TIDAL IN-STREAM ENERGY RESOURCE ASSESSMENT FOR SOUTHEAST ALASKA

Report to Alaska Energy Authority

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Executive Summary

This report is an assessment of the in-stream tidal energy resource in the southeast of Alaska prepared at the request of the Alaska Energy Authority (AEA).

Sites were evaluated to determine the magnitude of the available in-stream energy resource (defined to mean the 1) cross sectional area, 2) average depth, 3) the power density and 4) the total kinetic power in the stream) at each of the following sites.

- Cross Sound and Icy Strait: from Inian Islands to Lemesurier Island
- Wrangell Narrows: from Keene Island to Petersburg
- Chatham Strait: Kootznahoo Inlet
- Peril Strait: Sergius Narrows
- Prince of Wales Island: Tlevak and Tonowek Narrows
- Felice Strait: Harris Island, Snipe Island, and Indian Reef

Glacier and Lituya Bays, two large sites, were excluded from this assessment since they are wholly located within the boundaries of Glacier National Park. Two other sites for which preliminary permit applications have been filed with the Federal Energy Regulatory Commission (FERC) by private investors (i.e., tidal channels near Gustavus, AK and Gastineau Channel near Juneau, AK) were not evaluated due to low power density of the predicted currents.

The Cross Sound and Icy Strait show a massive energy potential, more that enough to meet the region's energy needs and enough to allow export of valuable green energy to Canada and the Pacific Northwest. In addition, high quality (strong power density) small (low average annual power) sites, such as Angoon (Kootznahoo Inlet) and Elfin Cove (Cross Sound), could provide power for remote locations.

This assessment points to several pieces of work which would be key next steps in the ongoing process of site development.

1. *Site feasibility and economic assessment.* Building off this resource study, a feasibility study identifying key issues to array build-out and a baseline economic assessment should be conducted for the most promising sites. Site geology, electrical interconnection, local environmental concerns, and multiple-use issues should be fully explored. EPRI would be well-positioned to carry out this work given its recent feasibility assessment of the North American in-stream resource and ongoing assessments of first-generation tidal energy projects.

2. *Detailed resource study.* Given the significant uncertainty associated with the resource estimates at some of the larger sites (e.g. Cross Sound), more detailed current profiling would help to further quantify the available and extractable resource, as well as lay the groundwork for turbine micro-siting. A detailed resource study would include both numerical calculations and field measurements (e.g. Acoustic Doppler Current Profiling).

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1. Introduction and Summary

A preliminary assessment of the in-stream tidal energy resource in the southeast of Alaska was carried out using NOAA (National Oceanic and Atmospheric Administration) data to estimate the tidal in-stream resource. Publicly available current predictions, range predictions, and digital bathymetric data for sites along the east and west coasts of the United States are provided by NOAA. Waterways in the southeast of Alaska were initially screened based on the strength of reported currents. The sites determined to warrant further investigation were:

- Cross Sound and Icy Strait: from Inian Islands east to Lemesurier Island
- Wrangell Narrows: from Keene Island north to Petersburg
- Chatham Strait: Kootznahoo Inlet
- Peril Strait: Sergius Narrows
- Prince of Wales Island: Tlevak and Tonowek Narrows
- Felice Strait: Harris Island, Snipe Island, and Indian Reef

The locations of these sites are shown on an aerial map of southeast Alaska in Figure 1 (northern half) and Figure 2 (southern half). The southeast of Alaska encompasses a multitude of constricted channels and inlets – not all of which have a corresponding NOAA current station. While it is unlikely that this assessment omits any large utility-scale (hundreds to thousands of megawatts (MW)) central power type sites, there are almost certainly additional small channels that could provide distributed generation (DG) scale resources of a few to tens of MW average power each. As such, the above list should not be taken as complete catalog of all available resources, but rather an instructive sampling of the available in-stream resource.

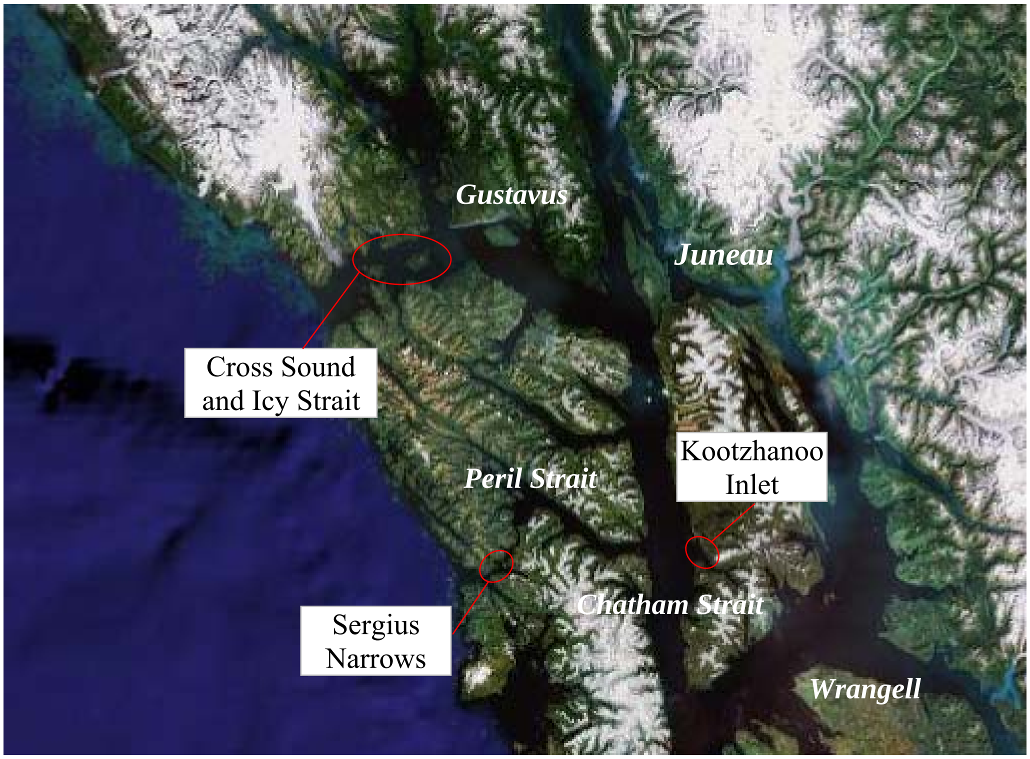

Figure 1 – Southeast Alaska (north) (Source: Google Maps)

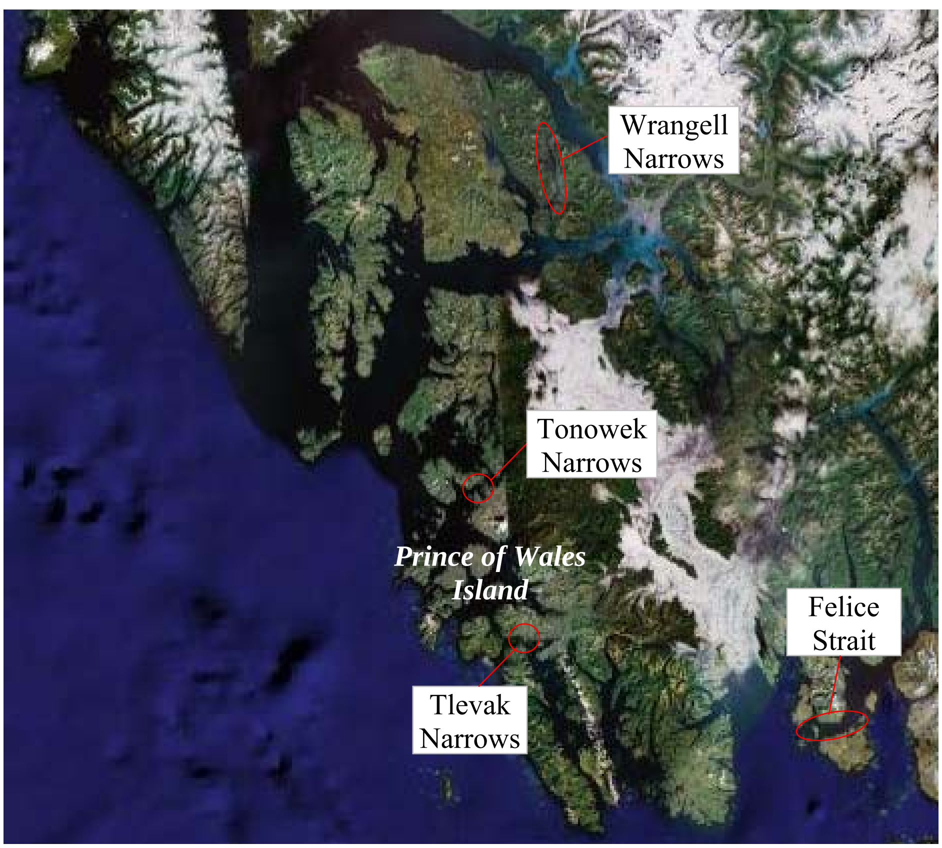

Figure 2 – Southeast Alaska (south) (Source: Google Maps)

Table 1 summarizes the in-stream tidal energy resource for each of the sites. Sites are characterized by four parameters:

- *Channel cross-section*: The cross-sectional area of channel through which current flows. Cross-sectional area tends to be a good predictor of the overall size of the kinetic resource.
- *Average depth*: Very shallow or very deep water complicates installation of in-stream turbines. Also, certain foundation types are most appropriate for certain depths.
- *Power density*: The kinetic power density of the flow. The higher the power density, the higher the quality of the resource and the more economic it is to extract. Power density tends to be a good predictor for cost of energy for a particular site.
- *Channel power*: The product of cross-sectional area and power density representing the average kinetic power present in the tidal channel. The larger the resource, the greater the economies of scale in array build-out. Estuary geography and environmental considerations will dictate what fraction of this kinetic power might be extracted by an array without significant environmental impact.

Water depth is a critical design parameter for tidal energy projects. The minimum depth is determined by blade clearance from the sea floor, blade diameter, and overhead clearance for the largest anticipated marine vessels and/or ice floes. Any depth beyond the minimum required will result in higher costs. The optimum depth for the largest turbines currently under development is approximately 30m.

Table 1 – Site Resource Summary

Site	Cross Section[1] m^2	Average Depth[2] m	Power Density[3] kW/m^2	Channel Power[4] MW
Cross Sound and Icy Strait				
South Passage (Icy Strait)	380,000	87	1.3	480
North Passage (Icy Strait)	490,000	110	0.9	420
South Inian Pass	34,000	46	4.3	150
North Inian Pass	660,000	230	2.5	1600
Wrangell Narrows				
Turn Point	4700	6.8	1.8	9
South Ledge	4800	5.5	2.6	12
Spike Rock	3500	4.8	2.6	9
Chatham Strait				
Kootznahoo Inlet[5]	3100	12	7.4	23
Peril Strait				
Sergius Narrows	5600	11	4.5	25
Prince of Wales Island				
Tlevak Narrows	12,000	18	1.5	18
Tonowek Narrows	15,000	18	0.7	11
Felice Strait				
Harris Island[6]	60	1	1.6	0.3
Snipe Island[7]	-	-	1.6	-
Indian Reef[7]	-	-	1.1	-

Table 2 qualitatively addresses the sites in the context of ongoing assessment of the North American tidal in-stream resource. An ideal utility-scale site would have a high power density and be deep enough to allow unimpeded surface traffic without being so deep that foundation installation becomes cost prohibitive.

[1] Annual average cross-sectional area
[2] Average depth of cross-section (MLLW reference)
[3] Depth averaged. 1/10th velocity profile assumed, consistent with turbulent flow.
[4] Annual average
[5] No modern bathymetric data available. Channel depth and cross-section estimated from navigational charts.
[6] Extremely shallow. Turbines would be exposed at low tide and experience high rates of corrosion.
[7] Nearby current stations indicate highly localized resource. No modern bathymetric data available. Resource not fully assessed.

Table 2 – Site Commercial Potential

Site	Power Density	Installation Depth	Average Annual Power
Cross Sound and Icy Strait[5]			
South Passage (Icy Strait)	Moderate	Moderately Deep	Large
North Passage (Icy Strait)	Moderate/Poor	Deep	Large
South Inian Pass	Very High	Optimal	Large
North Inian Pass	High	Very Deep	Enormous
Wrangell Narrows			
Turn Point	Moderate/High	Shallow	Small
South Ledge	High	Very Shallow	Small
Spike Rock	High	Very Shallow	Small
Chatham Strait			
Kootznahoo Inlet[6]	Extremely High	Very Shallow	Moderate
Peril Strait			
Sergius Narrows	Very High	Shallow	Moderate
Prince of Wales Island			
Tlevak Narrows	Moderate	Optimal	Moderate
Tonowek Narrows	Poor	Optimal	Small
Felice Strait			
Harris Island	Moderate	Very Shallow	Very Small
Snipe Island	Moderate	Very Shallow	Very Small
Indian Reef	Moderate/Poor	Very Shallow	Very Small

Overall, prospective in-stream tidal sites in the southeast of Alaska show a very high resource quality, but since many of the sites have small, shallow cross-sections, the total resource for each site is relatively small (Cross Sound and Icy Strait excepted), making them most suitable for distributed generation. In contrast, the sites in the Cross Sound and Icy Strait represent a vast, untapped potential for central power, utility-scale power plants. South Inian Pass and Kootznahoo Inlet also have strong potential to meet nearby, existing loads for Elfin Cove and Angoon, respectively. Any development of tidal energy projects in SE Alaskan waters must be done in such a way as to protect this sensitive environment in accordance with state, federal and local laws and regulations.

This report is broken down into eight major sections. The second section gives an overview of the methodology used to estimate site resources. The remaining six sections discuss the resource evaluation for each of the individual sites in southeast Alaska.

2. Methodology

The methodologies used in this report are those developed, defined and documented in EPRI report, "EPRI TP-001-NA: Guidelines for Preliminary Estimation of Power Production". Only an overview is given here. Readers interested in a higher level of detail for the underlying calculations should consult the referenced report.

2.1 Tidal Currents and Power

Tidal currents are driven by the twice daily rise and fall of the tides. In highly simplified terms, water flows downhill. As the tide rises at the inlet of an estuary, water flows in, filling the estuary basin. Likewise, as the tide falls, water flows out. As the moving waters pass through constrictions in the estuary, velocity increases due to conservation of mass. The power density of a tidal stream is given by:

$$P = \frac{1}{2}\rho V^3 \qquad \text{(Equation 1)}$$

where P is the power density (W/m^2), ρ is the density of the tidal stream (1024 kg/m^3), and V is the velocity of the stream (m/s). Due to the cubic dependency of power density on velocity, even small constrictions which slightly increase velocity can have substantial effects on power density.

For the NOAA current stations in southeast Alaska, it is assumed that the reported velocities are surface velocities. These velocities are assumed to be uniform across a channel. In the vertical direction, velocities are assumed to vary according to a $1/10^{th}$ power law such that:

$$V = V_o\left(\frac{z}{z_o}\right)^{1/10} \qquad \text{(Equation 2)}$$

where V_o is the surface velocity, z_o is the depth of the channel, V is the velocity at the depth of interest, and z is the depth of interest. This approximation is probably quite reasonable for a tidal estuary, but may be less valid for sites closer to the open ocean where the boundary layer is known to be thicker. This relation can be integrated over the depth of a channel to calculate depth-averaged velocity and power. For sites where the surface velocity is known, the average velocity over the entire depth is 91% of the surface velocity and the average power density over the entire depth is 77% of the surface power density.

For a site with a known power density, the product of the power density and channel cross-sectional area gives the total in-stream power in a channel. No estimates are given here of the environmentally extractable resource since recent work indicates this is strongly site dependent. The environmentally extractable resource is broadly defined as the fraction of the in-stream resource which can be extracted without significant environmental impact to the estuary. Effects of large-scale extraction are believed to include reduced volume of tidal exchange, reduced tidal range, alteration of timing and strength of tidal events (e.g. peak flood), and local changes to circulation.

2.2 Sources and Manipulation of Data

NOAA makes publicly available predictions for tidal currents, tidal range, and bathymetry. However, the data, as available, is not directly amenable to calculating resource potential.

Current data is presented as the timing and strength of peak ebb (outgoing), peak flood (incoming), and slack (high or low water with no currents). Assuming the tides are sinusoidal in nature, it is possible to determine the tides at any time from this data. For the purposes of this report, tidal currents are calculated in 30 minute intervals based on

Likewise, range data is presented as the timing of high and low tide. Assuming the tides are also sinusoidal in nature, a comparable procedure can be applied to generate the tidal range in 30 minute intervals. If necessary, a correction is applied to the timing of high and low water such that the predicted time for high or low water coincides with the timing of slack currents. This correction has only a minor impact on the magnitude of the calculated resource.

Bathymetric data is available in XYZ format – latitude, longitude, and depth. These data are plotted on a rectilinear grid using the Haversine formula to convert points of latitude and longitude into linear distances relative to a fixed reference. Since bathymetric coverage is usually not universal in the region of interest, some points on a generated grid may not contain data. A first-order interpolation routine is used to compute data for blank grid nodes by averaging depths from surrounding grids. Provided that bathymetric coverage is reasonably complete, this interpolation produces results in line with published navigational references.

Digitally gridded bathymetric data is used to calculate the cross-sectional area of the channel using the known width and depth of each grid cell. This gives the cross-sectional area at Mean Lower Low Water (MLLW). The MLLW reference is the average of the lower of the twice-daily low tides over the tidal epoch. Unless otherwise specified, depths in this paper are referenced to MLLW. Tidal range data is then used to compute an additional or removed prism of water corresponding to higher or lower tides. The product of channel cross section and power density yields the channel power throughout the year in 30 minute intervals. These points are then averaged to calculate annual average values (e.g. power density, channel power).

Gaps in current, range, and bathymetric data and general data quality issues are discussed in each report subsection.

3. Cross Sound and Icy Strait

The constrictions in the Cross Sound and Icy Strait produce locally high currents in a number of locations. While the only site in close proximity to an existing load is at South Inian Pass, just north of Elfin Cove (Figure 3), North Inian Pass and the passages to the north and south of Lemesurier Island offer a massive regional resource. A consideration of this resource should be included in the planning stages for the proposed Alaska-BC grid intertie.

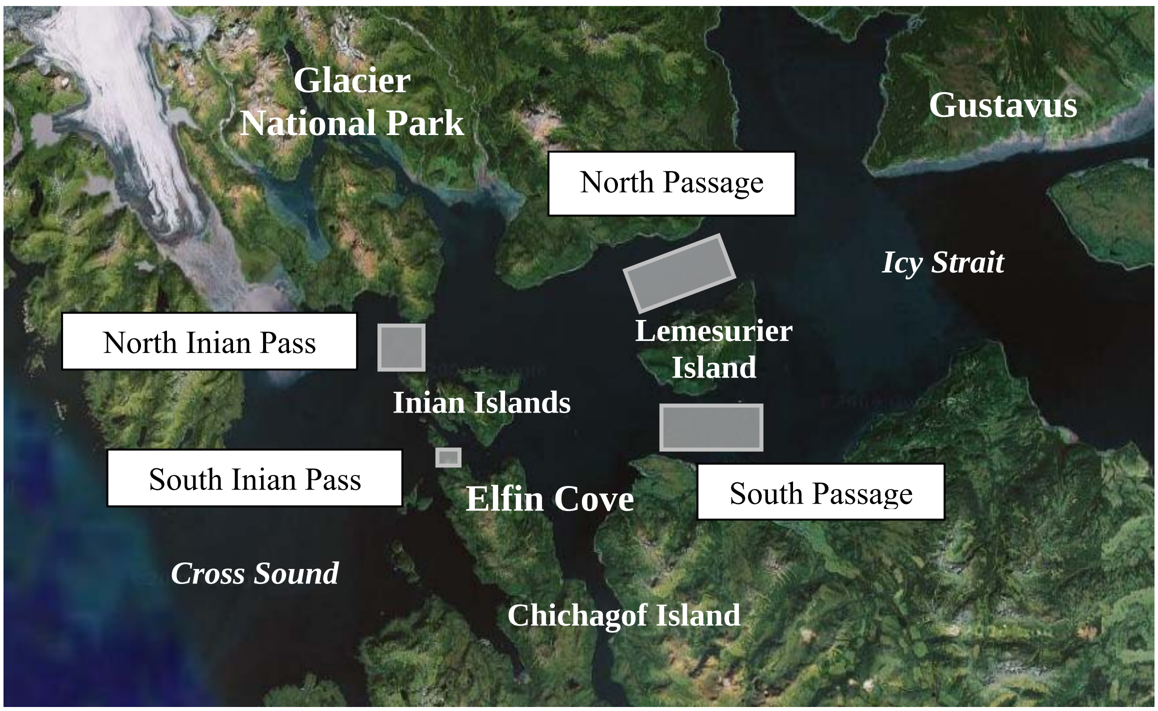

Figure 3 – Cross Sound and Icy Strait (Source: Google Maps)

3.1 South Inian Pass

Site Description and Resource

South Inian Pass is a constricted channel between Chichagof Islands and the Inian Islands as shown in Figure 4. Reported currents are very strong, particularly on ebb tides, and the channel is of moderate cross-sectional area, resulting in a large resource which might be economically harnessed with tidal in-stream turbines. The strait is part of the Alaska Marine Highway and any deployment of turbines would have to be compatible with shipping traffic.

Figure 4 – South Inian Pass (Source: Topozone)

Bathymetry for South Inian Pass and the location of the current station[8] are shown in Figure 5. To either side of the constriction, the channel widens considerably, with a commensurate reduction in current velocity. The channel is moderately deep, with an average depth of 45m and a maximum depth of 90m. The site bathymetry indicates that power densities may also be reasonably high east of the study area, to the north of Lacy Cove where there is a second wider, but shallower constriction.

[8] Stated coordinates for the current station place it 0.5 km inland from Pt. Lavinia. Location noted is the most probable location of the current station.

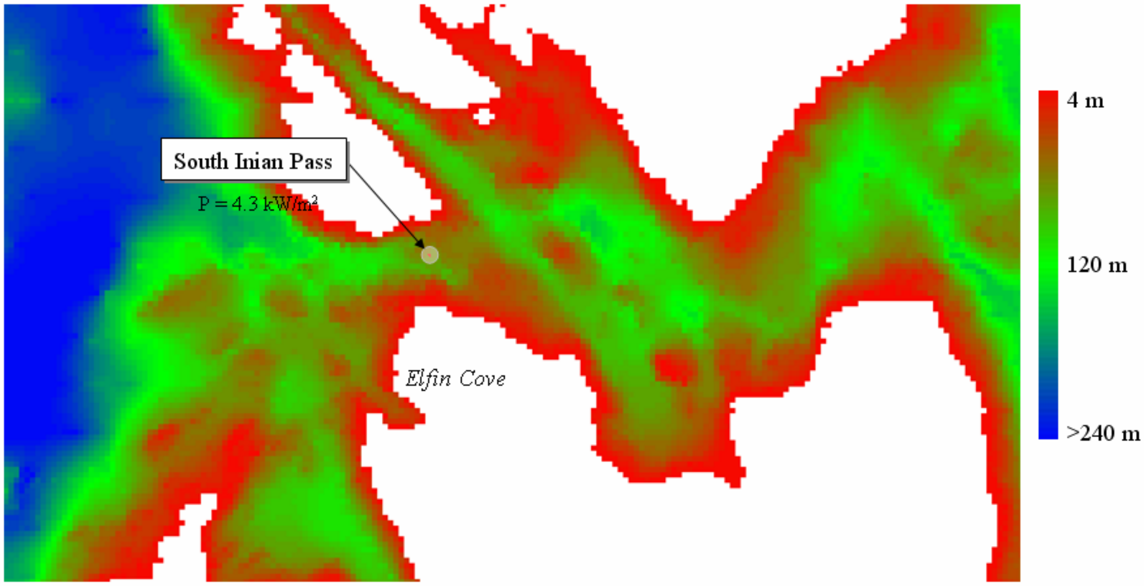

Figure 5 – South Inian Pass Bathymetry and Current Station

Site parameters for South Inian Pass are summarized in Table 3. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station.

Table 3 – South Inian Pass Site Parameters

Site	
Channel Width	720 m
Average Depth (MLLW reference)	46 m
Deepest Point (MLLW reference)	86 m
Average Cross-sectional Area	34,000 m^2
Maximum Surface Current	4.9 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	4.3 kW/m^2
Average Power Available	150 MW

A representative plot of channel power over a tidal cycle is given in Figure 6.

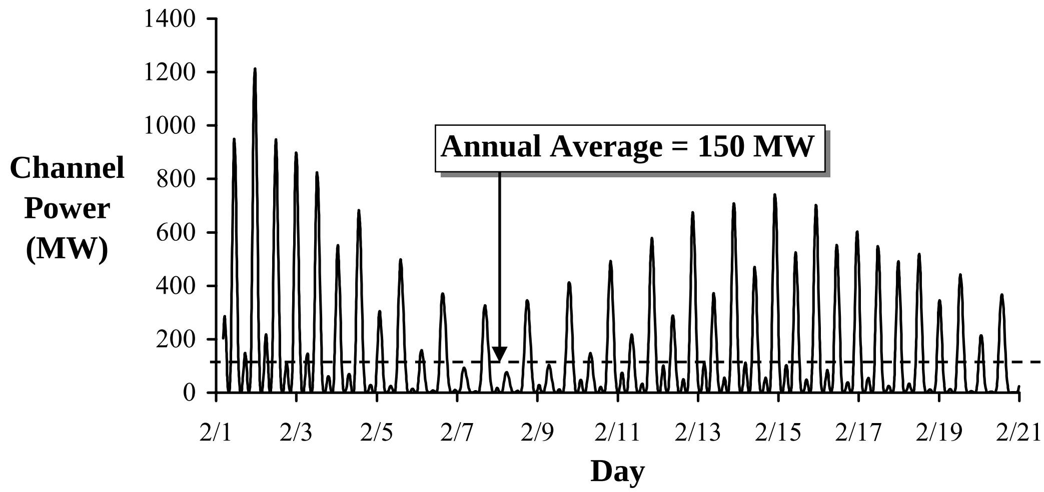

Figure 6 – Tidal Cycle Channel Power Variation in South Inian Pass (2006)

Monthly averaged channel power is shown in Figure 7.

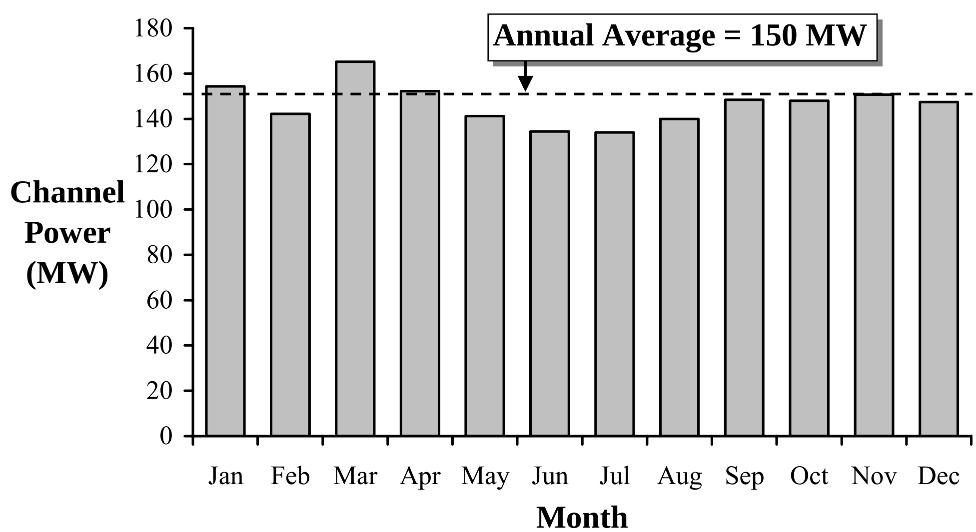

Figure 7 – Monthly Average Channel Power in South Inian Pass (2006)

Data Quality

Data quality for South Inian Pass is quite good. Regional bathymetry was surveyed in 1991 and the current station in South Inian Pass is referenced to a primary measurement station only a few miles north. The only data issue involves the published latitude and longitude of the current station, which places the current station more than half a kilometer inland. It has been assumed that the current station is actually located in the constricted region of South Inian Pass. Data sources are summarized in Table 4.

Table 4 – South Inian Pass Data Sources

Data	Latitude	Longitude	Name
Current	N 58°13.6'	W 136°21.3'	South Inian Pass
Range	N 58°13'	W 136°21'	Point Lavinia, South Inian Pass
Bathymetry			H10371

3.2 North Inian Pass

Site Description and Resource

North Inian Pass is a deep, constricted channel between the Inian Islands and Pt. Wimbledon as shown in Figure 8. Reported currents are strong, particularly on ebb tides, and the significant depth and width of the channel put this site in the top-tier of utility-scale tidal energy sites anywhere in North America. The northern half of the channel lies within Glacier National Park, which will have implications for commercial development.

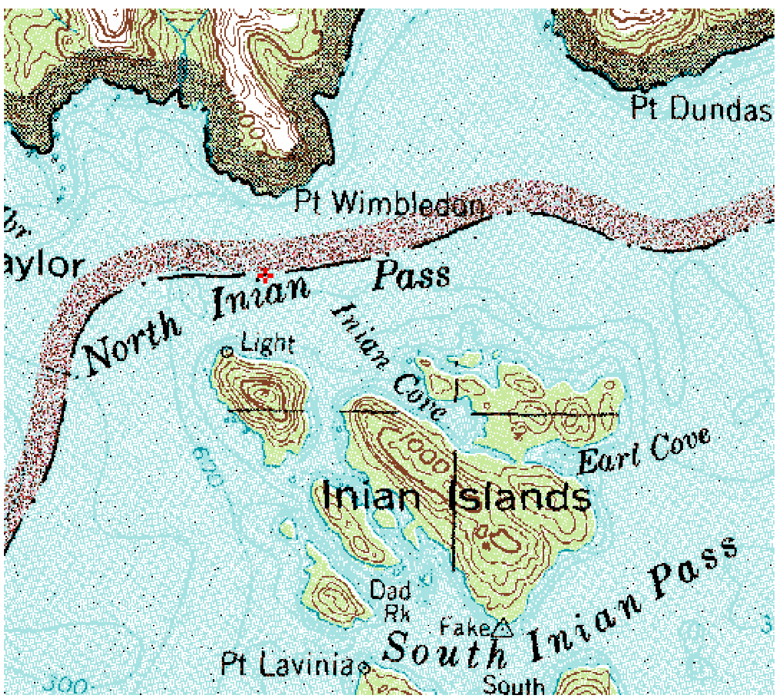

Figure 8 – North Inian Pass (Source: Topozone)

Bathymetry for North Inian Pass and the location and power density for the current station are shown in Figure 9. The constriction is approximately 2km long and to either side, the channel widens considerably, with a commensurate reduction in current velocity. The channel is very deep over most of its width, with a maximum deep approaching 300m.

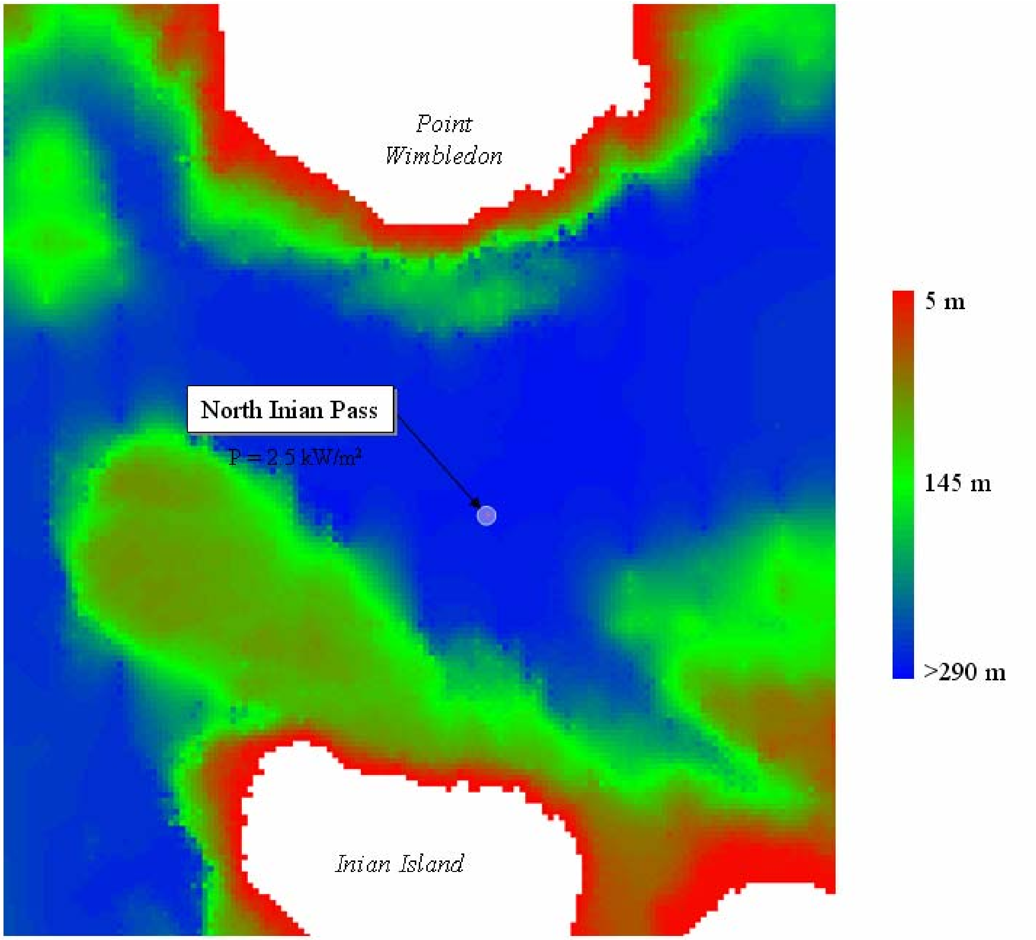

Figure 9 – North Inian Pass Bathymetry and Current Station

Site parameters for North Inian Pass are summarized in Table 5. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station.

Table 5 – North Inian Pass Site Parameters

Site	
Channel Width	2800 m
Average Depth (MLLW reference)	230 m
Deepest Point	280 m
Average Cross-sectional Area	660,000 m^2
Maximum Surface Current	4.1 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	2.5 kW/m^2
Average Power Available	1600 MW

A representative plot of channel power over a tidal cycle is given in Figure 10.

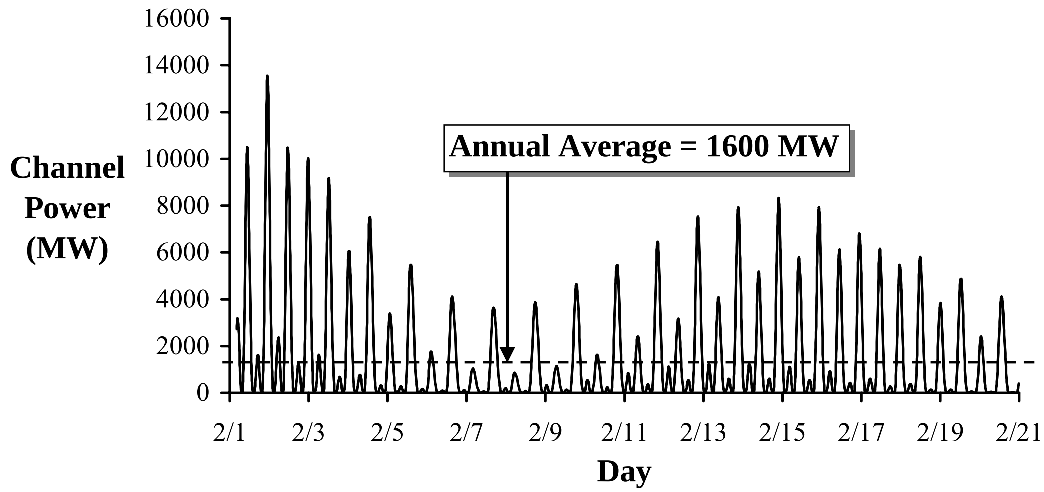

Figure 10 – Tidal Cycle Channel Power Variation in North Inian Pass (2006)

Monthly averaged channel power is shown in Figure 11.

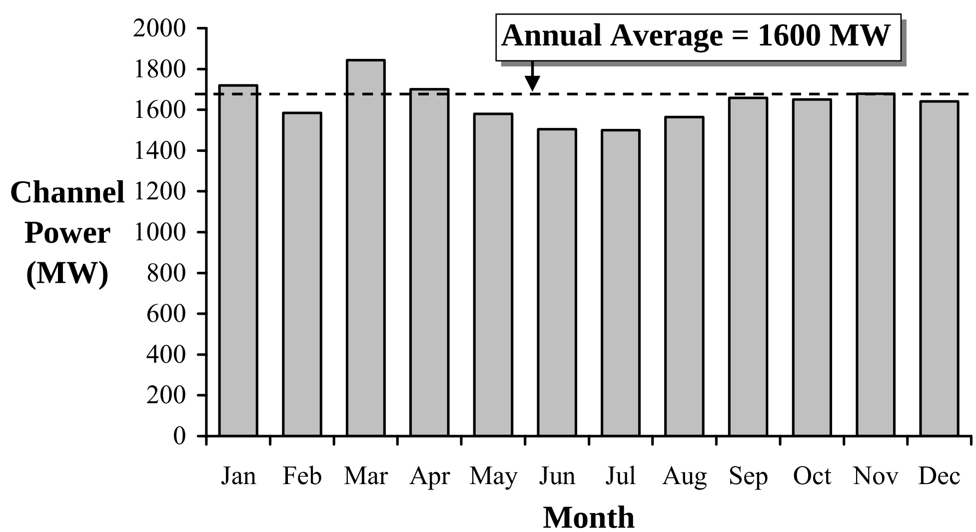

Figure 11 – Monthly Average Channel Power in North Inian Pass (2006)

Data Quality

Data quality for North Inian Pass is quite good. Channel bathymetry was surveyed in 1992 and the current station in North Inian Pass is a primary reference station. Clearly, given the width and depth of the channel, there are substantial uncertainties associated with extrapolation of this point measurement to the entire channel. However, since the station is located in the center of the channel in one of the deepest areas, the point measurement should reasonably proxy channel flow. The greatest uncertainty is in the assumed depth profile due to the extreme channel depth. Data sources are summarized in Table 6.

Table 6 – North Inian Pass Data Sources

Data	Latitude	Longitude	Name
Current	N 58°17'	W 136°23'	North Inian Pass
Range	N 58°16'	W 136°20'	Inian Cove, North Inian Pass
Bathymetry			H10419, H02558

3.3 South Passage (Icy Strait)

Site Description and Resource

South Passage is a wide, long channel between Lemesurier Island and Chichagof Island to the west of Gustavus, as shown in Figure 12. Reported currents are moderate, and strongest on ebb tide. While the resource quality is not exceptional, the large cross-sectional area of the channel means the site offers a large total resource. The channel is part of the Alaska Marine Highway and any deployment of turbines would have to be compatible with shipping traffic.

Figure 12 – South Passage (Source: Topozone)

Bathymetry for the South Passage and the location and power density for the current station are shown in Figure 13. The channel is quite deep in places, and has an average depth of nearly 90m. The channel cross-section increases, though not tremendously, to the east and west of the current station, so the reported power density may not be representative over the entire 5 km long channel.

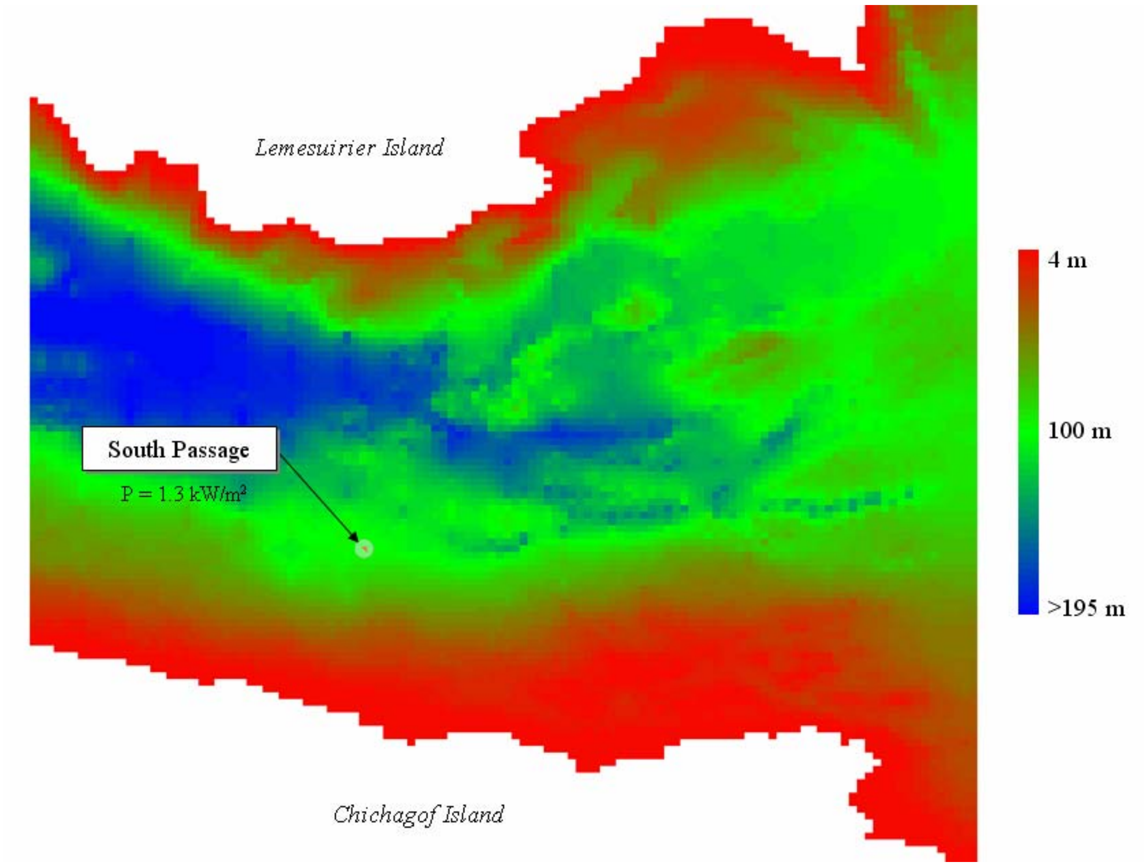

Figure 13 – South Passage Bathymetry and Current Station

Site parameters for the South Passage are summarized in Table 7. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station.

Table 7 – South Passage Site Parameters

Site	
Channel Width	4300 m
Average Depth (MLLW reference)	90 m
Deepest Point	190 m
Average Cross-sectional Area	380,000 m^2
Maximum Surface Current	3.3 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	1.3 kW/m^2
Average Power Available	480 MW

A representative plot of channel power over a tidal cycle is given in Figure 14.

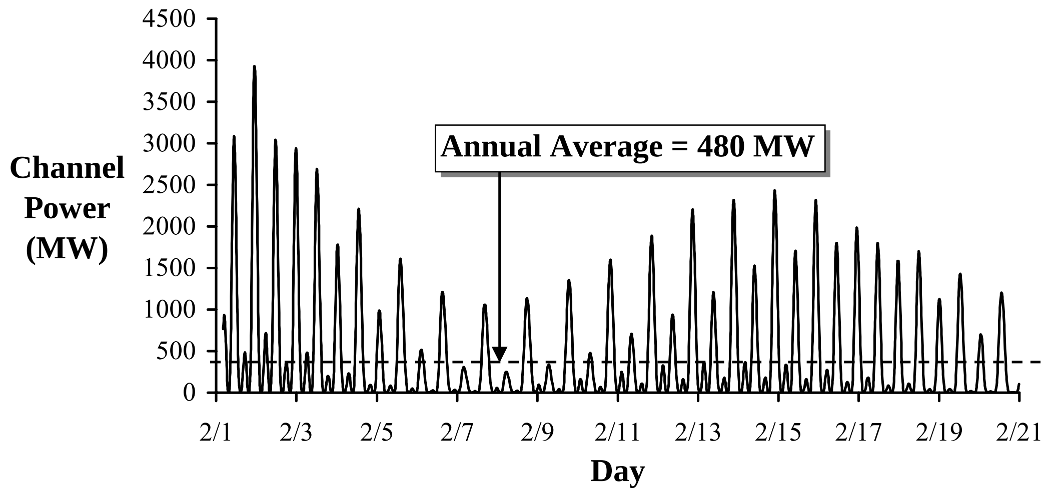

Figure 14 – Tidal Cycle Channel Power Variation in South Passage (2006)

Monthly averaged channel power is shown in Figure 15.

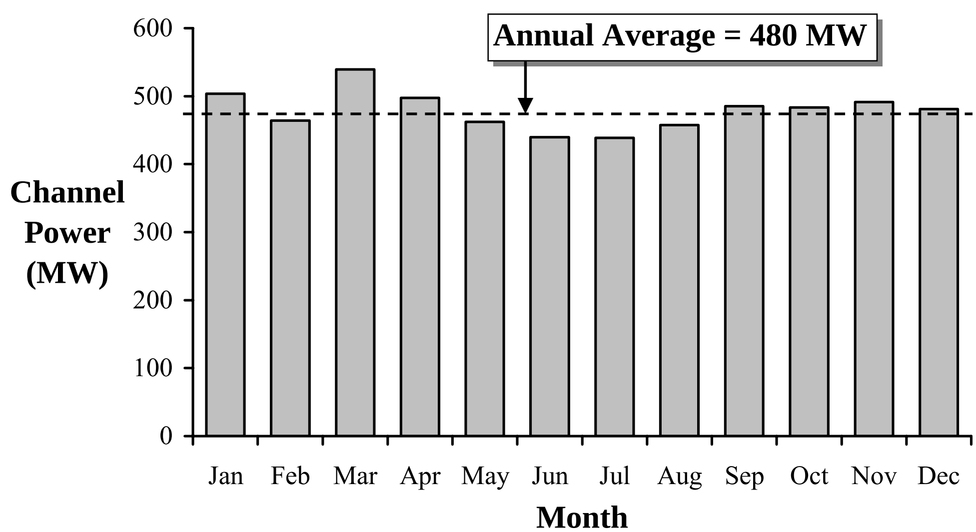

Figure 15 – Monthly Average Channel Power in South Passage (2006)

Data Quality

Data quality for the South Passage is quite good. Channel bathymetry was surveyed in 1990 and the current station is referenced to North Inian Pass, several miles to the northwest of the site. Clearly, given the width and depth of the channel, there are substantial uncertainties associated with extrapolation of this point measurement to the entire channel. Since the channel depth is not uniform at the cross-section and the reference station is located closer to the south shore, the extrapolation may overly estimate the available resource. Data sources are summarized in Table 8.

Table 8 – South Passage Data Sources

Data	Latitude	Longitude	Name
Current	N 58°14'	W 136°6'	South Passage
Range	N 58°13'	W 136°2'	Mud Bay, Goose Island
Bathymetry			H10335, H10336, H06339

3.4 North Passage (Icy Strait)

Site Description and Resource

The North Passage is a wide, long channel between Lemesurier Island and the mainland as shown in Figure 16. Reported currents are not particularly strong, so while the site has a large resource owing to its cross-sectional area, the quality of the resource is relatively low in comparison to other sites in the Cross Sound and Icy Strait. The northern half of the passage lies within Glacier National Park, which will have implications for commercial development.

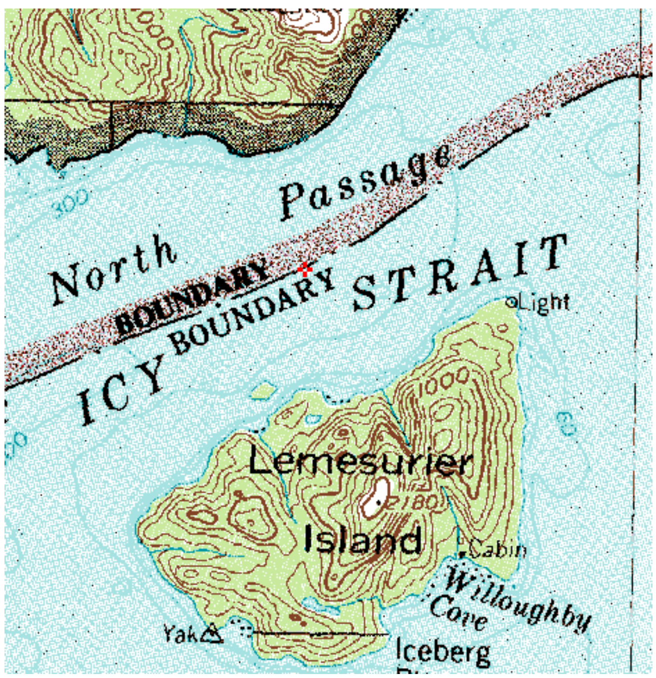

Figure 16 – North Passage (Source: Topozone)

Bathymetry for the North Passage and the location and power density of the current station are shown in Figure 17. The channel is uniformly deep, with an average depth of over 100m.

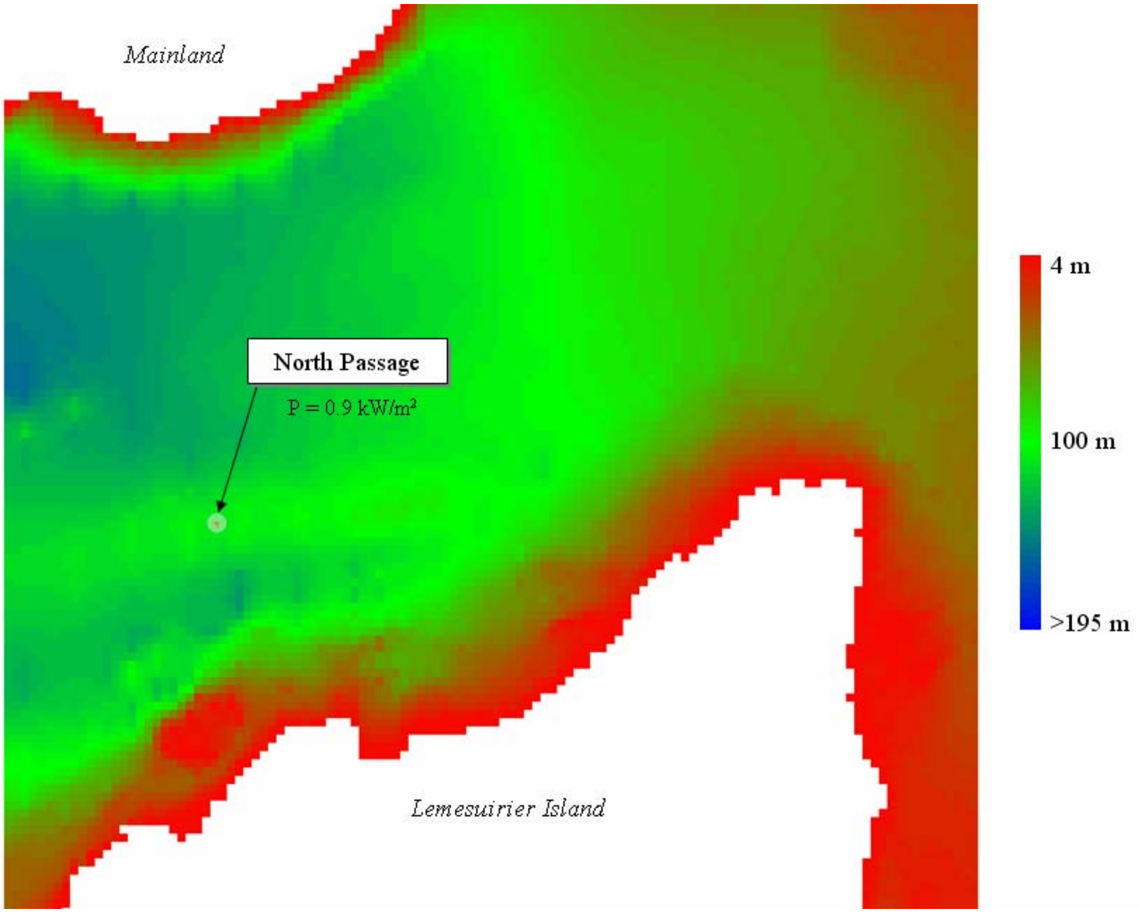

Figure 17 – North Passage Bathymetry and Current Station

Site parameters for the South Passage are summarized in Table 9. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station.

Table 9 – North Passage Site Parameters

Site	
Channel Width	4600 m
Average Depth (MLLW reference)	110 m
Deepest Point	140 m
Average Cross-sectional Area	490,000 m^2
Maximum Surface Current	2.9 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	0.9 kW/m^2
Average Power Available	420 MW

A representative plot of channel power over a tidal cycle is given in Figure 18.

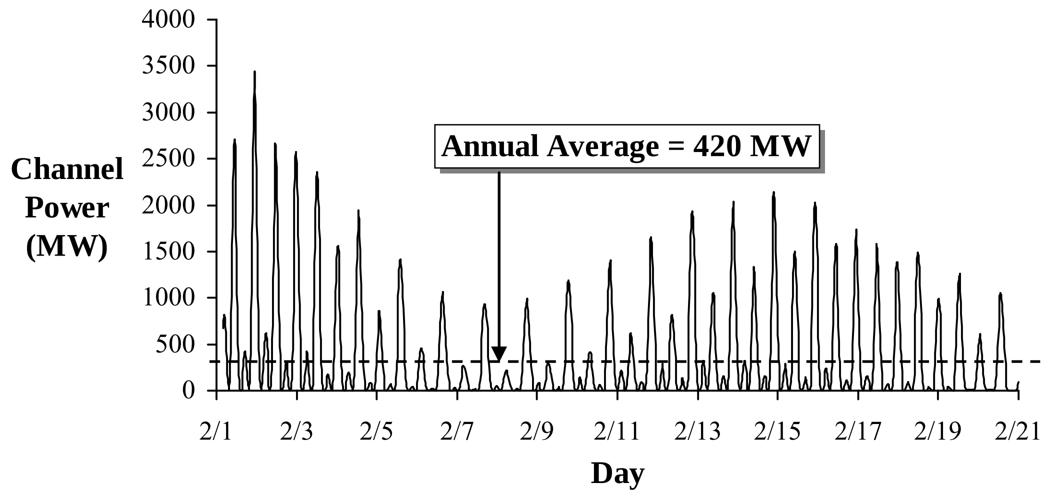

Figure 18 – Tidal Cycle Channel Power Variation in North Passage (2006)

Monthly averaged channel power is shown in Figure 19.

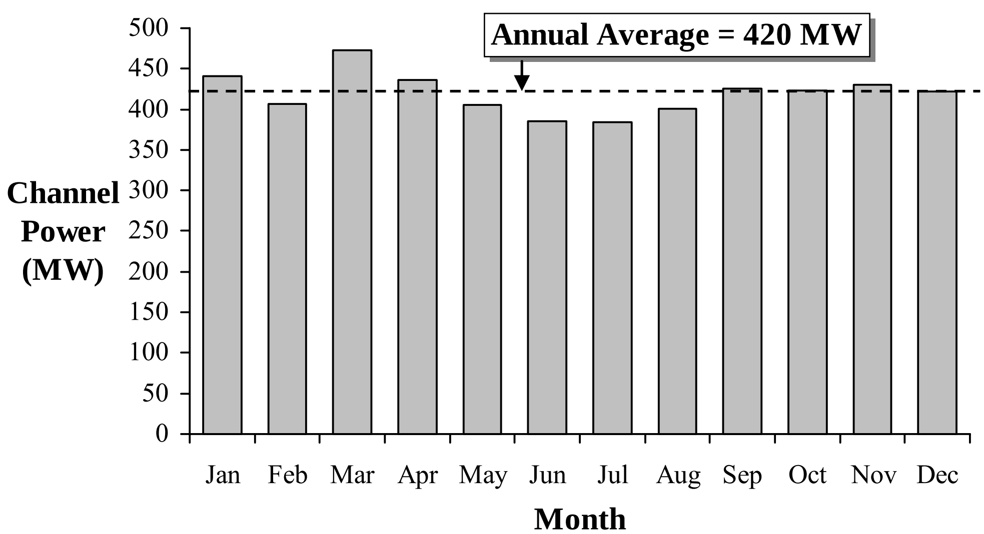

Figure 19 – Monthly Average Channel Power in North Passage (2006)

Data Quality

Data quality for the North Passage is quite good. Channel bathymetry was surveyed in 1990 and the current station is referenced to North Inian Pass, to the west of the site. Clearly, given the width and depth of the channel, there are substantial uncertainties associated with extrapolation of this point measurement to the entire channel. However, the channel geometry is reasonably regular in the region around the reference station and depth is nearly uniform, so the current station should reasonably proxy the entire channel. Data sources are summarized in Table 10.

Table 10 – North Passage Data Sources

Data	Latitude	Longitude	Name
Current	N 58°19’	W 136°7’	North Passage
Range	N 58°19’	W 136°2’	Lemesurier Island Light, North Passage
Bathymetry			H10335, H10336, H06339

4. Wrangell Narrows

The Wrangell Narrows is a shallow, narrow channel separating Kupreanof and Mitkof Islands. The passage is over 30 km long, and while the navigable waterway is often only a few hundred meters wide, there are large areas fouled by mud and rocks to either side of the main channel. An aerial map of the region is shown in Figure 20.

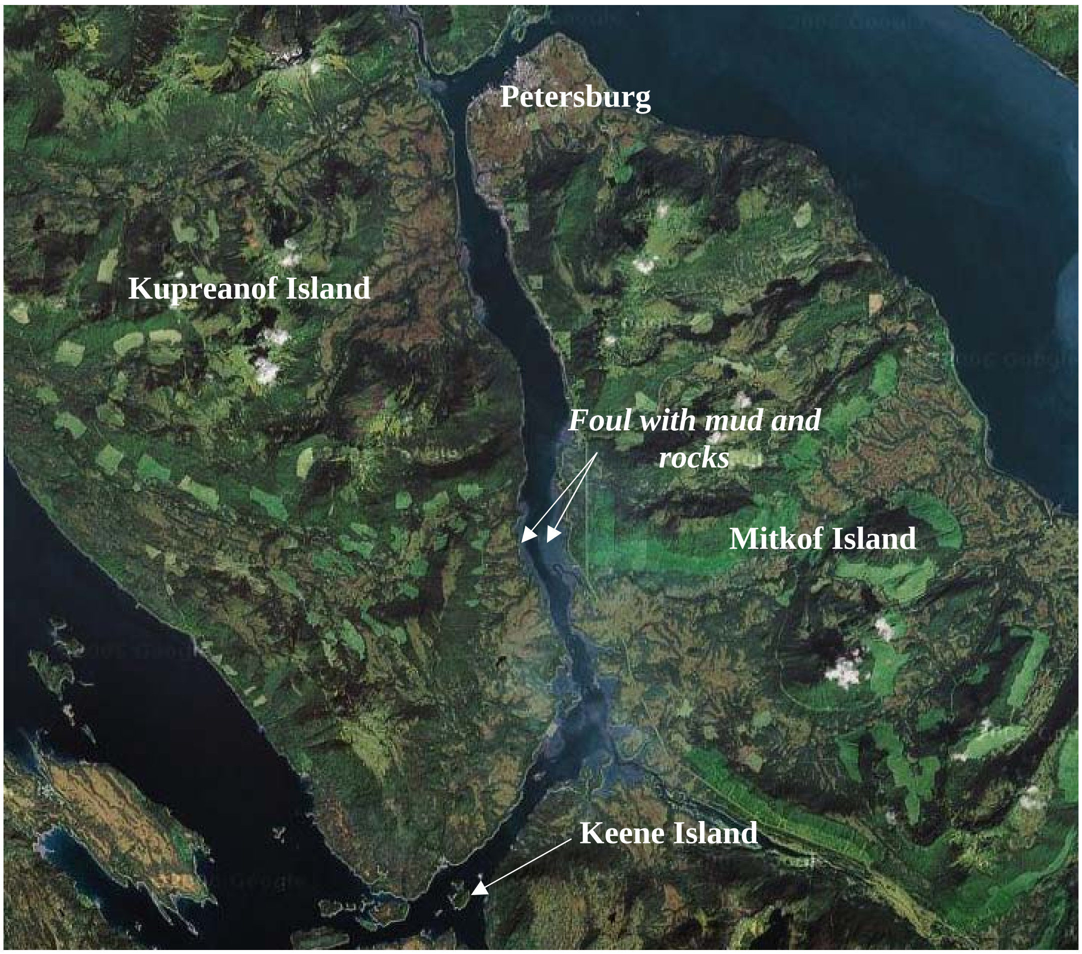

Figure 20 – Wrangell Narrows (Source: Google Maps)

A bathymetric map of the northern and southern portions of Wrangell Narrows with current stations and associated resource quality is given in Figure 21.

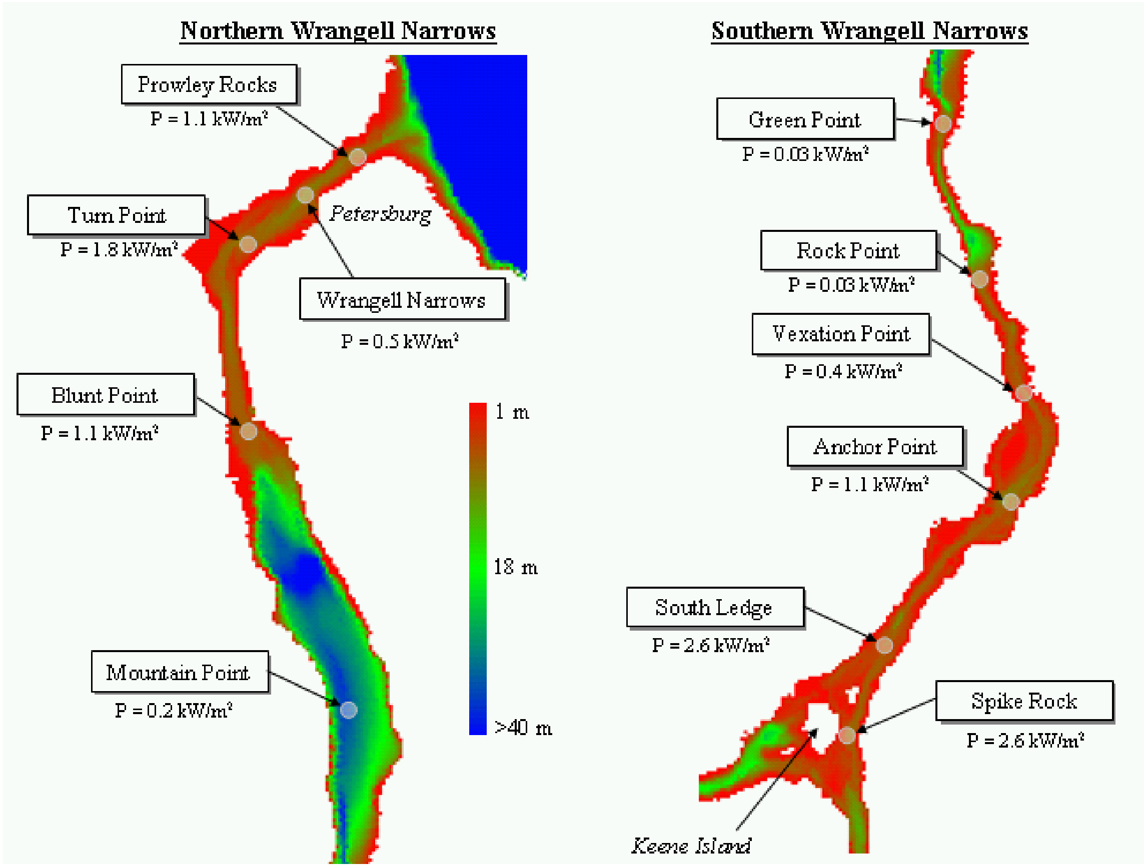

Figure 21 – Wrangell Narrows Bathymetric and Resource

The channel bathymetry reveals narrow, shallow channels in the regions of highest power density. This indicates that sites within the Wrangell Narrows will be of only modest size. Based on power density, the in-stream resource at Turn Point (near Petersburg) and Spike Rock and the South Ledge (near Keene Island) were considered for further analysis. The Wrangell Narrows is part of the Alaska Marine Highway and any array development must be compatible with continued shipping and ferry operations.

4.1 Turn Point

At Turn Point, the Wrangell Narrows turn sharply to the northeast. Directly north of the site is a large area of mud and rocks, which will be exposed at low tide and covered at high. A local map is shown in Figure 22.

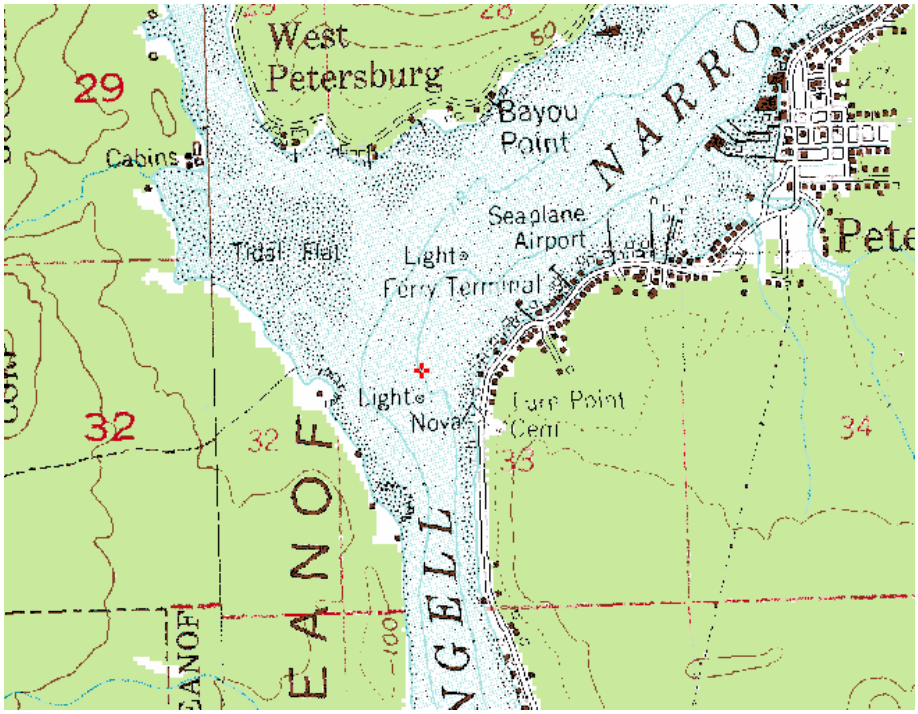

Figure 22 – Turn Point (Source: Topozone)

It is unclear whether the channel has sufficient width to accommodate both tidal turbines and shipping traffic. Site parameters for Turn Point are summarized in Table 9. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station.

Table 11 – Turn Point Site Parameters

Site	
Channel Width	510 m
Average Depth (MLLW reference)	6.8 m
Deepest Point	9.4 m
Average Cross-sectional Area	4700 m^2
Maximum Surface Current	3.4 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	1.8 kW/m^2
Average Power Available	8.6 MW

A representative plot of channel power over a tidal cycle is given in Figure 23.

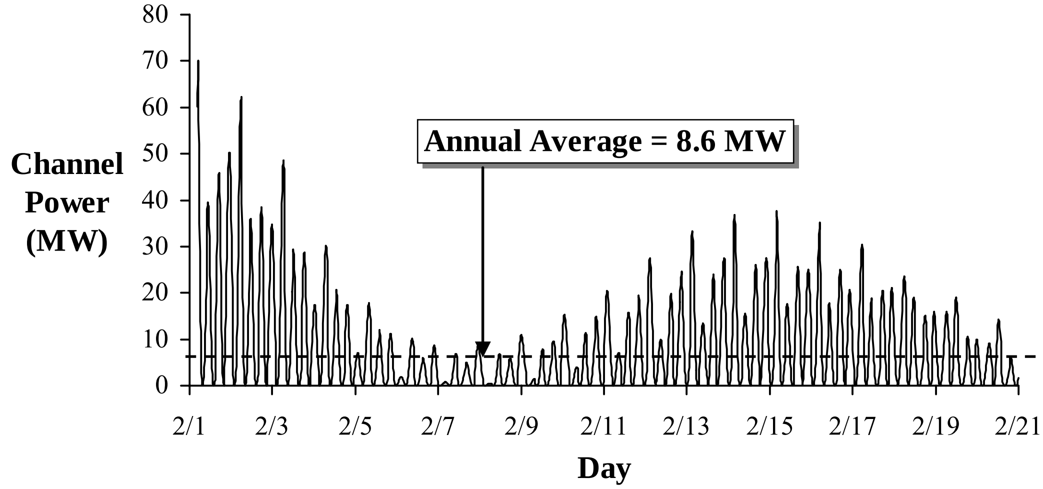

Figure 23 – Tidal Cycle Channel Power Variation at Turn Point (2006)

Monthly averaged channel power is shown in Figure 24.

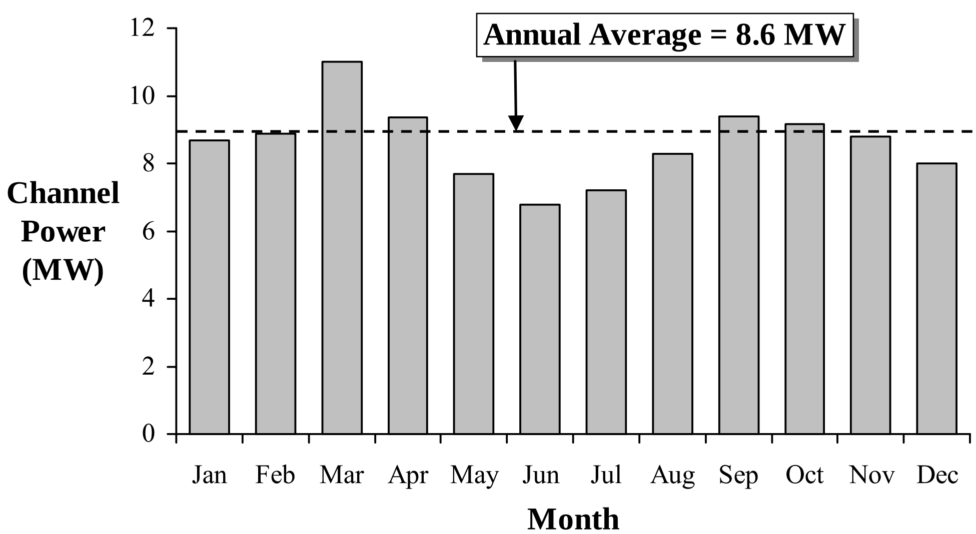

Figure 24 – Monthly Average Channel Power at Turn Point (2006)

Data Quality

Data quality for the Wrangell Narrows at Turn Point is good. Channel bathymetry was surveyed in mid to late 1970's and the current station is referenced to Wrangell Narrows near Petersburg, just a few miles to the northeast. The headland at Turn Point may generate large eddies, which would be disruptive to turbine operation. The potential for this sort of deleterious flow feature should be explored in a full feasibility study. Data sources are summarized in Table 12.

Table 12 – Turn Point Data Sources

Data	Latitude	Longitude	Name
Current	N 56°48.5’	W 132°59’	Turn Point
Range	N 56°49’	W 132°57’	Petersburg
Bathymetry			H09332, H09571, H09729, H09791, H09792, H09795

4.2 South Ledge

In the vicinity of the South Ledge, the Wrangell Narrows is a tightly constricted, shallow passage as shown in Figure 25.

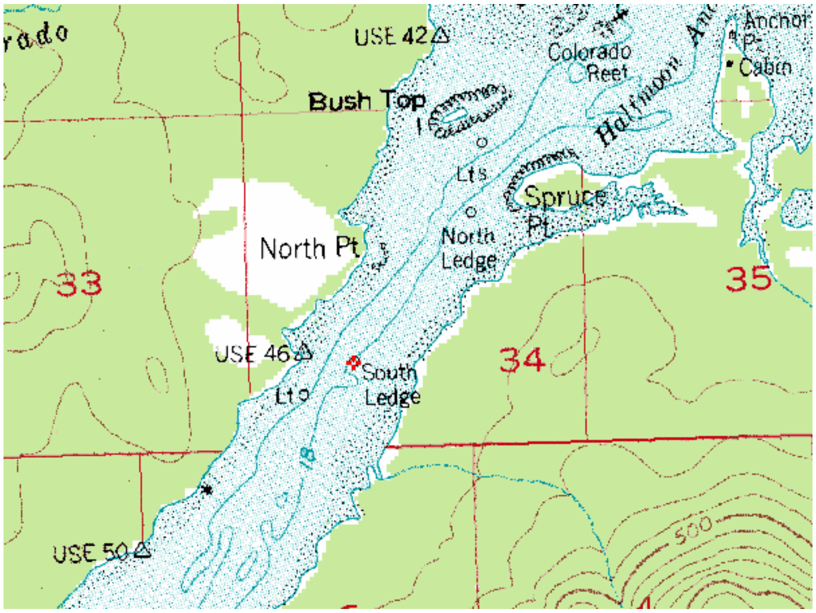

Figure 25 – South Ledge (Source: Topozone)

Bathymetry for the South Ledge and the location and power density of the current station are shown in Figure 26.

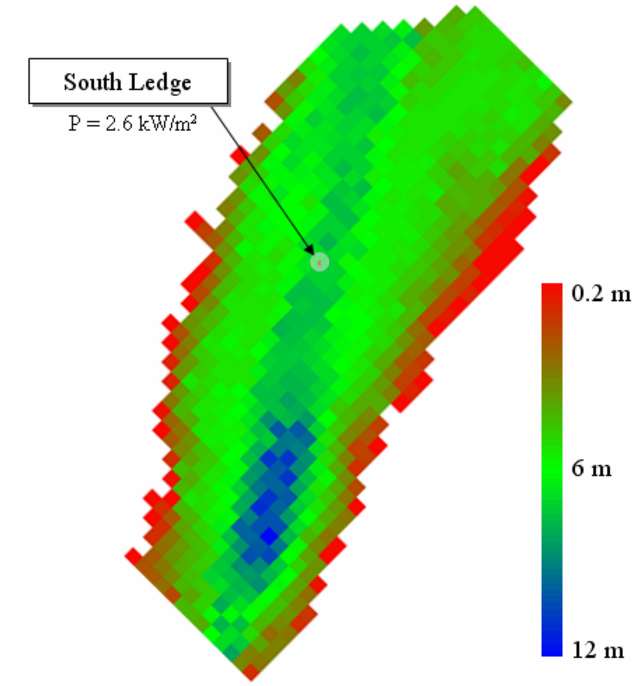

Figure 26 – South Ledge Bathymetry and Current Station

It is unclear whether the channel has sufficient width to accommodate both tidal turbines and shipping traffic. Site parameters for the South Ledge are summarized in Table 13. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station.

Table 13 – South Ledge Site Parameters

Site	
Channel Width	600 m
Average Depth (MLLW reference)	5.5 m
Deepest Point	7.4 m
Average Cross-sectional Area	4800 m^2
Maximum Surface Current	4.0 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	2.6 kW/m^2
Average Power Available	12 MW

A representative plot of channel power over a tidal cycle is given in Figure 27.

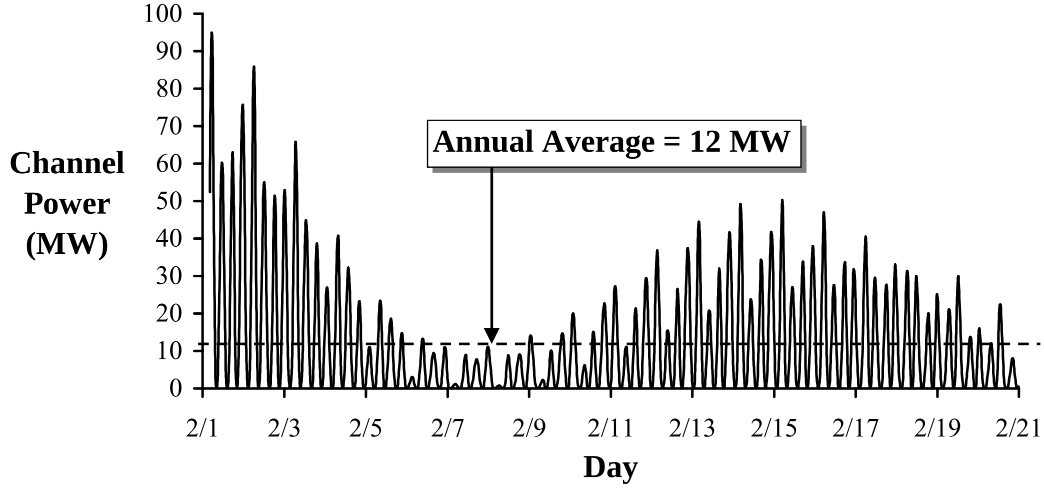

Figure 27 – Tidal Cycle Channel Power Variation at South Ledge (2006)

Monthly averaged channel power is shown in Figure 28.

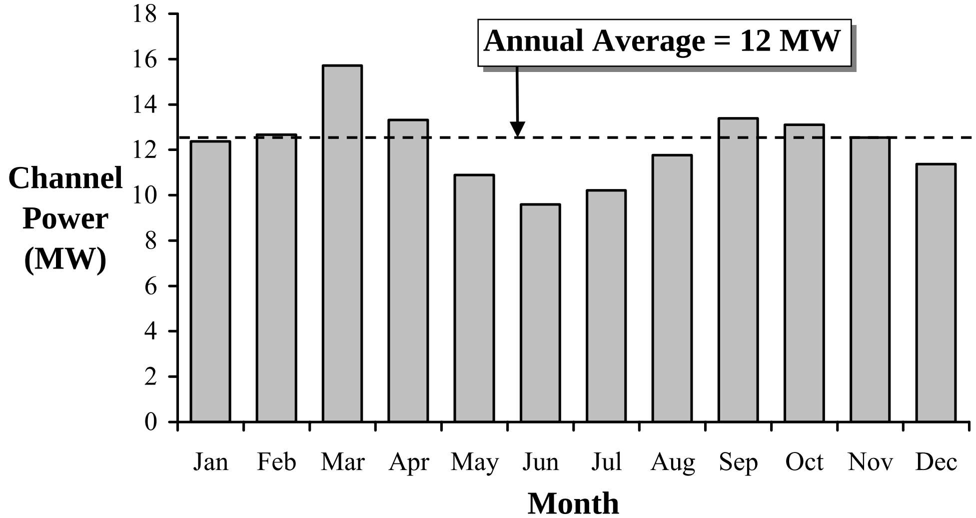

Figure 28 – Monthly Average Channel Power at South Ledge (2006)

Data Quality

Data quality for the Wrangell Narrows at South Ledge is good. Channel bathymetry was surveyed in mid to late 1970's and the current station is referenced to Wrangell Narrows near Petersburg. Data sources are summarized in Table 14.

Table 14 – South Ledge Data Sources

Data	Latitude	Longitude	Name
Current	N 56°37'	W 132°58'	South Ledge
Range	N 56°38'	W 132°56'	Anchor Point
Bathymetry			H09332, H09571, H09729, H09791, H09792, H09795

4.3 Spike Rock

To the east of Keene Island, the Wrangell Narrows forms a tight constriction with Mitkof Island as shown in Figure 29.

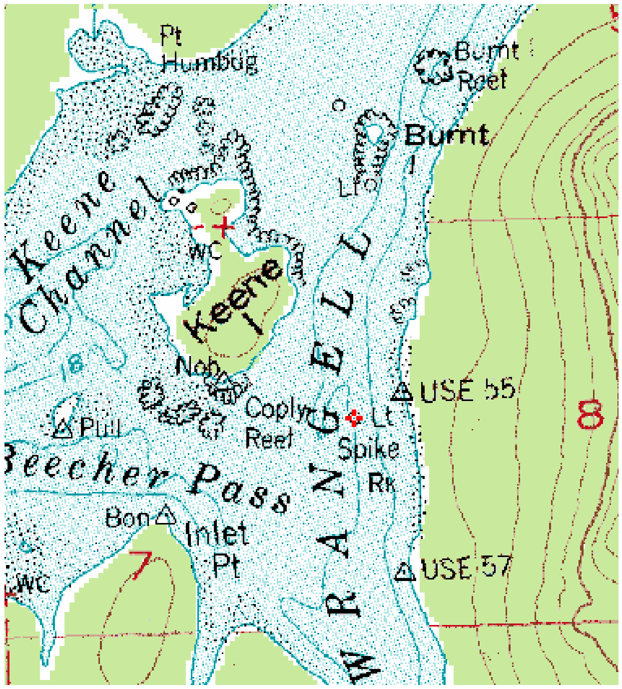

Figure 29 – Spike Rock (Source: Topozone)

Bathymetry for the Wrangell Narrows in the vicinity of Spike Rock and the location and power density of the current station are shown in Figure 30. The channel is extremely shallow.

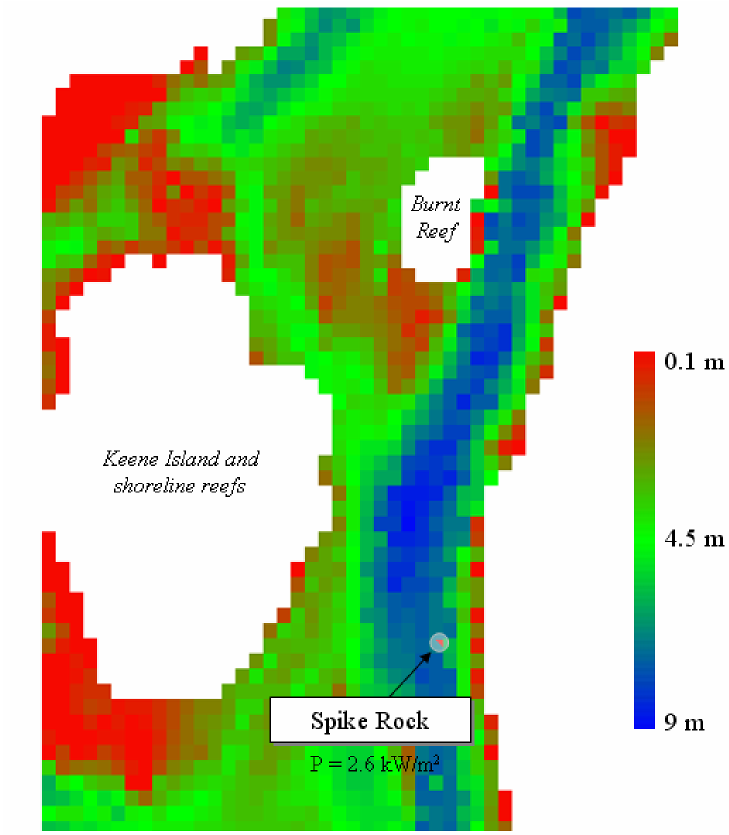

Figure 30 – Spike Rock Bathymetry and Current Station

It is unclear whether the channel has sufficient width to accommodate both tidal turbines and shipping traffic. Site parameters for Spike Rock are summarized in Table 15. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station.

Table 15 – Spike Rock Site Parameters

Site	
Channel Width	480 m
Average Depth (MLLW reference)	4.8 m
Deepest Point	7.4 m
Average Cross-sectional Area	3500 m^2
Maximum Surface Current	4.0 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	2.6 kW/m^2
Average Power Available	8.9 MW

A representative plot of channel power over a tidal cycle is given in Figure 31.

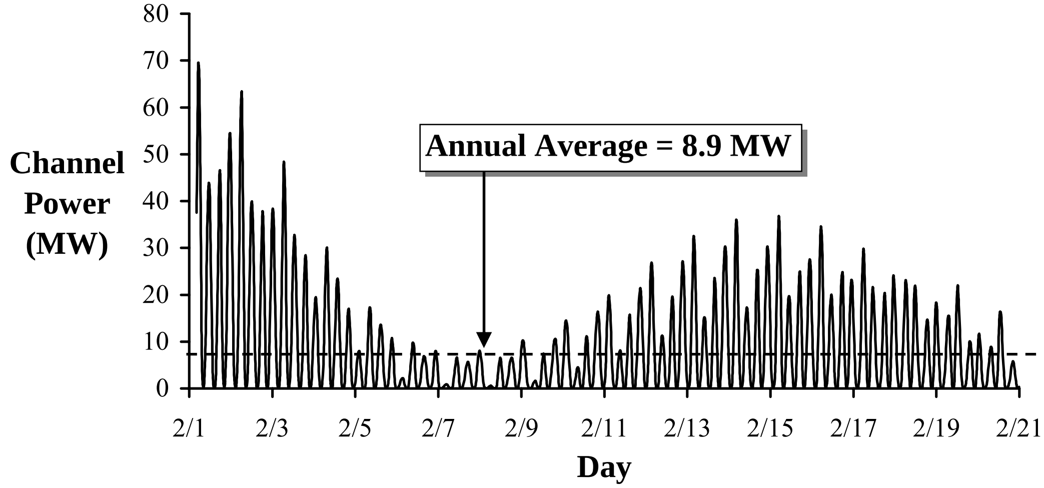

Figure 31 – Tidal Cycle Channel Power Variation at Spike Rock (2006)

Monthly averaged channel power is shown in Figure 32.

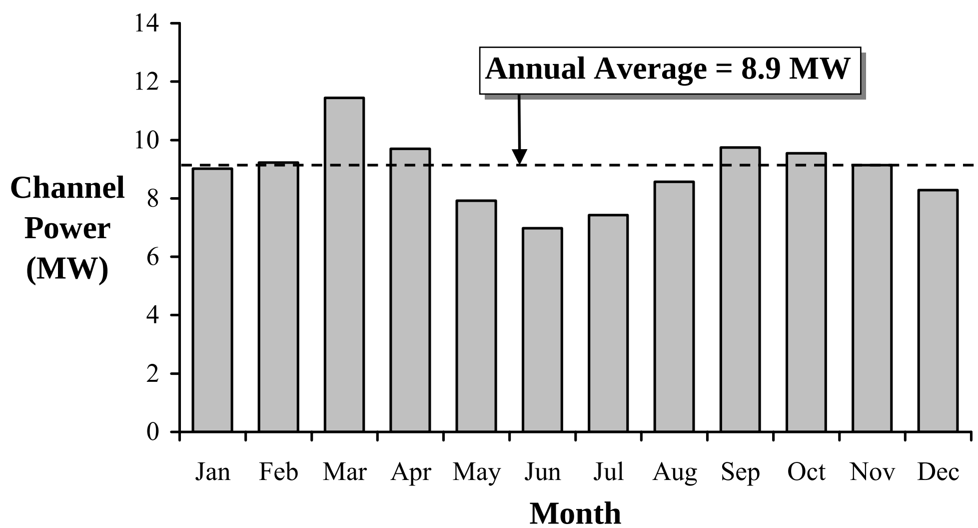

Figure 32 – Monthly Average Channel Power at Spike Rock (2006)

Data Quality

Data quality for the Wrangell Narrows at Spike Rock is good. Channel bathymetry was surveyed in mid to late 1970's and the current station is referenced to Wrangell Narrows near Petersburg. The channel bathymetry is somewhat difficult to resolve in places due to the many shallow reefs which ships of the time could not survey. However, since these gaps in bathymetric coverage are for extremely shallow areas, they should not introduce substantial error into the resource assessment. Data sources are summarized in Table 16.

Table 16 – Spike Rock Data Sources

Data	Latitude	Longitude	Name
Current	N 56°36.1’	W 132°58.6’	Spike Rock
Range	N 56°38’	W 132°56’	Anchor Point
Bathymetry			H09332, H09571, H09729, H09791, H09792, H09795

5. Chatham Strait

Chatham Strait is a wide, deep body of water separating Chichagof and Admiralty Islands. While currents are quite slow in Chatham Strait, Kootznahoo Inlet exhibits extremely high current velocities as water passes between Chatham Inlet and Mitchell Bay. An aerial map of the region is shown in Figure 20.

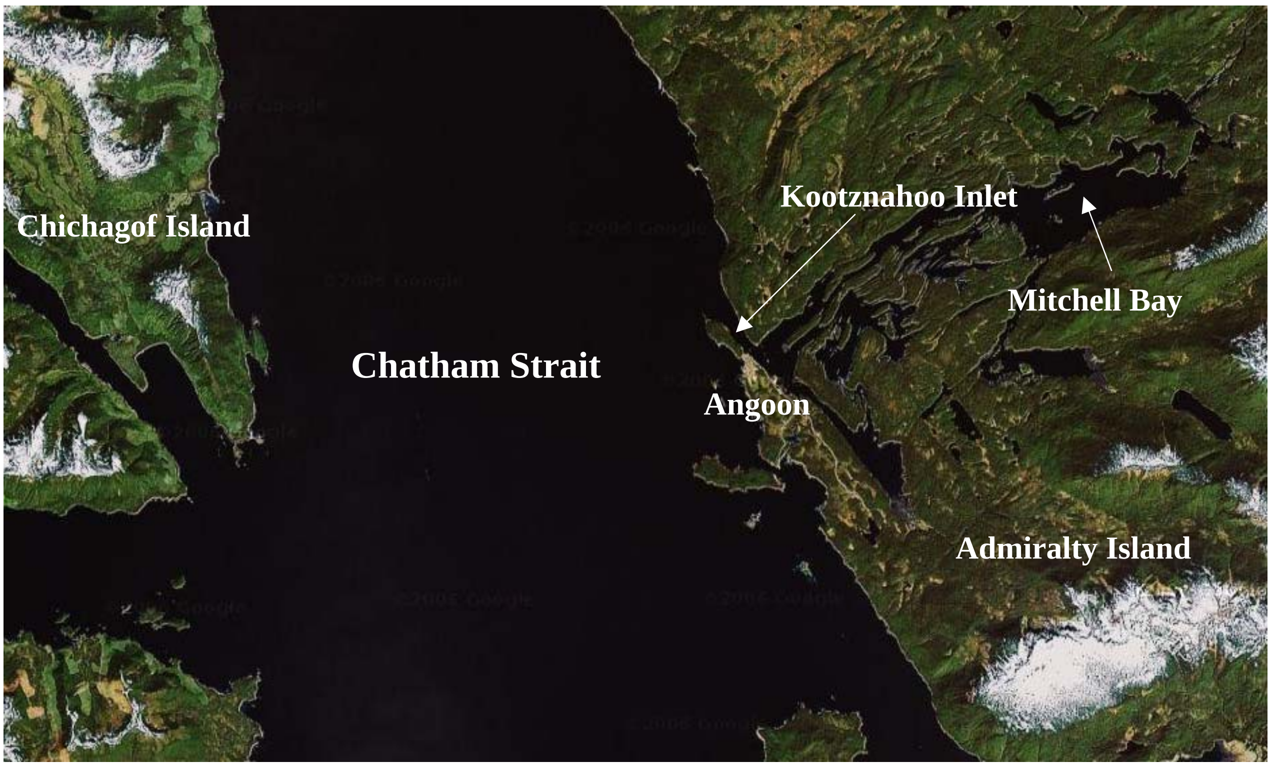

Figure 33 – Chatham Strait (Source: Google Maps)

5.1 Kootznahoo Inlet

Kootznahoo Inlet is a narrow, shallow channel just north of the city of Angoon as shown in Figure 34. The estimated location of the current station is marked by the red cross[9]. There is a very nearby load in Angoon.

[9] NOAA reference coordinates place the current station on land in Angoon. The assumption is that the current station is actually located in the constricted channel due north.

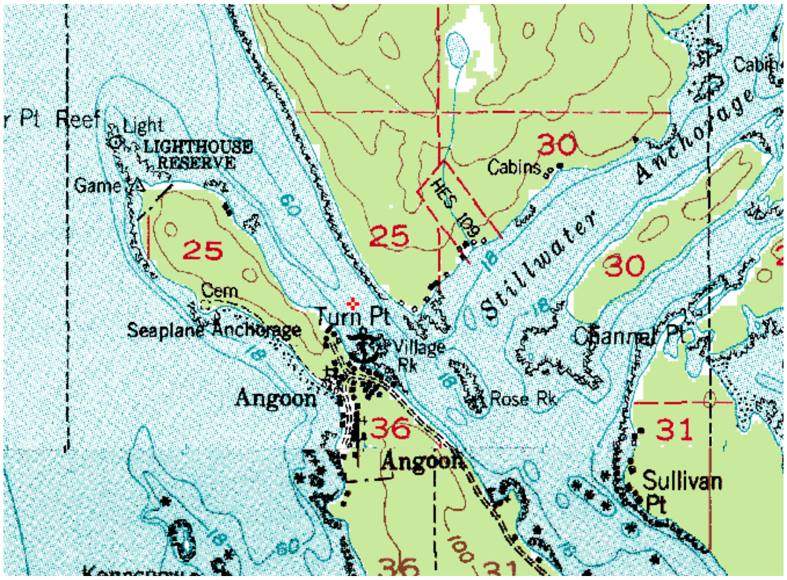

Figure 34 – Kootznahoo Inlet (Source: Topozone)

Site parameters for Kootznahoo Inlet are summarized in Table 17. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station. Kootznahoo Inlet has not been the subject of any modern bathymetric surveys and so channel width and average depth are estimated from a navigational chart (NOAA 17339). Additionally, the inlet is part of the Alaska Marine Highway and a ferry route and so any development of the in-stream resource must not restrict shipping and ferry access.

Table 17 – Kootznahoo Inlet Site Parameters

Site	
Channel Width	230 m
Average Depth (MLLW reference)	12 m
Average Cross-sectional Area	3100 m^2
Maximum Surface Current	5.5 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	7.4 kW/m^2
Average Power Available	23 MW

Being so close to a remote location, this site offers strong potential for distributed generation in the near-term. A representative plot of channel power over a tidal cycle is given in Figure 35.

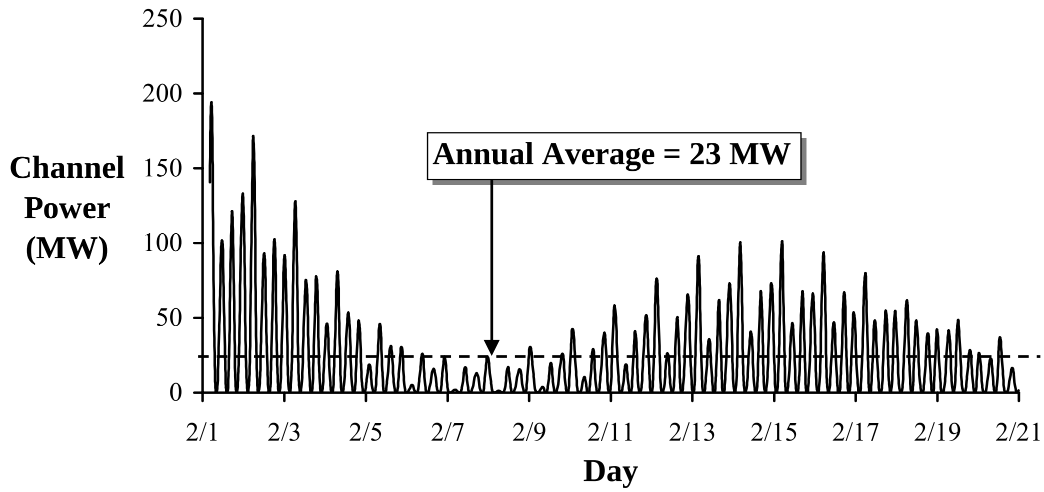

Figure 35 – Tidal Cycle Channel Power Variation in Kootznahoo Inlet (2006)

Monthly averaged channel power is shown in Figure 36.

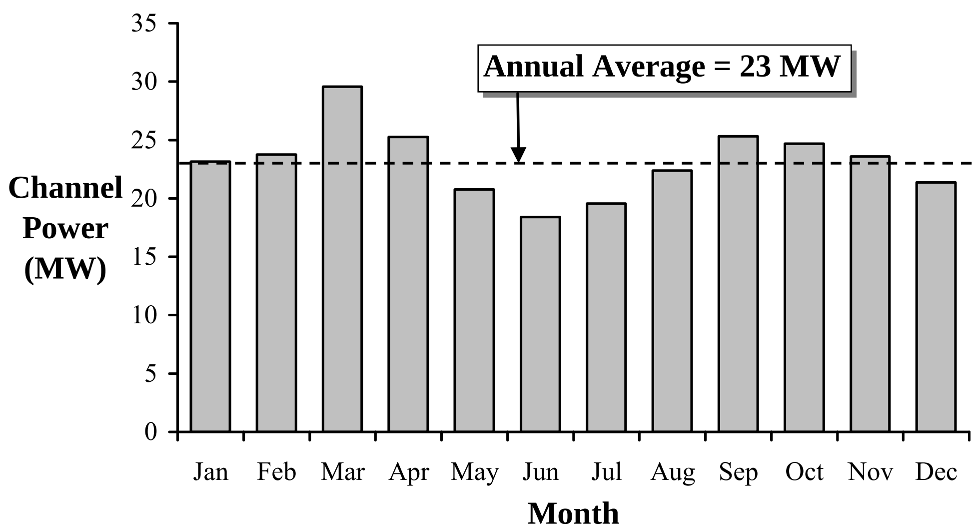

Figure 36 – Monthly Average Channel Power in Kootznahoo Inlet (2006)

In addition to the identified resource at Turn Point, the Coast Pilot, a publication of NOAA, comments on strong currents in a number of locations. Particularly, currents as strong as or stronger than those at Turn Point, are mentioned at Point Bridge and Passage Point. The Coast Pilot mentions considerable swirling and boiling in the water at these locations which is indicative of strong eddies. This extreme turbulence may be incompatible with in-stream turbines.

Data Quality

Data quality creates a significant source of potential error in the assessment of Kootznahoo Inlet. As previously noted, there are no modern bathymetric surveys of the channel. While the channel cross-section has been estimated from depths shown on navigation charts, the data underlying these charts is also likely quite old. The entire inlet area is currently listed as a critical survey need by the NOAA coastal survey group. The current station, which is referenced to Wrangell Narrows, roughly 70 miles to the southwest, has a reference coordinate inland of Turn Point. This combination of poor bathymetric data and uncertain current information increases the uncertainty associated with this resource assessment. Data sources are summarized in Table 18.

Table 18 – Kootznahoo Inlet Data Sources

Data	Latitude	Longitude	Name
Current	N 57°30.4’	W 134°34.8’	Turn Point, Kootznahoo Inlet
Range	N 57°32’	W 134°24’	Mitchell Bay
Bathymetry			NOAA Chart 17339

6. Peril Strait

Peril Strait separates Chichagof and Baranof Islands. In general, currents are quite slow, but at the southern end of the Sergius Narrows, the constriction produces a region of locally high velocity. An aerial map of the Peril Strait region is shown in Figure 20. The nearest load is Sitka, which currently derives all of its power from conventional hydroelectricity.

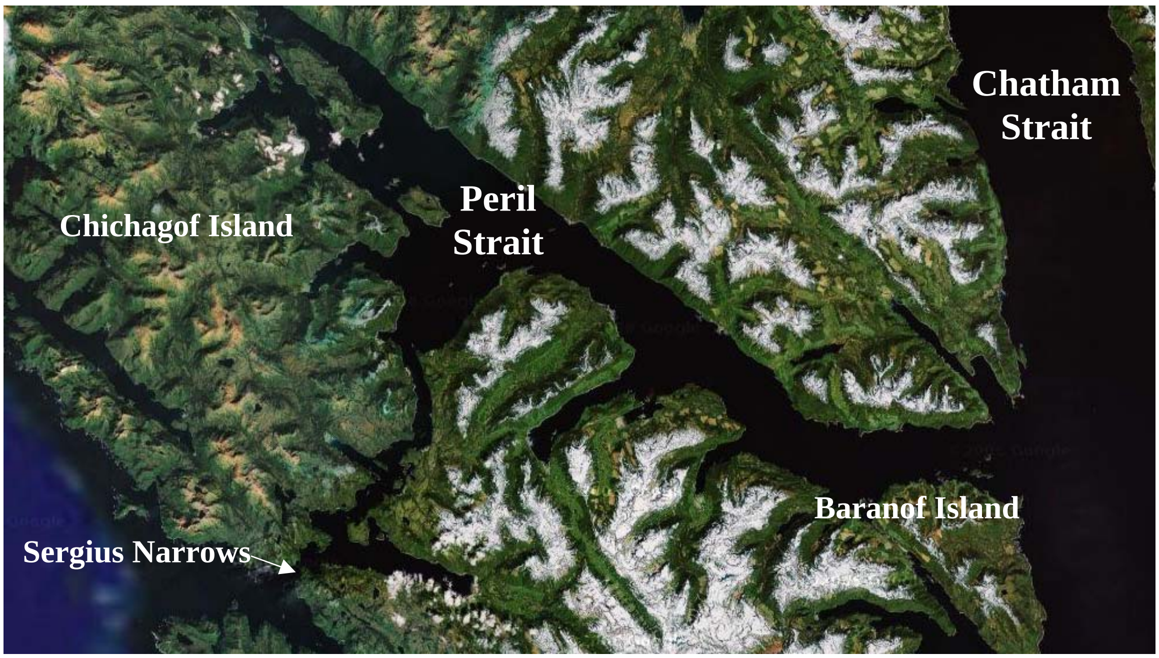

Figure 37 – Peril Strait (Source: Google Maps)

6.1 Sergius Narrows

The Sergius Narrows is a shallow channel connecting the Salisbury Sound to the Peril Strait. The most constricted section of the channel is at the southern terminus, as shown in Figure 38.

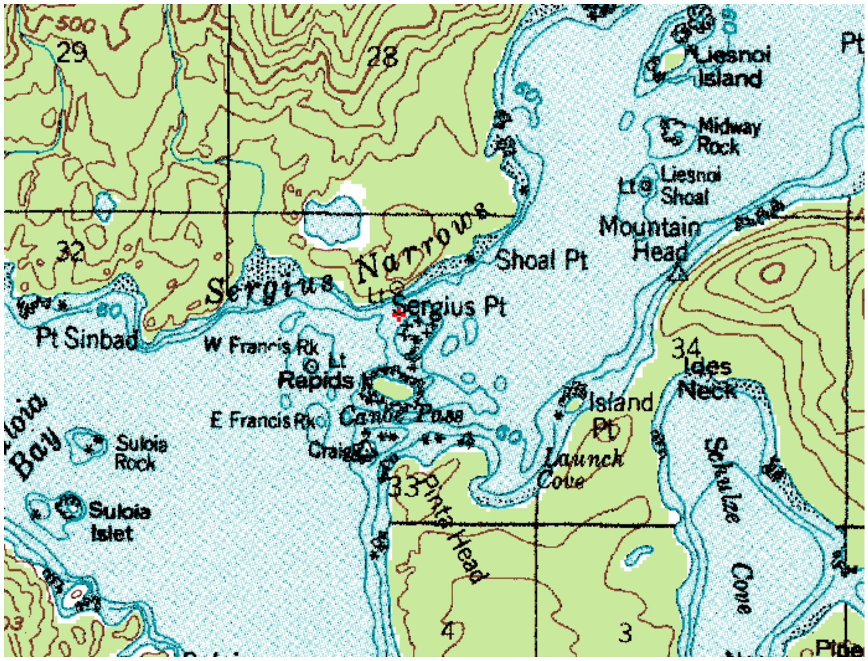

Figure 38 – Sergius Narrows (Source: Topozone)

Bathymetry for the Sergius Narrows and the location and power density of the current station are shown in Figure 39.

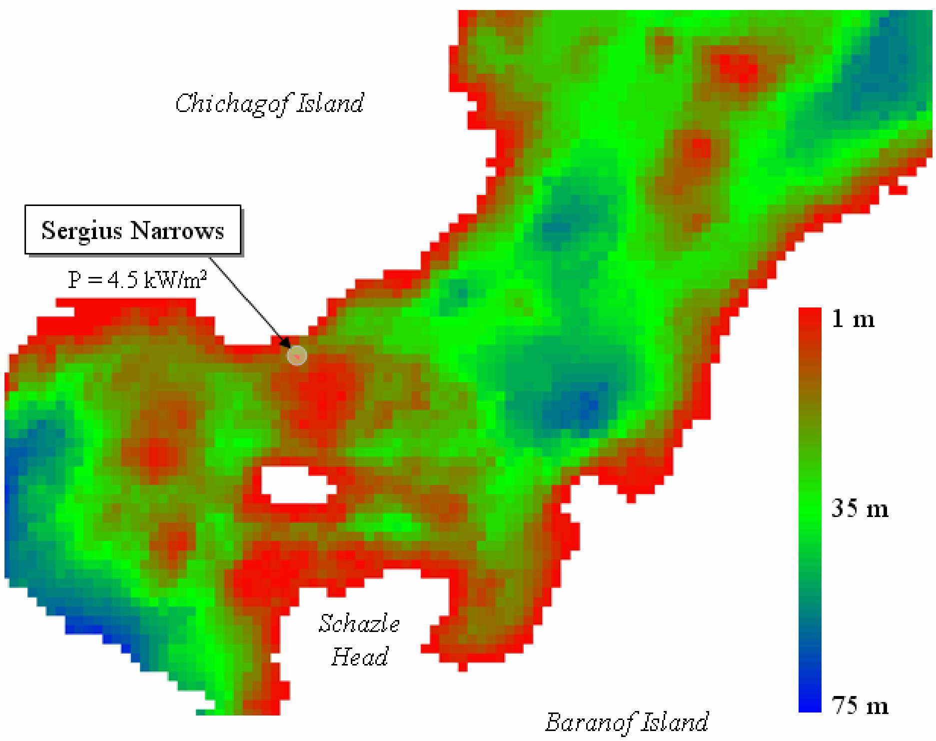

Figure 39 – Sergius Narrows Bathymetry and Current Stations

Site parameters for Sergius Narrows are summarized in Table 19. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station. The channel is part of the Alaska Marine Highway and a ferry route and so any development of the in-stream resource must not restrict shipping and ferry access.

Table 19 – Sergius Narrows Site Parameters

Site	
Channel Width	420 m
Average Depth (MLLW reference)	11m
Deepest Point	19 m
Average Cross-sectional Area	5600 m^2
Maximum Surface Current	4.8 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	4.5 kW/m^2
Average Power Available	25 MW

A representative plot of channel power over a tidal cycle is given in Figure 40.

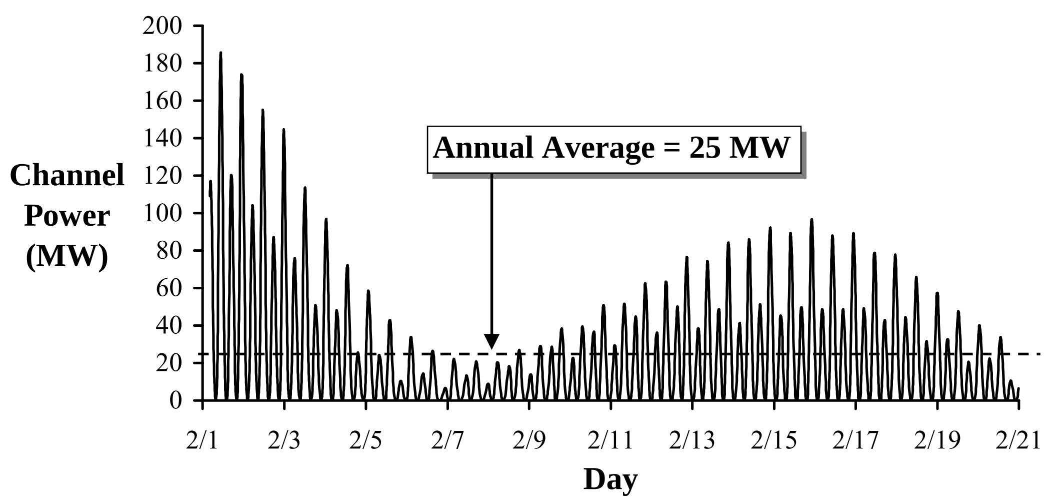

Figure 40 – Tidal Cycle Channel Power Variation in Sergius Narrows (2006)

Monthly averaged channel power is shown in Figure 41.

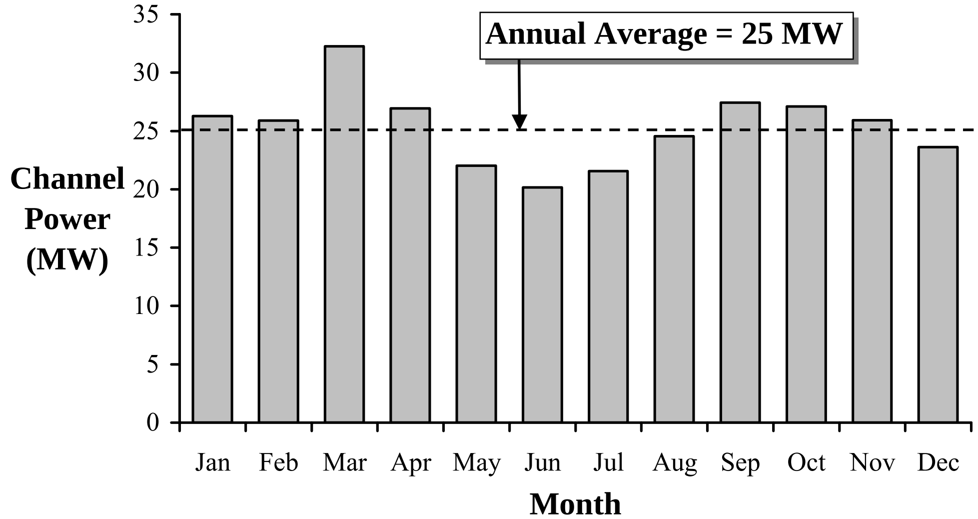

Figure 41 – Monthly Average Channel Power in Sergius Narrows (2006)

Data Quality

Data quality is excellent for the Sergius Narrows. Current data is provided by a primary reference station with multiple depth readings that confirm a blunt vertical velocity profile. A bathymetric survey was carried out in 1951 and 10m resolution data is available in some areas from more recent surveys. Data sources are summarized in Table 20.

Table 20 – Sergius Narrows Data Sources

Data	Latitude	Longitude	Name
Current	N 57°24.4'	W 135°37.9'	Sergius Narrows
Range	N 57°25'	W 135°38'	Sergius Narrows
Bathymetry			H07930, H07931

7. Prince of Wales Island

Prince of Wales Island is the largest southwestern island in the southeast of Alaska. The coastline is serrated by many channels and inlets. Two with particularly high currents within reasonable distance to a load in Craig are the Tonowek and Tlevak Narrows as shown in Figure 42.

Figure 42 – Prince of Wales Island (Source: Google Maps)

7.1 Tlevak Narrows

The Tlevak Narrows is a shallow, narrow channel between Dall Island and Prince of Wales Island. The highest currents are achieved in the narrow strait between Block Island and the northern headland of Dall Island, as shown in Figure 43. The nearest electrical load is in Craig, approximately 50 km to the north.

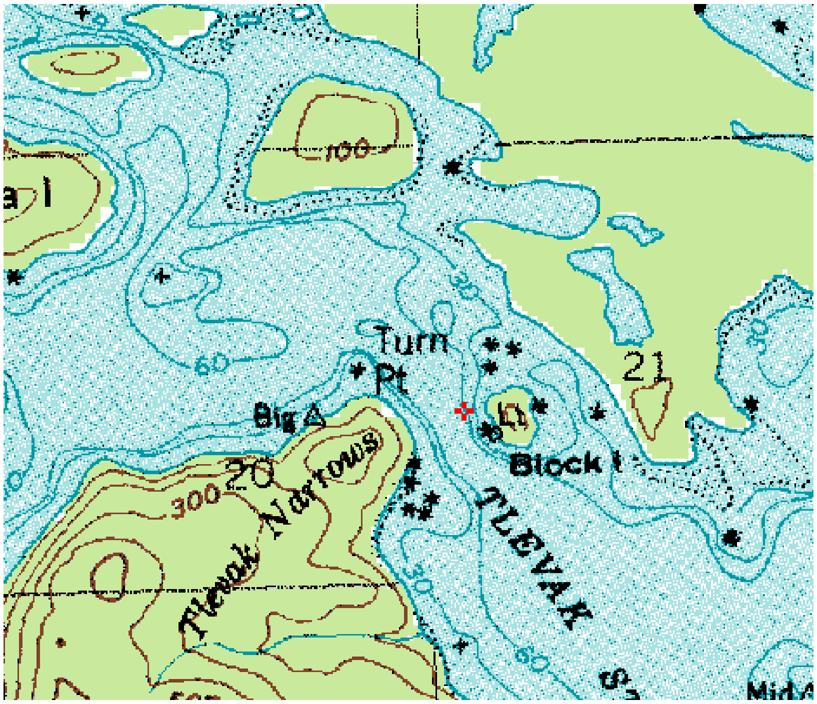

Figure 43 – Tlevak Narrows (Source: Topozone)

Bathymetry for the Tlevak Narrows and the location and power density of the current station are shown in Figure 44. To either side of Turn Point, the channel widens and deepens, which will give rise to slower currents. The reference current station is located to the northwest of Block Island. Further south, directly west of Block Island, the channel cross-sectional area decreases further and currents may be higher. Channel depth is moderate, averaging about 20m.

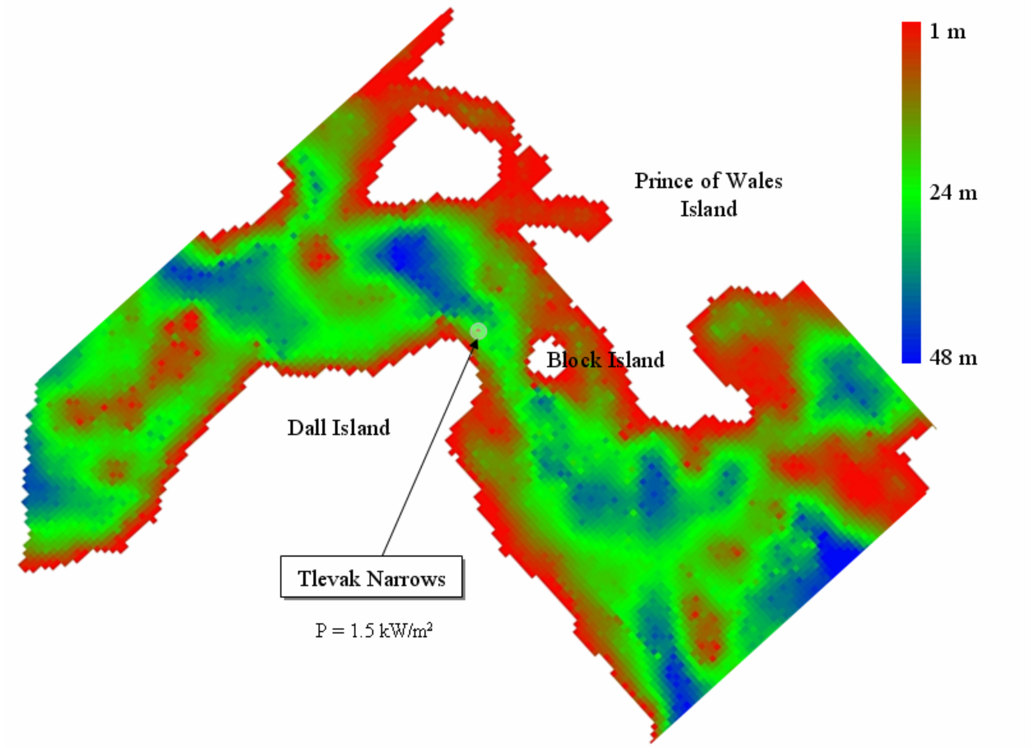

Figure 44 – Tlevak Narrows Bathymetry and Current Stations

Site parameters for Tlevak Narrows are summarized in Table 21. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station.

Table 21 – Tlevak Narrows Site Parameters

Site	
Channel Width	600 m
Average Depth (MLLW reference)	18 m
Deepest Point	31 m
Average Cross-sectional Area	12,000 m^2
Maximum Surface Current	3.7 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	1.5 kW/m^2
Average Power Available	18 MW

A representative plot of channel power over a tidal cycle is given in Figure 45.

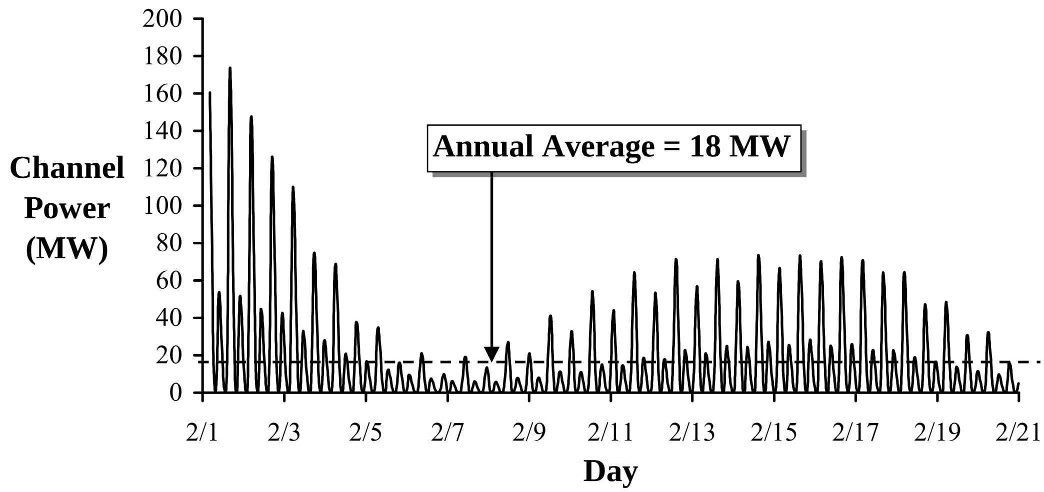

Figure 45 – Tidal Cycle Channel Power Variation in Tlevak Narrows (2006)

Monthly averaged channel power is shown in Figure 46.

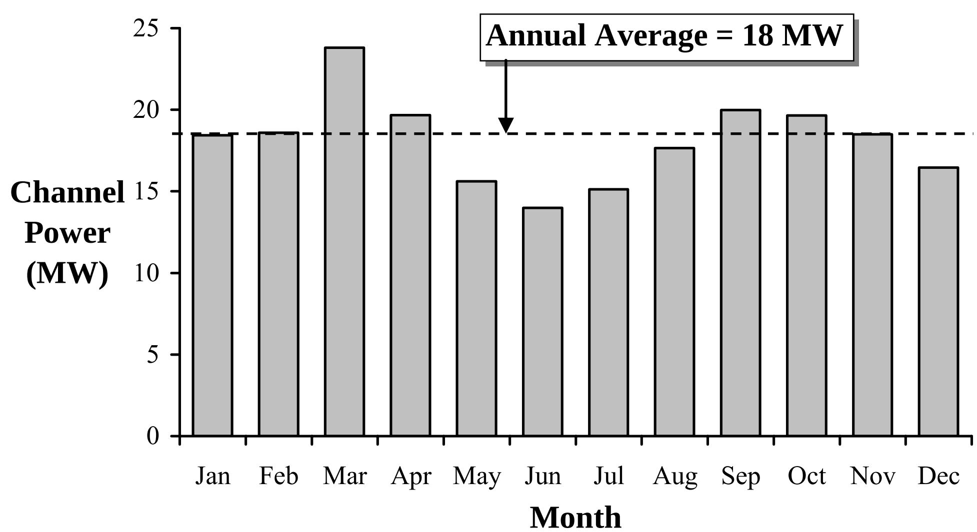

Figure 46 – Monthly Average Channel Power in Tlevak Narrows (2006)

Data Quality

Data quality is good for the Tlevak Narrows. Current data is provided by a secondary reference station, which is referenced to the Sergius Narrows, far to the north. Since both points are along the coast, the extrapolation is broadly justified. A bathymetric survey was carried out in the late 1950's and provides excellent coverage in the region of interest. The headland at Turn Point may generate large eddies, which would be disruptive to turbine operation. The potential for this sort of deleterious flow feature should be explored in a full feasibility study. Data sources are summarized in Table 22.

Table 22 – Tlevak Narrows Data Sources

Data	Latitude	Longitude	Name
Current	N 55°15.9'	W 133°7.3'	Tlevak Narrows, Turn Point, east of
Range	N 55°16'	W 133°7'	Tlevak Narrows
Bathymetry			H08457, H08458

7.2 Tonowek Narrows

The Tonowek Narrows is a shallow, narrow channel between Hecta Island and Prince of Wales Island. The highest currents occur in the narrow strait between Hecta and a headland of Prince of Wales Island, as shown in Figure 47.

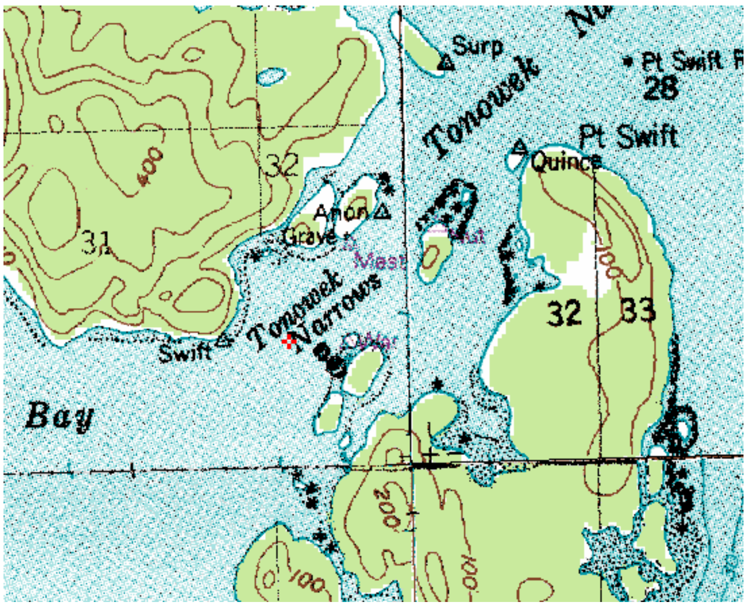

Figure 47 – Tonowek Narrows (Source: Topozone)

Bathymetry for the Tonowek Narrows and the location and power density of the current station are shown in Figure 48. Like the Tlevak Narrows, channel depth is moderate, averaging about 20m. However, the channel depth ranges from approximately 30m on the northwest side, to less than 10m on the southeast, so it is questionable whether or not the predicted currents are representative over the entire channel cross-section. Power densities are quite low compared to other sites in the Alaskan southeast. Since the nearest load is Craig, transmission line construction to harness a marginal resource would be difficult to justify.

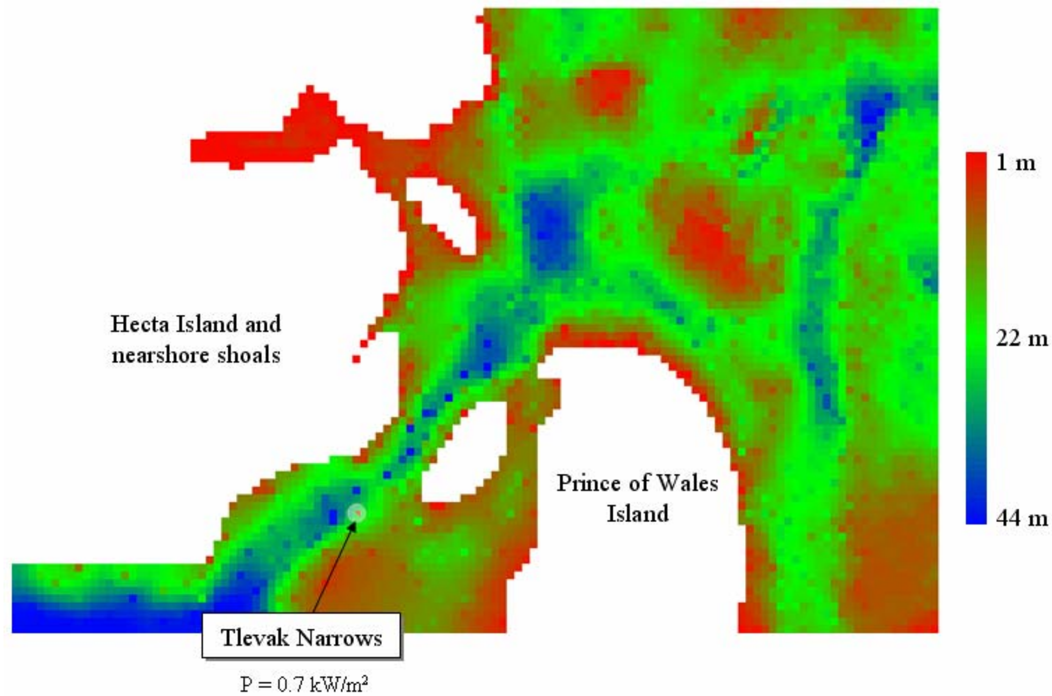

Figure 48 – Tonowek Narrows Bathymetry and Current Stations

Site parameters for the Tonowek Narrows are summarized in Table 23. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station.

Table 23 – Tonowek Narrows Site Parameters

Site	
Channel Width	750 m
Average Depth (MLLW reference)	18 m
Deepest Point	34 m
Average Cross-sectional Area	15,000 m^2
Maximum Surface Current	2.4 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	0.7 kW/m^2
Average Power Available	11 MW

A representative plot of channel power over a tidal cycle is given in Figure 49.

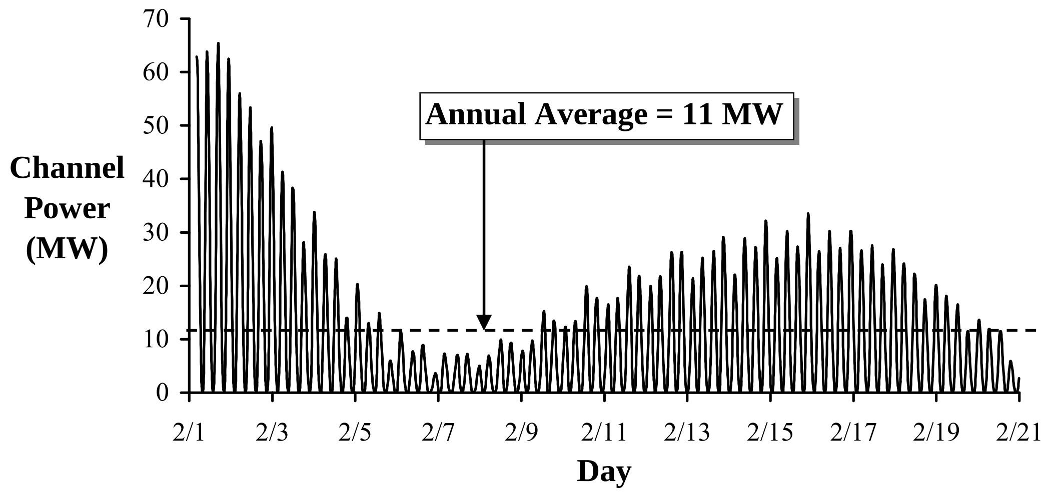

Figure 49 – Tidal Cycle Channel Power Variation in Tonowek Narrows (2006)

Monthly averaged channel power is shown in Figure 50.

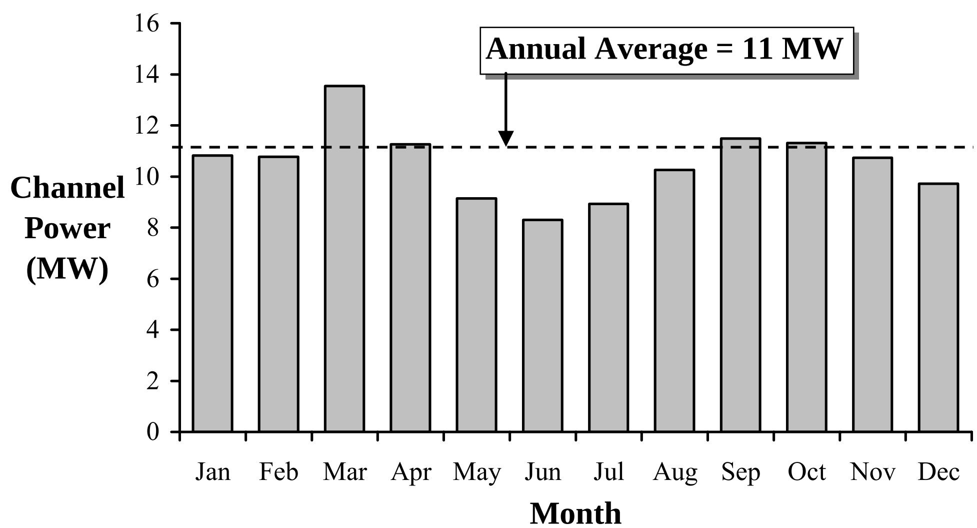

Figure 50 – Monthly Average Channel Power in Tonowek Narrows (2006)

Data Quality

Data quality is moderate for the Tonowek Narrows. Current data is provided by a secondary reference station, which is referenced to the Sergius Narrows, far to the north. Since both points are along the coast, the extrapolation appears to be broadly justified. No modern bathymetric surveys have been carried out in the narrows proper and bathymetric coverage from a survey early in the 1900's is incomplete and required significant interpolation to estimate the channel cross-section. Data sources are summarized in Table 24.

Table 24 – Tonowek Narrows Data Sources

Data	Latitude	Longitude	Name
Current	N 55°45.4'	W 133°20.4'	Tonowek Narrows
Range	N 55°44'	W 133°30'	Warm Chuck Inlet, Tonowek Bay
Bathymetry			H08036, H08392

8. Felice Strait

The Felice Strait separates Annette and Duke Islands at the southern end of southeast Alaska, just north of the border with British Columbia. Currents are of moderate strength throughout the strait, but several locations with high currents are noted in the NOAA predictions: Harris Island, Snipe Island, and Indian Reef. The nearest load to these sites is Metlakatla, on the west side of Annette Island. An aerial map of the region is shown in Figure 51.

Figure 51 – Felice Strait (Source: Google Maps)

While the current predictions indicate a number of sites with moderate power densities, investigation of site bathymetry indicates that none of these sites are really viable for commercial development. In the above cases, regions of high currents are associated with shallow reefs and islands, and these localized "hot spots" are either in water too shallow for commercial development or occupy a very small surface area.

8.1 Harris Island

Harris Island is separated from the larger Hotspur Island by a very narrow and shallow constriction as shown in Figure 52.

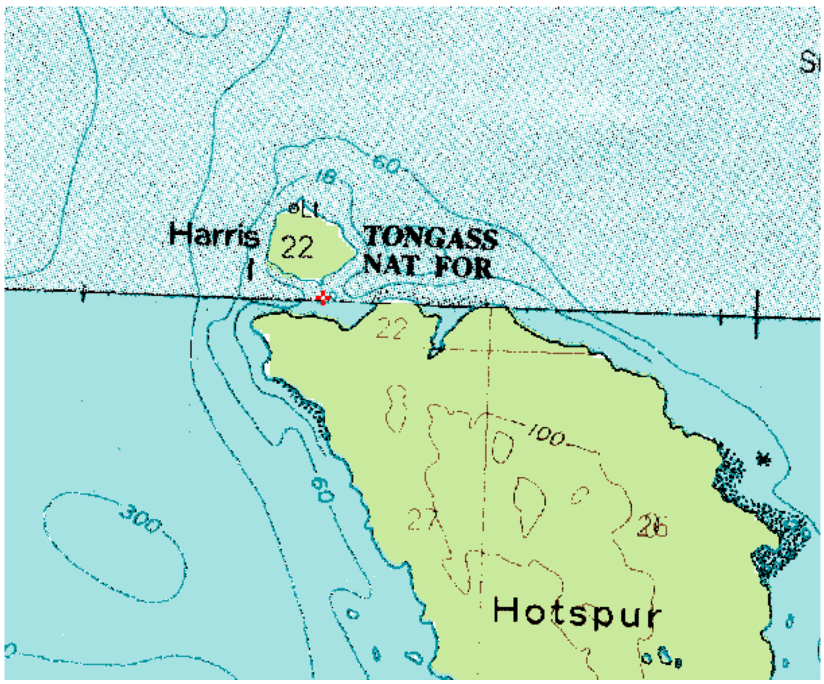

Figure 52 – Harris Island (Source: Topozone)

Bathymetry for the narrows between Harris and Hotspur Island and the location and power densities of regional current stations are shown in Figure 53. Outside of this constriction, power densities are too low for practical extraction of kinetic power with first generation turbines. The channel is very shallow (~1m) and narrow (~60m).

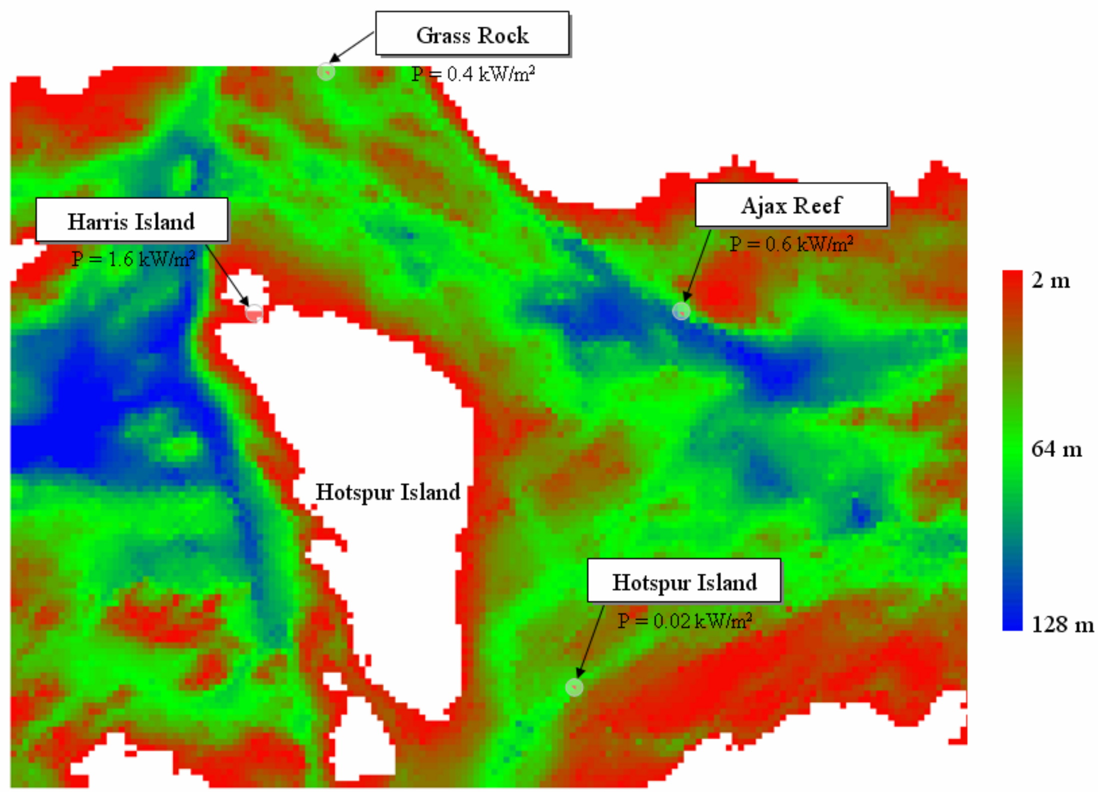

Figure 53 – Harris Island Bathymetry and Current Stations

Site parameters for Harris Island are summarized in Table 25. Channel cross-sectional area and depth are for a transect perpendicular to the flow direction running through the current reference station. The extremely shallow depth and high tidal range in the Felice Strait means that the channel will be exposed at Lowest Astronomical Tide (LAT). As a result, any turbines deployed here would have to be very short and would spend a significant amount of time each year exposed to the highly corrosive spray zone near the waterline. Given the size of the resource, even if this site were to be developed, it would not be suitable for powering more than a few homes.

Table 25 – Harris Island Site Parameters

Site	
Channel Width	60 m
Average Depth (MLLW reference)	1 m
Deepest Point	N/A
Average Cross-sectional Area	60 m^2
Maximum Surface Current	3.4 m/s
Tidal Energy Statistics	
Depth Averaged Power Density	1.6 kW/m^2
Average Power Available	300 kW

Data Quality

Data quality is moderate for Harris Island. Current data is provided by a secondary reference station, which is referenced to the Wrangell Narrows, far to the north. The presence of several other stations in the area confirms that localized high velocity currents are confined to the channel. A bathymetric survey was carried out in the 1970's but coverage is poor within the channel itself owing to the very shallow water. Data sources are summarized in Table 26.

Table 26 – Harris Island Data Sources

Data	Latitude	Longitude	Name
Current	N 55°0'	W 131°32'	Harris Island
Range	N 55°06'	W 131°12'	Mary Island Anchorage
Bathymetry			H03781, H04158, H09146, H09184, H09370

8.2 Snipe Island

Snipe Island is a tiny island centered on shallow area within the Felice Strait, as shown in Figure 54. The presence of a current station with very low velocities about 2 km to the west indicates that the currents reported around Snipe Island are not representative of the entire cross-section of Felice Strait, but are rather highly localized. The current reference station, marked by the red cross in Figure 54, has an estimated of power density of 1.6 kW/m^2.

Figure 54 – Snipe Island (Source: Topozone)

Given the small cross-sectional area through which the currents pass and the distance to a major load, no further analysis of the resource has been conducted for this site. There is, however, potential for a micro-generation project to power the Snipe Island light.

Data Quality

Data quality is moderate for Snipe Island. Current data is provided by a secondary reference station, which is referenced to the Sergius Narrows, far to the north. No modern bathymetric surveys have been carried out in this area, so the depth and cross-sectional area of the high current region obtain from navigational charts are of questionable accuracy.

8.3 Indian Reef

Indian Reef is a small, shallow region of water on the east side of Annette Island, as shown in Figure 55. The presence of two current stations with very low velocities in close proximity indicates that the currents reported around Indian Reef are not representative of the entire cross-section of Felice Strait. The current reference station, marked by the red cross in Figure 54, has a power density of 1.1 kW/m^2.

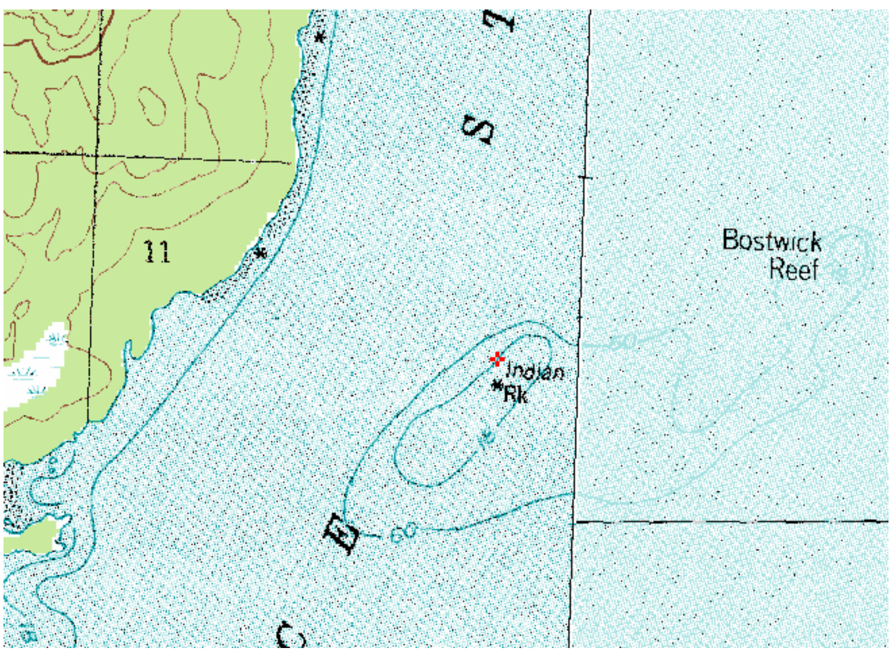

Figure 55 – Indian Reef (Source: Topozone)

Given the small cross-sectional area through which the currents pass and the distance to a load, no further analysis of the resource has been conducted for this site.

Data Quality

Data quality is moderate for Indian Reef. Current data is provided by a secondary reference station, which is referenced to the Sergius Narrows, far to the north. No modern bathymetric surveys have been carried out in this area, so the depth and cross-sectional area of the high current region obtain from navigational charts are of questionable accuracy.

9. Conclusion and Recommendations

A number of in-stream tidal sites have been identified in the southeast of Alaska. There is potential for both distributed and utility-scale power generation.

The Cross Sound and Icy Strait show a massive energy potential, more that enough to meet the region's energy needs and enough to allow export of valuable green energy to Canada and the Pacific Northwest. In addition, high quality (strong power density) small (low average annual power) sites, such as Angoon (Kootznahoo Inlet) and Elfin Cove (Cross Sound), could provide power for remote locations.

This assessment points to several pieces of work which would be key next steps in the ongoing process of site development.

1. *Site feasibility and economic assessment.* Building off this resource study, a feasibility study identifying key issues to array build-out and a baseline economic assessment should be conducted for the most promising sites. Site geology, electrical interconnection, local environmental concerns, and multiple-use issues should be fully explored. EPRI would be well-positioned to carry out this work given its recent feasibility assessment of the North American in-stream resource and ongoing assessments of first-generation tidal energy projects.

2. *Detailed resource study.* Given the significant uncertainty associated with the resource estimates at some of the larger sites (e.g. Cross Sound), more detailed current profiling would help to further quantify the available and extractable resource, as well as lay the groundwork for turbine micro-siting. A detailed resource study would include both numerical calculations and field measurements (e.g. Acoustic Doppler Current Profiling).

References

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