EXH. DRK-13
DOCKETS UE-22___/UG-22___
2022 PSE GENERAL RATE CASE
WITNESS: DAN'L R. KOCH

BEFORE THE
WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, **Complainant,** **v.** **PUGET SOUND ENERGY,** **Respondent.**	**Docket UE-22____** **Docket UG-22____**

TWELFTH EXHIBIT (NONCONFIDENTIAL) TO THE PREFILED DIRECT TESTIMONY OF

DAN'L R. KOCH

ON BEHALF OF PUGET SOUND ENERGY

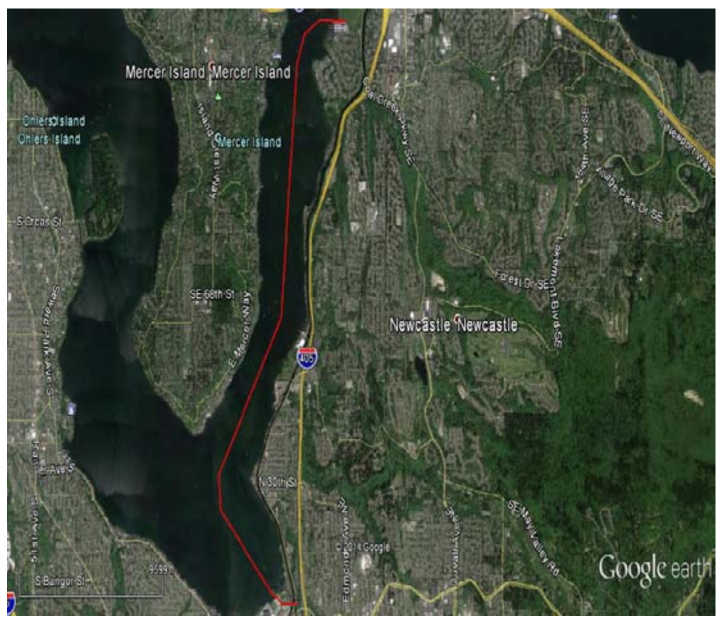
JANUARY 31, 2022

June 8, 2015

PUGET SOUND ENERGY

Eastside 230 kV Project

Lake Washington Submarine Cable Alternative
Feasibility Study - Final



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POWER ENGINEERS

PREPARED FOR: PUGET SOUND ENERGY
PREPARED BY: POWER ENGINEERS, INC

REVISION HISTORY		
DATE	REVISED BY	REVISION
06/08/15	POWER Engineers, Inc.	0-Issued

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0.0 EXECUTIVE SUMMARY

Puget Sound Energy (PSE) is planning an expansion of their 230 kilovolt (kV) transmission system on the east side of Lake Washington. PSE has requested a submarine cable feasibility study for a line section from near PSE's Shuffleton Service Center in North Renton, past the east side of Mercer Island to near PSE's Enatai substation north of I-90 at about 136th St. SE as an alternative to overhead construction. This study focuses on an engineering and constructability standpoint only. This study does not take into account:

1. Environmental, local, state, and federal permits and/or mitigation as required;
2. Acquisition of new right of way, easements, or properties;
3. Local land use preferences among the identified route alternatives; or
4. Underground landing preferences and routes to transition structures.

POWER Engineers, Inc. (POWER) was selected to study the conceptual cable system for this project. POWER identified a project study area for the underground portion of new 230 kV transmission lines and developed the criteria for the submarine transmission line route evaluation.

Overhead transmission lines generally have larger power transfer capacity when compared to an equivalent insulated cable in an underground insulation. Underground cable manufacturers are also limited in the size conductor they can produce to achieve a line rating with one cable per phase. POWER relied on various cable vendors to perform ampacity calculations to determine preliminary cable sizing requirements and concluded that multiple cables per phase would be needed to meet the desired rating for the Eastside 230 kV lines. Two major types of cable systems were evaluated and compared for use on the proposed submarine route; self-contained fluid-filled (SCFF) and cross-linked polyethylene (XLPE). Within the XLPE cable system, POWER compared single-phase cables with three-phase cables.

Engineering and construction requirements were discussed for the submarine option. While unique and different challenges exist, such as the uncertainty of the lake floor topography, acquisition of additional easements/right of way, existing utility (submarine) conflicts, the submarine option is ultimately constructible. A cost estimate at project schedule was created with summary tables located in Section 11 and 13. Based on this conceptual study, the result of the cost estimate is as follows:

Table 0-1 Cost Estimate Summary

Total EPC Contractor and Owner's Cost	**XLPE Cable System Costs**		**Total Cost**
	Material Costs	**Labor and Equipment Costs**	
EPC Contractor's Three-Phase Submarine Cable Supply, Delivery, and Installation for the 6.5 mile (10.4 km) corridor	$53,750,000	$87,188,000	$140,938,000
EPC Contractor's Landings and Tie to Overhead Lines	$10,285,000	$7,404,000	$17,689,000
Unallocated Costs	$0	$625,000	$625,000
SUBTOTAL	**$64,035,000**	**$95,217,000**	**$159,252,000**
Owner's Engineering, Project Management, and Permitting (5%)	$3,202,000	$4,761,000	$7,963,000
TOTAL	**$67,237,000**	**$99,978,000**	**$167,215,000**

The cost estimate in Table 0-1 does not include costs such as sales tax, real estate, environmental, permitting, utility internal costs such as AFUDC, labor and overhead, etc. These costs are variable and difficult to estimate without a more detailed assessment.

POWER performed a similar feasibility study investigating the practicality of land cables and underground installation methods in the report: "Eastside 230 kV Project Underground Feasibility Study", document STL 085-1244. The cost estimate and results from this report should not be compared to the estimates in document STL 085-1244 because of the differences in the design criteria. Further explanation can be found in Section 15.

Figure 0-1 Potential Submarine Path

1.0 INTRODUCTION

Puget Sound Energy (PSE) is planning an expansion of their transmission system on the east side of Lake Washington. This report summarizes the results of an investigation into the feasibility of providing a submarine cable alternative to overhead line construction for a line section from near PSE's Shuffleton Service Center in North Renton, past the east side of Mercer Island to near PSE's Enatai substation north of I-90 at about 136th St. SE. As part of this alternative, a section of line would also be installed underground from the north submarine cable landing to an overhead-underground transition terminal near I-90 and 136th St. SE and from the south landing to an overhead-underground terminal between Lake Washington Blvd. and Highway 405. The scope of this report is the submarine cable system extending between shore-based transition joint manholes or joint bays and costs; feasibility of the underground route segment is not discussed in this study.

Preliminary designs and cable routes have been developed for this report for concept planning and estimating purposes. However, final implementations will be subject to change, at least in detail. Nevertheless, the designs are considered to be sufficiently accurate for overview estimating and high level comparison of alternatives.

The alternative described herein was proposed mainly by PSE. POWER is not aware of and makes no representation as to how well this alternative will ultimately integrate with PSE's long term, overall electricity supply plans. Technical descriptions are provided, including cable types, installation methods, costs and regulatory issues to be considered. Conclusions and recommendations for supplemental work are also included.

2.0 BACKGROUND

PSE Planners foresee a need to reinforce the existing transmission system into the Eastside area, to accommodate load growth and ensure adequate long term system reliability.

Adequate reliability includes planning for the power system to withstand seismic events, including loss of critical substations and lines. This does not require that all stations and lines survive a major earthquake, but relatively fast service restoration should be assured, especially for the central business districts. This study therefore assumes that new circuit components would be engineered to survive design earthquakes for the area, taking into consideration geographical and routing constraints. Assessments of alternatives need to consider seismic geo-hazards, such as landslides and soil liquefaction, as well as provisions for crossing fault lines, to which underground and submarine transmission systems can be vulnerable.

3.0 GEOLOGICAL SETTING

The site is in a high seismicity zone, with a magnitude 6.5 earthquake recorded near Renton on April 27, 1965, causing minor damage. Figure 1 is a USGS map for the greater Seattle fault zone, showing three faults passing under Mercer Island and two under a possible submarine cable route[1]. Jacoby and others have reported on evidence of a large landslide southeast of Mercer Island about 1000 years ago (shown on Figure 3 as 'submerged forest'), suggested as having been triggered by a strong seismic event[2]. The south lake shore area near the proposed landing zone is comprised of material excavated during construction of the Lake Washington Ship Canal project from 1911 until official opening in 1934. It appears that this area

[1] USGS Quaternary Fault and Fold Database for the United States (http://earthquake.usgs.gov/hazards/qfaults/wa/sea.html; accessed March 2014)

[2] G. C. Jacoby, P. L. Williams, B. M. Buckley; Tree Ring Correlation Between Prehistoric Landslides and Abrupt Tectonic Events in Seattle, Washington; Source: Science, New Series, Vol. 258, No. 5088 (Dec. 4, 1992), pp. 1621-1623.

is susceptible to liquefaction (a process by which water-saturated sediment temporarily loses strength and acts as a fluid) caused by earth shaking[3].

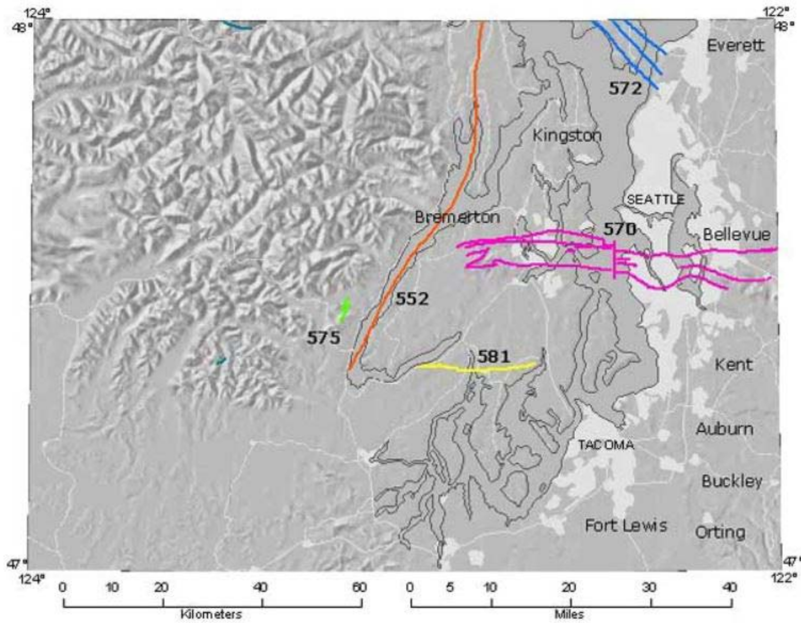


Figure 1: Seattle area fault map (credit: USGS)

Before construction of the Lake Washington Ship Canal project, Lake Washington's outlet was the Black River at the south end of Lake Washington, which joined the Duwamish River and emptied into Elliott Bay south of downtown Seattle. When the canal was opened the level of the lake dropped nearly nine feet (3 m). The canal to Puget Sound became the lake's only outlet, causing the Black River to dry up and disappear.

4.0 ACCESS TO SOUTH LAKE WASHINGTON

The Lake Washington Ship Canal, which runs through the City of Seattle, Washington, connects the fresh water body of Lake Washington with the salt water inland sea of Puget Sound. The Hiram M. Chittenden Locks accommodate the approximately 20-foot difference in water level between Lake Washington and Puget Sound. The Canal runs east/west, and connects Union Bay, Lake Union, the Montlake Cut, Portage Bay, the Fremont Cut, Salmon Bay, and Shilshole Bay, with the Sound, which empties into the Pacific Ocean.

The restrictions for navigation through the ship canal is determined by the large Chittenden Lock dimensions, which are approximately 80 feet wide by 825 feet long and 25 feet to 30 feet deep at mid channel. Other parts of the canal, such as the Fremont cut and the Montlake cut, have similar dimensions.

The only possible vessel passages currently available to the project site south of the I-90, are elevated fixed spans at the floating bridge termini with 29 feet (8.8 m) of vertical clearance[4] and the I-90 bridge

[3] S P Palmer, HW Schasse, D K Norman; Liquefaction Susceptibility for the Des Moines and Renton 7.5 minute Quadrangles, Washington; Washington State Department of Natural Resources; Dec. 1994. http://www.dnr.wa.gov/publications/ger_gm41_liquifaction_suscep_desmoines_renton_area.pdf (accessed April 2014)

[4] http://en.wikipedia.org/wiki/Lacey_V._Murrow_Memorial_Bridge (accessed April 2014)

crossing between Bellevue and Mercer Island with 71 feet (21.6 m) of vertical clearance as shown on NOAA Chart 18447.

5.0 LAKE WASHINGTON BATHYMETRY AND PRELIMINARY CABLE CORRIDORS

NOAA Chart 18447 describes Lake Washington bathymetry. Figures 2 and 3 have been extracted from the chart and show a lake bottom already congested with existing pipe and cable installations. Many of them provide power, gas, communications, and water service to Mercer Island from the east side of Lake Washington. Preliminary 230 kV cable corridors are shown in Figures 2 and 3, selected with a view to avoiding existing underwater utilities as much as reasonably possible, and if not possible, to cross at near ninety degrees.

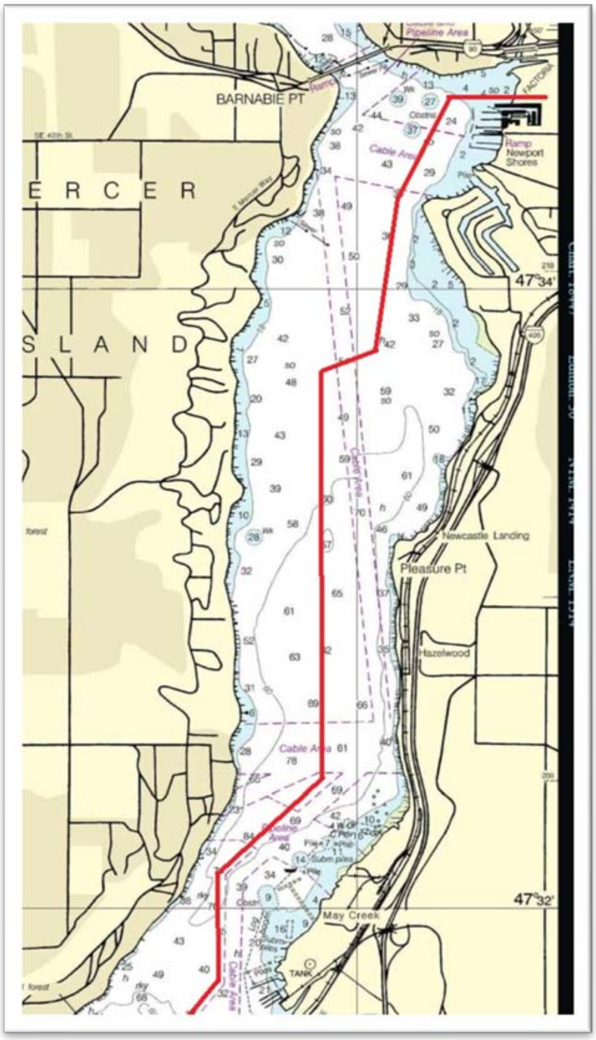


Figure 2: North route corridor

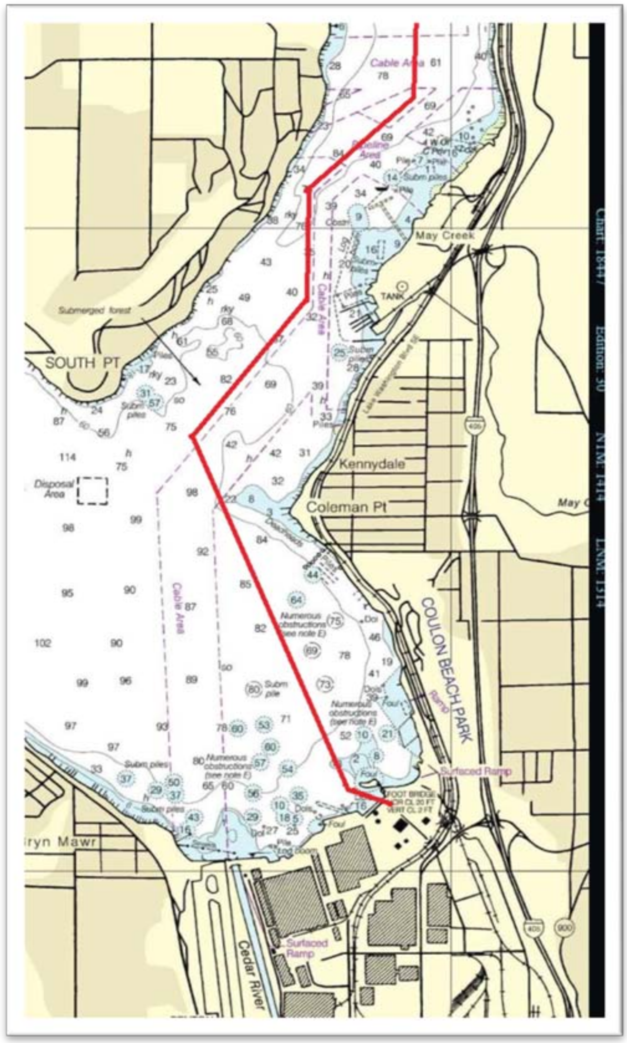


Figure 3: South route corridor

5.1. Underwater Utility Crossings

Figures 2 and 3 show at least five crossings of third party utilities to be managed organizationally and technically. The International Cable Protection Committee has developed recommendations for underwater cable crossings and offshore applications (www.iscpc.org). In the absence of any other clear domestic requirements, it is assumed that they would apply at least as guidelines, with ICPC Nos. 2 and 3 being most relevant[5] [6]. The recommendations provide generalized cable routing and notification criteria to be used when undertaking cable route planning activities where the proposed cable crosses, approaches close to, or parallels an existing or planned system. Perpendicular crossings are preferred, and crossing angles less than 45 degrees from the utility are to be avoided.

5.2. Underground Segments

Figures 4 and 5 show the conceptual routing of the land segments for the underground duct bank necessary to connect the submarine cable lengths to the overhead lines. Three splicing vaults would be utilized to transition the submarine cables to land cables. Each of the three cable runs would be physically separated with individual vaults and termination structures so that any two could continue to operate if the third were taken down (de-energized) for maintenance activities.

From the northern and southern landings off of Lake Washington, the XLPE submarine cables would be spliced to standard 230 kV XLPE cables with beach joints or similar techniques. Depending on detailed engineering, the land cables could be single-phase or three-phase. The land cables would be routed from the splice vault directly toward the underground to overhead transition structures via normal open trenching techniques. The northern landing area appears to be marshy and special construction techniques such as swamp pads may be required. A jack and bore or pipe-jacking trenchless crossing would be utilized to pass under the railroad. The full extent of constructability and routing to the transition structures has not been investigated and is not included in this report.

A complete description of 230 kV underground transmission line cable systems can be found in the report: "Eastside 230 kV Project Underground Feasibility Study", document STL 085-1244.

Figure 4: North Submarine Landing to Overhead Line

Figure 5: South Submarine Landing to Overhead Line

[5] ICPC Recommendation No. 2, Recommended Routing and Reporting Criteria for Cables in Proximity to Others; International Cable Protection Committee, January 2007

[6] ICPC Recommendation No. 3, Criteria to be Applied to Proposed Crossings Between Submarine Telecommunications Cables and Pipelines/Power Cables; International Cable Protection Committee, January 2007

6.0 ELECTRICAL DESIGN PARAMETERS

The following parameters were provided by PSE:

Normal AC operating voltage, phase-to-phase (kV rms)..230
Continuous AC over-voltage, phase-to-phase (kV rms)..242
15 minute AC over-voltage, phase-to-phase..255
Lightning impulse withstand voltage (BIL) (kV, crest)..1050
System frequency (Hz) 60
Type of grounding...multi-point, effectively grounded
Current carrying capacity (normal, emergency) .... as per Table 1
Short circuit level and duration..40 kA symmetrical for 15 cycles
Daily load factor (average/peak load in 24 hours)..0.6

Table 1: Required Transmission Capacity (as determined by PSE Planners)

Voltage (kV)	Normal Ratings				Emergency Ratings			
	Winter		Summer		Winter		Summer	
	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps
230	1012	2540	923	2317	1034	2596	972	2440

The Table 1 ratings are applicable to the overhead line sections and PSE requires any series cable system to have equivalent ratings. Cable conductor sizes would therefore need to be selected to meet these current ratings for the hottest winter (November to April) and summer (May to October) soil temperatures, as shown in Figures 12 and 13 below. At other times of the year the cables would operate below their normal maximum conductor temperature and would therefore be underutilized.

If actual 'normal' and 'emergency' line loadings are infrequent, it may be possible to provide adequate cable transmission capacity using two parallel three-phase cables with 1200 mm^2 or 1400 mm^2 copper conductors, instead of three parallel three-phase cables with 800 mm^2 copper conductors. This would be especially feasible if a dynamic rating system was applied to exploit short term cable overload capabilities, which are considerably higher and longer than for overhead conductors. Cable costs would be lower and terminal stations or poles less complex, since only two terminations per phase would be needed instead of three per phase. A related requirement to facilitate the two three-phase cable alternative would be a clear definition of PSE's planning and operating criteria for managing N-1 and N-1-1 outage events affecting loading of their connected network lines.

As with an underground cable circuit, there may be a need for reactive compensation with a submarine cable system although this is a system phenomenon and may only be justified following an extensive electrical system study. The following information will give the system planner a "ballpark" idea for the electrical characteristics that may be expected, but these values are also subject to refinement and revision should the project proceed further toward implementation.

Assuming 3-phase 800 mm^2 copper conductor cables, each of the three cables per phase would have capacitance of approximately 2.8×10^{-7} F/mile. This would result in a capacitance charging current of approximately 14 A/mile for each of the three cables per phase. If the system power factor was unity, the charging current would share equally between the two cable ends. Otherwise system studies would be required to determine reactive power flow at each cable end. Depending on final cable designs and cable ampacity requirements, reactive compensation (shunt reactors) may be needed to offset charging current to ensure that real power transmission capacity is adequate. For 100% compensation and unity power factor, the amount of inductive reactance needed for each side of the cable system would be approximately: 2.8 MVAr/mile, for each of the three cables.

Adding this much capacitance to a network can also result in transient over-voltage conditions, which should be thoroughly investigated for the application. Some examples are:

- Resonance phenomena
- Excessive Ferranti rise voltage on line energization, load rejection or light loading conditions
- Switching (connection/disconnection) of capacitors or reactors
- Re-closing after clearing a fault

If system studies show that reactive compensation is needed, reactors do not necessarily need to be located at cable terminals. Studies could also describe advantages and disadvantages of applying switched reactors.

7.0 PRELIMINARY CABLE SYSTEM SELECTION

There are three possible cable types that would be technically suitable for the application. All would be manufactured at a European or Asian cable factory since there are presently no capable factories in the Americas.

7.1. Self-contained Fluid-filled, Single Phase Cables

This cable type would be of single-core construction and similar to the 115 kV submarine cables serving Vashon Island since 1962[7], except with a larger conductor to meet current rating requirements, thicker insulation for 230 kV and copper armor instead of aluminum. SCFF cables require the use of pressurized insulating fluid within the conductor and insulation. A diagram of the Vashon cables is shown in Figure 6. Many similar cables are operating successfully in Alaska and a similar 242 kV, 600 MW rated submarine cable circuit with paper-polypropylene laminate (PPL) insulation was commissioned from mainland British Columbia to Vancouver Island in 2008 (Figure 7). This Lake Washington application would require six cables similar to the 2008 installation, with a copper conductor size of approximately 1600 mm^2, for 1012 MVA transmission.

Although self-contained fluid-filled cables are very reliable, there are less cable manufacturers capable of supplying them. Maintenance of the fluid pressurizing system is also relatively expensive and there are risks of fluid leaks into the environment.

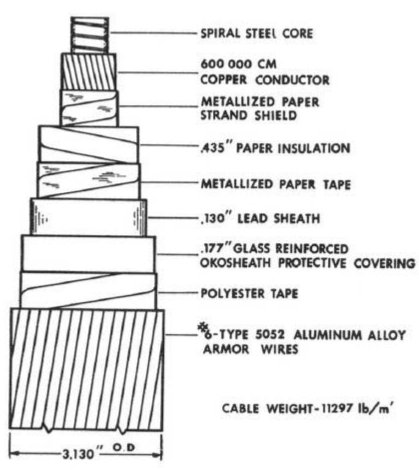


Figure 6: Vashon Island 115 kV self-contained fluid-filled cables

[7] R C Waldron; 115-kV Submarine Cable Crossing of Puget Sound; Paper 31 TP 65-33, IEEE Winter Power Meeting, New York, NY; January 31-February 5, 1965.

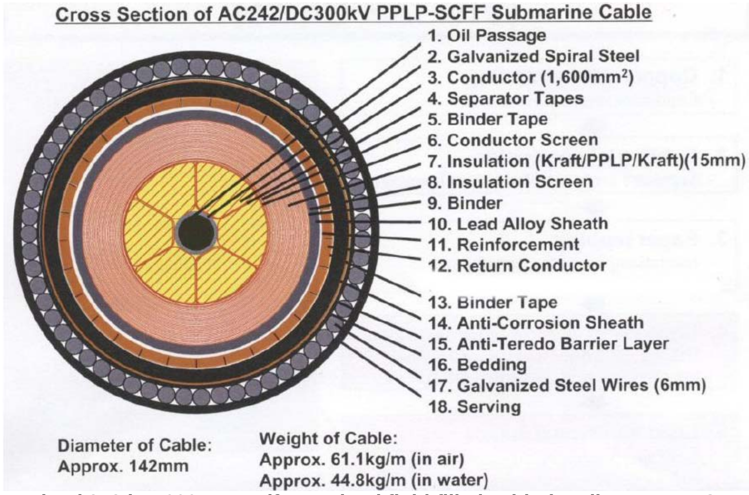


Figure 7: Vancouver Island 242 kV, 600 MW self-contained fluid-filled cable (credit: J-Power Systems; VISCAS Corp)

7.2. Cross-linked Polyethylene Insulation, Single-phase Cables

Long distance XLPE insulation submarine cables have only become commercialized at the 230 kV level within the last decade. Because the insulation is not pressurized with insulating fluid, risks of leaks into the environment are absent and maintenance costs are relatively low. The most extensive application in North America is the 345 kV, 602 MVA, 6.5 mile (10.4 km) link between Bayonne, NJ and Brooklyn, NY, commissioned in 2011. Figure 8 shows three of the Bayonne single-phase cables, which have copper armor wires. As with the SCFF cable type, six cables would be required, each with a copper conductor size of approximately 1600 mm^2, for 1012 MVA transmission. With a single layer of armor wires, the cables are typically coilable, which means that cable transportation and laying equipment does not require use of a turntable.

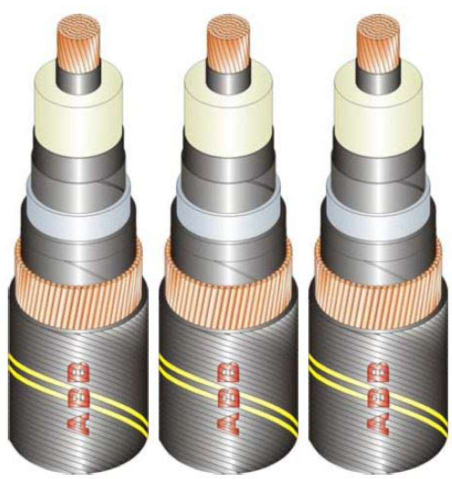


Figure 8: Bayonne 345 kV XLPE submarine cables (credit: ABB)

7.3. Cross-liked Polyethylene, Three-phase Cables

Three-phase cables with XLPE insulation have also been commercialized at the 230 kV level and above during the last decade, with capacities now up to about 400 MVA at the 230 kV level. The first and only 230 kV application in North America was in Lake Ontario from the Wolfe Island wind farm site, using 500 mm^2 copper conductors. Other applications are for several offshore European wind farms, notably the recently completed Danish Anholt wind farm project and the in-progress Dudgeon wind farm project in the U.K., both of which use 400 MVA rated three-phase cables. A photo of the Anholt cable, which uses 1600 mm^2 solid aluminum conductors, is shown in Figure 9.

Figure 9: Anholt wind farm 400 MW 220 kV cable (credit: NKT Cables and Energinet)

In order to strictly comply with this application's 1012 MVA normal transmission capacity requirements, three 340 MVA three-phase cables would be needed, each with a copper conductor size of approximately 800 mm^2. External cable diameter would be about 240 mm and weight in air about 81 kg/m.

Advantages and disadvantages of three-phase compared to single-phase designs are described in Table 2.

Table 2: 1-Phase vs. 3-Phase Cable Types Comparison

1-Phase	3-Phase
Pros	Pros
• Lighter weight	• Lower external magnetic field
• Smaller diameter	• Minimum sheath currents and voltages
• Longer lengths on drums	• Lower installation costs (since fewer cables)
• Possibly fewer joints – factory and on site	• Less impact on seabed (since fewer cables)
• Higher current rating	• Lower protection costs (since fewer cables)
• Improved security – can add a 4th cable for N-1	• Can easily include optional fiber optics
• Voltage rating up to 500 kV	• Narrower ROW requirements
• Reduced repair costs and spares	• Lower armor losses
• Lower material costs for each cable – but minimum 3	• Better stability in high water currents
	• Better corrosion resistance

Table 2: 1-Phase vs. 3-Phase Cable Types Comparison (cont.)

Cons	Cons
• Higher external magnetic field	• Lower current rating
• Greater installation costs (since more cables)	• Heavier
• Greater impact on seabed (since more cables)	• Larger diameter
• Protection costs increased (since more cables)	• Security of cable system decreased
• Sheath/shield current must be considered	• All 3 phases need to be repaired after a fault
• Wider ROW needed	• Larger laying and repair vessel needed
• Higher armor losses	• Two cables needed for N-1 unless an alternate supply
	• Higher material costs for cable – minimum one

7.4. Preliminary Selection of Cable Type for Feasibility Study Purposes

Table 3 compares characteristics of preliminary cable alternatives for 1012 MVA (2540 A) transmission in winter. These values are considered provisional and are subject to revision during the detailed engineering and design implementation stage.

Table 3: Preliminary Cable Alternatives

	SCFF 1-phase	XLPE 1-Phase	XLPE 3-phase
No. of cables	6	6	3
Land cable conductor size	1600 mm^2	1600 mm^2	800 mm^2
Land cable external diameter	132 mm	132 mm	240 mm
Land cable weight in air	46 kg/m	46 kg/m	81 kg/m
Lake cable conductor size	1200 mm^2	1200 mm^2	800 mm^2
Lake cable external diameter	125 mm	125 mm	240 mm
Lake cable weight in air	40 kg/m	40 kg/m	81 kg/m

On the basis of higher maintenance costs, perceived difficulties with permitting due to the pressurized insulation, and a dwindling number of manufacturers, the SCFF cable alternative was rejected for further consideration in this study.

The single-phase XLPE alternative assumes that the six cables would have larger conductor sizes for the shore ends, due to physical congestion at the landings requiring them to be closer together, and thus experiencing de-rating due to mutual heating effects. Transition joints would be located close to shore where wider submarine cable spacing could be maintained and deeper burial might not be required. Single-phase cables would have the smallest diameter, lightest weight and would be coil-able, which would lead to more flexible transportation and easier installation by domestic marine contractors, compared to three-phase alternatives. Transportation from a European or Asian factory could be done using a freighter to approach the site, where cables would be off-loaded onto a cable laying barge capable of passing under the open spans of the I-90 floating bridge (29 feet (8.8 m) vertical clearance). Assuming that most of the cable would be 1600 mm^2 copper conductor, the total weight for six cables for 6.5 miles (10.4 km), would be about 2900 tons. Figures 10 and 11 show a typical freighter-to-barge transfer operation for 600 MW 242 kV single-phase submarine cables.

Figures 10 and 11: Cable transfer from freighter to lay-barge; cable in hold of freighter prior to transfer

The XLPE 3-phase alternative would use three much heavier and larger, non-coilable cables. The same conductor size would be used throughout, since they would be less susceptible to mutual heating effects where in close proximity near the shore ends. Transportation from a European or Asian factory and cable laying would need to be done using a vessel with a turntable, capable of storing all three cable lengths. Assuming 800 mm^2 copper conductors, the total weight for three cables for 6.5 miles (10.4 km) would be about 2500 tons.

Since cable costs are fundamentally driven by weight, it appears that the three (3) three-phase cable solution would be optimum, especially considering a more narrow corridor, and provided that suitable vessels could be applied to transport the three cables from the factory, pass through the ship canal locks and lay the cables in south Lake Washington. It may be possible to transport cables on an ocean-going barge fitted with a large turntable and then trans-spooling cables one at a time to a local cable-lay barge with a turntable. Intermediate sized dedicated cable laying vessels with greater than 2100 tons capacity would not be capable of passing under the I-90 floating bridge. Multiple passes may be required for the complete installation of the cable system.

Cost estimates assume the latter three-phase cable alternative. However, it is assumed that the final cable type, size and installation methods will be based on additional studies to be done during a project's definition and implementation phases, as well as results of a competitive bidding process and performance-based specifications for a turn-key EPC contract.

7.5. Cable Standards

Cables would be specified with cross-linked polyethylene insulation, to at least meet the following requirements.

- IEC 62067 'Power Cables with Extruded Insulation and their Accessories for Rated Voltages above 150 kV up to 500 kV - Test Methods and Requirements'
- ELECTRA 171 'Recommendations for Mechanical Tests on Submarine Cables'
- CIGRE Technical Brochure TB 490 'Recommendations for Testing of Long AC Submarine Cables with Extruded Insulation for System Voltage above 30 (36) to 500 (550) kV
- AEIC CS9 'Specification for Extruded Insulation Power Cables and their Accessories Rated above 46 kV through 345 kVac'

7.6. Cable Temperature Instrumentation

It is recommended that cables be specified with integral optical fiber elements for distributed temperature sensing (DTS) along all three cable lengths. The addition of DTS opto-electronics would allow continuous temperature profiles between terminals at either end. A dynamic rating system is also recommended, to maximize safe normal and emergency loading capabilities based on actual measured cable temperatures, ambient temperatures and loading history. It would also be useful during an outage on one of the parallel sub-circuits, when loading of the remaining cable(s) could be higher than normal.

8.0 UNDERGROUND/SUBMARINE AND OVERHEAD COMPARISON

PSE is exploring alternative methods to overhead transmission lines per the request of neighborhoods and businesses within the project area that would be affected by the new 230 kV overhead structures. The cost difference between overhead transmission lines and alternative underground methods, including submarine cables, would be covered by a tariff to the customers in the project area. The difference in project cost would need to be presented up front before the alternative installation method could be constructed. Risks to the escalation of cost are outlined in Section 13.

8.1. Cost Difference

The cost to place new transmission lines underground or in water can be about 4 to 15 times the cost (depending on voltage) to build overhead lines of the same voltage and same distance due to time, materials, process, and the use of specialized labor or installation methods. Costs vary depending on region and design criteria for the transmission line as well as other factors that are unique to each transmission line.

8.2. Maintenance Differences

The present worth of the maintenance costs associated with underground and submarine lines are difficult to assess. Many variables are involved and many assumptions are required to estimate the cost. Factors that impact the maintenance costs for underground and submarine cables include:

- Cable repairs – underground and submarine lines are better protected against weather and other conditions that can impact overhead lines. If the cables experience a fault, however, the cost for finding its location and fixing the cable is sometimes 5 to 10 times more expensive than repairing a fault in and overhead line where the conductors are visible, readily accessible and easier to repair.
- Line outage durations – the durations of underground and submarine line outages vary widely depending on the operational voltage, site conditions, type of failure, material and equipment availability, repair personnel availability and ability, and cooperating weather. The extended line outages required for underground and submarine line repairs disrupt the service to the customers. The length and effect on the customer can be mitigated using redundant feeders, but the duration of such outages is still longer than those associated with overhead lines, and they have additional costs associated with them.

9.0 CABLE INSTALLATION

9.1. Environmental and Installation Parameters

Ambient soil/water temperature (maximum summer) .... 23 °C (May to Oct)
Ambient soil/water temperature (maximum winter)... 15 °C (Nov to Apr)
Burial depth (minimum) ....3-ft (1.0 m)
Burial depth (maximum)..5-ft (1.5 m)
Soil and lake bottom thermal resistivity (maximum)...1.0 °C-m/W
Cable separation distance in water (minimum)..16.5-ft (5.0 m)
Cable separation on land (minimum)...3-ft (1.0 m)

NOAA Climate Normals data describe the following average temperature extremes for Renton Municipal Airport, which is the closest weather station to the project site.

Maximum daily average surface temperature..78.0 °F (25.5 °C)
Minimum daily average surface temperature...36.0 °F (2.2°C)
Time daily between January 1 and lowest average temperature...0 days

Annual soil temperature variation at 1.0 m and 1.5 m depths for Renton are shown in Figures 12 and 13, with detailed calculations given in Appendix A.

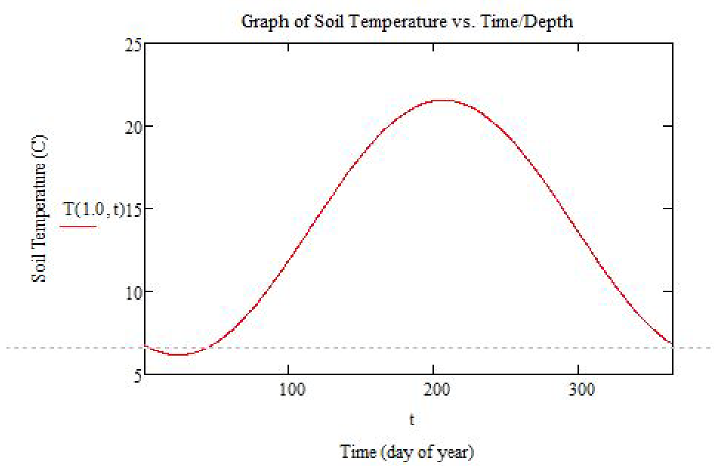


Figure 12: Soil temperature versus time of year for 3.3' (1.0 m) burial depth

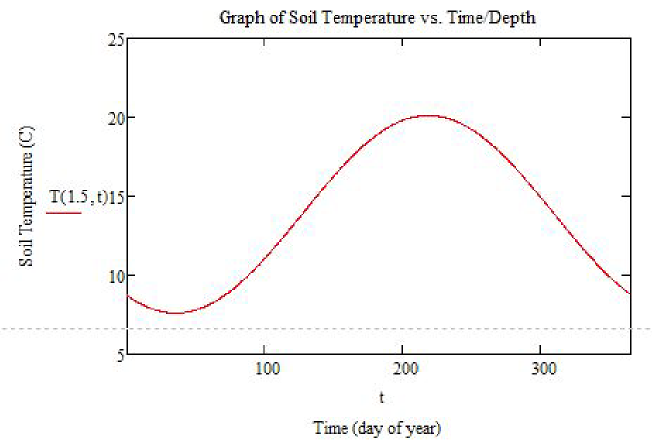


Figure 13: Soil temperature versus time of year for 4.9' (1.5 m) burial depth

The above annual temperature variations are a main factor in cable conductor size selection.

9.2. Cable Landings

Three individual three-phase 340 MVA cables would be laid in three transits of the cable route.

It is recommended that three conduits be pre-installed for each shore landing, using open cut trenching, sheet-piling and dredging methods. Burial depth is assumed to be about 5-ft (1.5 m). Horizontal directionally drilled (HDD) landings are fashionable, but not considered desirable for this site because the lake level is not subject to tidal variations or heavy wave action, as with open ocean landings. HDD installations would also substantially de-rate the cable capacity due to much deeper installation, requiring a larger conductor size and higher costs, as well as causing substantial public and commercial disturbance and environmental impact at the launching and punch-out areas. A HDD submarine cable landing is shown in Figure 14.

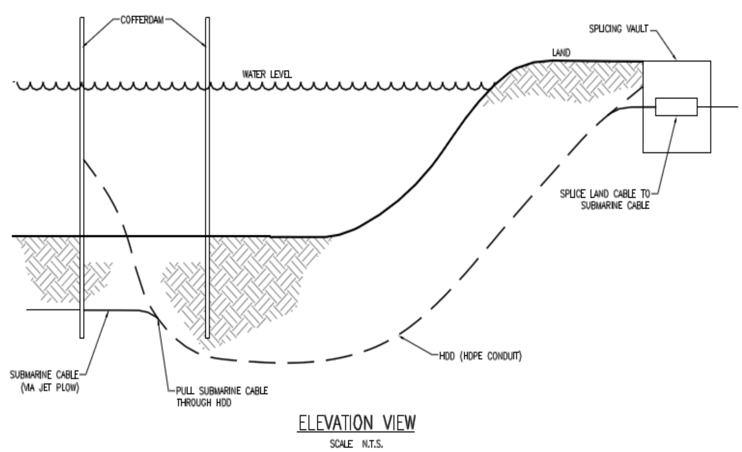


Figure 14: Submarine Cable Landing VIA HDD

The advantage of pre-installing conduits for the landings is that it minimizes site time for the submarine cable laying vessel, which typically has the most expensive day rate. An open trench landing is illustrated in Figure 15. Once the cables have been pulled into conduits and cut to final length, the voids between conduits and pipes would be filled with a bentonite-sand mixture to improve thermal performance.

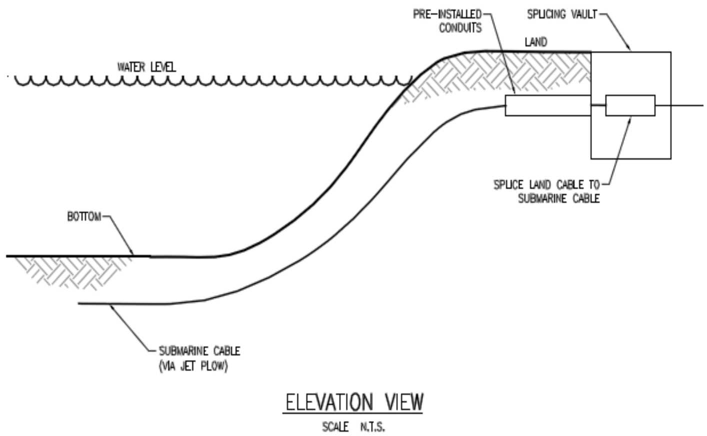


Figure 15: Submarine Cable Landing VIA Open Trench

Submarine/underground transition joints would be located on dry ground close to the shore. Part of the transition system would be installation of armor anchors and trifurcation of the three cores for single phase jointing operations. Since adjoining underground sections are presently proposed to have three cables per phase, a hybrid system would be needed to connect three submarine cable cores to three standard underground cables.Through detailed engineering, the total disturbed area will depend on the number and separation of the splice vaults and type of land cable.

9.3. Cable Laying

Figure 16 shows a typical lay-barge with dynamic positioning capabilities, suitable for laying and splicing 230 kV submarine cables in relatively shallow water, such as Lake Washington. The gantry might need to be lowered in order to pass under the I-90 bridge to the project site shown in Figures 2 and 3.

Figure 16: Typical lay-barge with dynamic positioning for 230 kV cable laying

9.4. Cable Spacing

Horizontal separation distance between the new cables would need to consider heating effects, maintenance requirements and minimizing common mode failure possibilities.

In order for the cables to have their full rated capacity, the parallel cables cannot be closer than 16.5 feet. Cables placed closer together than this will experience de-rating effects due to mutual heating effects. This minimum separation will mostly be the case in areas where the cable approaches the shoreline and transitions to on-land configurations.

Sufficient space would also need to be provided for a cable repair operation, which typically requires using a short length of replacement cable and two joints to repair a damaged section of cable. When the repaired section is dropped back to the lake bed, the cable forms an omega shape due to the additional length of cable added by the splice. If this was the only consideration, cable spacing a little greater than the water depth would be required to avoid violating the minimum separation (16.5 ft) distance. However, adequate space should be provided in case temporary anchors need to be placed during the repair operation.

In addition, to reduce the possibility of anchor dragging events damaging more than one cable, a separation distance of twice the water depth, or 100 yards minimum[8], is recommended for ocean applications. Since this part of Lake Washington is not subject to traffic by large vessels, the 100 yard criteria could be relaxed for at least parts of the planned cable corridor. With the maximum water depth along the proposed cable corridor in Figures 2 and 3 being less than 100 feet, and considering a lake bottom already congested with other utilities, it appears that 100 feet (30 m) cable separation at installation should be sufficient as a compromise where feasible.

9.5. Cable Protection

For cost estimating purposes, it is assumed that cables would be post-lay buried to about 3-ft (1.0 m) burial depth below the lake bottom. However, final burial depth would be based on a formal Burial Assessment Study, and it is possible that except for the shore landings, the cables could be simply laid on the lake bottom without burial, considering the relatively low risk of damage from fishing boats and large vessels south of the I-90 bridge.

10.0 REGULATORY APPROVALS

10.1. Public Consultation and Permitting Issues

Permitting is expected to be challenging. The following issues are likely to be raised during public meetings, by interveners and by regulators in response to permit applications:

Overall project:
- Demonstration that all alternatives been considered, including non-transmission alternatives,
- Demonstration that the project meets PSE's seismic design criteria and meets or significantly improves their seismic performance criteria,
- Aesthetic appearance of terminal stations or terminal poles.

During construction phases:
- Environmental impact on the aquatic environment,

[8] M. Sharples; Offshore Electrical Cable Burial for Wind Farms: State of the Art, Standards and Guidance & Acceptable Burial Depths, Separation Distances and Sand Wave Effect; BOEM Project No. 671, Contract M10PC00102; November 2011.

- Environmental impact on wetlands,
- Traffic disruption for private and commercial users,
- Neighborhood noise disturbance,
- Temporary loss of use for public parks and trails,
- Possible permanent damage to paved surfaces, sidewalks, parks and trails,
- Property acquisition for terminal stations or terminal poles.

During operation and maintenance:

- Perceptions of health risks from magnetic field exposure,
- Environmental effects from cable heating,
- Public disturbance for routine cable maintenance,
- Public disturbance for emergency underground cable repairs,
- Public disturbance for emergency submarine cable repairs.

At end of life:

- Demonstration of an end-of-life replacement or abandonment plan.

10.2. Preliminary Regulatory Approval Requirements

Following is a preliminary and partial list of requirements, mainly related to environmental reviews and permitting. It is recommended that should the project proceed further, a more comprehensive description of all legislated requirements be developed by specialists in order to have a more complete understanding of constraints on design, construction and maintenance activities.

Permits or approvals will be required from at least the following agencies:

- U.S. Army Corps of Engineers, for issuance of permits under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act.
- U.S. Fish and Wildlife Service and the National Marine Fisheries Service, for consultation under Section 7 of the Endangered Species Act.
- Washington State Department of Natural Resources, for issuance of an authorization (lease, easement, or other instrument) for installation of submarine cables on state-owned land.
- Washington State Department of Fish and Wildlife, for issuance of a Hydraulic Project Approval for work in Lake Washington.
- Washington State Department of Ecology, for issuance of a Water Quality Certification to certify that the permitted activity complies with state and federal water quality standards and to assure compliance with the Coastal Zone Management Act.
- City of Bellevue or City of Renton, for issuance of a Substantial Development Permit, Major Project Permit, and/or other exemptions or approval(s) to assure compliance with the State Shoreline Management Act and local codes and ordinances.
- Cities having jurisdiction over roads, streets, parks and trails located along the various routes, including: Renton, Mercer Island and Beaux Arts Village.
- Department of Archaeology and Historic Preservation compliance with Section 106 of the Historic Preservation Act.

11.0 FUTURE ACTIVITIES FOR PROJECT DEFINITION STAGE

Should steps be taken to proceed further with the project from this preliminary planning stage, the following minimum activities are recommended as part of a definition stage.

- Prepare a desktop study*
- Refine north and south cable landing points and discuss with property owners and agencies
- Perform a site bathymetric, geophysical and geological survey
- Refine proposed cable corridors
- Refine preliminary cable system designs, including realistic rating requirements
- Engage in discussions with owners of third party utilities that would be crossed by the new 230 kV cable system
- Engage in discussions with regulatory authorities
- Refine cost estimates with a formal Request for Information to turnkey submarine cable providers

*A desktop study might include the following:

Overview
Content
- Routing Selection and Landing
- Geology
- Climatology
- Seismology
- Commercial Operations, Restricted Areas and Obstructions
- Biological Factors
- Regulatory Factors

Site Visit
Route Recommendation
Survey Recommendation
Reporting and Documentation
Regular Status Reports
The Preliminary Site Visit Report
Desktop Study Report
Digital Format of DTS Report
DTS Report Quantities
Charting Requirements
- Description
- Chart Scales

As suggested above, a multi-sensor geophysical survey in Lake Washington would be used to support the development, permitting and eventual installation of the 230 kV cable system. POWER contacted a marine survey contractor for project specific cost information and for suggestions for typical survey programs. Typical survey programs for submarine cable systems consists of the acquisition of multi-sensor geophysical data which includes hydrographic, sub-bottom profiling, magnetometer, and side scan sonar imagery. Survey investigations will be performed within an approximate 600-foot wide corridor centered on the proposed cable route. Tracklines spacing within the survey corridor will be established at 50-foot intervals. Along all survey tracks the hydrographic, subbottom profiling and magnetometer data will be acquired. Side scan sonar imagery will be acquired along specific tracks with the intent of providing close to 100 percent overlapping coverage of the bottom within the entire survey corridor. As means of providing quality control and confirmation of data acquired along the primary tracklines, addition data will be acquired along a series of cross or "tie" lines set perpendicular to the survey corridor. For estimating purposes, the Contractor assumed that these tracklines would be spaced 500-feet apart along the entire proposed alignment. In total, the Contractor estimated approximately 95 statute miles of survey tracklines will have to be investigated to complete this task.

To complete the investigation, the Contractor would mobilize a 25 to 27-foot survey vessel, equipped for offshore survey work and outfitted with a stern mounted A-frame, winches (to tow the remote sensing equipment at depth), generator, and davits. The vessel will be staffed with a highly experienced field crew:

- Geologist/geophysicists project manager
- Electronics technician/vessel captain

The following survey instrumentation will be installed on the vessel to conduct the investigation:

- Differential Global Positioning System (DGPS) with positioning accuracy of ±3 feet
- HYPACK navigation and data-logging computer system
- Single-beam depth sounder
- Chirp subbottom profiler equipped with a 2-16 kHz tow vehicle
- Marine cesium magnetometer
- Dual-frequency (100 kHz and 500 kHz) side scan sonar system

Following the conclusion of the survey, the Contractor will process and interpret the acquired data sets. As with all remote-sensing investigations, the results of this investigation will vary depending on the nature of the sediments and bottom conditions existing at the project site. It is anticipated that data will be presented on a set of standard plan and profile cable route drawing sheets as follows:

- Survey trackline plot with labeled navigation event marks (scale TBD)
- Hydrographic data will be used to construct a contoured plan view drawing of the route corridor. The contour interval of this drawing will be 2 feet (scale TBD)
- Side scan sonar will be processed to generate a mosaic of the bottom within the survey corridor (scale TBD). This mosaic will be overlain by a features/target overview chart that will identify and key specific features/targets including utilities identified on the bottom to a summary table in the survey report
- Magnetometer data will be processed with the primary intent to identify anomalies including existing utilities present within the survey corridor. Anomalies will be plotted on the features target overview chart and included in a summary table in the report
- Subbottom profile data will be processed and used to construct a representative centerline profile of the proposed route. Subbottom reflectors and area of interest (nearsurface coarse bottom and/or rock) will be identified on the profile and presented as an overview on the survey trackline plot
- Survey report detailing each survey investigation and summary of results

The preliminary ROM budget for the geophysical survey would depend on the final level of effort and scope of services required (the estimate below includes ~7 days on-site acquiring data).

12.0 COST ESTIMATES

The Table 4 provides overview cost estimates for the selected 3-phase alternative, including an important list of assumptions listed below:

Table 4: Cost Estimate Summary

Total EPC Contractor and Owner's Cost	XLPE Cable System Costs		Total Cost
	Material Costs	Labor and Equipment Costs	
EPC Contractor's Submarine Cable Supply, Delivery, and Installation	$53,750,000	$87,188,000	$140,938,000
EPC Contractor's Landings and Tie to Overhead Lines	$10,285,000	$7,404,000	$17,689,000
Unallocated Costs	$0	$625,000	$625,000
SUBTOTAL	**$64,035,000**	**$95,217,000**	**$159,252,000**
Owner's Engineering, Project Management, and Permitting (5%)	$3,202,000	$4,761,000	$7,963,000
TOTAL	**$67,237,000**	**$99,978,000**	**$167,215,000**

Table 4 costs assume the following:

1. Costs are in 2014 US Dollars.
2. Corridor length is 6.5 mi (10.4 km) plus 3,000 feet of interconnecting duct bank.
3. Submarine cables are three-phase, 800 mm^2 copper conductors, XLPE insulation, lead alloy sheath, PE jacket, single armor.
4. Underground land cables are three-phase, 800 mm^2 copper conductors, XLPE insulation, lead sheath, PE jacket.
5. Three submarine cables are needed in parallel to meet 1012 MVA transmission capacity requirements with 0.6 daily load factor.
6. Cable costs are based on copper at $6,700/ton, lead at $2,100/ton and crude oil at $100/barrel.
7. Interconnecting duct bank is standard 4x4 configuration with native soil backfill.
8. Cables supplied from a cable factory in Asia or Europe and shipped to site by freighter or barge and transferred to a specially equipped cable laying barge.
9. Submarine cables are buried 1.0 m deep in water and 1.5 m deep on land to submarine/underground transition point; assuming no submerged forests are encountered.
10. Cable is laid in summer months using a barge with dynamic positioning (DP) thrusters.
11. No spare cable, accessories, or repair joints included in estimate.
12. Transitions from cable to overhead terminal stations or poles included in the underground costs and include one splicing vault at the submarine landing and one pull through vault at the underground to overhead transition structure per cable set for a total of six each.
13. Transitions from three submarine cables/phase to three underground cables/phase assume 1,800’ of duct bank at the north landing to overhead riser structures and 1,200’ at the south landing.
14. Vaults for transition from submarine to underground cables included in the underground costs.

15. Estimates are Class 5, as defined by AACE International, to be used only for concept screening purposes with low project definition.
    a. Class 5 estimates typically have accuracies in the following range:
        Low: -20% to -50%;
        High: -30% to +100 %
16. A 25% contingency has been applied.
17. Interest during Construction not included.
18. Reactive compensation requirements not determined and costs not included.
19. Cable costs do not include cable system type tests, which are assumed to have already been done.
20. Duties and taxes not included.
21. Construction All Risk Insurance costs not included.
22. Real estate, environmental studies, permitting, and mitigation costs are not included.

Travel time for a Panamax bulk freighter from S. Korea or Japan to Seattle is assumed to be about 15 days in each direction, plus 10 days for transshipment (www.searates.com), for a total return time charter duration of about 40 days. To this should be added time to clear port customs and to transfer cables to the lay-barge, totaling about 50 days. Time charter costs for a Panamax bulk freighter range between about $20K and $40K/day plus fuel (www.dryships.com). At $75K/day including fuel, the 50 day charter would cost about $3.75M, which is included in the Table 4 estimates. It's noteworthy that trans-oceanic shipping costs are dependent on daily supply and demand, and can be volatile, having doubled in the last six month period (see www.bloomberg.com/quote/BDIY:IND). Transportation by trans-oceanic barge and tugboats could ultimately be more economical, but a cost base was not available and insurance costs could be higher.

If the Lake Washington project proceeds further toward implementation, it is recommended that budgetary cost quotations be obtained from cable supply and installation contractors, in response to a formal Request for Information, with detailed supporting information about site conditions. Appendix B includes pricing break down for Table 4.

13.0 SCHEDULE

There are four main parts to the project schedule: engineering design and completion of construction documents, material procurement, civil construction and electrical construction. The timeline for engineering design and completion of construction documents is primarily a function of route length and complexity of route alignment. Material procurement is based on how quickly suppliers can supply the construction materials needed. Because many submarine cable vendors are presently busy (see Section 13.0), the lead time for the construction of the cable can vary. An overall schedule of approximately 24 months from contract award to substantial completion is typically needed for submarine cable procurement. PSE completed a permit assessment at the landings (not covered in this study) and found that time to acquire rights could be longer than 24 months. Many things can influence the sequence of events necessary to complete a successful project. Following is an approximate schedule. In summary:

Engineering, surveys, and project management:.................................... 15 months
Permitting and real estate acquisition .... 24+ months
Submarine cable manufacturing and delivery:....................................... 24 months
Submarine cable installation and commissioning:................................... 8 months

14.0 POTENTIAL RISKS TO PROJECT

The cost estimate in Section 12 and the schedule in Section 13 make many assumptions that a detailed desktop study may prove to be wrong. POWER identified many cost and schedule risks outlined in this section.

14.1. Cost Risk

This study assumed a load factor of 60%. PSE has determined that the load factor could potentially be anywhere from 70-80%. Depending on the increase, the higher load factor could affect the cable design. An ampacity study would determine if three (3) three phase cables could still handle the power rating with a new load factor. The ampacity study would also need to account for the submarine crossings of existing power cables. Existing power cables could derate the new cables and existing cables, potentially creating the need for a greater conductor size. Depending on the cable vendor, the biggest three phase cable that is made is approximately 1600 mm^2. Instead of a 340 MVA cable, a bigger conductor would be required to reach the same rating if the load factor is higher. This could potentially add anywhere from $50-$80 per foot for the cable. The increase of price to the cable would mean approximately $5.3M-8.5M to the overall cost of the project. If the ampacity study revealed that three (3) three phase cables would not be sufficient then six (6) single phase cables would be required. The conductor size of the single phase cables would be determined by an ampacity study. Installation costs would be effectively doubled with the single phase cables potentially costing an extra $65M. The ROW required would be twice the size and twice the cost of that required for the three phase cable option.

A formal Burial Assessment Study will help identify the risks involved from fishing boats and large vessels south of the I-90 bridge as described in section 8.5. It will also reveal the composition of the lake bottom. Installation costs vary directly with the time required to complete the cable installation. A Burial Assessment Study could reveal the need to bury the cables deeper, which would increase the time and cost of the installation of the project. If the lake bottom is rocky or otherwise too hard for jetting, the cable trench can be made using dredging or excavating. If the lake bottom is too hard for ploughing, the cable trench can be prepared before laying by cutting wheels, cutting chains, or other mechanical disintegrators. This is costly, slow, and only suitable for limited length of the cable route.

The Quendall Site is located on Lake Washington in the northernmost limits of the City of Renton, within a former industrial area that now includes residential and commercial uses. The physical address is 4503 Lake Washington Boulevard North. Shortly after the lowering of Lake Washington in 1916 to construct the Lake Washington Ship Canal, the Site, including newly exposed portions of the former May Creek Delta, was developed into a creosote manufacturing facility and manufactured creosote until 1969. The Site borders approximately 1500 ft. of Lake Washington shoreline. This site contributed to the buildup of dense non-aqueous phase liquid (DNAPL) contaminates and chemicals of concern (COCs) that have the potential to pose unacceptable risks to human health and the environment within the Site and the neighboring lake area[9]. The Site was home to many other industries other than the creosote factory that contributed to the buildup of DNAPL. The Site also contained a pole processing plant. Wood debris, including sunken and partially submerged logs, has accumulated on the beach adjacent to

[9] Anchor QEA, LLC, Aspect Consulting, LLC; Final Remedial Investigation Report Quendall Terminals Site, Renton, WA; Sept.2012. www.epa.gov/region10/pdf/sites/quendall_terminals/Final_remedial_investigation_quendall_terminals_vol_1_2_3.pdf

the site. This would suggest the presence of submerged logs in the lakebed in between the Site and the adjacent beach. The submarine cable would have to be routed around the contaminated area and avoid (or remove) the submerged logs. If the cable installation disturb the contaminates in the soil, PSE would be liable for the contaminated area and responsible for the cleanup and maintenance of the area. It is hard to estimate how much this could potentially cost PSE since the cost is directly correlated with the severity of the disruption.

Section 6.0 describes the potential need for reactive compensation to be installed. The final cable design and cable ampacity requirement will determine if shunt reactors are needed to offset the charging current. A system study would determine the number of shunt reactors to be installed and the cost will vary depending on the amount needed.

14.2. Schedule Risk

As in all projects, contractor availability and construction risks are present. Managing project and schedule risk would include reserving manufacturing space and locking-in pricing so project cost basis may be somewhat predictable. There are presently no North American cable manufacturers capable of making the described cables. Therefore supplies would come from Europe or Asia. Many European factories are busy with local projects until about 2018. However, Japanese and Korean cable factories are presently not as busy. The best way to reserve manufacturing space and lock in pricing is to call for proposals for turnkey supply and installation of submarine cables as early as possible, with a long proposal effective date before an order must be placed. 10-20% of the cable cost is commonly required to reserve floor space if the manufacturer allows it. Provisions could also be made for order cancellation varying on the manufacturer. Note that complete fixing of prices may not be entirely possible, since metal prices and currency values can be expected to fluctuate between quotation and delivery times. It is often to the purchaser's benefit to accept the risks of these price changes.

A project schedule typically accounts for inclement weather. On average, the Seattle area experiences 150 rainy days and 201 cloudy days per year[10]. The cable laying vessels require calm waters to lay the cable. Sustained inclement weather can delay a project schedule and also impact the cost of the project due to the daily cost of the submarine cable laying vessel.

Underwater surveys could help identify other potential risks involved to the project. The existence of an underwater forest, for instance, could impact the project schedule and well as have environmental and construction implications. A preferred and most feasible route option (alignment) will be identified based on the balance of overall anticipated (known) environmental impacts, overall costs, and other issues such as engineering constraints. The goal of this overall effort is to identify the Least Environmentally Damaging Practicable Alternative (LEDPA) to help minimize risks. Once a preferred route is identified and prior to the installation of a submarine cable, the route in which the cable burial is planned should have a route clearance or pre-grapnel run to clear the route of seabed debris that may delay the installation or discover a reason to change the route.

[10] http://en.wikipedia.org/wiki/Seattle (accessed October 2014)

15.0 COMPARISON TO UNDERGROUND (ON LAND) ESTIMATES

POWER performed a similar feasibility investigating the practicality of land cables and underground installation methods in the report: "Eastside 230 kV Project Underground Feasibility Study", document STL 085-1244. Document STL 085-1244 report gives cost estimates for three (3) different routes for both XLPE and HFFF cable systems. The cost estimate and results from this report should not be compared to document STL 085-1244 because of the differences in the design criteria. The Table 5 shows the difference in the design criteria.

Table 5: Comparison between Land and Submarine Design Criteria

	Circuits	Power Rating	Cable Type	Cables per Phase
HLY 019-0228 Submarine Feasibility	1	1012 MVA (2540 A)	Three Phase XLPE	3
STL 085-1244 Land Feasibility	2	800 MVA (2008A) per circuit	Single Phase XLPE	2

In order to compare the two underground installation options, the design criteria would have to be the same.

16.0 CONCLUSIONS AND RECOMMENDATIONS

A preliminary investigation has been carried out into methods and costs for providing a 230 kV, 1012 MVA submarine cable connection between the south end of Lake Washington, east of Mercer Island to the east shore near the I-90 bridge, a corridor distance of approximately 6.5 miles (10.4 km).

In order to minimize corridor width and costs, estimates have assumed using three (3) three-phase 340 MVA cable circuits in parallel. Should the project proceed, ultimate solutions could vary somewhat. Costs for the submarine cable route have been estimated at approximately $167.2M, based on stated assumptions, which include underground cable costs between terminal poles or stations and the submarine/underground transition points near the shores. The $167.2M does not include costs such as sales tax, real estate, environmental, permitting, utility internal costs such as allowance for funds used during construction (AFUDC), labor and overhead, etc. These costs are variable and difficult to estimate without a more detailed assessment.

Recommendations have been made for additional investigations, if this alternative is to be pursued further. The submarine cable life expectancy is 40 years.

APPENDICES

APPENDIX A
SOIL TEMPERATURES VS. DEPTH AND TIME OF YEAR, RENTON WA

Soil Temperature Variations with Time and Depth
(Prepared by A MacPhail, April 2014)

Soil temperature fluctuates annually and daily, affected mainly by variations in air temperature and solar radiation. The variation of daily soil temperatures at different depths, over an annual range, can be estimated using a sinusoidal function (Hillel, 1982; Marshall and Holmes, 1988; Wu and Nofziger, 1999). This program estimates soil temperatures and displays them as a function of time or depth, for user defined parameters.

Model Description:

The annual variation of daily soil temperature at different depths is described with the following sinusoidal function (Hillel, 1982), given that:

$$T(z,t) := Ta + \left(Ao \cdot e^{\frac{-z}{d}}\right) \cdot \sin\left[2\pi \cdot \frac{(t - to)}{365} - \frac{z}{d} - \frac{\pi}{2}\right]$$

t = time (days)

z = depth (m)

Ta = average soil temperature over one year, the constant value occurring at infinite depth (C)

Ao = amplitude of the annual soil temperature function, fluctuating around the average value (C)

d = the damping depth of annual fluctuation, characterizing the decrease in amplitude with a an increase in depth below the soil surface (m)

d = (2*Dh/☐)^1/2

Dh = thermal diffusivity, the change in temperature produced in a unit volume by the quantity of heat flowing through the volume in unit time under a unit temperature gradient

☐ = 2*pi/365 for annual fluctuation, (1/days)

to = the time lag from the arbitrary starting date (say January 1), to the occurrence of the minimum temperature of a year (C)

Note that if z = 0, the above equation for temperature variation at the soil/air interface reduces to:

$$T(0,t) := Ta + Ao \cdot \sin\left[2\pi \cdot \frac{(t - to)}{365}\right]$$

$Tmax := 25.5$

Maximum daily average surface soil temperature for a year (C)
(from NOAA Climate Normals for Renton Municipal Airport)

$Tmin := 2.2$

Minimum daily average surface soil temperature for a year (C)
(from NOAA Climate Normals for Renton Municipal Airport)

$z := 1.5$

Depth of temperature fluctuation (m)

$Dh := 0.05$

Thermal diffusivity (/day)

$to := 0$

Time lag from Jan. 1 to annual minimum daily average surface soil temperature (days)

$$Ta := \frac{Tmax + Tmin}{2}$$

Average soil temperature (C)

$Ta = 13.85$

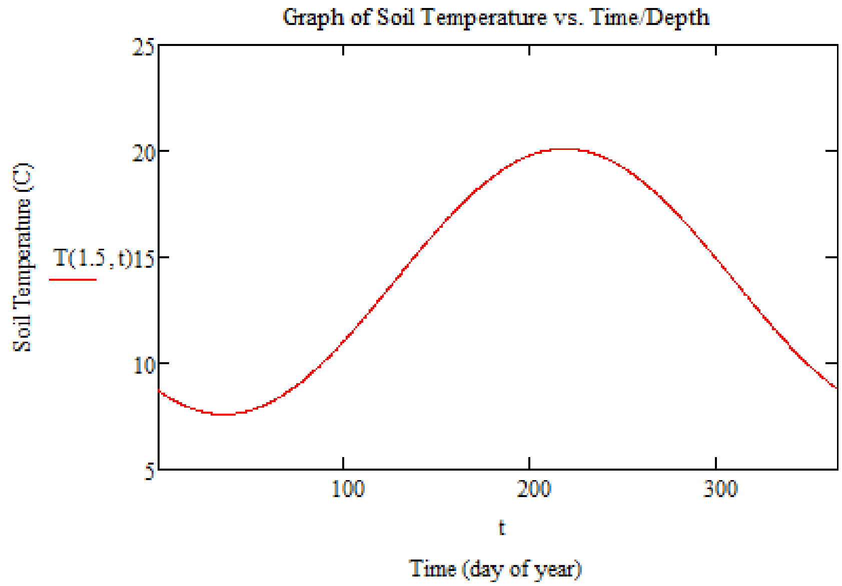
Amplitude of daily surface soil temperature fluctuation for a year (C)

$$Ao := \frac{Tmax - Tmin}{2}$$

$$\omega := 2 \cdot \frac{\pi}{365}$$

$$d := \sqrt{2 \cdot \frac{Dh}{\omega}}$$

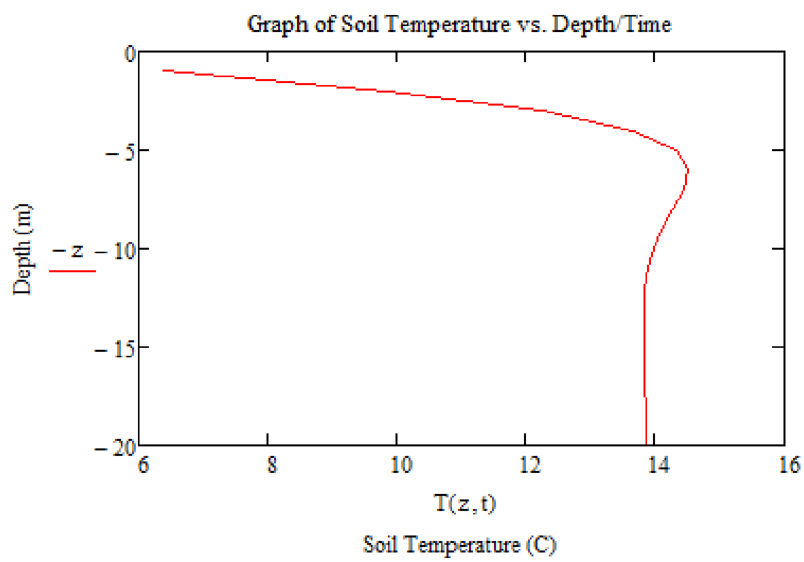
$$T(z,t) := Ta + \left(Ao \cdot e^{\frac{-z}{d}}\right) \cdot \sin\left[2\pi \cdot \frac{(t - to)}{365} - \frac{z}{d} - \frac{\pi}{2}\right]$$



$z := 1, 2 .. 20$

$$T(z,t) := Ta + \left(Ao \cdot e^{\frac{-z}{d}}\right) \cdot \sin\left[2\pi \cdot \frac{(t - to)}{365} - \frac{z}{d} - \frac{\pi}{2}\right]$$

$t := 10$



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APPENDIX B
COST ESTIMATE

COST ESTIMATES

EPC Contractor's Submarine Cable Supply, Delivery, and Installation	XLPE Cable System Costs		Total Cost
	Material Costs	Labor and Equipment Costs	
Submarine Cable	$43,000,000	$64,500,000	$107,500,000
Submarine Shipping Cost (Estimated)	$0	$4,000,000	$4,000,000
Mob/Demo	$0	$250,000	$250,000
EPC Engineering and Project Management	$0	$1,000,000	$1,000,000
SUBTOTAL	**$43,000,000**	**$69,750,000**	**$112,750,000**
25% Contingency	$10,750,000	$17,438,000	$28,188,000
TOTAL	**$53,750,000**	**$87,188,000**	**$140,938,000**

EPC Contractor's Landings and Tie to Overhead Lines	XLPE Cable System Costs		Total Cost
	Material Costs	Labor and Equipment Costs	
Duct Bank from Landings to Transition Structures	$3,043,000	$3,360,000	$6,403,000
Trifurcating Splice Vaults	$270,000	$330,000	$600,000
Pull Through Vaults	$210,000	$270,000	$480,000
Cable	$3,220,000	$420,000	$3,640,000
Trifurcating Splices	$87,000	$108,000	$195,000
Armor Anchor Bolts	$198,000	$90,000	$288,000
Terminations	$180,000	$468,000	$648,000
Arresters	$45,000	$45,000	$90,000
Grounding System and Cable Clamps	$166,000	$134,000	$300,000
Communication System	$23,000	$33,000	$56,000
Temperature Monitoring System, ft.	$336,000	$173,000	$509,000
Termination Structures	$450,000	$342,000	$792,000
Mob/Demo	$0	$150,000	$150,000
SUBTOTAL	**$8,228,000**	**$5,923,000**	**$14,151,000**
25% Contingency	$2,057,000	$1,481,000	$3,538,000
TOTAL	**$10,285,000**	**$7,404,000**	**$17,689,000**

Unallocated Costs	XLPE Cable System Costs		Total Cost
	Material Costs	Labor and Equipment Costs	
Preliminary Engineering	$0	$200,000	$200,000
Marine Survey and Geotech	$0	$200,000	$200,000
Land Survey and Geotech	$0	$100,000	$100,000
SUBTOTAL	**$0**	**$500,000**	**$500,000**
25% Contingency	$0	$125,000	$125,000
TOTAL	**$0**	**$625,000**	**$625,000**

COST ESTIMATES

Total EPC Contractor and Owner's Cost	XLPE Cable System Costs		Total Cost
	Material Costs	**Labor and Equipment Costs**	
EPC Contractor's Submarine Cable Supply, Delivery, and Installation	$53,750,000	$87,188,000	$140,938,000
EPC Contractor's Landings and Tie to Overhead Lines	$10,285,000	$7,404,000	$17,689,000
Unallocated Costs	$0	$625,000	$625,000
SUBTOTAL	**$64,035,000**	**$95,217,000**	**$159,252,000**
Owner's Engineering, Project Management, and Permitting (5%)	$3,202,000	$4,761,000	$7,963,000
TOTAL	**$67,237,000**	**$99,978,000**	**$167,215,000**