Update to the 2004
Puget Sound Area Study Group ("PSASG") Report:

Assessment of Puget Sound Area / Northern Intertie
Curtailment Risk

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Attachment B: PSA System Reinforcements

Attachment C: Procedure for Combining Nomograms

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Summary:

This status report was prepared by the PSASG members, it responds to a number of enquiries from groups in BC and the US Pacific Northwest regarding the risk of Puget Sound Area/Northern Intertie (PSANI) curtailments, and updates the 2004 Puget Sound Area Study Group (PSASG) Report. It is important to acknowledge the system reinforcement and operating procedures that have been implemented to reduce the measured curtailment risk since 2003. However, the risks of PSANI / Canadian Entitlement curtailments remain a significant concern due to the increasing frequency and duration of multiple concurrent forced and planned outages.

South-to-North Curtailment Risk:

Significant progress to increase the robustness of the Puget Sound Area transmission system has been made since 2003, and it is expected that the region can continue to build on this success. Figure 1 below summarizes the South-to-North curtailment risk measure reductions since 2003. Status updates of previously identified Puget Sound Area operating procedures and system upgrades are shown in Appendix B.

Despite this progress there were fourteen N-1 operating conditions in Winter 2007 that had operating points (at 25 deg F) below the firm load obligations. Whether South-to-North transmission curtailments would be required following a forced outage of any of these lines, depends on the then-current output of generators located in the Puget Sound Area, temperature and load. A classification was developed to rate these fourteen N-1 operating conditions based on an expectation of how Puget Sound Energy, Seattle City Light and Snohomish PUD would run their generators during winter. The PSANI curtailment risk for these N-1 operating conditions was classified as:

<table>
<thead>
<tr>
<th>Classification</th>
<th>Number of Operating Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>1</td>
</tr>
<tr>
<td>High</td>
<td>6</td>
</tr>
<tr>
<td>Medium</td>
<td>4</td>
</tr>
<tr>
<td>Low</td>
<td>3</td>
</tr>
</tbody>
</table>

1 In terms of operations, N-0 refers to All Lines being In Service and for this operating condition BPA Operations will prepare to withstand loss of the next worst contingency. N-1 refers to one transmission element already being out of service, and as a result BPA Operations will prepare to withstand the loss of a second or more elements. An N-1 operating condition is sometimes referred to as the Primary Contingency and the next worst subsequent contingency is sometimes referred to as the Secondary Contingency.

2 The firm load obligations include the Net Puget Sound Area load, South-to-North firm transmission to deliver the Canadian Entitlement and other South-to-North firm transmission rights on the Northern Intertie (e.g. Puget Sound Energy’s calculated share of real-time Westside Northern Intertie Operating Transfer Capability). When expressed as transfer capability on the Northern Intertie, this firm load obligation can range from a low of 1217 MW (i.e. the 2007/08 amount for the Canadian Entitlement with no allowance for other firm South-to-North transmission rights) to more than 1500 MW (i.e. the 2009/10 amount for the Canadian Entitlement (1326 MW) plus allowance for PSE’s and other South-to-North firm contractual rights). It is also worth noting that the range is not fixed as the value of the Canadian Entitlement can and does vary significantly: since 1999 the Canadian Entitlement has varied from a low of 1171 MW to a high of 1515 MW (including losses), although the effects of the higher number were not felt in the Puget Sound Area as a portion had been pre-sold under a 30 year power sale that fully expired in 2003. Lastly, while 3/14ths of the Canadian Entitlement may be delivered on the East Side of the Northern Intertie, it is conceivable that the entire obligation could be required to be delivered to the West-side of the Northern Intertie.
North-to-South Curtailment Risk:

There have been significant reductions in North-to-South curtailment risk since 2003; these improvements are summarized in Figure 2. While the improvements have been substantial to date, Summer 2007 provided numerous reminders that there is still more work to do as the Northern Intertie was at risk of large derates when more than one line (often low voltage lines) were taken out of service.

In general, the worst case scenario for North-to-South transfers occurs at high temperatures; for Summer 2007 there were nine N-1 operating conditions that had operating points (at 85F) below the contracted firm obligations. The curtailment risk for these contingencies was classified as:

- High: 2 N-1 operating conditions
- Low: 7 N-1 operating conditions

Recommendations for further reducing curtailment risks are summarized on page 31 following the Conclusions.

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3 In August 2007, Powerex held 1099 MW of firm North-to-South transmission from the BC border (including Skagit/High Ross transmission), PSE had firm rights up to 450 MW and other parties (i.e. SNPD) may have had North-to-South firm rights. The actual North-to-South committed use is unclear given the combination of PTP contracts, ownership rights and delivery from the Federal Columbia River Transmission System.
Figure 1: South-to-North Transmission Curtailment Risk Measure – Winter

Figure 2: North-to-South Transmission Curtailment Risk Measure - Summer
Background:

The Puget Sound Area transmission system delivers firm electricity to loads in the Pacific Northwest as well as electricity to the BC/US border pursuant to US government obligations under the Columbia River Treaty. As South-to-North transmission curtailments in the Puget Sound Area can impact Canadian Entitlement Returns and/or load service in the Seattle area, curtailment risk has been the focus of considerable discussion and study.

In February 2004, the Puget Sound Area Study Group was formed and in their November 2004 report they introduced a method for measuring Transmission Curtailment Risk. The Transmission Curtailment Risk in the Puget Sound Area has decreased since 2003: Attachment A shows the decline in the Transmission Curtailment Risk Measure (TCRM) for the Winter and Summer nomograms from 2003 through 2007.

The biggest reduction in South-to-North Curtailment Risk came from the Kangley-Echo Lake line being put in service in December 2003. Subsequent reductions in South-to-North Curtailment Risk have accrued from system reinforcements and operating procedure changes that are described in Attachment B. The increase in the TCRM between 2005 and 2006 is primarily due to Intalco’s load increasing from 200 MW in 2005 to 400 MW in 2006. As shown above, system reinforcements and operating procedures have also reduced the North-to-South curtailment risk.

Need for curtailments for N-1 Operating Conditions:

NI Nomograms calculate what the Northern Intertie limit should be in order to withstand the next worst contingency. When All Lines are In Service (ALIS) there is considerable transmission capacity. However, when one element is taken out of service the remaining transmission system is sometimes not able to withstand the next worst contingency. This could involve loss of a 500 kV, a 230 kV or a 115 kV line or transformers, it could also involve loss of multiple elements as a result of a breaker failure. As a result, when preparing the nomograms the PowerWorld program will adjust flows on the Northern Intertie to ensure that all remaining lines remain within limits post-contingency: this may result in a Northern Intertie flow that is less than what is required to meet the firm contractual obligations. Consequently, for some N-1 operating conditions BPA operations may need to initiate curtailments in anticipation of the next worst contingency, even if the probability of occurrence of that next worst contingency is very low. Greater investigation of these probabilities and options to manage curtailment risk could prove useful.

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4 Appendix B of the Nov 2004 Puget Sound Area Upgrade Study Report
(http://209.221.152.82/ntac/pdf/PSASG%20Final%20Draft.pdf) describes the TCRM Methodology.

5 Transmission Curtailment Risk Measures is effectively the sum of all points curtailed MW below 1500 MW, for PSE generation ranging from 260 MW to 1000 MW, for all nomograms in a particular season. Note that this method sums all the possible curtailed MW with no consideration of their relative or absolute probabilities of occurrence. As such the method is useful for gauging reliability changes / improvements, but the absolute values may have limited applicability.
South-to-North Curtailment Risk Assessment: Winter’07

The impact of transmission curtailments in the Puget Sound Area could be particularly severe if they occurred during a winter artic express. Consequently, it is prudent to consider the worst case and analyze the risk of curtailment at low temperatures.

In Winter 2007 there were fourteen potential N-1 operating conditions that had operating points (at 25 deg F) below the firm load commitments. Based on likely operating conditions (PSE=750 MW, SCL/SNPD = 460 MW), the relative PSANI curtailment risk was classified as:

- **Very High** - Curtailments expected regardless of PSA generation levels;
- **High** - Curtailments expected for PSA generation levels noted above or Nomograms contain significant operating blind spots;
- **Medium** - Curtailments are not expected for PSA generation levels noted above, but are possible for lower PSA generation scenarios or additional elements out of service;
- **Low** - Curtailments are only expected for unlikely PSA generation levels or additional elements out of service;

### Very High

<table>
<thead>
<tr>
<th>N-1 Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>910</td>
<td>Echo Lake - Maple Valley 500kV Line O/S</td>
</tr>
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</table>

### High

<table>
<thead>
<tr>
<th>N-1 Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>911</td>
<td>Echo Lake - Monroe - SnoKing 500kV Line O/S</td>
</tr>
<tr>
<td>931</td>
<td>Tacoma-Covington #2 230kV line O/S</td>
</tr>
<tr>
<td>928</td>
<td>Snohomish-Murray #1 230kV line O/S</td>
</tr>
<tr>
<td>904</td>
<td>Chief Joseph-Monroe 500kV line</td>
</tr>
<tr>
<td>916</td>
<td>Monroe - Snohomish - Horse Ranch #1 &amp; #2 230kV Lines O/S</td>
</tr>
<tr>
<td>903</td>
<td>Bothell - SnoKing #1 or #2 230kV Line O/S</td>
</tr>
</tbody>
</table>

### Medium

<table>
<thead>
<tr>
<th>N-1 Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>914</td>
<td>Monroe-Custer #1 or #2 500kV line</td>
</tr>
<tr>
<td>918</td>
<td>Raver-Echo Lake 500kV line</td>
</tr>
<tr>
<td>905</td>
<td>Chief Joseph - Snohomish #3 or #4 345kV line O/S</td>
</tr>
<tr>
<td>925</td>
<td>Sedro-Bothell-Horse Ranch 230kV line O/S</td>
</tr>
</tbody>
</table>

### Low

<table>
<thead>
<tr>
<th>N-1 Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>930</td>
<td>SnoKing-Maple Valley #1 or #2 230kV line</td>
</tr>
<tr>
<td>923</td>
<td>Schultz-Echo Lake 500kV line</td>
</tr>
<tr>
<td>922</td>
<td>Sammamish-Maple Valley 345kV line</td>
</tr>
</tbody>
</table>

The curtailment risk for these N-1 conditions is shown graphically in combined nomograms below. Appendix C provides a description and example of how the combined nomograms are prepared.

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6 The delivered amount of the Canadian Entitlement was 1220 MW for the period of 1 August 2006 to 31 July 2007. The delivered amount of the Canadian Entitlement will be 1217 MW for the period of 1 August 2007 to 31 July 2008. The CE can and does vary from year to year. Over the last 8 years it has been as low as 1171 MW and as high as 1515 MW. Moreover, other companies have firm South-to-North rights on the Northern Intertie.
Figure 3: Very High Curtailment Risk (South-to-North) for N-1 Conditions

Echo Lake-Maple Valley 500kv Line O/S
Temp= 25F, 2007 HW (910)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

-3000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
3000
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
PSE Generation (MW)
Ingledow-Custer limit (MW)

2007/08 CE MW = 1217

2009/10 CE + Other NL rights

S-N Westside Limit=2000 MW
S>N SCL+SNOH Gen= 140 MW
S>N SCL+SNOH Gen= 460 MW
S>N SCL+SNOH Gen= 775 MW
N>S Westside Limit=2850 MW
N>S SCL+SNOH Gen= 140 MW
N>S SCL+SNOH Gen= 460 MW
N>S SCL+SNOH Gen= 775 MW

Unsafe operating area
Safe operating area
Potential safe op. area
Danger area: blind spot
Figure 4a: High Curtailment Risk (South-to-North) for N-1 Conditions

Echo Lake-Monroe-SnoKing 500kV Line O/S
Temp= 25F, 2007 HW (911)

Tacoma-Covington #2 230kV line O/S
Temp= 25F, 2007 HW (931)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

- S-N Westside Limit = 2000 MW
- S-N SCL + SNOH Gen = 140 MW
- S-N SCL + SNOH Gen = 460 MW
- S-N SCL + SNOH Gen = 775 MW
- N-S Westside Limit = 2850 MW
- N-S SCL + SNOH Gen = 140 MW
- N-S SCL + SNOH Gen = 460 MW
- N-S SCL + SNOH Gen = 775 MW

2007/08 CE MW = 1217
2009/10 CE + Other NI rights

Unsafe operating area
Safe operating area
Potential safe op. area
Danger area: blind spot

APPENDIX P to BC Hydro’s 2008 LTAP
Figure 4b: High Curtailment Risk (South-to-North) for N-1 Conditions

Snohomish-Murray #1 230kV line O/S
Temp= 25F, 2007 HW (928)

Chief Joseph - Monroe 500kV Line O/S
Temp= 25F, 2007 HW (904)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

Unsafe operating area
Potential safe op. area
Safe operating area
Danger area: blind spot
Figure 4c: High Curtailment Risk (South-to-North) for N-1 Conditions

Monroe - Snohomish - Horse Ranch #1 & #2
230kV Lines O/S
Temp= 25F, 2007 HW (916)

Bothell - SnoKing #1 or #2 230kV Line O/S
Temp= 25F, 2007 HW (903)
Figure 5a: Medium Curtailment Risk (South-to-North) for N-1 Conditions

Monroe-Custer #1 or #2 500kV line O/S
Temp= 25F, 2007 HW (914)

Raver-Echo Lake 500kV line O/S
Temp= 25F, 2007 HW (918)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

- S-N Westside Limit=2000 MW
- S-N SCL+SNOH Gen= 140 MW
- S-N SCL+SNOH Gen= 460 MW
- S-N SCL+SNOH Gen= 775 MW
- N-S Westside Limit=2850 MW
- N-S SCL+SNOH Gen= 140 MW
- N-S SCL+SNOH Gen= 460 MW
- N-S SCL+SNOH Gen= 775 MW
- Canadian Entitlement

Potential safe op. area
Safe operating area
Unsafe operating area
Danger area: blind spot

S-N Westside Limit=2000 MW
S+N SCL+SNOH Gen= 140 MW
S+N SCL+SNOH Gen= 460 MW
S+N SCL+SNOH Gen= 775 MW
N-S Westside Limit=2850 MW
N-S SCL+SNOH Gen= 140 MW
N-S SCL+SNOH Gen= 460 MW
N-S SCL+SNOH Gen= 775 MW
Canadian Entitlement

2009/10 CE + Other NI rights
2007/08 CE MW = 1217

APPENDIX P to BC Hydro’s 2008 LTAP
Figure 5b: Medium Curtailment Risk (South-to-North) for N-1 Conditions

Chief Joseph - Snohomish #3 or #4 345kV line O/S
Temp= 25F, 2007 HW (905)

Sedro-Bothell-Horse Ranch 230kV line O/S
(S>N NI separation scheme armed at 100MW)
Temp= 25F, 2007 HW (925)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

Unsafe operating area  Safe operating area
Potential safe op. area  Danger area: blind spot
Figure 6a: Low Curtailment Risk (South-to-North) for N-1 Conditions

SnoKing-Maple Valley #1 or #2 230kV line O/S
Temp= 25F, 2007 HW (930)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

S-N Westside Limit=2000 MW
S-N SCL+SNOH Gen= 140 MW
S-N SCL+SNOH Gen= 460 MW
S-N SCL+SNOH Gen= 775 MW
N-S Westside Limit=2850 MW
N-S SCL+SNOH Gen= 140 MW
N-S SCL+SNOH Gen= 460 MW
N-S SCL+SNOH Gen= 775 MW
Canadian Entitlement

2007/08 CE MW = 7217

Schultz-Echo Lake 500kV line O/S
Temp= 25F, 2007 HW (923)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

S-N Westside Limit=2000 MW
S-N SCL+SNOH Gen= 140 MW
S-N SCL+SNOH Gen= 460 MW
S-N SCL+SNOH Gen= 775 MW
N-S Westside Limit=2850 MW
N-S SCL+SNOH Gen= 140 MW
N-S SCL+SNOH Gen= 460 MW
N-S SCL+SNOH Gen= 775 MW
Canadian Entitlement

2007/08 CE MW = 7217
Figure 6b: Low Curtailment Risk (South-to-North) for N-1 Conditions

Sammamish-Maple Valley 345kV line O/S
Temp= 25F, 2007 HW (922)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

- S-N Westside Limit=2000 MW
- S-N SCL+SNOH Gen= 460 MW
- S-N SCL+SNOH Gen= 775 MW
- N-S Westside Limit=2850 MW
- S-N SCL+SNOH Gen= 140 MW
- N-S SCL+SNOH Gen= 460 MW
- S-N SCL+SNOH Gen= 775 MW
- Canadian Entitlement

PSE Generation (MW) vs. Ingledow-Custer limit (MW)

- Unsafe operating area
- Safe operating area
- Potential safe op. area
- Danger area: blind spot
North-to-South Curtailment Risk Assessment: Summer’07

The impact of North-to-South transmission curtailments are most severe during summer heat waves when the need for power in West is high. Consequently, when assessing North-to-South curtailment risk it is prudent to consider the worst case and analyze the risk at high temperatures.

In Summer 2007 there were nine potential N-1 operating conditions that had operating points (at 85 deg F) below the contracted firm obligations. Based on likely operating conditions (PSE=750 MW, SCL/SNPD = 460 MW), the relative curtailment risk was classified as:

- **High**: Curtailments expected for PSA generation levels noted above or Nomograms contain significant operating blind spots;
- **Low**: Curtailments are only expected for unlikely PSA generation levels or additional elements out of service;

<table>
<thead>
<tr>
<th>High</th>
<th>Low</th>
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</thead>
<tbody>
<tr>
<td>111 Echo Lake - Monroe - SnoKing 500kV Line O/S</td>
<td>103 Bothell - SnoKing #1 or #2 230kV Line O/S</td>
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<tr>
<td>125 Sedro-Bothell-Horse Ranch 230kV line O/S</td>
<td>116 Monroe - Snohomish - Horse Ranch #1 &amp; #2 230kV Lines O/S</td>
</tr>
<tr>
<td></td>
<td>118 Raver-Echo Lake 500kV line</td>
</tr>
<tr>
<td></td>
<td>130 SnoKing-Maple Valley #1 or #2 230kV line</td>
</tr>
<tr>
<td></td>
<td>129 SnoKing 500/230kV Transformer Bank #1 O/S</td>
</tr>
<tr>
<td></td>
<td>114 Monroe-Custer #1 or #2 500kV line</td>
</tr>
<tr>
<td></td>
<td>113 Monroe 500/230kV Transformer Bank #1 O/S</td>
</tr>
</tbody>
</table>

The curtailment risk for these contingencies is shown graphically in combined nomograms shown below.

While relatively few operating points are below the 1500 MW screening threshold, it is important to note that many of limiting facilities that were identified at 85F have limited transfers at other times of the year in combination with other outages. The impact of multiple outages is discussed in the next section.

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7 The delivered amount of the Canadian Entitlement was 1220 MW for the period of 1 August 2006 to 31 July 2007. The delivered amount of the Canadian Entitlement will be 1217 MW for the period of 1 August 2007 to 31 July 2008. The CE can and does vary from year to year. Over the last 8 years it has been as low as 1171 MW and as high as 1515 MW. Moreover, other companies have firm South-to-North rights on the Northern Intertie.
Figure 7: High Curtailment Risk (North-to-South) for N-1 Conditions

Echo Lake - Monroe - SnoKing #1 500kV Line O/S
Temp= 85F, 2007 HS (111)

Snedo Woolley - Bothell - Horse Ranch Tap #1
230kV Line O/S (S>N NI SEPERATION SCHEME ARMED AT 100MW)
Temp= 85F, 2007 HS (125)
Figure 8a: **Low Curtailment Risk (North-to-South) for N-1 Conditions**

- **Bothell – Snoking #1 or #2 230kV Line O/S**
  - Temp = 85F, 2007 HS (103)

- **Monroe-Snohomish-Horse Ranch Tap #1&2**
  - 230kV Line O/S
  - Temp = 85F, 2007 HS (116R)

**Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation**

- **Unsafe operating area**
- **Potential safe op. area**
- **Safe operating area**
- **Danger area: blind spot**
Figure 8b: Low Curtailment Risk (North-to-South) for N-1 Conditions

Raver - Echo Lake #1 500kV Line O/S
Temp= 85F, 2007 HS (118)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

Unsafe operating area
Potential safe op. area
Danger area: blind spot

Snooking - Maple Valley #1 or #2 230kV line O/S
Temp= 85F, 2007 HS (130)
Figure 8c: Low Curtailment Risk (North-to-South) for N-1 Conditions

SnoKing 500/230kV Transformer Bank#1 O/S
Temp= 85F, 2007 HS (129)

Monroe - Custer #1 or #2 500kV Line O/S
Temp= 85F, 2007 HS (114)
Figure 8d: Low Curtailment Risk (North-to-South) for N-1 Conditions

Monroe 500/230kV Transformer Bank #1 O/S
Temp= 85F, 2007 HS (113)
Issues of adjusting the Northern Intertie flow for PSA outages:

There are two reliability concerns that stem from adjusting the Northern Intertie to compensate for outages on the Puget Sound Area transmission system:

1) Negative NI nomogram operating points may produce blind spots and as a result Operators may not realize that the system is vulnerable to specific contingencies. In some cases, these contingencies could result in a cascading outage;

2) Adjusting NI flows may cause limits to be placed on inter-regional flows in order to resolve local load service problems; in some cases, however, even full curtailment of the NI can be ineffective in preventing local load service lines from overloading following the next worst contingency.

3) In recent years, BC has relied on the Canadian Entitlement for domestic load service; consequently, entitlement curtailments could result in curtailment of BC loads.

One option for addressing these issues would be to develop a Nomogram study methodology that treats Northern Intertie firm schedules as inputs, rather than outputs of the nomogram methodology.
Real-time Alternatives to PSANI curtailments:

While system operators must always prepare the transmission system to survive the next worst contingency, there are often alternatives to curtailing transmission schedules. The PSASG has helped reduce the overall curtailment risk by proposing operating procedures that help raise the South-to-North NI limits. The key to developing operating alternatives is found by analyzing these deeper contingency scenarios⁸ in order to determine:

1) if the limiting facility can be tripped or opened without impact;
2) if the transmission system can be reconfigured to reduce the overload on the limiting facility;
3) if a Remedial Action Scheme (RAS) can reduce the impact of the next worst contingency;
4) if the transmission system can be reconfigured to reduce the number of elements that will be forced out of service during the Next Worst Contingency;

Examples of these techniques being successfully applied include:

- The Bothell – SnoKing #1 or #2 230 kV line O/S nomogram’s limiting facility is the remaining Bothell – SnoKing line. It turns out that the South to North PSA transfer limits increase dramatically if the second Bothell-SnoKing line is taken out of service concurrently with the first Bothell-SnoKing line. Figure 2 illustrates the difference between the Bothell – SnoKing #1 OR #2 230 kV line O/S nomogram and the Bothell – SnoKing #1 AND #2 230 kV line O/S nomogram. This is an example of tripping the limiting facility.

- The Snohomish-Murray #1 230 kV line O/S nomogram. The impact of this contingency is significantly reduced when Snohomish PUD initiates the Delta sectionalizing scheme thereby redistributing load in its service territory. Figure 3 illustrates the impact of the sectionalizing scheme.

- The Sedro-Bothell-Horse Ranch 230 kV line O/S nomogram. The impact of the next worst contingency, loss of the two Monroe-Custer 500 kV lines, is significantly reduced by arming the Northern Intertie Separation scheme at 100 MW. Figure 4 illustrates the impact of arming the NI separation scheme at 100 MW.

- The Echo Lake-Maple Valley 500 kV line O/S nomogram. The next worst contingency (Breaker Failure (BFR) on the Covington 230 kV East bus) can be significantly reduced by switching the Covington-Creston 230 kV line to the Covington West Bus. Figure 5 illustrated impact of improving next worst contingency.

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⁸ WECC refers to the deeper contingency scenarios (N-1-2 or N-2-2 contingencies) that Operations is trying to anticipate as Category C and Category D events.
Figure 9: Example of Opening the Limiting Facility

Before Opening Limiting Facility
Bothell - SnoKing #1 or #2 230kV Line O/S
Temp = 25F, 2007 HW (903)

After Opening Limiting Facility
Bothell - SnoKing #1 and #2 230kV Line O/S
Temp = 25F, 2007 HW (935)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

-3000  -2500  -2000  -1500  -1000  -500   0   500   1000  1500  2000  2500  3000
PSE Generation (MW)

Ingledow-Custer limit (MW)

2007/08 CE MW = 1217
2009/10 CE + Other NI rights

S-N Westside Limit=2000 MW
S>N SCL+SNOH Gen= 140 MW
S>N SCL+SNOH Gen= 460 MW
S>N SCL+SNOH Gen= 775 MW
N-S Westside Limit=2850 MW
S>N SCL+SNOH Gen= 140 MW
N>S SCL+SNOH Gen= 460 MW
N>S SCL+SNOH Gen= 775 MW

Canada Entitlement

Unsafe operating
Potential safe op. area
Safe operating area
Danger area: blind
**Figure 10: Example of Sectionalizing**

**Before Sectionalizing Scheme**

**Snohomish-Murray #1 230kV line O/S**  
Temp = 25F, 2007 HW (928)

**After Sectionalizing Scheme**

**Snohomish-Murray #1 230kV line O/S**  
(Snohomish North of Delta sectionalizing scheme in service)  
Temp = 25F, 2007 HW (934)

---

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

- S-N Westside Limit ≤ 2000 MW
- S-N SCL + SNOH Gen = 140 MW
- S-N SCL + SNOH Gen = 460 MW
- S-N SCL + SNOH Gen = 775 MW
- N-S Westside Limit ≤ 2600 MW
- S-N SCL + SNOH Gen = 140 MW
- S-N SCL + SNOH Gen = 460 MW
- N-S SCL + SNOH Gen = 775 MW
- Canadian Entitlement

---

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

- S-N Westside Limit ≤ 2000 MW
- S-N SCL + SNOH Gen = 140 MW
- S-N SCL + SNOH Gen = 460 MW
- S-N SCL + SNOH Gen = 775 MW
- N-S Westside Limit ≤ 2600 MW
- S-N SCL + SNOH Gen = 140 MW
- S-N SCL + SNOH Gen = 460 MW
- N-S SCL + SNOH Gen = 775 MW

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- Unsafe operating
- Potential safe op. area
- Safe operating area
- Danger area: blind

---

2007/08 CE MW = 1217

2009/10 CE + Other NI rights
Figure 11: Example of Arming a Remedial Action Scheme

**Before:** NI Scheme Arming = 500 MW

Sedro-Bothell-Horse Ranch
230kV line O/S
Temp= 25F, 2004 HW (847)

**After:** NI Scheme Arming = 100 MW

Sedro-Bothell-Horse Ranch 230kV line O/S
(S>N NI sep scheme armed at 100MW)
Temp= 25F, 2007 HW (925)

Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

- S-N Westside Limit=2000 MW
- S>N SCL+SNOH Gen= 140 MW
- S>N SCL+SNOH Gen= 460 MW
- S>N SCL+SNOH Gen= 775 MW
- N-S Westside Limit=2850 MW
- S>N SCL+SNOH Gen= 140 MW
- N-S SCL+SNOH Gen= 460 MW
- N-S SCL+SNOH Gen= 775 MW
- Canadian Entitlement

2009/10 CE + Other NI rights

2007/08 CE MW = 1217

S-N Westside Limit=2000 MW
S>N SCL+SNOH Gen= 140 MW
S>N SCL+SNOH Gen= 460 MW
S>N SCL+SNOH Gen= 775 MW
N-S Westside Limit=2850 MW
S>N SCL+SNOH Gen= 140 MW
N-S SCL+SNOH Gen= 460 MW
N-S SCL+SNOH Gen= 775 MW
Canadian Entitlement

2009/10 CE + Other NI rights

2007/08 CE MW = 1217

S-N Westside Limit=2000 MW
S>N SCL+SNOH Gen= 140 MW
S>N SCL+SNOH Gen= 460 MW
S>N SCL+SNOH Gen= 775 MW
N-S Westside Limit=2850 MW
S>N SCL+SNOH Gen= 140 MW
N-S SCL+SNOH Gen= 460 MW
N-S SCL+SNOH Gen= 775 MW
Canadian Entitlement

2009/10 CE + Other NI rights

2007/08 CE MW = 1217

---

Unsafe operating

Potential safe op. area

Safe operating area

Danger area: blind
Figure 12: Example of using Auxiliary bus

**Before switching line to Aux Bus**

*Echo Lake-Maple Valley 500kV Line O/S  Temp= 25F, 2007 HW (910)*

---

**After switch line to Aux Bus**

*Echo Lake - Maple Valley 500kV Line O/S (Covington - Creston 230kV line bypassed to Covington West Auxiliary Bus)*

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Immediate Concerns:

Echo Lake–Maple Valley 500 kV contingency’s very high risk of curtailment

The most severe forced outage on the Puget Sound Area transmission system is the Echo Lake – Maple Valley 500 kV contingency. After losing this major energy source to south King County, the System Operators must prepare for the next worst contingency, which is a Breaker Failure at the Covington substation that trips three more 230 kV lines supplying south Seattle region, thereby triggering an overload of the remaining 230 kV line connected between Covington and Duwamish in south Seattle.

As illustrated above in Figure 5, there is a switching option to reduce the impact of the Covington breaker failure; however, it takes 2 hours to switch the Covington-Creston 230 kV line onto the Covington Auxiliary bus. Consequently, until the switching procedure is complete the region is at risk of a cascading voltage collapse in the event that a Breaker Failure on the Covington 230 kV East bus. Under current operating procedures, BPA would curtail the Canadian Entitlement flow on the Westside of the Northern Intertie to zero after an Echo Lake-Maple Valley 500 kV forced outage. It is important to emphasize that curtailing the Canadian Entitlement for this contingency does not eliminate the risk of a cascading outage in the Puget Sound Area.

To address this problem for Winter 2007/08 BPA Operations is planning (pending some final operating studies) to by-pass the Covington-Creston 230 kV to the western Auxiliary bus for the period of 15 November 2007 to 1 February 2008, although depending on operating requirements this line may be switched back to its normal breaker position.

Pending System Reinforcements

Covington-Berrydale 230 kV line:

Puget Sound Energy is planning to construct by December 2008 a 230 kV line between Covington and Berrydale that is rated in excess of 1,000 MW. It is anticipated that this reinforcement will reduce the curtailment risk for the following N-1 operating conditions:

- Echo Lake – Maple Valley 500kV Line O/S
- Tacoma-Covington #2 230kV line O/S
- Tacoma-Covington #2 230kV Line (Christopher – O’Brien section only)
- Raver - Echo Lake #1 500kV Line O/S
- Schultz-Echo Lake #1 500kV line O/S
On-going Operating Concerns:

Impact of Outages on Northern Intertie Transfer Capability:

During the spring and fall, and increasingly during the summer, transmission lines need to be taken out of service for maintenance and upgrades. While significant and valiant efforts go into coordinating the regional outage plan, it has become increasingly difficult to schedule maintenance without impacts on inter-regional transfer capability.

During Summer 2007 there were often multiple concurrent planned and forced outages that needed to be taken into account when determining the actual operating nomogram limits. Consequently, on several occasions sub-transmission lines, that were constructed to serve local loads, caused limits to be imposed on inter-regional flows because they would overload if the next worst contingency occurred. This type of situation occurs because the Puget Sound Area transmission system is highly networked and as a result there are several subtransmission paths that are connected in parallel with the 500 kV grid.

The most striking example of overlapping outages this past summer occurred on Saturday, 25 August 2007. Through tremendous coordination the impact of this necessary maintenance work was minimized by deferring some outages and scheduling the outage between 04:00-09:00 on a Saturday when temperatures and loads were low. The situation was that Echo Lake - Maple Valley #1&2 500kV had to be taken out of service for maintenance & the Tacoma - Raver #1&2 500kV Lines were forced out of service for months. The next worst contingency was the N-2 loss of Raver - Covington #1&2 500kV. To gauge the outage scheduling challenge, consider the combined nomogram for this scenario at 70F as shown in Figure 13; it demonstrates that the safe operating area for this N-2-2-2 scenario is very small - the impact on inter-regional transfers could have been severe. As the number of planned outages is expected to increase in the coming years the outage scheduling challenges will become increasingly difficult to manage, in particular as the Puget Sound Area is experiencing robust load growth. It is important that the region focus on effective measures and reinforcements that will enable outages to be taken with greater flexibility and minimal impacts. A precursor for identifying viable solutions would be for the Puget Sound Area to establish a Transmission Adequacy Guideline that clarifies the desired level of service for firm loads and transfers through the Puget Sound Area.

The TCRM looks only at single N-1 operating contingencies. As a future study refinement would be to look at multiple concurrent planned and forced outage scenarios and develop long-term and short-term tools to effectively manage these scenarios.

Lastly, forecasting potential transmission curtailments on the Northern Intertie is a difficult but important challenge for market participants as transmission congestion impacts their generation plans. As Northern Intertie OTC (Operating Transfer Capability) limits are a function of load,
PSA generation levels and temperature, there is a wide range of uncertainty associated with OTC forecasts. As an example, Figure 14 compares the actual lowest OTC each day for 1 July – 31 August 2007 with an Optimistic forecast and a Pessimistic forecast. As the region reviews ways to increase the robustness of the Puget Sound Area transmission system, it should investigate how to reduce the number of significant derates at very high and very low temperatures, as it this is often when the West depends most on inter-regional transfers of electricity.

11 The Actual OTC each day was taken as the lowest OTC recorded between HE12 and HE20; the optimistic forecast was based on: Temp = 70F, PSE Gen=525 MW and SCL/SNPD Gen = 140 MW; the Pessimistic forecast was based on: Temp=85F, PSE Gen=1000 MW and SCL/SNPD Gen = 775 MW.
Figure 13: Example of Summer 2007 Outage Scheduling Challenges

Echo Lake - Maple Valley #1&2 500kV & Tacoma - Raver #1&2 500kV Lines O/S (Bypass Covington-Creston to Covington West 230kV Bus)
Temp= 70F, 2007 HS (219R)
Figure 14: Uncertainty in Northern Intertie Transfer Capability
Conclusions:

In Winter 2007 there were fourteen potential N-1 operating conditions in Winter 2007 that could have resulted in operating points (at 25 deg F) below the level required to meet firm load obligations on the Westside of the Northern Intertie. The associated PSANI curtailment risk was classified as Very High for 1 contingency and High for 6 contingencies.

While the risks of PSANI / Canadian Entitlement curtailments is still of concern, however it is important to acknowledge the system reinforcement and operating procedures that have been implemented since 2003 to reduce the curtailment risk. Significant progress has been made to date and it is expected that the region can continue to build on this success.

Recommendations:

Phase 1 Recommendations:
To prepare for Winter 2007/08, it is recommended the Puget Sound Area Study Group:

1) Develop an operating option for an Echo Lake-Maple Valley forced outage that will eliminate the risk of a cascading outage, considering that it has been demonstrated that curtailment of the Canadian Entitlement is ineffective (complete – 15 October 2007);

2) Explore options for each High Risk and Very High Risk nomogram to reduce the curtailment risk, including:
   i. Reconfiguring the transmission system to reduce the impact of the next worst contingency;
   ii. Sectionalizing the transmission system before the next worst contingency;
   iii. Opening the limiting facility automatically;
   iv. Arming a Remedial Action Scheme to reduce the impact of the next worst contingency.

3) Review the Northern Intertie nomograms for negative operating points and implement operating practices to avoid these operating blind spots12.

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12 Northern Intertie nomograms are unidirectional; hence a set of nomograms is prepared for South-to-North flows and another set for North-to-South flows. A problem with this unidirectional approach is that for some nomograms a South-to-North next worst contingency could still cause an overload of a limiting facility when flow is North-to-South; however, the associated North-to-South nomogram will not highlight this as a problem because the problems caused by the South-to-North contingency are resolved by increasing North-to-South flows. We have labeled the unsafe area of overlap between the North-to-South and South-to-North nomograms as an operating blind spot.
Phase 2 Recommendations:

4) Establish a Transmission Adequacy Guideline for the Puget Sound Area that clarifies the desired level of service for firm loads and transfers through the Puget Sound Area;

5) Determine when the Puget Sound Area will need major system reinforcements to withstand All Lines in Service (N-0) and N-1 Operating Conditions. This may include reinforcements outside the Puget Sound including cross Cascades reinforcements or compensation.

6) Develop portfolios of projects that would ensure that the Puget Sound Area system is able to meet the newly established PSA Transmission Adequacy Guideline;

Phase 3 Recommendations:

7) Investigate Nomogram study methodologies that treat Northern Intertie firm schedules as inputs, rather than outputs of the nomogram methodology.
(PSE Gen = 260 MW to 100 MW; TTC Threshold=1500 MW)

Transmission Curtailment Risk Measure (S-N)
Winter Nomograms

Transmission Curtailment Risk Measure (N>S)
Winter Nomograms

Transmission Curtailment Risk Measure (S>N)
Summer Nomograms

Transmission Curtailment Risk Measure (N>S)
Summer Nomograms
Attachment B: PSA System Reinforcements

Puget Sound Area Study Group Project Status Review

In the Fall of 2005 the PSANI Policy Group completed a review of mitigation efforts to reduce transmission curtailments in the Puget Sound Region. From the Puget Sound Area Group’s (PSASG) initial study completed in 2004 three portfolios were identified. In addition subsequent projects were identified through additional study work. This document provides and update on the projects identified in 2005 and provides a representation of the benefits realized by the completion of the projects to date.

- Project planned but funding not committed
- Project funding committed and permitting underway
- Project complete and in-service.

1. Project Status:

Shown below, the identified projects are grouped according to their stage of development as of the Fall of 2005 and their current status:

Portfolio #1 Projects Completed or Underway:

1. **Arm NI Separation Scheme at 100 MW of S-N flow for N-2 Monroe-Custer.**
   - **(BCTC):** The S-N separation scheme RAS arming at this level is currently being used for selected outage conditions and will be reviewed seasonally. This change resulted in approximately a 46% reduction in the South-to-North TCRM Summer 2004
   - **Status:** Currently in use

2. **Bothell-Snohomish #2 upgrade (BPA - $0.3 million):** This project was part of BPA’s G-1 project. Project was completed in summer 2005. This project could result in a 32% improvement for North to South flows.
   - **Status:** Completed in 2005

3. **Upgrade Snohomish Bus Sectionalizing Breaker (BPA - $0.5 million):** This project is expected to be completed by November 2005 and could result in a South to North improvement of approximately 11% reduction in the Summer 2006 South-to-North TCRM compared to Summer 2005.
   - **Status:** Completed in March 2006
4. **Additional 500 kV breaker at Echo Lake (BPA - $1.0 million):** This project is expected to be completed by Fall 2006. This project was initially identified to eliminate the N-S generation dropping RAS for the BKR 5117 failure. In addition, BKR failure 5117 is also the most limiting outage for Puget Sound import capability. Installation of this breaker will allow higher load service to Puget Sound loads while delivering CE.

   **Status:** Completed in Fall 2006.

5. **Reconductor Bothell-Sammamish 230 kV line (PSE - $5 million):** PSE will reconductor this line with Falcon ACSS to increase the capacity of the Snohomish/King County system and improve reliability to PSE’s Sammamish substation. It could result in a 13% reduction in North-to-South TCRM compared to Summer 2005. Expected completion is Fall 2005.

   **Status:** Completed in November, 2005

6. **Reconductor the SCL-owned section of the Bothell-Sammamish 230kV transmission line (SCL/BPA - $? Million):** This work is being funded by BPA and will be done in conjunction with PSE’s reconductoring of their section of this line. Expected completion is Fall 2005.

   **Status:** Completed in November, 2005

**Portfolio #1 Projects in Development:**

7. **Refine RAS Controller/Arming (BPA - $0.25 million):** BPA has scheduled replacement of its RAS controller for April 2006. Following this, BPA and the members of the Puget Sound Area Study Group will perform studies in order to recommend refinements to existing RAS schemes and new RAS schemes for deeper contingencies in the Puget Sound Area.

   **Status:** 2007 Study and implementation.

8. **Covington-Berrydale 230kV (PSE - $7.0 million):** PSE has begun designing and permitting the new two-mile line between BPA’s Covington substation and PSE’s Berrydale substation. This line increases the capacity of the North of Covington system and improves load service reliability to PSE’s Berrydale and Talbot substations. The project is expected to be completed in December 2007 (TCRM rework) and is expected to result in a 15% South to North improvement.

   **Status:** Construction planned for 2008
Portfolio #1 Projects Deferred:

9. **Uprate PSE 115 kV lines (PSE):** There may be a need for increasing the rating of two 115-kV lines; Falcon-Earlington and Fall City-Tolt. While the existing line ratings have the potential to limit south to north capacity they are less limiting than the Maple Valley-Snoking 230kV lines so any increase in line rating should be coordinated with improvements to the Maple Valley-Snoking lines. The O’Brien-Falcon 115-kV line has appeared as a limitation in the 2005 summer nomograms and PSE has determined that the operating temperature of the conductor can be increased to 100 degrees C.

   **Status: Still in deferral**

10. **Horse Ranch tap to Snohomish (BPA) ($3.0 million)** This project was part of the BPA’s G-1 project and was intended to reduce North to South constraints associated with the Horse Ranch breaker failure. Alternative solutions (e.g. second breaker at Horse Ranch) need to be studied as well as benefits of the RAS controller need to be considered.

    **Status: Still in deferral**

11. **Tap Bothell-Sammamish into Snoking (BPA):** This $4.0 million project was also part of BPA’s G1 project. This project initially addressed approximately 13% of the curtailment risk. However, the implementation of the Bothell-Snoking higher emergency ratings have reduced the benefit of this project.

    **Status: Still in deferral**
As a result of on-going work by PSASG we have identified the following additional projects to further improve transfer capability.

**Additional Projects Completed:**

12. **Connect Covington-Creston to Covington Auxiliary Bus whenever beneficial during outage conditions (BPA):** This operational solution addresses North of Covington constraints similar to the Covington-Berrydale project. It has resulted in a S-N improvement of 15%.

   **Status: Currently in use.**

13. **Operate the BPA section of the Bothell-Snoking 230 kV lines at 110 C operating temperature (BPA):** Operating these lines to match the rating of the SCL owned sections has resulted in a South to North improvement of 7%.

   **Status: BPA owned sections have been reconducted to support a 110C rating.**

14. **BCTC has revised its operating procedures** to provide generator tripping at lower arming levels for the North to South flows. This has significantly reduced the risk of curtailments during some outage conditions by providing additional protection should a subsequent unplanned outage occur.

   **Status: Currently in use on an as needed basis.**

**Additional Projects in Development:**

15. **Bothell-Snoking-Maple Valley reconductoring (BPA):** A plan is being developed to reconductor BPA’s line sections of the Bothell-Snoking 230-kV #1 & #2 and the Maple Valley-Snoking 230-kV line #2 to increase the capacity of these lines to match SCL’s line sections 100 degree C rating. This has resulted in a south to north improvement of 7%.

   **Status: BPA section of the Maple Valley-Snoking #2 230kV line reconducted in 2006.**

16. **SCL’s 115kV line upgrades (SCL) – Resag, raise, and move under-built distribution to meet clearance requirements for all 115 kV transmission lines in the Seattle City Light System. Work is progressing to complete all 115 kV transmission upgrades by 2007. Five of the ten upgrades are scheduled to be done in 2005.**

   **Status: SCL has completed 4 of 10 upgrades, will complete 1 more by end of 2007, and 3 are scheduled for 2008 and the last 2 are scheduled for 2009.**
17. **BCTC will provide additional RAS communication capability:** This will be done once the BPA RAS controllers have been replaced, and will allow BCTC to accept additional RAS channels from BPA so that generator dropping can be refined to increase capacity for certain outages.

**Status:** To be completed in 2007 pending Item 7 above.

### Future Study Work:

The Puget Sound Area parties have identified the following further study work:

18. **Assessment of impacts to South King County transformer improvements due to PSE’s build of the Covington-Berrydale 230-kV line;**

   **Status:** Study completed with a need targeted for the 2014 time frame.

19. Determine individual RAS settings (i.e. arming levels, generation levels) for each outage after installation of new RAS controller;

   **Status:** 2007 study work

20. Investigate new RAS schemes for deeper contingencies in the Puget Sound Area;

   **Status:** Future study

21. **Long term Echo Lake- Monroe cutplane improvements; – cost, benefit, and feasibility of Echo Lake-Monroe No. 2 or alternative project;**

   **Status:** Future study

22. South of Sedro Improvement study that will include connecting the Horse Ranch tap to Snohomish, along with identification and analysis of other potential projects;

   **Status:** Future study

23. **Ongoing NWPP/Puget Sound Area NERC screening studies identifying future load service reliability concerns;**

   **Status:** High level NWPP screening studies completed in 2006.
24. Assess the impact of Seattle’s Alaskan Way Viaduct rebuild and relocation of SCL 115kV transmission cables.

   **Status: Future study**

25. Snohomish PUD added a sectionalizing scheme at its Delta Switchyard.

   **Status: In service Fall 2006**

26. PSE Sedro Wooley breaker improvements.

   **Status: In service Fall 2006**

2. **Project Impacts:**

   A measure of curtailment risk, Transmission Curtailment Risk Measure (TCRM), was developed as part of the PSASG study work in order to compare the relative impacts of constraints with the Puget Sound region and projects to address them. Below is a comparison of seasonal TCRMs based on BPA’s Northern Intertie nomogram studies. These charts track Winter South to North (S-N) and North to South (N-S) and Summer S-N and N-S. Please refer to the charts shown in Appendix A.
PUGET SOUND AREA TRANSMISSION PORTFOLIO 3
2004

PROJECTS:

- Upgrade Tolt-Fall City & Earlington-Falcon 115kV lines
- Expand Custer-Monroe 1&2 RAS
- Remote HR Tap into Snohomish
- Uprate Snohomish Bothell #2
- Reconductor Bothell-Sammamish
- Install 500kV Breaker at Echo Lake
- Tap Bothell-Sammamish into Snohomish (BPA)
- Install 500kV Breaker at Echo Lake
- Upgrade Snohomish Bus Section Breaker
- Construct Monroe-Echo Lake #2
- Construct Covington Berrydale 230kV line
- Uprate Tolt-Fall City & Earlington-Falcon 115kV lines
- Install 500kV Breaker at Echo Lake
- Tap Bothell-Sammamish into Snohomish (BPA)

FUNDING:

- Project planned but funding not committed
- Project funding committed and permitting underway
- Project complete and in-service

APPENDIX P to BC Hydro's 2008 LTAP
Attachment C: Procedure for Combining Nomograms

The Northern Intertie Nomograms are used by BPA Operations as unidirectional tools, consequently, operating points that go below zero as truncated to zero for the limits in a particular direction. It is important to bear in mind that the negative points are used to create an interpolation slope and are not used as actual operation points.

One of the innovations of the Puget Sound Area Study Group that is still being reviewed is a procedure to combine the South-to-North and North-to-South nomograms together in order to identify Safe, Potentially Safe, and Unsafe operating areas as well as potential Blind Spots. While the combined nomograms are not used by BPA Operations they provide additional insight on the conditions that limit the operating flexibility of the Puget Sound Area transmission system. The procedure for combining nomograms is explained below by means of an example.

It is important to note that this procedure is intended to inform the Transmission Operations and Planning processes in the Puget Sound Area but cannot be used at this time as an operating tool. There are different RAS schemes associated with each direction which makes it impossible to consider the negative points as actual operating points; furthermore, the flow assumptions for the East Side Northern Intertie are 100 MW for South-to-North basecase and 300 MW for the North-to-South basecase. These sensitivities could affect the size or presence of the “Blind Spots”. It is felt that resources should focus on solutions rather than refining the operating study process.

Definition of terms for categorizing operating areas

- **Safe operating area:** System remains within limits following the next worst contingency, regardless of PSA generation levels.

- **Potentially safe operating area:** Depending on PSA generation, the system may not remain within limits following the next worst contingency.

- **Unsafe operating areas:** System **WILL NOT** remain within limits following the next worst contingency, regardless of PSA generation levels.

- **Danger area: blind spot:** Depending on PSA generation levels, a specific contingency may cause a transmission element to exceed its limits. With current tools, the System Operators may not be aware of this risk.
**Figure 15a: Example of procedure for combining Nomograms**

**Step 1: Import S>N Nomogram**

Tacoma-Covington #2 230kV line O/S  
Temp= 25F, 2007 HW (931)

**Step 2: Evaluate S>N Operating Areas**

Tacoma-Covington #2 230kV line O/S  
Temp= 25F, 2007 HW (931)

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**APPENDIX P to BC Hydro’s 2008 LTAP**

Page 45 of 51
Figure 15b: Example of procedure for combining Nomograms (cont.)

**Step 3: Import & Invert N>S Nomogram**
Tacoma-Covington #2 230kV line O/S
Temp= 25F, 2007 HW (931)

- Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

**Step 4: Evaluate N>S Operating Areas**
Tacoma-Covington #2 230kV line O/S
Temp= 25F, 2007 HW (931)

- Sensitivity of South-North Ingledow-Custer limits to PSE, SCL, and SNOH Generation

Legend:
- Unsafe operating
- Potential safe op. area
- Safe operating area
- Danger area: blind
Figure 15c: Example of procedure for combining Nomograms (cont.)

Step 5: Combine & Identify blind spots
Tacoma-Covington #2 230kV line O/S
Temp= 25F, 2007 HW (931)

Step 6: Combine all Operating Areas
Tacoma-Covington #2 230kV line O/S
Temp= 25F, 2007 HW (931)
Attachment D: Detailed 2007 Nomogram Analysis

The TCRM results shown below are for all operating points below 1500 MW for PSE Generation ranging from 100 MW to 1400 MW. Consequently these TCRM results are more extreme than those summarized in Appendix A which were for PSE Generation ranging from 260 MW to 1000 MW.

The rationale for identifying TCRMs with the full range of PSE generation is that facilities that don’t pass this threshold test often show up as limiting elements in the operating time frame when multiple transmission lines are out of service.

The TCRM results are grouped by:
- Direction: South-to-North and North-to-South
  - Primary Contingency – the first element assumed out of service
  - Secondary Contingency – the next worst contingency
  - Limiting Facility – the facility that will overload if Secondary Contingency occurs
### 2007 Winter (17 Nov 2006) Outage NI Nomograms – South to North

#### SUMMARY FOR S-N FOR PSE Gen Range of 100 to 1400 MW  FIRM TTC THRESHOLD = 1500

<table>
<thead>
<tr>
<th>% of Risk</th>
<th>TCRM</th>
<th>Ranked Primary</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.7%</td>
<td>92,852</td>
<td>910 - Echo Lake - Maple Valley 500kV Line O/S Total</td>
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<tr>
<td>6.1%</td>
<td>58,591</td>
<td>925 - Sedro-Bothell-Horse Ranch 230kV line O/S (S&gt;N NI sep scheme armed at 100MW) Total</td>
</tr>
<tr>
<td>5.8%</td>
<td>55,574</td>
<td>903 - Bothell - SnoKing #1 or #2 230kV Line O/S Total</td>
</tr>
<tr>
<td>5.7%</td>
<td>54,651</td>
<td>914 - Monroe - Custer #1 500kV Line O/S Total</td>
</tr>
<tr>
<td>5.6%</td>
<td>53,433</td>
<td>904 - Chief Joseph - Monroe 500kV Line O/S Total</td>
</tr>
<tr>
<td>5.2%</td>
<td>49,480</td>
<td>928 - Snohomish-Murray #1 230kV line O/S Total</td>
</tr>
<tr>
<td>4.6%</td>
<td>43,424</td>
<td>911 - Echo Lake - Monroe - SnoKing 500kV Line O/S Total</td>
</tr>
<tr>
<td>4.3%</td>
<td>40,627</td>
<td>931 - Tacoma-Covington #2 230kV line O/S Total</td>
</tr>
<tr>
<td>3.6%</td>
<td>34,155</td>
<td>934 - Snohomish-Murray #1 230kV line O/S (Snohomish North of Delta sectionalizing scheme in service)</td>
</tr>
<tr>
<td>3.5%</td>
<td>33,638</td>
<td>932 - Echo Lake - Maple Valley 500kV Line O/S (Covington - Creston 230kV line bypassed to Covington)</td>
</tr>
<tr>
<td>3.0%</td>
<td>28,459</td>
<td>916 - Monroe - Snohomish - Horse Ranch #1 &amp; #2 230kV Lines O/S Total</td>
</tr>
<tr>
<td>2.3%</td>
<td>22,216</td>
<td>918 - Raver - Echo Lake #1 500kV Line O/S Total</td>
</tr>
<tr>
<td>2.3%</td>
<td>21,690</td>
<td>905 - Chief Joseph - Snohomish #3 or #4 345kV line O/S Total</td>
</tr>
<tr>
<td>2.0%</td>
<td>19,535</td>
<td>901 - Bellingham - Custer 230kV Line O/S Total</td>
</tr>
<tr>
<td>1.9%</td>
<td>18,570</td>
<td>917 - Murray - Custer #1 500kV Line O/S (S&gt;N Seperation Scheme Armed @ 100MW) Total</td>
</tr>
<tr>
<td>1.9%</td>
<td>18,123</td>
<td>924 - Sedro Woolley-Bellingham #1 230kV line O/S Total</td>
</tr>
<tr>
<td>1.9%</td>
<td>17,992</td>
<td>926 - Sedro Tap section of Murray-Custer #1 230kV line O/S Total</td>
</tr>
<tr>
<td>1.8%</td>
<td>17,345</td>
<td>923 - Schultz-Echo Lake #1 500kV line O/S Total</td>
</tr>
<tr>
<td>1.8%</td>
<td>16,735</td>
<td>930 - SnoKing-Maple Valley #1 or #2 230kV line O/S Total</td>
</tr>
<tr>
<td>1.7%</td>
<td>16,594</td>
<td>902 - Bothell-Horse Ranch Tap Section of Sedro-Bothell-Horse Ranch230kV line O/S Total</td>
</tr>
<tr>
<td>1.6%</td>
<td>15,726</td>
<td>912 - Horse Ranch Tap section of Monroe - Snohomish - Horse Ranch 230kV Line O/S Total</td>
</tr>
<tr>
<td>1.6%</td>
<td>14,983</td>
<td>921 - Bothell - Sammamish 230kV Line O/S Total</td>
</tr>
<tr>
<td>1.6%</td>
<td>14,961</td>
<td>933 - Raver - Echo Lake #1 500kV Line O/S (Covington - Creston 230kV line bypassed to Covington)</td>
</tr>
<tr>
<td>1.5%</td>
<td>14,654</td>
<td>922 - Sammamish - Maple Valley #1 230kV Line O/S Total</td>
</tr>
<tr>
<td>1.5%</td>
<td>14,468</td>
<td>927 - Snohomish-Bothell #1 or #2 230kV line O/S Total</td>
</tr>
<tr>
<td>1.5%</td>
<td>14,462</td>
<td>908 - Covington - Maple Valley #2 230kV line O/S Total</td>
</tr>
<tr>
<td>1.5%</td>
<td>14,290</td>
<td>900 - All Lines In Service Total</td>
</tr>
<tr>
<td>1.5%</td>
<td>14,265</td>
<td>919 - Rocky Reach - Maple Valley #1 345kV Line O/S Total</td>
</tr>
<tr>
<td>1.5%</td>
<td>14,189</td>
<td>920 - Rocky Reach - Maple Valley #1 operating at 230kV Total</td>
</tr>
<tr>
<td>1.5%</td>
<td>14,170</td>
<td>915 - Monroe - Sammamish #1 230kV Line O/S Total</td>
</tr>
<tr>
<td>1.5%</td>
<td>14,153</td>
<td>906 - Chief Joseph - Snohomish #3 or #4 operating at 230kV Total</td>
</tr>
<tr>
<td>1.4%</td>
<td>13,556</td>
<td>909 - Custer 500/230kV Bank #1 or #2 O/S Total</td>
</tr>
<tr>
<td>1.4%</td>
<td>13,431</td>
<td>913 - Monroe 500/230kV Transformer Bank O/S Total</td>
</tr>
<tr>
<td>1.3%</td>
<td>12,850</td>
<td>929 - SnoKing 500/230kV Transformer Bank #4 O/S Total</td>
</tr>
</tbody>
</table>

Total 954,002
SUMMARY FOR S-N FOR PSE Gen Range of 100 to 1400 MW  FIRM TTC THRESHOLD = 1500

<table>
<thead>
<tr>
<th>% of Risk</th>
<th>TCRM</th>
<th>Ranked Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>48.1%</td>
<td>458,761</td>
<td>N-2: Murr - Cust #1 &amp; Belling - Cust #1 230kV Total</td>
</tr>
<tr>
<td>9.2%</td>
<td>88,052</td>
<td>BFR: Covington 230kV East Bus &amp; Christopher Tap Total</td>
</tr>
<tr>
<td>8.0%</td>
<td>76,260</td>
<td>BFR: Bellingham 230kV Bus Total</td>
</tr>
<tr>
<td>8.0%</td>
<td>76,043</td>
<td>N-2: Echo Lk-Maple VL/Rocky Rch-ML Total</td>
</tr>
<tr>
<td>5.8%</td>
<td>54,860</td>
<td>BFR: Snohomish 230kV Bus Sect #3 Total</td>
</tr>
<tr>
<td>3.6%</td>
<td>34,762</td>
<td>BFR: 4526 Monroe-EchoLK-SnoK 500 kV #1 &amp; Mon-Cust #2 500kV Total</td>
</tr>
<tr>
<td>3.5%</td>
<td>33,824</td>
<td>N-2: Chief Joe - Snohomish 3&amp;4 345kV Total</td>
</tr>
<tr>
<td>2.2%</td>
<td>20,592</td>
<td>MOD - BFR: Covington 230kV East Bus &amp; Christopher Tap Total</td>
</tr>
<tr>
<td>2.0%</td>
<td>19,137</td>
<td>BFR: 5114 Rav-Echo Lk #1 &amp; Mon-EchoLK-SnoK #1 500kV Total</td>
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<tr>
<td>1.9%</td>
<td>18,105</td>
<td>N-2: Chief Joe - Snohomish 3&amp;4 345kV Total</td>
</tr>
<tr>
<td>1.4%</td>
<td>13,500</td>
<td>N-2: Monroe - Cust #1&amp;2 500kV Total</td>
</tr>
<tr>
<td>1.2%</td>
<td>11,613</td>
<td>BFR: 5111 Monroe-EchoLK-SnoKing #1 500kV &amp; Echo Lk Caps Total</td>
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<tr>
<td>1.1%</td>
<td>10,937</td>
<td>N-1: Bothell - SnoKing #1 230kV Total</td>
</tr>
<tr>
<td>1.0%</td>
<td>9,919</td>
<td>N-2: Murr - Cust #1 &amp; Sedro W - Belling #1 230kV Total</td>
</tr>
<tr>
<td>0.9%</td>
<td>8,796</td>
<td>BFR: 4672 Chief Jo-Mon 500kV &amp; Mon Caps Total</td>
</tr>
<tr>
<td>0.7%</td>
<td>6,811</td>
<td>3TM: Monroe-Echo LK-SnoK 500kV Total</td>
</tr>
<tr>
<td>0.6%</td>
<td>6,000</td>
<td>BFR: 734 Sedro-Both-HRanch &amp; Sedro-Belling #1 230kV Total</td>
</tr>
<tr>
<td>0.4%</td>
<td>3,616</td>
<td>T-1: Custer - Portal Way 230/115kV Bank Total</td>
</tr>
<tr>
<td>0.1%</td>
<td>1,071</td>
<td>N-1: Schultz-Kangley Tap 500kV line Total</td>
</tr>
<tr>
<td>0.1%</td>
<td>733</td>
<td>N-2: Schultz-Raver #3&amp;4 500kV Total</td>
</tr>
<tr>
<td>0.0%</td>
<td>434</td>
<td>BFR: 4526 Mon-Echo Lk-SnoK 500kV &amp; Mon-Cust #2 500kV Total</td>
</tr>
<tr>
<td>0.0%</td>
<td>144</td>
<td>N-1: Bellingham - Custer W #1 230kV Total</td>
</tr>
<tr>
<td>0.0%</td>
<td>29</td>
<td>N-1: Raver - Echo Lake #1 500kV Total</td>
</tr>
</tbody>
</table>

954,002

<table>
<thead>
<tr>
<th>% of Risk</th>
<th>TCRM</th>
<th>Ranked Limiting Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>57.7%</td>
<td>550,192</td>
<td>Branch CUSTER W (40321) TO PORTALWY (42001) CKT 1 [230.00 - 115.00 kV] Total Total</td>
</tr>
<tr>
<td>10.4%</td>
<td>99,330</td>
<td>Branch COVINGTN (40303) TO Creston (46415) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>9.2%</td>
<td>88,052</td>
<td>Branch COVINGTN (40303) TO DUWAMISH (46423) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>5.8%</td>
<td>54,860</td>
<td>Branch SNOH S2 (41328) TO SNOH S3 (40992) CKT 3 [230.00 - 115.00 kV] Total Total</td>
</tr>
<tr>
<td>4.3%</td>
<td>41,068</td>
<td>Branch BOTHELL (46403) TO SNOH S1 (41004) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>3.2%</td>
<td>30,357</td>
<td>Branch MURRAY (40767) TO SNOH S1 (41327) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>2.8%</td>
<td>26,929</td>
<td>Branch SNOH S3 (41329) TO SNOH S4 (41330) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>2.3%</td>
<td>21,798</td>
<td>Branch BOTHELL (46403) TO SNOH S3 (41008) CKT 2 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>1.7%</td>
<td>16,191</td>
<td>Branch MURRAY (40767) TO SEDRO NT (42103) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>1.5%</td>
<td>14,093</td>
<td>Branch MAPLE VL (40689) TO SNOH S1 (41004) CKT 2 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>0.4%</td>
<td>3,741</td>
<td>Branch HRTAP MS (40963) TO SNOH S4 (41330) CKT 2 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>0.4%</td>
<td>3,616</td>
<td>Branch SEDRO (42100) TO SEDRO NT (42103) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>0.2%</td>
<td>2,149</td>
<td>Branch MAPLE VL (40689) TO SNOH S3 (41008) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>0.1%</td>
<td>892</td>
<td>Branch ARLINGTON (42160) TO BEVERLY (45608) CKT 1 [115.00 - 115.00 kV] Total Total</td>
</tr>
<tr>
<td>0.1%</td>
<td>733</td>
<td>Branch RAVER (40869) TO RAVSCH12 (40974) CKT 1 [500.00 - 500.00 kV] Total Total</td>
</tr>
</tbody>
</table>

954,002
# TCRM Calculation for 2007 Summer Outage NI Nomograms – North to South

## SUMMARY FOR N-S FOR PSE Gen Range of 100 to 1400 MW FIRM TTC THRESHOLD = 1500

<table>
<thead>
<tr>
<th>% of Risk</th>
<th>TCRM</th>
<th>Ranked Primary</th>
</tr>
</thead>
<tbody>
<tr>
<td>60.4%</td>
<td>56,906</td>
<td>125 - Sedro Woolley - Bothell - Horse Ranch Tap #1 230kV Line O/S (S&gt;N NI SEPERATION SCHEM</td>
</tr>
<tr>
<td>35.0%</td>
<td>32,918</td>
<td>111 - Echo Lake - Monroe - SnoKing #1 500kV Line O/S Total</td>
</tr>
<tr>
<td>1.1%</td>
<td>1,022</td>
<td>114 - Monroe - Custer #1 or #2 500kV Line O/S Total</td>
</tr>
<tr>
<td>0.9%</td>
<td>882</td>
<td>116R - Monroe-Snohomish-Horse Ranch Tap #1&amp;2 230kV Line O/S Total</td>
</tr>
<tr>
<td>0.8%</td>
<td>787</td>
<td>117 - Murray - Custer #1 230kV Line O/S (S&gt;N NI SEPERATION SCHEME ARMED AT 100MW) Tol</td>
</tr>
<tr>
<td>0.4%</td>
<td>336</td>
<td>129 - SnoKing 500/230kV Transformer Bank #1 O/S Total</td>
</tr>
<tr>
<td>0.4%</td>
<td>334</td>
<td>113 - Monroe 500/230kV Transformer Bank #1 O/S Total</td>
</tr>
<tr>
<td>0.3%</td>
<td>304</td>
<td>118 - Raver - Echo Lake #1 500kV Line O/S Total</td>
</tr>
<tr>
<td>0.3%</td>
<td>304</td>
<td>133 - Raver - Echo Lake #1 500kV Line O/S (Covington-Creston bypassed to Covington 230kV West</td>
</tr>
<tr>
<td>0.2%</td>
<td>195</td>
<td>103 - Bothell - SnoKing #1 or #2 230kV Line O/S Total</td>
</tr>
<tr>
<td>0.1%</td>
<td>137</td>
<td>130 - SnoKing - Maple Valley #1 or #2 230kV line O/S Total</td>
</tr>
<tr>
<td>0.0%</td>
<td>34</td>
<td>135 - Bothell - SnoKing #1 AND #2 230kV Lines O/S Total</td>
</tr>
<tr>
<td>0.0%</td>
<td>2</td>
<td>112 - Horse Ranch Tap section of Monroe-Snohomish-Horse Ranch Tap #1&amp;2 230kV Line O/S incl</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% of Risk</th>
<th>TCRM</th>
<th>Ranked Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>44.5%</td>
<td>41,874</td>
<td>N-2: Murr - Cust #1 &amp; Belling - Cust #1 230kV Total</td>
</tr>
<tr>
<td>22.1%</td>
<td>20,810</td>
<td>N-2: Monroe - Custer #1&amp;2 500kV Total</td>
</tr>
<tr>
<td>14.9%</td>
<td>14,055</td>
<td>BFR: Bothell 230kV Bus Sect #3 Total</td>
</tr>
<tr>
<td>9.8%</td>
<td>9,201</td>
<td>BFR: Horse Ranch 230kV Bus Total</td>
</tr>
<tr>
<td>2.2%</td>
<td>2,072</td>
<td>BFR: Bothell 230kV Bus Sect #1 Total</td>
</tr>
<tr>
<td>2.0%</td>
<td>1,845</td>
<td>N-2: Snohomish - Bothell #1&amp;2 230kV Total</td>
</tr>
<tr>
<td>1.7%</td>
<td>1,560</td>
<td>3TM: Mon - Sno - Horse Rrch 230kV Total</td>
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<tr>
<td>0.9%</td>
<td>878</td>
<td>BFR: A178 or A182 Snoh Bus Sect#4 &amp; Mon-Sno-HRanch 230kV Total</td>
</tr>
<tr>
<td>0.8%</td>
<td>745</td>
<td>BFR: Maple Valley 230kV Bus Section #3 &amp; Klahanie Total</td>
</tr>
<tr>
<td>0.6%</td>
<td>555</td>
<td>BFR: 4526 Monroe-EchoLK-SnoK 500 kv #1 &amp; Mon-Cust #2 500kV Total</td>
</tr>
<tr>
<td>0.3%</td>
<td>289</td>
<td>3TM: Monroe-Echo LK-SnoK 500kV Total</td>
</tr>
<tr>
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<td>N-1: Monroe - HRNCHTAP MS Total</td>
</tr>
<tr>
<td>0.1%</td>
<td>48</td>
<td>BFR: 5111 Monroe-EchoLK-SnoKing #1 500kV &amp; Echo Lk Caps Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% of Risk</th>
<th>TCRM</th>
<th>Ranked Limiting Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.7%</td>
<td>28,948</td>
<td>Branch CUSTER W (40321) TO PORTALWY (42001) CKT 1 [230.00 - 115.00 kV] Total Total</td>
</tr>
<tr>
<td>21.3%</td>
<td>20,023</td>
<td>Branch MURRAY (40767) TO SEDRO NT (42103) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>14.9%</td>
<td>14,055</td>
<td>Branch BOTHELL (46403) TO SNOK S3 (41008) CKT 2 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>13.7%</td>
<td>12,926</td>
<td>Branch ARLINGTON (42160) TO BEVERLY (45608) CKT 1 [115.00 - 115.00 kV] Total Total</td>
</tr>
<tr>
<td>13.3%</td>
<td>12,566</td>
<td>Branch MONROE (40747) TO SAMMAMISH (42300) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>2.2%</td>
<td>2,072</td>
<td>Branch BOTHELL (46403) TO SNOH S1 (41327) CKT 2 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>2.0%</td>
<td>1,845</td>
<td>Branch BOTHELL (46403) TO HRNCHTAP (42321) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>0.8%</td>
<td>787</td>
<td>Branch HRNCHTAP (42321) TO SEDRO (42100) CKT 1 [230.00 - 230.00 kV] Total Total</td>
</tr>
<tr>
<td>0.8%</td>
<td>745</td>
<td>Branch BROAD ST (46409) TO UNIVERSITY (46453) CKT 1 [115.00 - 115.00 kV] Total Total</td>
</tr>
<tr>
<td>0.2%</td>
<td>195</td>
<td>Branch BOTHELL (46403) TO SNOH S1 (41004) CKT 1 [230.00 - 230.00 kV] Total Total</td>
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94,162