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Inventory and Assessment of Tidal Energy Resources Near Northern Communities
Part 1: Review and Analysis of Available Information

Report No.: NRC-OCRE-2020-TR-013

Prepared for: Polar Knowledge Canada

Revision 1.0
Date: 2020-03-31

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Abstract

Polar Knowledge Canada (POLAR) wishes to investigate and assess the potentially exploitable tidal energy resources located near communities in northern Canada and make the information available to stakeholders through a software application/tool with functionality for geospatial analysis and interactive mapping. This first work package constitutes a preliminary assessment of prior tidal energy resource assessments, energy needs in northern communities, and available oceanographic and energy use data for future tidal energy modelling efforts. Based on the results of this scoping review, the four northern communities of greatest interest for detailed hydrodynamic study of local tides at present are: Iqaluit, Kuujjuaq, Igloolik and Cape Dorset.

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1. Introduction

The National Research Council (NRC) is the Government of Canada's premier research organization supporting industrial innovation, the advancement of knowledge and technology development, and fulfilling government mandates. The NRC's Ocean, Coastal and River Engineering (NRC-OCRE) Research Centre supports a broad cross-section of industry sectors by developing creative and practical solutions to engineering challenges in rivers, lakes and marine environments, with a particular focus on harsh and extreme conditions. We provide expertise and tools to identify, adapt, and integrate advanced solutions into systems that improve the performance and safety of ocean, coastal, and marine operations, meet the challenges of climate change, and protect infrastructure, property and people from severe weather events and other environmental risks. The NRC-OCRE owns and operates comprehensive test facilities, including ice tanks, wave basins, wave flumes, and state-of-the-art numerical hardware and tools, located both in St. John's and Ottawa.

NRC-OCRE has prepared this report as part of Work Package 1 as documented in NRC-OCRE Proposal PL200067, "Inventory and Assessment of Tidal Energy Resources Near Northern Communities." The three work packages described in the proposal were developed in response to needs identified by Polar Knowledge Canada (POLAR). POLAR wishes to investigate and assess the potentially exploitable tidal energy resources located near communities in northern Canada and make the information available to stakeholders through a software application/tool with functionality for geospatial analysis and interactive mapping. This first work package constitutes a preliminary assessment of prior tidal energy resource assessments, energy needs in northern communities, and available oceanographic and energy use data to support future tidal energy modelling efforts. The second work package, to be completed later in 2020, will focus on developing a new numerical tide model (or models) and apply it (them) to predict the spatial and temporal variation of tidal flows and kinetic energy densities near a select number (nominally three) of northern communities. In the third and final work package, NRC-OCRE will develop a "light" or "bare bones" digital web or desktop atlas with best available information on tidal energy resources for regions where focused modelling was competed in Work Package 2.

2. Background

2.1. General Background

Polar Knowledge Canada (POLAR) is responsible for advancing Canada's knowledge of the Arctic, strengthening Canadian leadership in polar science and technology, and promoting the development and distribution of knowledge of other circumpolar regions, including Antarctica. Under the Polar Knowledge Canada Science and Technology (S&T) program, one of the key priorities is Alternative and Renewable Energy and helping remote northern communities reduce dependence on fossil fuels for energy generation. Although wind and solar technologies are part of the energy solution for the north, they are both dependent on weather-driven, highly variable resources and therefore cannot be expected to completely remove diesel dependency. POLAR are committed to assisting in developing new knowledge and capabilities that will help reduce the dependency on diesel and have therefore identified tidal energy as an emerging clean energy technology that, in a community with the appropriate oceanographic and coastal conditions, could be a steady — or at least more predictable — renewable energy source.

Nunavut's energy system is unique in Canada as it is the only province or territory that has no primary energy production or centralized grid; every community has its own isolated electricity grid developed to

meet local needs. The Territory also relies exclusively on imported fossil fuels (specifically, diesel) for its energy needs. For example, in 2015-2016 the territory imported 244 million liters of fuel, which provided for nearly all the electricity generation, transport, and heating in Nunavut. The fuel is predominantly purchased and shipped in bulk during the short summer season as part of the annual sea lift and is then stored in tank facilities within each community. Tank storage of diesel fuel comes with several environmental and social risks, including spills and seepage into local soils, fumes affecting air quality, and the risk of a fire removing a community's only energy source for several weeks or months at a time. The territorial government-owned Qulliq Energy Corporation (QEC) is responsible for the generation of electricity in the territory, maintaining 26 stand-alone diesel plants in 25 communities (two plants in Iqaluit).

Renewable energy is slowly being introduced into communities and mining sites. To date this effort has tended to involve deployment of small-scale solar photovoltaic (PV) systems mounted on municipal buildings within some communities (such as Sanikiluaq), and exploring the potential for wind generation. However, both wind and solar are heavily dependent on transient weather conditions. Without significant advances in storage technology, neither are currently viable as year-round solutions in the north, due to long periods of darkness in winter and high year-round per-capita energy demand in most communities. Large-scale hydro and/or run-of-river hydro are not necessarily seen as viable options due to distances from communities, the duration and depth of freeze ups, the difficulty of attaining appropriate funding for hydro and transmission infrastructure in the north, and increased social resistance to mid- and large-scale hydroelectric projects in Canada in recent years, which may raise concerns with local people. Hydrokinetic river power, where devices are placed directly into the river flow without the need for weirs, dams, or other environmentally disruptive engineered works, may prove more viable, especially technologies that can be placed low enough in the water column to be below any surface ice in winter.

POLAR wishes to investigate the feasibility of exploiting renewable tidal energy resources to reduce the dependence of northern communities on fossil fuels for energy generation. Hence, the objectives of the three planned work packages are to 1) investigate and quantify the tidal energy resources near communities in northern Canada, 2) assess the feasibility of harnessing these renewable and predictable energy sources to offset diesel generation in northern communities, and 3) disseminate the study findings to stakeholders through an interactive mapping tool. The proposed study focuses on tides and tide-driven currents (as opposed to waves and/or river currents) as large tides and tidal currents are known to exist at multiple locations within the Arctic archipelago, and exploitation of tide-related resources for energy generation is likely to be more feasible than wave or river hydrokinetic energy over the short to medium term.

In 2006, the NRC published an inventory of wave and tidal energy resources across Canada, based on analysis of available datasets and existing numerical model output (see Cornett, 2006). Several promising sites in northern Canada were identified (see Figure 1); however, the findings were associated with a high degree of uncertainty due to a paucity of field data and an absence of high-resolution modelling and targeted regional studies. The findings in this inventory report were also not linked to proximity to communities that may be able to directly harness the resource; it was concerned instead with identifying the spatial location and potential scale of northern tidal resources, not their usability. Thus, this first work package begins with a review of this report to identify northern communities in close proximity to sites where tidal stream energy extraction is likely possible.

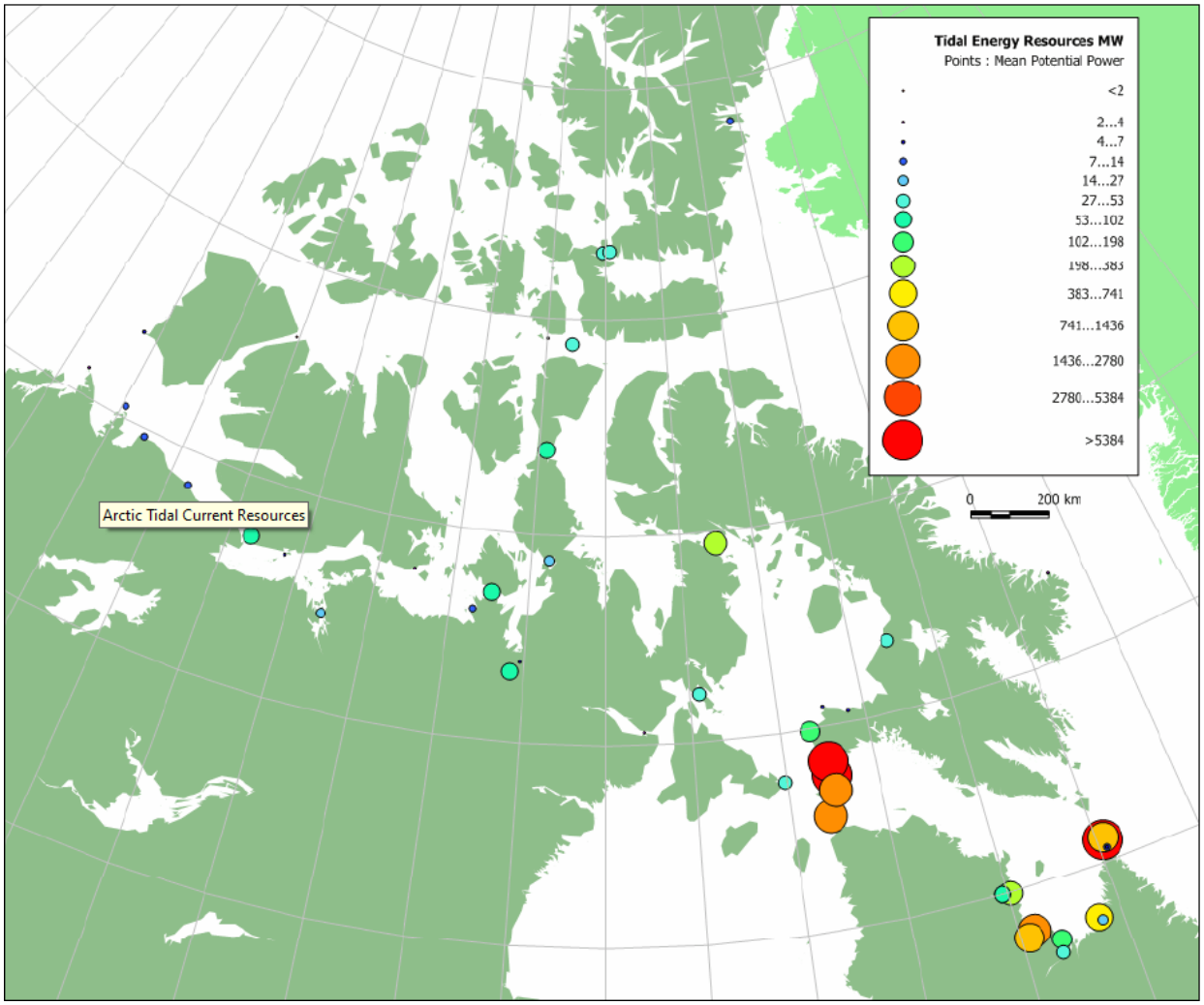

Figure 1. Potential tidal energy sites in northern Canada (from Cornett, 2006).

2.2. Tidal energy background

Tidal energy refers to, simply, energy extracted from the Earth's tides. There are two categories of tidal energy extraction methods. Tidal range technologies utilize the natural rise and fall of the tide to store water behind a man-made structure (Neill *et al.*, 2018), which can then be released through a turbine (or turbines) in a powerhouse to generate electricity. In principle, tidal range power operates similarly to a hydroelectric dam; it requires a structure which interrupts the natural flow in a channel, and generates power based on the pressure head differential behind the structure and the turbine outlet. The engineered structures required for tidal range energy extraction are called a barrage if it crosses and blocks the mouth of a bay or estuary (like a dam crosses a river), or a lagoon if it is a fully enclosed artificial structure surrounded by open water without fully obstructing the tidal channel it is located within. Several tidal barrages have been built around the world since the 1960s, including France's La Rance Tidal Generating Station (240 MW, 1966), Nova Scotia's Annapolis Royal Generating Station (20 MW, 1984), and South Korea's Sihwa Lake Tidal Power Station (254 MW, 2011). However, the environmental impacts of impounding water within an estuary or bay combined with the high cost of construction for barrages (Flynn, 2015) has meant few

jurisdictions have committed to large tidal barrage schemes in recent years. In contrast to barrages, no tidal lagoon proposal in the world has gone forward as of 2020, though a private proposal to build a tidal lagoon along the Severn River near Bristol continues to seek funding in the UK. The scope of this study, however, is focused on tidal flows and in-stream tidal power.

Many in-stream tidal energy conversion technologies have undergone significant development over the past decade and are at various stages of readiness for deployment (Segura *et al*., 2018; Laws & Epps, 2016). Unlike with tidal range schemes, no enclosure or extensive modification of natural water channels is required for in-stream tidal energy generation. Instead, hydrokinetic turbines or other energy conversion devices are placed directly in the flow stream of a tidal channel. While this means that power can only be generated when the water is flowing with sufficient speed, the times at which power can be generated (or not) can be predicted with minute-level accuracy. The predictability of tidal power is a significant advantage over wind and solar power, which are reliant on weather conditions. Thus, it can be hard to forecast energy generation more than a few hours or days in advance. That said, in-stream tidal energy remains a pre-commercial technology, with many devices considered experimental and not cost-competitive with established technologies as of 2020. However, several technologies are being deployed in Europe at large scale and are ready for commercial deployment in jurisdictions where the cost of energy is high or government subsidies are available.

Canada has also pursued in-stream tidal energy through a variety of efforts. Though some experimental turbines have been tested in British Columbia, Nova Scotia has invested most heavily in utility-scale tidal energy development in the Bay of Fundy (MacDougall, 2015; Sangiuliano & Mastrantonis, 2017). Most of Nova Scotia's effort has been focused on MW-scale devices at the Fundy Ocean Research Centre for Energy (FORCE) on the Minas Basin (Flynn, 2015; Sangiuliano & Mastrantonis, 2017), located near the north shore of Minas Passage in the upper Bay of Fundy. Five 'berths' for tidal energy projects — complete with pre-built grid connections and provincial zoning approvals — exist at FORCE. All tidal devices at FORCE will receive an annual production-dependent feed-in tariff (FIT) rate for the electricity they generate, ranging from $0.42/kWh to $0.53/kWh (Nova Scotia Department of Energy, n.d.). However, as of 2020, none of these berths have operating turbines deployed, and several companies appear to have refocused near-term efforts on less costly smaller-scale deployments to further de-bug and prove their technologies.

Many questions relevant to tidal energy development in northern Canadian waters have yet to be addressed. Chief among these, given Canadian winter conditions, is the survivability and operation of tidal energy devices in sea ice. Some early studies have been conducted in Alaska (Kasper *et al*., 2015), yet their results are on early experimental designs and it remains to be seen whether the engineering challenges associated with ice can be addressed by either industry or researchers. NRC has recently developed a frazil ice research facility to further investigate these questions (Richard & Cornett, 2019).

Of equal importance is the risk posed by tidal energy devices to marine life, including both mammals, fish, and the benthic population (Kerr *et al*., 2014). Studies to date (Shields *et al*., 2009; Polagye *et al*., 2011; Bradley *et al*., 2015) have found that fish and marine mammals generally avoid tidal energy technologies in the water, with no collisions yet reported in the literature. However, most such studies have been conducted in Europe, and the transferability of these studies to Canadian waters remains unproven. No field study to determine what species are of concern to the public in northern communities in the context of tidal energy has yet been conducted, but one could be done in line with the methods of Nova Scotia's

Strategic Environmental Assessments for tidal energy (Wright, 2014; Doelle, 2009), or the scholarly engagements pursued by Devine-Wright (2011a; 2011b) in Northern Ireland.

3. Methods

This report provides a review of the literature and available data for northern communities in Canada, with a focus on identifying: (1) prior assessments of tidal energy resources in the north, (2) energy needs in communities, (3) the availability of supporting oceanographic, energy demand, and geographic data for renewed tidal modelling efforts in the north, and (4) priority communities for which new tidal energy resource assessments should be conducted. Each of these focus areas required different resources. The methods used in the conducting the literature review are described below, while the main results of the review are discussed in Section 4.

3.1. Prior assessments of tidal energy resources in the north

The only known assessment of tidal energy resources in northern Canada that has been identified was led by Dr. Andrew Cornett of NRC-OCRE and published in 2006 (Cornett, 2006). This report was reviewed to identify sites with potential for tidal energy development that are (relatively) close to existing communities. These sites and communities are presented in Table 1. Approximate distances from communities to the potential tidal resources identified by Cornett (2006) was verified using the ruler tool in Google Earth Pro to measure the distance from the coordinates given by Cornett for each site to each community's airport; these results are reported in Table 3.

3.2. Identifying energy needs in northern communities

Summary profiles of energy consumption, power demand, and other important variables are necessary to determine priority sites for technical tidal resource assessment in northern Canada. The best available data for such profiles comes from the Remote Communities Energy Database (Natural Resources Canada, 2016). This database includes information on population, peak power demand, installed generation capacity, number of generators, generator size, renewable and non-renewable energy generators installed, annual energy consumption, annual fuel consumption, local fuel prices, and much more. The information presented in Table 2 (see below) was developed from this database.

3.3. Availability of supporting data

Several types of data are required to support Work Package 2 (detailed numerical modelling of tides and tidal currents near selected northern communities). These include continuous water level measurements (from which tidal characteristics and tide predictions can be determined), measurements of tidal currents (for model calibration) and high-resolution bathymetric datasets. Water level data can be obtained from the Canadian Tides and Water Levels Data Archive maintained by the Canadian Hydrographic Service (CHS) of Fisheries and Oceans Canada (DFO). One possible source of bathymetric data is the Non-Navigational (NONNA-100) Bathymetric Data Archive provided by the Canadian Hydrographic Service (CHS), which has a spatial resolution of approximately 100m. NRC is also investigating the potential availability of bathymetric data from the CHS at higher resolution. Two other datasets which can potentially be used for spot

verification of the work will be the hull-mounted ADCP current data collected by the CCGS Amundsen in the Canadian Arctic (2015-17) and the ArcticNet 15'x30' Basemaps.

3.4. Identifying priority communities for further study

Several criteria were used to identify communities to be considered for further study in Work Packages 2 and 3. They are:

1. Population: at least 1,000 people.
2. Annual energy demand: ≥5000 MWh.
3. Strength of tidal resource: mean maximum depth averaged current speed ≥2 m/s.
4. Proximity of tidal resource: <50 km from community, preferably within a channel <5 km from land.
5. Availability of oceanographic data: *at least:* tide levels and bathymetry. *Additional/helpful:* currents, ice frequency/thickness/persistence, bottom type (a consideration for design of anchoring/mounting options).

A brief rationale for adopting these criteria is presented in what follows. For population, communities should have at least 1,000 residents to ensure a sufficient population to maintain energy demand in the near to mid-term, so that investments in infrastructure can be justified. The threshold for annual energy demand is set at 5,000 MWh on the assumption that a reasonable capacity factor for still-unproven tidal energy technologies will be around 30%, so that even a small tidal facility of ≤5000 kW capacity will be able to generate no more than 30% of a community's annual demand. As most currently available (pre-)commercial tidal turbines require a cut-in speed of ~1.5 m/s with operating design speeds of 2-3 m/s, communities without access to sites with mean maximum depth averaged current speeds above 2 m/s are likely not appropriate for further consideration, given the current state of available technologies. Proximity to a good tidal resource is also vital due to the high cost of installing power transmission lines, particularly subsea lines. Underwater transmission lines in Atlantic Canada can cost on the order of $1M/km, however these transmission are much larger and more costly than the power cable required for a 500 kW installation. As power cable installation costs are likely to be higher in the Canadian north than in southern Canada, any tidal resource located more than 50 km from a community is likely not suitable for further study in the near-term. Finally, high-quality oceanographic data is required to build and calibrate accurate computer models of tidal flows. Information on local water level fluctuations and bathymetry must be available to support model development, but additional datasets including information on currents, ice seasons, geomorphology, are also useful to support resource assessment.

4. Results

This section provides summary tables of results from the literature review described above.

Table 1. Communities of interest for tidal energy assessment in northern Canada.
(based on Cornett, 2006)

Community Name	*Nearby Tidal Sites*	*Site Latitude*	*Site Longitude*	*Mean Maximum Depth Average Current Speed*	*Mean Power Density*	*Average Passage Depth*	*Channel Cross-Sectional Area*	*Mean Power Potential*
		deg	deg	m/s	kW/m^2	m	m^2	MW
Nunavut								
Cape Dorset	MI-SI	63.81	-77.50	-	0.89	204	6,571,070	10,426
	MI-BI	64.15	-77.57	-	1.02	229	6,008,750	7,584
Naujaat	HC	66.15	-84.42	2.63	2.11	8	16,800	35
	WBN	65.31	-87.74	2.84	2.68	unidentified	1,440	4
Igloolik	LN	69.71	-82.59	2.63	2.11	100	151,950	321
Gjoa Haven	JRS	66.69	-95.87	2.19	1.22	10	61,360	75
	EI	68.55	-97.40	3.06	3.35	25	19,050	64
	SB	69.42	-93.83	1.97	0.89	10	23,920	21
Resolute	RB	68.86	-94.91	1.31	0.26	8	12,600	3
Grise Fiord	CS	76.51	-90.30	1.53	0.42	15	92,400	39
	HG	76.54	-89.66	1.53	0.42	15	84,700	35
Quebec								
Ivujivik & Salluit	NI-U	62.83	-77.93	-	0.14	228	14,678,442	1,972
	SI-NI	63.45	-77.41	-	0.36	147	3,277,608	1,704
Kuujjuaq	KE	58.52	-68.17	2.63	2.11	40	92,400	195
	KN	58.18	-68.32	2.95	3.00	30	14,400	43
Northwest Territory								
Sachs Harbour & Ulukhaktok	CP	70.27	-124.78	1.75	0.63	10	20,800	13
	PP	69.83	-122.69	1.75	0.63	10	20,800	13
	CK	71.98	-126.13	1.09	0.15	20	40,800	6
	OP	70.66	-128.27	1.09	0.15	10	20,800	3

Notes:

1) QC and NT communities are identified together because of close proximity to identical sites.

2) The NT sites share identical or slightly scaled power densities, depth-averaged current speeds, channel cross-sectional areas, and mean power potential; these sites may be duplicating results for different parts of the same channel and thus may not all be realistically harvestable.

3) Abbreviations used for tidal sites to aid table legibility; abbreviations stand for site names used by Cornett (2006), and are as follows (in the order they appear above):

MI-SI: Mill Island-Salisbury Island
MI-BI: Mill Island-Baffin Island
HC: Hurd Channel
WBN: Wager Bay Narrows
LN: Labrador Narrows
JRS: James Ross Strait
EI: Egg Island
SB: Spence Bay
RB: Resolute Bay
CS: Cardigan Strait
HG: Hells Gate
NI-U: Nottingham Island-Ungava
SI-NI: Salisbury Island-Nottingham Island
KE: Koksoak Entrance
KN: Koksoak Narrows
CP: Cape Parry
PP: Pearce Point
CK: Cape Kellet
OP: Observation Point

Table 2. Energy profiles of communities near tidal resources in northern Canada.
Adapted from Remote Communities Energy Database (Natural Resources Canada, 2016)

Community Name	*Population*	*Site Latitude*	*Site Longitude*	*Annual Peak System Load*	*Total Diesel Gen. Capacity*	*Number of Diesel Generators*	*Annual Diesel Electricity Generated*	*Annual Fuel Consumption*	*Price of Diesel Fuel*
		deg	deg	kW	kW		MWh/yr	L	$/L
Nunavut									
Cape Dorset	1,441	64.23	-76.54	1,644	2,260	3	5,685	1,798,012	0.98
Naujaat	1,082	66.53	-86.25	834	1,400	3	4,115	995,912	1.16
Igloolik	1,682	69.38	-81.8	1,209	2,370	4	6,587	1,893,420	1.02
Gjoa Haven	1,324	68.63	-95.88	960	1,820	3	5,619	1,454,142	1.27
Resolute	198	74.7	-94.83	916	1,810	5	4,607	1,394,183	1.07
Grise Fiord	129	76.42	-82.9	221	570	3	1,237	354,690	1.08
Pangnirtung	1,481	66.14	-65.72	1,196	2,000	4	6,506	1,736,386	0.99
Iqaluit	7,740	63.75	-68.52	9,738	25,730	8	59,140	15,432,595	1.19
Quebec									
Ivujivik	414	62.42	-77.92	460	980	3	2,373	626,866	1.40
Kuujjuaq	2,754	58.10	-68.41	3,576	6,010	5	20,333	4,766,839	1.40
Salluit	1,483	62.20	-75.65	1,428	1,878	3	8,326	1,946,667	1.40
Northwest Territory									
Sachs Harbour	103	71.99	-125.24	Null	795	3	954	307,836	1.17
Ulukhaktok	396	70.73	-117.75	Null	1,160	3	2,069	610,275	1.15

Notes:

1) All population, consumption, and cost figures above are for 2016, the most recent year for which the RCED has data in Nunavut and Quebec. For Northwest Territory communities, data year is 2015.

2) Pangnirtung is included in this table despite not having identified tidal resources in Cornett (2006) for several reasons. The community sits on Pangnirtung Fjord, within the Cumberland Sound, which Cornett's study identified as having a tidal *range* of 3.6 m. Though Cornett's maps suggest this region has a root-mean square speed below 0.05 m/s, the models for the arctic region in his study were based on WebTide; it is possible the data for this region is erroneous, given the large tidal range in the area. The region's significant population (third largest community near a possible tidal site) and large tidal range may make it worth considering.

3) Iqaluit is included in this table despite not being in Cornett's study at all. Frobisher Bay's tides were not modeled in the 2006 Marine Renewable Energy Resource Inventory. Canadian Hydrographic Service tables show a daily tidal range of up to 11 m in Iqaluit. Iqaluit is also Nunavut's largest settlement, with the greatest energy demand. These factors make its inclusion in future tidal modelling efforts a natural choice.

Table 3. Approximate distances from identified communities to tidal sites identified by Cornett (2006).

Community Name	***Site Name***	***Approximate Distance & Direction from Community***
Cape Dorset	Mill Island-Salisbury Island	65 km, SW
	Mill Island-Baffin Island	50 km, W
Naujaat	Hurd Channel	90 km, E-SE
	Wager Bay Narrows	140 km, S
Igloolik	Labrador Narrows	50 km, W-NW
Gjoa Haven	James Ross Strait	130 km, N-NE
	Egg Island	60 km, W
	Spence Bay	120 km, NE
Resolute	Resolute Bay	Coincident
Grise Fiord	Cardigan Strait	200 km, W
	Hells Gate	200 km, W
Ivujivik	Nottingham Island-Ungava	50 km, N
	Salisbury Island-Nottingham Island	120 km, N
Salluit	Nottingham Island-Ungava	130 km, W-NW
	Salisbury Island-Nottingham Island	170 km, NW
Kuujjuaq	Koksoak Entrance	50 km, N
	Koksoak Narrows	10 km, N
Sachs Harbour	Cape Parry	200 km, S
	Pearce Point	260 km, S-SE
	Cape Kellet	30 km, W
	Observation Point	180 km, SW
Ulukhaktok	Cape Parry	260 km, W-SW
	Pearce Point	210 km, SW
	Cape Kellet	320 km, NW
	Observation Point	380 km, W

Note: Approximate distance & direction from community is determined using the ruler tool in Google Earth Pro, measured from community airports to the coordinates given in Table 1 for each identified site.

Table 4. Community ratings based on established criteria[1].

Community Name	***Population >1,000***	***Annual Energy Demand >5,000 MWh***	***Strength of Tidal Resource[2]***	***Sites within 50 km***
Cape Dorset	1,441	5,685	N/A; 18,010 MW	1
Gjoa Haven	1,324	5,619	2 – 3 m/s; 160 MW	0
Grise Fiord	No	No	1.5 m/s; 74 MW	0
Igloolik	1,682	6,587	2.6 m/s; 320 MW	1
Iqaluit	7,740	59,140	N/A	0
Naujaat	1,082	No	2.6 m/s; 39 MW	0
Pangnirtung	No	6,506	N/A	0
Resolute	No	No	1.3 m/s; 3 MW	1
Ivujivik	No	No	N/A; 3,676 MW	1
Kuujjuaq	2,754	20,333	2.6 – 2.9 m/s; 238 MW	2
Salluit	1,483	8,326	N/A; 3,676 MW	0
Sachs Harbour	No	No	1 – 1.75 m/s; 35 MW	0
Ulukhaktok	No	No	1 – 1.75 m/s; 35 MW	0

Note: 1) Available oceanographic data is excluded from this table due to pending data requests from other government departments. 2) Although the criteria set out in Section 3.4 focused on current velocity, due to the lack of a current velocity reported for the sites near Cape Dorset, Salluit, and Ivujivik, estimated potential power generation (in MW) is reported for all sites while these three have a value of N/A for currents. Similarly, Iqaluit and Pangnirtung are given ratings of "N/A" as they were not identified as sites for tidal stream power in Cornett's (2006) report but are of interest for other reasons. See Section 5 for further discussion.

Figure 2. Map indicating the 13 communities discussed in Table 1 and Table 2.
Map data: Google 2020.

5. Conclusions

Based on the results of this scoping review, four northern communities have been identified as being more suitable than others as potential locations for future deployments of tidal energy technologies to help offset diesel power generation. The identified communities are: Iqaluit, Kuujjuaq, Igloolik and Cape Dorset. Interest in Cape Dorset and Igloolik is based primarily on their close proximity to large tidal resources identified by Cornett, while Iqaluit (and Frobisher Bay, on which it sits) was not identified as a high-energy location in the Cornett (2006) study. However, it is important to note that the 2006 study findings for northern Canada should be associated with a high degree of uncertainty due to the paucity of field data and the absence of high-resolution modelling and targeted regional studies available at that time. It is quite possible, even likely, that many other high-energy sites exist throughout north Canada, in addition to those identified in Cornett (2006).

Kuujjuaq, likewise, is in very close proximity to a strong tidal resources identified by Cornett (2006). Moreover, its larger population and higher fuel consumption may make it a particularly attractive location for future tidal power development. Ocean Renewable Power Company (ORPC) — a private tidal developer — is already considering an in-stream turbine deployment near the mouth of the Koksoak River near Kuujjuaq. As described in Richard and Cornett (2019), NRC-OCRE recently worked with ORPC to investigate whether hydrokinetic turbines could operate successfully in water with high concentrations of frazil ice. NRC will consult with OPRC to ascertain whether they or their partners have performed any detailed resource assessment work near Kuujjuak, including oceanographic data collection or numerical tide modelling.

Iqaluit is Nunavut's largest settlement, and the largest coastal community in northern Canada. As the tidal range exceeds 11 m in Frobisher Bay, Iqaluit's relatively large population and economy make it a likely candidate for any first pilot tidal plants in the north. Cape Dorset and Igloolik, though smaller, are near known tidal resources, and are large enough communities that infrastructure development and local skills acquisition in the tidal sector may be a good fit with federal economic development goals in Nunavut.

It must be noted that all sites identified in the Arctic region in Cornett's (2006) report were assessed, in part, based on hydrodynamic modelling in WebTide. WebTide is a graphical user interface for a tidal prediction program and was developed by the Bedford Institute of Oceanography. At the time of the Cornett (2006) report, WebTide's arctic dataset had been released in 2002, and was known to have several deficiencies that may underestimate tidal current speeds. One of these deficiencies is the fact that the smallest grid-cell size had an edge length of 2 km; while this is reasonable for open ocean modelling, it can introduce significant error in areas with narrow coastal channels.

This review has identified other communities where further data review and future modelling may be of interest in light of the fact that the results for northern Canada in Cornett (2006) must be associated with a high degree of uncertainty. Among these are:

- Gjoa Haven, NU: Located on southeastern King William Island, Gjoa Haven is on a large bay with three identified tidal potential sites with combined energy potential of 160 MW along the channels that feed that bay. Only one of the sites Cornett identified is less than 100 km away (Egg Island), but it is possible other nearby tidal channels may be of interest in the future.
- Naujaat, NU: Naujaat is located on the Nunavut mainland on a bay that is fed by the two channels that separate Southampton Island from the mainland. Hurd Channel, 90 km to Naujaat's east, is identified by Cornett (2006) as having 35 MW of tidal potential. The Wager Bay Narrows, south of Naujaat and splitting off to the west of the channel that leads north to Naujaat, were assessed as having 4 MW of potential.
- Salluit, QC: Located within Nunavik, the Inuit region that makes up northern Quebec (and part of Inuit Nunangat), Salluit lies on a channel on the southern side of the Hudson Strait. This channel varies in width, but near Salluit is between 1.6 and 3 km across. Tidal range at Salluit can exceed 5 m. Although Cornett identified tidal potential sites within the Hudson Strait, rather than the channel on which Salluit lies, it is likely there is strong tidal potential in this region given its location along the Strait and high tidal range.
- Pangnirtung, NU: While Cornett (2006) suggests a range >3.5 m in Cumberland Sound, tidal velocities in the Sound are indicated to have RMS speeds below 0.05 m/s. If higher resolution

bathymetric data is available it may be worthwhile to develop a hydrodynamic model of the flows in Cumberland Sound to reassess the accuracy of these initial estimates.

Based on the criteria developed in this review, several communities near potential tidal sites identified in Cornett (2006) can be put at a lower priority for future consideration and study. Namely: Grise Fiord (NU), Resolute (NU), Sachs Harbour (NT), Uuakhaktok (NT), and Ivujivik (QC). All of these communities are likely too small to justify the high cost and relative high risk of still-unproven tidal energy technologies. Additionally, the remaining Nunavik communities of northern Quebec around Ungava Bay were screened according to these criteria, and excluded from the tables in this report as they all fell well below both the population and annual energy demand criteria thresholds. However, given that the tide range in this region is very large, it is quite likely that good high-energy sites worth developing may exist near some of these communities.

6. References

Bradley, P. T., Evans, M. D., & Seitz, A. C. (2015). Characterizing the Juvenile Fish Community in Turbid Alaskan Rivers to Assess Potential Interactions with Hydrokinetic Devices. *Transactions of the American Fisheries Society*, 144(5), 1058–1069. https://doi.org/10.1080/00028487.2015.1064474

Brown, T. & Määttänen, M. (2009). Comparison of Kemi-I and Confederation Bridge cone ice load measurement results. *Cold Regions Science & Technology, 55*, 3-13.

Browne, T., Frederking, R., & Poirier, L. (2018). Ice Load Analysis - Champlain Bridge Estacade. *NRC-OCRE Technical Report – Protected A*, OCRE-TR-2018-032.

Cornett, A. (2006). Inventory of Canada's Marine Renewable Energy Resources. *NRC Technical Report*, CHC-TR-041.

Devine-Wright, P. (2011a). Place attachment and public acceptance of renewable energy: A tidal energy case study. *Journal of Environmental Psychology, 31*(4), 336-343.

Devine-Wright, P. (2011b). Enhancing local distinctiveness fosters public acceptance of tidal energy: A UK case study. *Energy Policy, 39*(1), 83-93. doi: 10.1016/j.enpol.2010.09.012

Doelle, M. (2009). Role of Strategic Environmental Assessments in Energy Governance: A Case Study of Tidal Energy in Nova Scotia's Bay of Fundy. *Journal of Energy & Natural Resources Law, 27*(2), 112–144. https://doi.org/10.1080/02646811.2009.11435210

Flynn, B. (2015). Ecological modernisation of a 'Cinderella renewable'? The emerging politics of global ocean energy. *Environmental Politics, 24*(2), 249-269. doi: 10.1080/09644016.2014.1000638

Kasper, J.L., Johnson, J.B., Duvoy, P.X., Konefal, N., & Schmid, J. (2015). A review of debris detection methods. Portland, Oregon: Northwest National Marine Renewable Energy Center.

Kerr, S., Watts, L., Colton, J., Conway, F., Hull, A., Johnson, K., … Vergunst, J. (2014). Establishing an agenda for social studies research in marine renewable energy. *Energy Policy, 67*, 694–702. https://doi.org/10.1016/j.enpol.2013.11.063

Laws, N. D., & Epps, B. P. (2016). Hydrokinetic energy conversion: Technology, research, and outlook. *Renewable and Sustainable Energy Reviews, 57*, 1245–1259. https://doi.org/10.1016/j.rser.2015.12.189

MacDougall, S. L. (2015). The value of delay in tidal energy development. *Energy Policy, 87*, 438–446. https://doi.org/10.1016/j.enpol.2015.09.034

Natural Resources Canada. (2018). Remote Communities Energy Database. [Data] Retrieved from: https://atlas.gc.ca/rced-bdece/en/index.html

Neill, S. P., Angeloudis, A., Robins, P. E., Walkington, I., Ward, S. L., Masters, I., Lewis, M. J., Piano, M., Avdis, A., Piggott, M. D., Aggidis, G., Evans, P., Adcock, T. A. A., Židonis, A., Ahmadian, R., & Falconer, R. (2018). Tidal range energy resource and optimization – Past perspectives and future challenges. *Renewable Energy, 127*, 763–778. https://doi.org/10.1016/j.renene.2018.05.007

Polagye, B., Van Cleve, B., Copping, A., & Kirkendall, K. (eds.) (2011). Environmental Effects of Tidal Energy Development. US Department of Commerce. NOAA Technical Memorandum NMFS F/SPO-116.

Richard, M. & Cornett A. (2019). NRC Frazil Ice Research Facility. Proc. 2019 Annual Conference of the Canadian Society of Civil Engineering (CSCE). Laval, Canada.

Sangiuliano, S., & Mastrantonis, S. (2017). From Scotland to New Scotland: Constructing a sectoral marine plan for tidal energy for Nova Scotia. *Marine Policy, 84*, 1–11. https://doi.org/10.1016/j.marpol.2017.06.023

Segura, E., Morales, R., & Somolinos, J. A. (2018). A strategic analysis of tidal current energy conversion systems in the European Union. *Applied Energy, 212*, 527–551. https://doi.org/10.1016/j.apenergy.2017.12.045

Shields, M. A., Dillon, L. J., Woolf, D. K., & Ford, A. T. (2009). Strategic priorities for assessing ecological impacts of marine renewable energy devices in the Pentland Firth (Scotland, UK). *Marine Policy, 33*(4), 635–642. https://doi.org/10.1016/j.marpol.2008.12.013

Wright, G. (2014). Strengthening the role of science in marine governance through environmental impact assessment: a case study of the marine renewable energy industry. *Ocean & Coastal Management, 99*, 23–30. https://doi.org/10.1016/j.ocecoaman.2014.07.004