# Kangley – Echo Lake Double-Line Outage Probability Analysis

**May 28, 2002 RPEWG Approved**

**William A Mittelstadt wmittelstadt@bpa.gov**
**Bonneville Power Administration TBL**

## Executive Summary

This report presents an analysis of the risk of a double-contingency outage of the Raver – Echo Lake 500 kV line and the planned re-termination of the Schultz – Raver 500 kV line to Echo Lake Substation that will share common rights of way (ROW) for 9.5 miles. For simplicity this is known as the Kangley – Echo Lake case. The case is also intended to serve as a model for analysis of other projects in the WECC system having low risk of occurrence submitted to the approved WECC Phase I Probabilistic Based Reliability Criteria (PBRC) Performance Category Evaluation (PCE) Process. Under this process a project with an accepted Mean Time Between Failure (MTBF) in the range 30 to 300 years may be adjusted to Category D but with the added condition of "No Cascading" allowed. A project with a MTBF in excess of 300 years is considered an "Extreme Event" in the same sense as all other events in NERC Category D. This presentation follows the Probability Reliability Evaluation Work Group (RPEWG) recommended steps given in Appendix A.

Analysis of the Kangley – Echo Lake case indicates that this double contingency (N-2) qualifies to be moved to Category D. This is based on the following findings and mitigating factors:

- Robust design features are applied to this corridor including single pole reclosing, overhead ground wires and 2.0 per-unit design
- The primary time of peak loading on the Kangley – Echo Lake corridor will be in the winter period whereas the highest historical record of line outages west of the Cascades is in the summer period.
- The estimated exposure time during which an N-2 outage may result in flows outside defined limits is less than 50 hours/year out through the year 2010.
- Operation outside defined limits constitutes a thermal overload rather than a voltage or transient stability consequence.
- Historical operation once the Schultz-Raver line has been reterminated at Echo Lake in 2002 or 2003 will provide additional demonstration of line performance.
- The estimated MTBF considering some of the key mitigating factors is in excess of 450 years. (The estimated MTBF without mitigating factors is 22 years.)

Based on these findings it is recommended that this N-2 outage be moved to Category D (Extreme Events) with no other conditions or requirements.

The material presented in this report constitutes a reasonable basis for analysis of N-2 line outage events in the Performance Category Evaluation process for use by WECC member systems.

# Introduction

The WSCC (now WECC) has approved the use of probabilistic analysis for transmission system planning. The long range plan is to consider three factors: outage probability, event impact, and event cost. In this context the composite risk associated with a set of events for a particular contingency (i.e. Kangley – Echo Lake N-2) is:

$$Risk = \sum_{z \, \varepsilon \, Z} P_z I_z C_z$$

where

> $\boldsymbol{P_z}$ is the probability of event z
> $\boldsymbol{I_z}$ is the Impact of event z
> $\boldsymbol{C_z}$ is the associated cost of event z
> **z** is summed over the set of all events **Z** for a particular contingency

The Phase I implementation which has been approved by WECC addresses event probability. Since procedures for addressing impact and cost have not yet been developed these elements are brought into the analysis qualitatively. Impact includes a description of the consequences (for example loss of load) and the amount of time the system would be exposed to that impact (exposure). Cost is an estimate of the dollar value of the impact sustained, for example $/MW.

Phase I standards are based on an estimate of event Mean Time Between Failure (MTBF). Looking at the probability of all events in isolation presents a difficulty since the sum of the products is not equal in general to the product of the sums as shown below:

$$Risk = \sum_{z \in Z} P_z I_z C_z \neq \sum_{z \in Z} P_z \sum_{z \in Z} I_z \sum_{z \in Z} C_z$$

Accordingly, to perform this analysis correctly the events are separated into two groups:
Group x: summed over the set of all events **X** for which an impact may occur; and
Group y: summed over the set of all events **Y** for which events which no impact will occur.

$$Risk = \sum_{x \in X} P_x I_x C_x + \sum_{y \in Y} P_y I_y C_y$$

The later class (y) represent reasonable exclusions where it is reasonably understood that no impact would occur at any time. The Phase I MTBF therefore may be estimated on the summation of events for which an impact is possible and treating the impact and cost as being the same for all outages:

$$Risk = I \bullet C \sum_{x \in X} P_x = I \bullet C / MTBF$$

where

$$MTBF = 1/(\sum_{x \in X} P_x) \, .$$

## Project Description

The Bonneville Power Administration plan of service addressed in this report is to re-terminate one of the Schultz – Raver 500 kV lines into Echo Lake. The re-terminated line will run 9.5 miles on a common right of way with the existing Raver – Echo Lake 500 kV line.

This project represents an improvement in reliability over the present system because it relieves dependence on the Raver-Echo Lake 500 kV line in the south to north direction. This is accomplished by shifting a portion of the 2200 MW of flow from Raver to Echo Lake onto the Schultz-Raver #2 500 kV line. Early project plans were to construct a second Raver-Echo Lake 500 kV line however the present plan was found to be less costly and more reliable. The cost is lower due to shorter line construction and the need to add only one 500 kV line terminal rather than two. The preferred plan distributes the cross-Cascade flow more evenly to the 500/230 transformation in the Seattle area, minimizes parallel line placement in the Raver-Echo Lake corridor, increases reactive margin in the area and reduces the impact of the low probability loss of the entire Raver station. It was also found that future 500/230 transformation in the Puget Sound area can be delayed a few years because of the more even distribution of cross-Cascade flow and that the project improves South to North transfer capability to deliver U.S.-Canadian Treaty power to Canada during winter peak load conditions. And finally, with series capacitors installed at Schultz on the Schultz-Raver #1 and the Schultz-Echo Lake lines, flow can be controlled between Raver and Echo Lake by judicious switching of the series capacitors at Schultz, increasing the flexibility of the system for outages.

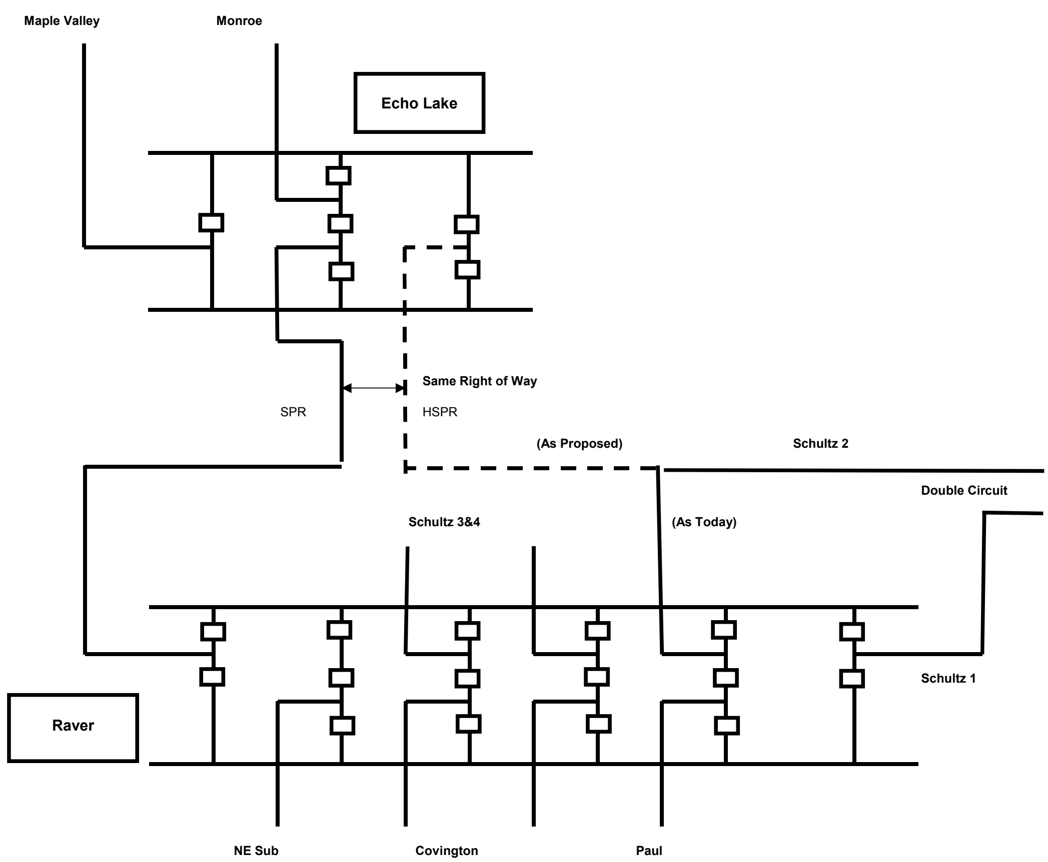



**Figure 1. Substation Configurations**

## Mitigating Factors

*Physical Layout and Transmission Construction*
Separately provided Adobe files illustrates the physical layout of the project. The new construction connecting the Schultz line to Echo Lake from Kangley will be on single circuit steel tower with average span length of 1150 feet, centerline spacing of 150 feet and 2.0 per unit clearances. Standard spacing is 125 feet. The ROW in this area is mostly forested over mostly flat and rolling and some steep terrain and has a length of 9.5 miles. The new line section from Kangley to Echo Lake will be shield wire equipped. The existing Raver – Echo Lake line is not shield wire equipped. Tables 1-3 (page 14) provides a summary of circuit information.

*Substation Configurations*
Figure 1 illustrates the layout of Raver and Echo Lake Substations. These are both breaker and half arrangements. Since Echo Lake is the only substation common to both lines the risk of terminal caused outages is cut in half. At Echo Lake it would require a combination of both a breaker out for maintenance and either a (1) stuck breaker or (2) false trip for a fault on one line to result in loss of both circuits due to station configuration.

*Protective Relaying*
The relaying on the existing Raver-Echo Lake 500 kV line will be replaced with state-of-art conventional single pole relaying. The total line length is 12 miles. The Schultz – Echo Lake 500 kV line (77 miles) will be equipped with new state-of-art Hybrid Single Pole Switching. With hybrid single pole relaying, the 1LG fault is tripped single pole initially at about 3 cycles; opened three pole at 50 cycles; and reclosed three pole at 65 cycles. Relays used by BPA are tested by EMTP simulator before installation. However, for the case under consideration high-speed three-pole reclosing is sufficient since the contingency is not stability limited.

*Isochronic Level*
A separately provided Adobe file illustrates that the parallel ROW will be in a low isochronic level area of not more than 3 lightning events per square mile in a seven year period. The west of the Cascades is typically a low lightning occurrence area compared to other areas in the WECC.

*Aircraft Hazard*
The closest public airport is about 4.5 miles (Sultan Public Airport). The right of way is of very low hazard from aircraft.

*Fire Hazard*
During the period 1/1/1990 to present there have been no outages on the Raver – Echo Lake 500 ROW due to fire. Also, no fire caused outages have been recorded on the Monroe – Custer or Paul Allston 500 kV ROWs. Raver – Echo Lake is not an agricultural area subject to field burning. Risk of brush fire would be extremely low during the winter season when highest loads are experienced. The largest percentage of line outages due to fire in the NW occur on areas east (other side) of the Cascade Mountains. Risk of fire outage of the lines on this planned ROW is considered as low.

## Identification of Statistical Base

Statistics have been acquired from historical records on the following cases of two lines on the same right of way west of the Cascade Mountains. These were selected on the basis of having terrain and climatic conditions similar to the Kangley – Echo Lake corridor. These in combination provide over 2715 mile-years of historical data spanning a period of 17 years.

| | |
|---|---|
| 1. Monroe – Custer 500, 1&2 | 89 miles |
| 2. Paul – Allston 500, 1&2 | 48 miles |
| 3. Custer – Ingledow 500, 1&2 | 23 miles |

Table 4 provides a summary of line outage events since January 1, 1985 for these three corridors. Those cases of overlapping events to be used for this analysis are shown as shaded. Also shown as information whether or not each case is equipped with single pole reclosing (SPR) and/or overhead ground wire (OHGW).

History files for the Echo Lake – Raver and Schultz – Raver #2 lines from the time the Echo Lake Substation was established (11/93) to present have not shown any overlapping outages of these same two lines which are the same lines which will constitute the Kangley – Echo Lake corridor once the Schultz line is reterminated at Echo Lake.

## MTBF Analysis Part I – Uncorrected

### Analysis of Historical Events

The analysis presented in this section treats the historical data simply at face value and does not take into consideration differences in the Kangley – Echo Lake corridor from the historical data base used nor other mitigating effects.

First N-2 events 1-5 in Table 4 are examined. In this record there is one terminal related outage and four line related outages over the 17 year period for data representing 2715 mile-years of historical information. Without consideration of differences in the Kangley – Echo Lake case this leads to the following simple estimation of outage probabilities:

Terminal Caused Events

P = (1 event)(1 terminal K-EL/2 terminals in data)/(17 years) = 0.029 events/year

Line Caused Events

P = (4 events)(9.5 miles K-EL)/(2715 mile-years of data) = 0.014 events/year

### *Independent Events*

In addition to the above historical record we consider the likelihood of independent events on each line that would result in loss of both lines on the ROW. For the purpose of this analysis to be considered a threat the two events must be considered to happen within 30 minutes, a period before readjusted. By examining the historical records of Raver – Echo Lake and Schultz – Raver 1-4 we arrive at the following statistics:

| Category | | Raver – Echo Lake | Schultz - Raver |
|---|---|---|---|
| Events | | 4 | 29 |
| Mileage | | 12 | 77 |
| Outage Rate (events/year/mile) | x | 0.0465 | 0.0119 |
| Average Outage Duration (minutes) | y | 3.75 | 13.7 |
| Joint Probability | | 3.65 E-06 | 1.33 E-05 |

Table 6. Line outage event history

In each case the joint probability is computed as the probability that the first line will trip out multiplied by the conditional probability that the second line will trip out as indicated by the bracketed terms (i.e. if A, then B plus if B then A):

Joint Probability = [(Line 1 x)(Line 1 miles)][(Line 1 y/8760/60) (Line 2 x)(Line 2 miles)]

P = 3.65E-06 + 1.33E-05 events/year

***Human Caused Events***
Over the period 1985 through 2001 (17 years) BPA experienced 21 events resulting in two or more outages on the 500 kV grid categorized as HUMAN ELEMENT caused. There are a total 470 combinations of pairs of lines leaving the 500 kV stations. The uncorrected probability of this occurring at the Echo Lake Substation is simply computed as follows:

P = (21 events)/((17 years)(470 combinations)) = 0.0027 events/year

***Breaker Maintenance and Breaker Failure Caused Events***
Breaker maintenance on the 500 kV system is an average of two days per year and is scheduled when a system impact risk is not present. Modern 500 kV breaker failures (Puffer type) occur at the rate of once per 479 years. This is based on statistics from CIGRE surveys[2] conducted in 1981 and 1994 (does not open on command; does not interrupt current). The estimated probability of a breaker failure occurring during the two day maintenance period considering the two combinations that are possible is:

Py = (2 days/365 days/year)(2 combinations/479 years) = 2.29 E-5 events/year

**Composite MTBF Estimate (Uncorrected)**

In this section we combine the results from the historical analysis and the analysis of predictable events. The following Table 7 summarizes the individual and composite results.

| Event | P | MTBF |
|---|---|---|
| Case | Events/year | years |
| Historical | | |
| Terminal | 2.94E-02 | 34 |
| Line | 1.40E-02 | 71 |
| Independent | 3.65E-06 | 273973 |
| Independent | 1.33E-05 | 75188 |
| Human | 2.73E-03 | 366 |
| BF&M | 2.29E-05 | 43668 |
| Total | 4.62E-02 | 22 |

Table 7. Summary of results (uncorrected).

## MTBF Analysis Part II – Corrected

### Analysis of Historical Events

The MTBF analysis just presented represents a face value analysis and does not take into consideration design features unique to the Kangley – Echo Lake corridor nor the mitigation factors discussed. For this reason we will reexamine the validity of each statistic from Table 4 as to its applicability to the proposed corridor and make any adjustments as needed. Governing factors used in this analysis are as follows:

1. Lightning performance with and without static wires
2. Effect of high-speed reclosing, single pole reclosing or hybrid single pole reclosing
3. Station configuration
4. Maintenance practices

***Lightning Performance***
Historical outage information developed for NW 500 kV transmission grid indicates that the outage rate for lines equipped with overhead ground wires (OHGW) is approximately 25% (1/4) of that for lines without OHGW as shown in Table 5. This fact will be used in estimating the outage probability of the lightning caused events in Table 4.

***Event 1***
This case shows the cause of the two line outage to be "lightning/configuration." This event is the case of a breaker out for maintenance at Allston and a fault occurring on the Paul-Allston #2 line. The Paul-Allston #1 line tripped out as a result of misoperations of a transformer protection relay. This case is not applicable to Echo Lake since a transformer is not involved. The estimation of the probability of a breaker failure and breaker under maintenance is estimated separately in this report.

***Event 2***
The second event is due to lightning initiating outage of both lines for 2-3 minutes. Since the Paul – Allston lines are not equipped with OHGW it is reasonable to assume that likelihood of

this event will be reduced for the new construction portion Kangley – Echo Lake. Accordingly the probability of this N-2 event is divided by four

Px = (1 event)(9.5 miles)/(2715 mile-years)/4 = 8.75E-04 events/year
Py = 0

***Event 3***
This case shows the cause of the two line outage to be "weather." The Monroe-Custer #1 line recloses within the same minute as the initiating fault and the #2 line recloses within two minutes. This is treated as a y class event since high-speed reclosing is involved and the outage thermal limited. If it were determined to be lightning it would reduced by 25%.

Px = 0
Py = (1 event) (9.5 miles)/(2715 mile-years) = 3.50E-03 events/year

***Event 4***
This case shows the cause of the two line outage to be "lightning." The Monroe-Custer #2 line recloses within the same minute as the initiating fault and the #1 line recloses within five minutes. This is treated as a y class event since high-speed reclosing is involved and the outage thermal limited. Addition of the OHGW to the Schultz – Echo Lake line reduces the risk of this event by a factor of four.

Px = 0
Py = (1 event) (9.5 miles)/(2715 mile-years)/4 = 8.75E-04 events/year

***Event 5***
This case shows the cause of the two line outage to be "lightning." The Monroe-Custer #1 and #2 lines both reclose within the same minute as the initiating fault. This is treated as a y class event since high-speed reclosing is involved and the outage thermal limited. Addition of the OHGW to the Schultz – Echo Lake line reduces the risk of this event by a factor of four.

Px = 0
Py = (1 event) (9.5 miles)/(2715 mile-years)/4 = 8.75E-04 events/year

***Independent Events***
No changed is introduced here relative to the information in Part I.

***Human Caused Events***
Over the period 1985 through 2001 (17 years) BPA experienced 21 events resulting in two or more outages on the 500 kV grid categorized as HUMAN ELEMENT caused. Of these a total of 10 are be classified as not preventable. Preventable human caused events are those that would be avoided by not scheduling substation maintenance and testing during times at which a two line outage would place the system at risk. For 10 non-preventable events occurring within a sample of thirty four 500 kV stations in a 17 year period the estimated MTBF of loss of the Echo Lake – Raver and Echo Lake – Schultz line is 799 years. The probability analysis is based on the assumption that human caused trip of any pair of two lines in the substation is equally probable. The number of combinations that can occur for each substation is determined (for example a substation with six lines has 15 combinations. The calculation is as follows:

Px = (10 events)/((17 years)(470 combinations)) = 1.25E-03 events/year
Py = (11 events)/((17 years)(470 combinations)) = 1.38E-03 events/year

***Breaker Maintenance and Breaker Failure Caused Events***
The analysis is the same as Part I except for the distinction that the breaker failure under breaker maintenance conditions is considered a no-impact event since breaker maintenance would be scheduled at a time that there would be no impact for the N-2 system outage. Accordingly, the estimated probability of a breaker failure occurring during the two day maintenance period is:

Px = 0
Py = (2 days/365 days/year)(2 breaker failure/479 years) = 2.29 E-5 events/year

**Composite MTBF Estimate (corrected)**

In this section we combine the results from the historical analysis and the analysis of predictable events. The following table shows the individual and composite results. The estimated MTBF for the Kangley – Echo Lake corridor for which there may be a risk of system impact is 470 years.

| Event | $P_X$ | $MTBF_x$ | $P_Y$ | $MTBF_Y$ |
|---|---|---|---|---|
| Case | Events/year | years | Events/year | years |
| Event 2 | 8.75E-04 | 1140 | 0.00E+00 | |
| Event 3 | 0.00E+00 | | 3.50E-03 | 286 |
| Event 4 | 0.00E+00 | | 8.75E-04 | 1140 |
| Event 5 | 0.00E+00 | | 8.75E-04 | 1140 |
| Independent | 3.65E-06 | 274000 | 0.00E+00 | |
| Independent | 1.33E-05 | 75100 | 0.00E+00 | |
| Human | 1.25E-03 | 800 | 1.38E-03 | 725 |
| BF&M | 0.00E+00 | | 2.29E-05 | 43700 |
| Total | 2.14E-03 | 470 | 6.63E-03 | 151 |

Table 8. Summary of results.

Based on this analysis the estimated MTBF for Kangley – Echo Lake applicable to the Phase I process is 470 years. Considering only that portion that is related to lines being on the same ROW the estimate is 1140 years.

**Exposure Analysis – Seasonal Considerations**

Based on the whole year corrected analysis we conclude that the estimated MTBF is well above the threshold for no cascading of 300 years. As a further consideration it is noted that the period of greatest incidence if lightning is May through October. The risk of incurring a system impact is further reduced by limiting operation above the defined operating limit to the period November through April.

**Exposure Analysis – Load Duration Curve**

Exposure as used here is simply that fraction of time that the system would be exposed to operation outside normal planning limits should a N-2 outage occur. To make this assessment we start by examining historical flows on the Raver – Echo Lake 500 kV line. This is done by making a composite of the years 1999-2001 and plotting a load duration curve as shown in Figure 2. Further, since these years did not experience an 1:20 extreme cold weather condition one of the three years the load duration curve was recalculated with a 12% increase in loading for a period of 10 days during the heaviest loading period of the winter. This difference is also shown on the load duration curve.

Next, we turn attention to the January 2006 Normal Winter base case with stressed representation. This case represents a combined Raver – Echo Lake and Schultz – Raver #2 flow of 3000 MW. The limiting flow at which the outage of these two lines results in an outage is determined by studies to be 2830 MW at which point the two Covington 230/115 kV banks reach the bushing limit of 1250 MVA. Figure 3 is a realignment of the load duration curves of Figure 2 such that the normal winter peak corresponds to 3000 MW. This figure also includes a curve adjusting the flow to the year 2010 assuming 1.53% load growth and raising the Canadian Entitlement return from 1275 MW to 1500 MW. This results in an exposure increasing from 2 hours/year to 41 hours per year over the period 2006 to 2010 assuming extreme cold weather in one of three years.

While various factors can increase the exposure time this serves to illustrate that overall the exposure to impacts from the N-2 outage is very small. If in Phase 2 the risk is computed based on the conditional probability of the outage and being in a condition of risk assuming 2010 exposure, the likelihood of an event occurring at the time of risk would be further reduced by the factor (41/8760)). While this method is not a forecast of what will actually happen, it clearly indicates that the risk to the system is extremely low.

**Impact Analysis**

This section describes briefly the impact of a sustained two line outage of the Kangley-Echo Lake corridor at a time when the system would be in an exposure condition as discussed in the previous section. The potential impact is thermal overload of Covington 500/230 banks 4 and 5 and their respective bushings above the following established emergency limits:

| | |
|---|---|
| Covington 500/230 #4 bank limit | 1428 MVA |
| Covington 500/230 #5 bank limit | 1422 MVA |
| Covington 230 #4 bushing limit | 1250 MVA |
| Covington 230 #5 bushing limit | 1250 MVA |

By 2006 it is planned to replace the bushings which will raise the emergency thermal limit to the bank limit. In the event that the loading exceeded the emergency ratings the banks would continue to operate but incurring loss of life. Relays are not used to remove the banks from service on overcurrent so the banks would remain in service until operator action is taken.

Proper modeling of the system impact in the event that the disturbance propagated from loss of the two 500 kV lines as well as the two Covington transformer banks would require detailed modeling of load representation under tap changer action, a capability not in use by WECC members. However, within the context of present capabilities a transient stability study was performed. The result of this 20 second study is illustrated as Figure 4. No transient stability problems are observed in the case and the lowest voltage observed in the system during the 20 second study was a drop of about 11% at BALDI 230. Generator field voltages were not observed to exceed their over-excitation limit. Figures 5 and 6 illustrate pre- and post-disturbance flows.

**Alternatives**

Alternatives for re-termination of the Schultz – Raver 500 kV line to Echo Lake Substation are detailed on a separate fact sheet provided with this report. Four other alignments of the line into Echo Lake across the Cedar River Watershed are detailed that are similar electrically but with shorter mileages of parallel construction (alternatives 2,3,4A and 4B). These of equal or greater MTBF than the corridor evaluated in this report (alternative 1). Also presented are four other electrically different alternatives (A,B,C,D).

**Conclusions**

- A statistical corridor analysis has been conducted for the Kangley – Echo Lake N-2 corridor outage based on statistics from similar lines. Taking into consideration robustness features planned for this case it has been estimated that the MTBF is over 450 years. The estimate would be significantly large if factors not related to lines on the same ROW were omitted.
- The risk of a two line outage is further reduced during the period November through April when the likelihood of a lightning caused outage is minimal. This is the period under south to north transfers during which transfers over the corridor are expected to be highest.
- By analysis of the historical loading on the Raver – Echo Lake and Schultz – Raver lines it has been estimated that flows on this corridor will have a very low likelihood of exceeding the level where impacts would be sustained for the N-2 outage. The joint probability of this N-2 outage at a time the outage would exceed the Covington 500/230 bank limit is extremely small corresponding to the range 2-41 hours/year over the period 2006 through 2010. The joint probability of an N-2 outage and being exposed to system risk is extremely small.
- In the event of a sustained outage of both lines in the Kangley – Echo Lake corridor at a time when flows exceed a defined limit for this outage the immediate result will be to exceed the thermal design limit of the emergency 1250 MVA bushing limit of the Covington 500/230 kV banks. By 2006 BPA will have replaced the bank bushings, increasing the operating limit to the 1422 and 1428 MVA emergency ratings of the banks that will further reduce risk. The expected impact of operation above the bank emergency limit would be transformer bank loss of life. Transient stability studies assuming loss of the two lines followed by outage of the Covington banks does not result in system cascading.
- Historical records will be maintained once the Schultz – Raver line has been moved to the Kangley – Echo Lake corridor. The estimate of MTBF will be revised as appropriate based on actual performance.

Additional information in line outage history data used in this report is available on request.

## References

[1] "An IEEE Survey of U.S. and Canadian Overhead Transmission Outages at 230 kV and Above," Data Analysis Task Force, Working Group on Statistics of Line Outages, IEEE paper 93 WM 054-7 PWRD.
[2] CIGRE Study Committee 13 Report.
[3] Data taken from BPAT Operations and Planning Historical Outage Database.

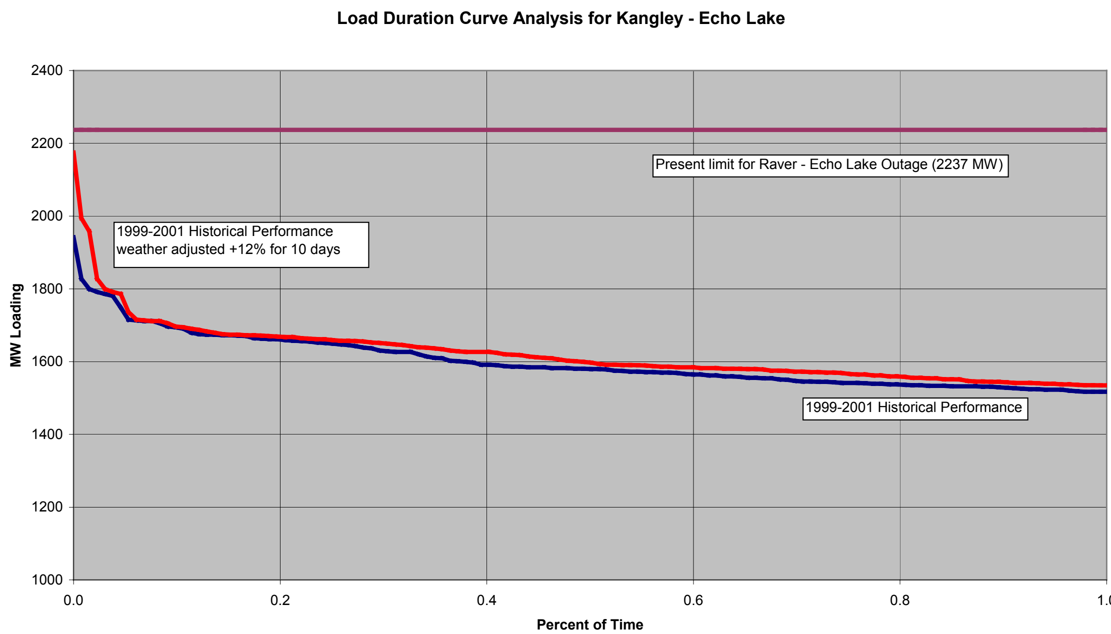



**Figure 2. Load duration curve based on historical records 1999-2001.**

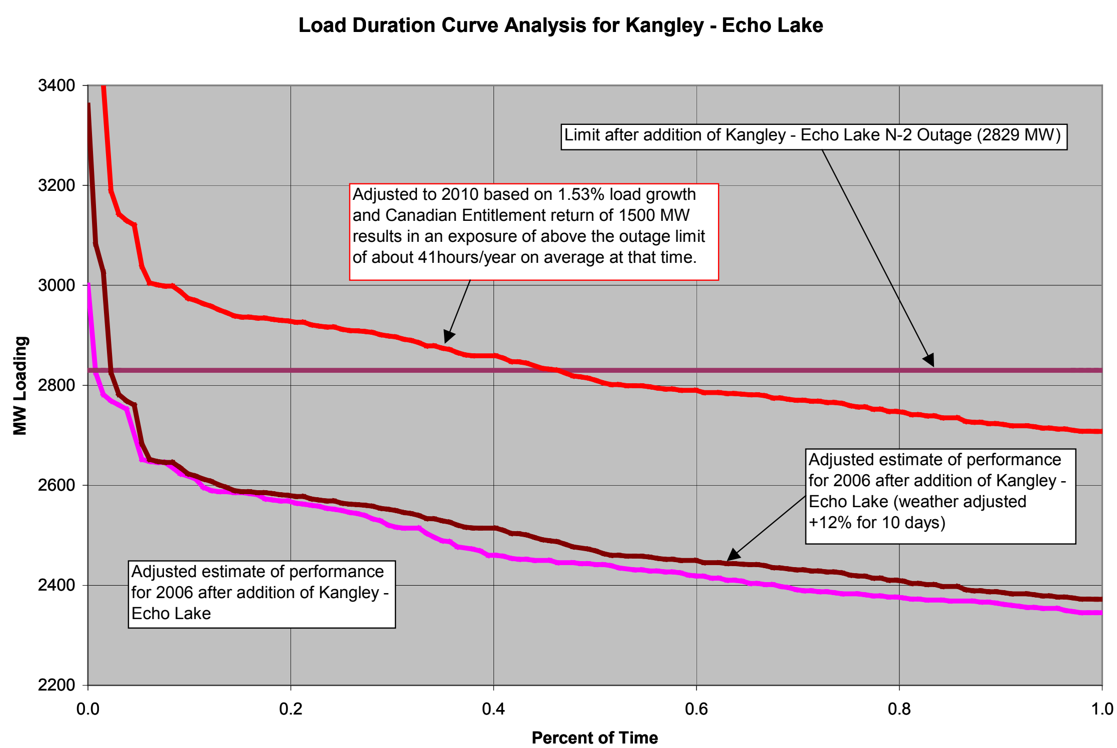



**Figure 3. Load duration curve adjusted to represent January 2006 conditions.**

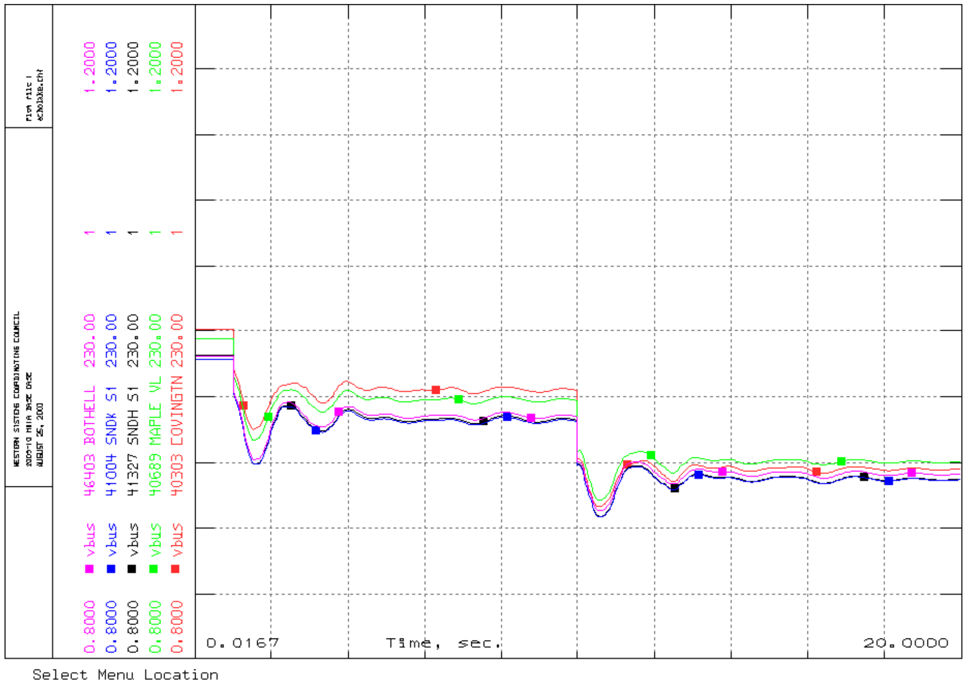


**Figure 4. Transient stability study for loss of Raver-Echo Lake and Schultz-Echo Lake followed by loss of both Covington 500/230 kV banks. Lowest voltage deviation during the swing is to 0.89 PU at BALDI 230.**

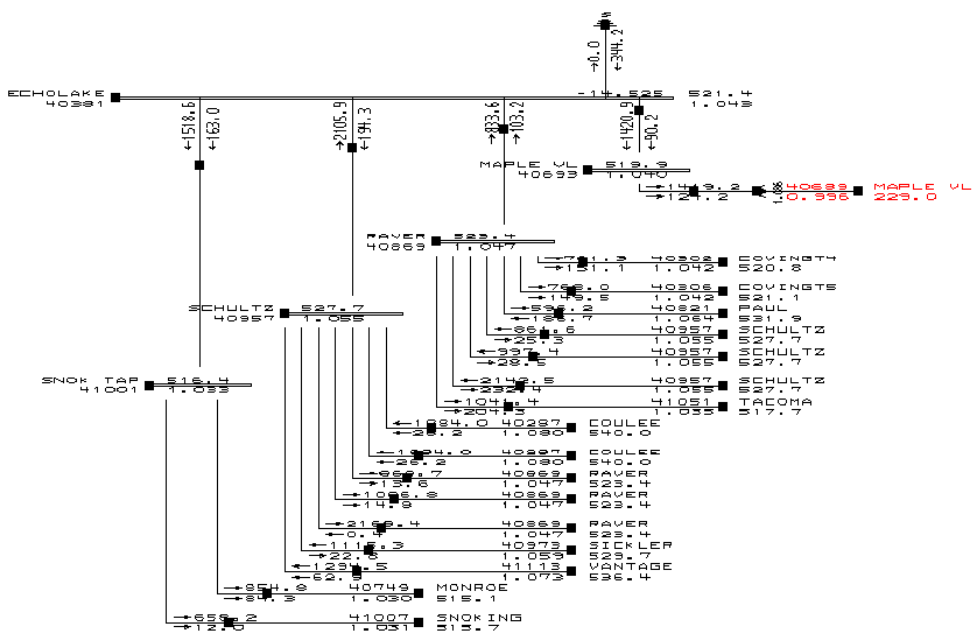


**Figure 5. Pre-disturbance flows for case of Figure 4.**

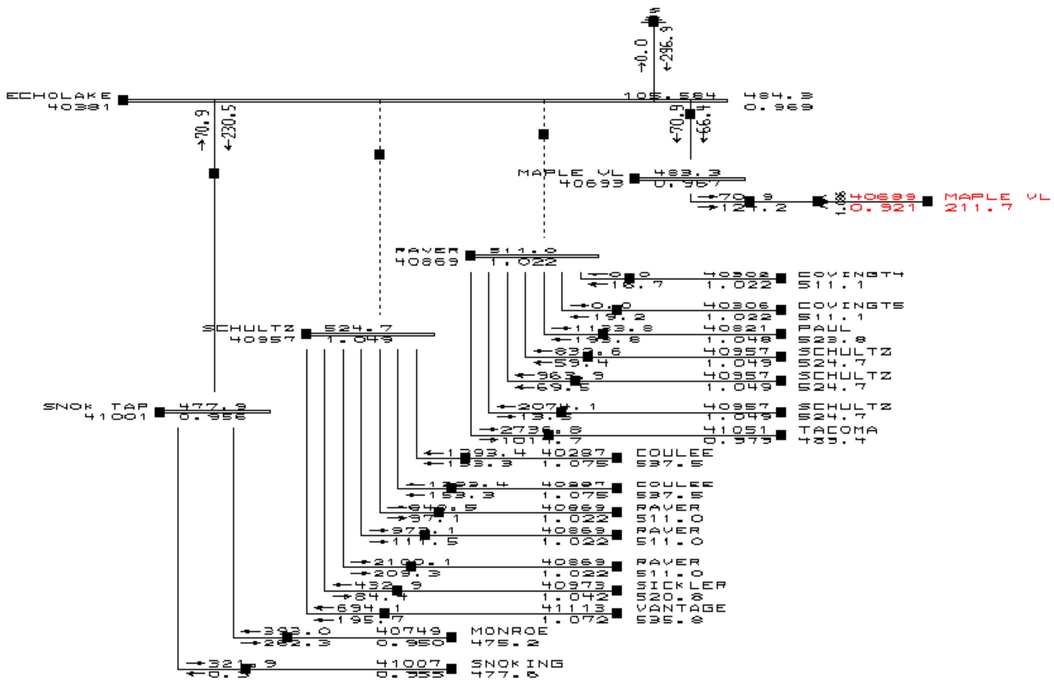



**Figure 6. Post-disturbance flows for case of Figure 4.**

Table 1. Inventory

| Approx year of Initial Operation | Voltage | Owners | Circuit Description | Length (miles) |
|---|---|---|---|---|
| Nov-93 | 500 | BPA | Raver - Echo Lake | 12 |
| Sep-94 | 500 | BPA | Schultz - Raver #2 | 77 |
| | | | | |

Table 2. Multiple Circuit Corridor

| Corridor Information | | | | Identification of Circuits in the Corridor | |
|---|---|---|---|---|---|
| Corridor Description | Number of Circuits In Corridor | Number of Circuits on Multi-circuit Structures | Total Length of Common Corridor (miles) | Name of Circuit #1 | Name of Circuit #2 |
| Kangley - Echo Lake | 2 | 0 | 9 | Raver - Echo Lake | Schultz - Raver #2 |
| | | | | | |

Table 3. Line Crossings

| Circuit A - (Circuit on Top) | Circuit B - (Circuit Below) | Circuit C - (Circuit Below) |
|---|---|---|
| No 500 kV crossings involved | | |
| | | |

Table 4. Specific Outage Information Used [3].

| Event | line name | out datetime (datevalue) | in datetime (datevalue) | Min. Ovlp. | dispatcher cause | SPS Equipt | OHGW Equipt | Kangley - Echo Lake Adjustment Basis |
|---|---|---|---|---|---|---|---|---|
| | **Automatic Line Outages 01/01/85-01/01/02** | | | | | | | |
| | **Source: Technical Operations (TOT), Operations & Planning, x2937, 29Mar01** | | | | | | | |
| 1 | PAUL-ALLSTON 2 (500 kV) | 4/25/89 16:41 | 4/25/89 16:42 | 1 | Lightning | Yes | No | OHGW & SPS |
| 1 | PAUL-ALLSTON 1 (500 kV) | 4/25/89 16:41 | 4/25/89 19:58 | | Forced (Configuration) | Yes | No | No Tx at Echo Lake |
| 2 | PAUL-ALLSTON 1 (500 kV) | 7/13/93 15:21 | 7/13/93 15:23 | 2 | Lightning | Yes | No | OHGW |
| 2 | PAUL-ALLSTON 2 (500 kV) | 7/13/93 15:21 | 7/13/93 15:24 | | Lightning | Yes | No | OHGW |
| 3 | MONROE-CUSTER 1 (500 kV) | 1/20/93 12:06 | 1/20/93 12:06 | 0 | WEATHER | No | No | SPS |
| 3 | MONROE-CUSTER 2 (500 kV) | 1/20/93 12:06 | 1/20/93 12:08 | | WEATHER | No | No | - |
| 4 | MONROE-CUSTER 1 (500 kV) | 6/7/98 21:38 | 6/7/98 23:43 | | Lightning | No | No | OHGW |
| 4 | MONROE-CUSTER 2 (500 kV) | 6/7/98 21:41 | 6/7/98 21:41 | 0 | Lightning | No | No | OHGW & SPS |
| 5 | MONROE-CUSTER 1 (500 kV) | 10/3/98 14:25 | 10/3/98 14:25 | 0 | Lightning | No | No | OHGW & SPS |
| 5 | MONROE-CUSTER 2 (500 kV) | 10/3/98 14:25 | 10/3/98 14:25 | | Lightning | No | No | OHGW & SPS |

Table 5 Lightning Historical Data Summary. This shows that lines with OHGW have approximately 1/20 the outage rate of lines without OHGW West of Cascade [3].

| **Double Ground Wire** | **With OHGW** | | | **Without OHGW** | | | **Ratio** |
|---|---|---|---|---|---|---|---|
| **District** | **Events** | **Miles** | **Events/mile/year** | **Events** | **Miles** | **Events/mile/year** | **w/wo** |
| **East of Cascades** | | | | | | | |
| WALA | 13 | 184.0 | | 66 | 238.2 | | |
| REDM | 56 | 1583.8 | | 36 | 375.6 | | |
| SPOK | 10 | 130.6 | | 28 | 170.3 | | |
| WALA SPOK | 21 | 260.5 | | 0 | 0.0 | | |
| WALA REDM | 0 | 0.0 | | 9 | 82.6 | | |
| WALA SPOK REDM | 0 | 0.0 | | 41 | 97.3 | | |
| | **100** | **2158.9** | **0.00272** | **180** | **964.0** | **0.01098** | **0.25** |
| **West of Cascades** | | | | | | | |
| SNOH | 1 | 16.1 | | 47 | 411.6 | | |
| OLYM | 0 | 0.0 | | 35 | 237.6 | | |
| EUGE | 0 | 135.1 | | 27 | 191.5 | | |
| OLYM EUGE | 0 | 0.0 | | 1 | 19.5 | | |
| SNOH OLYM | 0 | 0.0 | | 14 | 69.3 | | |
| | **1** | **151.2** | **0.00039** | **124** | **929.5** | **0.00785** | **0.05** |
| **Spanning Cascades** | | | | | | | |
| WALA REDM EUGE | 0 | 0.0 | | 1 | 224.1 | | |
| REDM OLYM | 0 | 0.0 | | 13 | 161.8 | | |
| REDM EUGE | 0 | 0.0 | | 51 | 226.9 | | |
| SPOK SNOH | 1 | 174.3 | | 47 | 505.3 | | |
| WALA SPOK REDM OLYM | 0 | 0.0 | | 29 | 180.3 | | |
| | **1** | **174.3** | **0.00034** | **141** | **1298.4** | **0.00639** | **0.05** |

**Analysis based on single circuit lines**

## Appendix A. RPEWG Recommended Analysis Steps

### Seven step Process for PBRC adjustment:

1. Provide Complete Project Description, and why it is being considered for PBRC adjusted rating, including supportive data:
    a. Overview of terminations
    b. Physical Layout and Transmission Construction
    c. Substation Configurations
    d. Protective Relaying
    e. Isochronic Level
    f. Aircraft Hazard
    g. Fire Hazard

2. Identify the Statistical Base to be used:
    a. Historical
    b. Similar Lines
    c. Mileage
    d. Terrain
    e. Climate

3. Determine Uncorrected of Mean Time Between Failure (MTBF)

    - All events should be counted and considered, and then select events and circumstances can be removed on a case-by-case basis.

4. Provide a Corrected Estimate of MTBF (based on Project Robustness Features)

    - A partial list of events that may be justified out is included in section 3.6 of the PBRC process.
    - Consider various robustness features introduced to reduce the risk of outage. For examples see reference [1].

5. Complete Exposure Analysis. (Refer to example)

6. Illustrate the Consequences of Outage (Refer to example)

7. Conclude the how the adjustment meets the PBRC criteria (refer to example)

**Reference**

[1] Robust Line Design Features, RPEWG working paper, 5/28/02.

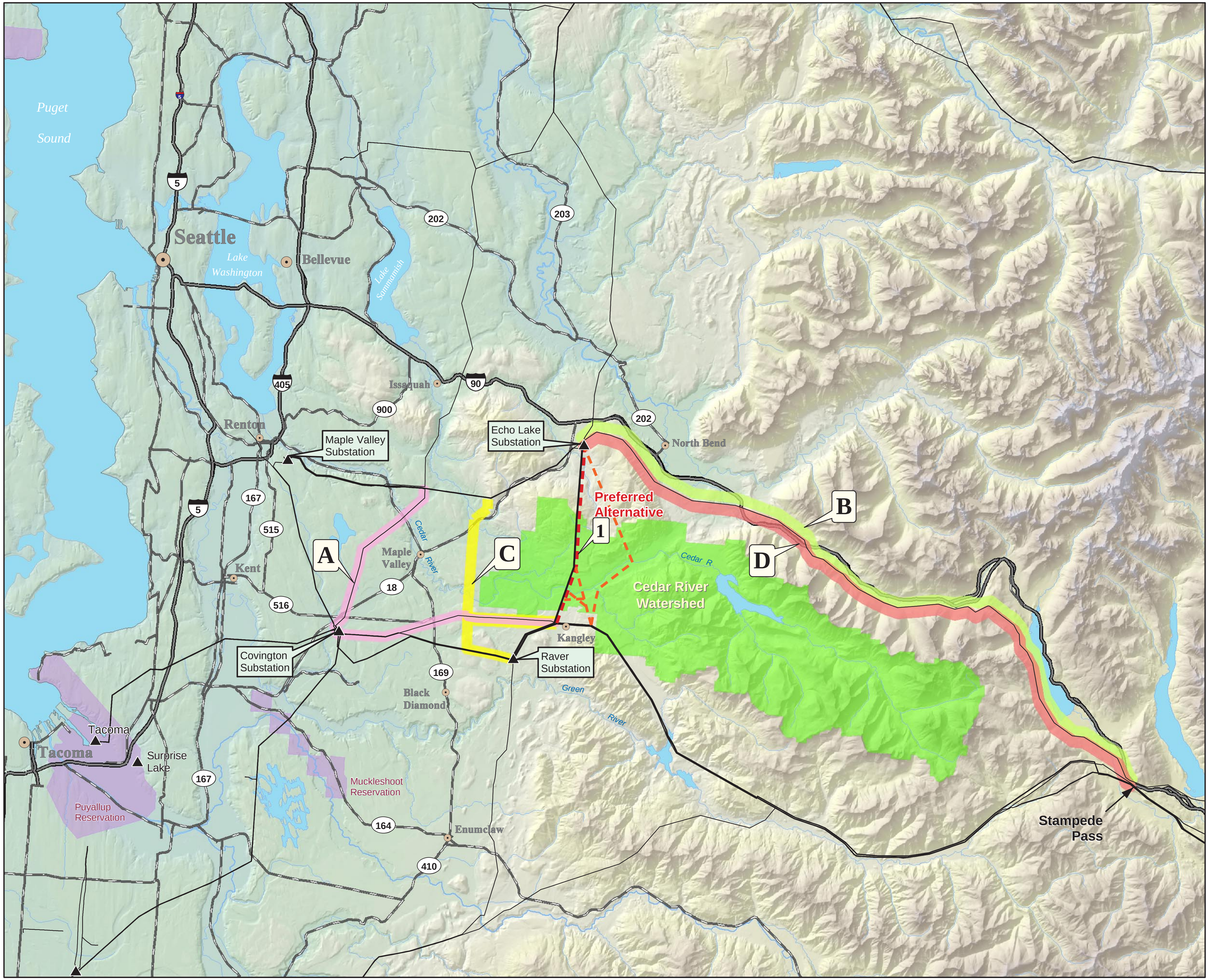
# Kangley-Echo Lake
## Transmission Line Project

Bonneville Power Administration (BPA) is committed to providing reliable power to the Northwest region. BPA is proposing to build new infrastructure projects to improve the reliability of the transmission system and to meet future power needs. The Kangley-Echo Lake Transmission Line Project is the first of these infrastructure projects.

**Proposal**

The proposed 500-kilovolt (kV) transmission line would connect with BPA's existing Echo Lake Substation in the Maple Valley area of Washington. There are several route alternatives currently under consideration. The proposed line is needed to improve system reliability in the King County area and to enhance the return of power to Canada as required by the Columbia River Treaty. The alternatives include:

| Alternatives that would not cross the Cedar River Watershed | |
|---|---|
| Alternative A | Rebuild BPA's existing Covington to Maple Valley 230-kV transmission line to a double-circuit 500-kilovolt (kV) line. The new towers would be about 175-ft. tall. The new 500-kV line would be constructed on existing right-of-way. Each end of the new line would be connected to existing unused 500-kV circuits such that the new line would be connected to the Raver and Echo Lake Substations. The northern vacant circuit would need to be connected to Echo Lake Substation with a short line on BPA property. |
| Alternative B | Rebuild about 38 miles of BPA's existing Rocky Reach-Maple Valley 345-kV transmission line to a double-circuit 500-kV line. The new towers would be about 175-ft. tall. The new 500-kV line would be connected to the existing Schultz–Raver No. 2 500-kV transmission line just east of Stampede Pass and to Echo Lake Substation at the west end. The line would cross I-90 twice. Almost all of this route would be on existing right-of-way. |
| Alternative C | Construct a new single-circuit 500-kV line from near the community of Kangley or from BPA's Raver Substation on mostly new 150-foot wide right-of-way. New towers would be about 135 ft. tall. The new line could pass through the Ravensdale and Hobart areas and would be connected to an existing vacant (unused) Echo Lake-Maple Valley 500-kV circuit. The vacant circuit would then need to be connected to a new bay in the Echo Lake Substation. This option would require the purchase of new right–of-way. |
| Alternative D | Construct a new single-circuit 500-kV transmission line from east of Stampede Pass to Echo Lake Substation. The new line would be adjacent to the existing Rocky Reach-Maple Valley 345-kV line. New towers would be about 135 ft. tall. The line would cross I-90 twice. A new 150-foot wide right-of-way would need to be acquired. |
| **Alternatives that would cross the Cedar River Watershed** | |
| Alternative 1 | Construct a new single-circuit 500-kV transmission line from a tap point on BPA's Schultz-Raver No. 2 500-kV line near Kangley, Washington, to its Echo Lake Substation. This line would run parallel to an existing BPA line and be about 9 miles long. BPA would acquire a new 150-ft. wide right-of-way for the line. (See map.) New towers would be about 135 ft. tall. |
| Alternative 2 | Construct a new single-circuit 500-kV line starting about 1.5 miles east of Alternative 1. The line would traverse northwest about 3 miles before continuing north paralleling the existing Raver-Echo Lake transmission line into Echo Lake Substation. This alternative would be about 9 miles long. BPA would acquire a new 150-ft. wide right-of-way for the line. (See map.) New towers would be about 135 ft. tall. |
| Alternative 3 | Construct a new single-circuit 500-kV line beginning at the same point as Alternative 2. From this point, it would traverse northeast, then turn north-northwesterly to Echo Lake Substation. This line would be about 10 miles long, or about 1-1/4 miles longer than Alternative 1. BPA would acquire a new 150-ft. wide right-of-way for the line. (See map.) New towers would be about 135 ft. tall. |
| Alternatives 4 A and B | 4A<br>Construct a new single-circuit 500-kV line beginning at the same point as Alternative 2. About one-third of the way along Alternative 2, this alternative turns northwest and follows the same alignment as Alternative 1. This line would be about 9 miles long. BPA would acquire a new 150-ft. wide right-of-way for the line. (See map.) New towers would be about 135 ft. tall.<br>4B<br>Construct a new line beginning at the same point as Alternative 2. About half way along Alternative 2, this alternative would traverse southwest to connect with Alternative 1. This line would be about 9 miles. BPA would acquire a new 150-ft. wide right-of-way for the line. (See map.) New towers would be about 135 ft. tall. |




# ADDITIONAL ALTERNATIVES to be CONSIDERED

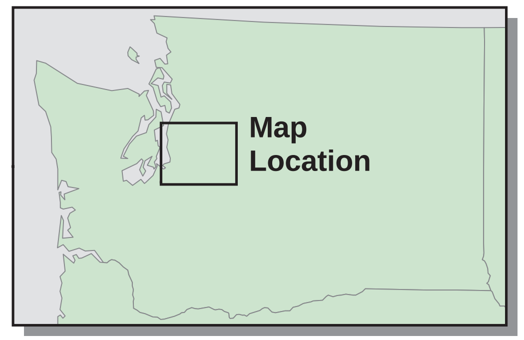
## Kangley - Echo Lake Transmission Line Project

### Legend

- Existing BPA Transmission Lines
- Proposed Transmission Line Alternatives Under Consideration
- BPA Substations

### Alternatives

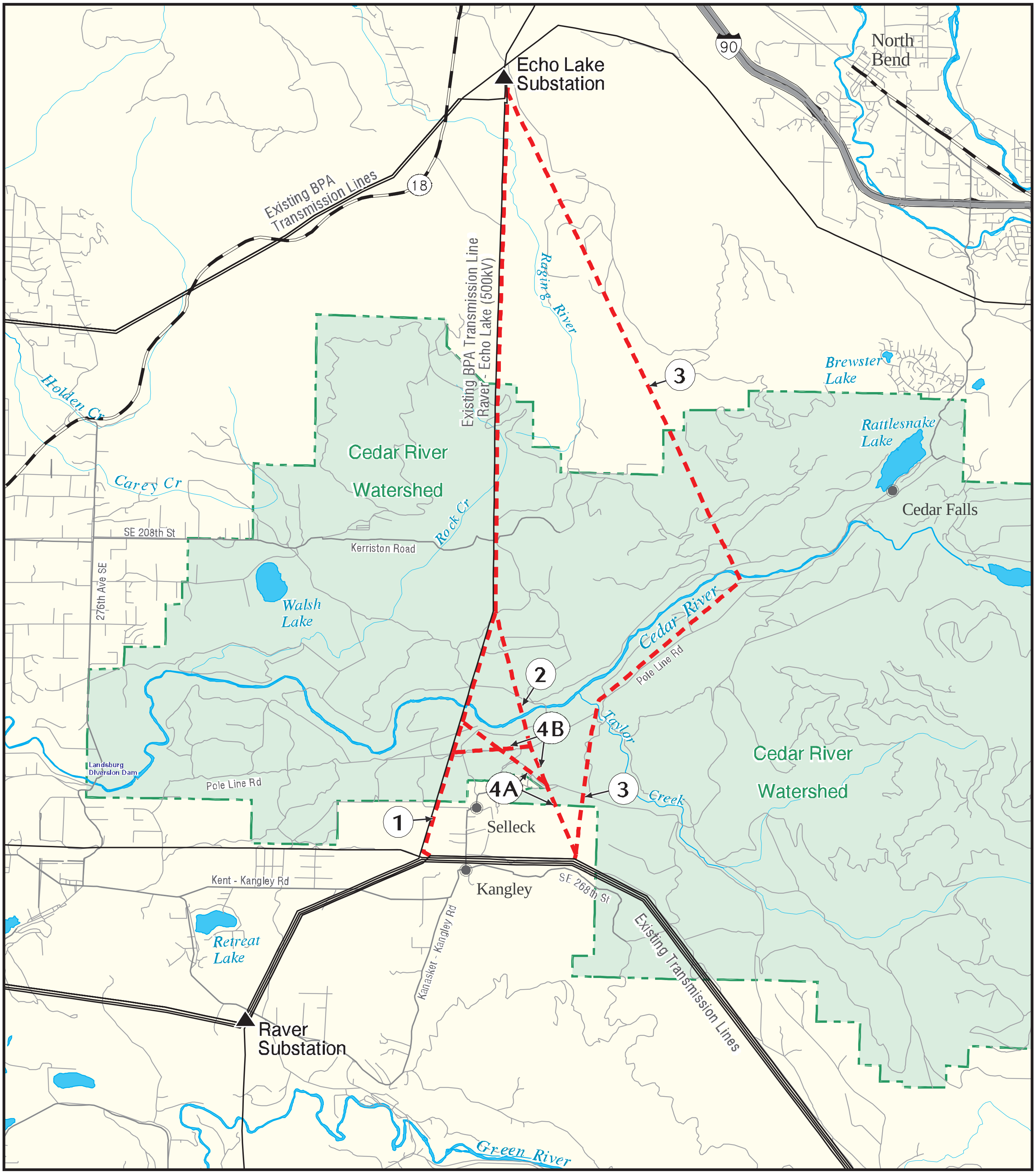
- **A** Construct New Single-Circuit 500-kV Line from tap near Kangley to Covington Substation. Rebuild Covington - Maple Valley 230-kV to Double-Circuit 500-kV
- **B** Rebuild Portion of Rocky Reach-Maple Valley 345-kV to Double-Circuit 500-kV from East of Stampede Pass to Echo Lake Substation
- **C** Construct New Single-Circuit 500-kV Line West of the Cedar River Watershed to the Echo Lake - Maple Valley Lines
- **D** Construct New Single-Circuit 500-kV Line from East of Stampede Pass Adjacent to Rocky Reach-Maple Valley Line




N

0 3 6 9 12
Miles

*May 10, 2002*




# KANGLEY - ECHO LAKE TRANSMISSION PROJECT

BONNEVILLE POWER ADMINISTRATION
gis
GEOGRAPHIC INFORMATION SYSTEM
April 11, 2001


N

0mi 1mi 2mi

0km 1km 2km 3km

Existing Transmission Lines

Proposed Transmission Line Alternatives Under Consideration

Existing Substations

4B Alternative

# Robust Line Design Features

## Background

With more demands for use of land there is increasing difficulty in opening up new Rights Of Way (ROW) for transmission. At the same time it is essential that the transmission system be developed from the standpoint of assuring adequate system reliability. Accordingly, objective guidelines are needed for making decisions affecting these factors. This policy addresses design and planning considerations in relationship to risk of common mode multiple line outages with the goal of improving expectations of what can be expected in terms of line outage performance and complementing probabilistic methods.

## Risk Factors

The following is a list of risk factors to be considered in ROW planning for cases where it is the goal that the N-2 outage be of very low probability. Generally risk increases with common ROW distance.

R1 Risk of fire affecting both lines
R2 Risk of one tower falling into another line
R3 Risk of a conductor from one line being dragged into another line
R4 Risk of lightning strikes tripping both lines
R5 Risk of an aircraft flying into both lines
R6 Risk of station related problems resulting in loss of two lines for a single event
R7 Risk of snow or earth slides
R8 Risk of loss of two lines due to an overhead crossing

## Design Variables

The following are design variables which affect the credibility of each of the above Risk Factors:

V1 Substation breaker configuration (R6)
V2 Circuit centerline spacing (R1,R2,R3,R8)
V3 Span length (R3)
V4 Tower design (R2,R7,R8)
V5 Use of shield wires for lightning (R4)
V6 Conductor support systems (R8)
V7 Use of dead-end versus suspension towers (R3)
V8 Use of single pole reclosing (R4)
V9 Vegetation management (R1)
V10 Fire watch curtailments (R1)
V11 Shortening of line on common ROW (R1-R8)
V12 Tower grounding (R4)
V13 Protective relaying design and settings (R6)

**Example Mitigation:**

The following guidelines are based on either eliminating the risk of each factor or reducing its risk such that the combined MTBF is maximized enabling upgrading of case classification.

*Centerline Spacing (elimination of risk)*
Lines separated by more than the height of the adjacent tower structure where fire exposure risk is minimal and the ROW is not in an area of expected air traffic. Wider separation of 1000-2000 feet in areas where dry fuels would be present to support a fire affecting both lines before it could be detected and loading reduced.

*Line Crossings (elimination of risk)*
Use of robust tower and conductor support systems of overhead line
Spacing of lines by more than one span length in cases where dropping of conductor is a credible risk.
Overhead line cannot cascade into crossing

*Substation Configuration (elimination of risk)*
Substations configured such that a fault on one line followed by breaker failure will not result loss of the parallel line.

*Locational Hazards (elimination of risk)*
In areas where risk is increased due to locational hazards the centerline spacing is increased.
Proximity to flight traffic pattern (increase centerline spacing to not less than one span length)
Proximity to slide areas (increase centerline spacing to be clear of slide area)

*Vegetation Management (elimination of risk)*
Procedures in place for increased vegetation management in areas where accumulation of combustible fuel could result in line tripping in less then 30 minutes of initiation of a fire.
Operational procedures in place to which can allow reporting of fire and reduction of transfer levels within 30 minutes.

*Lightning Mitigation (reduction of risk)*
Use of overhead shield wires to minimize risk of loss of two lines due to lightning
Single-pole reclosing to minimize risk of loss of both lines due to a strike affecting both circuits
Estimate MTBF from typical area statistics:

- Probability of common mode lightning event/year/mile with and without shield wire
- Probability of common mode event resulting in three pole trip of both circuits with/without SPR

*Protective Relaying (elimination of risk)*
Certification that settings and design are such that a single fault condition will not result in loss of more than one parallel line.

Robust Line 3.doc
6/28/02