Canada Ocean Energy Atlas (Phase 1)

Potential Tidal Current Energy Resources

Analysis Background

May 2006

Prepared For:
Canadian Hydraulics Centre, Ottawa, Ontario as part of a contract for Natural Resources Canada

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1. INTRODUCTION

This report provides an analysis background to a preliminary tidal current resource inventory for Canadian waters completed for Phase 1 of the Canada Ocean Energy Atlas Project.

The estimated tidal current energy for Canada is the total potential resource available in tidal flows. The estimates are “potential” resources NOT “economically realisable” resources. At this early stage of the Ocean Atlas development, energy calculations are based on preliminary estimates of existing tidal flows and no consideration has been given to the following factors:

- Environmental Impacts
- Technological developments and limitations in tidal power extraction
- Climate related factors (e.g., ice, global climate change)
- Site location versus power grid accessibility and power demand
- Hydrogen economy developments
- The effect of potential energy extraction schemes on existing flow conditions
- Economic factors.

Mean vs Rated Site and Turbine Capacity

There may be some potential for confusion when comparing the power values referenced in this study with those of conventional thermal or hydroelectric generating facilities with which the public is most familiar. With conventional power generation, reference is usually made to the rated power of the facility which is the value stamped on the manufacturer’s nameplate. It is generally the goal of conventional facility owners to operate the facility near this rated capacity. Moreover, the day-to-day variability of conventional energy resources is relatively minor which allows these facilities to operate near their rated capacity for relatively continuous periods of time. This means that rated capacity is generally a good first approximation to the actual power production of a conventional power plant.

For wind power it is often the case that wind farm capacities are quoted in turbine rated capacity rather than the more realistic mean annual power potential. Wind power is much more temporally variable and uncertain than tidal power, but both these sources of renewable energy peak for quite short periods.

In the case of tidal current energy extraction, the resource potential goes to zero two to four times per day and reaches its peak annual value for only a few hours per year. For this reason, it is much more instructive to speak of *mean power* in the context of tidal power as such a definition integrates the effect of the highly variable daily and annual variation of the resource. The Mean Potential Power detailed in this report can be converted to megaWatt.hours per year by multiplying the mean power (MW) by 8,760 (the number of hours in a year).

2. DATA SOURCES

Triton has undertaken a preliminary tidal resource inventory for Canadian marine waters including the East and West Coasts and Arctic Canada. This inventory was based on a variety of data sources including:

- Canadian Sailing Directions;
- Nautical Charts and Tide Books;
- Tide and tidal current constituent data;
- Numerical Tidal modelling data

Data from these data sources has been assembled into a database and documented in spreadsheet tables and in the GIS program Manifold (www.manifold.net) for data viewing and interpretation by the study team.

2.1 NAUTICAL AND BATHYMETRIC INFORMATION

Nautical data including Canadian Sailing Directions and tide books were purchased for the whole of Canada and reviewed in detail. In addition, all the available electronic nautical charts, a total of 489 charts, were purchased from Nautical Data International (NDI), St. John's, Newfoundland in raster format and areas of potential tidal current resource were identified.

The Canadian Hydrographic Service has a total of 950 nautical charts for all regions of Canada. Deducting approximately 250 charts for the Great Lakes, St. Lawrence River and Mackenzie River systems and interior British Columbia, there are about 700 charts relevant to this study. Therefore, 70% of Canadian (saltwater) Marine Charts are presently available in electronic raster format. A majority of the non-electronic charts are for areas such as Hudson Bay and Strait, Ungava Bay and the Arctic Regions.

Paper copies of the non-electronic charts were reviewed from Triton's own chart database and at the map library at the University of British Columbia.

Table 1 and Table 2 below show the Canadian Sailing Directions and Tide and Current books used for this study.

Table 1: Canadian Sailing Directions

Number	Description
P100	Arctic Canada, Vol. 1, 1994
P102	Arctic Canada, Vol. 2, 1985
P104	Arctic Canada, Vol. 3, 1994
P112	Labrador & Hudson Bay, 1988
P118	BC (S. Portion), Vol. 1, 2004
P120	Great Slave Lake & Mackenzie River, 1989
P122	Gulf of St. Lawrence, 1992
ATL100E	Atlantic Coast, General Information 1992
ATL101E	Newfoundland, Northeast & East Coasts
ATL102E	Newfoundland, East and South Coasts
ATL103E	Newfoundland, Southwest Coast
ATL104E	Cape North to Cape Canso
ATL105E	Cape Canso to Cape Sable
ATL106E	Gulf of Maine and Bay of Fundy, 2001
ATL107E	St. John River, 1994
ATL110E	St. Lawrence River, Cap Whittle/
ATL111E	St. Lawrence River/Île Verte to Québec, 1999
ATL112E	St. Lawrence River/Cap-Rouge to Montréal
ATL120E	Labrador, Camp Islands to Hamilton Inlet
ATL121E	Labrador, Hamilton Inlet to Cape Chidley
Volume 1 Pacific	British Columbia South 1987
Volume 11 Pacific	British Columbia North 1987

Table 2: Canadian Tide and Current Tables

Volume	Description
Vol 1	Atlantic Coast and Bay of Fundy / Côte de l'Atlantique et baie de Fundy, 2006
Vol 2	Gulf of St. Lawrence / Golfe du Saint-Laurent, 2006
Vol 3	St. Lawrence and Saguenay Rivers / Fleuve Saint-Laurent et rivière Saguenay, 2006
Vol 4	Arctic and Hudson Bay / L'Arctique et la baie d'Hudson, 2006
Vol 5	Juan de Fuca Strait & Strait of Georgia / Détroits de Juan de Fuca et de Georgia, 2006
Vol 6	Discovery Passage & West Coast of Vancouver Island / Discovery Passage et côte Ouest de l'île de Vancouver, 2006
Vol 7	Queen Charlotte Sound to Dixon Entrance / Queen Charlotte Sound à Dixon Entrance, 2006

2.2 TIDAL CONSTITUENT DATABASE

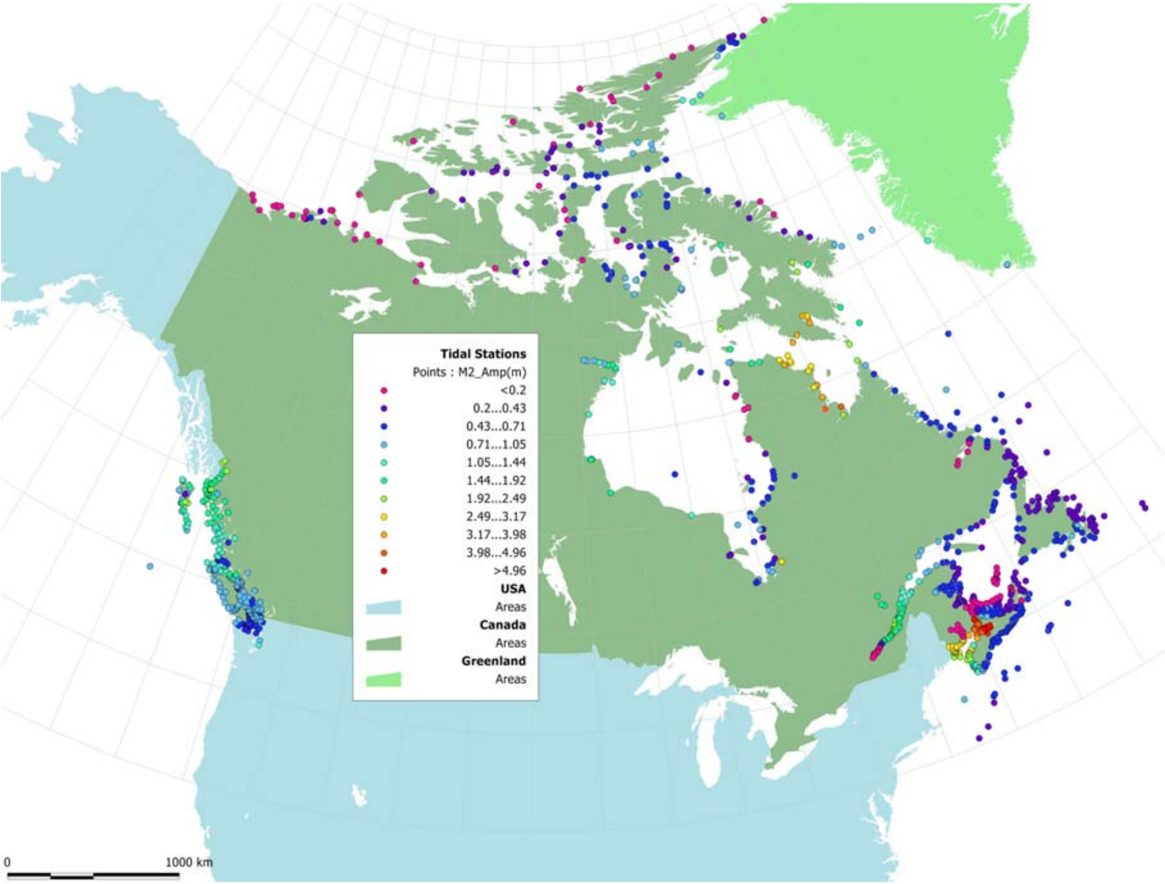
The Canadian Hydrographic Service maintains a database of more than 1030 tidal station constituent files. These tidal (height) constituent files are based on recorded water levels and are used to calculate the tidal heights each year for the CHS Tide and Currents Tables. Because of the practical difficulties of measuring tidal currents, the number of verified tidal current stations available for Canada is quite small (probably less than 50). The Pacific Coast is by far the best serviced area in the country, with a total of 24 stations with current constituents. On the Atlantic Coast there are only two current sites in the Tide and Current tables and these sites are in low current areas of the Bay of Fundy.

It is understood from scientists at the Bedford Institute of Oceanography that many current measurements have been recorded in the Atlantic Region but these have never been assembled into a verified database. CHS headquarters in Ottawa is presently in discussions with their regional offices to agree to a framework for assembling all the current measurement data for Canada.

Figure 1 shows the location of tidal height stations in Canada. The colour of the “dots” indicates the amplitude of the semi-diurnal (twice a day) M2 tidal constituent which gives a good indication of relative tidal range except in places like Juan de Fuca Strait and the Strait of Georgia (Pacific Coast) where the diurnal (once a day) component is also important.

A general overview of the physics of tides and tidal constituents is given in Section 3.1 for reference.

Figure 1: Tidal Stations in Canada



2.3 TIDAL MODELLING

Data from numerical tidal models of Canadian Waters was used to provide additional information for the tidal current power assessment. The finite element models used by Triton for this study are shown in Table 3.

Table 3: Tidal Models

Model Region	Model Grid Source	Number of Model Calculation Nodes	Notes
British Columbia South	Triton & IOS*	132,000	Model run for this study
Queen Charlotte Islands	Triton & IOS*	7,600	Model run for this study
Hudson's Bay Region	Triton & BIO*	45,000	Model run for this study
Gulf of St. Lawrence	Triton & PWGSC*	7,800	Model run for this study
North West Atlantic	BIO/WebTide	17,100	Model results provided by BIO
Arctic	BIO/WebTide	17,400	Model results provided by BIO
Bay of Fundy North	BIO/WebTide	75,000	Model results provided by BIO

*original source of model grid; grid further developed and expanded by Triton.

IOS – Institute of Ocean Sciences, Sidney, BC

BIO – Bedford Institute of Oceanography, Bedford, N.S.

Triton’s finite element harmonic tidal model Tide2D (see appendix for Tide2D data sheet) was used to provide tidal height and current velocities data at each node in the model domains for a varying number of tidal constituents on the model driving boundary.

Purpose-designed code was written to convert Fundy format (BIO) results to Trigrid (IOS) and to compute for both formats the mean tidal power from the calculated current constituents at each node in the model domains. This latter analysis is equivalent to doing a current prediction for each model node for a full year. Mean current power was then estimated from the indicative formula average $\sum (½ \times \rho \times U^3)$. These conversion codes were implemented in Triton’s in-house Coastal Engineering Analysis Package (CEAPack) which is described in the appendix.

The model results (including tide height, current and mean power) were input via CEAPack, into Tecplot (www.tecplot.com) for visualization and analysis. Tecplot allows the user to extract data along cross-section lines. This method was used to estimate potential tidal power at locations where no accurate current measurements are presently available (e.g., Hudson’s Strait, Minas Basin and Discovery Pass).

Figure 2 through Figure 6 show the model domains for a selection of tidal models used for this study with contoured depths in metres.

Figure 2: Hudson Bay Tidal Model Region (depths in metres)

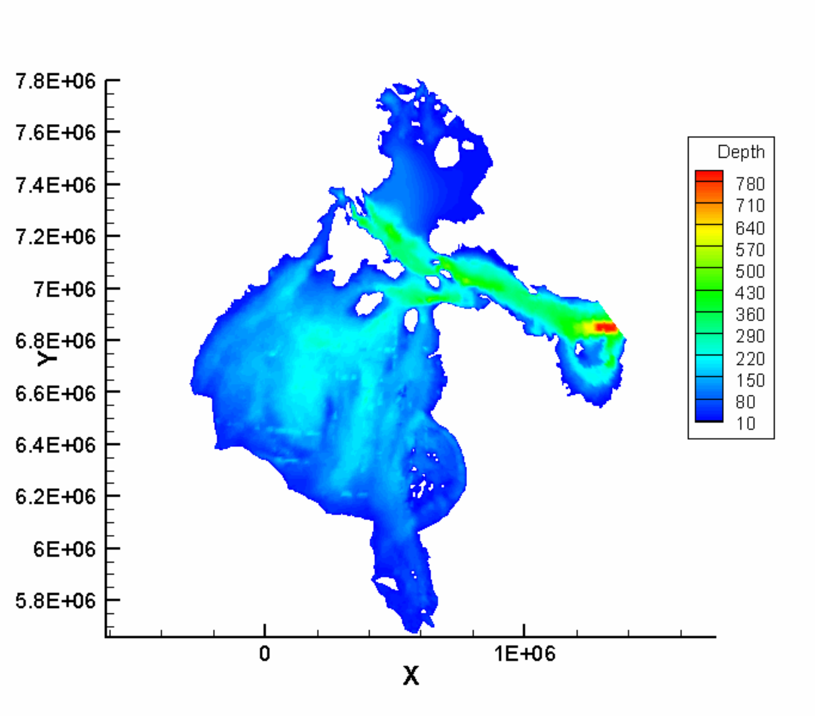


Figure 3: Gulf of St. Lawrence Tidal Model Region (depths in metres)

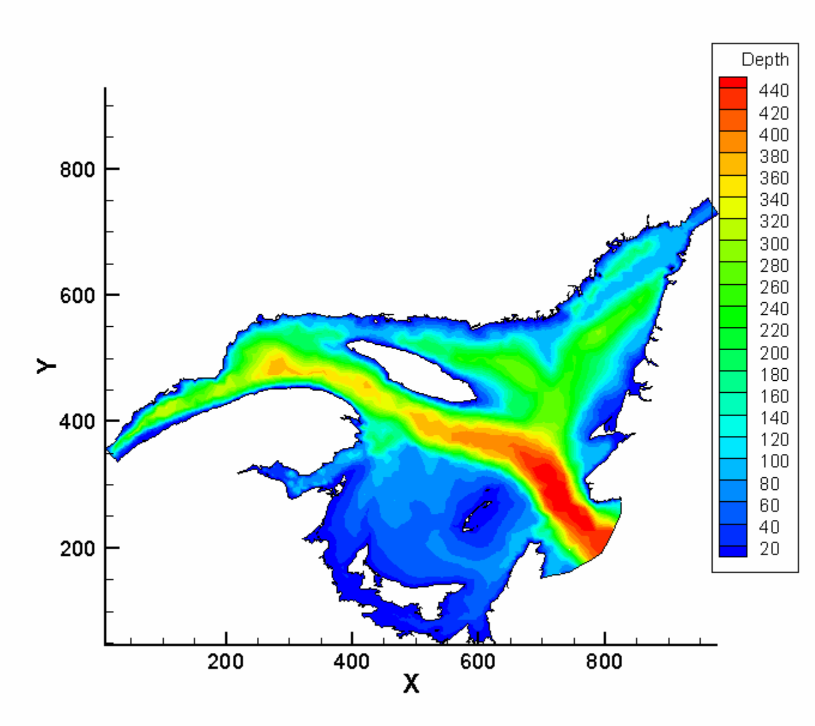


Figure 4: Bay of Fundy North Tidal Model Region (depths in metres)

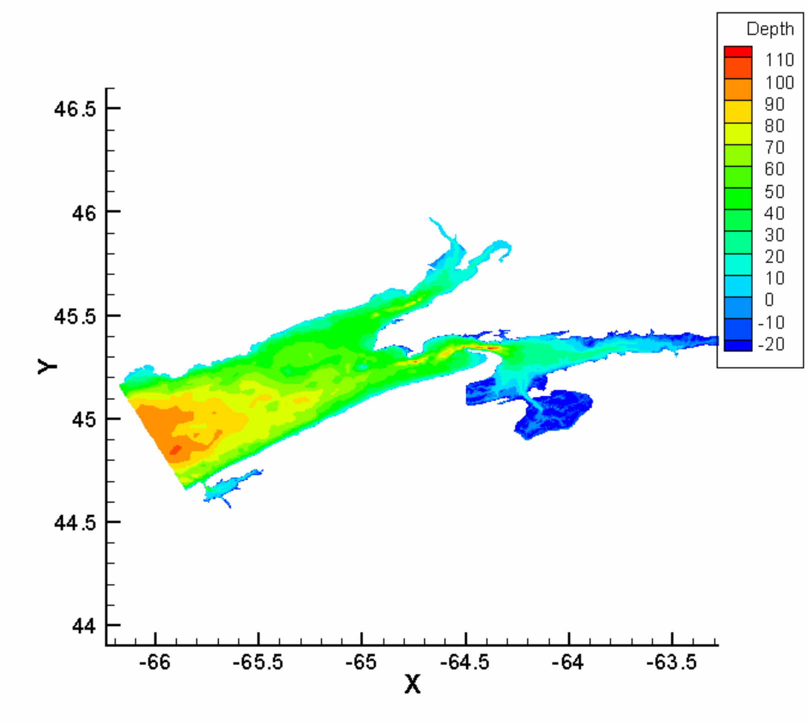


Figure 5: British Columbia Coast South Tidal Model Region (depths in metres)

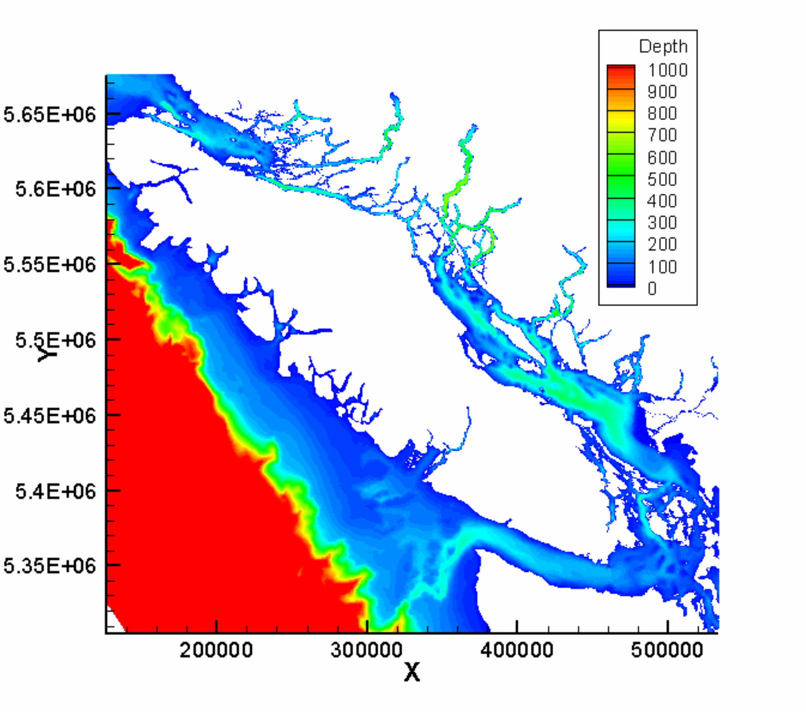
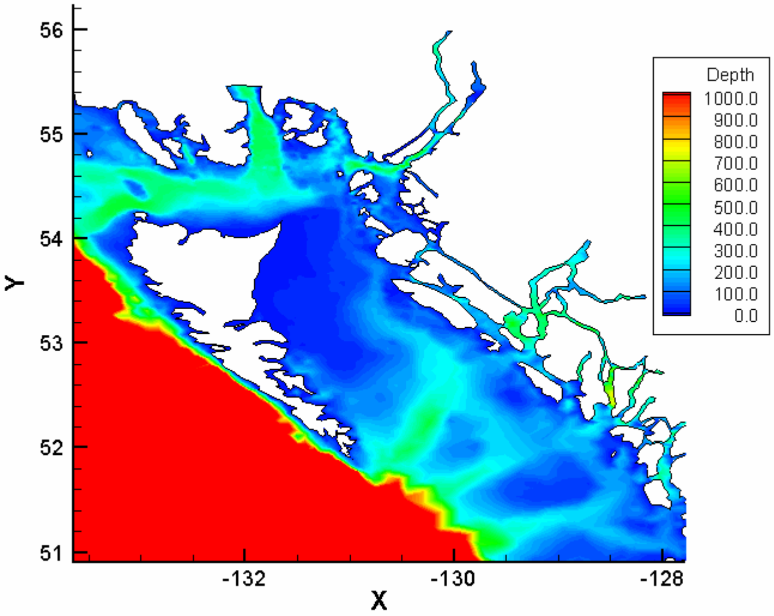


Figure 6: Queen Charlotte Islands Tidal Model Region (depths in metres)



3. ANALYSIS METHODOLOGY

3.1 TIDES AND TIDAL CURRENTS IN CANADA

Tidal current energy is derived from the flow of coastal ocean waters in response to the tides. A background understanding of tides is helpful in understanding this report, therefore a brief description is included below.

Tides and tidal currents are generated by gravitational forces of the sun and moon on the ocean waters of the rotating earth. Because of its proximity to the earth, the moon exerts roughly twice the tide-raising force of the sun. Tides repeat themselves once every 24 hrs and 50 minutes or the lunar day, which is the time it takes a point on the earth to rotate back to the same position relative to the moon during each daily revolution.

The sun's and moon's gravitational forces creates two "bulges" in the earths ocean waters one directly under or closest to the moon and other on the opposite side of the earth. These "bulges" are the two tides a day observed in many places in the world. Unfortunately, this simple concept is complicated by the fact that the earth's axis is tilted at 22.5 degrees to the moons orbit – the two bulges in the ocean are not equal unless the moon is over the equator. This difference in tide height between the two daily tides is called the diurnal inequality or declinational tides and they repeat on a 14 day cycle as the moon rotates around the earth.

Spring and neap tides have been known for many centuries. Spring tides occur at the time of new or full moon when the sun and moon's gravitational pull is aligned. These tides occur at a 15 day cycle and the combination of this cycle and that of the 14 day declinational tidal cycle explains some of the variability of the tides through the months of the year. There are more than a hundred harmonic constituents or cyclic components of the tide each with a different cycle time. These constituents combine so that tides completely repeat themselves every 18.6 years.

Tides move as shallow water waves in ocean and coastal waters. Despite its name a shallow water waves can exist in any depth of water. Their main characteristic is that the whole depth of water moves as the wave passes. This is unlike wind waves which, except in very shallow water near shore, only move the top few tens of metres of the water column. Shallow water waves move at a celerity related to the square root of the water depth which in the open sea can be several hundred kilometres per hour. In the open ocean tides are small, rarely exceeding 0.5 m. However, as the tidal wave enters coastal waters it slows down, shoals (increases in height) and is reflected in coastal basins. This explains how a small deep ocean tide can result in 15 m tides in Minas Basin (Bay of Fundy), 8 m tides at Prince Rupert (Pacific Coast) and 11 m tides in Ungava Bay (Leaf Bay/Lac aux Feuilles) and Iqualuit.

As discussed above, the total tidal wave is made up of components (constituents) with different harmonic periods and amplitudes. The principal semi-diurnal or twice-daily components are M2 (moon, twice daily) and S2 (sun, twice daily) and the principal diurnal or once-daily components are K1 and O1. Like all diurnal components, the K1 and O1 result from the declination of the moon relative to the earth during the monthly tidal cycle. In coastal waters, these different components may resonate in the bays and straits along the coast depending on their wavelength determined by water depth and the size and shape of the basin. This process is much like the slopping of water in a bathtub. For example, the Bay of Fundy is perfectly "tuned" in terms of water depth and shape to the semi-diurnal tide entering at its mouth. In BC, the small diurnal tides at Victoria and the increasing tide range as one moves north in Strait of Georgia result from the “tuning out” of the M2 tide in Juan de Fuca Strait and the resonance or tuning of the M2 tide in Strait of Georgia respectively.

Tidal currents result from the passage of the tidal wave. Contrary to popular belief, large tidal currents do not necessarily require a large tidal range. Some of the largest tidal flows in the world occur between the islands on the east side of the Philippines where the tidal range is small but the tide is high in the Pacific at the same time that the tide is low within the Philippine Islands. In technical terms, this is described as the two tides being 180 degrees (or half a cycle) out of phase; the result is very large tidal currents.

Another factor that impacts the magnitude of tidal currents is the presence of narrow passages; these passages result in a narrowing and concentration of tidal flow. However, the flow through a passage is constrained by the loss of energy due to friction. If this loss exceeds a certain value the flow will start to reduce and, in the case of a tidal inlet, (e.g., Minas Channel, NS and Nakwakto Rapids, BC), the tidal range and resulting flows are reduced. There is clearly a limit to the energy that can be extracted, either by nature (in friction) or harnessed (with a tidal power plant).

In British Columbia, some of the highest velocity tidal current flows in Canada occur through the passages between Strait of Georgia and Johnstone Strait. The tidal range is moderate (5 m), but the tides from the Pacific through Johnstone Strait are roughly 180 degrees out of phase with the tides in Strait of Georgia entering south of Vancouver Island.

From a tidal current perspective, it is also important to understand that semi-diurnal tides produce twice the current of the diurnal tide of the same height. This is because the semi-diurnal tide rises in half the time of the equivalent diurnal tide. This is particularly important in British Columbia where many of the potential tidal current power sites are located in areas where the diurnal tide component is strong. On the other coasts of Canada (Arctic and Atlantic), the semi-diurnal tidal component typically dominates the tidal regime (see Section 3.3)

3.2 THEORETICAL BASIS

In concept, tidal current energy may be viewed as being extracted directly from the kinetic energy of a tidal stream, or as being extracted from the potential[1] energy of impounded tidal water. In reality, the two are closely related since the extraction of kinetic energy from a tidal stream increases the slope of the hydraulic grade line yielding “partially impounded” water on alternating ends of the tidal channel. Figure 7 shows a hypothetical tidal site that will be used to describe the approach followed in the assessment of tidal stream energy.

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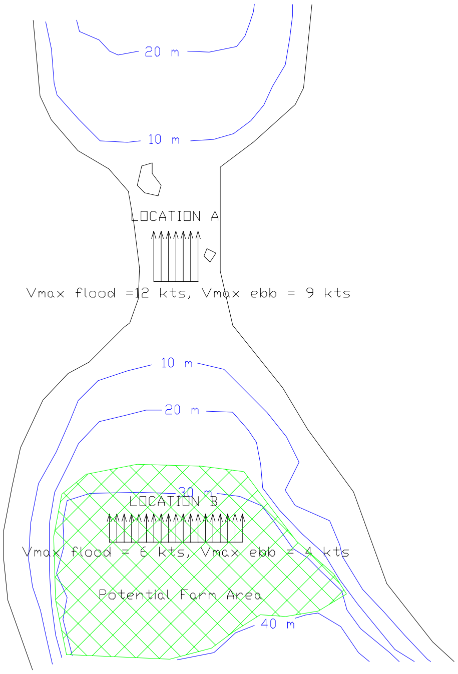
[1] Potential (energy) is used here in its technical meaning of energy resulting from vertical position such as tidal height. Elsewhere in this report the common meaning of “latent” is used.

Figure 7: Definition Sketch



Location A is representative of those locations typically described by the Canadian Hydrographic Service as "narrows" or "tidal rapids" which are critical to marine navigation. For this reason, information pertaining to these areas was used as a primary basis of the overall assessment of Canadian tidal resources.

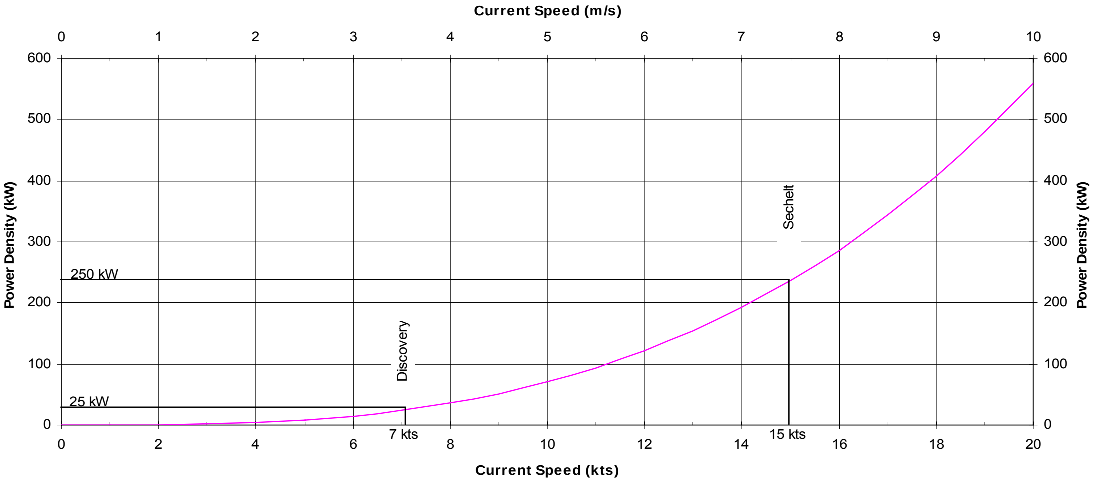
For the example shown, the flood/ebb maximum currents in the narrows peak at 12 knots/9 knots a few times per year. It is at this location that the theoretical power (energy flux) across the channel cross section is computed and tabulated for potential sites throughout Canada. The theoretical instantaneous power $P_{\text{cross section}}$ (W) in a flow cross-section is given by:

$$P_{cross\,section} = \frac{1}{2}\rho A_{cross\,section} U^3$$

where ρ is the density of water (kg/m^3), $A_{\text{cross section}}$ is the cross sectional area (m^2), and U is the instantaneous current velocity (m/s). The average value of this parameter throughout the year yields the mean theoretical power at each site considered.

Figure 8 shows the sensitivity of the power calculation to the current speed selected.

Figure 8: Sensitivity of Power to Current Speed



Recent theoretical work by Garrett, Cummins and others at the University of Victoria and the Institute of Ocean Sciences, Sidney, BC, has shown that the kinetic energy approach (U^3) described above may have some limitations in a number of tidal current flows such as tidal inlets and tidal passages. This work is described in two papers by Dr. Chris Garrett and Dr. Patrick Cummins (Garrett, 2004; Garrett, 2005). The authors (with help from Dr. Mike Foreman and Dr. Graig Sutherland at IOS) continue to validate their theoretical approach by using a tidal model of Discovery Passage/Johnstone Strait, BC The results of this modelling work will be published in the near future. (pers. comm. Mike Foreman).

A similar modelling approach was used by Triton for the BC Hydro Green Energy Study (Triton, 2002) to investigate the probable magnitude of the extractable tidal energy in the Discovery Passage/Johnstone Strait system. This report is available at www.triton.ca. The results showed that 600 MW of tidal energy could be extracted from this system without significant impacts in the tidal regime in the adjacent tidal water bodies although tidal currents in Discovery Passage were reduced by about 10%. No attempts were made in this study to find the maximum extractable power available from this system. Hopefully, the continuing work of Garrett and Cummins will allow a determination of the extractable power as limited by site specific tidal dynamics.

These new theoretical and modelling studies will provide an improved understanding of the tidal dynamics of tidal current power extraction. Unfortunately, the technical data required for each site, such as detailed tidal models and tidal measurements is considerable, and its application is not appropriate for this early stage of the Canada Ocean Energy Atlas development.

It is therefore believed that theoretical mean power (based on tide stream kinetic energy) remains a reasonable preliminary benchmark to gauge the relative tidal current potential of various sites. The reader must however be aware that kinetic energy is only loosely related to the extractable power since extractable power is highly dependant on the physical characteristics of the site, local tidal dynamics and the technology applied.

3.3 PRACTICAL METHODOLOGY

The data sources used for this study are described in Section 2. The practical analysis methodology employed was as follows:

A. Identify and locate all potential current power sites documented in the Sailing Directions and Tide and Current Tables for Canada (see Table 1 and Table 2). Estimate maximum flood and ebb current speeds.

B. Locate these potential sites on the 489 salt water digital charts available for Canada and estimate width and depth of flow.

C. Identify significant potential current sites not covered by digital charts, specifically Hudson's Strait, Ungava Bay and Arctic Region. Review paper chart copies (from UBC map library) and estimate width and depth of flow.

D. Supplement chart data, particularly in remote regions, with satellite mapping data in Google Earth.

E. For large sites with limited (or non-existent) current measurement, estimate potential stream cross-sectional tidal current power from tidal model results (see Section 2.3)

Table 4 shows, in green text, the data collected for each of the identified Canadian tidal current sites. Text in red are calculated parameters. "Column" 1 through 15 correspond to the columns in Table 7 and Table 8 (Section 4 Selected Study Results).

A total of 260 sites were identified: 190 of these sites had an estimated tidal current power potential greater than 1 MW (see Section 4).

Table 4: Data Assembly

Column	Description
1	Region
2	Province
3	Site Name
4	CHS Chart
5	Latitude of Site
6	Longitude of Site
7	CHS Current Station Number
8	Maximum Current Speed Flood (Knots) Vf
9	Maximum Current Speed Ebb (Knots) Ve
10	Mean Maximum Depth Averaged Current Speed (m/s) Umax = (Vf+Ve)/2 x 0.5148[1] x 0.85[2]
11	Annual <u>mean</u> power density based on the expression ½ x $^{4}/(3\pi)$ x U^3, where U is the annual mean peak flood and ebb current velocity equal to 0.9 and 0.7[3] times their large tide mean depth and cross-section averaged values respectively. Currents are assumed to vary sinusoidally.
12	Representative channel width at location of maximum currents (m)
13	Representative channel depth at location of maximum currents (m)
14	Representative channel area at mean tide at location of maximum currents (m^2)
15	Mean cross sectional potential power at location of maximum currents computed from the product of the annual mean power density and the mean channel area. (MW)

Notes:

1. Conversion to m/s
2. Cross-section averaging
3. This factor has been used for all locations except British Columbia, where diurnal tidal currents are strong. In BC, a factor of 0.5 was used in Vancouver Island Mainland and 0.6 used in the Queen Charlotte Islands and Pacific Mainland North regions. This assumption reduces relative BC tidal current power potential compared to the remainder of the country and must be checked with detailed tidal modelling.

4. SELECTED STUDY RESULTS

4.1 POTENTIAL TIDAL CURRENT ENERGY SUMMARY TABLES

Table 5 shows the estimated mean potential tidal current energy by Provinces in Canada for sites with a mean power greater than 1 MW.

Table 5: Canada Potential Tidal Current Energy by Province

Province	Potential Tidal Current Energy (MW)	Number of Sites (-)	Average Size (MW)
Northwest Territories	35	4	9
British Columbia	4,015	89	45
Quebec	4,288	16	268
Nunavut	30,567	34	899
New Brunswick	636	14	45
PEI	33	4	8
Nova Scotia	2,122	15	141
Newfoundland	544	15	36
TOTAL	**42,240**	**191**	**221**

Table 6 shows the distribution of mean potential power by Regions with Canada. Note that more than 80% of potential tidal current power is in regions presently impacted by winter ice conditions.

Table 6: Canada Potential Tidal Current Energy by Region

Region	Potential Tidal Current Energy (MW)
Vancouver Island Mainland	3,580
Pacific Mainland North	353
Queen Charlotte Islands	81
Arctic	1,008
Hudson Strait	29,595
Ungava	4,112
St. Lawrence River	153
Gulf of St Lawrence	537
Atlantic North	65
Atlantic South	30
Bay of Fundy	2,725
TOTAL	**42,240**

Table 7 shows the 50 largest potential tidal current power sites in Canada. Table 8 shows the 50 sites in Canada with the largest Mean Power Density (MW/m^2).

Table 7: Canada Tidal Current Power Sites (50 largest sites)

Region	Province	Site Name	Chart	Latitude	Longitude	Current Station	Max. Speed Flood (knots)	Max. Speed Ebb (knots)	Mean Max. Depth Ave. Speed (m/s)	Mean Power Density (kW/m2)	Passage Width (m)	Average Depth of Passage (m)	Flow Cross-sectional Area (m2)	Mean Potential Power (MW)
Hudson Strait	Nunavut	Mill Island-Salisbury Island	5450	63.81	-77.50		8	8		0.887	32054	204	6571070	10426
Hudson Strait	Nunavut	Mill Island-Baffin Island	5450	64.15	-77.57		8	8		1.020	26125	229	6008750	7584
Hudson Strait	Nunavut	Gray Strait	5456	60.54	-64.69		6	6	2.63	2.110	6000	550	3307800	6979
Hudson Strait	Nunavut	Nottingham Island-Ungava	5450	62.83	-77.93		8	8		0.136	64098	228	14678442	1972
Bay of Fundy	Nova Scotia	Minas Basin	4010	45.35	-64.40		7.5	7.5	3.28	6.036	4376	56	274113	1903
Hudson Strait	Nunavut	Salisbury Island-Nottingham Island	5450	63.45	-77.41		8	8		0.360	22146	147	3277608	1704
Ungava	Quebec	Smoky Narrows	5468	58.92	-69.27		12	12	5.25	16.880	1500	55	92400	1560
Ungava	Quebec	Algernine Narrows	5468	58.79	-69.60		10	10	4.38	9.768	2000	59	130400	1274
Vancouver Island Mainland	British Columbia	Seymour Narrows	353902	50.13	-125.35	5000	16	14	6.56	18.160	769	41	33331	786
Hudson Strait	Nunavut	Lacy/Lawson Islands	5456	60.60	-64.62		7	7	3.06	3.351	2750	80	223575	749
Ungava	Quebec	Riviere George Entrance	5335	58.76	-66.12		8	8	3.50	5.001	3000	35	125100	626
Gulf of St Lawrence	Newfoundland	Strait of Belle Isle	4020	51.45	-56.68					0.201	26069	49	1298236	373
Vancouver Island Mainland	British Columbia	N. Boundary Passage	346201	48.79	-123.01		4	4	1.75	0.498	5158	140	734949	366
Vancouver Island Mainland	British Columbia	Discovery Pass. S.	353901	50.00	-125.21		7	7	3.06	3.676	1459	42	65626	327
Arctic	Nunavut	Labrador Narrows	7487	69.71	-82.59		6	6	2.63	2.110	1500	100	151950	321
Vancouver Island Mainland	British Columbia	Boundary passage	344101	48.69	-123.27		3.5	3.5	1.53	0.334	4472	175	793760	265
Ungava	Quebec	Riviere Arnaud (Payne) Entrance	5352	59.98	-69.84		9	9	3.94	7.121	2300	9	32200	229
Bay of Fundy	New Brunswick	Clarks Ground	4340	44.59	-66.64		6	6	2.63	2.110	4092	22	102300	216
Vancouver Island Mainland	British Columbia	Current Passage 2	354401	50.39	-125.86		6	6	2.63	1.681	1502	80	123931	208
Vancouver Island Mainland	British Columbia	Weyton Passage	354601	50.59	-126.82		6	6	2.63	1.681	1535	75	118985	200
Ungava	Quebec	Koksoak Entrance	5376	58.52	-68.17		6	6	2.63	2.110	2000	40	92400	195
Hudson Strait	Nunavut	Cape Enouolik	7065	64.95	-78.33		5	5	2.19	1.221	5000	25	142500	174

Region	Province	Site Name	Chart	Latitude	Longitude	Current Station	Max. Speed Flood (knots)	Max. Speed Ebb (knots)	Mean Max. Depth Ave. Speed (m/s)	Mean Power Density (kW/m2)	Passage Width (m)	Average Depth of Passage (m)	Flow Cross-sectional Area (m2)	Mean Potential Power (MW)
Pacific Mainland North	British Columbia	Nakwakto Rapids	355001	51.10	-127.50	6700	14	16	6.56	29.062	434	10	5643	164
Vancouver Island Mainland	British Columbia	Current Passage 1	354401	50.41	-125.87		5	5	2.19	0.973	1398	100	143331	139
Vancouver Island Mainland	British Columbia	Dent Rapids	354301	50.41	-125.21	5530	11	8	4.16	6.672	420	45	19955	133
Vancouver Island Mainland	British Columbia	South Pender Is	344101	48.72	-123.19		4	4	1.75	0.498	1985	100	203416	101
Bay of Fundy	New Brunswick	Devils Half Acre	4340	44.54	-66.69		6	6	2.63	2.110	2133	18	44793	95
Vancouver Island Mainland	British Columbia	Yaculta Rapids	354301	50.38	-125.15		10	10	4.38	7.782	539	20	12135	94
St. Lawrence River	Quebec	Passage de Ile aux Coudre	1233	47.43	-70.43		5	6	2.41	1.625	1700	30	56100	91
Vancouver Island Mainland	British Columbia	Arran Rapids	354301	50.42	-125.14	5600	14	10	5.25	13.447	271	22	6629	89
Ungava	Quebec	Nakertok Narrows	5352	60.00	-70.27		9	9	3.94	7.121	1100	6	12100	86
Bay of Fundy	New Brunswick	Old Sow	4114	44.92	-66.99		6	6	2.63	2.110	625	60	39375	83
Arctic	Nunavut	Bellot Strait	7752	72.00	-94.48		8	8	3.50	5.001	1000	16	16400	82
Arctic	Nunavut	Cache Pt Channel	7710	68.62	-113.55		5	5	2.19	1.221	6000	10	62400	76
Vancouver Island Mainland	British Columbia	Secheldt Rapids 2	351403	49.74	-123.90	9999	14.5	16	6.67	27.599	261	8	2739	76
Arctic	Nunavut	James Ross Strait	7083	66.69	-95.87		5	5	2.19	1.221	5900	10	61360	75
Bay of Fundy	New Brunswick	Head Harbour Passage 1	4114	44.95	-66.93		5	5	2.19	1.221	890	65	60520	74
Bay of Fundy	Nova Scotia	Northwest Ledge	4118	44.30	-66.42		4	4	1.75	0.625	5334	18	117348	73
Ungava	Quebec	Mikitok Narrows	5352	60.00	-70.27		9	9	3.94	7.121	700	8	9590	68
Arctic	Nunavut	Egg Island	7735	68.55	-97.40		7	7	3.06	3.351	750	25	19050	64
Pacific Mainland North	British Columbia	Otter Passage	3742	53.00	-129.73	8535	6	6	2.63	1.860	620	50	32860	61
Vancouver Island Mainland	British Columbia	Gillard Passage 1	354301	50.39	-125.16	5500	13	10	5.03	11.835	237	16	4393	52
Vancouver Island Mainland	British Columbia	Scott Channel	362501	50.79	-128.50		3	3	1.31	0.210	9970	22	244256	51
Vancouver Island Mainland	British Columbia	Active Pass	344201	48.86	-123.33	3000	8	8	3.50	3.984	561	20	12628	50
Bay of Fundy	New	Gran Manan Channel	4340	44.78	-66.86		2.5	2	0.98	0.111	5446	80	452018	50

Region	Province	Site Name	Chart	Latitude	Longitude	Current Station	Max. Speed Flood (knots)	Max. Speed Ebb (knots)	Mean Max. Depth Ave. Speed (m/s)	Mean Power Density (kW/m2)	Passage Width (m)	Average Depth of Passage (m)	Flow Cross-sectional Area (m2)	Mean Potential Power (MW)
	Brunswick													
Arctic	Nunavut	Seahorse Point	7065	63.83	-80.13		5	5	2.19	1.221	2000	20	40800	50
Bay of Fundy	Nova Scotia	The Hospital	4242	43.44	-66.00		4	4	1.75	0.625	3600	18	79200	50
Gulf of St Lawrence	Newfoundland	Pointe Armour	4020	51.45	-56.86		4	5	1.97	0.890	1500	35	53700	48
Gulf of St Lawrence	Newfoundland	Forteau	4020	51.41	-56.95		4	5	1.97	0.890	1500	35	53700	48
Pacific Mainland North	British Columbia	Beaver Passage	3747	53.73	-130.37	8545	4	4	1.75	0.551	810	100	83430	46
Arctic	Nunavut	Nettilling Fiord	7051	66.72	-72.83		8	8	3.50	5.001	1700	5	9180	46
Vancouver Island Mainland	British Columbia	Nahwitti Bar 1	354901	50.89	-127.99		5.5	5.5	2.41	1.295	2993	9	34417	45
TOTAL														**40697**

Notes:

1. The tidal current site data shown in yellow in Table 7 and Table 8 were derived from tidal model results (see Section 4.3 and Section 2.3.
2. Some of the tidal current sites shown in Table 7 and Table 8 are located in close proximity to each other in the same tidal channel or tidal inlet (e.g. Seymour Narrows/Discovery Passage in BC and Smoky Narrows and Algernine Narrows in Leaf Bay, Ungava, PQ). The total extractable power available from such adjacent sites will depend on the specific characteristics of the driving tidal dynamics, site geometry and the energy extraction technology used.

Table 8: Canada Potential Tidal Current Power Sites (50 sites ranked by power density kW/m^2)

Region	Province	Site Name	Chart	Latitude	Longitude	Current Station	Max. Speed Flood (knots)	Max. Speed Ebb (knots)	Mean Max. Depth Ave. Speed (m/s)	Mean Power Density (kW/m2)	Passage Width (m)	Average Depth of Passage (m)	Flow Cross-sectional Area (m2)	Mean Potential Power (MW)
Pacific Mainland North	British Columbia	Nakwakto Rapids	355001	51.10	-127.50	6700	14	16	6.56	29.062	434	10	5643	164
Vancouver Island Mainland	British Columbia	Secheldt Rapids 2	351403	49.74	-123.90	9999	14.5	16	6.67	27.599	261	8	2739	76
Vancouver Island Mainland	British Columbia	Seymour Narrows	353902	50.13	-125.35	5000	16	14	6.56	18.160	769	41	33331	786
Ungava	Quebec	Smoky Narrows	5468	58.92	-69.27		12	12	5.25	16.880	1500	55	92400	1560
Bay of Fundy	New Brunswick	Reversing Falls	4141	45.26	-66.09		12	12	5.25	16.880	90	15	1746	29
Pacific Mainland North	British Columbia	Kildidt Narrows	393701	51.89	-128.11		12	12	5.25	14.880	75	2	375	6
Vancouver Island Mainland	British Columbia	Arran Rapids	354301	50.42	-125.14	5600	14	10	5.25	13.447	271	22	6629	89
Vancouver Island Mainland	British Columbia	Gillard Passage 1	354301	50.39	-125.16	5500	13	10	5.03	11.835	237	16	4393	52
Ungava	Quebec	Algernine Narrows	5468	58.79	-69.60		10	10	4.38	9.768	2000	59	130400	1274
Vancouver Island Mainland	British Columbia	Hole-in-the-Wall 1	353901	50.30	-125.21	5100	12	9.5	4.70	9.667	189	8	1985	19
Vancouver Island Mainland	British Columbia	Yaculta Rapids	354301	50.38	-125.15		10	10	4.38	7.782	539	20	12135	94
Ungava	Quebec	Riviere Arnaud (Payne) Entrance	5352	59.98	-69.84		9	9	3.94	7.121	2300	9	32200	229
Ungava	Quebec	Nakertok Narrows	5352	60.00	-70.27		9	9	3.94	7.121	1100	6	12100	86
Ungava	Quebec	Mikitok Narrows	5352	60.00	-70.27		9	9	3.94	7.121	700	8	9590	68
Atlantic South	Newfoundland	Placentia Gut	4841	47.25	-53.96		9	9	3.94	7.121	80	3	336	2
Vancouver Island Mainland	British Columbia	Dent Rapids	354301	50.41	-125.21	5530	11	8	4.16	6.672	420	45	19955	133
Pacific Mainland North	British Columbia	Draney Narrows`	393102	51.47	-127.56		9	9	3.94	6.277	139	8	1463	9
Pacific Mainland North	British Columbia	Hidden Inlet	399401	54.95	-130.33		9	9	3.94	6.277	142	3	781	5
Bay of Fundy	Nova Scotia	Minas Basin	4010	45.35	-64.40		7.5	7.5	3.28	6.036	4376	56	274113	1903
Vancouver Island Mainland	British Columbia	Upper rapids 2	353701	50.31	-125.23	5030	9	9	3.94	5.673	242	18	4955	28
Vancouver Island Mainland	British Columbia	Gillard Passage 2	354301	50.40	-125.15	5500	10	8	3.94	5.673	393	10	4916	28

Region	Province	Site Name	Chart	Latitude	Longitude	Current Station	Max. Speed Flood (knots)	Max. Speed Ebb (knots)	Mean Max. Depth Ave. Speed (m/s)	Mean Power Density (kW/m2)	Passage Width (m)	Average Depth of Passage (m)	Flow Cross-sectional Area (m2)	Mean Potential Power (MW)
Vancouver Island Mainland	British Columbia	Gillard Passage 3	354301	50.39	-125.16	5500	10	8	3.94	5.673	92	5	686	4
Pacific Mainland North	British Columbia	Outer Narrows	355001	51.09	-127.63		7	10	3.72	5.288	210	17	4206	22
Vancouver Island Mainland	British Columbia	Gabriola Pass.	347501	49.13	-123.70	3300	8.5	9	3.83	5.213	137	8	1435	7
Ungava	Quebec	Riviere George Entrance	5335	58.76	-66.12		8	8	3.50	5.001	3000	35	125100	626
Arctic	Nunavut	Bellot Strait	7752	72.00	-94.48		8	8	3.50	5.001	1000	16	16400	82
Arctic	Nunavut	Nettilling Fiord	7051	66.72	-72.83		8	8	3.50	5.001	1700	5	9180	46
Vancouver Island Mainland	British Columbia	Porlier Pass	347303	49.01	-123.59	3100	9	8	3.72	4.779	339	15	5926	28
Vancouver Island Mainland	British Columbia	Quatsino Narrows	368106	50.55	-127.56	9200	9	8	3.72	4.779	207	18	4240	20
Vancouver Island Mainland	British Columbia	Dodds Narrows	347501	49.14	-123.82	4000	9	8	3.72	4.779	91	9	1047	5
Pacific Mainland North	British Columbia	Hawkins Narrows	372201	53.41	-129.42		8	8	3.50	4.409	55	3	301	1
St. Lawrence River	Quebec	Travers de Saint-Roch	1233	47.36	-70.26		7.5	7.5	3.28	4.121	500	15	9000	37
Vancouver Island Mainland	British Columbia	Active Pass	344201	48.86	-123.33	3000	8	8	3.50	3.984	561	20	12628	50
Vancouver Island Mainland	British Columbia	Nitinat Narrows	364703	48.67	-124.85		8	8	3.50	3.984	61	20	1376	5
Vancouver Island Mainland	British Columbia	Discovery Pass. S.	353901	50.00	-125.21		7	7	3.06	3.676	1459	42	65626	327
Hudson Strait	Nunavut	Lacy/Lawson Islands	5456	60.60	-64.62		7	7	3.06	3.351	2750	80	223575	749
Arctic	Nunavut	Egg Island	7735	68.55	-97.40		7	7	3.06	3.351	750	25	19050	64
Bay of Fundy	Nova Scotia	Petit Passage	4118	44.39	-66.21		7	7	3.06	3.351	335	18	7035	24
Ungava	Quebec	McLean Strait	-	60.35	-64.63		7	7	3.06	3.351	200	8	2200	7
Hudson Strait	Nunavut	McLelan Strait	4773	60.35	-64.63		7	7	3.06	3.351	200	8	1880	6
Bay of Fundy	New Brunswick	Lubec Narrows	4114	44.86	-66.98		6	8	3.06	3.351	180	3	1080	4
Ungava	Quebec	Koksoak Narrows	5376	58.18	-68.32		5	8.5	2.95	3.004	400	30	14400	43
Pacific Mainland North	British Columbia	Porcher Narrows	3761	53.90	-130.47	8551	7	7	3.06	2.954	120	10	1560	5
Arctic	Nunavut	Wager Bay Narrows	5440	65.31	-87.74		6	7	2.84	2.683	3600		1440	4
Vancouver Island	British	Green Pt Rap. 1	354301	50.44	-125.51		7	7	3.06	2.669	440	25	12093	32

Region	Province	Site Name	Chart	Latitude	Longitude	Current Station	Max. Speed Flood (knots)	Max. Speed Ebb (knots)	Mean Max. Depth Ave. Speed (m/s)	Mean Power Density (kW/m2)	Passage Width (m)	Average Depth of Passage (m)	Flow Cross-sectional Area (m2)	Mean Potential Power (MW)
Mainland	Columbia													
Vancouver Island Mainland	British Columbia	Whirlpool Rapids	354401	50.46	-125.76		7	7	3.06	2.669	321	28	9804	26
Vancouver Island Mainland	British Columbia	Lower Rapids 1	353701	50.31	-125.26		7	7	3.06	2.669	371	8	3891	10
Vancouver Island Mainland	British Columbia	Race Passage	344001	48.31	-123.54	1200	6	7	2.84	2.137	884	20	19885	42
Vancouver Island Mainland	British Columbia	Stuart Narrows	354701	50.90	-126.94		6	7	2.84	2.137	261	7	2478	5
Hudson Strait	Nunavut	Gray Strait	5456	60.54	-64.69		6	6	2.63	2.110	6000	550	3307800	6979
Arctic	Nunavut	Labrador Narrows	7487	69.71	-82.59		6	6	2.63	2.110	1500	100	151950	321
Bay of Fundy	New Brunswick	Clarks Ground	4340	44.59	-66.64		6	6	2.63	2.110	4092	22	102300	216
TOTAL														**16441**

4.2 TIDAL RESOURCE MAPS

Figure 9 shows a map (in Manifold GIS) of the Canadian tidal current sites ranked by potential mean power. Figure 10, Figure 11 and Figure 12 show detail areas of this map, namely: Pacific Coast, Hudson's Strait/Ungava Bay and the Atlantic Coast respectively. These latter three maps are at approximately the same scale.

Figure 9: Canada Potential Tidal Current Resource Sites

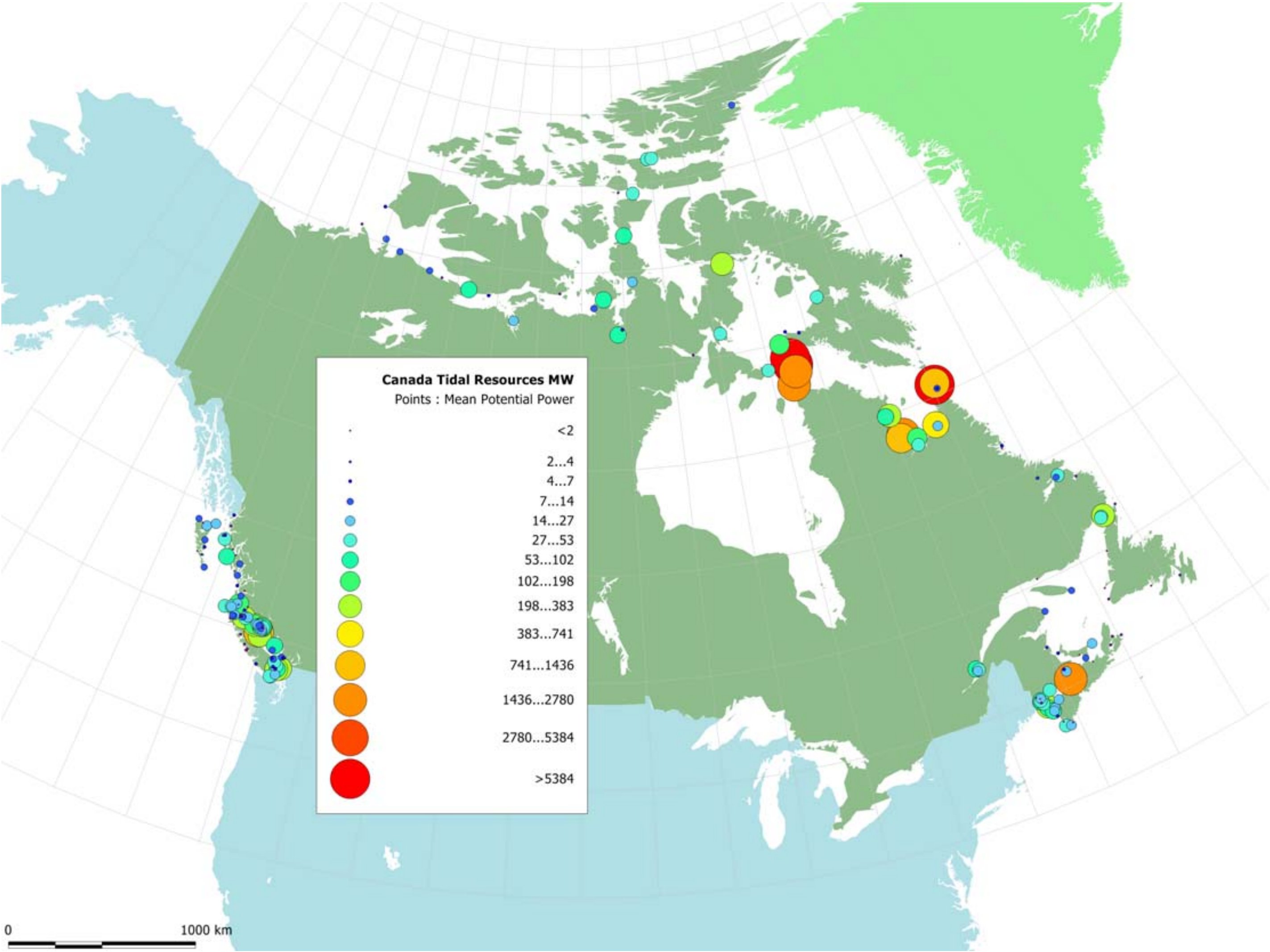


Figure 10: Potential Tidal Current Resource Sites - Pacific Coast

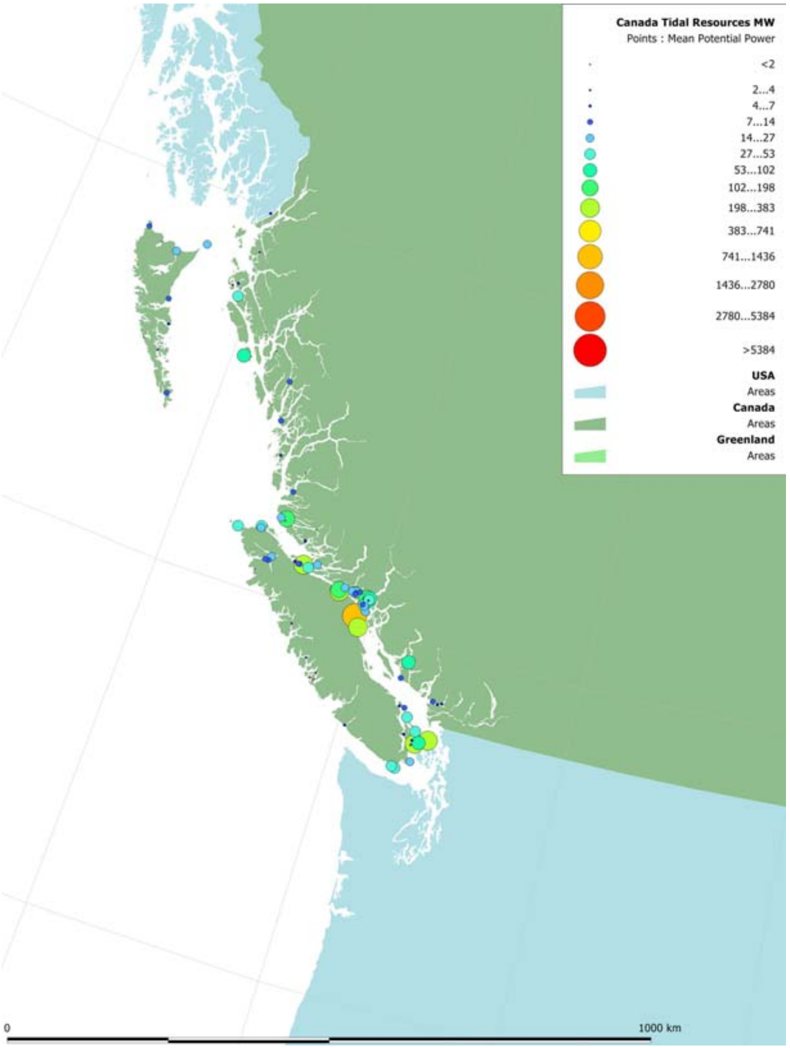


Figure 11: Potential Tidal Current Resource Sites - Hudson's Strait and Ungava Bay

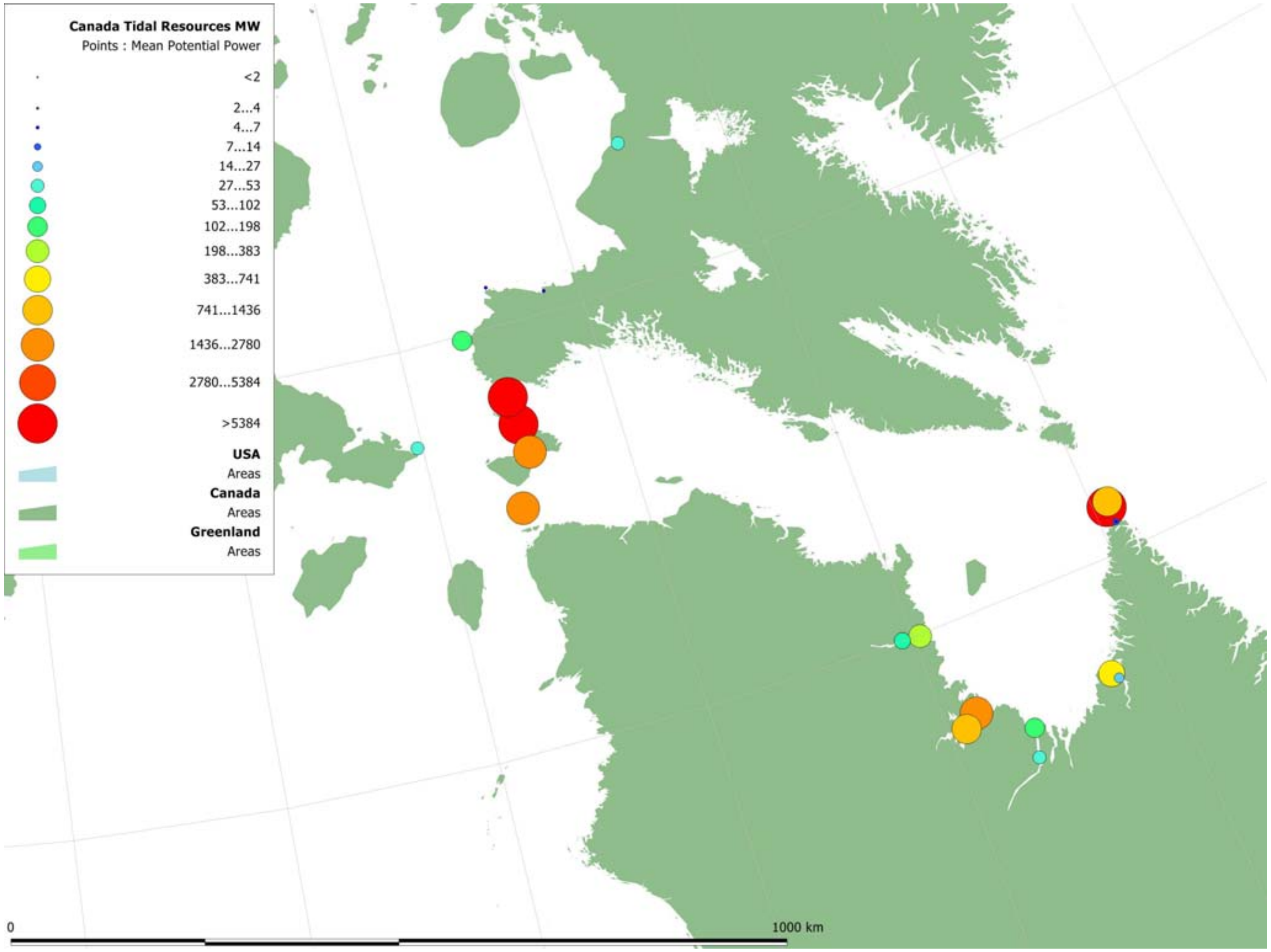
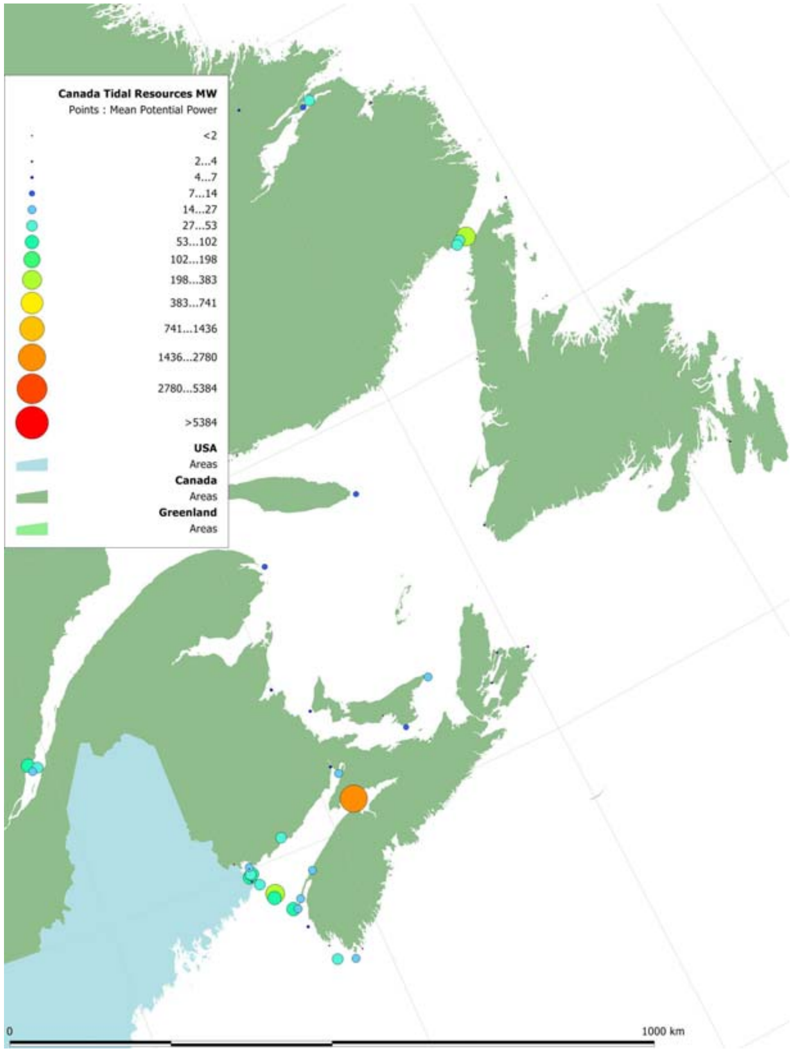


Figure 12: Potential Tidal Current Resource Sites - Atlantic Coast



4.3 POTENTIAL TIDAL CURRENT ENERGY DENSITY MAPS

Figure 13 through Figure 16 show maps of power density in units W/m for the Pacific Coast, Hudson's Strait, Atlantic Coast and Bay of Fundy North respectively. The power density colour scales for all four maps are similar. These maps were developed from tidal model results.

Figure 13: Power Density - Pacific Coast

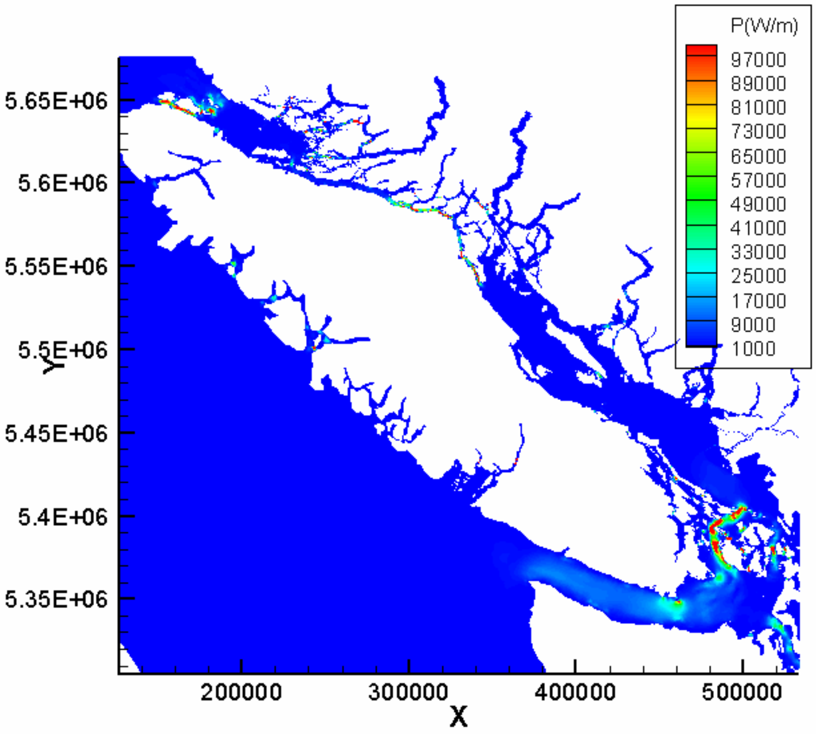


Figure 14: Power Density - Hudson's Strait

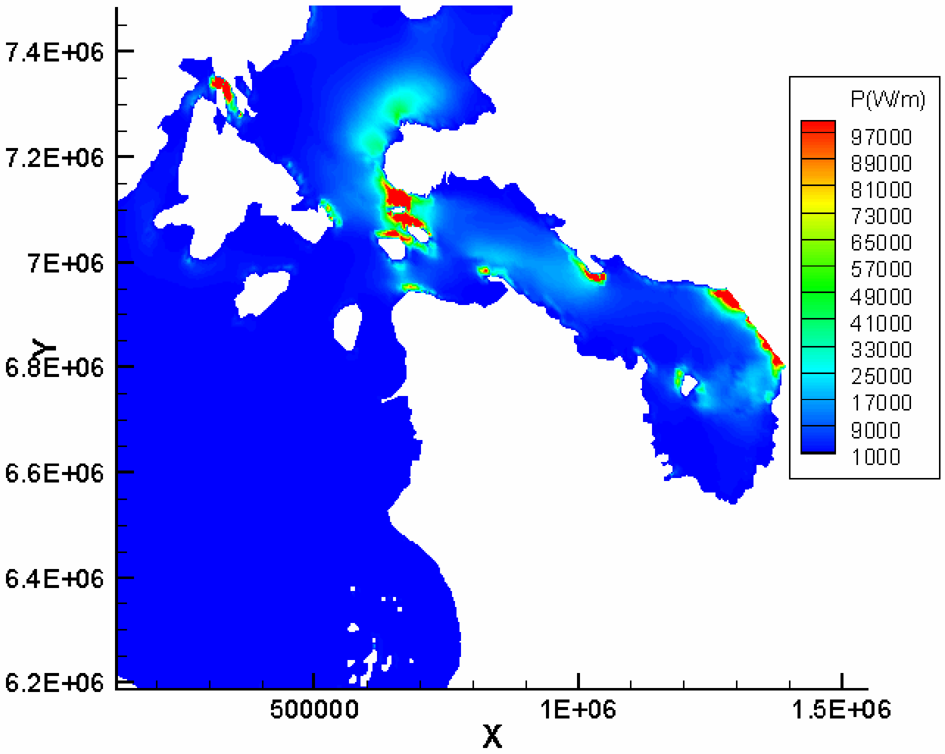


Figure 15: Power Density - Atlantic Coast

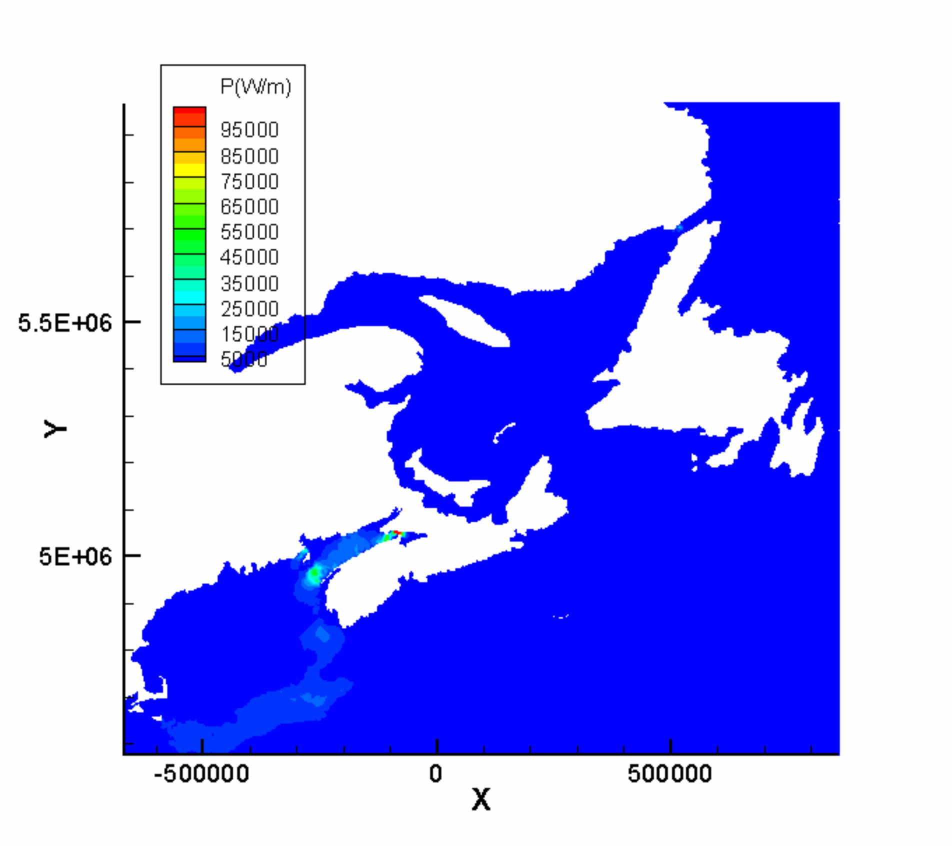
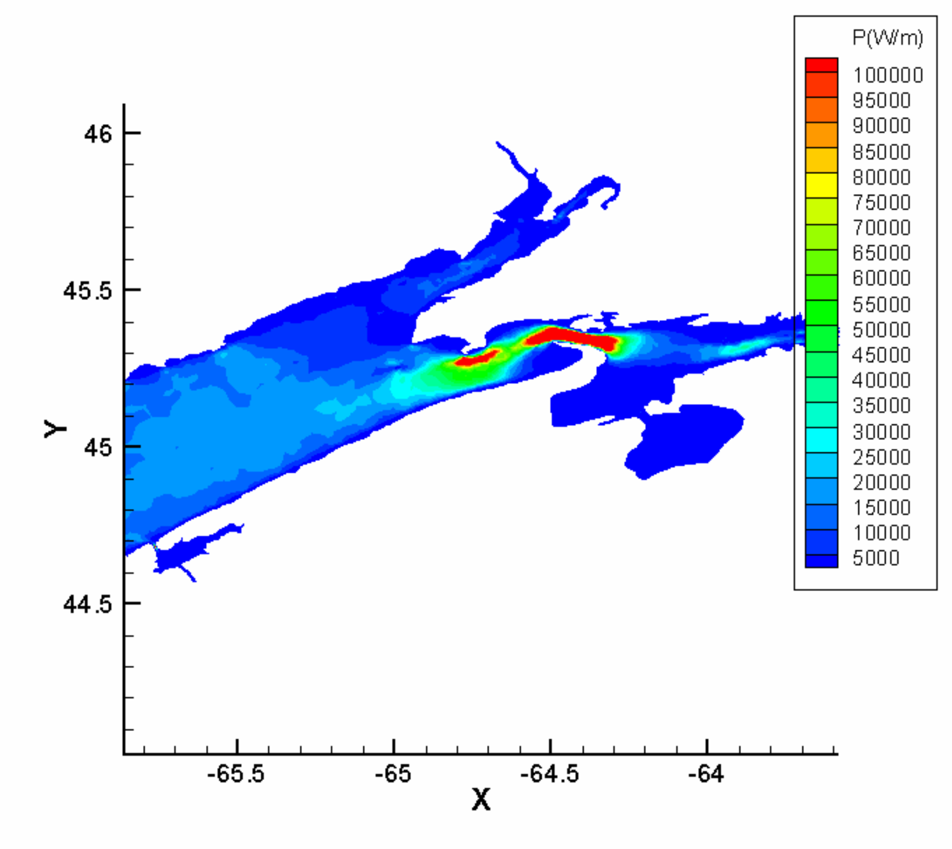


Figure 16: Power Density - Bay of Fundy North



5. *SUMMARY AND RECOMMENDATIONS FOR FURTHER STUDIES*

5.1 SUMMARY

As detailed in this summary report, Phase 1 of the Canada Ocean Energy Atlas project has identified a significant tidal current energy resource in Canada. The potential tidal energy in this country is estimated to exceed a mean power of 42,000 MW or about 365 TW.hours/year. To put this figure in perspective, this represents over 70% of Canada's present annual electrical power consumption.

The estimated Canadian tidal current energy resource is an indication of the **potential** energy available, **not** the actual power that can be exploited. Environmental, technological, climate and economic factors will determine what proportion of the potential can be utilised.

5.2 RECOMMENDATIONS FOR FUTURE STUDIES

5.2.1 Modelling

This preliminary study has identified a number of major tidal current power resources across Canada. It is recommended that near-term modelling studies should concentrate on three specific areas.

- Minas Basin, Nova Scotia
- Georgia and Johnstone Straits, British Columbia.
- Hudson's Strait and Ungava Bay

The objective of these modelling studies should be to improve the definition of the tidal current resources available, to provide estimates of extractable energy and to make an initial evaluation of the environmental impact of tidal energy extraction.

5.2.2 Mapping

A principal objective of the Canada Ocean Energy Atlas Project is to make information on Ocean Energy readily available to the Public. As it is clear that Ocean Energy data is primarily geographically-based, the value of a Geographic Information Systems (GIS) for disseminating this information is clear. Over the course of this project, Manifold GIS (www.manifold.net) has been used with success by Triton Consultants. Manifold provides an ideal user-friendly and economic platform for displaying and interrogating geographical-oriented data. GIS packages (such as Manifold) can be easily implemented as web-based applications and this would appear to be the best way to make Canadian Ocean Energy data available to the Public.

It is recommended that a web-based GIS system be implemented during the next phases of the Ocean Energy Atlas Project.

6. REFERENCES

Garrett, C. & Cummins, P., 2004. Generating power from tidal currents. J. Waterway Port Coastal Ocean Eng 130 114-118

Garrett, C. & Cummins, P., 2005. The power potential of tidal currents in channels. Proc. R. Soc. A (2005) 461, 2563-2572

Triton Consultants Ltd., 2002. Green energy study for British Columbia. Phase 2: Mainland.

APPENDICES

APPENDIX A

CEAPack Description

CEAPACK

Coastal Engineering Analysis Package

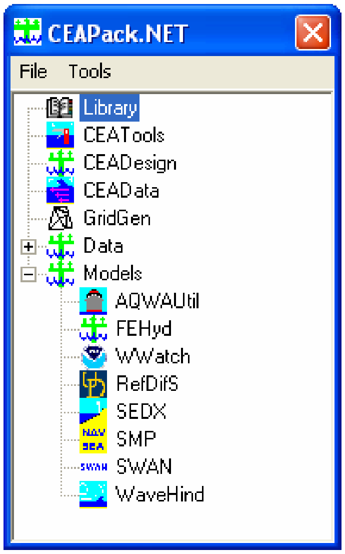
OVERVIEW

CEAPack is a unified analysis and design toolbox useful to the practicing coastal engineering design consultant. It contains tools for tackling problems as numerically intensive as spectral wave hindcasting and the assessment of the dynamic behaviour of floating bodies, to simple but laborious tasks such as computing pile interference and rubble-mound breakwater volume.

The modules within CEAPack are implemented upon Microsoft Windows .NET framework with a standard user interface and data conventions common to all modules. This standardization frees the user from focusing on data manipulation and allows him to concentrate on the engineering issues.

CEAPack is presently configured with over 30 routines implemented in the following four modules which are called from the CEAPack Launcher interface shown below:

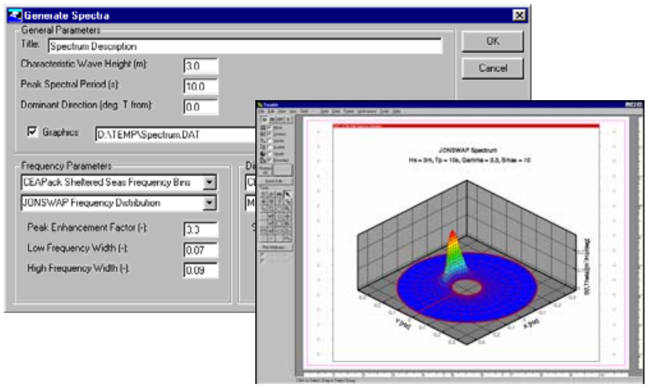
- **CEATools** - Calculates scientific and engineering properties indirectly related to coastal engineering design (e.g., tidal prediction, fluid properties, simple wave generation/propagation, sediment transport)
- **CEADesign** - Design aids directly related to coastal engineering design (e.g., breakwater armour size determination, submarine pipeline stability, floating body stability)
- **CEAData** - 1D, 2D and 3D constant and time-varying dataset conversion, analysis, and visualization (e.g., finite element grid generation, statistical analysis, animation)
- **Models** - A number of individual programs for simulating coastal processes. Many of these are based on existing public-domain or research code that have been modified to fit the CEAPack framework.



CEATools

CEATools contains routines for completing scientific and engineering calculations such as:

- Tidal harmonic analysis and prediction
- Steady wind wave generation
- Monochromatic and spectral wave transformation
- Wave height distribution
- Propeller wash current generation
- Initiation of sediment transport


Generate Spectra

General Parameters

Title: Spectrum Description

Characteristic Wave Height (m): 3.0

Peak Spectral Period (s): 10.0

Dominant Direction (deg. T from): 0.0

☑ Graphics D:\TEMP\Spectrum.DAT

Frequency Parameters

CEAPack Sheltered Seas Frequency Bins

JONSWAP Frequency Distribution

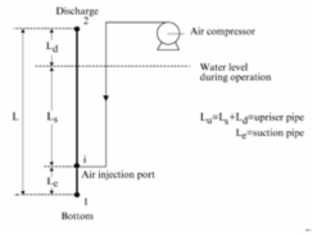
Peak Enhancement Factor (-): 3.3

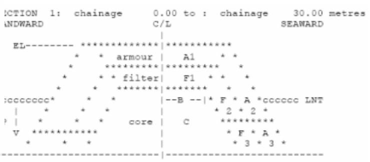
Low Frequency Width (-): 0.07

High Frequency Width (-): 0.09

CEADesign

CEADesign contains routines to assist in the design of rubble-mound breakwaters, caisson structures, dredged channels, floating structures, piled structures, pipelines and ports. Design parameters such as minimum structure dimensions, applied forces, and structure response and efficiency are calculated.

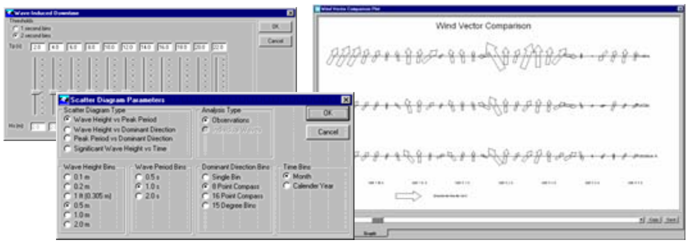



```
:CTION  1:  chainage     0.00 to :  chainage    30.00 metres
\NDWARD                  C/L                    SEAWARD
                         |
 EL--------  ************|***********
        *   *  armour |    A1    * *
       *       *********|*********    *
      *      * * filter|    F1  * *    *
     *      *     *******|*******    *    *
:cccccccc*     *    *        |--B --|* F * A *cccccc LNT
 |    *     *    *           |      * 2 * 2 *
? |   *       *    *    core |   C     *********
 V  ***********              |          * F * A *
   *      *    *             |           * 3 * 3 *
-----------------------------|-----------------------
```

CEAData

CEAData is based on the National Center for Supercomputing Applications Hierarchical Data Format (HDF) with invented conventions for the storage of virtually any type of structured or unstructured mesh and associated scalar and vector time-varying data.

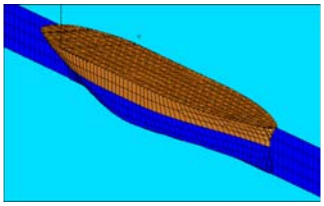
CEAData contains routines for importing data, performing correlation and event analyses, visualizing data and exporting to other formats. In addition, several simple models are included such as 1D wave generation, sediment transport calculation, tide prediction, etc.

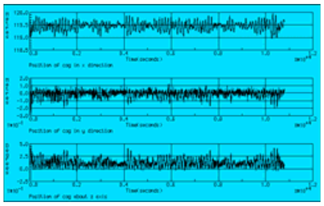


Models

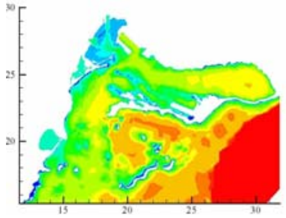
CEAPack contains GUI interfaces and/or pre– and post-processors to several industry-standard numerical models including the following:

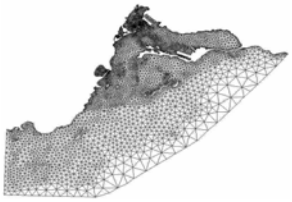
- SMP (US Navy)
  - vessel motion analysis for single free-floating vessels of standard shape
- DynMoor (Triton)
  - dynamic mooring analysis model based on SMP results
- AQWA (Century Dynamics)
  - vessel motion and mooring analysis for multiple floating and fixed bodies of arbitrary shape





- WaveHind (Triton)
  - 1D wave generation model
- SWAN (Delft University)
  - 2D shallow water wave generation and propagation model
- WaveWatch III (US NOAA)
  - 2D coastal ocean water wave generation and propagation model
- REFDIF (University of Delaware)
  - 2D refraction-diffraction phase-averaging short wave propagation model
- FUNWAVE (University of Delaware)
  - 2D refraction-diffraction phase-resolving short wave propagation model





- Tide2D (Roy Walters)
  - 2D harmonic tidal model
- RICOM (Roy Walters)
  - 2D/3D semi-implicit semi-Lagrangian hydrodynamic model
- SEDX (Public Works Canada)
  - alongshore sediment transport calculator
- SBeach and Genesis (US Army)
  - 2D vertical and 2D horizontal shoreline evolution models

Supported Data Formats

CEAPack was designed to leverage the many advanced features that already exist in various industry-standard commercial software packages. In addition to those formats supported implicitly in the models interfaces described previously, a wide variety of import and/or export file format options are supported including:

- Standard
  - ASCII format (DAT, CSV)
  - Binary format (XLS, PDF, MDF, DBF)
  - Images formats (BMP, EMF, GIF, ICO, JPG, PNG, TIF, WMF)
  - Animation formats (AVI)
- Data Visualization
  - Golden Software Surfer Grid format (GRD)
  - TecPlot format (DAT, PLT)
- Grid Generation
  - TriGrid, Institute of Ocean Sci. format (NGH)
- Geographic Information Systems
  - ESRI Shape File format (SHP)
  - Manifold Project format (MAP)
  - MapGen format (DAT)
- Engineering and Scientific
  - AutoDesk AutoCAD formats (DXF, SCR)
  - Danish Hydraulic Institute Litpack formats
  - Canadian Marine Environmental Data Service formats
  - Meteorological Service of Canada formats
  - US NOAA meteorological formats
  - US NOAA raster nautical chart format (BSB)
  - World Meteorological Organization Gridded Binary format (GRB)
  - Unidata NetCDF format (NC, CDF)
  - US National Center for Supercomputing Applications HDF5 format (H5)
  - Canadian Hydrographic Service water level, current and bathymetry formats
  - Geodetic Survey Division, Natural Resources Canada format (GHOST)
  - various meteorological and oceanographic instruments from vendors such as InterOcean, Sontek, Seabird, RD Instruments

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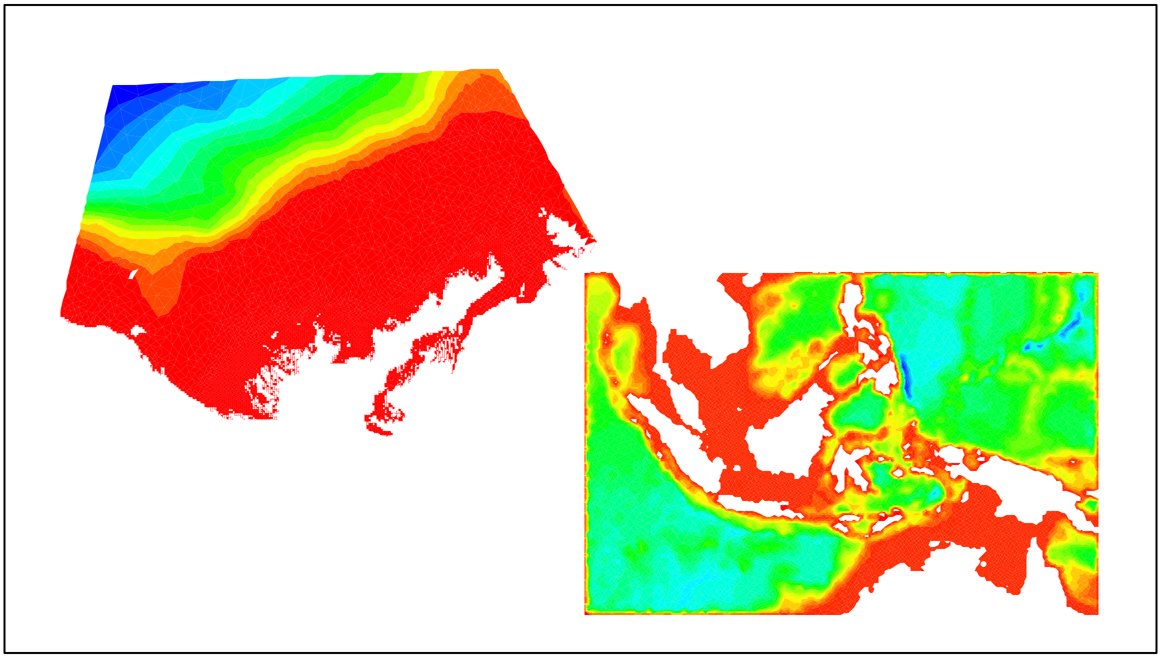
APPENDIX B

Hydrodynamic Model Tide 2D Description

TRITON

Technical Data Sheet

HYDRODYNAMIC MODELLING



Triton maintains a suite of finite element programs for the assessment of free surface flow in two and three dimensions. All programs were developed by Dr. Roy Walters formerly of the US Geological Survey. The program modules include:

Tide2D	Two-dimensional frequency domain solution of the non-linear shallow water equations	WEq	Two dimensional time domain solution of the non-linear shallow water equations
Tide3D	Three-dimensional frequency domain solution of the non-linear shallow water equations	XTide	Two dimensional frequency domain solution of the non-linear shallow water and advection-dispersion equations

Depending on the application, either a frequency domain (harmonic) or time domain (time-stepping) solution may be more appropriate. All modules use a finite element discretisation in space and a harmonic expansion or predictor-corrector approach in time (Walters, 1987). The shallow water equations solve the two or three-dimensional continuity and momentum equations using standard Galerkin techniques. The spatial domain is discretised by defining a set of two-dimensional triangular elements in the horizontal plane, and a sigma coordinate system in the vertical for the third dimension if required.

A typical analysis sequence following the finite element grid generation stage (using the commercially-available TriGrid package) begins with the computationally efficient two-dimesional frequency domain analysis (Tide2D) of steady conditions and harmonic driving components. Short (two to three week) time segments of particular interest are examined using the more-computationally intensive and detailled two-dimensional timestepping solution (WEq). Depending on the importance of three dimensional effects (e.g., salinity, temperature, freshwater influx), Tide3D can be used to with marginal computational penalties over Tide2D. XTide is used to quickly assess dispersion of conservative pollutants.