budget for 2008 is $12 million.[22]

Spending for vegetation management is tracked under the following headings:

- Distribution Brush – captures the cost of herbicide brush control on distribution circuits
- Distribution Maintenance 4yr and 6yr cycles – includes routine pruning and tree removal to maintain clearances for distribution lines
- Transmission 55-115 kV – captures all vegetation management costs associated with regular maintenance of these transmission lines.
- Transmission 230 kV – captures all vegetation management costs associated with regular maintenance of 230 kV transmission lines.
- Tree Watch – includes the costs of removing hazard trees specifically targeted to improve reliability and is tracked under distribution, 55-115 kV transmission and 230 kV transmission
- Hot Spotting – includes costs for rectifying emergent problems, such as pruning of cycle buster trees and removal of emergent hazard trees within 12 feet of the conductors. PSE vegetation management staff, other PSE staff, customers or the public may identify emergent work requiring corrective action. Hot spotting is also tracked under distribution, 55-115 kV transmission and 230 kV transmission.
- Substations – includes costs for substation tree work and weed control, weed control in storage yards and landscaped settings.

Costs associated with major storm events are tracked outside of the vegetation management budget.

Budget tracking processes and systems will be covered in Information & Data Systems.

Work Planning [23]

Transmission lines of 55 and 115 kV are on a static 3-year maintenance cycle. The 230 kV system is being examined on an annual basis and work prioritized while working towards meeting the new NERC standard.

About 2,000 miles of distribution are maintained every year, with work being performed on either a 4-yr or 6-yr cycle. Work is generally scheduled based on the last maintenance date but the work coming due is reviewed and prioritized. The priority of the work may be changed by the 3-year average interruption frequency or customer requests.

Once PSE input on the work has been provided, the implementation of the work plan and the monitoring of whether the work plan is being met is in the hands of the contracted consulting utility foresters. PSE receives monthly reports from the contractor, Asplundh, which provides the information on work completed. The monthly report provides information on circuits recently completed, the percent of completeness of circuits currently being worked, circuits that have been prepared for the crews to begin work, and information on hot spotting and storm work.[24] The report covers both capital and O & M work.

Tree Watch dollars are assigned based on the outage experience and are generally applied to rural areas.

Maintenance Cycles

The maintenance cycle is derived from the clearance established on work completion and tree growth rates, which determine the amount of time until trees are again encroaching on the limit of the minimum tolerated distance of approach to conductors. The task of maintaining the minimum limit of approach is complicated by the fact that there are inter- and intra-tree species differences in growth rates, a large range of variability in growth rates in response to climatic conditions and the dispersion of the tree population over a broad range of soil types, and other geo-physical conditions that influence tree growth rates. As a consequence, the consumption of the established protective air space following a maintenance event is highly variable. Given this circumstance, utilities are faced with the decision of either establishing a maintenance cycle where no tree is ever allowed to exceed the limit of approach or accepting some level of encroachment over the limit of approach. The first option is very expensive (i.e., maintenance cost can triple) because the level of monitoring must be substantially increased and either much work must be done before it is required based on safety and reliability concerns or tree crews must make multiple (at least annual) passes over the same geographic area.[25] A decision to tolerate some breaching of limits of approach is made in the context of the attendant safety and reliability risks, which are influenced by line voltage and the change in risk over time as the encroachment increases. Hence, most utilities base cycles on average growth rates and tolerate some intrusion on the limits of approach on distribution voltages, particularly the lower voltages. On transmission systems, typically no encroachment of the limits of approach is tolerated.

PSE is using a 3-year cycle on transmission and 4 and 6 year maintenance cycle on distribution.[26]

Hot Spotting

Within the Utility Vegetation Management (UVM) industry, sites that must be worked outside of the planned maintenance cycle because of their variable tree growth rates are referred to as hot spots.

PSE, similar to most electric utilities, dedicates funds to address hot spots, in their specific case, about 4% of their total VM budget. The hot spot coordinator prioritizes the assignment of these dedicated dollars. The consulting utility foresters may identify a need for a hot spot program on a particular circuit and then seek the funding to complete this work.[27]

Some amount of hot spots are identified by "call ins" comprised of customer calls (90%) and internal PSE calls (10%). The "call ins" must be checked within two weeks to determine whether it is a legitimate hot spot in need of work.[28]

The most common tree species involved in hot spots on the PSE system are big-leaf maple, black cottonwood, red alder, Douglas fir and willows.[29]

Tree Removals

Tree removals play a substantial role in the cost-effectiveness of a vegetation management program. Pruning costs are repetitive, whereas removals decrease both the size of the utility forest and the tree liability (see Vegetation Management Concepts & Principles) and shift work to lower-cost methods. This is not to suggest that the removal of all trees in the utility forest can be economically justified. Typically, the removal cost of a hazard tree exceeds the present value cost of pruning over any reasonable timeframe. For example, a 15-inch diameter at breast height (dbh) tree removal cost of $100 exceeds the present value of 40 years of pruning on a five-year maintenance cycle. The removal of brush and smaller trees (4"–12" dbh), on the other hand, typically has a discounted payback period ranging from less than one maintenance cycle to two cycles.

In 1998, PSE initiated an intensive hazard tree removal program called "Tree Watch" and the initial phase ran for 6 years. Some funds, about $2,000,000 annually,[30] are still designated as Tree Watch but both the need and the level of funding are said to be substantially lower.[31] Under Tree Watch any tree with a defect, capable of striking the line is removed.

Under the normal VM program identified hazard trees are removed only if they are within 12 feet of the right of way edge unless they represent an imminent threat to the line. Trees beyond 12 ft can be removed by anyone (no need for electrical training). Therefore, PSE considers such trees to be a customer responsibility.[32]

The ratio of removals in routine maintenance over the period of 2003 to 2007 is about 10%.[33] When Tree Watch work is included the ratio of removals to all trees handled is 24%.[34]

Herbicides [35]

On the 230 kV transmission system herbicide use is part of the routine maintenance practice. On the high voltage distribution, herbicides are used where appropriate, such as in cross-country right of way. Foliar herbicide treatments are restricted to a few rural feeders on the distribution system, though stump treating is routinely performed.

Herbicides are also used for the annual control of plant growth within substations.

Alternatives to Pruning

The repetitive nature of pruning costs, which will be incurred from several to many decades into the future, drives utilities to search for other solutions. Part of that solution is to educate the public to "plant the right tree in the right place," thereby avoiding additions to the tree-pruning workload. However, there are also solutions that either eliminate the need for pruning or reduce or eliminate the reliability concerns arising from tree in-growth. These options include:

- tree replacement,
- line moves,
- under-grounding,
- changing the construction configuration,
- the use of tree wire, and
- the use of tree growth regulators (TGR's).

Naturally, the cost of actions taken that eliminate the need for pruning should be less than the avoided cost of pruning over some reasonable timeframe. The use of tree wire cannot likely be justified by avoided pruning costs. Rather, it must be justified by improvements in reliability or safety. TGRs limit tree growth, thereby extending the maintenance cycle. TGR use should be justified by avoided pruning costs.

PSE attempts to do a tree replacement program in each operating area each year. These are usually with a municipal or parks authority.[36] These projects target problem areas comprised of hot spots or cycle buster trees. Beyond the fact that the tree replacement projects should address problem areas, there are no eligibility criteria.[37]

PSE also has a tree voucher program that is used to eliminate cycle buster trees located on private property. The tree voucher program is not actively promoted but rather, tends to be used to address customer objections or complaints.[38]

PSE has installed tree wire to avoid interruptions caused by limited tree to conductor clearance and where small branch shedding results in phase-to-phase faults. In some instances the type of construction has been changed to reduce the risk of phase-to-phase faults. Under-grounding is also considered, though due to the cost, only in locations where there are enduring reliability problems.[39]

PSE has experimented with TGR's in the past but the case for continued use was not compelling and sometimes negative. At the present time TGR's are not used operationally. PSE has and continues to periodically undertake small pilot projects or testing.

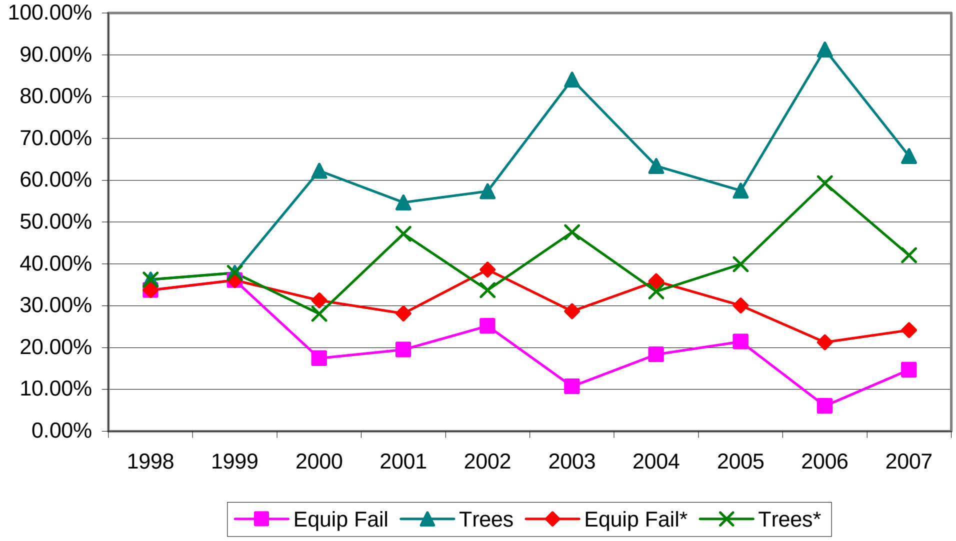
Reliability

Tree-related service interruptions are the largest contributor to PSE's outage experience as shown in *Exhibit 3-9*.[40] Further, PSE's outage experience is completely aligned with tree-caused service interruptions (*Exhibit 3-10*).[41]

For the purposes of this report, a particular convention has been adopted. *Exhibit 3-10* is based on outage statistics that include major storms. As this work is focused on identifying means of reducing future storm damage, it should be assumed that all data and graphs referring to PSE's outage experience are based on statistics that include major storms, unless it is explicitly stated otherwise.

As discussed in the section Vegetation Management Concepts and Principles, the examination of the trend in tree-related outages will provide an indication of the budget's adequacy. Tree-caused interruptions (including major storms) are presented in *Exhibit 3-10*. There are a number of statistics that could be used to detail tree-caused interruptions, such as the industry standard System Average Interruption Frequency Index (SAIFI)(*Exhibit 3-11*), System Average Interruption Duration Index (SAIDI)(*Exhibit 3-12*), and Customer Average Interruption Duration Index (CAIDI). We prefer to use as a starting point total customer hours interrupted, which reflects both the number and duration of incidents and thereby, presents the full outcome of the vegetation management program. SAIFI and SAIDI can provide guidance on the types of tree-caused interruptions. For example, increasing customer hours, decreasing SAIFI and increasing SAIDI suggest an increased portion of tree-related outages is arising from tree failure. These types of outages frequently damage equipment, breaking conductors, cross arms, and poles, and are often remote or have difficult access contributing to lengthy restoration times.

Exhibit 3-9
PSE Outage Experience
By Main Causes



* Excluding major storms

Exhibit 3-10
10-Yr. PSE Outage Experience
(includes major storms)

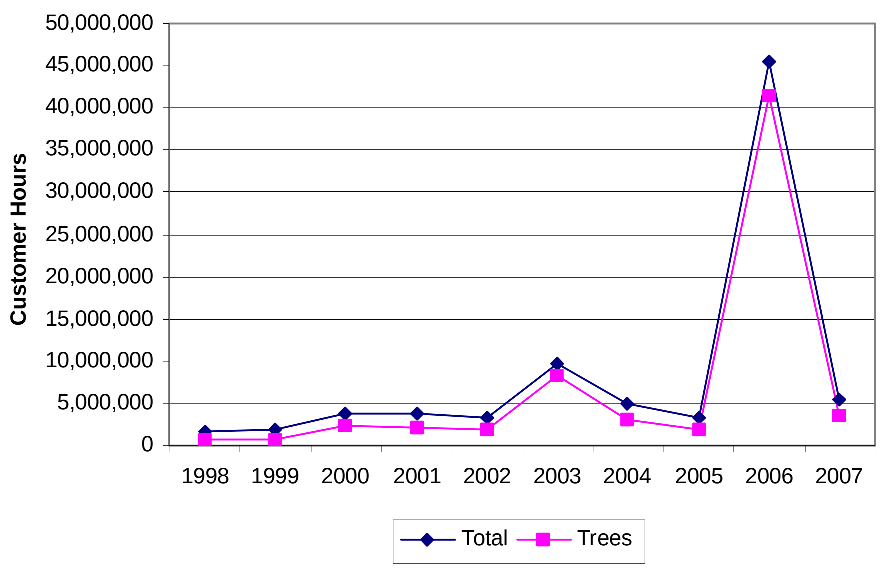
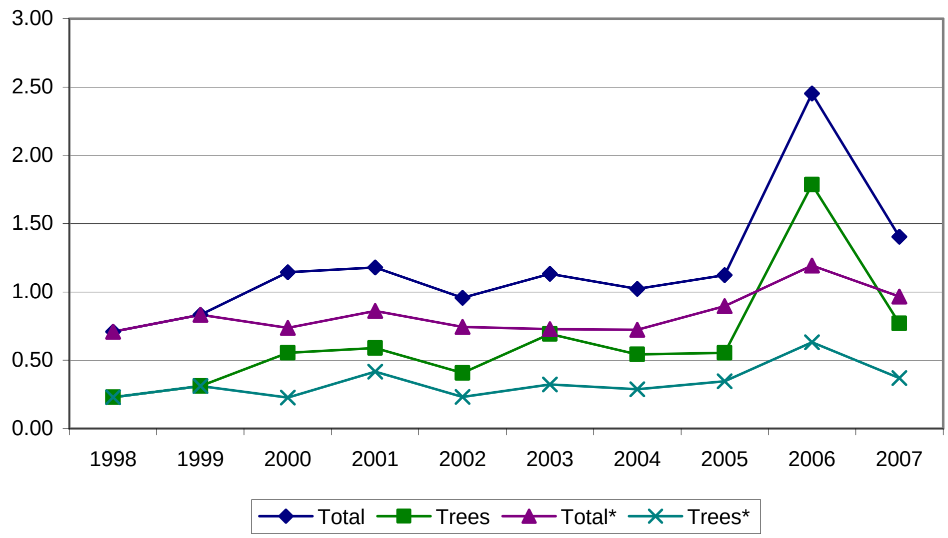
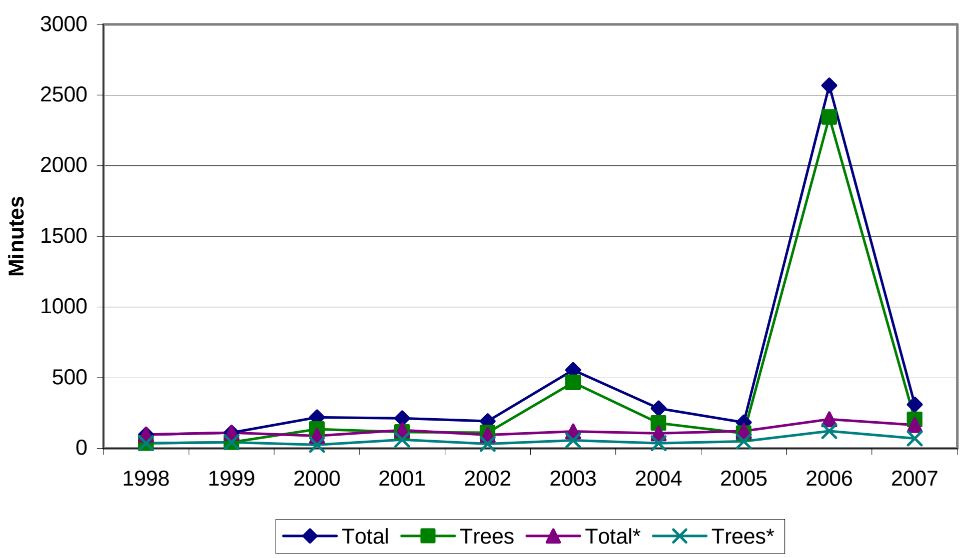


Exhibit 3-11
PSE 10-Yr SAIFI



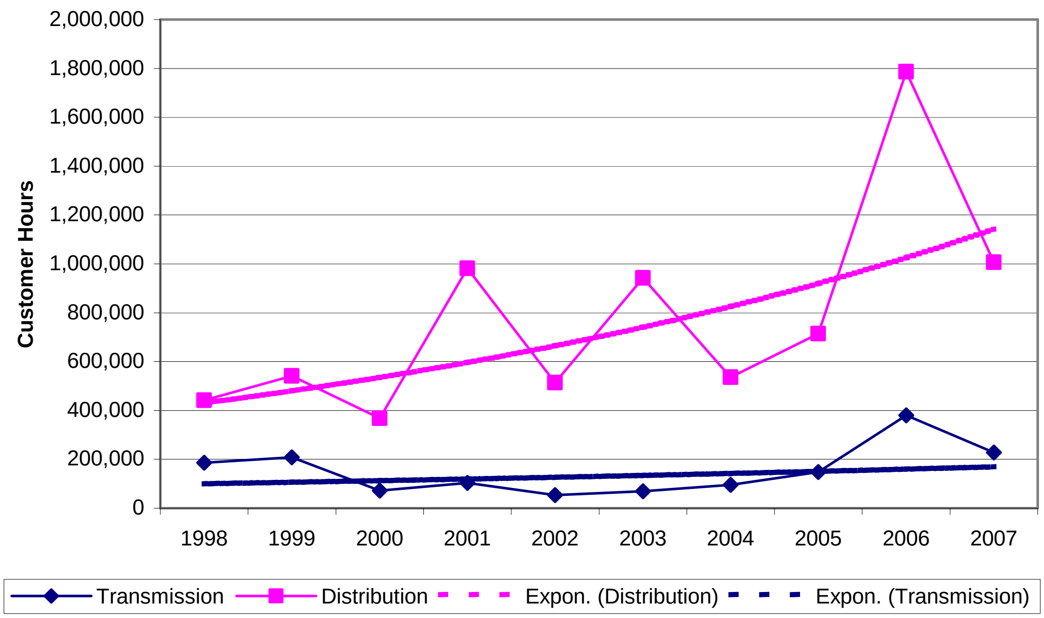
* Excluding major storms

Exhibit 3-12
PSE 10-Yr SAIDI



* Excluding major storms

Exhibit 3-13
PSE Tree-caused Outage Experience
Excluding Major Storms



Tree SAIFI and SAIDI were calculated (*Exhibit 3-11* and *Exhibit 3-12*) based on an assumption of a constant total number of 1,063,000 customers. Both indices show a slightly increasing trend in tree-related outages. Customer hours, which capture both the number of incidents and the duration, are presented in *Exhibit 3-13*. The data generated on major storms days has been removed. Even so, there is a clear and substantial effect arising from the stormy weather experienced in late 2006. *Exhibit 3-13* also provides exponential (see Vegetation Concepts and Principles) trend lines for both transmission and distribution tree-caused outages.

The Manager, Contract Management, who examines tree-related outages on a daily basis, is aware of the trend and is seeking to address it in the budgets for 2009 and 2010.

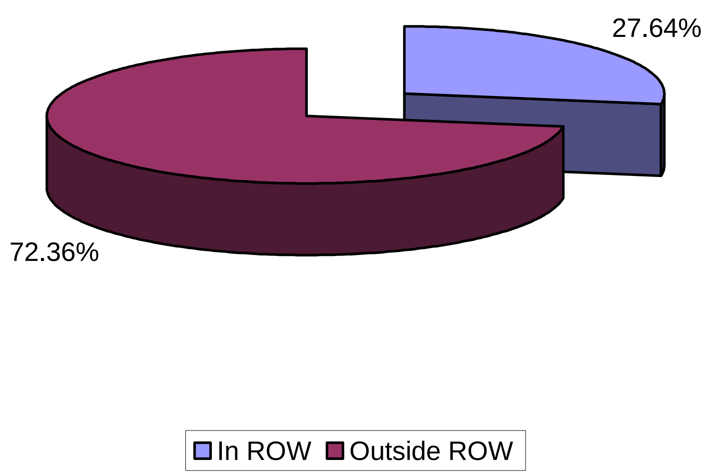
PSE divides tree-related outage causes into those arising from:

- Trees originating outside the right of way, which are usually due to broken trunks or branches or uprooted trees (tree failure or in-fall)
- Trees within the right of way, which arise predominantly from in-growth into the conductors or the flashover zone (in-growth) but may also be caused by whole tree or branch failure
- Vegetation, which would typically be vines[42]

However, PSE also investigates some of the tree-caused outages, at which point more detailed information on the tree that caused the incident is recorded. Arborists collect this data, rather than the linemen who restore the electric service. PSE staff investigates all 230 kV outages. Contracted Arbormetrics personnel investigate all 55, 115 kV and whole circuit distribution tree-caused outages.

There is considerable difference between the SAP outage tracking system and the tree incident investigations in reporting on the location of trees within or outside of the right of way. The SAP outages from 1998 through 2007 indicated 59% of tree-caused outages arise from outside the right of way. The outage investigations performed by arborists for the same time period shows 72% to arise from outside the right of way. Current 2008 outage investigation data shows this percentage to be even higher at 94%. The source of the SAP outage data is linemen dispatched to bring a circuit into service. As they are not trained in arboriculture, are often working in adverse weather conditions with a need to move quickly to the next trouble spot and conceivably in darkness, the data collected during the outage investigations (*Exhibit 3-14*) will be considered the authority regarding the location of trees causing outage events.

Exhibit 3-14
Location of Problem Trees
1998-2007 Data



Contracting

PSE uses a sole source contract for vegetation management work. Payments are based on time and materials. Asplundh Tree Expert Co. is the supplier. Each area has a budget to perform work on the miles of line due based on the maintenance cycle. The contractor must perform all the work on a circuit keeping costs contained within the assigned dollars. There are price modifiers based on meeting the production goal of completing the circuit for the assigned budget, work quality and customer satisfaction goals.[43]

The Quality Assurance (QA) functions are contracted to Arbormetrics Solutions Inc. In addition to the QA function, Arbormetrics manages the hot spot program, checks hot spots that are called in and performs the tree-caused outage investigations. Arbormetrics is currently developing a new QA process.[44]

Productivity

Production goals are set for the contractor based on the history of the circuit. The goal is set in dollars to complete the work. The goal may be adjusted only if the contractor raises an early alarm that the work volume is significantly changed form the past and cannot reasonably be completed with the assigned funds.[45]

Quality Assurance

PSE uses third-party auditors to review 100% of the vegetation management work performed. When work on a circuit is complete the consulting utility forester releases the circuit for audit. The circuit is checked for completeness, pruning quality and the meeting of cycle specifications.[46]

PSE also performs random audits on a small percentage of the completed and audited work.[47]

Should the contractor disagree with an auditor call back, the auditor is the final authority.[48]

Within the UVM industry, third party audits have gained in popularity over the last fifteen years. Some of the reasons include:

1. greater cost effectiveness because third party auditors are typically not part of a collective bargaining unit,
2. more productive because they know the subject area, and are actually working rather than attending company meetings,
3. because they are often professionally trained in arboriculture, their audits are better received by the contractor supervisors, that is there is less of a gap in perception between the auditor and the contractor,

4. generally, when audits are performed by internal staff, it is next to impossible to adhere to job qualification requirements and the area is used to place company employees who require a temporary placement or have become incapable of meeting the demands of another position,
5. it is extremely tempting for the company to use these employees for all sorts of emergent issues,
6. the number and quality of audits is or becomes inadequate and ultimately, the company has QA staff but not a QA program.

The documentation for the Quality Assurance program provides the expectations for the different voltage classes and sets out a scoring methodology that provides the basis for contractor rate modifications.[49] Beyond the Audit Standards, further information regarding expectations was garnered from PSE and Arbormetrics staff.

- The crew foreman is to report exceptions due to issues beyond his control.[50]
- The auditor inspects the work within two months of its completion to identify any that is deficient. Most auditor inspections are completed within two weeks of work completion.[51]
- Deficiencies may include inadequate clearance to meet the cycle goal, missed locations, and poor arboricultural quality.[52]
- Such exceptions to acceptable work must be rectified at the contractor's expense.[53]
- The contractor may challenge the exceptions, but ultimately it is the auditor's decision.[54]

The results of the QA inspection are documented with the circuit report.[55] The circuit report indicates that either the circuit can be considered complete or specifies the further work required.[56]

Information & Data Systems

Work completed is tracked in the internally developed VM database, called CMIS. This database is populated with information from crew timesheets. The information captured includes costs, miles completed, trees, etc. When a circuit is completed and closed, CMIS schedules the next cycle of maintenance work.[57]

The CMIS database forms the nerve center for managing the budget and the work plan. Work is identified and grouped into such areas as distribution 4 or 6 year cycle, 55-115 kV maintenance, 230 kV maintenance, hot spotting, Tree Watch, etc. (see *Exhibit 3-8*). Each circuit has an associated estimate of costs based on its history or in the case of 230 kV lines based on an estimate derived from a patrol. As the work progresses, actual costs can be compared to the estimate and adjustments are made accordingly.[58]

PSE maintains computer files tracking the extent of circuit completion, audit status and scores, the number of any "go backs" arising from the audits and their completion date.[59] There is a final report for each circuit worked. It includes information on miles, costs, audit scores, production/cost scores, the next maintenance cycle year and what if any mid-cycle work is recommended.[60]

Outages are tracked in SAP. Additionally, PSE maintains a database of outage investigations conducted by arborists.[61]

Decision Support

The examination of new ideas or alternate technologies may occur within the VM group but more frequently is initiated, analyzed and recommended by others, such as engineering. Actions such as the installation of tree wire are in response to ongoing outage problems but VM staff is not aware of any established process or developed business case that could be systematically used to justify the use of tree wire or to justify alternatives to repetitive pruning. Rather, it appears business cases are developed on a one off as needed basis.[62]

Field Conditions and Observations

1. **Cascade-White River 230 kV[63]**

- Clear width is ~ 50 ft but conifers are allowed closer.
- Some conifers occur in the wire zone.
- There has been recent work to widen the right of way.
- Clear width (CW, distance from conductor to adjacent tree boles[2]) seems typical for 230 kV but the crown diameter of adjacent trees is such that there's an appearance of a much lower CW. Side clearance (tree to conductor) is 6-7 feet.
- Currently working on clearing wire zone but work is not yet complete.
- There is lots of brush within the right of way but none is threatening continuity of service.

2. **O'Brien-Long Lake 115 kV with Fragaria distribution underbuild[64]**

- Work was last done on the distribution in 2004 and is now due.
- The 115 kV system is on a 3-year cycle for hazard tree. Pruning work is done in conjunction with the distribution work.
- Three instances of overhangs on the 115 kV line were seen.
- The CW on 115 kV is about 15 feet.
- One hot spot was seen on the 12.5 kV distribution.

[2] bole (botany), that part of the trunk of a tree beneath the point where branching commences. From Wikipedia, the free encyclopedia

- Where the distribution dropped to single-phase, the right of way was found to be full of brush.
- Side clearances on distribution only were about 2 feet with a CW ranging from 6 to 10 feet.

3. LOL-21; 3-phase 12.5 kV[65]

- Circuit was last done in 2005.
- This area is a little more open than the previous circuits viewed.
- CW is 6 to 10 feet
- Not hot spots or other issues were noted.

4. Long Lake-South Bremerton 115 kV much with distribution underbuild[66]

- Distribution work done in 2005.
- Clearances observed are good with one exception of a spot with 2 feet clearance to 115 kV.

5. Chico-12, 34.5 kV[67]

- This circuit was completed in 2006
- The three-phase has a CW of 6-10 feet.
- All clearances are good.
- Where the circuit drops to single-phase
  - Generally the CW is 4-10 feet
  - There are some tree boles 1-2 feet from the conductor.
  - Some overhangs with less than 12 feet of clearance were seen.
  - No burners were evident.
  - Along Tayuheh Lake Rd some boles are within 2 feet but clearances are good.
  - Along Wildcat Rd CW is 3 feet and greater; clearances are good.

6. Bucklin Hill-12 12.5 kV[68]

- Circuit should have been done in 2007
- Was hot spotted in 2004
- Part of the circuit already done at this point in time
- 1 spot trees in neutral
- 12.5 kV drops to 7 kV
  - lots of brush underneath to be removed
  - a fair amount of brush is to the neutral and six spans were seen where growth extended beyond the neutral, a couple very close to primary

- one location the neutral was touching a tree bole

- there is only 2 feet of clearance on some of the overbuilt 115 kV

7. GRV-16[69]

- Just trimmed
- 4-year cycle
- mostly about 4 feet to boles

8. GRV-12[70]

- Due in 2008 but not yet done
- 4-year cycle
- a few locations trees in primary
- a few spots where there is only 1 foot of clearance to 115 kV

9. GRV-15[71]

- 4-year cycle
- just completed
- all clearances good

10. HOL-13[72]

- Completed in 2007
- Good clearances

11. HEM-16[73]

- 4-year cycle
- currently in mid-cycle
- one spot with 1 foot clearance to three-phase
- some spots within 1 foot of neutral

12. HEM-15[74]

- 4-year cycle
- just past mid-cycle
- several spots with only 1 foot clearance

13. ORT-22[75]

- Done in 2007
- Clearances are good
- Work/pruning quality good

14. GWR-13

- 6-year cycle
- done 2 years ago
- much runs through DNR
- heavy re-growth on deciduous
- some boles within 2 feet of single-phase
- some 1-2 foot clearance of boles from 55 kV in new development

15. ORC-17[76]

- Boulevard trees
- Due in 2008 but not yet done
- Some is to primary conductors but most of it is not urgent (grow into one phase only)
- About 10-20% is within 1-2 feet of the conductors
- Did see one occurrence of a major overhang with only a foot clearance to line

16. TOL-16[77]

- 4-year cycle
- completed in 2007
- all clearances good and quality is good

17. DUV-13[78]

- 4-year cycle
- completed in 2007
- all clearances good and quality is good

18. DUV-15[79]

- 4-year cycle
- due in 2009
- a lot runs through timber company land
- some locations with 1 foot clearance but amounts to less than 10%

19. BOS-SAM 230 kV[80]

- All clear underneath

4. Audit Findings & Conclusions

Finding 4-1 The PSE organization supports a responsive vegetation management program.

The Manager, Contract Management responsible for VM, is in regular communication with the Vice President.[81] Twenty years ago, this was unusual but over that timeframe, utilities have realized vegetation plays such an important role in system reliability and the VM department must have direct access to and support in the form of corporate sponsorship. This is particularly true for utilities such as PSE where trees are the principle cause of uncontrolled service interruptions.

The senior level responsiveness is illustrated by the implementation of the Tree Watch program,[82] tree failure studies[83] and the current budget plan for increased funding for 2009 and 2010.[84]

Finding 4-2 The annual budgeting process does not incorporate the capacity to respond quickly to emerging conditions.

The development of the budget begins with the historical costs for the circuits scheduled for maintenance during the following year. While the contractor is asked to bring to PSE's attention any circuit that is expected to vary considerably from the cost estimate, it would appear that the contractor would in most cases make this finding in the year the work is to be completed. Where the value of the found work exceeds the budget, it will result in work being deferred. The following year's budget would provide the first opportunity to address the shortfall. Any failure to respond at the first opportunity will introduce cost inefficiencies (see Vegetation Management Concepts and Principles).

This finding is not that PSE's budgeting process varies from industry standards but that it is typical.

The ability to respond quickly to emergent situations is important from both a cost and reliability perspective. Many utilities have been overwhelmed with the emergence of a staggering number of pest killed hazard trees or triple the average growth rates coming out of a drought (California late 1980s to early 1990s, Louisiana, Alabama, Arkansas, California & Arizona late 1990s to early 2000s, mid-Atlantic states early 2000s, British Columbia late 1990s to present).

Very few utilities have developed processes ensuring a quick response to emergent vegetation conditions (i.e. within one year or less of detection). Such responsiveness is not supported by the regulatory process, which requires a proceeding with the attendant time delay of a year or more and virtually unassailable evidence of need. Consequently, an optimally responsive VM can only be achieved when a utility is willing to accept the risk that it may ultimately fail to prove the harm that would have occurred but for its timely response, leaving its shareholders to shoulder the cost of action. This is not to suggest that we envision a superior method to protecting the interests of the ratepayer than the adversarial system of regulatory proceedings designed to bring forward the best available information. Rather, the intent is to highlight that there are consequences inherent to the regulatory process. One example is that for most UVM programs the largest determinant of the budget is last year's budget. It is easy to justify – in a sense the path of least resistance. Another is that, while a quick response to emergent vegetation conditions may best serve the cost and reliability interest of the ratepayer, delaying the response will make the emergent work and the attendant consequences more evident and thereby facilitate the justification of a response and its attendant costs.

Finding 4-3 The VM work delivered in the field is consistent with the expressed standards and specifications.

With few exceptions, the field observations found that the standards ands specifications are being met.[85] The few exceptions are not unexpected as PSE must be responsive to land owners who may place greater importance on tree retention and aesthetics than on the safety and reliability concerns underlying PSE's standards.

Finding 4-4 PSE's current VM program is well organized with the potential for only a minor improvement in cost effectiveness.

We have concluded PSE's VM program is a highly managed program with only a minor potential for cost improvement. This statement is made in the context of our knowledge of the UVM industry.

Much of the context for the UVM industry has been provided in Vegetation Management Concepts and Principles. To elaborate, it has been, and still is, not uncommon for a utility's vegetation management program to be based on reactive hot spotting. As a hot spotting program evolves, a stage is reached where completing one maintenance cycle costs 30% more than a planned program.[86] With the increased cost, the VM program falls progressively further behind. The evolution does not cease at the point where all work is reactive but continues to add work volume (moving to the right in *Exhibit 2-4*). It is at this stage that tree-related outages are noticeably expanding exponentially. It is quite possible for the entire work volume to increase by 100-400% over a dozen years. It is not possible to substantiate these statements with references. They arise from involvement and familiarity with vegetation inventories, conference presentations, personal observations, and communications with industry peers. When utilities find themselves in such circumstances they direct research towards a resolution rather than studying and documenting what delivered them into the situation.

Considering PSE's vegetation management program in the context of *Exhibit 2-4*, it is relatively stable, with only a slight movement to the right side of the graph. PSE's VM program stands in stark contrast to the reactive program described in the previous paragraph. PSE's program is a managed program.

The Hot Spotting expenditures are running at 4–9% of the normal maintenance costs (includes pruning, brush control and standard hazard tree removal). This is at the low end of industry recommendations. The low amount of resources dedicated to hot spotting is positive as hot spotting is very cost ineffective, costing 30% more per unit of work than preventative maintenance.[87]

Exhibit 4-15
PSE Hot Spotting Based On
Vegetation Management Expenditures (millions $)

	2003	2004	2005	2006	2007
Preventative Maintenance[1]	7.32	7.55	7.80	8.03	8.11
Hot Spotting	.69	.45	.37	.40	.43
% Hot Spotting	**8.56**	**5.63**	**4.47**	**4.76**	**4.98**

[1] Excludes Tree Watch

That PSE uses hot spotting should not be viewed as a negative. Rather, it is a prudent action. It is not cost effective to eliminate all hot spotting. A certain amount arises simply from the inherent variability in tree growth rates. Leaders in the UVM industry typically recommend restricting hot spotting expenditures to less than 15% of total pruning costs, with the 5-10% range providing a good balance between reliability and costs. This approach is not successful if the utility ignores the conditions in the field and restricts the amount spent on hot spotting due to its cost inefficiency, so as to fall within the recommended parameters. While the latter approach will save money by dedicating it to where it is spent more efficiently, reliability ultimately deteriorates.

PSE's recent history of hot spotting suggests that it may be possible to reduce hot spotting to about 4%, saving about $30,000. The small amount of potential savings is indicative of the overall efficiency of PSE's VM program.

Finding 4-5 The maintenance cycles are appropriate for the local tree growth rates.

There is no industry-accepted definition for a vegetation management maintenance cycle. In fact, some utilities claim they do not perform work on a cycle but only in response to an emerging need, usually as indicated by outage statistics. The resistance to specifying a maintenance cycle stems from the fact that re-growth rates are highly variable conjoined with a specific but selective interpretation of a maintenance cycle, as requiring work on every tree not meeting the standard post-work tree-to-conductor clearance. Pruning trees that will not encroach on the limits of approach prior to the next maintenance needlessly increases maintenance costs. Ecological Solutions Inc. consultants recognize the inefficiency of arbitrarily imposed pruning cycles and therefore, base their assessment of a stated or implied maintenance cycle not on whether every tree with the potential to grow into conductors has been pruned but rather on the resulting amount of conductor encroachment just prior to the maintenance event and whether the work has been organized to minimize costs by limiting non-productive work, such as travel.

As the action necessary for avoiding all tree-related interruptions would not be acceptable to the public in terms of costs and aesthetic impacts on private property and the environment, the utility is faced with balancing service reliability, costs and aesthetics. The balance PSE has chosen results in 5% hot spotting (*Exhibit 3-8*, *Exhibit 4-15*), which falls within the lower end of the range common in the industry (<15%). Ecological Solutions Inc., however, contends that, while funding to address hot spots is essential to reliability, an adequately funded VM program on a 3-year maintenance cycle can mitigate hot spots with only 2% of the VM budget.[88] As PSE's maintenance cycle varies from 3 to 6 years depending on voltage and customer density, the number of hot spots that will emerge is necessarily greater. The expenditure of only 5% of the routine maintenance budget is indicative of good pruning quality and a cost effective choice in maintenance cycle length.

It is noted that PSE is performing hot spot work for reliability and safety. This contrasts with the option of not performing hot spotting due to its poor cost effectiveness and tolerating increased tree encroachment and consequently, reliability and safety risks.[89]

If PSE's maintenance cycles were too long, there would either be numerous locations with strong and extensive evidence of burning or evidence of a very active hot spotting program. Evidence of a very active hot spotting program would be seen in the aging of pruning cuts and their distribution over several years. Neither of these conditions was found in the field. This suggests hot spot work is identified by a mid-cycle patrol, thereby grouping work sites by proximity and minimizing the amount of non-productive travel.

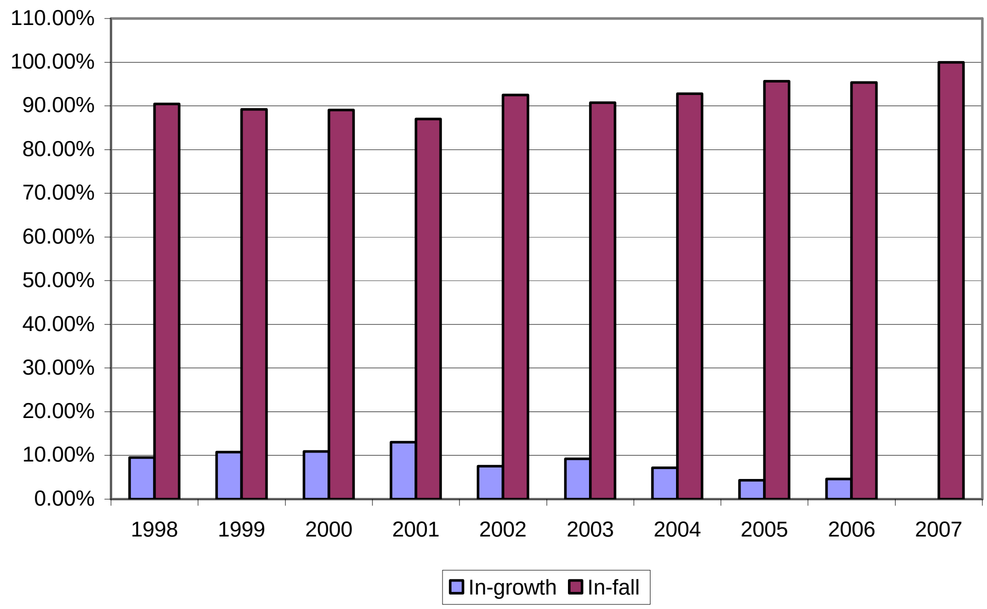
PSE uses 3-year, 4-year and 6-year maintenance cycles. Work that emerges in mid-cycle is addressed through the hot spot program. A six-year pruning cycle is longer than what is typical for a program that delivers good reliability and was the subject of careful scrutiny by Ecological Solutions Inc. However, the results of the VM program, as verified in the field,[90] are very few hot spots. The worst case circuits, that is circuits due for work in the current year, have few if any burners and at most up to 10% of spans that are at risk of having phase to phase contacts if VM work is not completed by the end of the growing season. This observation leads to the conclusion that the chosen maintenance cycles and mid-cycle mitigation or hot spotting are delivering a program with an appropriate balance between reliability, safety and costs.

The Bucklin Hill-12, GRV-12 and ORC-17 circuits provide an indication of the suitability of the maintenance cycles. All three circuits were either due or overdue for work at the time of inspection. On GRV-12 and ORC-17 there were a few burners (one phase contact only). On Bucklin Hill-12, which is on a 6-year maintenance cycle and overdue by a year, there were no burners but six spans where tree growth extended beyond the neutral.[91]

Another indicator of the suitability of the maintenance cycles is the ratio of tree-related outages arising from in-growth trees. Trees growing into the primary conductors result in burners. Burners do not necessarily cause a fault, particularly on distribution such as 12.5 kV and lower voltages. The risk of a fault and a consequent outage is much higher however, if a tree branch crosses phases.[92] Thus, burners may be considered a precursor of in-growth outages. As the majority of the regular maintenance work is pruning to provide a clearance between trees and electrical conductors, a suitable maintenance cycle results in a low ratio of in-growth outages.

Data regarding the amount of in-growth outages has been gleaned from the tree-caused outage investigations. For most of the last ten-year period, in-growth trees have accounted for less than 10% of all tree-related outages (*Exhibit 4-16*). Further, the trend for in-growth outages has been decreasing. The effort dedicated to the tree-caused outage investigations has not been uniform from 1998 through 2007, with a particularly small sample set for 2007. This may have resulted in the sample not accurately representing the total tree-caused outage results for 2007.

Exhibit 4-16
PSE Tree-caused Outages
In-growth vs. In-Falls



Finding 4-6 PSE's service interruption experience is driven by trees.

Tree-related service interruptions are the largest contributor to PSE's outage experience (*Exhibit 3-9*). Further, an examination of tree-related outages versus total outage statistics reveals that trees are the primary driver of PSE's outage experience (*Exhibit 3-10*, *Exhibit 3-11*, *Exhibit 3-12*).

It is not uncommon that trees are the primary cause of service interruptions on electric distribution systems often accounting for 25-40% of all uncontrolled outages. However, PSE's tree-related outages are much higher averaging over 60% and comprising as much as 90% in years with particularly severe major storm events (*Exhibit 3-9*).

The high ratio of tree-related outages warrants further study to characterize the outages and identify possible mitigation options and justifies high-level corporate support.

Finding 4-7 Vegetation Management funding needs to be increased to arrest the trend of increasing outages.

Exhibit 3-13 shows PSE's tree-related outages are on an increasing trend over the last ten-year period.

While the trend lines (*Exhibit 3-13*) for both distribution and transmission are skewed somewhat to the upside by the storms of late 2006, the trend should not be discounted on this basis as the data arises from "normal" operating conditions. In Vegetation Management Concepts and Principles it was revealed that vegetation management work and outages expand exponentially. Thus, one must expect if the issue of increasing customer hours of tree-related incidents is not addressed it is only a matter of time until PSE is witness to rapidly deteriorating reliability. Indeed, the outage experience of 2007 appears to be consistent with the trend established over the previous 6 years on distribution and 4 years on transmission. Hence, tree-related distribution outages may be on the cusp of a major breakout (*Exhibit 2-5*).

The intention to increase VM funding in 2009 and 2010 is justified by the increasing outage trend.

Exhibit 4-16 and *Exhibit 4-17* provide an indication of the source of the need for increased funding, and where it needs to be directed to arrest the trend of increasing tree-related service interruptions – the removal of hazard trees located outside the right of way.

The following finding provides more detail on this issue.

Finding 4-8 Off right of way trees are increasingly contributing to outages.

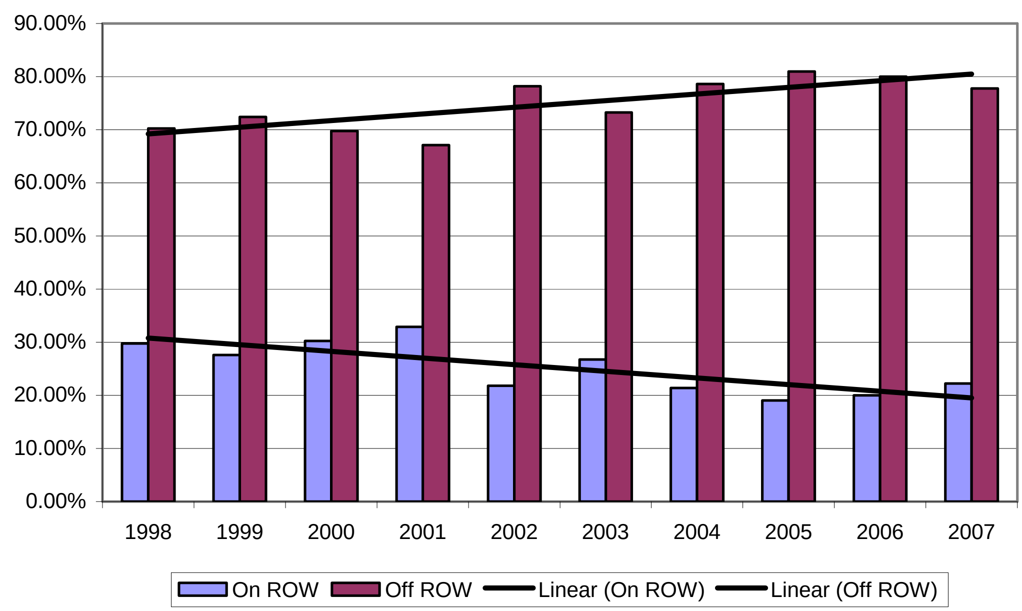
PSE has recognized that the vast majority of tree-related outages arise from branch, trunk or whole tree failures (*Exhibit 4-16*) predominantly from trees located outside the right of way (*Exhibit 4-17*). In fact, PSE designed and launched its Tree Watch program in 1998 to address this source of service interruptions.

It is a common misconception that when a tree is removed the risk associated with it is gone forever. Utility lines, however, are exposed to a great number of trees, herein referred to as the utility forest. A forest is a dynamic entity, which goes through either episodic or ongoing periods of renewal and mortality. Tree mortality in a forest is an ongoing process, which may at times be accelerated by environmental conditions.[93] Consequently, any utility hazard tree removal event provides a reliability benefit of a limited duration.[94] Without a further intervention the reliability benefit erodes over time.

While Tree Watch funding has continued, though at a considerably reduced level, it is of interest that since 2003, the last year of major Tree Watch funding, the ratio of off right of way tree-caused outages has increased roughly 10%. This would indicate that the Tree Watch program realized the objective of improving reliability and also that the current annual hazard tree removal volume falls below the annual increment.

To illustrate the erosion of the reliability benefit associated with a hazard tree removal event Ecological Solutions Inc. will provide an estimate of the benefit duration for the Tree Watch program. Doing so requires a quantification of PSE's electric system tree exposure and mean tree mortality rate (See Natural Tree Mortality).

Exhibit 4-17
Location of Trees Causing Outages
On the PSE Electric System



Finding 4-9 Experiencing 265 transmission tree-caused outages in the last ten years is indicative that a better understanding of tree exposure risk is required.

PSE has experienced 265 tree-caused outages on its transmission system in the last ten years. Considering the size of the transmission system this frequency of interruptions seems high. To understand why PSE's tree-related outages are greater than industry norms requires a better understanding of tree risk and how it varies from industry average tree risk.

Finding 4-10 PSE's rate of tree-caused service interruptions are not due to a sub-standard VM program.

Through data requests, interviews and field inspections, it has been determined that PSE has a sound vegetation management program that compares very favorably to the industry norms. On this basis, it is concluded that PSE's relatively high incidence of tree-caused service interruptions is not due to a sub-standard VM program but must be related to differences in physical conditions.

5. Review of Outage Data

The intent of this section is to use the available outage data to determine the source of tree-related outages to assess whether the outages are avoidable through an extension of the current VM program.

There has been considerable advancement since 1994 in understanding how trees cause phase-to-phase faults that arise from tree in-growth.[95] The current understanding of in-growth outages is that trees contacting a single distribution phase do not typically cause outages, particularly when the voltage is 13 kV or less. Sustained outages occur when a branch forms a substantial bridge between phases.[96] Most tree-related outages are due to tree failures and these trees are outside the right of way.[97]

Finding 5-11 Improving reliability will need to focus on limiting the potential for the in-fall of trees.

Exhibit 4-16 shows that for the PSE system, only about 10% of tree-related outages are due to in-growth trees. Since 2005 in-growth trees have comprised less than 5% of all tree-related outages. If cost is not a concern, then these outages can be considered avoidable. If a balance between costs and reliability is desired, it is unlikely that the in-growth ratio can be further reduced for a reasonable cost. The data set contains no in-growth outages on transmission lines. The data (*Exhibit 4-16*) reveals improvements in reliability need to focus on reducing in-fall trees.

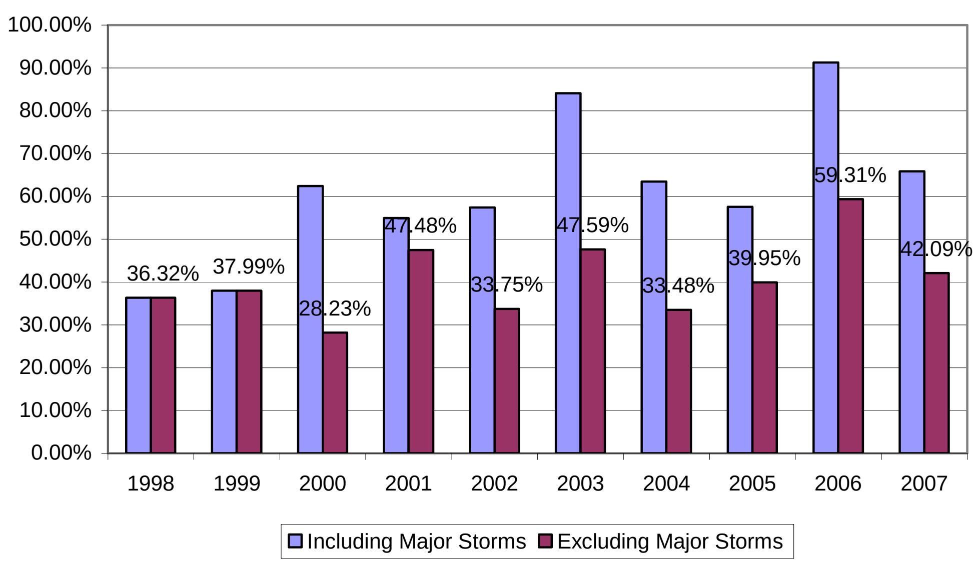
Exhibit 4-17 shows 70-80% of tree-related outages arise from outside the right of way. Achieving a major reduction in tree-related outages will necessarily involve a means of avoiding fall-ins from outside the right of way. The fact that 20-30% of the tree-related outages originate from within the right of way suggests that the right of way itself may also be a source of reliability improvement.

Regardless of the location of trees causing outages within or outside the right of way, about 95% arise from some form of tree failure. Tree failures include limb breaks, trunk breaks and uprooting. To avoid such tree failures PSE will need a more aggressive hazard tree program or to reduce the electric system's exposure to trees. This is not new to PSE as the introduction of the Tree Watch program was based on the same conclusion. PSE's outage experience, shown in *Exhibit 3-10* and *Exhibit 5-18*, reveals tree-related outages to be at the lowest levels in 1998 and 1999. Storms have increased the percentage of tree-related outages in 2003 and 2006. The average percent of tree-related outages since 2000, excluding the storm years of 2003 and 2006, is 60%. The over 20% increase from the 1998 and 1999 levels illustrates that even such an aggressive response as Tree Watch provides reliability benefits measured in years not decades (for further information see Natural Tree Mortality). The history shown in *Exhibit 5-18* also suggests the Tree Watch funding was front-loaded. There are a number of possible explanations for the 20% increase in tree-related outages since 1999.

1. PSE employed a successful hazard tree identification and removal strategy in 1998 and 1999 but subsequently changed some elements of the Tree Watch program that ultimately made the program less effective.
2. Many of the trees that fail and cause interruptions are not hazard trees but seemingly healthy trees.
3. The number of hazard trees annually added to PSE's utility forest exceeds the average number of trees removed per year by the Tree Watch program.
4. While the Tree Watch program removed a lot of trees, perhaps it was in fact, a small percentage of the total tree exposure.

The first explanation is unlikely as PSE was closely monitoring the effects of Tree Watch and any contrary results arising from an intended improvement would have been detected and the change reversed. The second explanation is valid as verified through the tree-caused outage investigations, which shows that from 1998 through 2007 about 56% of the failed trees appeared to be in good health. As the tree-caused outage investigations are using the insight provided by what might be termed destructive sampling, rather than non-intrusive visual assessments, 56% is the minimum amount of the failed trees that would not be targeted by the VM program. Trees in fair health represent another 12% that would not be targeted. The latter two explanations are plausible but their evaluation requires a quantification of the total tree exposure and local tree mortality rates.

Exhibit 5-18
Percent Tree-caused Outages



To reduce tree-related outages it will be necessary to find superior ways of identifying and predicting tree failure and/or reducing the extent of tree exposure, particularly on the higher voltage transmission lines. The experience compiled in the tree-caused outage investigations reveals better identification of hazard trees will address at most 20% of the tree-caused outages. The extent to which hazard tree outages can be reduced is unknown. Tree conditions can change in a matter of months and it is not possible to have eyes on the full system at all times. On the other hand, reducing the extent of tree exposure addresses line contacts from both hazard trees and healthy trees under all weather conditions. To better understand the mitigation options for reducing tree-caused outages available to PSE, it is necessary to quantify the extent of tree exposure and thereby, define the size of the challenge.

6. Review Tree-caused Outage Investigations

PSE or its contractors investigate all transmission tree-related outages and whole circuit distribution outages.[98] The data from these investigations, for the period of 1998 through 2007, was provided to Ecological Solutions Inc. for analysis. Some of the information derived from this data has already been presented and discussed (re: tree-caused outage investigations). In this review the data is parsed several ways and where possible, general recommendations on practices to increase reliability are provided.

It was stated in the previous section that the tree-caused outage investigations show that 56% of the trees that caused an outage were in good health. The remaining 44% is comprised of trees that are in fair health (12%), poor health (10%) and dead (10%) plus 12% of the tree-caused outage events where no determination could be made regarding the specific tree that caused the outage.

Finding 6-12 A more frequent inspection cycle for hazard trees and a focus on problem tree species may reduce tree-caused interruptions as much as 20%.

As 20% of the failed trees were either dead or in poor health, a more frequent inspection cycle for hazards trees holds the potential to reduce tree-related outages. Focusing on the five most problematic tree species will optimize the efficacy of increased hazard tree patrols (*Exhibit 6-19*).

The distance the offending tree is offset from the conductor (clear width) is reported in the outage investigations. There is no substantial difference in the distance from the conductor when the data is segregated based on tree health. The mean distances sorted by tree health range from 22 feet to 30 feet (*Exhibit 6-20*). This indicates that the standard practice of limiting hazard tree removals to either imminent threats or those within 12 feet and 18 feet of the line for distribution and transmission respectively, is giving rise to tree-caused faults. The Tree Watch approach, which does not place limits on hazard trees removed based on their proximity to the line, will prove more successful. The observed proximity of the failed trees to conductors supports the contention that an increased frequency of inspections for hazard trees holds the potential to reduce tree-related outages. However, for such a change to be effective all observed hazard trees must be addressed but particularly those trees located within 30 feet of a conductor (see *Exhibit 6-20*).

Exhibit 6-19
Major Contributing Species
to Tree-caused Interruptions

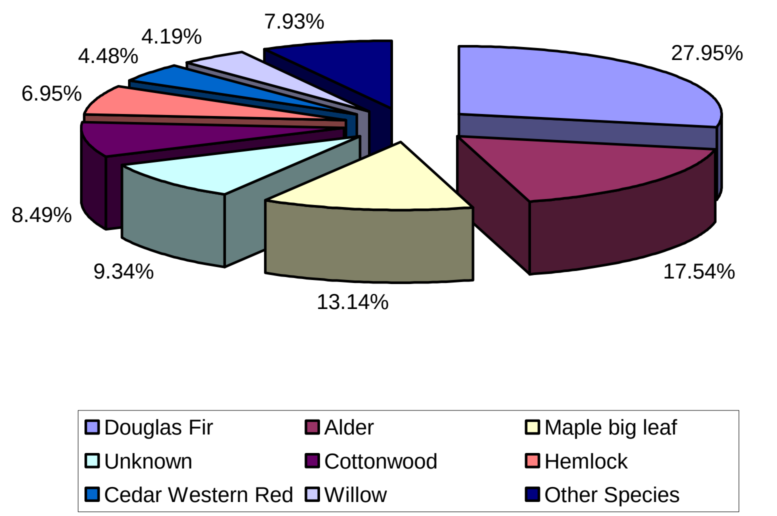


Exhibit 6-20
Condition and Location of Failed Tree 1998-2007

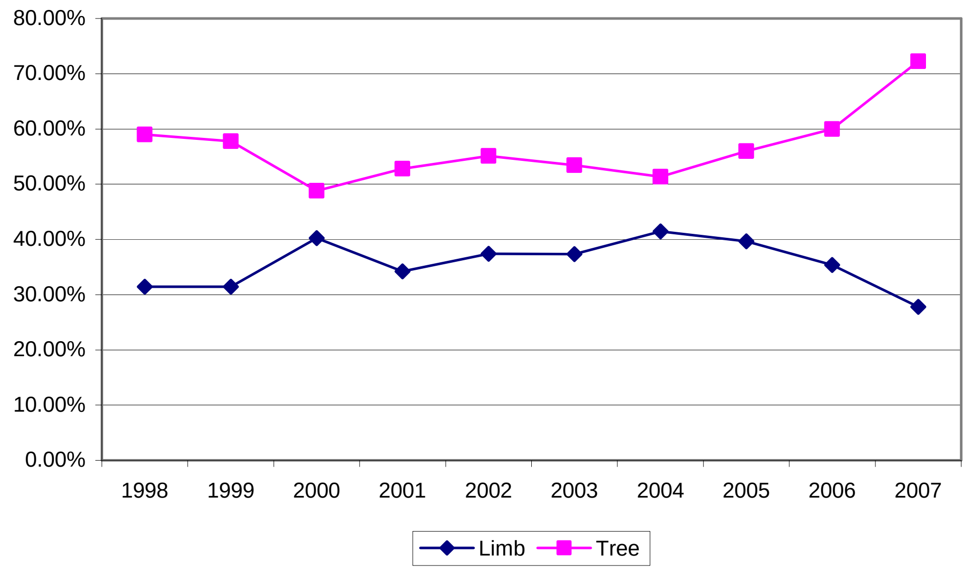
Tree Health	Clear Width (ft)
Good	22
Fair	28
Poor	30
Dead	29
Average	**25**

It is interesting to note that the trees in good health that failed and caused outages have the lowest mean conductor off-set of 22 feet. This is indicative that hazard trees close to the right of way edge have been successfully identified and removed. This information may also provide guidance for a strategy of reducing the extent of tree exposure.

Finding 6-13 Limb failures account for 35% of all tree-caused outages.

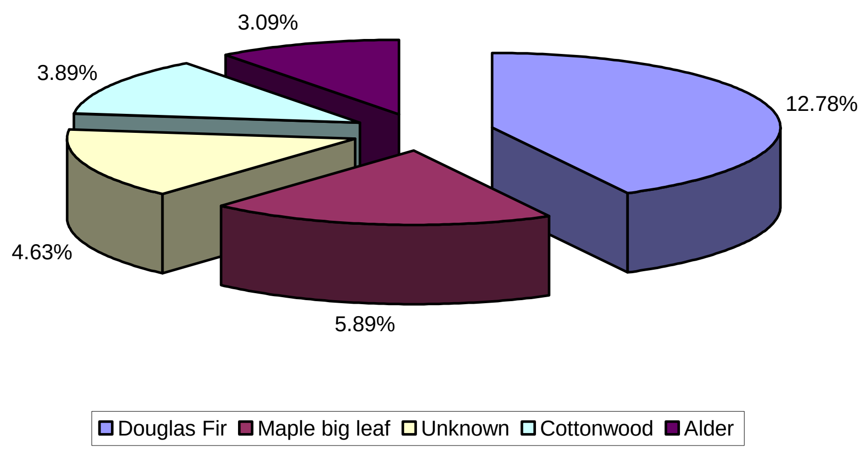
A large percentage of PSE's tree-caused outages are due to limb failures (35%), which either damage electrical equipment or cause phase-to-phase faults (*Exhibit 6-21*). On average, over the 1998-2007 period, about 36% of the in-fall type outages were limb failures.

Exhibit 6-21
PSE Tree-caused Outages By Failure Type
1998-2007



A further examination of the data reveals that a few species account for the majority of the limb failures (*Exhibit 6-22*). These are Douglas fir, big-leaf maple, black cottonwood and red alder. As the investigations data reveals these tree species to have a propensity for limb failure, an action that will improve reliability is to not tolerate any conductor overhangs by these tree species. Considering the location of the trees from which the limbs failed provides further guidance (*Exhibit 6-23*). We can assume that trees located on the right of way (clear width of 12 ft for distribution and 18 feet for 55 and 115 kV) shed branches that were overhanging the conductor. This assumption is supported by fact that the mean offset for within right of way trees is only 10 feet (*Exhibit 6-24*). Douglas fir is by far the greatest problem species but big-leaf maple, black cottonwood and to a lesser extent red alder also contribute to outages from trees located within the right of way. From a reliability perspective, the best option to avoid overhanging branches by these tree species is simply to not tolerate these trees within the right of way. The benefit will be the elimination of 9 % of the tree-caused outages (30.28% limb failures by these species X 29.12% within ROW portion). The second but less assured option is to insist on branch length reduction to remove overhangs wherever these trees are to remain within the right of way. This approach does not eliminate the possibility of windthrown limbs from the within right of way trees causing service interruptions.

Exhibit 6-22
Main Species for Limb Failures



Only 6% of the tree-related outages have occurred due to tree failures from within the right of way. The mean clear width for these trees was 12 feet. Once again, the greatest outage risk reduction will be achieved by the removal of these trees from the right of way. Removing within right of way trees may meet with public resistance. However, PSE would be well served by insisting on absolutely no overhangs for line segments between the substation and the first protective device.

The experience of Baltimore Gas & Electric and the former Niagara Mohawk distribution (now National Grid) is that the greatest return in line security for the dollar invested in maintenance of 34.4 kV lines arises from actions taken between the substation and the first protective device. These actions include removal of all overhangs[99] and increasing the clear width.[100] The experience of these utilities illustrates that an approach that is focused on the specific risk-reducing actions, which if realized will impact the most customers, provides a better return in line security than a broader approach, which fails to make distinctions between risk levels.

Exhibit 6-23
Percent of All Limb Failure Outages
1998-2007

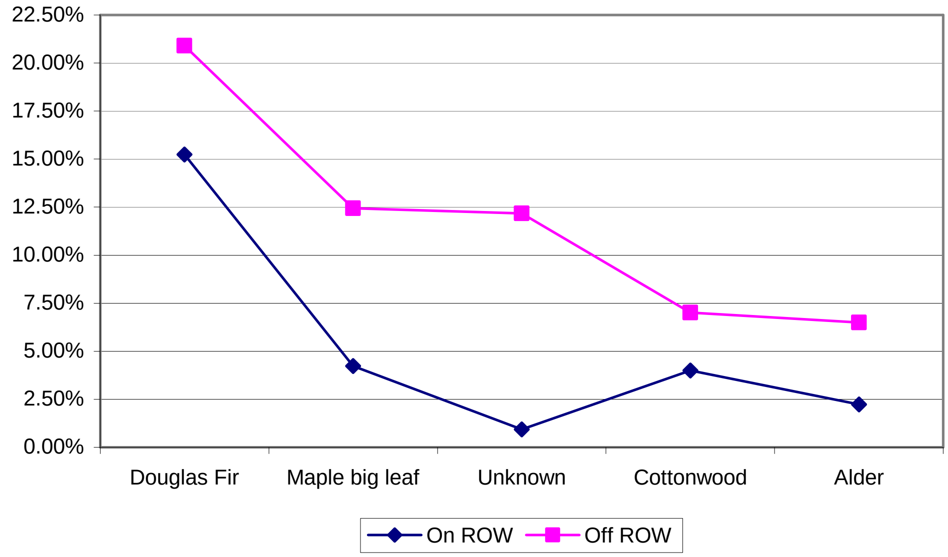


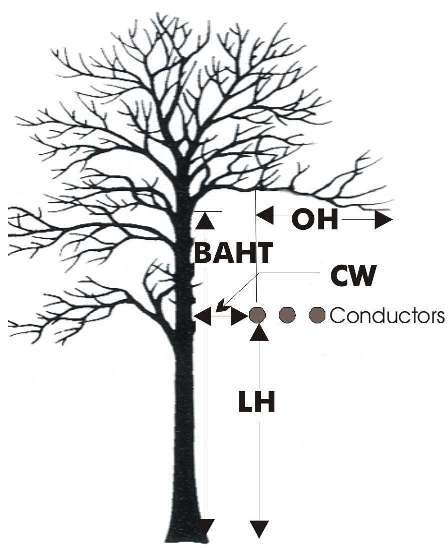
Exhibit 6-24
Tree Limb Caused Outages 1998-2007

Limb Origin	Clear Width (ft)
On ROW	10
Off ROW	24

An explanation of the reduction in tree risk and the attendant improvement in reliability that arises from increasing 34.4 kV clear width, as National Grid has done, was provided in a presentation to the International Society of Arboriculture in 2003 in Montreal. Although the specifics of the National Grid case are not included, the reasoning and potential for reliability improvements are found in the Journal of Arboriculture paper, "Effects of Tree Mortality on Power Line Security."[101]

Baltimore Gas & Electric has used a strategy of removing overhanging branches.[102] Not only can branches fail under load stress and fall into conductors but also, branches overhanging the conductor increase the risk of a conductor contact should the whole tree fail.[103] The extent of the increased risk can be calculated by comparing a base case, where branches above the conductor are pruned back just to the extent that there is no overhang (θ_{1}), with a case where branches do overhang the conductor (θ_2) (*Exhibit 6-25*).

Exhibit 6-25
Variables for Branches Overhanging Conductor



BAHT = branch attachment height
CW = clear width
LH = line height
OH = overhang

To illustrate the calculation of the risk (R) associated with an overhanging branch using measurable variables, an example is provided. Assume the following are the found variables:

- Line height (LH) is 28 feet.
- Point of overhanging branch attachment (BAHT) is 46 feet.
- Clear width (CW) is 11 feet.
- Branch overhang (OH) is 15 feet.

The fall parallel to the line, with total branch length equal to the CW, is expressed as:

$$\theta_1 = \sin^{-1}\left(CW \div \sqrt{\left(\left(\sqrt{BAHT^2 + CW^2}\right)^2 - LH^2\right)}\right) \times \frac{180}{\pi}$$

$$=16.77°$$

The situation with an overhanging branch and a tree fall, such that the branch just contacts the conductor, is expressed as:

$$\theta_2 = \sin^{-1}\left(\left(CW + OH\right) \div \sqrt{\left(\left(\sqrt{BAHT^2 + \left(CW + OH\right)^2}\right)^2 - LH^2\right)}\right) \times \frac{180}{\pi}$$

$$= 35.47°$$

The degrees of increased risk exposure resulting from the branch overhang are calculated.

$\theta_2 - \theta_1 = 18.7°$

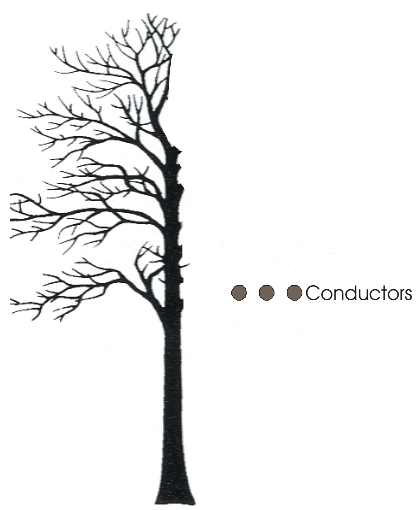
The risk of a conductor contact on tree failure for the overhang condition is calculated.

$R = 0.5+((\theta_2 - \theta_1)*2/180)*0.5$

$= 0.60$

For the example conditions, the overhanging branch has increased the risk of a conductor contact on tree failure by 20.8% ((0.60-0.5)/0.5).[104]

Exhibit 6-26
Ground-to-Sky Utility Pruning



There are greater gains in line security available if 'ground-to-sky' pruning is done (*Exhibit 6-26*). Although the public may resist 'ground-to-sky' pruning, it might receive a better reception if the benefits in reliability can be articulated. The risk of a line strike on failure of a tree that has been 'ground-to-sky' pruned can be calculated by determining the arc of exposure of 360°. For the above variables, and assuming total tree height is 70 feet, R(isk) is 0.314. The improvement, relative to the example previously provided when the tree had an overhang, is 48%. Conversely, situations of trees with overhang matching the stated variables may be expected to have 92% more outage incidents than 'ground-to-sky' pruned trees.

The reliability improvement available in shifting from a situation of tolerating branch overhangs to 'ground-to-sky' pruning on the conductor side justifies serious consideration, especially on line segments where an outage incident would impact the whole circuit. As the height of the trees affects the feasibility and cost of 'ground-to-sky' pruning, PSE will need to make site-based determinations. The financial component of the feasibility assessment of 'ground-to-sky' pruning can serve as base against which other options can be compared and thereby, justified.

Finding 6-14 There is virtually no reliability improvement available through more frequent pruning.

It has been shown that for voltages below 25 kV, a tree in contact with a single conductor is unlikely to cause a fault. Faults arise from tree branches bridging phases, resulting in phase-to-phase faults.[105] As the field inspection found no instances where phase-to-phase faults could currently occur, shortening the pruning cycle would increase costs without contributing to improving reliability.

Further, the tree-caused outage investigations data shows there is virtually no reliability improvement available through an extension of the current vegetation management program. Reducing outages arising from within the right of way would require a change in standards. Considering the effective use of hot spotting witnessed in the field, PSE must be patrolling its system on mid-cycle to identify the emergent issues. Hence, increasing the identification and removal of hazard trees would necessitate annual patrols. In addition to the costs associated with the increased frequency of patrols, crews would also need to be dispatched on a hot spot basis to address the hazard trees. The cost of such an effort versus the value of the potential reliability improvement would require careful evaluation.

The tree-caused outage investigations also show that apparently healthy trees cause at least 56% of the tree-related outages. PSE's experience in this regard is consistent with other utility findings.[106] It would be reasonable to expect that as wind or ice loading on trees increases, the trees with faults would begin to fail and be removed from the population. Consequently, under high stress loading such as those experienced during major storms the majority of trees that result in service interruptions will be apparently healthy trees, trees not targeted by conventional vegetation management programs. These interruptions can only be avoided by pre-emptive actions that reduce the extent of the electric system's exposure to trees. Doing so effectively, will require a quantification of that exposure.

7. Determine Outside ROW Tree Exposure

The first phase of determining the extent of tree exposure for the transmission system is to establish the extent of treed edge. This was accomplished by the random selection of 400 points along the transmission system (*Exhibit 7-27*). Randomization was achieved by placing a grid on a PSE system map and the generation of two sets of random numbers or grid coordinates. In grids containing more than one voltage class of line, assignment preference was given to 55 kV and 230 kV over 115 kV to ensure adequate representation for the application of large sample statistics. Hence, the number of samples chosen for each voltage class is not based on its ratio to system line miles. Of the 400 sample points, 54 were assigned to 55 kV, 270 to 115 kV and 76 to 230 kV.

Aerial photographs at the sample points were used to determine the amount of treed edge on each side of the line over a one-mile segment.

Finding 7-15 75% of PSE's electric system is treed.

The data was assembled and analyzed to determine the mean percent of treed edge at a 95% confidence level. PSE's transmission system has 74.94% ± 2.14 of treed edge. As the transmission and distribution systems overlap completely, the 74.94% of treed edge applies to all of PSE electric system.

Exhibit 7-28 presents the percent of treed edge both on the system level and by voltage class. The 55 kV lines appear to have a greater tree exposure. A likely reason for this is that east of the Cascades, where the ecology is quite different from coastal areas, 55 kV lines are not represented.

The second phase of determining the extent of tree exposure involves the derivation of the depth of wooded area adjacent to the right of way and the number of trees per acre. This was accomplished by the selection of a subset of the 400 random sample points for the collection of field data. At 109 sample points, the low point line height, clear width from the conductor to adjacent tree boles, height of the co-dominant canopy, height and species of dominant trees[3] were recorded for each side of the right of way (218 edge samples). Three replicate forest samples were taken on each side of the right of way using a BAF 10 angle gauge. Every tree of 4 inches or greater diameter at breast height (dbh) within the BAF 10 plot was recorded by species and dbh. Over 11,000 tree records were documented.

Finding 7-16 The outside right of way portion of PSE's utility forest averages 272 trees per acre.

The samples taken in the forest were used to determine the number of trees per acre. PSE's utility forest supports an average of 272 ± 13 trees per acre.

[3] Dominant trees are emergent above the general, or co-dominant canopy

Exhibit 7-27
Random Sample Points to Assess % Treed Edge

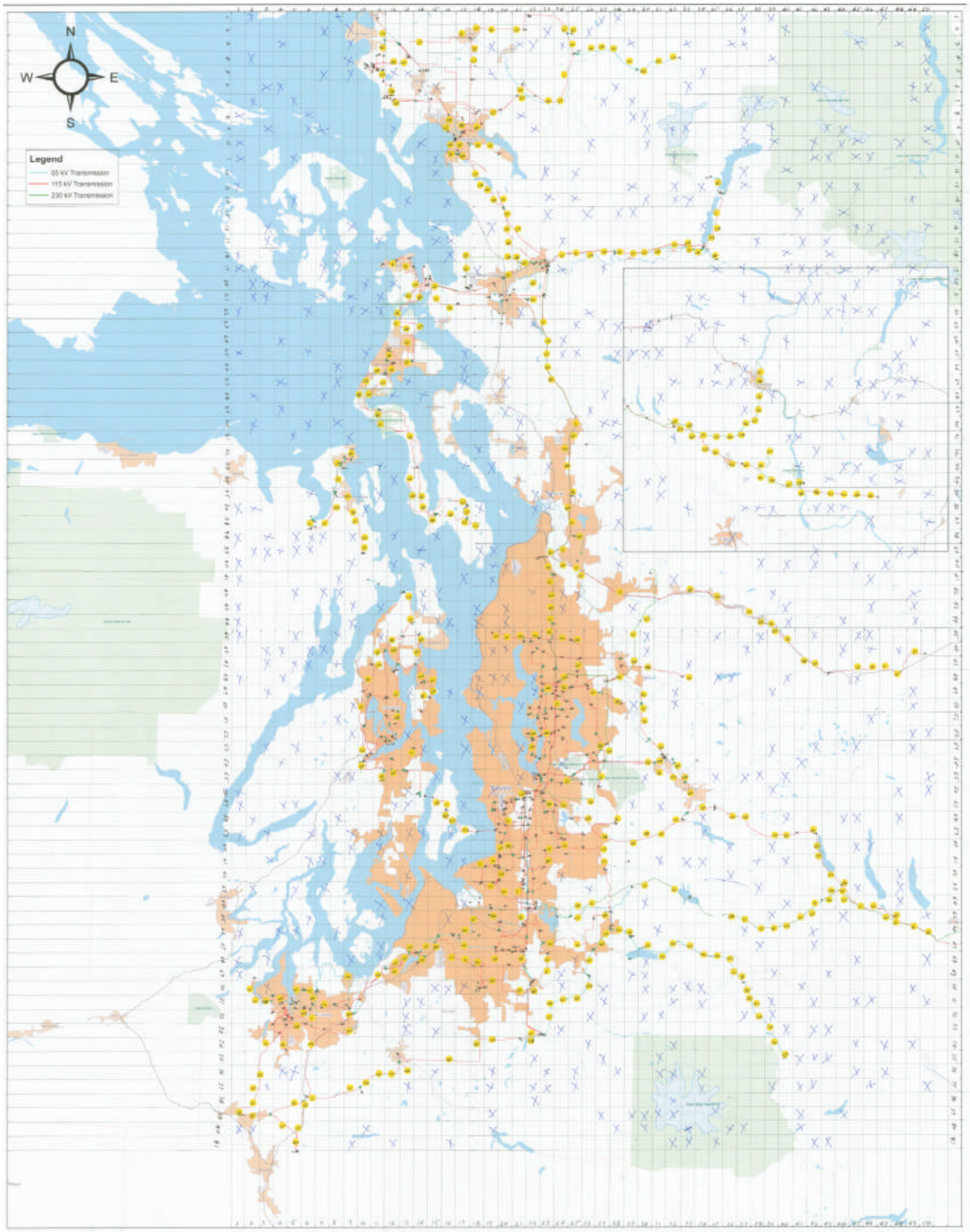


Exhibit 7-28
PSE System - Percent Treed Edge

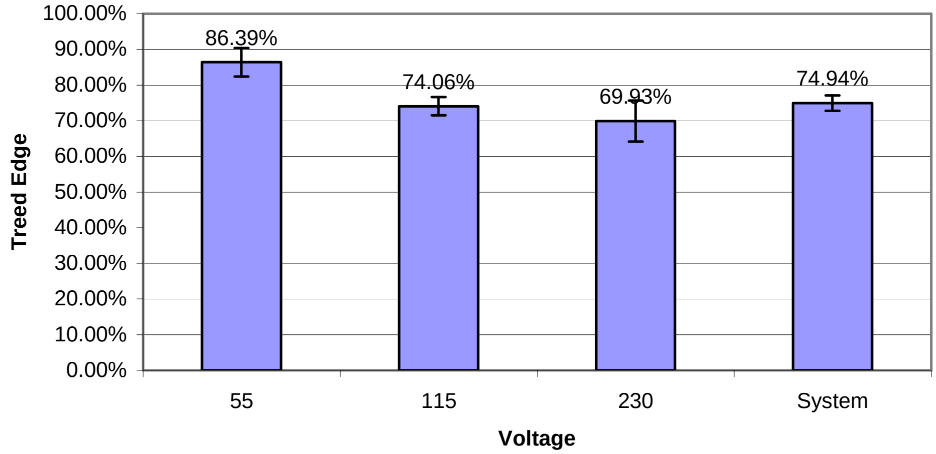


Exhibit 7-29
PSE Transmission Mean Field Variables

Voltage (kV)	Wire Zone (ft)	Clear Width (ft)	Line Height (ft)	Tree Height (ft)	Trees per Acre
55	8 ± 1	38 ± 7	43 ± 3	95 ± 7	237 ± 26
115	10 ± 1	44 ± 5	45 ± 1	98 ± 4	300 ± 30
230	34 ± 3	52 ± 6	48 ± 3	91 ± 7	352 ± 35
System	**17 ± 2**	**45 ± 3**	**45 ± 1**	**95 ± 3**	**272 ± 13**

Data collected from the 218 edge samples, segregated by voltage class is presented in *Exhibit 7-29*. The units are presented as variable mean ± 95% confidence interval. A couple of the mean variables warrant comment. Clear widths appear to be only slightly lower than other utilities.[107] [108] [109] The mean clear width is, however, misleading for 55 kV and 115 kV lines where many miles run along roadside with a very restricted clear width on one right of way side. Focusing on the mean clear width will critically under-estimate the risk of line strikes on tree failure. This irregularity is addressed when undertaking further statistical analysis.

Mean tree heights (*Exhibit 7-30*) found along PSE electric lines are considerably greater than those found along other systems. PSE's mean tree heights are 15 to over 30 feet greater than those found in similar work done on the National Grid USA transmission system.[110] The greater tree height increases the amount of tree exposure.

Exhibit 7-30
Mean Tree Height (ft)

Voltage (kV)	Co-dominant Height	Dominant Height
55	88 ± 7	103 ± 18
115	81 ± 5	100 ± 5
230	72 ± 6	105 ± 11
System	**80 ± 4**	**102 ± 5**

Utility Forest

Finding 7-17 PSE transmission is exposed to more than 4.2 million danger trees.

Using the variables of line height, tree height and clear width in triangulation, the depth of area supporting trees, which on failure could strike the power line, was calculated. Multiplying the line miles X the percent forested edge X acres supporting trees that could strike the line X trees per acre provides the size of the utility forest outside the right of way. *Exhibit 7-31* provides information on PSE's transmission utility forest. There are 4,219,053 trees located outside the transmission right of way, which on failure could strike a transmission line (danger trees). The tree exposure can also be stated as 1,995 danger trees per line mile.

While the potential treed right of way acres have been calculated for PSE transmission in an attempt to present a comprehensive statement of the size of the utility forest, the figure is inaccurate due to the extent of 55 and 115 kV lines along roadways. No field measurements were taken to quantify the portion of the within right of way utility forest that is paved. The right of way acres are based on the assumption that due to seeding and vegetative reproduction, trees are most likely to be established within the right of way where there are adjacent trees.

Exhibit 7-31
PSE Transmission Utility Forest

Voltage (kV)	Potential ROW Treed Acres	Danger Tree Acres	Danger Trees	Danger Trees per Line Mile
55	1,245	1,414	384,663	2,697
115	14,503	12,729	3,462,335	2,105
230	3,867	1,368	372,054	1,135
System	**19,616**	**15,511**	**4,219,053**	**1,995**

Utility Forest Characteristics

In addition to quantifying the number of danger trees outside the right of way, the forest sampling comprised of over 11,000 records provides comprehensive view of the species composition of the utility forest (*Exhibit 7-32*). For the ease of comparison the graph of major contributing species to tree-caused interruptions previously presented in *Exhibit 6-19* is repeated in *Exhibit 7-33* in a slightly adjusted form that better aligns with species composition. In examining the species composition versus the role of species in contributing to outages (*Exhibit 7-32* vs. *Exhibit 7-33*) it is seen the species contribute to outages based on factors beyond simply their number within the population. For example, western hemlock, the second most common species in the utility forest, contributes to outages at a rate well below that suggested by its composition numbers. Big leaf maple on the other hand, contributes heavily to outages based on its representation within the population.

Finding 7-18 Of identifiable species, big leaf maple has the highest hazard rating.

By comparing the contribution to outages with the percent of the species' representation in the population a table was developed to identify the types of tree exposure that represent the greatest risk to line security (*Exhibit 7-34*). It is interesting to note that three deciduous species, big leaf maple, black cottonwood and red alder represent the greatest risk to PSE transmission lines. It is noted that "other species" hold the highest hazard rank. It is possible that the species involved are cultivated species, species either not present in the native forest population or present only in very low numbers. The seventh ranked species in contributions to outages are willows. In the forest sampling, willows comprised only 0.06% of the population. The sampling protocol required a forest depth of at least 30 feet. This suggests that willows causing outages are cultivated and/or occur in strips less than 30 feet wide. The hazard ranking provided in *Exhibit 7-34* should help to focus PSE efforts in identifying conditions of above average risk to reliability.

Exhibit 7-32
PSE Utility Forest Species Composition

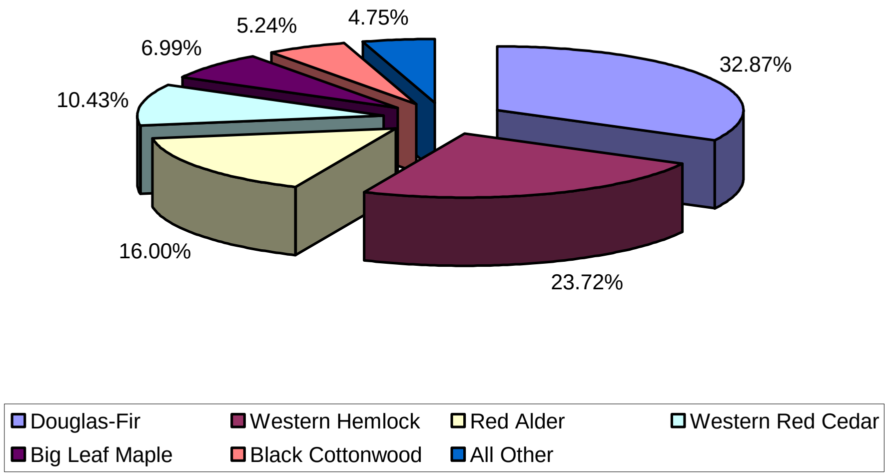


Exhibit 7-33
Major Contributing Species to Tree-caused Interruptions

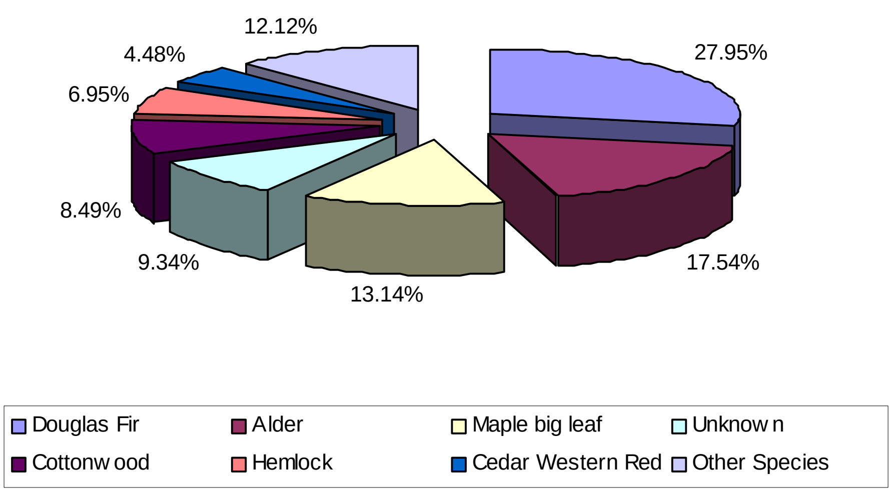


Exhibit 7-34
Failure/Hazard Ranking

Species	Composition Rank	Failure/Hazard Rating	Failure/Hazard Rank
Douglas-Fir	1	0.85	5
Western Hemlock	2	0.29	7
Red Alder	3	1.10	4
Western Red Cedar	4	0.43	6
Big Leaf Maple	5	1.88	2
Black Cottonwood	6	1.62	3
All Other[1]	7	2.55	1

[1] Minor species contributing to outages include willows, native cherry, true firs, poplars, other cedars, madrone

Tree height data was recorded by codominant and dominant trees. Codominant trees, as used here, comprise a distinct canopy height. Dominant trees are emergent to that canopy. The main dominant tree species are Douglas fir, western hemlock, black cottonwood, western red cedar and red alder. Dominant trees ranged 20 to 70 feet over the codominant trees within the sampled stands averaging 40 feet more in height. When the dominant trees are sparse or widely spaced, they are subject to enormous wind loading. Consequently, sites with dominant/emergent trees require careful monitoring and hazard evaluations.

Natural Tree Mortality

Tree mortality is an ongoing process in the forest. By applying the natural tree mortality rate to the utility forest the number of hazard trees that develop annually across the system can be calculated. The natural tree mortality rates are derived from forest research[111] [112] [113] and in the absence of data have been estimated based on mortality rates of similar species in other geographic areas. The mortality rates were then applied to PSE's most common tree species based on their frequency of occurrence within the utility forest to derive a weighted tree mortality rate (*Exhibit 7-35*).

Exhibit 7-35
Estimated Tree Mortality

Species	Trees	Mortality	Weighting	Weighted Mortality
Douglas-Fir	3707	0.60%	22.242	
Western Hemlock	2675	3.00%	80.25	
Red Alder	1804	3.00% *	54.12	
Western Red Cedar	1176	0.60% *	7.056	
Big Leaf Maple	788	1.00% *	7.88	
Black Cottonwood	591	2.50% *	14.775	
All Other	536	1.00% *	5.36	
Total	**11277**	**1.67%**	**191.683**	**1.70%**

* Estimated

Finding 7-19 PSE transmission is exposed to about 72,000 hazard trees.

Applying the annual mortality rate to the danger trees within PSE transmission utility forest, the number of trees that become decadent, or hazard trees, each year can be calculated (*Exhibit 7-36*). PSE is challenged with identifying and evaluating 71,714 hazard trees each year (the annual hazard tree increment).

It should be noted that for many of the species (*Exhibit 7-35*) mortality has been estimated. The rate of tree mortality impacts the expectation for the number of hazards trees added annually to the utility forest. Every 0.1% change in tree mortality impacts the annual hazard tree increment by about 4,200 trees. It is suggested that PSE undertake a literature search to improve upon the estimated tree mortality. (Data can be updated beginning with the Excel file 'outage investigations.xls Sheet3' and subsequently using the links between spreadsheets.)

Tree mortality is an ongoing process throughout the year rather than an event that happens at a particular time. Consequently, because it is impossible to be working everywhere on the transmission system at one time, if PSE removes 71,714 hazard trees per year, it has an ongoing residual population of almost 72,000 hazard trees. These hazard trees are distributed across the transmission system. Only actions, which reduce PSE transmission's overall tree exposure (total utility forest population decrease), can reduce the annual hazard tree increment.

Does this mean that PSE needs to remove 72,000 trees per year? No. If we assume that a hazard tree can fall anywhere within the 360° of a circle, then there is a limited arc of exposure where tree fall would intercept a conductor. This arc of exposure is a small part of the possible range of fall. Hence, decadent trees that begin to lean are more likely to have a lean that indicates a fall away from the line. Such trees need not be removed for reliability purposes. Further, trees that by height are capable of striking the line but are located far back in the stand may not be able to fall through the surrounding forest to strike the line. Field assessments need to be made about which hazard trees are likely to fall through forest stand to the line. It is not possible to provide a definitive answer regarding what portion of the 72,000 hazard trees will have a high probability of line contact on failure and need to be removed.

Some guidance can be provided by considering leaning trees and examining the arc of exposure for the various voltage classes. Choosing a location in the mean centre of the adjacent danger trees it is calculated that the mean arc of exposure for 115 kV danger trees is 23% of a circle. Adding a 10% margin for safety, provides 33% of leaning trees that would be designated a threat to the line. From this it is calculated that 16,495 (23%)to 23,666 (33%) trees are likely to interfere with power lines on failure. The lean of trees towards the line is only one consideration but it demonstrates that only some fraction of the approximately 72,000 trees in decline will need intervention.

If less than the annual increment in hazard trees is removed, the population of hazard trees both increases and over time this standing population becomes susceptible to failure under decreasing stress load levels.

Exhibit 7-36
Hazard Tree Population

Voltage (kV)	Danger Trees	Hazard Trees
55	384,663	6,538
115	3,462,335	58,852
230	372,054	6,324
System	**4,219,053**	**71,714**

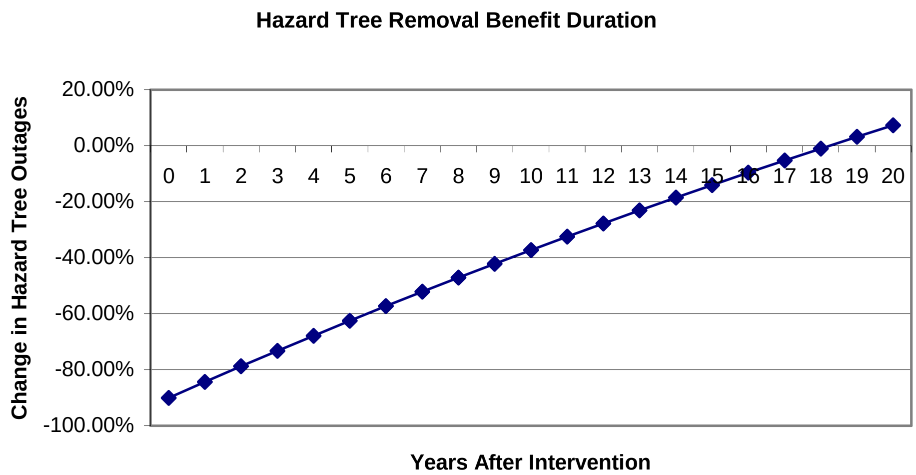
The rate of development of hazard trees has serious implications for a hazard tree program. It is apparent that with the addition of about 72,000 hazard trees each year, the reliability benefits of the hazard tree program have a limited duration.

To illustrate, data garnered from this work and information about the Tree Watch program were used to calculate the duration of benefit for Tree Watch (*Exhibit 7-37*). Tree Watch was initially applied to the distribution system. The distribution data collected in this work is specific to distribution lines that are under strung to transmission lines. As such, the tree exposure used in modeling reliability benefit duration underestimates the tree exposure for the distribution system as a whole. *Exhibit 7-37*[4] shows

[4] Assumptions: Trees/system mi removed=75; Outage reduction=90%; tree height=95; line height=33; clear width=41; tree mortality-1.7%; Mean RF=31.44%

the hazard tree benefit duration to be 18 years. Re-generating the graph (not shown) using assumptions[5] for mean distribution line height, clear width and tree risk, the benefit duration is reduced to 8 years. However, whether the benefit duration is 8 years or 18 is immaterial to the key concept conveyed in *Exhibit 7-37*, which is that the reliability benefit of hazard tree removal in a given year, such as 1998, erodes every year until there is another intervention that removes accrued hazard trees.

Exhibit 7-37
Tree Watch Program – Estimated Duration of Benefit



When Tree Watch was launched it was unprecedented in the utility industry for the number of trees removed per mile. This aggressive program provides a reliability benefit for 8 to 18 years. While the benefit is of a limited duration, were hazard trees not removed the utility forest would be increasingly populated by trees that will fail under decreasing levels of stress load, leading to deteriorating reliability.

The duration of benefit presented in *Exhibit 7-37* provides a clear indication that a hazard tree program that is a one-time effort or event will result in a gradual erosion of reliability back to pre-effort levels. Equilibrium can be reached by annually removing the hazard tree increment.

[5] Assumptions: Trees/system mi removed=75; Outage reduction=90%; tree height=95; line height=30; clear width=20; tree mortality-1.7%; Mean RF=50.99%

8. Quantify Outside ROW Tree Risk by Voltage Class

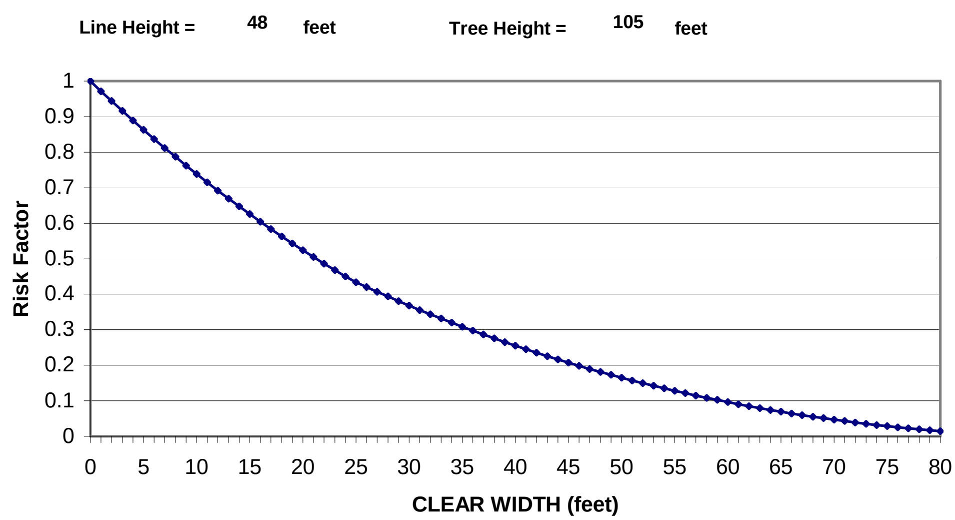
Tree Exposure Risk

Tree exposure risk is comprised of two factors: the number of trees capable of striking the line on failure; and, the average arc of line exposure to a falling tree. To quantify tree risk, Ecological Solutions has developed the Optimal Clear Width Calculator. Using the field variables line height, tree height, clear width and tree density, the proprietary Optimal Clear Width Calculator, produces a measure of the tree exposure risk. It is expressed as the Risk Factor.

To illustrate the Risk Factor (RF), the mean variables, line height 48 feet, dominant tree height 105 feet, tree density 252 trees/Ac, for 230 kV lines were used to generate *Exhibit 8-38*. The mean clear width is 52 feet, which produces a RF of 0.1497. *Exhibit 8-38* shows that a clear width of 0 feet will have a RF of 1 and a RF of 0 is reached when the clear width is so great that no tree on failure will strike the line (tree-free).

While Risk Factor is related to probability, it is not the pure mathematical probability of a line strike on tree failure. First, the RF attempts to account for the possible interactions between trees. Second, the scale for the RF (see *Exhibit 8-38*) extends to 1. The RF assumes, on tree failure, an equal probability of a fall anywhere within 360°. Wind direction, particularly, strong winds from other than the prevailing wind direction, topography, etc. may challenge this assumption at a site level. On the system level the variability, while broad, is nonetheless ultimately limited and the probability will approach ½ the RF.

Exhibit 8-38
Line Strike Risk



The Risk Factor was calculated for each of the 218 right of way edges sampled using the measured variables. The RF's were then calculated for each voltage class. As a considerable amount of the 55 and 115 kV system is along roadsides, with one small and one quite large clear width, the mean clear width does not adequately reflect the tree risk. No specific record was made during the sampling to distinguish the lines running along roadsides. Therefore, the data was segregated based on the assumption that 55 and 115 kV lines with a clear width ≥ 50 feet have a roadway between the conductor and the forested edge (designated by Side=Street in *Exhibit 8-39*). This assumption was derived from a review of the aerial photographs to establish a decision point clear width. Only one street-side clear width of less than 50 feet was found. Aerial photographs also revealed some clear widths of greater than 50 feet were not adjacent to roads. While not all the aerial photographs were reviewed, where the assumption was found to be incorrect the designation of ROW or Street side was corrected. Street-side edges comprise about 11% of edges sampled. The tree exposure risk by voltage class is presented in *Exhibit 8-39*.

Finding 8-20 PSE transmission tree exposure risk is substantially greater than that seen at other utilities.

The RF ratings in *Exhibit 8-39* illustrate the relevance of distinguishing between the right of way side and street-side. The RF rating for the street side on 55 kV is about 50% less than that found on other utility systems. However, the RF for the right of way side of 55 kV is 2 to 3 times greater than that of other utility systems.[114]

Exhibit 8-39
Tree Exposure Risk

Voltage (kV)	Side	Risk Factor (%)
55	ROW	30.47
55	Street	7.86
55	Both	27.64
115	ROW	29.67
115	Street	5.18
115	Both	25.81
230	Both	13.55
System		**22.73**

For 115 kV lines the street side has a RF similar to that on other utility systems but the RF for the right of way side is 4 to 5 times greater. The RF for 230 kV is about 3 times greater than that found on other systems.[115]

Due to the influence of weather and the tree failure rates, PSE's greater tree risk cannot be directly extended to an expectation of an equal multiple of tree-caused outage incidents.

Note generating the RF from mean variables (*Exhibit 8-38*) produces a somewhat different result from that derived by calculating the mean from the RF for each of the 230 kV right of way edges sampled (*Exhibit 8-39*).

Controllable Variables and their Relationship to Risk

Typically utilities use two variables, clear width and line height, at the point of line design and installation to limit the tree risk. Consequently, it would be expected that as voltage increases, the clear width and line height would also increase. Scatter diagrams of the field sampled clear widths (*Exhibit 8-40*) and line heights (*Exhibit 8-41*) show this trend. The other variables studied that influence tree risk, tree height and tree density, are not variables that utilities control to any extent prior to line installation.

Exhibit 8-40
Clear Width Scatter Diagram

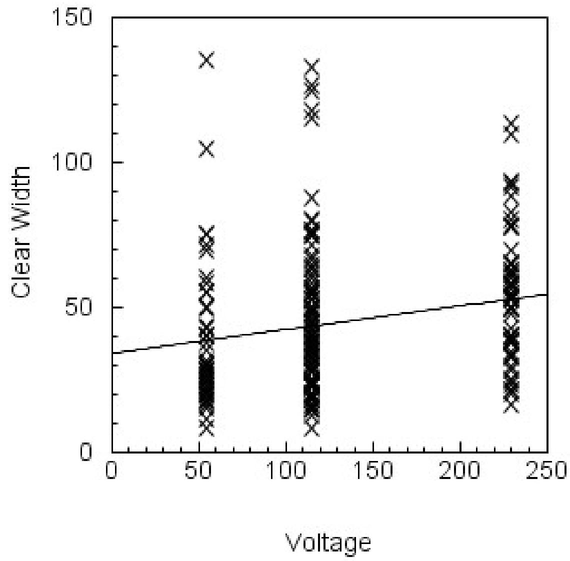
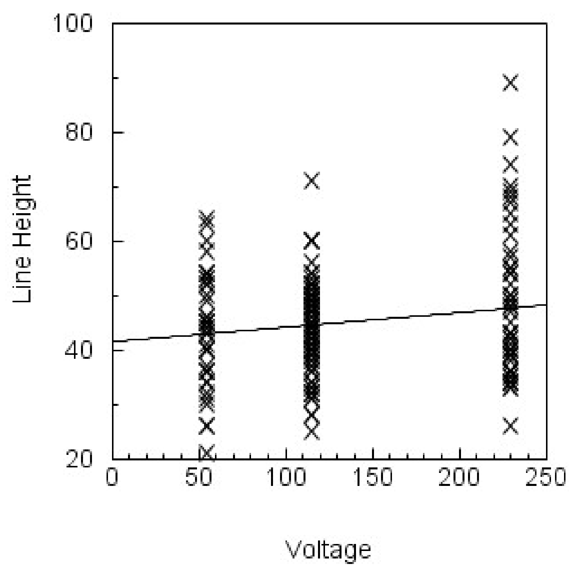


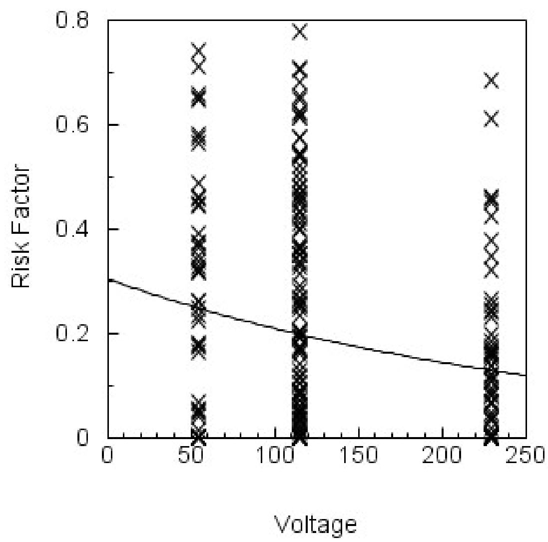
Exhibit 8-41
Line Height Scatter Diagram



Finding 8-21 **Clear width and line height increase with voltage class and tree risk (RF) decreases with voltage class (*Exhibit 8-40*, *Exhibit 8-41*, *Exhibit 8-42*).**

Exhibit 8-40 and *Exhibit 8-41* show clear width and line height increase with voltage class. Both of these contribute to a reduction in the amount of tree exposure. As the Risk Factor (RF) is derived from clear width, line height, tree height and tree density, it is expected that RF decreases with increasing voltage. *Exhibit 8-42* reveals this to be true.

Exhibit 8-42
Risk Factor Scatter Diagram



The relationship of the variables to tree-related outage experience is statistically examined in the following section.

9. Statistical Analysis

Clear width, line height, tree height and tree density were measured in the field through the random sample of 218 transmission line edges. Using these variables, the number of system-wide trees of exposure, the number of trees per mile of right of way edge and the mean Risk Factor for each voltage class were calculated. This section will examine both the measured and calculated variables relationship to the outage experience.

Data was analyzed using CoHort Software (CoHort Software, 2005. CoStat. www.cohort.com. Monterey, California.)

Prior to considering the outage experience it is instructive to assess whether and how the variables change based on voltage class. This is done by calculating and charting the variable means, by voltage class. An analysis of variance and a multiple means test (Student-Newman-Keuls) was performed for each of the variables. The letters above the bars provide the results of the comparison of means. Letters above the bar that are the same are not significantly different whereas, letters that are distinct are significantly different at minimum 95% level.

Exhibit 9-43 presents the mean clear width by voltage class. The clear width for 230 kV lines is significantly greater than that for the 55 and 115 kV lines.

Exhibit 9-43
Transmission Clear Width

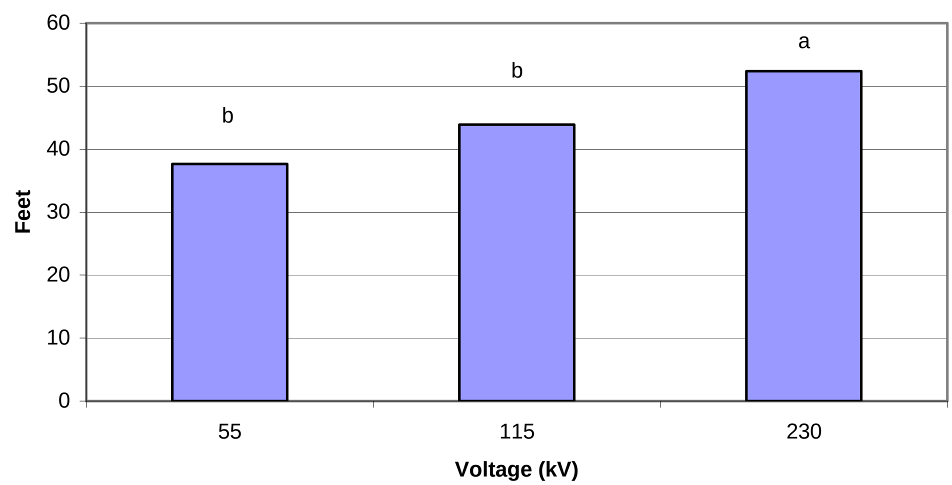


Exhibit 9-44 shows that the mean 230 kV line height is significantly greater than the mean height of 55 kV lines. The 115 kV mean line height falls between these two and is not statistically different from either.

Exhibit 9-45 provides the mean tree height by voltage class. As expected, there are no significant differences in the tree height along the various voltage classes. The result is expected because utilities do not change the voltage class of a line based on the height of surrounding trees. No chart is provided for the per acre tree density based on the voltage class. This is not a variable that utilities strive to control.

Exhibit 9-44
PSE Transmission Line Height

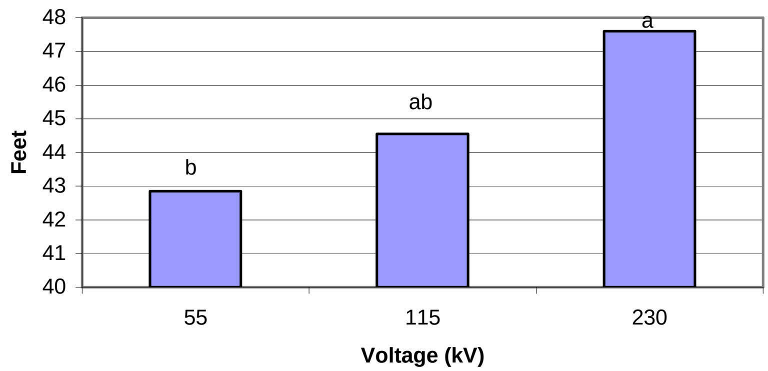
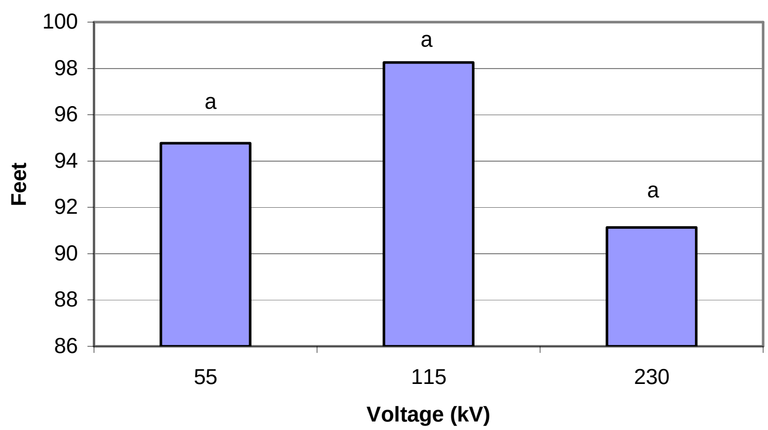


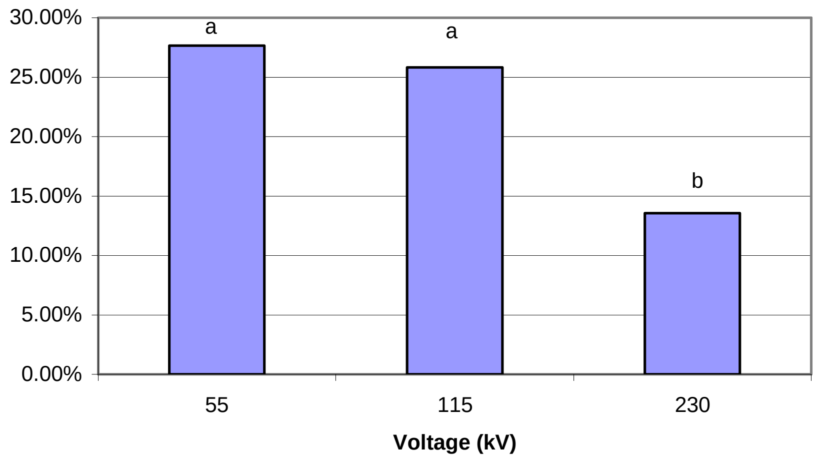
Exhibit 9-45
PSE Tree Height



Finding 9-22 Clear width and line height have not been used to the extent necessary to distinguish the tree risk on 115 kV lines from that faced on 55 kV.

It has been stated that a tree Risk Factor was calculated for each sample edge based on the found clear width, line height, tree height and tree density. The mean voltage class RF ratings are provided in *Exhibit 9-46*. The mean RF for 230 kV lines is significantly less than that of the 55 and 115 kV lines. The fact that no significant difference appears between the 55 and 115 kV voltage classes draws attention to the potential for a considerable negative impact on reliability by trees by affecting 115 kV lines. While both the clear width and line height for 115 kV lines are greater than those of 55 kV lines, ultimately, PSE has not used clear width or line height to the extent necessary to effectively manage the greater impact on system reliability for interruptions occurring on the 115 kV system.

Exhibit 9-46
Transmission Tree Risk Factor



To study the relationship between variables and tree-caused outage incidents it is necessary to segregate the data by voltage class and to express outage incidents by an equal unit, regardless of system miles. The voltage of lines was not directly identifiable from the outage reporting system. A solution was developed which involved PSE staff providing the voltage for the list of transmission lines. This information was used to create another table in the Access database. Querying the database, the number of tree-related outage incidents per year by voltage class was generated. This data was then transformed to express the average annual number of tree-caused outage events per 1,000 miles of line for each voltage class. It is reported as the annual incident frequency, F_{AI}. The results derived from data for 1998 through 2007 are presented in *Exhibit 9-47*.

Exhibit 9-47
Transmission Tree-related Outages
Annual Incident Frequency

Voltage (kV)	F_{AI} 1000 mi^{-1}
55	28.05
115	12.77
230	2.14

The correlation of the variables to the annual outage frequency was then examined. Results were not in line with expectations as no significant correlation was found for any variable. This failure would prevent the provision of a valid regression to predict outage events from field variables.

Right of Way Division

It has been mentioned previously that a considerable amount of the 55 and 115 kV system runs along roads. This results in one very small clear width and one quite large clear width. It was speculated that the average clear width obfuscates the actual tree risk. To test this premise, the data was parsed by identifying right of way and street sides for the 55 and 115 kV lines. As previously stated, this was done on the basis of assigning clear widths equal to or greater than 50 feet to street-side and the remainder to right of way side. This data was refined and corrected by use of the aerial photographs. All the variable means were rerun on the basis of this division.

The F_{AI} then needed to be calculated for the two different types, Street and ROW, for the 55 and 115 kV lines. Data from the outage investigations was used to establish that 8.46% of the outages have an offset of 50 feet or greater. It was assumed these outages are equally distributed between right of way side and street-side. The 8.46% of the F_{AI} was then pro-rated based on the number samples for each category (i.e. 55 kV street-side = 6/48). The resulting variable means are presented in *Exhibit 9-48*.

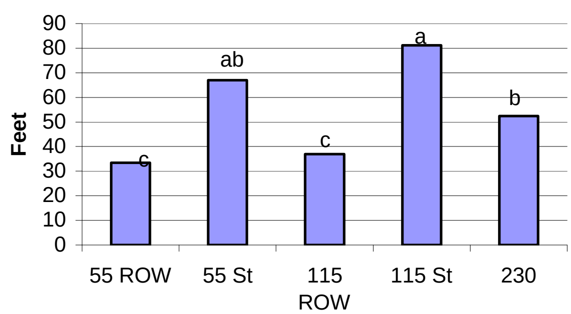
Exhibit 9-48
Key Variables for PSE Transmission
(At Found Sag)

Voltage (kV)	Clear Width	Line Height	Tree Height	Risk Factor	Tree Exposure	Trees mi^{-1} Edge	F_{AI} 1000 mi^{-1}
55 ROW	33	43	94	.3047	359,728	1,442	27.75
55 St	67	43	100	.0786	20,333	570	0.30
115 ROW	37	45	97	.2967	3,392,215	1,224	12.60
115 St	81	43	103	.0518	99,771	193	0.17
230	52	48	91	.1355	372,054	568	2.14

F_{AI} = annual incident frequency

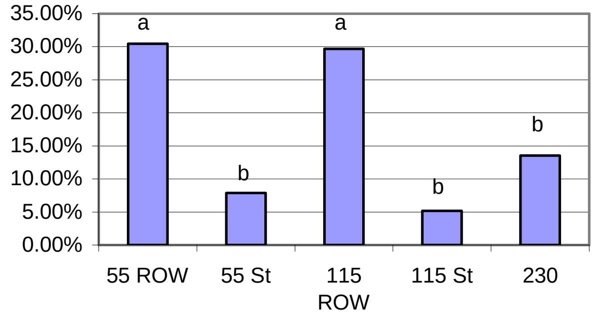
Graphs showing the means comparisons for a number of the variables were previously presented. The division of the right of way into right of way side and street-side, however, yields different results. The comparison of means for clear width (*Exhibit 9-49*) and Risk Factor (*Exhibit 9-50*) are provided. There are no significant differences in the means for line height and tree height segregated by voltage class and right of way side.

Exhibit 9-49
Transmission Clear Width



The clear widths between right of way side and street-side are found to be significantly different. The RF reflects this result (*Exhibit 9-50*) as the right of way side has a significantly greater risk rating than the street-side or the 230 kV lines.

Exhibit 9-50
Transmission Tree Risk Factor



The correlation of the variables to outage frequency was again tested. Two significant correlations were found: trees mi^{-1} edge and RF (*Exhibit 9-51*).

Exhibit 9-51
Variable Relation To Interruption Experience
(F_{AI} 1000 mi^{-1})

Variable (means)	Correlation Coefficient (r)	P(r=0)
Clear Width	-0.8238	0 .0864 ns
Line Height	-0.2760	0.6530 ns
Tree Height	-0.4114	0.4914 ns
Total Tree Exposure	0.2513	0.6835 ns
Trees mi^{-1} Edge	0.9172	0 .0282 *
Risk Factor	0.8878	0.0443 *

* significant - 95% level
** highly significant - 99% level
ns not significant

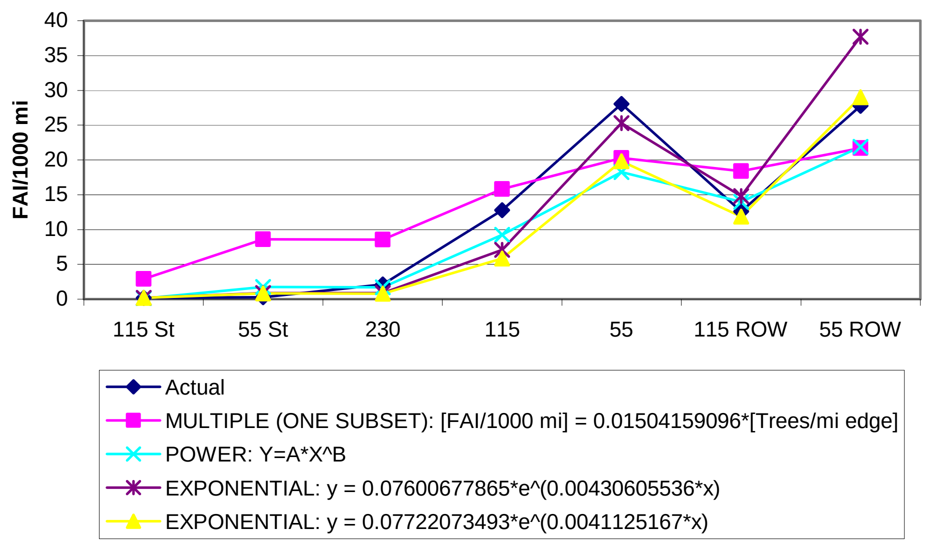
The lack of a significant correlation between F_{AI} and clear width and F_{AI} and line height indicates that any difference in outage experience between voltage classes cannot be positively attributed to the differences in right of way width or line height.

Finding 9-23 The annual tree incident frequency can be predicted from the extent of tree exposure per mile of right of way edge.

There is a very strong, significant correlation between F_{AI} and the number of trees per mile of right of way edge (*Exhibit 9-51*). The correlation co-efficient (r) of 0.9172 indicates that over 91% of the annual tree-related outage events can be explained by transmission line exposure to trees. Hence, actions that reduce the amount of tree exposure will have a very positive effect on reliability.

To better understand the relationship between annual outage incidents and tree exposure a regression was sought for F_{AI} 1000 miles^{-1} and trees mi^{-1} edge. Not knowing the nature of the relationship, various types of regression were run. The results were examined for the best fit to the actual outage experience and those results are presented in *Exhibit 9-52*.

Exhibit 9-52
Outages Based on Trees mi^{-1} Edge



The smallest residuals (variance of calculated values from actuals) were yielded by the exponential regression. The data set that excluded the mean overall values for 55 and 115 kV proved the best fit (yellow in *Exhibit 9-52*). The exponential regression is:

F_{AI} 1000 mi^{-1} = 0.07722073493*e^(0.0041125167* Trees mi^{-1} edge) (*Equation 1*)

For this regression, the coefficient of multiple determination, $r^2 = 0.9012$ and $P(0) = 0.0136$. That is, 0.9012 of the variation in F_{AI} 1000 mi^{-1} is explained by the regression and the probability that the null hypothesis is valid is 0.0136. Another way of stating this is that the regression has a chance of error of only 1.36%.

The above equation will permit forecasts of the resulting annual outage frequency following actions that reduce the extent of tree exposure.

Finding 9-24 The annual tree incident frequency can be predicted from the Risk Factor.

The second variable that is significantly correlated to F_{AI} 1000 mi^{-1} is RF (*Exhibit 9-51*). Given that trees mi^{-1} edge was found to have a significant correlation to F_{AI} 1000 mi^{-1}, this result is expected as the RF reflects both aspects of tree exposure, the number of trees and arc of exposure to line strikes. The correlation coefficient (r) is 0.8878 with 0.0443 chance of error.

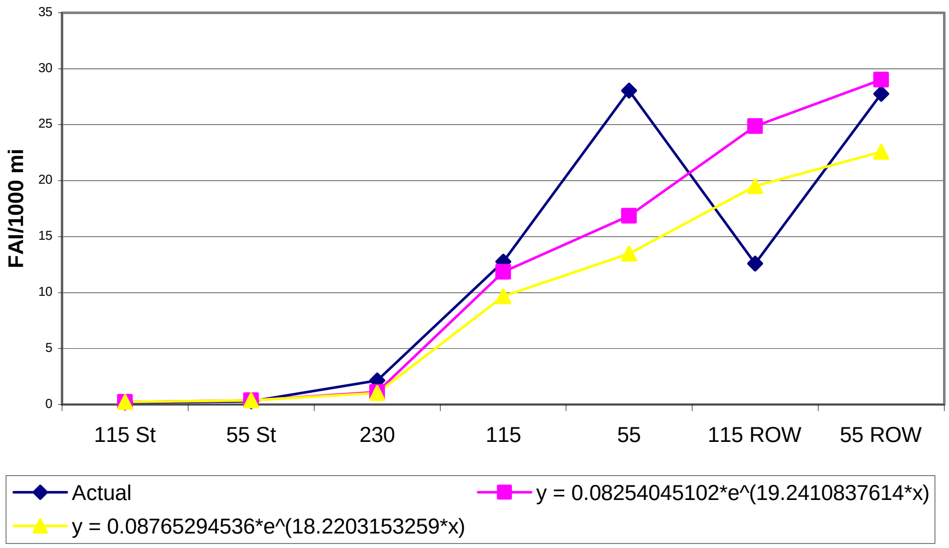
For easy reference, the RF ratings are provided in *Exhibit 9-53*.

Exhibit 9-53
Average Tree Risk Factor
At Found Sag

Voltage (kV)	Risk Factor	Multiple Means Test
55 ROW	.3047	A
55 St	.0786	B
115 ROW	.2967	A
115 St	.0518	B
230	.1355	B

To better define the relationship between RF and F_{AI} 1000 mi^{-1} a regression was sought. Past work in this area has established that the relationship is exponential in nature. A best fit to actual experience was sought comparing the use of seven data points, 55 ROW, 55 St, 55, 115 ROW, 115 St, 115, 230 with five data points, 55 ROW, 55 St, 115 ROW, 115 St, 230 (*Exhibit 9-54*). Using only the five data points provided the smallest residuals by a very narrow margin and a slightly better r^2 value. Consequently, the regressions produced by both data sets, which yielded highly significant results, could legitimately be used. However, to be consistent with the previous variable discussed, trees mi^{-1} edge, it is the regression produced from the 5 data point set that is presented here. The data points for 55 and 115 kV in the five-point set were subsequently calculated using the found regressions, shown in yellow in *Exhibit 9-52* and *Exhibit 9-54*.

Exhibit 9-54
Outages Based on Risk Factor
Exponential Regression



The exponential regression is:

F_{AI} 1000 mi^{-1} = 0.08765294536*e^(18.2203153259*RF) (*Equation 2*)

The regression coefficient of multiple determination, r^2 = 0.9559 and P(0) = 0.0040. That is 0.9559 of the variation in F_{AI} 1000 mi^{-1} is explained by the regression and the probability that the null hypothesis is valid is 0.0040. Another way of stating this is that the regression has a chance of error of only 0.40%.

This highly significant result provides confidence in the use of this regression to predict the reliability impact of various management decisions. The RF is derived from field measurable variables of clear width, line height, tree height and tree density. The work undertaken in this project has established the average tree density to be 272 trees per acre. The clear width, line height and adjacent tree height are easily measured in the field.

Regression Preference

Two regressions to predict expected outages have been provided. One requires the resulting trees mi^{-1} edge after an intervention and the other requires the resulting RF. Is one of these regressions superior?

Finding 9-25 The regression using trees mi^{-1} edge has the best fit to the outage frequency.

The regression for the RF has a slightly higher r^2 value with a lower probability of error than the regression for trees mi^{-1} edge. However, it is the regression using the trees mi^{-1} edge that has the lowest residuals (best fit to data). *Exhibit 9-55* shows that at low incidence of tree-caused outages RF has a better fit to the data but at higher levels and overall, the regression using trees mi^{-1} edge has a better fit as indicated by the smaller positive sum of the residual values.

Exhibit 9-55
Regression Fit to Data

	Outages 1000 mi^{-1} yr^{-1}		
	Means (1998-2007)	**RF**	**Trees mi^{-1} Edge**
115 St	0.17	0.23	0.17
55 St	0.30	0.37	0.81
230	2.14	1.03	0.80
115			
ROW	12.60	19.51	11.86
55 ROW	27.75	22.58	29.00
Total Residuals		**13.3142**	**3.8337**

If initiatives are to be undertaken to reduce tree-caused interruptions the greatest impact can be had by focusing on right of way segments, which currently have a high incidence of outages. Generally, the regression using trees mi^{-1} edge is the recommended algorithm for predicting the outcome of the intervention.

There is one exception. It is quite conceivable that PSE may choose to apply the findings of this work to the 230 kV system, where the outage incidence is already quite low. In that case the algorithm using the variable RF is a superior choice.

The use of the found regressions will be further discussed in the Recommendations & Operational Options section.

10. Historical Wind Data

While some tree-caused interruptions may occur with little or no stress loading on trees, the majority will occur when there is wind, ice or snow loading on trees. For the purposes of this work only wind loading is examined.

In the first attempt to obtain wind data, data was drawn from the National Climatic Data Center. The utility of this data was limited as reporting is necessary only for winds in excess of 50 knots, though there is some voluntary reporting for lower wind speeds. Secondly, there are multiple geographic units for the reporting, some of it based on counties but much of it based on reporting areas that have no direct relation to county boundaries. This makes it difficult to relate the wind events to the location of a tree-caused interruption.

Consequently, wind data was purchased by PSE from CompuWeather. The data provides maximum wind speeds for all days between January 1, 1998 and December 31, 2007 with winds equal to or greater than 15 mph. The data is comprised of approximately 33,000 records. Data was obtained from nine airfields: Bellingham International (Whatcom), Friday Harbor (San Juan), Everett Snohomish (Snohomish), Seattle Tacoma International (King), Tacoma Narrows (Pierce), Bremerton (Kitsap), Olympia (Thurston), Stampede Pass (King/Kittitas) and Ellensburg Bowers (Kittitas).

For Jefferson, Island and Skagit counties there either were no airfields or the data set was considerably less than the ten-year period desired. It was considered that data from Bremerton (Kitsap County) would adequately represent the conditions for Jefferson County. Island County is covered by data from Friday Harbor (San Juan County). Skagit County is considered covered by the data from Bellingham International (Whatcom County).

There were some limitations in the wind data provided. There was no reporting from Ellensburg Bowers' airfield from January through September 1998. This lack is immaterial as there were no tree-related transmission outages in Kittitas County through this period. No data is available for Friday Harbor for 1998. To compensate for this, a correlation between the data from Bellingham International and Friday Harbor was tested. A highly significant correlation, with an r-value of 0.6916, was found. The wind speeds experienced at Bellingham International were applied to Friday Harbor for 1998.

A summary of the transmission tree-caused outages experienced from 1998 through 2007 by county is presented in *Exhibit 10-56*. This data was examined in a number of ways to assess the relationship between tree-caused interruptions and wind speed.

Exhibit 10-56
1998-2007 Transmission Tree-caused Outages by County

County	55 kV	115 kV	230 kV	Total
Island		32		32
Jefferson	1	2		3
King	26	59	1	86
Kitsap		53		53
Kittitas		2	2	4
Pierce	2	17	4	23
Skagit	3			3
Snohomish		17		17
Thurston	6	12		18
Whatcom	7	19		26
Total	45	213	7	265

Exhibit 10-57
Scatter Diagram for Transmission Interruptions 1998-2007
Based on Wind Speed

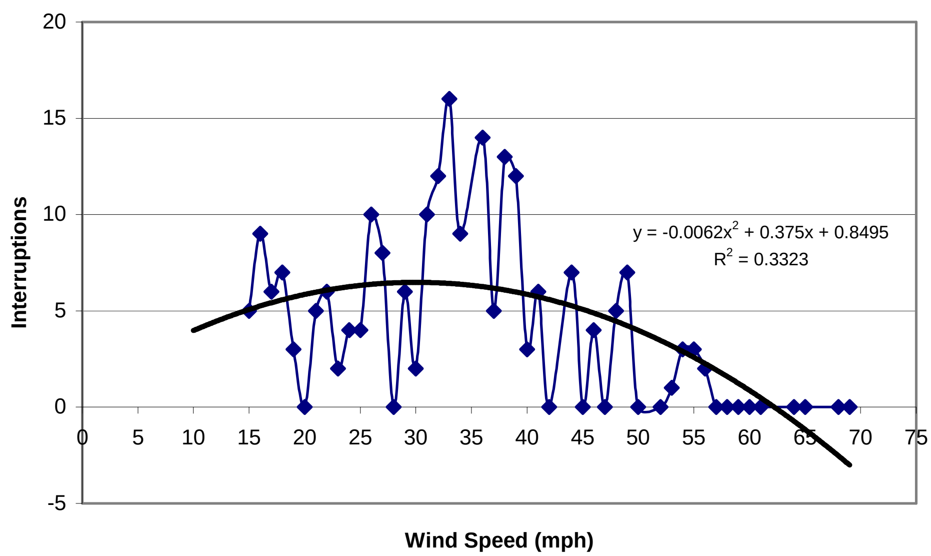


Exhibit 10-58
Weibull Distribution for Transmission Outages
1998-2007

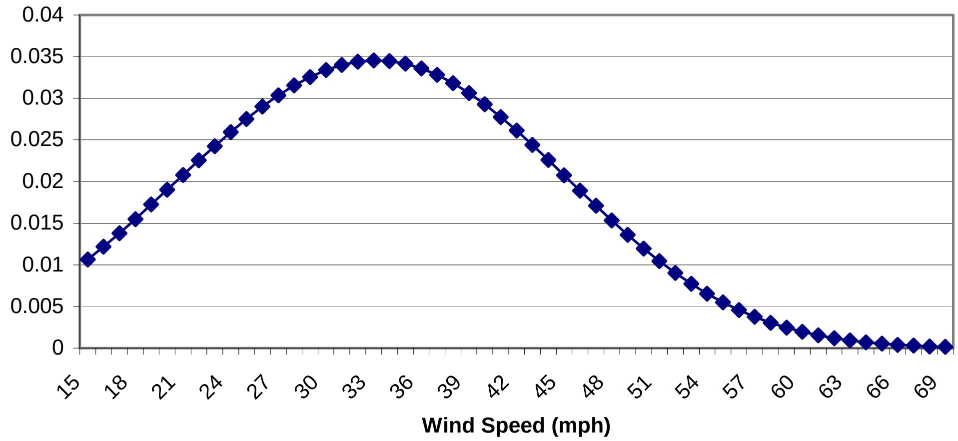
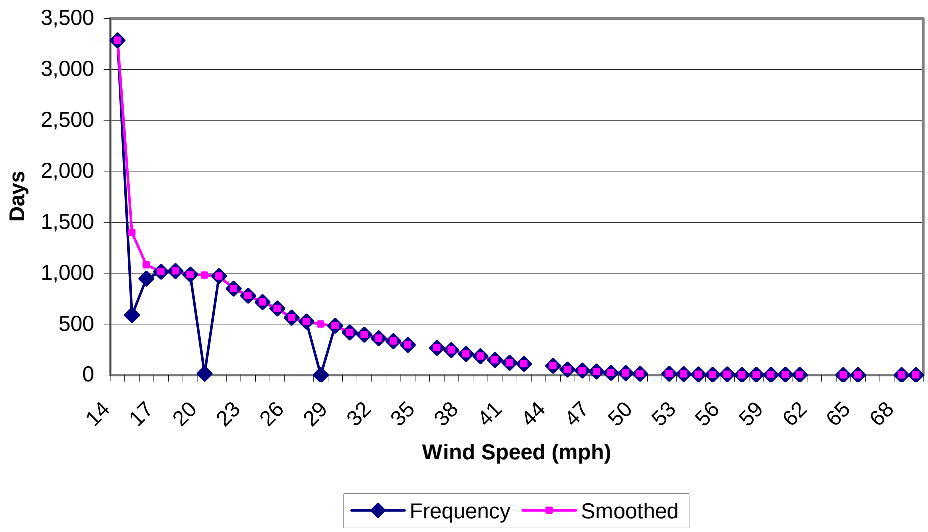


Exhibit 10-59
PSE Service Territory 10 Year Wind Frequency



Note: Y-axis is number of days when winds of a specific speed were experienced

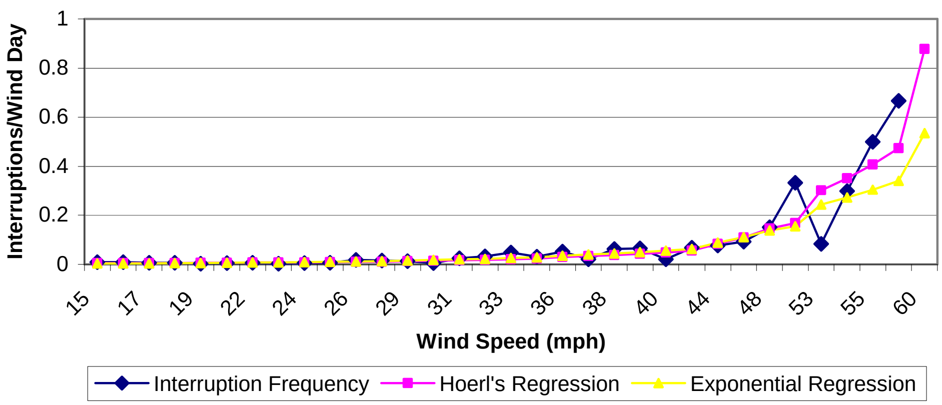
Finding 10-26 The incidence of high wind intensities (>45 mph) is low but when they do occur the rate of tree failures is high (*Exhibit 10-59*, *Exhibit 10-60*).

To begin an examination of the last ten years of wind impacts a scatter plot of the transmission outages was first prepared (*Exhibit 10-57*). The scatter diagram reveals what appears to be a normal distribution of outage incidents. The distribution of the data points indicates a quadratic equation is required to model interruptions based on wind speed. A quadratic trend line was added using the options available in MS Excel. However, this trend line lacks accuracy as it seriously underestimates the amplitude of the curve and thereby, the outage distribution. Consequently, a Weibull distribution, which offers considerably more flexibility in fitting curves, was applied (*Exhibit 10-58*). The Weibull distribution is fitted to the data by adjusting the variables α and β.

There are two key observations that emerge from *Exhibit 10-57*: first, at high wind levels of ≥ 60 mph outage events are not being added; second that the peak of tree-caused outages occurs at winds between 30 to 40 mph. It is possible that the perception of outage events not being added when winds exceed 60 mph is simply due to the relatively low frequency of such high intensity wind events. On the other hand, winds of 30 to 40 mph may be both damaging and relatively common. Such speculation is confirmed by graphing the ten-year history of the frequency of experienced wind intensities (*Exhibit 10-59*).

In further analysis the wind data was sorted to provide the number of days of specific wind intensities. It was then possible to calculate the interruption frequency for each day of exposure to a specific wind level. The data is presented in *Exhibit 10-60*. Statistical testing found two forms of regression, Exponential and Hoerl's, which yielded high r^2 values of 0.8426 and 0.8617 respectively, both with a probability of error of 0.0000. The output of these two regression algorithms is also shown in *Exhibit 10-60*. When the regressions are applied to winds over 56 mph both yield a mounting wall of interruptions. There is no method of determining from the ten-year wind and outage data what the worst-case interruption scenario might be.

Exhibit 10-60
Interruption Frequency



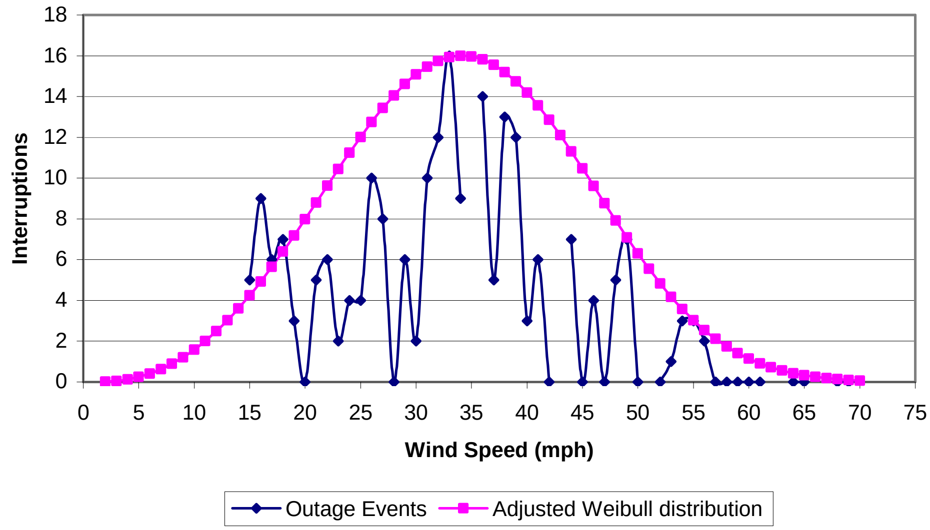
The ten-year data set of wind speeds and outage events is a very rich data set and yet is limited to the conditions experienced from 1998 through 2007. Hence, to extend the data beyond intensities experienced we use statistical modeling, specifically, the Hoerl's regression. The regression is approaching an exponential limit at 60 mph. The number of interruptions forecast by the regression at winds of 70 mph is about 5 times higher than at 60 mph. We have no way of knowing whether this is correct or whether tree-caused interruptions top out at some lower number.

There is some research that suggests tree damage does top out.[116] In a study examining wind gust effects on trees in the aftermath of hurricane Hugo, it was reported that:

- Tree "damage was nil below gust speeds of 60 km/hr"
- "Damage (defoliation, minor branch breakage, major branch breakage, trunk snap, and tipping) began at gust speeds of about 60 km/hr, increased rapidly with gust speeds to 130 km/hr, and although highly variable, did not worsen at higher gust speeds."
- "Strength of wood in the branches and bole makes a relatively minor contribution to resistance to breakage at high wind speeds."

The referenced work, subsequent to hurricane Hugo, deals with wind gusts, whereas this work uses sustained winds. There appears to be some agreement between the hurricane Hugo findings and PSE's outage experience at high winds. However, there is a sharp contrast in Francis and Gillespie's finding of no tree damage below 60 km/hr and PSE's experience of the most tree-caused transmission outages having occurred at winds of 30 to 40 mph.

Exhibit 10-61
Modeling Transmission Interruptions Based On Wind Speed
1998-2007



The Weibull distribution is a probability density distribution. The area under the graph=1. Consequently, the y-axis in *Exhibit 10-58* is not the number of interruptions. Be applying a constant, derived from relating the Weibull term at the interruption maximum to the number of interruptions produces *Exhibit 10-61* where the y-axis is interruptions. Considering the impact of transmission outage events, the Weibull distribution was set to the high side so as not to underestimate the number of outages.

Testing the correlation between the adjusted Weibull values and interruptions yields a correlation coefficient of 0.652 with a probability of error of 0.0000. While the result is very highly significant, caution is in order given r-value. As has been stated the adjusted Weibull values will tend to overestimate the outages. The r-value could be improved upon by running iterations of the Weibull distribution adjusting the constant applied.

The transmission outage experience over the last ten years can be modeled using the following algorithm (stated in MS Excel terms):

Interruptions=Weibull(WS,3.3,37,false)*463.25, where WS is wind speed. (*Equation 3*)

This algorithm is, however, backward looking. It produces a long-term (10-year) interruption expectation based on an assumption of a similar frequency of wind events as the last ten-year period. Such an assumption may be reasonable but the algorithm is limited in that it does not accommodate calculation of expected interruptions for a single wind event nor can it incorporate a different distribution of wind intensities.

The algorithm is based on the conditions that existed over the time period of 1998 through 2007. These conditions include the standards applied to transmission lines and the resulting size of the utility forest and the range of weather conditions. The algorithm is useful only if the status quo conditions and practices are maintained. Clearly, the intent of this work being to identify actions that decrease tree-related outages or storm damage, it can reasonably be expected that the status quo will not be maintained. However, should the regulator or the public prevent PSE from undertaking actions which decrease the size of the utility forest, then PSE can use the algorithm to predict the next ten years of customer minutes of outages arising from the transmission system.

To convert the outage incidents into customer minutes lost it is necessary to calculate average customer minutes per outage. Based on the 1998 through 2007 transmission outage data, the average customer minutes per transmission outage event are 1,219,714.

Modeling Tree-caused Outages In Response to Wind

If standards impacting the size of the utility forest are to change, another means of analysis and modeling that is responsive to this change is required. Ideally the model would have the capacity to forecast long-term impact of changes in vegetation management standards and the interruption expectations for a single storm event.

Modeling long-term impacts will be addressed first as analysis addressing long-term forecasts has already been presented. The Weibull adjusted Interruptions are divided by the tree exposure (DT) and the mean transmission system tree risk to produce the 10-year tree failure rates (*Exhibit 10-62*).

Conversely, calculating the expected outage events requires the inputs of the tree failure rate at the specified wind speed, the number of danger trees (DT) and system mean Risk Factor (RF). The algorithm is:

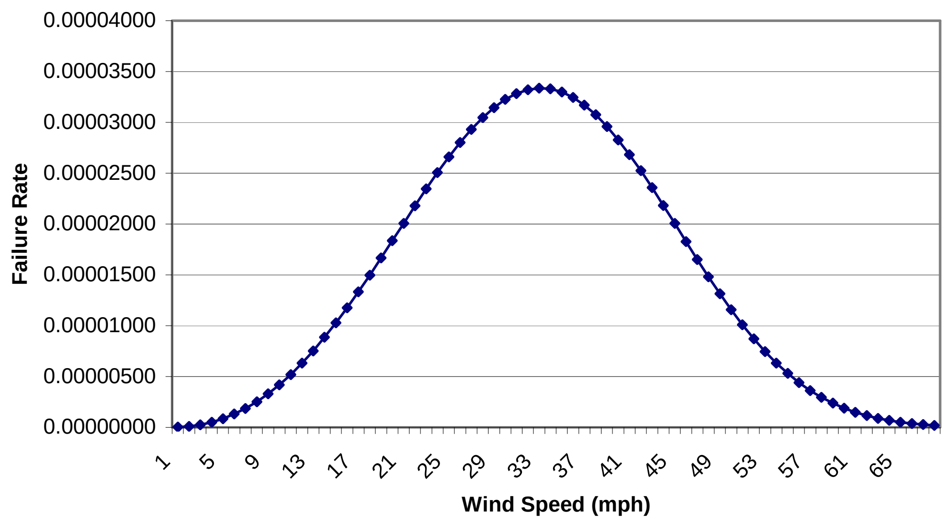
Expected Interruptions = DT*10-year tree failure rate @ WS*0.5*mean RF; (*Equation 4*)
where DT is total exposure to danger trees, RF is Risk Factor, WS is wind speed.

An Excel file with the calculated tree failure rates at wind speeds between 15 to 69 mph will be provided.

This approach to calculating expected outages is responsive to changes in vegetation management standards. Changes in vegetation management standards will influence both the RF and the amount of tree exposure (DT). As the tree failure rate is dependent on the wind speed and the tree species and their composition within the utility forest, changes in vegetation management standards are unlikely to affect the tree failure rate. On a system where hazard trees constituted the major cause of tree-related outages, one would expect the tree failure rate to be susceptible to change. This is not the case on PSE's system due to the Tree Watch program. Further, the data indicates that 68% of the trees causing outages are in good or fair health and maximum of only 20% of outages that might be avoidable with an even more rigorous hazard tree program (*Finding 6-12*). Tree failure rates were derived from the 265 transmission outage events that occurred from 1998 through 2007. The use of the over 30,000 distribution outage statistics over the same time frame would refine the tree failures but cannot be computed at this time because the extent of tree exposure along the distribution system is unknown.

Once the new values, resulting from a change in vegetation management standards, for RF and DT are calculated, the new profile of expected outage events over the next ten years can be calculated.

Exhibit 10-62
PSE Transmission 10-Year Tree Failure Rate

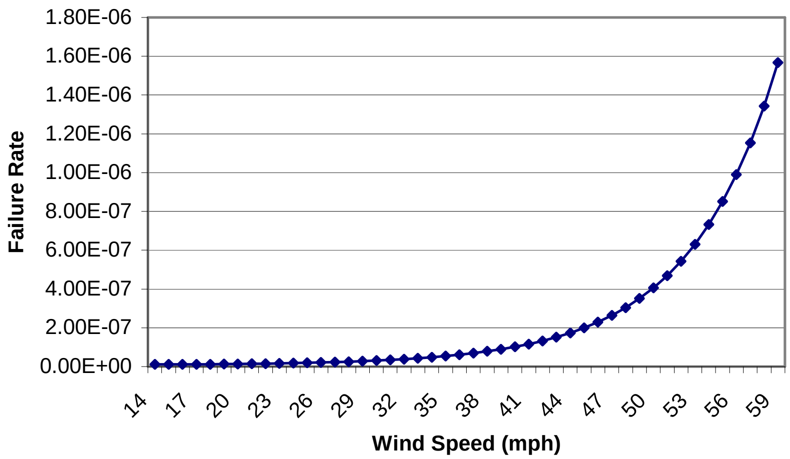


In developing the model to predict the impact of a single storm of a specific intensity the Hoerl's regression previously presented in *Exhibit 10-60*, which provides a smoothed interruption frequency per wind intensity day, is divided by the total tree exposure (DT) and the mean transmission system tree risk to provide the tree failure rate (*Exhibit 10-63*). The failure rates presented in *Exhibit 10-63* will also be provided in an MS Excel file.

To calculate the expected transmission interruptions for a specific wind storm intensity:

Expected Interruptions = DT*tree failure rate @ WS*0.5*mean RF; (*Equation 5*)
where DT is total exposure to danger trees, RF is Risk Factor, WS is wind speed.

Exhibit 10-63
PSE Transmission Tree Failure Rate



To illustrate, consider the following example. Assume you wish to know the number of transmission interruptions that can be expected for winds at 40 mph. Currently:

DT = 4,219,053 Mean RF = 22.73% Failure rate @ 40 mph = 1.016E-07

Expected Interruptions = 4,219,053*.0000001016*0.2273*0.5 = 0.0487

1/0.0487 = 20.5

Hence, one transmission outage is expected for about every 21 days of exposure to 40 mph winds.

Summary of Wind Data Relationship to Outage Experience

It has been found that over the last ten years the frequency of relatively low winds events is much higher than high wind events (*Exhibit 10-59*). It has also been established that most of the tree-caused outages occurred at mid-range wind intensities of 30-40 mph (*Exhibit 10-61*). The incidence of outages experienced increases on high wind intensity days (*Exhibit 10-60*). Accordingly, tree failure rates increase with wind intensity (*Exhibit 10-63*). The data suggests that the tree failure rate will top out at some wind intensity level but precisely where that point is, is unknown. In light of these observations, questions arise about how reductions in outages arising from intervention will be related to wind events. This will be explored with the operational options in the next section.

11. Operational Options to Reduce Tree-related Outages

It was statistically established that of all the field variables examined only the trees mi^{-1} edge and RF, both measures of tree exposure, are significantly correlated to the annual interruption frequency (*Finding 9-23, Finding 9-24*). The r-values were 0.92 and 0.89, respectively. Such a strong relationship as exists between tree exposure and outage experience is not likely to be found in any other area, with the possible exception of system protection in the form of redundancy. Consequently, substantially improving reliability will necessarily entail vegetation management and specifically, managing the extent of tree exposure.

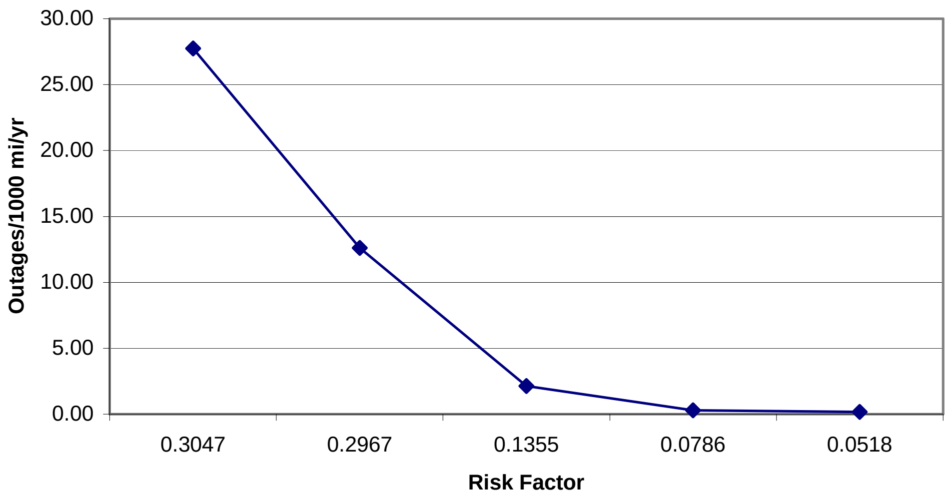
There are three variables that affect the extent of tree exposure: line height, clear width and tree height. To manage tree-related outages one or more of these variables will need to be manipulated. As it is not realistic to think that the tree risk can be eliminated, the question becomes what amount of tree risk are the utility, the regulator and the public willing to accept? It is tempting to try to establish a standard line height or clear width for each voltage class. However, neither of these variables nor the tree height was significantly correlated to the outage experience. This informs us that one or more of the variables are so variable between sample locations as to thwart a significant correlation. The two identified in *Exhibit 9-51* are tree height and line height. That there is variability in tree height is readily understood. It also informs us that failing to assess tree risk on a local basis via measures of tree exposure will unnecessarily increase the cost of reliability improvement.

Tolerated Risk

An essential element of this project is the identification of valid measures of tree risk and to quantify what the current level of risk is. Risk Factor and trees mi^{-1} edge have been found to be valid measures of tree risk due to their relationship to the outage experience (*Exhibit 9-51*). The baseline RF values for the voltage class and sides are presented in *Exhibit 9-53*. The status quo conditions for trees mi^{-1} edge are found in *Exhibit 9-48*. The current outage experience as expressed by the found regressions for RF and trees mi^{-1} edge is found in *Exhibit 9-55*. As the regressions smooth the data, the beginning values (prior to intervention) produced by the regression, rather than the actual values, should be used as the basis of comparison.

The elimination of all tree risk not being a feasible option due to costs, environmental and stakeholder concerns, PSE will need to determine what level of tree risk is tolerable. This is a decision that PSE in conjunction with its stakeholders will need to make. *Exhibit 11-64*, a graph of the information provided in *Exhibit 9-53*, serves as a guide to RF ratings that will result in reliability improvements.

Exhibit 11-64
Relationship of Risk Factor to Outages



An approach to setting tolerable tree risk with its justification will be forwarded here. It will serve as a means of illustrating how the reliability impact of changes in vegetation management practices can be quantified.

Through the field sampling and the derivation of the RF for each edge sampled it was found that there are right of way edges where the RF appears anomalous in that it greatly exceeds the mean voltage class RF (see PSE Field Variables in Appendix). Some of the anomalously high Risk Factors may arise due to adjacent trees, which are considerably taller than the mean tree height. Where that is not the case, the high risk must arise from either a clear width or line height that is well below the mean. Were it not for the street-side line segments that serve to increase the mean clear width, it would be definitive, based on the means alone, that there is an established precedence for greater clear widths and line heights.

The quantification of the current tree risk presented in this work is new to PSE. As such, it is difficult for PSE to determine what constitutes a reasonable, tolerable risk. Further, some guidance regarding the sensitivity of measures of tree risk to changes in the variables would be useful. Given these considerations, in conjunction with the observation of line segments of anomalous high tree risk, we propose that PSE identify line segments where the tree exposure risk exceeds the mean tree exposure risk for the voltage class and undertake interventions that will reduce the site tree exposure risk to the voltage class mean tree exposure risk. At this point, neither the cost of such an undertaking nor the feasibility from a landowner and public relations perspective, are known. However, it establishes a beginning point for evaluation. The reliability benefits of this approach are detailed in Example 1, appearing later in this section.

Operational Options

The variables involved in the measures of tree exposure are line height, clear width, tree height and tree density. These are used in the derivation of the RF. However, tree density is not a variable that can be controlled. Rather, it is a reflection of the species characteristics, soil types and fertility and climatic conditions. Line height, tree height and clear width can be modified and doing so changes tree exposure.

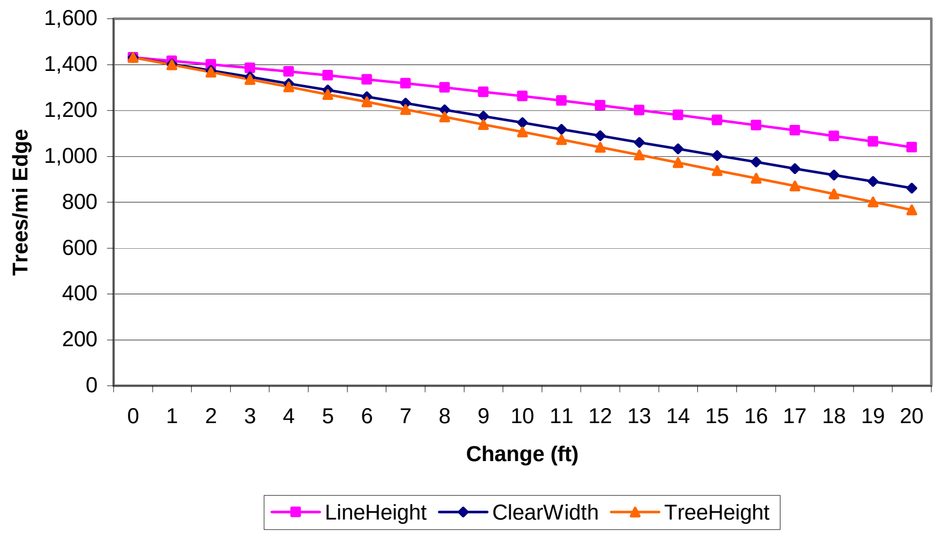
Decreasing tree exposure benefits reliability both during storm and non-storm conditions. Increasing the clear width entails the removal of trees. Provided that any re-emergent brush is controlled, it provides an enduring reliability benefit. The extent of the benefit will erode slightly over time based on the increase in height of the adjacent danger trees. In using the tree height variable, trees undergo crown reduction through pruning. The response to the pruning will vary with the tree species pruned. However, where the crown reduction is severe and well into old wood, generally, regrowth will be non-existent. Where crown reduction removes only a few years growth, regrowth is likely and the pruning will need to be repeated at intervals. The persistence of the reliability benefit derived from adjusting line height depends on the rate of change in the height of the adjacent danger trees.

Finding 11-27 The change in tree exposure per a unit change in a variable (clear width, line height, tree height) is variable both within and between variables.

Is the change in tree exposure the same for each unit of change in the variable? *Exhibit 11-65* and *Exhibit 11-66* provide the answer as derived from 55 kV on the narrow or right of way side. Changes in line height produce the least change in tree exposure measured both as trees mi^{-1} and RF.

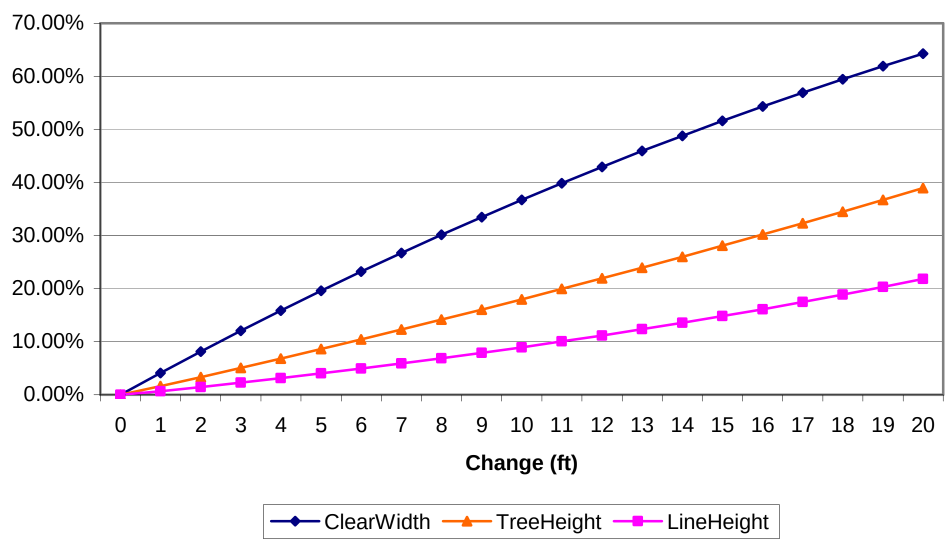
Adjusting line height is not likely to be a viable alternative for the 55 and 115 kV lines. There may be circumstances along the 230 kV system where adjusting line height is an economical approach to reducing tree risk. For line height adjustments to yield a competitive return in improved reliability for each dollar invested generally requires that the existing clear width is approximately ½ the tree height (see *Exhibit 11-67*) and/or that the spread between tree height and line height is not great (~ 20 ft).

Exhibit 11-65
Sensitivity of Tree Exposure to Change in Variable



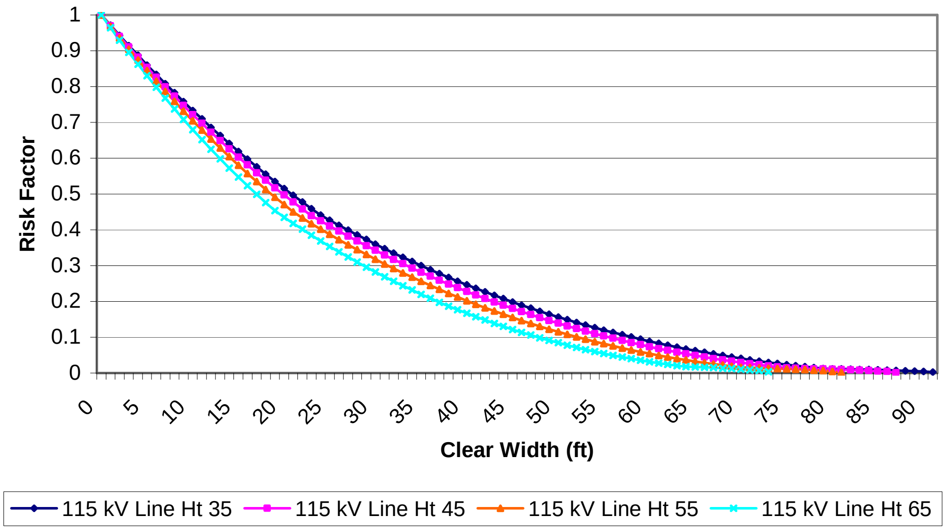
55 kV ROW side

Exhibit 11-66
RF Sensitivity to Variable Change



55 kV ROW side

Exhibit 11-67
Line Strike Probability
Sensitivity to Line Height



To further illustrate the sensitivity of RF to changes in the variables, we examine a change of 10 feet in each of the variables from the mean values for 115 kV. The result is provided in *Exhibit 11-68*.

Exhibit 11-68
Risk Factor Sensitivity to Variable Δ

		Changed Variable			
115 kV	**Mean**	**Clear Width**	**Line Height**	**Tree Height**	**Improvement**
Clear Width	44	54	44	44	**41.79%**
Line Height	45	45	55	45	**13.32%**
Tree Height	98	98	98	88	**25.95%**
Risk Factor	0.1892	0.1101	0.1640	0.1401	

Generally, adjustments in clear width yield the largest change in tree risk. Consequently, in illustrating the potential for reliability improvement, it will be the clear width variable that is adjusted.

Example 1

For the first example, the system wide impact of identifying and addressing line segments of tree risk exceeding the voltage class mean risk is examined. In this case, the 55 and 115 kV lines have not been segmented into right of way and street-side. The reliability improvement possible is shown in *Exhibit 11-69*. Across the transmission system reliability is expected to improve 37%. Underlying this forecast is the assumption that the sampling has accurately captured the ratio of line segments where the RF exceeds the voltage class mean RF. As the influence of wind is not included, a further assumption is that wind events experienced going forward occur at the same frequency as that experienced from 1998 through 2007.

A quick visual guide to what a change from a system RF of 22.73% to 14.29% means can be obtained by looking at *Exhibit 11-64*.

Exhibit 11-69
Forecasting Reliability Improvement
For Reducing Site RF's to Voltage Class Mean RF

	Tree Risk		Tree Risk for Records with RF=<Mean RF		Tree Risk for Records with RF>Mean RF			Tree Risk After Work	
	No. of Records	Ave. Risk Factor (%)	No. of Records	Ave. Risk Factor (%)	No. of Records	Ave. Risk Factor (%)	Risk Factor After Work (%)	Ave. Risk Factor (%)	Improvement (Weighted Average)
55 kV	48	27.64	25	9.70	23	47.14	27.64%	18.30	33.80%
115 kV	108	25.81	60	8.84	48	47.02	25.81%	16.39	36.52%
230 kV	62	13.55	38	3.77	24	29.02	13.55%	7.55	44.23%
System	218	22.73						14.29	37.10%

Exhibit 11-70
Finding Mean Variable Adjustment for Intervention

	Ave. Risk Factor	Closest From OCWC	Clear Width Before	Clear Width After	Line Height	Tree Height
55 kV	18.30%	17.94%	38	44	43	95
115 kV	16.39%	16.30%	44	47	45	98
230 kV	7.55%	7.40%	52	54	48	91
System	14.29%	14.13%				

The closest possible fit for the new RF in the column headed Tree Risk After Work in *Exhibit 11-69* is sought in the Optimal Clear Width Calculator (OCWC) retaining the values for line height and tree height. For the closest RF the clear width is recorded for the voltage class (*Exhibit 11-70*).

Using the mean clear widths after intervention in *Exhibit 11-70* the total tree exposure (DT) after intervention can be calculated. It is 3,900,168 trees. This is a reduction of 318,885 trees (4,219,053-3,900,168).

With the derivation of the new values for system RF and the amount of system tree exposure, or danger trees, the algorithms set out in *Equation 4* and *Equation 5* can be applied to a specific wind speed or to a range of wind values. By applying the algorithms to a range of wind values, the impact of the intervention on expected outages based on wind speed and the outages expected over ten years of mean wind values can be compared to the status quo.

The algorithm:

Expected Interruptions = DT*10-year tree failure rate @ WS*0.5*mean RF (*Equation 4*)
produces *Exhibit 11-71*. It assumes a similar wind distribution as that experienced over the period of 1998 through 2007. The difference in expected interruptions between before and after intervention is a 42.5% reduction. The result falls within the range of improvement shown in *Exhibit 11-69*.

It is difficult to assess which approach produces a more accurate result. In using the RF to determine the extent of reliability improvement arising from reducing the RF to the voltage class mean for all line segments where the RF is currently greater than the voltage class mean, a level of detail permitting the weighting of results is available. On the other hand, it could be argued that in using the above algorithm (*Equation 4*), which derives from a 10-year outage history for the transmission system, that the ratio of high tree risk segments to low tree risk segments is reflected in the data. The algorithm (*Equation 4*) incorporates the variable of wind, whereas the use of RF is based on mean wind conditions for the outage data. It was previously established that the tree exposure provided a better fit to the outage experience (*Finding 9-25*) and consequently, we can place more confidence in the estimate of a 42.5% outage reduction.

The algorithm:

Expected Interruptions = DT*tree failure rate @ WS*0.5*mean RF; (*Equation 5*)
produces *Exhibit 11-72*.

In *Exhibit 11-72* one observes that there is a substantial benefit to the proposed intervention at high wind speeds. The benefit is actually a uniform 42.5% reduction at all wind speeds. The benefit simply becomes more apparent at higher wind speeds, where the number of interruptions is greater.

Exhibit 11-71
10 Year Outage Expectations
Before and After Intervention

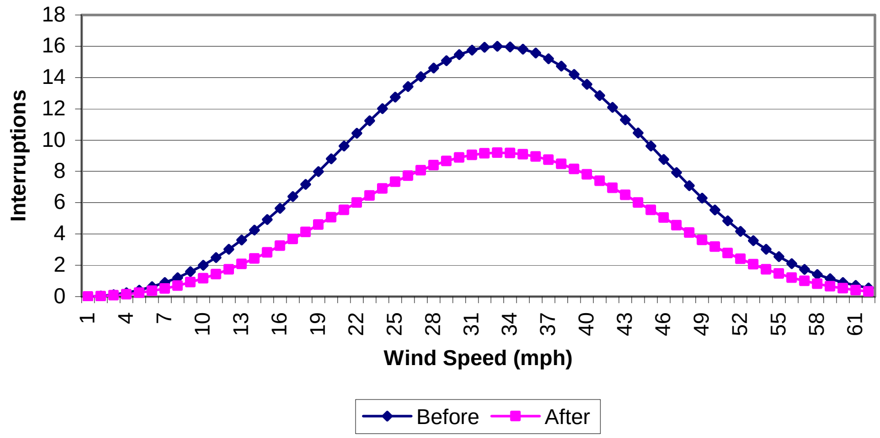
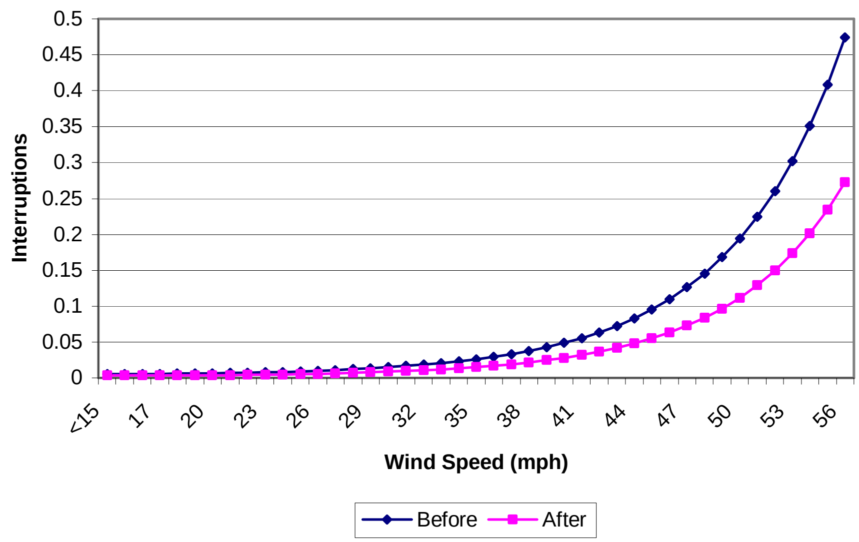


Exhibit 11-72
Outages per Wind Intensity Event
Before and After Intervention



Having established a process to assess the reliability benefit of a contemplated intervention, we need to add costs to be able to compare the merits of multiple options. The cost can be derived from PSE's unit cost per removal (of hazard trees) times the change in system tree exposure, keeping in mind these will be large removals. If an annual patrol for hazard trees is not the standard practice, the cost of such patrols should be added for 3 to 5 years following widening, as trees that were previously interior to the forest will be somewhat unstable as edge trees. Until the edge trees stabilize, their failure rate will be greater than that used in the calculations. If this higher failure rate is not offset by the reduction in the arc of line exposure, there is a possibility that tree-caused outages may increase in the short term.

Depending on the variable adjusted to achieve reductions in tree exposure, the benefit may be enduring and constitute a right of way upgrade. As trees capable of interfering with the transmission of electricity are a liability to a utility, it can be argued that (permanent) reductions in that liability should be treated as capital improvements the same as actions which increase asset value.

Example 2

It has been identified that roadside 55 and 115 kV lines commonly have very restricted clear widths on one side (*Exhibit 9-49*) that are significantly different from other clear widths. PSE may wish to assess what might be done to reduce tree-related interruptions on the 115 kV lines.

Once again using the clear width variable, which averages 37 feet for 115 kV ROW side, PSE can assess the reliability impact of increasing clear width on these line segments such that the average clear width becomes 47 feet. The model provided to PSE will reveal such a change in clear width results in the trees mi^{-1} edge being reduced from 1209 to 965. Applying *Equation 1*:

F_{AI} 1000 mi^{-1} = 0.07722073493*e^(0.0041125167* Trees mi^{-1} edge) (*Equation 1*)
to both of these values provides F_{AI} 1000 mi^{-1} of 11.15 and 4.08.

The consequence of increasing clear width along 115 kV ROW side to average 47 feet is reliability of this component of the 115 kV system will be improved 63%. The impact on transmission system reliability can also be calculated to be an improvement of 47%. As no wind variable exists in *Equation 1* the assumption underlying the change in reliability is that future wind experience matches the winds experienced over the outage history of 1998 to 2007.

Costs can be estimated by calculating the number of trees to be removed. That is:

(1209 trees mi^{-1} edge – 965 trees mi^{-1} edge)*2 edges*1386 mi of 115 kV ROW = 676,368 trees.

To find the impact of this action on SAIDI:

- Total current system F_{AI} 1000 mi^{-1} produced by the regression for trees mi^{-1} edge (*Equation 1*) is 41.23

- Total system F_{AI} 1000 mi^{-1} produced by the regression for trees mi^{-1} edge (*Equation 1*) after the intervention is 34.16
- Current system F_{AI} is 20.37
- System F_{AI} after the intervention is 9.59
- Average customer minutes per transmission interruption = 1,219,714

The reduction of customer minutes used in calculating SAIDI is:
(System F_{AI} before intervention - System F_{AI} after intervention)* 1,219,714 min
= (20.37 – 9.59) * 1,219,714 min
= 13,148,517 min

Example 3

While there are many permutations available for forecasting the reliability impact of considered actions one needs presentation to illustrate a change in form of the algorithms *Equation 1* and *Equation 2*. *Equation 1* can be rewritten in the form

Trees mi^{-1} edge=[$\log_e$ (F_{AI} 1000 mi^{-1}/0.07722073493)]/0.0041125167.

Equation 2 can be rewritten in the form

RF=[$\log_e$ (F_{AI} 1000 mi^{-1}/ 0.08765294536)]/ 18.2203153259.

This is how these algorithms can be useful. Let us assume that the regulator directs PSE to take such action as necessary so that there will be no more than 1 tree-related outage incident on the 230 kV system in 10 years.

First, this expectation needs to be stated as F_{AI} 1000 mi^{-1}. It is 0.31 (1000 mi/327.8 mi*1 incident/10 years). Then,

Trees mi^{-1} edge =Ln(0.31/0.07722073493)/0.0041125167

=338

To achieve the target reliability along the 230 kV system, trees mi^{-1} edge need to be reduced from the current mean of 584 to 338. The closest clear width, which achieves this exposure reduction, is 63 feet. Hence, the target reliability can be attained by increasing the current mean 230 kV clear width of 52 feet to a mean of 63 feet.

The cost for the increase in clear width is:
2 sides*(63 ft – 52 ft)/8.25 ft = 2.67 Ac/mi

2.67 Ac/mi*328 mi*0.699 forested edge = 612 Ac
612 Ac*272 trees/Ac = 166,464 trees

Cost = 166,464 trees * unit cost of removal + cost of additional patrols, landowner permissions, etc. – restoration costs avoided.

The target reliability could also be achieved by increasing line height from a mean of 48 feet to 62 feet. Line height is measured at the maximum sag position or lowest ground clearance point.

In section Regression Preference it was stated that for the 230 kV system the regression using RF is the superior choice, having a better fit to outage experience. Determining the number of trees affected by the considered intervention is a multi-step process requiring access to the Optimal Clear Width Calculator and is not presented here as the process was covered in Example 1. The calculation of the new mean RF to achieve no more than 1 outage in 10 years follows.

RF = Ln(0.31/ 0.08765294536)/ 18.2203153259
= 0.0693

The benefit in using the RF is that it requires site measurement of the variables line height, tree height and clear width and the derivation of the site RF to assess not only if but how much work needs to be done. Should the site RF fall below the requirement of 0.0693, no work is necessary. This is not the case outlined above for trees mi^{-1} edge, where any clear width of less than 63 feet would be increased to that level without regard to the height of adjacent trees.

12. Conclusions & Recommendations

The first element of this project was an audit of PSE's vegetation management program. The findings and conclusions for this element were presented in Section 4, Audit Findings & Conclusions. The key findings are *Finding 4-6*, that PSE's service interruption experience is driven by trees (*Exhibit 3-9*); *Finding 4-9* that a better understanding of tree exposure risk is required; *Finding 4-10* that PSE's rate of tree-caused interruptions is not due to a sub-standard vegetation management program.

Finding 4-9 would logically lead to a recommendation to obtain a better understanding of tree exposure risk. This was anticipated and the project protocol was designed accordingly. The implied recommendation is fully satisfied by the work presented in sections 7 through 11.

In a review of outage data it was found that 90-95% of system (transmission and distribution) tree-related interruptions arise from tree in-falls. Clearly, obtaining a meaningful reduction in tree-caused outages will require a focus on limiting tree in-fall (*Finding 5-11*). Examining the location of the in-fall trees it was found that 20-30% of in-fall outages occur from trees located within the right of way.

Recommendation 12-1 **Increase the frequency of hazard tree patrols along transmission lines (*Finding 5-11*, *Finding 6-12*).**

Recommendation 12-2 **Remove all identified hazard trees located within 40 feet of a conductor (Refer to *Finding 5-11*, *Finding 6-12*, *Exhibit 6-20*).**

Only 20% percent of the in-fall trees could be identified as hazard trees. This observation does suggest two possible paths to reliability improvement. The first is to increase the frequency of hazard tree patrols. It is also possible that hazard trees located some distance within the forest stand are not being identified or addressed. The PSE VM clearance standards place a restriction on 55 and 115 kV lines limiting hazard tree removals beyond 18 feet from the conductor to trees that are an imminent threat. It is not known whether the hazard trees are not being picked up in patrols or simply not addressed because at the time of the patrol they do not appear to pose an imminent threat.

Douglas fir, red alder, big-leaf maple, black cottonwood, and hemlock are the primary identifiable species involved in tree-caused interruptions. These species warrant additional scrutiny during hazard tree patrols.

Recommendation 12-3 **Hazard tree patrols should place additional emphasis on evaluating the health of Douglas fir, red alder, big-leaf maple, black cottonwood and Western hemlock (Refer to *Exhibit 6-19*, *Exhibit 6-22*, *Exhibit 7-34*, *Finding 5-11*, *Finding 7-18*).**

On PSE's system, limb failures account for 35% of all tree-caused outages. On the transmission system limb overhangs are not tolerated. Consequently, any limbs causing outages must be windthrown. The main species involved are Douglas fir, big-leaf maple, black cottonwood and red alder. During hazard tree patrols, limbs of these species need to be evaluated for health, viability, strength of attachment, etc. Increasing the distance between limbs and conductors holds the potential to improve reliability but we have no way of quantifying the extent of that potential.

A substantial amount (68%) of tree-caused outages arise from trees of apparent good or fair health. There is nothing in conventional vegetation management programs that addresses these trees and the associated risk due to failure. However, if PSE is to markedly improve reliability it must address these healthy trees, which are the largest cause of interruptions. In the absence of any indicator that one tree has a higher probability of failure then the next tree, there is only one means of doing so. It is to reduce the transmission system's exposure to trees.

Recommendation 12-4 **Dedicate uniform effort and resources to the tree-caused outage investigations (*Finding 6-12*, *Finding 6-13*, *Finding 6-14*).**

Data from the tree-caused outage investigations added considerable insight to tree-caused outages. However, the effort dedicated to these investigations has been quite variable over the last 10 years. These investigations provide information, which requires arboricultural knowledge and, therefore, cannot be supplied through the outage reporting system. Considering the extent to which trees drive PSE's outage experience it is important to have good data to identify opportunities for improvement and to monitor the results of interventions. Should PSE begin to make use of the species hazard ranking provided, it is only through the tree-caused outage investigations that PSE will be able to evaluate the merit and/or refine the rankings.

Along PSE power lines an average of 75% of the edge is treed. The transmission system is exposed to about 4.2 million trees of which, about 72,000 are estimated to be hazard trees. Due to natural tree mortality, the hazard tree population needs to be considered as an ongoing population even if the annual increment is removed. Tree mortality was estimated for 5 of 7 species (*Exhibit 7-35*). PSE should seek to replace the estimates of mortality with rates derived from local research. It is difficult to assess what ratio of the 72,000 trees annually becoming decadent have a high probability to realize the potential to strike the line on failure. Factors such as dominance, location within the forest stand, slopes and existing lean influence the probability of line strike on failure. Most of the tree exposure is along 115 kV lines. Calculating the arc of exposure for a tree of mean height, located in the center of the danger tree stand on a 115 kV line of mean height, it is found that mean arc of exposure is 23% of a circle. As judgments need to be made regarding, which trees are to be removed, we assume a 10% safety margin. On this basis it is estimated that approximately 20,000 trees will annually be designated as hazard trees requiring removal.

Recommendation 12-5 Set tolerated tree exposure risk standards by voltage class and apply these on any new construction (Refer to *Finding 9-22*).

Current right of way clear widths and line heights used for 55 kV and 115 kV fail to significantly differentiate the tree risk (*Finding 9-22*, *Exhibit 9-46*, *Exhibit 9-50*). Two significant correlations of field variables to tree-caused outages were found. They are trees mi^{-1} edge and Risk Factor (*Exhibit 9-51*). Both are measures of tree exposure. If the objective is to have fewer tree-caused interruptions on 115 kV because such outages have a greater customer impact than 55 kV outages, then the 115 kV lines and their right of ways must be designed to have a significantly lower tree exposure than 55 kV lines.

Recommendation 12-6 Use the found relationships and regressions to run "what if" scenarios to test the reliability impact of possible interventions (Refer to *Finding 9-23*, *Finding 9-24*, *Finding 9-25*, *Finding 10-26*, *Exhibit 10-61*, *Exhibit 11-71*, *Exhibit 11-72*).

The relationship between tree exposure and interruptions is not only statistically significant but also very strong with an r-value of 0.9172 for trees mi^{-1} edge and 0.8878 for RF. These correlations are so strong it will be exceedingly difficult to find other causes, including engineering options that have a greater effect on reliability.

Regression equations were derived for both trees mi^{-1} edge and RF. In both cases the exponential regression provides the best fit to outage data. The algorithms are:

F_{AI} 1000 mi^{-1} = 0.07722073493*e^(0.0041125167* Trees mi^{-1} edge) (*Equation 1*)

F_{AI} 1000 mi^{-1} = 0.08765294536*e^(18.2203153259*RF) (*Equation 2*)

The regression equations are strongly supported by statistics. The coefficient of multiple determination, r^2, is 0.9012 with a probability of error of 0.0136 for *Equation 1*. *Equation 2* has an r^2 of 0.9559 with a probability of error of 0.0040. That is, both regressions explain more than 90% of the changes in annual outage frequency with very little risk of error. These findings make it clear that avoiding tree-caused interruptions entails reducing tree exposure. Further, these regressions put the reliability impact of possible vegetation management actions on a quantitative basis of return in reliability for each dollar invested, making vegetation management options directly comparable with engineering options.

Examining wind data and its relationship to tree-caused interruptions it was found that when interruptions are graphed based on the wind speed at which they occurred (*Exhibit 10-57*), interruptions follow a normal curve. Most tree-related outages have occurred at winds between 30 and 40 mph. This is a product of both the frequency of occurrence of this intensity of wind events and the tree failure rate when exposed to such winds (*Exhibit 10-57*, *Exhibit 10-59*, *Exhibit 10-60*). The tree failure rate increases with wind speed in an exponential relationship (*Exhibit 10-60*).

Outages can be modeled over a 10-year period and for wind events of specific intensity. The algorithms are:

Expected Interruptions = DT*10-year tree failure rate @ WS*0.5*mean RF; (*Equation 4*)
where WS is wind speed, and

Expected Interruptions = DT*tree failure rate @ WS*0.5*mean RF; (*Equation 5*)
where WS is wind speed.

Statistically the relationship between wind speed, number of wind events and tree-caused outages is very strong with extremely low levels of error. Modeling serves to smooth the data. From the wind speed versus outage data, tree failure rates were calculated. The calculated tree failure rates are not likely to change much with changes to the vegetation management program. Thus the tree failure rates permit modeling of expected outages over a range of wind speeds and time frames.

In considering the outage response to wind, two questions emerge. Is it possible to make the electric system tolerant of winds up to a specific speed? Is it possible to harden the system so that fewer tree-caused outages are experienced during strong winds and/or major storm events?

The answers are found in the intervention Example 1 and the associated *Exhibit 11-71* and *Exhibit 11-72*. In the purest sense, the system cannot be made tolerant of specific wind speeds. The calculations behind *Exhibit 11-71* and *Exhibit 11-72* reveal the intervention results in a uniform percentage outage reduction across all wind speeds. Practically, however, an intervention may appear to make the system tolerant of lower levels of wind. For example, currently 1 outage incident is expected annually at a wind speed of 20 mph. If an intervention reduces outages by 50% then it may appear that the system is now resistant to winds of 20 mph. However, when examined over the long rather than annual term, it will be found that an outage incident occurs every two years at 20 mph winds.

Exhibit 11-72 reveals it is possible to reduce the reliability impact of major storms. Indeed the reliability improvement resulting from an intervention, which reduces the extent of tree exposure, is more apparent under high wind conditions.

Sensitivity of tree exposure to changes in a unit change of a variable, clear width, line height and tree height, is variable both within each variable and between variables. Generally, changes in clear width produce the largest change in tree exposure. However, when a line is to undergo a re-design it may prove advantageous to explore the potential to mitigate tree-related outages through a range of line heights.

Through this work, PSE has quantified the extent of transmission line tree exposure and thereby, the scale of the challenge to storm harden the transmission system. Due to the outage and extensive wind data sets, statistically significant relationships between variables have been found and permit modeling of expected outages resulting from changes in vegetation management standards. It should be recognized, however, that the focus on the transmission system where there were 265 tree-caused outage incidents over ten years, fails to harness the insight to be gained from over 34,000 tree-related distribution outages over the same period. One area where a similar evaluation of the distribution system would serve particularly well is in refining the calculated tree failure rates.

Through the use of examples, the potential to improve reliability has been demonstrated. Substantially improving reliability involves reducing the transmission system's tree exposure. All the means of doing so, increasing clear width, increasing line height and reducing tree height are generally, viewed negatively by the public. However, with the ability to state the ensuing reliability benefit for such actions, PSE may be positioned to find the balance of publicly desired reliability and their sentiments for tree preservation.

[1] Guggenmoos, S., T.E. Sullivan. 2007. *Outside Right-of-Way Tree Risk Along Electrical Transmission Lines*. Utility Arborist Association Mar. 2007. http://www.utilityarborist.org/images/Articles/SideTreeRisk.pdf
[2] Pennsylvania Public Utility Commission. 2006. Electric Service Reliability in Pennsylvania 2005. Pennsylvania Public Utility Commission, Harrisburg, PA, August 2006
[3] Florida Public Service Commission. 2005 Electric Utility Distribution Reliability Report http://www.floridapsc.com/utilities/electricgas/distributionreports.aspx
[4] EnergyOnline Daily News, Aug 7, 1996. Energy Department Calls Last Month's Western Outage 'Preventable'. Ric Teague, Ed. LCG Consulting. http://www.energyonline.com/news/articles/Archive/outage.asp
[5] EnergyOnline Daily News, Aug 26, 1996. California PUC on Big Outage: Let Us Know When a Line's Down. Ric Teague, Ed. LCG Consulting. http://www.energyonline.com/news/articles/Archive/outage2.asp
[6] Cieslewicz, Stephen R., Robert R. Novembri, 2004. *UTILITY VEGETATION MANAGEMENT FINAL REPORT*. FEDERAL ENERGY REGULATORY COMMISSION, UNITED STATES GOVERNMENT. FEDERAL INVESTIGATION OF THE AUGUST 14, 2003 NORTHEAST BLACKOUT. MARCH 2004
[7] UCTE, Oct. 27, 2003. Interim Report of the Investigation Committee on the 28 September 2003 Blackout in Italy, 2003
[8] / Interview 1
[9] / Information Response 17
[10] / Interview 1
[11] / Interview 1
[12] / Interview 1
[13] / Interview 1
[14] / Interview 1
[15] / Information Responses 1, 2, 3, 6
[16] / Interview 1 and Information Responses 7, 7.2, 16
[17] / Interview 1 and 7
[18] / Interview 7
[19] / Interview 1
[20] / Interview 1 and Information Response 14
[21] / Interview 1
[22] / Information Response 14
[23] / Interview 1
[24] / IR12 Work Completed Monthly Report
[25] Cieslewicz, S.R., 2005. *The State of the Utility Vegetation Management (UVM) Industry. Are We ready to Comply with New Regulatory Requirements and Expectations?* Electric Energy T & D Magazine, Jaguar Media Inc., Lachenaie, Quebec, September/October 2005
[26] / Interview 1
[27] / Interview 5
[28] / Interview 1
[29] / Interview 1
[30] / Information Response 14
[31] / Interview 1
[32] / Interview 1
[33] / Information Response 11
[34] / Information Response 11, 14
[35] / Interview 1
[36] / Interview 1,5
[37] / Interview 1
[38] / Interview 1
[39] / Interview 1
[40] / Information Response 15
[41] / Information Response 15
[42] / Information Response 15
[43] / Interview 1
[44] / Interview 1
[45] / Interview 1 and Information Response 7.2
[46] / Interview 1 and Information Responses 7, 7.2
[47] / Interview 1
[48] / Interview 1
[49] / Information Response 7
[50] / Interviews 1, 4, 5

[51] / Interviews 4, 5
[52] / Interviews 1, 4, 5
[53] / Interview 1
[54] / Interview 1
[55] / Information Response 7.2
[56] / Information Response 7.2
[57] / Interview 7
[58] / Interview 1 and 7
[59] / Information Response 7.2
[60] / Information Response 7.2
[61] / Interviews 1, 7 and Information Response 15
[62] / Interview 1
[63] / Interview 2
[64] / Interview 3
[65] / Interview 3
[66] / Interview 3
[67] / Interview 3
[68] / Interview 4
[69] / Interview 4
[70] / Interview 4
[71] / Interview 4
[72] / Interview 4
[73] / Interview 5
[74] / Interview 5
[75] / Interview 5
[76] / Interview 5
[77] / Interview 6
[78] / Interview 6
[79] / Interview 6
[80] / Interview 6
[81] / Information Response 17
[82] / Interview 1
[83] / Information Response 9
[84] / Interview 7
[85] / Interviews 2, 3, 4, 5, 6
[86] Guggenmoos, S. *TransAlta Utilities Reporting System-A Management Tool*. Journal of Arboriculture, 16(2), 1990.
[87] Guggenmoos, S. *TransAlta Utilities Reporting System-A Management Tool*. Journal of Arboriculture, 16(2), 1990.
[88] Based on experience with TransAlta Utilities, FortisBC (formerly West Kootenay Power)
[89] Kentucky Public Service Commission. Final Report Focused Management Audit of The Hazard Service Area of American Electric Power/Kentucky. Schumaker & Company, March 24, 2003.
[90] / Interviews 2, 3, 4, 5, 6
[91] / Interviews 4, 5
[92] Goodfellow, J.W. 2005. Investigating Tree-caused Faults. Transmission & Distribution World, November 2005.
[93] Guggenmoos, S. *Effects of Tree Mortality on Power Line Security*. Journal of Arboriculture, 29(4), July 2003
[94] Guggenmoos, S. *Effects of Tree Mortality on Power Line Security*. Journal of Arboriculture, 29(4), July 2003
[95] Rees, Jr. William T., Timothy C. Birx, Daniel L. Neal, Cory J. Summerson, Frank L. Tiburzi, Jr., and James A. Thurber, P.E. 1994. Priority Trimming to Improve Reliability. ISA Conference presentation, Halifax, Nova Scotia, 1994
[96] Goodfellow, J.W. 2005. Investigating Tree-caused Faults. Transmission & Distribution World, November 2005
[97] Guggenmoos, S. *Effects of Tree Mortality on Power Line Security*. Journal of Arboriculture, 29(4), July 2003
[98] / Interview 7
[99] Rees, W.T. 2005. BGE Transforms Vegetation Program. Transmission & Distribution World, Nov. 1, 2005
[100] Finch, K.E., C. Allen 2001. Understanding Tree Caused Outages. EEI Natural Resource Conference, Palm Springs, CA, Apr. 2001
[101] Guggenmoos, S. *Effects of Tree Mortality on Power Line Security*. Journal of Arboriculture, 29(4), July 2003
[102] Rees, W.T. 2005. BGE Transforms Vegetation Program. Transmission & Distribution World, Nov. 1, 2005
[103] Guggenmoos, S. 2007. *Increased Risk of Electric Service Interruption Associated with Tree Branches Overhanging Conductors*. UAA Quarterly, 15(4), Fall 2007.
[104] For a more detailed explanation including diagrams see Guggenmoos, S. 2007. *Increased Risk of Electric Service Interruption Associated with Tree Branches Overhanging Conductors*. UAA Quarterly, 15(4), Fall 2007.
[105] Goodfellow, J.W. 2005. Investigating Tree-caused Faults. Transmission & Distribution World, November 2005.

[106] P. Simpson, R. Van Bossuyt. "Tree-Caused Electric Outages," *Journal of Arboriculture* 22(3): p.117, May 1996.
[107] Guggenmoos, S., T.E. Sullivan. 2007. *Outside Right-of-Way Tree Risk Along Electrical Transmission Lines*. Utility Arborist Association Mar. 2007. http://www.utilityarborist.org/images/Articles/SideTreeRisk.pdf
[108] Guggenmoos, S., T.E. Sullivan. 2006. *Side Line Tree Risk Assessment and Mitigation*. UAA Quarterly, 14(4), Fall 2006.
[109] Guggenmoos, S. *Quantification of Vegetation Management Work, Risks & Resource Requirements*. Ecological Solutions Inc. for AltaLink Management Ltd. March 2006. Alberta Energy and Utilities Board, AML 2007-2008 GTA Volume 2 Appendices excluding Depreciation Study. https://www3.eub.gov.ab.ca/eub/dds/iar_query/ShowAttachment.aspx?DOCNUM=449798, Appendix F, April 13, 2006.
[110] Guggenmoos, S., T.E. Sullivan. 2006. *Side Line Tree Risk Assessment and Mitigation*. UAA Quarterly, 14(4), Fall 2006.
[111] Campbell, Sally, Leon Liegel, tech coords. 1996. Disturbance and forest health in Oregon and Washington. Gen. Tech. Rep. PNW-GTR-381. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: Oregon Department of Forestry: Washington Department of Natural Resources. 105 p. Ch. 1, Mortality Trends.
[112] Crookston, Nicholas L. 1997. Suppose: An Interface to the Forest Vegetation Simulator. In: Teck, Richard; Moeur, Melinda; Adams, Judy. 1997. Proceeding: Forest vegetation simulator conference. 1997 February 3-7, Fort Collins, CO. Gen. Teck. Rpt. INT-GTR-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.
[113] Curtis, R.O., G.W. Clendenen, J.A. Henderson, 2000. True Fir-Hemlock Spacing Trials: Design and First Results. USDA, Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-492, May 2000.
[114] Guggenmoos, S., T.E. Sullivan. 2006. *Side Line Tree Risk Assessment and Mitigation*. UAA Quarterly, 14(4), Fall 2006.
[115] Guggenmoos, S., T.E. Sullivan. 2006. *Side Line Tree Risk Assessment and Mitigation*. UAA Quarterly, 14(4), Fall 2006.

[116] Francis, J.K., A.J.R. Gillespie 1993. *Relating Gust Speed to Tree Damage in Hurricane Hugo, 1989*. Journal of Arboriculture 19(6): November 1993 p. 368.

Appendix

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CORRELATION
2008-11-07 17:01:28
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X1 Column: 8) FAI/1000 mi
X2 Column: 2) ClearWidth
Broken Down By:
Keep If:
Lines: 1

The Pearson Product Moment Correlation Coefficient ('r') is a measure
  of the linear association of two independent variables.
If the probability that r=0 ('P(r=0)') is <=0.05, r is significantly
  different from 0 and the variables show some degree of correlation.

X1 Column: 8) FAI/1000 mi
X2 Column: 2) ClearWidth

      Corr (r)     S.E. of r    P(r=0)       n
 ------------- ------------- --------- -------
   -0.82376197 0.32732054322 .0864 ns        5

CORRELATION
2008-11-07 17:01:33
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X1 Column: 8) FAI/1000 mi
X2 Column: 3) LineHeight
Broken Down By:
Keep If:
Lines: 1

The Pearson Product Moment Correlation Coefficient ('r') is a measure
  of the linear association of two independent variables.
If the probability that r=0 ('P(r=0)') is <=0.05, r is significantly
  different from 0 and the variables show some degree of correlation.

X1 Column: 8) FAI/1000 mi
X2 Column: 3) LineHeight

      Corr (r)     S.E. of r    P(r=0)       n
 ------------- ------------- --------- -------
   -0.27604441 0.55491725676 .6530 ns        5

CORRELATION
2008-11-07 17:01:38
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X1 Column: 8) FAI/1000 mi
X2 Column: 4) TreeHeight
Broken Down By:
Keep If:
Lines: 1

The Pearson Product Moment Correlation Coefficient ('r') is a measure
  of the linear association of two independent variables.
If the probability that r=0 ('P(r=0)') is <=0.05, r is significantly
  different from 0 and the variables show some degree of correlation.

X1 Column: 8) FAI/1000 mi
X2 Column: 4) TreeHeight

      Corr (r)     S.E. of r    P(r=0)       n
 ------------- ------------- --------- -------
   -0.41138468 0.52623272631 .4914 ns        5

CORRELATION
2008-11-07 17:01:43
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X1 Column: 8) FAI/1000 mi
```

```
X2 Column: 5) RiskFactor
Broken Down By:
Keep If:
Lines: 1

The Pearson Product Moment Correlation Coefficient ('r') is a measure
  of the linear association of two independent variables.
If the probability that r=0 ('P(r=0)') is <=0.05, r is significantly
  different from 0 and the variables show some degree of correlation.

X1 Column: 8) FAI/1000 mi
X2 Column: 5) RiskFactor

      Corr (r)     S.E. of r    P(r=0)       n
 ------------- ------------- --------- -------
    0.88779943 0.26571424062 .0443 *         5

CORRELATION
2008-11-07 17:01:47
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X1 Column: 8) FAI/1000 mi
X2 Column: 6) Tree Exposure
Broken Down By:
Keep If:
Lines: 1

The Pearson Product Moment Correlation Coefficient ('r') is a measure
  of the linear association of two independent variables.
If the probability that r=0 ('P(r=0)') is <=0.05, r is significantly
  different from 0 and the variables show some degree of correlation.

X1 Column: 8) FAI/1000 mi
X2 Column: 6) Tree Exposure

      Corr (r)     S.E. of r    P(r=0)       n
 ------------- ------------- --------- -------
    0.25128098 0.55882551543 .6835 ns        5

CORRELATION
2008-11-07 17:01:52
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X1 Column: 8) FAI/1000 mi
X2 Column: 7) Trees/mi edge
Broken Down By:
Keep If:
Lines: 1

The Pearson Product Moment Correlation Coefficient ('r') is a measure
  of the linear association of two independent variables.
If the probability that r=0 ('P(r=0)') is <=0.05, r is significantly
  different from 0 and the variables show some degree of correlation.

X1 Column: 8) FAI/1000 mi
X2 Column: 7) Trees/mi edge

      Corr (r)     S.E. of r    P(r=0)       n
 ------------- ------------- --------- -------
    0.91719071 0.23004434866 .0282 *         5
```

```
REGRESSION: EXPONENTIAL: Y=A*E^(B*X)
2008-11-07 17:06:47
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X Column: 5) RiskFactor
Y Column: 8) FAI/1000 mi
Keep If:

Total number of data points = 7
Number of data points used = 7
Regression equation:
y = 0.08254045102*e^(19.2410837614*x)
R^2 is the coefficient of multiple determination.  It is the fraction
of total variation of Y which is explained by the regression:
R^2=SSregression/SStotal.  It ranges from 0 (no explanation of the
variation) to 1 (a perfect explanation).

R^2 = 0.9532599207

For each term in the ANOVA table below, if P<=0.05, that term was a
significant source of Y's variation.

Source                              SS       df        MS         F     P
------------------------ ------------- -------- --------- --------- ---------
Regression               26.0615650868        1 26.061565 101.97457 .0002 ***
x                        26.0615650868        1 26.061565 101.97457 .0002 ***
Error                      1.277846254        5 0.2555693
------------------------ ------------- -------- --------- --------- ---------
Total                    27.3394113408        6

Table of Statistics for the Regression Coefficients:

Column                         Coef.  Std Error  t(Coef=0)      P      +/-95% CL
------------------------ ---------  ---------  ---------  ---------  ---------
Intercept                -2.494467  0.4267231  -5.845634  .0021 **   1.0969266
x                        19.241084  1.9053887  10.098246  .0002 ***  4.8979576

Degrees of freedom for two-tailed t tests = 5
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

      Row             X     Y observed     Y expected       Residual
---------  -------------  -------------  -------------  -------------
        1       0.051775       0.170046  0.22351881642  -0.0534728164
        2       0.078614       0.296623  0.37461807765  -0.0779950776
        3       0.135451       2.135448   1.1182413703   1.0172066297
        4       0.258124      12.769839  11.8475217942  0.92231720578
        5       0.276425      28.050491  16.8483004522  11.2021905478
        6       0.296673      12.599793  24.8745017412  -12.274708741
        7       0.304684      27.753868  29.0199514466  -1.2660834466

REGRESSION: EXPONENTIAL: Y=A*E^(B*X)
2008-11-07 17:08:39
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X Column: 5) RiskFactor
Y Column: 8) FAI/1000 mi
Keep If:

Total number of data points = 5
Number of data points used = 5
Regression equation:
y = 0.08765294536*e^(18.2203153259*x)
R^2 is the coefficient of multiple determination.  It is the fraction
of total variation of Y which is explained by the regression:
R^2=SSregression/SStotal.  It ranges from 0 (no explanation of the
variation) to 1 (a perfect explanation).
```

R^2 = 0.95585268367

For each term in the ANOVA table below, if P<=0.05, that term was a significant source of Y's variation.

Source	SS	df	MS	F	P
Regression	19.1382643742	1	19.138264	64.9543	.0040 **
x	19.1382643742	1	19.138264	64.9543	.0040 **
Error	0.88392597087	3	0.294642		
Total	20.0221903451	4			

Table of Statistics for the Regression Coefficients:

Column	Coef.	Std Error	t(Coef=0)	P	+/-95% CL
Intercept	-2.43437	0.4611646	-5.278744	.0133 *	1.4676317
x	18.220315	2.2607468	8.0594231	.0040 **	7.1947054

Degrees of freedom for two-tailed t tests = 3
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

Row	X	Y observed	Y expected	Residual
1	0.051775	0.170046	0.22514441492	-0.0550984149
2	0.078614	0.296623	0.36714508005	-0.0705220801
3	0.135451	2.135448	1.03416037606	1.10128762394
4	0.296673	12.599793	19.5134806889	-6.9136876889
5	0.304684	27.753868	22.5800887724	5.1737792276

```
REGRESSION: MULTIPLE (ONE SUBSET)
2008-11-10 11:34:16
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
  X Columns:
       7) Trees/mi edge
  Y Column: 8) FAI/1000 mi
Keep If:
Calculate Constant: false

Total number of data points = 7
Number of data points used = 7
Regression equation:
col(8)[FAI/1000 mi] =
 0.01504159096*col(7)[Trees/mi edge]


R^2     = 0.86339466616    AIC = 27.2306239414    MSEP    = 49.0115959041
adj R^2 = 0.84062711052    BIC = 29.5084017191    PRESS   = 375.678412771
PRE R^2 = 0.66924779757    MAE = 5.73181891067    LOO MAE = 6.85970424203

For each term in the ANOVA table below, if P<=0.05, that term was a
significant source of Y's variation.

Source                              SS       df        MS         F     P
------------------------ ------------- -------- --------- --------- ---------
Regression               1626.29696654        1  1626.297  37.92215 .0008 ***
col(7)[Trees/mi edge]    1626.29696654        1  1626.297  37.92215 .0008 ***
Error                    257.310878496        6 42.885146
------------------------ ------------- -------- --------- --------- ---------
Total                    1883.60784504        7

Table of Statistics for the Regression Coefficients:

Column                       Coef.  Std Error  t(Coef=0)      P      +/-95% CL
------------------------ ---------  ---------  ---------  ---------  ---------
col(7)[Trees/mi edge]    0.0150416  0.0024426  6.1580963  .0008 ***  0.0059768

Degrees of freedom for two-tailed t tests = 6
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

      Row     Y observed     Y expected       Residual
---------  -------------  -------------  -------------
        1       0.170046   2.8987395403  -2.7286935403
        2       0.296623  8.57906815235  -8.2824451523
```

```
        3       2.135448   8.5361345181  -6.4006865181
        4      12.769839  15.8343058187  -3.0644668187
        5      28.050491  20.2873263905  7.76316460951
        6      12.599793  18.4117741836  -5.8119811836
        7      27.753868  21.6825734479  6.07129455213

REGRESSION: POWER: Y=A*X^B
2008-11-10 11:34:29
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X Column: 7) Trees/mi edge
Y Column: 8) FAI/1000 mi
Keep If:

Total number of data points = 7
Number of data points used = 7
Regression equation:
y = 4.91736668e-8*x^2.73785586098
R^2 is the coefficient of multiple determination.  It is the fraction
of total variation of Y which is explained by the regression:
R^2=SSregression/SStotal.  It ranges from 0 (no explanation of the
variation) to 1 (a perfect explanation).

R^2 = 0.85594868171

For each term in the ANOVA table below, if P<=0.05, that term was a
significant source of Y's variation.

Source                                 SS       df        MS         F      P
------------------------ ------------- -------- --------- --------- ---------
Regression              23.4011330959        1 23.401133 29.709852 .0028 **
ln(x)                   23.4011330959        1 23.401133 29.709852 .0028 **
Error                   3.93827824492        5 0.7876556
------------------------ ------------- -------- --------- --------- ---------
Total                   27.3394113408        6

Table of Statistics for the Regression Coefficients:

Column                       Coef.  Std Error  t(Coef=0)      P      +/-95% CL
------------------------ ---------  ---------  ---------  ---------  ---------
Intercept               -16.82791  3.3533713  -5.018206  .0040 **   8.6201153
ln(x)                   2.7378559  0.5022967  5.4506745  .0028 **   1.2911948

Degrees of freedom for two-tailed t tests = 5
If P<=0.05, the coefficient is significantly different from 0.

Residuals:
```

Row	X	Y observed	Y expected	Residual
1	192.714956	0.170046	0.08861386286	0.08143213714
2	570.356432	0.296623	1.72847862818	-1.4318556282
3	567.502104	2.135448	1.70489873635	0.43054926365
4	1052.70153	12.769839	9.25483643064	3.51500256936
5	1348.748709	28.050491	18.2403279127	9.81016308727
6	1224.05763	12.599793	13.9858552267	-1.3860622267
7	1441.507983	27.753868	21.8835800941	5.8702879059

```
REGRESSION: EXPONENTIAL: Y=A*E^(B*X)
2008-11-10 11:34:41
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X Column: 7) Trees/mi edge
Y Column: 8) FAI/1000 mi
Keep If:

Total number of data points = 7
Number of data points used = 7
Regression equation:
y = 0.07600677865*e^(0.00430605536*x)
R^2 is the coefficient of multiple determination.  It is the fraction
of total variation of Y which is explained by the regression:
R^2=SSregression/SStotal.  It ranges from 0 (no explanation of the
variation) to 1 (a perfect explanation).

R^2 = 0.90952496344

For each term in the ANOVA table below, if P<=0.05, that term was a
significant source of Y's variation.
```

Source	SS	df	MS	F	P	
Regression	24.8658771001	1	24.865877	50.263863	.0009	***
x	24.8658771001	1	24.865877	50.263863	.0009	***
Error	2.47353424068	5	0.4947068			
Total	27.3394113408	6				

Table of Statistics for the Regression Coefficients:

Column	Coef.	Std Error	t(Coef=0)	P		+/-95% CL
Intercept	-2.576933	0.6154727	-4.186916	.0086	**	1.582123
x	0.0043061	6.0737e-4	7.0897012	.0009	***	0.0015613

```
Degrees of freedom for two-tailed t tests = 5
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

      Row             X     Y observed     Y expected       Residual
---------  -------------  -------------  -------------  -------------
        1     192.714956       0.170046   0.1742801042  -0.0042341042
        2     570.356432       0.296623  0.88608147336  -0.5894584734
        3     567.502104       2.135448  0.87525739461   1.26019060539
        4     1052.70153      12.769839  7.07139887197   5.69844012803
        5    1348.748709      28.050491   25.301251575   2.74923942496
        6     1224.05763      12.599793  14.7896435286  -2.1898505286
        7    1441.507983      27.753868  37.7233940298  -9.9695260298

REGRESSION: MULTIPLE (ONE SUBSET)
2008-11-10 11:35:06
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
  X Columns:
       7) Trees/mi edge
  Y Column: 8) FAI/1000 mi
Keep If:
Calculate Constant: false

Total number of data points = 5
Number of data points used = 5
Regression equation:
col(8)[FAI/1000 mi] =
 0.01334128907*col(7)[Trees/mi edge]


R^2     = 0.81221643389    AIC = 19.7863085154    MSEP    = 52.6005623725
adj R^2 = 0.76527054236    BIC = 22.1613085154    PRESS   = 412.963081626
PRE R^2 = 0.28083779273    MAE = 5.48049111358    LOO MAE = 7.72176532259

For each term in the ANOVA table below, if P<=0.05, that term was a
significant source of Y's variation.

Source                               SS       df         MS         F      P
------------------------ ------------- -------- --------- --------- ---------
Regression               758.373803703        1  758.3738 17.301119 .0142 *
col(7)[Trees/mi edge]    758.373803703        1  758.3738 17.301119 .0142 *
Error                    175.335207908        4 43.833802
------------------------ ------------- -------- --------- --------- ---------
Total                    933.709011611        5
```

```
Table of Statistics for the Regression Coefficients:

Column                     Coef.   Std Error  t(Coef=0)      P      +/-95% CL
------------------------ --------- ---------  ---------  ---------  ---------
col(7)[Trees/mi edge]    0.0133413  0.0032075  4.1594613  .0142 *    0.0089053

Degrees of freedom for two-tailed t tests = 4
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

      Row     Y observed     Y expected       Residual
---------  -------------  -------------  -------------
        1       0.170046  2.57106593611  -2.4010199361
        2       0.296623  7.60929003224  -7.3126670322
        3       2.135448  7.57120961729  -5.4357616173
        4      12.599793  16.3305066802  -3.7307136802
        5      27.753868  19.2315746979   8.5222933021

REGRESSION: POWER: Y=A*X^B
2008-11-10 11:35:22
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X Column: 7) Trees/mi edge
Y Column: 8) FAI/1000 mi
Keep If:

Total number of data points = 5
Number of data points used = 5
Regression equation:
y = 1.42057852e-7*x^2.55052829654
R^2 is the coefficient of multiple determination.  It is the fraction
of total variation of Y which is explained by the regression:
R^2=SSregression/SStotal.  It ranges from 0 (no explanation of the
variation) to 1 (a perfect explanation).

R^2 = 0.82785074922

For each term in the ANOVA table below, if P<=0.05, that term was a
significant source of Y's variation.

Source                              SS       df        MS         F     P
------------------------ ------------- -------- --------- --------- ---------
Regression               16.5753852783        1 16.575385 14.426739 .0320 *
ln(x)                    16.5753852783        1 16.575385 14.426739 .0320 *
Error                    3.44680506682        3  1.148935
```

```
----------------------- ------------ -------- --------- --------- ---------
Total                   20.0221903451       4
```

Table of Statistics for the Regression Coefficients:

Column	Coef.	Std Error	t(Coef=0)	P	+/-95% CL
Intercept	-15.76703	4.3685797	-3.609189	.0365 *	13.90277
ln(x)	2.5505283	0.6715001	3.7982547	.0320 *	2.1370129

Degrees of freedom for two-tailed t tests = 3
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

Row	X	Y observed	Y expected	Residual
1	192.714956	0.170046	0.09554471692	0.07450128308
2	570.356432	0.296623	1.52087836588	-1.2242553659
3	567.502104	2.135448	1.50154108202	0.63390691798
4	1224.05763	12.599793	10.6657469437	1.93404605631
5	1441.507983	27.753868	16.1851794138	11.5686885862

REGRESSION: EXPONENTIAL: Y=A*E^(B*X)
2008-11-10 11:35:35
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\correlation2.dt
X Column: 7) Trees/mi edge
Y Column: 8) FAI/1000 mi
Keep If:

Total number of data points = 5
Number of data points used = 5
Regression equation:
y = 0.07722073493*e^(0.0041125167*x)
R^2 is the coefficient of multiple determination. It is the fraction
of total variation of Y which is explained by the regression:
R^2=SSregression/SStotal. It ranges from 0 (no explanation of the
variation) to 1 (a perfect explanation).

R^2 = 0.90124765518

For each term in the ANOVA table below, if P<=0.05, that term was a
significant source of Y's variation.

```
Source                              SS       df        MS         F      P
----------------------- ------------ -------- --------- --------- ---------
```

Regression	18.0449521001	1	18.044952	27.379025	.0136	*
x	18.0449521001	1	18.044952	27.379025	.0136	*
Error	1.97723824501	3	0.6590794			
Total	20.0221903451	4				

Table of Statistics for the Regression Coefficients:

Column	Coef.	Std Error	t(Coef=0)	P	+/-95% CL
Intercept	-2.561087	0.7255336	-3.529936	.0386 *	2.3089718
x	0.0041125	7.8596e-4	5.2324971	.0136 *	0.0025013

Degrees of freedom for two-tailed t tests = 3
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

Row	X	Y observed	Y expected	Residual
1	192.714956	0.170046	0.17058120923	-5.3520923e-4
2	570.356432	0.296623	0.80614881705	-0.509525817
3	567.502104	2.135448	0.7967411857	1.3387068143
4	1224.05763	12.599793	11.8564281361	0.74336486393
5	1441.507983	27.753868	28.9954345492	-1.2415665492

CORRELATION
2008-11-20 13:11:08
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\Outage frequency_T cumulative.dt
X1 Column: 3) Avg Max Speed
X2 Column: 1) Incidents
Broken Down By:
Keep If:
Lines: 1

The Pearson Product Moment Correlation Coefficient ('r') is a measure
of the linear association of two independent variables.
If the probability that r=0 ('P(r=0)') is <=0.05, r is significantly
different from 0 and the variables show some degree of correlation.

X1 Column: 3) Avg Max Speed
X2 Column: 1) Incidents

Corr (r)	S.E. of r	P(r=0)	n
0.97552834	0.0777370969	.0000 ***	10

```
CORRELATION
2008-11-20 13:11:28
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\Outage frequency_T cumulative.dt
X1 Column: 3) Avg Max Speed
X2 Column: 2) CustMin
Broken Down By:
Keep If:
Lines: 1

The Pearson Product Moment Correlation Coefficient ('r') is a measure
  of the linear association of two independent variables.
If the probability that r=0 ('P(r=0)') is <=0.05, r is significantly
  different from 0 and the variables show some degree of correlation.

X1 Column: 3) Avg Max Speed
X2 Column: 2) CustMin

      Corr (r)     S.E. of r    P(r=0)       n
 ------------- ------------ --------- -------
    0.98366119 0.06365008442 .0000 ***      10

CORRELATION
2008-11-19 15:24:38
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\Outage frequency.dt
X1 Column: 4) Avg Max Speed
X2 Column: 2) Incidents
Broken Down By:
Keep If:
Lines: 1

The Pearson Product Moment Correlation Coefficient ('r') is a measure
  of the linear association of two independent variables.
If the probability that r=0 ('P(r=0)') is <=0.05, r is significantly
  different from 0 and the variables show some degree of correlation.

X1 Column: 4) Avg Max Speed
X2 Column: 2) Incidents

      Corr (r)     S.E. of r    P(r=0)       n
 ------------- ------------ --------- -------
    0.78613657 0.23360201104 .0120 *         9

CORRELATION
2008-11-19 15:25:01
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\Outage frequency.dt
```

```
X1 Column: 4) Avg Max Speed
X2 Column: 3) CustMin
Broken Down By:
Keep If:
Lines: 1

The Pearson Product Moment Correlation Coefficient ('r') is a measure
  of the linear association of two independent variables.
If the probability that r=0 ('P(r=0)') is <=0.05, r is significantly
  different from 0 and the variables show some degree of correlation.

X1 Column: 4) Avg Max Speed
X2 Column: 3) CustMin

      Corr (r)     S.E. of r    P(r=0)       n
 ------------- ------------- --------- -------
    0.72051569 0.26209516917 .0285 *         9

REGRESSION: MULTIPLE (ONE SUBSET)
2008-11-20 13:12:36
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\Outage frequency_T cumulative.dt
  X Columns:
       3) Avg Max Speed
  Y Column: 1) Incidents
Keep If:
Calculate Constant: false

Total number of data points = 10
Number of data points used = 10
Regression equation:
col(1)[Incidents] =
 0.29091492972*col(3)[Avg Max Speed]


R^2     = 0.96560379964    AIC = 16.3232276431    MSEP    = 5.11917585241
adj R^2 = 0.96178199961    BIC = 18.5207585073    PRESS   = 53.7810210234
PRE R^2 = 0.92576866001    MAE = 1.97427513483    LOO MAE = 2.22022427653

For each term in the ANOVA table below, if P<=0.05, that term was a
significant source of Y's variation.

Source                              SS       df        MS         F     P
------------------------ ------------- -------- --------- --------- ---------
Regression               1175.81330146        1 1175.8133 252.65681 .0000 ***
col(3)[Avg Max Speed]    1175.81330146        1 1175.8133 252.65681 .0000 ***
Error                    41.8841660652        9 4.6537962
```

```
----------------------- ------------ -------- --------- --------- ---------
Total                   1217.69746752      10
```

Table of Statistics for the Regression Coefficients:

Column	Coef.	Std Error	t(Coef=0)	P	+/-95% CL
col(3)[Avg Max Speed]	0.2909149	0.0183021	15.895182	.0000 ***	0.0414022

Degrees of freedom for two-tailed t tests = 9
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

Row	Y observed	Y expected	Residual
1	1.703704	2.91992391343	-1.2162199134
2	3.153704	4.91646231224	-1.7627583122
3	4.384473	6.50082982038	-2.1163568204
4	5.504473	7.77906522066	-2.2745922207
5	6.80177	9.43573410721	-2.6339641072
6	8.593437	10.8048344585	-2.2113974585
7	11.482326	12.2515974594	-0.7692714594
8	15.815659	13.5760301505	2.23962884951
9	17.565659	15.3215197288	2.24413927121
10	18.565659	16.2912360642	2.27442293578

REGRESSION: EXPONENTIAL: Y=A*E^(B*X)
2008-11-20 13:13:22
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\Outage frequency_T cumulative.dt
X Column: 3) Avg Max Speed
Y Column: 1) Incidents
Keep If:

Total number of data points = 10
Number of data points used = 10
Regression equation:
y = 1.27825889459*e^(0.0509181536*x)
R^2 is the coefficient of multiple determination. It is the fraction
of total variation of Y which is explained by the regression:
R^2=SSregression/SStotal. It ranges from 0 (no explanation of the
variation) to 1 (a perfect explanation).

R^2 = 0.97733769168

For each term in the ANOVA table below, if P<=0.05, that term was a

```
significant source of Y's variation.

Source                            SS       df        MS         F      P
------------------------ ------------- -------- --------- --------- ---------
Regression               5.51009123782        1 5.5100912 345.00905 .0000 ***
x                        5.51009123782        1 5.5100912 345.00905 .0000 ***
Error                    0.12776687891        8 0.0159709
------------------------ ------------- -------- --------- --------- ---------
Total                    5.63785811673        9

Table of Statistics for the Regression Coefficients:

Column                         Coef.  Std Error  t(Coef=0)      P      +/-95% CL
------------------------ ---------  ---------  ---------  ---------  ---------
Intercept                0.2454989  0.1021787  2.4026416  .0430 *    0.2356246
x                        0.0509182  0.0027413  18.574419  .0000 ***  0.0063215

Degrees of freedom for two-tailed t tests = 8
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

      Row             X     Y observed     Y expected       Residual
---------  -------------  -------------  -------------  -------------
        1      10.037037       1.703704  2.13094662327  -0.4272426233
        2           16.9       3.153704  3.02229268104  0.13141131896
        3      22.346154       4.384473  3.98813544713  0.39633755287
        4          26.74       5.504473  4.98807638143  0.51639661857
        5      32.434685        6.80177  6.66595471406  0.13581528594
        6      37.140873       8.593437  8.47095785108  0.12247914892
        7      42.114021      11.482326  10.9120436745  0.57028232547
        8      46.666667      15.815659  13.7588111784  2.05684782158
        9      52.666667      17.565659  18.6750489745  -1.1093899745
       10             56      18.565659  22.1295875255  -3.5639285255

REGRESSION: MULTIPLE (ONE SUBSET)
2008-11-20 13:14:06
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\Outage frequency_T cumulative.dt
  X Columns:
       3) Avg Max Speed
  Y Column: 2) CustMin
Keep If:
Calculate Constant: false

Total number of data points = 10
Number of data points used = 10
```

Regression equation:
col(2)[CustMin] =
 359770.0524*col(3)[Avg Max Speed]

```
R^2     = 0.99375580741    AIC = 279.531801118    MSEP    = 1.38103013e12
adj R^2 = 0.99306200824    BIC = 281.729331983    PRESS   = 1.40530656e13
PRE R^2 = 0.95934249453    MAE = 907381.208951    LOO MAE = 1009227.66285
```

For each term in the ANOVA table below, if P<=0.05, that term was a significant source of Y's variation.

Source	SS	df	MS	F	P	
Regression	1.79827608e15	1	1.7983e15	1432.3393	.0000	***
col(3)[Avg Max Speed]	1.79827608e15	1	1.7983e15	1432.3393	.0000	***
Error	1.12993374e13	9	1.2555e12			
Total	1.80957542e15	10				

Table of Statistics for the Regression Coefficients:

Column	Coef.	Std Error	t(Coef=0)	P		+/-95% CL
col(3)[Avg Max Speed]	359770.05	9506.093	37.846258	.0000	***	21504.276

Degrees of freedom for two-tailed t tests = 9
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

Row	Y observed	Y expected	Residual
1	3950261.48148	3611025.32743	339236.154051
2	5209717.53148	6080113.88556	-870396.35408
3	8539830.53148	8039476.99552	500353.535964
4	8959755.65148	9620251.20117	-660495.54969
5	9940321.00283	11669028.322	-1728707.3192
6	11459637.9612	13362173.8254	-1902535.8642
7	16108124.5167	15151363.5419	956760.97478
8	18010708.5167	16789269.2319	1221439.2848
9	19798047.7667	18947889.5463	850158.220402
10	20190851.7667	20147122.9344	43728.8323258

REGRESSION: EXPONENTIAL: Y=A*E^(B*X)
2008-11-20 13:14:40

```
Using: C:\Documents and Settings\Sig\My Documents\ECOSYNC\VM\PSE\Outage frequency_T cumulative.dt
X Column: 3) Avg Max Speed
Y Column: 2) CustMin
Keep If:

Total number of data points = 10
Number of data points used = 10
Regression equation:
y = 3166204.88648*e^(0.03565989617*x)
R^2 is the coefficient of multiple determination.  It is the fraction
of total variation of Y which is explained by the regression:
R^2=SSregression/SStotal.  It ranges from 0 (no explanation of the
variation) to 1 (a perfect explanation).

R^2 = 0.95717900433

For each term in the ANOVA table below, if P<=0.05, that term was a
significant source of Y's variation.

Source                          SS       df        MS         F      P
------------------------ ------------- -------- --------- --------- ---------
Regression              2.70254942408        1 2.7025494 178.82424 .0000 ***
x                       2.70254942408        1 2.7025494 178.82424 .0000 ***
Error                     0.120903046        8 0.0151129
------------------------ ------------- -------- --------- --------- ---------
Total                   2.82345247008        9

Table of Statistics for the Regression Coefficients:

Column                      Coef.  Std Error  t(Coef=0)      P      +/-95% CL
------------------------ ---------  ---------  ---------  ---------  ---------
Intercept               14.968044  0.0993963  150.58961  .0000 ***  0.2292082
x                       0.0356599  0.0026667  13.372518  .0000 ***  0.0061493

Degrees of freedom for two-tailed t tests = 8
If P<=0.05, the coefficient is significantly different from 0.

Residuals:

      Row              X      Y observed      Y expected       Residual
---------  -------------  -------------  -------------  -------------
        1      10.037037  3950261.48148  4528783.54933  -578522.06785
        2           16.9  5209717.53148  5784523.09641  -574805.56493
        3      22.346154  8539830.53148  7024437.95396  1515392.57752
        4          26.74  8959755.65148  8215965.69823   743789.95325
        5      32.434685  9940321.00283  10065876.8442  -125555.84141
```

6	37.140873	11459637.9612	11905177.0163	-445539.05512
7	42.114021	16108124.5167	14215249.4061	1892875.11059
8	46.666667	18010708.5167	16720945.8143	1289762.70247
9	52.666667	19798047.7667	20710100.9723	-912053.20553
10	56	20190851.7667	23324116.2997	-3133264.5329

PSE Field Variables

Voltage	SamplePoint	Side	StructureID	WireZone	ClearWidth	LineHeight	CODSTreeHeight	DOMTreeHeight	RiskFactor
115	1	R	1	4	24	51	43	82	32.36%
	1	R	2	4	22	52	40	93	40.75%
	5	L	1	28	23	47	71		26.42%
	5	R	1	28	37	46	43		0.00%
	8	L	1	5	15	50	114		70.40%
	8	L	2	1	15	60	107		64.63%
	10	L	1	7	75	48	73		0.00%
	10	R	1	7	117	48	65	119	0.00%
	11	R	13.1	12	8	43	64	100	77.67%
	11	R	13.2	12	12	43	64	100	67.87%
	22	L	23.2	7	16	41	118		65.35%
	22	R	23.5	7	47	40	60	96	17.09%
	23	L	9.1	5	28	39	56		10.16%
	23	R	9.1	5	41	45	138		39.82%
	24	L	1	8	40	34	115		33.05%
	24	R	1	8	76	38	109		5.69%
	29	L	17.18	4	27	50	84	123	48.00%
	29	L	2	8	22	50	80	116	53.94%
	31	R	1	8	38	48	55	87	16.91%
	31	R	2	8	36	48	60	95	25.32%
	33	R	25.13	6	15	43	77		50.62%
	33	R	25.14	6	15	43	58		34.70%
	38	L	8.10	13	16	48	108		61.22%
	38	R	8.11	13	33	44	110		35.80%

Voltage	SamplePoint	Side	StructureID	WireZone	ClearWidth	LineHeight	CODSTreeHeight	DOMTreeHeight	RiskFactor
115	39	L	14.7	8	20	28	110		57.17%
	39	L	14.8	8	24	48	112		49.05%
	44	L	1	8	48	40	107		20.20%
	44	L	2	8	52	41	89		8.85%
	46	R	1	10	45	52	58	98	16.02%
	46	R	2	10	55	52	46	90	4.92%
	49	L	4.0	1	58	49	121		19.02%
	49	R	4.0	1	124	49	110		0.00%
	59	L	3.6	8	80	50	88		0.00%
	59	R	3.7	8	79	50	86		0.00%
	64	L	1.13	1	23	40	100		45.66%
	64	R	2.2	8	36	33	97		27.92%
	67	R	3.12	8	18	50	87		46.39%
	67	R	3.13	8	14	49	73	124	70.27%
	72	L	15.10	21	29	32	63		16.65%
	72	L	15.11	21	34	33	55		6.69%
	75	L	11.4	22	55	37	126		23.27%
	75	R	11.4	22	126	36	133		0.31%
	79	R	1	6	60	44	132		20.24%
	79	R	2	6	60	44	132		19.73%
	83	L	125.14	15	30	54	104		35.90%
	83	L	126.1	30	31	71	135		42.81%
	91	L	10.4	5	64	40	63		0.00%
	91	R	10.4	5	24	46	70	104	45.27%
	92	L	1	8	27	44	121		47.52%
	92	R	1	8	42	51	55	111	24.56%
	98	L	7.1	15	35	25	110		36.66%

Voltage	SamplePoint	Side	StructureID	WireZone	ClearWidth	LineHeight	CODSTreeHeight	DOMTreeHeight	RiskFactor
115	98	L	7.2	15	35	28	104		34.83%
	100	L	3.1	8	52	49	85		8.54%
	100	R	3.1	8	23	49	100		44.39%
	104	L	5.11	8	49	43	60	101	16.60%
	104	L	5.12	8	49	43	65	89	11.06%
	111	L	3.13	6	49	60	63	82	1.66%
	111	R	31.3	6	22	60	64	133	57.04%
	119	R	1	26	42	50	45	76	3.54%
	119	R	2	26	48	50	56	87	8.07%
	121	L	19.12	8	30	47	72		18.73%
	121	L	19.13	8	40	40	78		12.62%
	129	R	17.11	12	76	45	53	95	2.12%
	129	R	17.11.	12	24	45	49	63	19.75%
	133	R	25.10	7	61	45	76	90	5.55%
	133	R	25.11	7	132	50	81	136	0.00%
	135	L	6.9	20	23	34	42	73	34.92%
	135	R	6.9.	21	67	34	63	90	3.26%
	137	L	4.10	6	24	43	90	125	54.05%
	137	L	4.9	6	24	43	90	125	53.39%
	142	L	1	7	19	47	105		54.28%
	142	R	1	7	34	42	103		33.60%
	143	L	1	3	71	44	48	77	0.00%
	143	L	2	3	71	44	48	77	0.00%
	146	L	35.14	10	18	42	115		62.05%
	146	R	35.14	10	115	42	88		0.00%
	149	L	3.5	10	44	48	110		26.23%
	149	R	3.5	10	44	48	110		25.09%

Voltage	SamplePoint	Side	StructureID	WireZone	ClearWidth	LineHeight	CODSTreeHeight	DOMTreeHeight	RiskFactor
115	152	L	1	26	63	31	62		0.00%
	152	R	1	26	38	32	58		4.96%
	153	L	6.14	12	44	41	66		2.93%
	153	R	6.14	12	40	41	66		6.84%
	156	R	108.10	9	52	39	92		10.22%
	156	R	18.11	9	50	42	86		8.36%
	157	L	1.9	6	56	49	150		28.71%
	157	R	1.9	6	19	56	127		61.25%
	158	R	125.12	7	32	47	66	100	36.05%
	158	R	125.13	1	35	40	63	121	39.38%
	160	L	14.4	6	20	38	89		46.24%
	160	L	14.5	6	18	38	94		53.79%
	164	L	11.4	12	23	48	66	92	41.70%
	164	R	11.10	12	39	52	63	86	19.02%
	170	R	1	24	75	53	88		0.00%
	170	R	2	24	75	52	97		0.73%
	172	L	1	12	44	40	70	113	25.51%
	172	L	2	12	46	40	53	90	13.95%
	176	L	2.12	12	32	31	60	122	43.10%
	176	R	2.12	12	87	37	46	107	1.32%
	178	L	14.9	12	18	60	70	127	61.85%
	178	R	14.9	12	54	49	102		11.38%
	182	L	2.6	1	66	54	62	105	4.48%
	182	L	2.7	1	63	54	68	112	8.62%
	184	L	12.1	5	28	32	46		4.64%
	184	R	12.1	6	74	36	62	118	7.95%
	185	R	96.13	8	37	42	40	109	31.34%

Voltage	SamplePoint	Side	StructureID	WireZone	ClearWidth	LineHeight	CODSTreeHeight	DOMTreeHeight	RiskFactor
115	185	R	96.15	8	25	48	124		51.72%
	193	L	4	30	54	49	48	83	4.23%
	193	R	4	30	56	39	45	75	3.27%
Summary for 'Voltage' = 115 (108 detail records)									
Avg				*10*	*44*	*45*	*81*	*100*	*25.81%*
230	4	L	8.1	24	32	40	41	82	26.17%
	4	R	8.1	24	78	52	63	100	1.46%
	12	L	1	60	57	39	48	111	15.63%
	12	R	1	60	37	42	43	82	17.31%
	20	L	35.3	24	60	55	106		8.62%
	20	L	35.4	24	62	55	112		10.66%
	36	R	68.4	38	49	43	70		3.16%
	36	R	68.5	38	49	43	75		4.59%
	57	L	86.7	38	47	61	74		0.00%
	57	R	86.7	38	38	57	78		7.77%
	63	L	21.15	12	52	42	65	122	19.59%
	63	R	21.14	12	52	42	65	122	24.15%
	71	L	92.2	38	40	34	40		0.00%
	71	R	92.2	38	50	34	114		23.89%
	81	R	58.5	38	65	36	65		0.00%
	81	R	58.6	38	61	39	82		3.07%
	86	L	86.8	38	23	36	51	91	45.86%
	86	R	86.8	38	16	35	77	126	68.34%
	94	L	1	40	49	58	63	107	15.80%
	94	R	1	40	53	49	47	109	15.41%
	99	L	77.9A	38	29	49	58		6.18%
	99	R	77.9A	38	38	49	63		3.29%

Voltage	SamplePoint	Side	StructureID	WireZone	ClearWidth	LineHeight	CODSTreeHeight	DOMTreeHeight	RiskFactor
230	106	L	10.1	24	58	38	60	90	6.63%
	106	R	10.1	24	92	35	53	140	7.97%
	108	L	1	60	38	89	55	93	0.00%
	108	R	1	60	33	79	92		18.18%
	116	L	17.2	38	34	33	58		14.75%
	116	R	17.2	38	39	34	72		16.49%
	125	L	12.7	26	88	47	85		0.00%
	125	R	12.6	26	113	40	83		0.00%
	131	L	17.1	38	58	65	79		0.00%
	131	R	17.1	38	53	63	98		9.30%
	144	L	1	25	21	54	60		13.57%
	144	L	2	25	49	69	73		0.00%
	145	L	70.5	40	57	67	89		0.53%
	145	R	70.5	40	54	68	112		10.70%
	161	L	107.6	36	69	36	68	77	0.00%
	161	R	107.4	39	33	34	30		0.00%
	162	L	1	40	56	54	116		16.15%
	162	L	2	40	54	54	97		12.00%
	163	L	1.28	30	64	33	46	112	11.96%
	163	R	1.28	32	40	36	52	101	25.15%
	174	R	1	43	20	74	47	95	37.37%
	174	R	2	43	20	70	56	88	31.78%
	197	R	90.7	38	38	50	154		45.02%
	197	R	90.8	38	40	45	134	151	42.03%
	202	L	5.13	8	80	48	48	78	0.00%
	202	L	5.14	8	77	48	44	84	0.00%
	207	R	68.6	38	42	43	72		6.39%

Voltage	SamplePoint	Side	StructureID	WireZone	ClearWidth	LineHeight	CODSTreeHeight	DOMTreeHeight	RiskFactor
230	207	R	68.7	38	28	55	81		22.99%
	215	R	55.7	38	53	34	83		11.53%
	215	R	55.8	38	65	26	77		3.97%
	216	L	13.6	26	91	48	66		0.00%
	216	R	13.6	26	77	50	58		0.00%
	234	L	26.7	26	25	50	46	87	34.53%
	234	R	26.7	26	82	50	42	82	0.00%
	241	L	25.5	26	93	39	56	85	0.00%
	241	R	25.4	26	109	41	50	201	13.48%
	261	R	83.6	38	21	43	133		60.87%
	261	R	83.7	38	24	39	98		45.53%
	401	L	20.1	38	62	40	68		0.00%
	401	L	20.2	38	61	40	63		0.00%
Summary for 'Voltage' = 230 (62 detail records)									
Avg				*34*	*52*	*48*	*72*	*105*	*13.55%*
55	16	L	21.15	10	24	45	102		44.61%
	16	R	21.15	10	29	45	95		33.57%
	34	L	1.3	1	27	54	127		48.58%
	34	R	1.5	1	55	64	92		4.65%
	78	L	22.15	10	50	40	126		25.82%
	78	R	22.15	10	24	40	100		44.30%
	102	L	7.17	7	30	40	55	92	31.64%
	102	R	7.17	7	30	40	92		32.59%
	114	R	1	20	25	36	105		45.75%
	114	R	2	20	35	36	107		34.50%
	115	L	1	1	15	60	57		0.00%
	115	R	1	1	40	63	72		0.00%

Voltage	SamplePoint	Side	StructureID	WireZone	ClearWidth	LineHeight	CODSTreeHeight	DOMTreeHeight	RiskFactor
55	123	R	1	7	16	53	84		0.00%
	123	R	2	7	18	52	84		0.00%
	124	L	1	8	19	34	163		70.70%
	124	R	1	8	60	34	84		5.00%
	127	L	27	6	22	26	91		45.45%
	127	R	27	6	17	26	91		56.32%
	136	L	1	0	71	36	84		3.91%
	136	L	2	1	75	34	75		0.00%
	159	L	164	8	8	31	79		73.95%
	159	R	164	8	11	30	77		65.60%
	187	L	7.3	9	21	32	39	63	31.87%
	187	R	7.3	9	26	43	48		0.00%
	198	L	1	6	20	36	140		64.86%
	198	R	1	6	28	36	97		38.70%
	210	L	6.6	8	26	21	66	80	36.27%
	210	R	6.6	8	75	26	54		0.00%
	235	L	1	20	58	54	98		6.64%
	235	R	1	20	28	54	92		31.41%
	240	L	1	7	69	53	89		1.11%
	240	L	2	8	55	46	115		17.12%
	245	L	21.4	10	37	50	84		16.32%
	245	R	21.4	10	42	52	110		24.48%
	247	L	23.4	9	31	58	75		22.20%
	247	R	23.4	9	40	49	75		17.73%
	251	L	1	7	43	45	52		0.00%
	251	R	1	6	23	54	66		17.60%
	256	L	1	5	104	40	78	146	5.06%

Voltage	SamplePoint	Side	StructureID	WireZone	ClearWidth	LineHeight	CODSTreeHeight	DOMTreeHeight	RiskFactor
55	256	R	1	5	49	46	89	118	23.28%
	402	L	39.3	12	28	44	98		36.89%
	402	L	39.4	12	30	45	105		37.22%
	403	L	25.7	10	21	44	121		57.25%
	403	L	25.8	10	20	44	117		57.71%
Summary for 'Voltage' = 55 (44 detail records)									
Avg				*8*	*36*	*43*	*90*	*100*	*27.52%*
66	17	L	9	6	40	37	63	96	25.72%
	17	R	8	6	40	43	102		25.92%
	97	L	1	6	135	41	46	107	0.00%
	97	R	1	6	17	45	60	122	64.53%
Summary for 'Voltage' = 66 (4 detail records)									
Avg				*6*	*58*	*42*	*68*	*108*	*29.04%*

Tree Failure Rates

Wind Speed	Per Wind Incident Tree Failure rate	Wind Speed	10 Year Failure rate (DT)
		1	2.1308E-08
		2	1.04926E-07
		3	2.66572E-07
		4	5.16418E-07
		5	8.6216E-07
		6	1.30984E-06
		7	1.86417E-06
		8	2.52859E-06
		9	3.30531E-06
		10	4.19521E-06
		11	5.19777E-06
		12	6.31092E-06
		13	7.53097E-06
<15	1.14352E-08	14	8.85243E-06
15	1.14105E-08	15	1.17682E-05
16	1.15397E-08	16	1.33419E-05
17	1.18086E-08	17	1.49758E-05
18	1.22107E-08	18	1.66543E-05
19	1.27445E-08	19	1.83604E-05
20	1.34132E-08	20	2.00749E-05
21	1.42239E-08	21	2.17774E-05
22	1.51869E-08	22	2.34459E-05
23	1.63166E-08	23	2.50576E-05
24	1.76304E-08	24	2.65891E-05
25	1.91499E-08	25	2.80171E-05
26	2.0901E-08	26	2.93185E-05
27	2.29141E-08	27	3.04713E-05
28	2.52252E-08	28	3.14549E-05
29	2.78762E-08	29	3.22511E-05
30	3.09165E-08	30	3.28439E-05
31	3.44033E-08	31	3.32211E-05
32	3.84037E-08	32	3.33735E-05
33	4.29954E-08	33	3.32965E-05
34	4.82696E-08	34	3.24557E-05
36	6.13067E-08	36	3.1704E-05
37	6.93376E-08	37	3.07468E-05
38	7.85932E-08	38	2.96006E-05
39	8.92704E-08	39	2.82857E-05
40	1.01599E-07	40	2.68252E-05
41	1.15848E-07	41	2.52449E-05

42	1.32333E-07	42	2.18352E-05
44	1.73547E-07	44	2.00623E-05
45	1.99214E-07	45	1.82813E-05
46	2.29018E-07	46	1.65183E-05
47	2.63655E-07	47	1.47974E-05
48	3.03946E-07	48	1.314E-05
49	3.50852E-07	49	1.15642E-05
50	4.05505E-07	50	8.71372E-06
52	5.43613E-07	52	7.45779E-06
53	6.30482E-07	53	6.32149E-06
54	7.32016E-07	54	5.30579E-06
55	8.50779E-07	55	4.40879E-06
56	9.89796E-07	56	3.62613E-06
57	1.15263E-06	57	2.95146E-06
58	1.34351E-06	58	2.37691E-06
59	1.56739E-06	59	1.8936E-06
60		60	1.492E-06
61		61	6.81667E-07
64		64	5.12848E-07
65		65	2.02952E-07
68		68	1.453E-07
69		69	1.453E-07