Electricity Innovation Institute

E2I EPRI Survey and Characterization of Potential Offshore Wave Energy Sites in Washington

Report	E2I EPRI WP WA 003
Principal Investigator	George Hagerman
Contributors:	Roger Bedard and Mirko Previsic
Date	May 17, 2004

Table of Contents

1. Introduction

The purpose of this report is to identify and characterize potential offshore sites in Washington for a 1,500 MWh annual energy output (500kW at 40% capacity factor) wave energy power plant feasibility demonstration and an envisioned 300,000 MWh per year (100 MW at 40% capacity factor) commercial plant. Sufficient data are provided to enable the Washington State Advisory Group to select a single site for a subsequent concept-level design, performance analysis and cost estimate.

Four potential sites, each corresponding to a coastal county, are characterized in this report, as listed below (in order of north to south) and mapped in Figure 1. Also listed for each county is the most likely harbor for servicing wave energy devices or staging offshore service vessels:

- Clallam County – Neah Bay
- Jefferson County – no developed harbor
- Grays Harbor County – Hoquiam
- Pacific County – South Bend

Section 2 of this report describes the various site characteristics that were used to evaluate the potential suitability of a given county coastline for siting an offshore wave power plant. Section 3 provides a characterization of each the seven counties in terms of attributes such as marine industry, harbor infrastructure, potential conflicts, public acceptance and unique opportunities. The wave energy resource, bathymetry and coastal grid interconnection data for all counties is summarized in Section 4. The detailed wave energy resource characterization data, the bathymetry and surficial geology data and the grid interconnect data are contained in Appendices A, B and C, respectively. Section 5 of this report describes the competing uses of sea space. Finally, a list of references cited is provided as Section 6.

Figure 1. Washington map showing four coastal counties and the best harbor in each county for servicing a potential wave energy power plant. The Jefferson County coastline does not contain any developed harbors and has a much lower wave energy development potential than the other three coastal counties.

2. Site Selection Criteria

The site selection criteria used in this assessment are:

- Wave energy resource characteristics attributes (little if any sheltering by coastal features and deep water relatively close to shore as the bathymetry at a site can have a significant effect on the local wave energy due to refraction, shoaling and other wave transformation processes. Sea state "hot" spots (ie, areas of wave focusing) are desirable. Short distance to the required depth is also desirable.
- Candidate site bathymetry and surficial geology to minimize any potential problems in system mooring and cable routing (bottom material, potential for sediment mobility under severe conditions, and bottom changes over time)
- Coastal utility grid and substation loads and capacities and availability of onshore grid interconnection point with a capability of handling the 1,500 MWh per year pilot plant supply and with potential for growth to a 300,000 MWh per year commercial plant.
- A potential pathway from the 1,500 MWh per year pilot plant to a commercial scale plant
- Regional electricity cost, demand and growth forecasts
- Regional shipyard labor and infrastructure for device fabrication and assembly
- Local service vessels and waterfront infrastructure for system deployment, retrieval, and offshore servicing or in-harbor repair
- Minimal conflict with competing uses of sea space (shipping lanes, fishing grounds, and protected marine areas) and likelihood of public acceptance
- Regulatory complexity (federal, state and local)
- Unique site opportunities; e.g., an existing floating platform, an existing power transmission cable connected to a grid substation, an existing easement (e.g., a treated sewage pipe) or other factor that would make the site desirable (e.g., minimize the cost, minimize the schedule, transition plan from pilot to commercial, etc) for either the pilot or commercial application

3. Site Characterizations

3.1. Clallam County – Neah Bay

Neah Bay is about 5 miles east of Cape Flattery and is used extensively by small vessels as a harbor of refuge in foul weather. The buoyed entrance to the bay is between Waadah Island and Baada Point. Depths of 14 to 16 feet can be carried into the bay. Anchorage within the bay can be had in depths of 20 to 40 feet, with a sandy bottom.

The Makah Indian T-head pier with a 300-foot face and privately marked at each end by a light is about 375 yards W of Baada Point. Two cooperative fish piers, 1 mile and 1.2 miles southwest of Baada Point, have facilities for icing and supplying fishing boats. Limited berthage, electricity, gasoline, diesel fuel, water, and ice are available. Both piers have reported depths of 12 feet off the ends. There are many small-craft floats extending along the southern shore of the bay. Neah Bay has no public haul-out or repair facilities. State highway 112 extends along the Strait of Juan de Fuca, eastward to Port Angeles, but there is no rail connection.

The likely fabrication site for the AquaEnergy pilot plant is Port Angeles, 56 miles east of Cape Flattery. The harbor there is entered from the east, between Ediz Hook to the north, a low and narrow sand spit 3 miles long, and the main shore to the south. The harbor is about 2.5 miles long and can be easily accessed by the largest vessels, which frequently use it when refueling, making topside repairs, waiting for orders or a tug, and when weather-bound.

This harbor is protected from all except SE winds, which occasionally blow during the winter. During SE winter gales, the wind is not usually felt but some swells roll in. The depths are greatest along the northern shore and decrease from 30 to 15 fathoms in the middle of the harbor; from the middle, the depths decrease regularly to the southern shore, where the 3-fathom curve in some places in the eastern part is nearly 0.2 mile from the beach.

Extra caution in navigating the waters inside Ediz Hook should be exercised because of the large number of submerged deadheads or sinkers in the area. Deadheads or sinkers are logs that have become adrift from rafts or booms, have become waterlogged, and float in a vertical position with one end just awash, rising and falling with the tide.

Port Angeles is on the southern shore of the harbor. Logs, lumber, plywood, newsprint, pulp, shakes and shingles, and petroleum products are the principal commodities handled. Tugs to 1,200 hp are stationed at Port Angeles, and tugs to 5,000 hp are available from Seattle with advance notice.

In addition to two port operated terminals and three private terminals along the south and west sides of the harbor, there are several small piers and wharves at which tugs and other floating equipment moor. For a complete description of the port facilities refer to Port Series No. 37, published and sold by the U.S. Army Corps of Engineers.

Water, ice, and marine supplies are available. Diesel oil and gasoline are available at the port boat haven. Fuel bunkering is available by barge. Port Angeles has several companies and

facilities to perform major topside repairs to large oceangoing vessels; the nearest dry-docking facilities are in Seattle/Tacoma.

Port Angeles Boat Haven, operated by the port, is a large, small-craft basin in the southwest part of the harbor that can accommodate a large fleet of fishing vessels and pleasure craft. The controlling depth at the basin entrance is 20 feet, with a depth of 15 feet in the basin and alongside the berths. A boatyard at the east end of the basin has a marine railway that can handle craft to 100 tons, and also has a 225-ton lift.

Deployment of wave energy devices fabricated in Port Angeles or retrieval of a device for in-harbor service at repair facilities there (since no such facilities exist at Neah Bay) must contend with tidal currents, heavy fog, and dense shipping traffic in transiting to and from the pilot plant site off Makah Bay.

TIDAL CURRENTS: The flood current entering the Strait of Juan de Fuca sets with considerable velocity over Duncan and Duntze Rocks, but, instead of running in the direction of the channel, it has a continued set toward the Vancouver Island shore which is experienced as far as Race Rocks. The flood current velocity is greater along the northern shore of the strait than along the southern shore.

The ebb current is felt most along the southern shore of the strait, and between New Dungeness Light and Crescent Bay there is a decided set S and W, especially during large tides. With the wind and swell against the current, a short choppy sea is raised near the entrance to the strait. The current movement is complicated by a large daily inequality. The Tidal Current Tables should be consulted for times and velocities.

Tide rips occur off the prominent points and in the vicinity of the banks. These are particularly heavy off Cape Flattery, Race Rocks, Dungeness Spit, and Point Wilson, at times becoming dangerous to small vessels.

FOG: Sea fog at the entrance to the Strait of Juan de Fuca from the Pacific in fog. Sea fog is at its worst from about July through October. Local land fog extends the visibility hazard into the winter. Fog is most frequent at the western end of the Strait. Here, visibilities drop to less than 0.75 mile (1.4km) on about 55 days annually, compared to about 35 days in the eastern end. Dense fog sometimes hangs over the ocean entrance to the Strait for days at a time; this is most likely during calms or light breezes. It the appearance of a wall. Often the fog is carried east on the sea breeze. When this happens, the fog usually penetrates farther east along the southern shore. Thus it is much more likely to reach Port Angeles or Port Townsend than Victoria, BC. In springtime, the eastern penetration of an infrequent fog is somewhat less, to only 40-45 miles from the ocean entrance, about 5-10 miles short of Port Angeles.

SHIPPING TRAFFIC: The Traffic Separation Scheme, Strait of Juan de Fuca consists of five schemes: the Western Approach and the Southwestern Approach from the ocean, and in the Strait, the Western Lanes, the Southern Lanes to Port Angeles, and the Northern Lanes to Victoria; and two precautionary areas, one NNW of Cape Flattery and

the other N of Port Angeles. Each scheme consists of inbound and outbound traffic lanes separated by separation zones. Each precautionary area is marked by a lighted yellow buoy. The purpose of these buoys is to assist in the separation of inbound and outbound vessels transiting the Strait of Juan de Fuca to eliminate as much as possible the cross-channel vessel traffic that occurs between the entrance to the Strait of Juan de Fuca at Cape Flattery and the pilot stations at Port Angeles and Victoria, BC. It is recommended that all vessels navigate so as to leave these buoys to port.

On the Pacific Ocean coast of Clallam County, the only developed harbor is at La Push, located about 0.4 miles above the entrance of the Quillayute River. The river entrance is protected by a jetty on the SE side and a dike on the NW side, but is still sometimes dangerous, especially in heavy weather from the south. Weather conditions that make the entrance hazardous normally occur only in winter, usually in December and January. A channel leads from the sea to a small-craft basin with anchorage depths in the range of 7 to 10 feet. La Push is a sport fishing center and has about 96 berths, electricity, gasoline, diesel fuel, water, ice, a launching ramp, and some marine supplies. A good highway connects La Push with U. S. Highway 101 north of Forks.

La Push is located about 20 miles south of Cape Flattery. Service vessels transiting from La Push to Makah Bay must transit around Cape Alava and Umatilla Reef. Neah Bay is much closer to the AquaEnergy pilot plant site and can be entered or exited in most weather conditions.

3.2. Jefferson County

With the exception of two tribal land parcels (Hoh Reservation and the northwest corner of the Quinalt Reservation), the Pacific coastline of Jefferson County is owned entirely by Olympic National Park. Moreover, a U.S. Navy operating and exercise area parallels the entire coastline off Jefferson County. The cross-shelf width of this area extends from the 3-mile limit of state jurisdiction to about 50 miles offshore.

Indian settlements exist on reservation lands at the mouths of the Hoh River and Queets River. There is no developed harbor or significant maritime infrastructure at either locations.

Clallam County Public Utility District (PUD) provides electric service to 200 residents of the northwestern portion of Jefferson County in the Hoh River area. Grays Harbor County PUD that provides electricity to 172 residents of the southwestern portion of Jefferson County in the Queets/Clearwater and Quinault areas.

As already noted, wave energy levels off Jefferson County are lower than in the other three coastal counties. This, combined with sparse onshore maritime and electric utility infrastructures and potential conflict with Naval operations, make Jefferson County a poor candidate for wave energy development in the near future.

3.3. Grays Harbor County – Hoquiam

Grays Harbor entrance is about 40 miles north of the Columbia River entrance and 93 miles south of Cape Flattery. The bay and its tributaries furnish an outlet to an extensive timber area. Grays Harbor is an important lumber port in the foreign and domestic trade. Oil is delivered by tanker; logs, lumber, pulpwood, and wood chips are shipped out. The entrance to Willapa Bay is about 2 miles wide, but shoals extending south from Point Brown contract the navigable channel to a width of 0.7 mile. From its entrance the bay extends eastward for 15 miles to the mouth of Chehalis River.

Hoquiam is on the river of that name, and Aberdeen is on Chehalis River. South Aberdeen is across the river, but is part of the city of Aberdeen. Cosmopolis is a small town on the south side of Chehalis River just above South Aberdeen. The main channel of Chehalis River is crossed by U.S. Route 101 highway drawbridge at Aberdeen, about 1.4 miles above Cow Point. The bridge has a clearance of 35 feet.

The jettied entrance to Grays Harbor is marked by two lighted ranges and buoys. Inside the bay, a Federal dredging project provides channel depths of 36 feet to about Cow Point, thence 30 feet to Cosmopolis, about 9 miles above the bay entrance. The channel inside the bay to Cosmopolis is well marked. There is no deep-draft navigation above Cosmopolis.

In the entrance, the average current velocity is about 1.9 knots on the flood and 2.8 knots on the ebb, but velocities may reach 5 knots. In the channels through the bay, the velocities seldom exceed 3 knots. 88) The mean range of tide at Aberdeen is 7.9 feet, and the diurnal range of tide is 10.1 feet. A range of about 14 feet may occur at the time of maximum tides.

The Port of Grays Harbor operates three marine terminals. In addition to the port-operated terminals, there are more than seven private deep-draft piers and wharves in the Hoquiam, Aberdeen, and Cosmopolis area. For a complete description of the port facilities refer to Port Series No. 35, published and sold by the U.S. Army Corps of Engineers.

Grays Harbor is served by the Burlington Northern Railroad and the Union Pacific Railroad. Two U.S. highways serve Aberdeen and Hoquiam. Bowerman Airport, owned and operated by the Port of Grays Harbor, is just west of Hoquiam. Tugs up to 2,200 hp are available at Hoquiam.

There are no facilities for major repairs to large oceangoing vessels in Grays Harbor; the nearest such facilities are in Portland, Oregon. There are several marine railways in Grays Harbor, the largest of which is at a shipyard on the west bank of the Hoquiam River 1 mile above its mouth. This railway can handle vessels to 400 tons, 80 feet long or 34 feet wide for hull repairs. Machine shops and foundries are nearby and can make some engine repairs. Electronic repair services also are available.

3.4. Pacific County – South Bend

Willapa Bay entrance is 24 miles north of the Columbia River entrance and is used primarily by fishing and oyster boats. No deep-draft vessels have entered Willapa Bay since 1976. Oyster beds cover much of the shoaler areas of the bay. Lumber, fish, and other sea foods are shipped by rail and truck from South Bend and Raymond.

The entrance to Willapa Bay is between Cape Shoalwater to the north, and Leadbetter Point to the south. The entrance is in the north part of the bay, which consists of two arms; a southern arm, 18 miles long, and an eastern arm, 10 miles long. Both arms are filled with extensive shoals, large areas of which bare at low water. Willapa River flows into the eastern arm of the bay. Lights, buoys, daybeacons, and lighted and unlighted ranges mark the channel through the eastern arm and in Willapa River to South Bend and Raymond. There are no bridges over the main channel.

Willapa Bar extends about 3 miles outside of a line joining Cape Shoalwater and Leadbetter Point. The bar channel is continually shifting, and depths over it vary from season to season. Because of the frequent changes in the position of the bar and difficulty in dredging the bar to project depth, depths have consistently been less than the 26-foot project depth.

The currents off Willapa Bar are variable and uncertain. Velocities of 3 to 3.5 knots have been observed between Blunts Reef and the Swiftsure Bank. In the entrance to Willapa Bay, the current velocity is about 2.5 knots. Currents of 4 to 6 knots occur at times; the velocity is greatest on the ebb, particularly with S wind. In the Willapa River channel at South Bend, the velocity is about 1.2 knots on the flood and 1.4 knots on the ebb.

The mean range of tide at South Bend is 7.8 feet, and the diurnal range of tide is 9.8 feet. A range of about 14 feet may occur at the time of maximum

South Bend is on the south bank of Willapa River, 8 miles above the river entrance. The principal industries are lumbering, oystering, and fishing; two canneries are operating here. Willapa Harbor Airport is on the north bank of the river about 2.5 miles upriver. Raymond, the principal town, is on the south bank of Willapa River 3 miles above South Bend.

Both South Bend and Raymond have small-craft moorages operated by the respective towns, with diesel oil, gasoline, water, ice, and some marine supplies available. The largest of two marine railways at South Bend can handle vessels 60 feet long and 19½ feet wide for hull repairs. A nearby machine shop and foundry does some engine repair work. The nearest tugs are available at Hoquiam in Grays Harbor.

Given that Grays Harbor has a more consistently located and deeper entrance channel and a much better developed onshore maritime infrastructure, and that its entrance is only 16 miles north of the entrance to Willapa Bay, it is recommended that wave power projects sited off Pacific County be serviced by vessels and repair facilities at Grays Harbor.

4. Wave Energy Resource Characterization, Bathymetry and Grid Interconnect Overview

4.1. Wave Energy Resource Characterization

The State of Washington has an excellent offshore wave energy resource.

Two primary sources for wave measurements were used to characterize Washington's wave energy resource, as described below and located as shown in the left half of Figure 2.

1. The National Oceanic and Atmospheric Administration (NOAA)-operated meteorological buoys in the North Atlantic, North Pacific, Gulf of Mexico and Great Lakes. The NOAA buoys off Washington are shown in the following figure.

2. Coastal Data Information Program

3. Wave hindcast models are computer programs that numerically generate and propagate wave energy based on input atmospheric pressure from historical meteorological charts. Hindcasting is used to predict winds that would have occurred for a given set of past pressure distributions, and these winds are then used to numerically generate the associated waves. Sophisticated wave hindcast has been developed by the U.S. Army Corps of Engineers. The Army's hindcast model is referred to as the Wave Information System (WIS) and is available on the Web.

The right half of Figure 2 shows the annual average incident wave power per meter of wave crest width available off the coast of Washington in the 20- to 40-meter depth range (leftmost curve with square shape data points) and in very deep water beyond the seaward edge the continental shelf. (rightmost curve with diamond shaped data points).

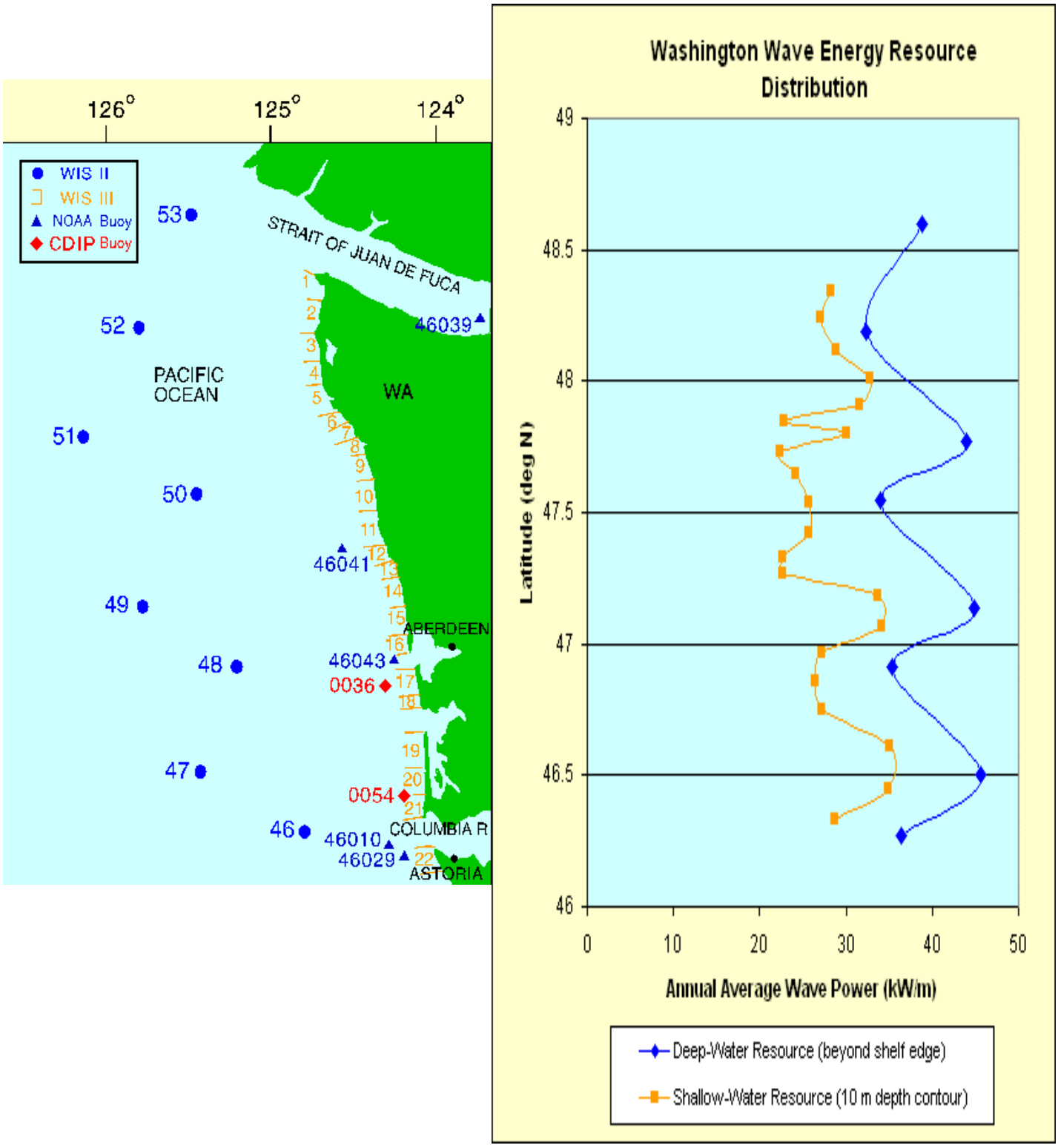

Figure 2. Washington Annual Average Wave Power (squares represent the 20- to 40-m depth range and diamonds represent very deep water off the continental shelf)

Temporal Variation

Month-to-month variations in wave energy flux off the entrance to the Columbia River is plotted in Figure 3. The high mean monthly fluxes during the winter are due to a few individual storms that have peak wave fluxes as high as 200 kW/m.

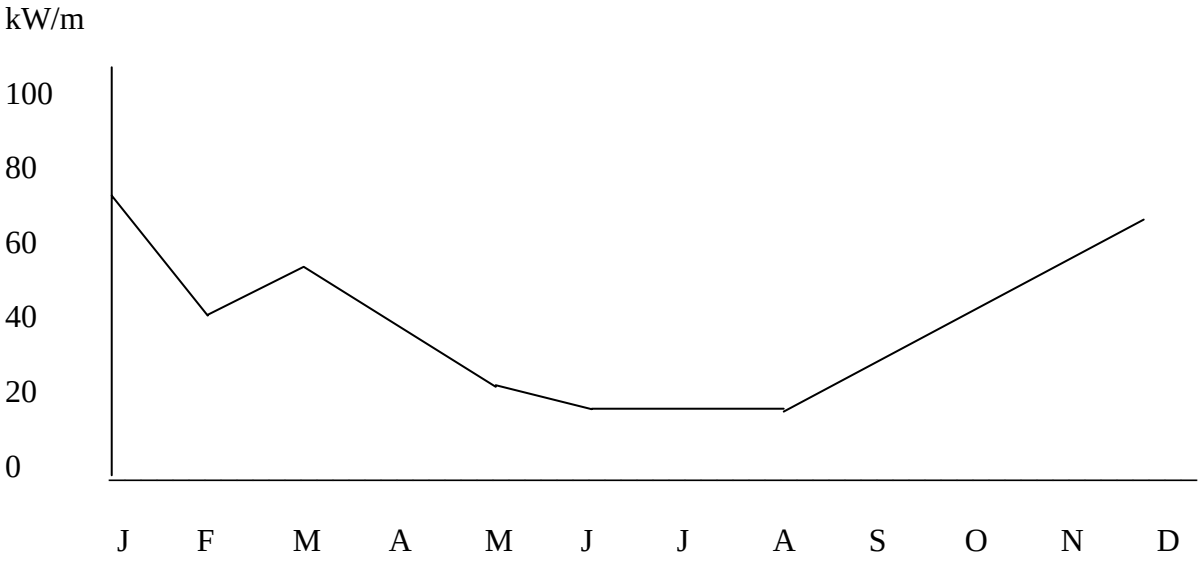

Figure 3. Seasonal Variation in Wave Energy Flux off the Columbia River Entrance

Detailed wave energy charactization data will be provided in Appendix A.

4.2. Bathymetry and Surficial Geology

Subsection to be prepared later. This subsection will contain an overview and the details will be in Appendix B.

4.3. Grid Interconnect Data

The coastal Washington electric grid is shown in Figure 4. Details of each coastal substation is provided in Appendix C.

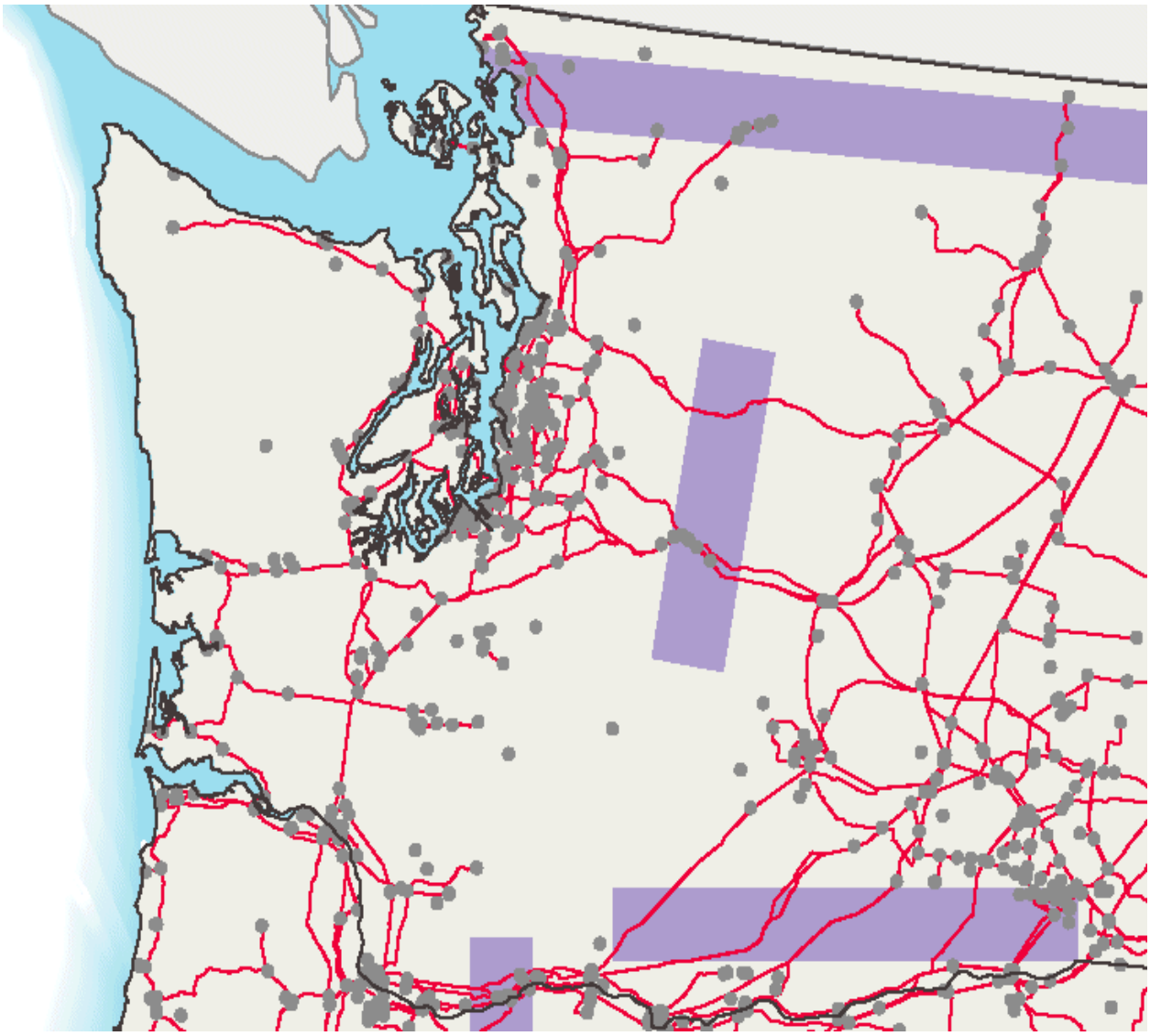

Figure 4. Washington Coastal Electric Utility Grid

5. Competing Uses of Sea Space

Washington's ocean area stretches approximately 160 miles from Cape Flattery to the Columbia River entrance, and is subject to a wide variety of existing uses, including commercial shipping, Navy exercise and underwater sound range areas, commercial and sport fishing grounds, and a wide variety of environmentally sensitive areas where wave power plant siting should be either avoided or chosen with detailed attention to potential impacts.

5.1. Shipping Lanes and Other Excluded Areas

5.1.1. Shipping Lanes and Offshore Navigation Routes

Based on the West Coast Offshore Vessel Traffic Risk Management Project, co-sponsored by the Pacific States/British Columbia Oil Spill Task Force and the U.S. Coast Guard Pacific Area, it is recommended that, where no other traffic management areas exist such as port Traffic Separation Schemes, vessels of 300 gross tons or larger transiting along the coast anywhere between Cook Inlet and San Diego should voluntarily stay a minimum distance of 25 nautical miles offshore, which would be well beyond the site of any wave power plant having an economically feasible submarine power cable transmission distance to shore.

Shipping traffic off the California-Oregon-Washington coast frequently must navigate in thick weather. Between San Francisco and Portland, fog and haze occur 15-25% of the time. Fog reduces visibilities to less than 0.5 mile (0.9 km) on about 3 to 8 days per month. Dead reckoning courses are long, and the effect of currents is uncertain. Coast Pilot 7 suggests vessels transiting off the coast of Washington proceed on rhumb lines through the following positions:

48°26'N., 124°47'W.; off Cape Flattery, Washington

48°10'N., 124°52'W.; off Umatilla Reef, Washington

46°11' N, 124°12' W; off the Columbia River entrance

5.1.2. Submarine Cables and Pipelines

A U.S. Navy Underwater Tracking Range is west of the mouth of Queets River, about 6 to 10 miles offshore. Underwater cables, several feet above the ocean bottom and over an area about 1 mile wide, extend northeast from the upper east side of the tracking range, at about 47°32.5'N., 124°30'W., to the shore at about 47°36.3'N., 124°22.5'W.

5.1.3. Ocean Disposal Sites

Ocean disposal involves transporting dredged material offshore on a barge or in a hopper dredge to be dumped in open ocean waters. The U.S. Environmental Protection Agency (EPA)

regulates the permitting of such sites. EPA-permitted dredge disposal sites are designated outside the Columbia River entrance.

5.1.4. Military Warning Areas

Military Warning Areas are ocean areas that the U.S. Department of Defense uses for training exercises or other military operations. They may have restrictions on use by non-military vessels, over-flight by commercial or private aircraft, and/or civilian communications.

There is a large U.S. Navy operating andexercise area that parallels the Washington coastline from about 10 miles north of Point Brown (Grays Harbor entrance) to Cape Alava, extending from 3 miles offshore to about 50 miles offshore.

5.2. Commercial and Sport Fishing Grounds

Between early December and mid-August, heavy concentrations of commercial crab traps and associated gear are placed off Grays Harbor, the Columbia River entrance, and Destruction Island, anywhere between the shoreline and the 30-fathom (55-meter) depth contour.

5.3. Environmentally Sensitive Areas

Subsections arranged from landward (where visual impact is main concern) to shoreline (power cable crossing) to nearshore to offshore.

5.3.1. Olympic National Park

Olympic Nation Park is known for its biological diversity. Isolated for eons by glacial ice, and later the waters of Puget Sound and the Strait of Juan de Fuca, Olympic National Park contains over 60 miles of wild Pacific coast -the largest section of wilderness coast in the lower 48 states

5.3.2. Olympic Coast Marine Sanctuary

Olympic Coast National Marine Sanctuary encompasses about 3,300 square miles off of the Olympic Peninsula, extending 135 miles along the Washington Coast from about Cape Flattery to the mouth of the Copalis River. The seaward boundary of the Sanctuary varies from about 25 to 40 miles offshore. This includes most of the continental shelf, as well as parts of three important submarine canyons, the Nitinat Canyon, the Quinault Canyon and the Juan de Fuca Canyon. The Sanctuary shares 48 miles of coastline with Olympic National Park, including some of the last remaining wilderness coastline in the lower 48 states. Olympic National Park and the Sanctuary share resource management jurisdiction in the intertidal zone.

Sanctuary waters include many types of crucial habitat. Nearshore kelp beds, subtidal reefs, rocky and sandy intertidal zones, submarine canyons and plankton-rich upwelling zones all support biodiversity. Significant natural resources include 29 species of marine mammals and

nesting seabirds, including haulouts for Steller sea lions and nest sites for peregrine falcons, both protected under the Endangered Species Act.

Three national wildlife refuges are located within the Olympic Coast Marine Sanctuary: Flattery Rocks NWR, Quillayute Needles NWR and Copalis Rock NWR. These refuges protect over 800 named and unnamed offshore rocks, seastacks and islands.

Figure 5. Location Map of Olympic Coast Marine Sanctuary.

6. References

To be provided later

Appendix A. Wave Energy Resource Characterization

To be provided later

Appendix A. Bathymetry and Surficial Geology

To be provided later

Appendix C. Grid Interconnection Data

To be provided later