TIDAL ENERGY

1. Resource

There is substantial tidal flow around Vashon Island due to the average diurnal water level variation. National Ocean and Atmospheric Administration (NOAA) data show a typical water level variation at Tacoma of over 4.0 m. See Figure 1. Tidal flow through the Colvos Passage on the west side of Vashon Island has a unique unidirectional pattern flowing only in a northern direction. This unusual tidal flow pattern in the Passage is probably caused by the ebbing current from the Narrows, west of Tacoma, that is naturally directed into the Passage by the land formation at Point Defiance. Flood tidal flow in East Passage around Vashon Island, follows a more typical reversing pattern. Flow in Colvos Passage may also be affected by the time difference between the ebb tidal induced currents flowing first from Bremerton area past Blake Island, north of Vashon Island and then later from Tacoma. Flow patterns in the region have been studied and documented in and report titled "Current Structure in Elliot Bay Washington: 1977-1996" Reference [1].

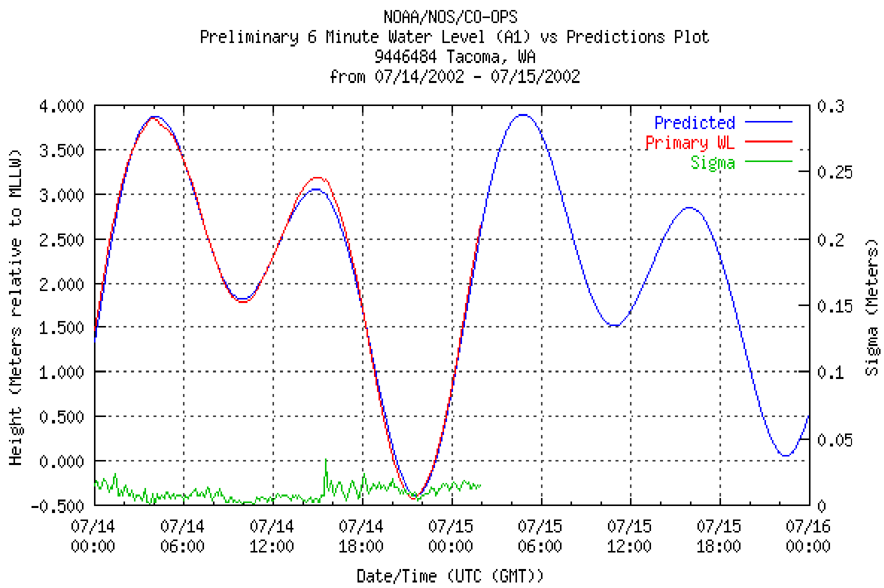


Figure 1 Tide driven water level variations near Vashon Island

1.1 Data Collection, Approach and Sources

Tidal flow direction and velocity data were provided by IERE from several sources. The hourly current flow rates were obtained from local tidal flow charts [2]. Flow rates were the highest in the North end of the Colvos Channel, and off Cove Point in the vicinity of the under-sea power cable crossing. Figure 2 shows the maximum predicted flow rate of 1.5 knots that occurs in coincidence with maximum ebb current at Tacoma Narrows. The current is over 1 knot for a six-hour period around the peak and some of that energy could be captured from the flow. For the next six hours the current ranges from "weak and variable," to 0.6 knots, which is too low to provide usable power.

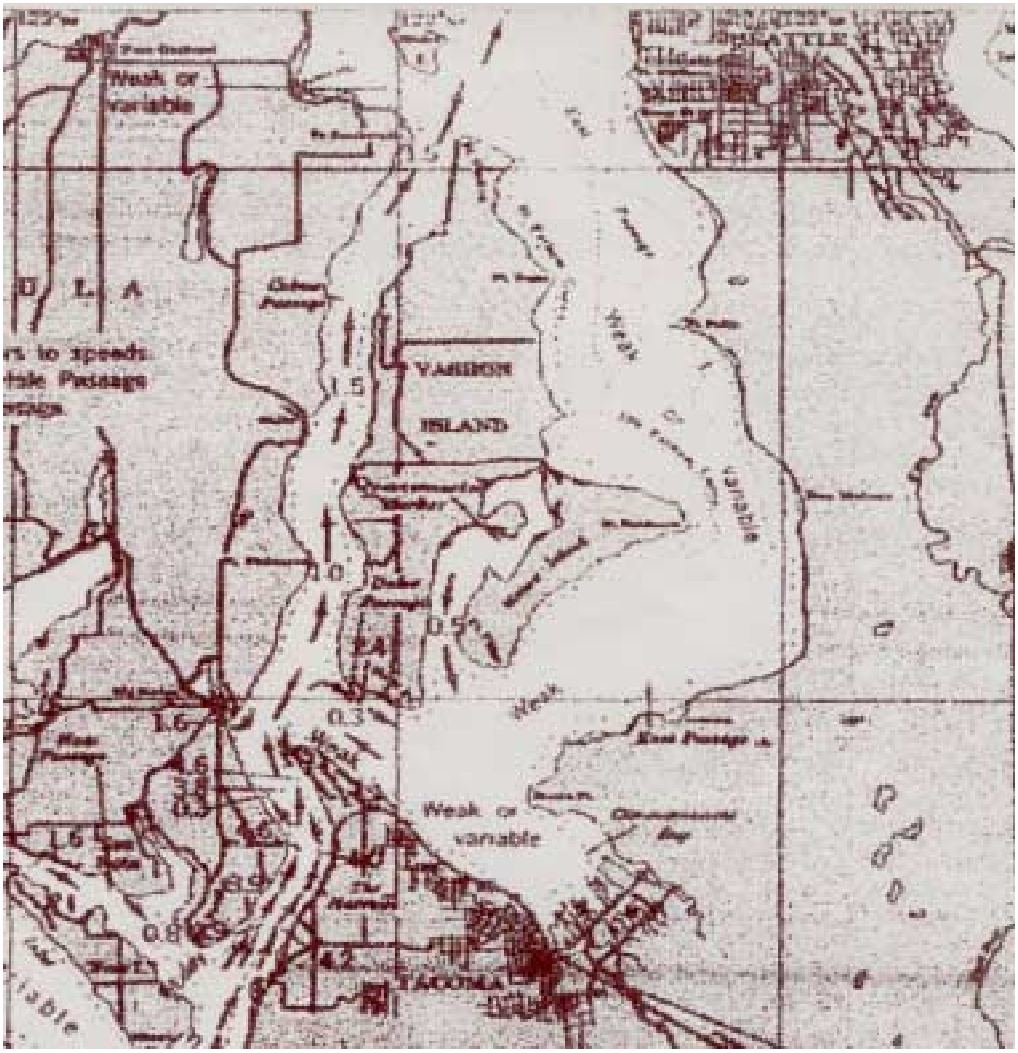


Figure 2 Tidal Current Chart - Maximum Ebb at Tacoma Narrows

1.2 Tidal Resource Potential

These tidal flows were used to estimate the resource potential input to the tidal energy turbines. See table 1 for a summary of the estimated available tidal energy. However, flow rates were only available as averages and are likely to vary considerably between diurnal tidal cycles. This is a potential source of error since there is a large difference in height in daily tides in the vicinity. For example, at the Tacoma Tidal Station, the mean range between high and low tide is 2.5 m, but the diurnal range is 3.6m, 44% higher Normally one tide each day is much higher than the other, which means the currents are much higher on alternating tidal cycles. . Figure 1 shows the typical difference in water level between two tidal cycles for Seattle. This is tidal variation is very important to energy systems because the energy production is function of the cube of the flow velocity. This means that if the flow is 3.0m/s instead of 1.5m/s, a factor of two difference in water flow velocity, there is eight times the energy in the former stream. The result is that energy production may be underestimated.

2. Applicable Technologies

A variety of tidal energy conversion devices have been designed and prototypes built and tested. Tidal energy traditionally involves erecting a dam across the opening to a tidal basin and harnessing the captured water using traditional hydropower technologies. A more appropriate approach for Vashon Island is to extract energy directly from tidal flow streams.

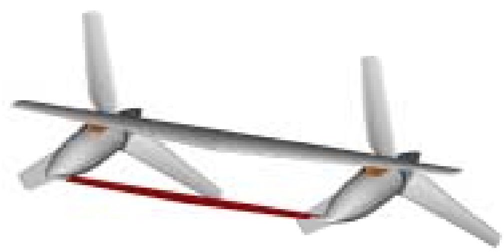


Figure 3 Aquantis Ocean Energy System

Several ocean energy systems are currently being developed that could potentially be deployed in Colovas Passage with out the need for a dam or impoundment. Typically systems are designed for use in run-of-the-river, ocean current, or tidal energy conversion applications. Different approaches under development in the U.S. and U.K., involving both horizontal and vertical axis turbines. An example of one promising system is the Aquantis ocean energy system being designed for use in the Gulf Stream off the coast of Florida is shown in Figure 3. Characteristics of various ocean energy systems are shown in Table 1.

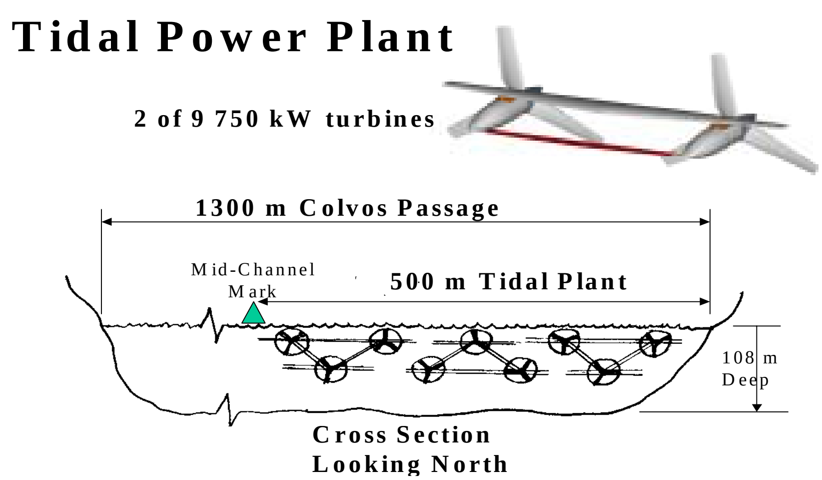
Table 1. Ocean Energy System Characteristics

	Developer	Configuration	Rotor Diameter (m)	Units - Rating (kW)	Plant Capacity (MW)
Aquantis	Dehlsen Associates, LLC, Santa Barbara, CA	Multi-blade, horizontal axis turbine	30	750kW x 9	6.75
Underwater Electric Kite	Abacus Controls, Inc., Somerville, NJ	Dual unit shroude horizontal axis hydroturbine	Approx. 3	90 kW x 60 dual units	5.4
Electric Power from Ocean Currents	GCK Technologies, San Antonio, TX	Unknown			
Blue Energy	Blue Energy Ltd.	Ducted vertical ax turbine	Approx. 7	250kW x 31 dual units	7.75

1.3. Energy Production Estimates

There are important issues to be addressed in the configuration of the tidal energy conversion system. First, the Colvos Passage must remain navigable so it is assumed that tidal energy converter may not extend beyond mid-channel, meaning turbines from 50 to 400m from shore. Also there are limits to the amount of energy that can be extracted from an open flow channel. If too many turbines are placed in the passage, the device will appear as a dam to the flowing water, which will simply stop moving or it will bypass the turbines and their will be no energy capture. To avoid this problem, the turbines in the conceptual design were placed in two rows, 5 turbines in top (near surface) row with 2 rotor diameter (2d) spacing and 4 in row at 3d depth. See Figure 4. These

Figure 4. 6.75 MW Tidal Power Plant



assumptions were used in developing the potential tidal power estimate of 6.75 MW and annual energy production of nearly 13 GWh/year. Table 2 lists energy estimated production for various time periods, based on the typical tidal cycle (Add data from Excel Spreadsheet). Because the turbines were not optimized for the available and relatively low flow rates in the Colvos channel, the plant capacity factor is only 22%. Capacity factor of over 40% should be achievable with an optimized system, which could double the energy production. Table 3 summarizes the resource level, and technology characteristics and operating costs.

Table 2. Tidal Energy in Colvos Passage

Case Data:

Total Average Flow = 28,000 m^3/sec discharge in northern direction

Tidal Cycles - 2 /day

C-Plane - 9 turbines, 30m diameter rotor, 12 degree pitch 750kW rated power at 1.6m/s = 6.75MW

Properly optimized turbines could double the energy production and plant Capacity Factor

Turbine configuration - Two rows, 5 turbines in top (near surface) row with 2d spacing and 4 in row at 3d depth

One typical Tidal cycle Mid Channel in Colvos Passage					
	Time	Current	C-Plane Output	Diurnal Energy	Potential Annual Energy
Units	Hours before/after Maximum Flood at Tacoma Narrows	m/sec	MW	MWh/day	MWh/year
	-1	0.3	Below Cut-in	0	
	Max Flood	Weak	Below Cut-in	0	
	1	Weak	Below Cut-in	0	
	2	0.3	Below Cut-in	0	
	3	0.6	Start generating	0	
	4	1.1	2.25	4.5	
	5	1.3	3.15	6.3	
	Max Ebb	1.5	5.45	10.9	
	7	1.3	3.15	3.3	
	8	1.2	2.95	5.9	
	9	1.1	2.25	4.5	
	10	0.6	Below Cut-in	0	
Total Energy				35.4	12,921

Assumptions:
1. Half of Colvos Passage must remain unobstructed for navigation purposes
2. Tidal cycle flows are similar - need to study diurnal variation
3. Flow rate is uniform to depth of 90m and beyond 50m off shore
4. Low Speed Turbine Technology could increase energy capture by 20 to 30%
5. Aquantis C-Plane turbine (Picture) is one candidate design

Table 3. Resource and Technology Characteristics of Tidal Power Plant in Colvos Passage

	Values	Assumption
Tidal Induced Current	0 to 1.5 m/s	Estimate from tidal current charts – Diurnal hourly measurements are needed
Average Daily Flow	14,000 m^3	Discharge in Northern direction from half of Passage – assuming half is reserved for navigation
Turbine	750 kW 30 m diameter	Estimate for Aquantis, LLC turbine – would need to be optimized for the low flow in Colvos Passage
Annual Energy Production	13 million kWh/year	9 turbines
Total Rated Capacity	6.75 MW	20% capacity factor – could be increased by a factor of 1.5 or more by properly optimizing the turbine design
Operation & Maintenance	$0.02 to $0.03/kWh	Including labor, parts, periodic overhaul, insurance and taxes

1.4 Environmental Considerations

Tidal energy systems are generally considered to be relatively benign when compared to other hydropower systems or to fossil-fueled plants. The rotating turbine blades in a tidal plant have the potential of impacting fish. However, since these turbines are operating in a free stream with low flow rates, the blades will turn very slowly reducing the likelihood of impacts. Further, the pressure drop in the rotor plane will be orders of magnitude less than the pressure drop experienced in conventional hydroturbines. It is this pressure drop that is one of main causes of fish kills in conventional turbines in high dams. Because of the lack of experience with tidal power and because of the salmon feeding and spawning grounds around Vashon Island, this is an area that needs further study.

1.5 References

1. Curtis C. Ebbesmeyer, Carol A. Coomes, Jeffrey M. Cox, Timothy J. Crone, Keith A. Kurrus and Eric C. Noah, Evans-Hamilton, Inc. and Randy Shuman, King County Dept. of Natural Resources, “Current Structure in Elliott Bay, Washington: 1977–1996,” Puget Sound Research, 1998.
2. Tidal current charts for Tacoma Narrows.
3. Hydropower Energy - Environmental Issues and Mitigation, U.S. Department of Energy, http://www.eren.doe.gov/RE/hydro_enviro.html, July 2002.