Siting tidal energy projects through resource characterization and environmental considerations

Andrea E. Copping, Lysel Garavelli, Zhaoqing Yang, Taiping Wang, Mithun Deb, and Candace Briggs

Abstract— **The development of tidal energy technologies is dependent on the ability to site and gain regulatory permission to deploy and operate devices. This paper sets out a framework for reaching preliminary siting of tidal devices, drawing from case studies from three locations in the US where research studies have provided information in support of tidal deployments. Tidal developers determined that waters of the San Juan Islands in northern Washington State, coastal Maine, and waters of Cook Inlet in Alaska were likely tidal development areas. Using numerical models and field observations, we characterized tidal resources at a scale that will allow for optimization of energy extraction. We examined the natural and human infrastructure constraints for deploying and operating tidal devices and arrays including channel widths, bathymetry, vessel traffic, ferry lanes, and grid interconnects, in order to narrow siting options, as well as the biological resources, with a focus on populations of endangered marine mammals and fish, and the critical habitats that support them. The biological resources were then related to the applicable regulatory requirements in place in US for federal and state statutes. Based on these analyses, preferred deployment locations were delineated and processes for meeting regulatory requirements laid out, including post-installation monitoring plans that will be needed. This initial assessment of logistical, regulatory, and environmental conditions for the deployment of a tidal technology is a first step toward the achievement of regulatory compliance for tidal energy projects.**

Keywords—**biological resources, regulatory consistency, resource characterization, siting, tidal energy.**

I. Introduction

THE development of tidal energy technologies has progressed to where devices can be deployed, operated, maintained, and recovered with some level of assurance that they will produce adequate levels of power. Equally important to further the tidal energy industry is the ability to site and gain regulatory permission to deploy and operate these devices [1]. Siting of tidal energy projects entails optimizing the tidal energy resource for power production, while minimizing the potential for damage and downtime for tidal turbines due to extreme environmental conditions or other hazards, while ensuring that the installation and operation will meet regulatory requirements without creating any damage to the marine environment or other users of the ocean [2], [3]. This paper sets out a methodology for reaching preliminary siting of tidal devices, drawing from case studies from three locations in the US where research studies have provided information in support of tidal deployments.

II. Methods

A rapid assessment framework was developed to organize and apply siting and regulatory acceptance information for tidal sites in the US. Three water bodies in the US were chosen by a tidal developer for potential tidal stream development: the waters surrounding the San Juan Island archipelago in northern Washington State of the Salish Sea, Western Passage in coastal Maine, and Cook Inlet in Alaska (Fig. 1). Information was gathered to support the siting and regulatory requirements for

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deployment within those water bodies, with some preferred siting locations. While considerably more detailed studies would be needed to site and meet regulatory requirements for deployment and operation, this information provides a first order analysis to support development.

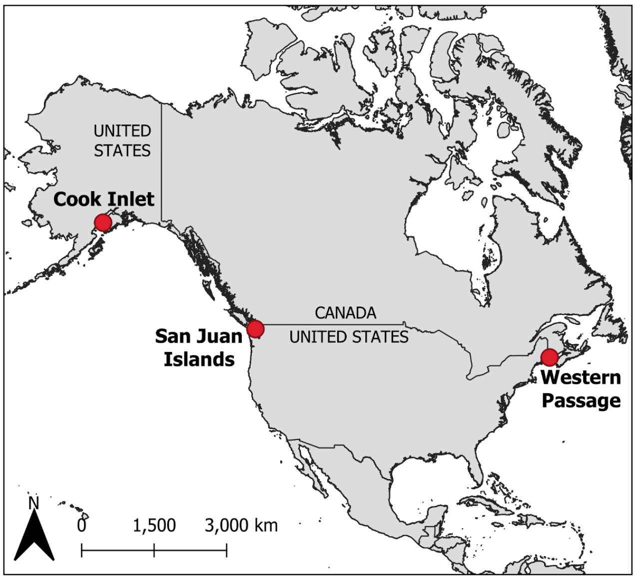

Fig. 1. Map of the three study areas (red circle) for the development of a tidal energy project in the US: Cook Inlet (Alaska), San Juan Islands (Washington), Western Passage (Maine).

The tidal resources available at each site were examined using data outputs from numerical models and field measurements. Publicly available data and information on bathymetry, biological resources and their conservation status, habitats, and infrastructure such as channel widths, shipping and ferry routes, and onshore grid connections, were collected and analyzed for siting and regulatory needs. A spatial analysis was carried out to determine the optimum site within a water body, and the framework for an environmental monitoring program developed to assist with meeting post-consenting needs.

A full analysis of each of the three waterbodies is available [4], [5].

III. RESULTS AND DISCUSSION

A. *Siting and Acceptance Framework*

A framework was developed for rapid resource and environmental assessment for tidal energy development. The stepwise process begins with assessing the available tidal resources and bathymetry for deployment; identifies infrastructure that will exclude development; examines the key biological resources and their protection and conservation status under US regulations; looks for infrastructure that will benefit a tidal project; compares available biological data to regulatory needs; and identifies likely development areas through spatial analysis (Table I).

Each step in the framework process was tested against the information generated through numerical models and field data collection, and publicly available information. Examples of the application of each step for each of the US water bodies identified in this study are shown in the subsequent sections.

B. *Tidal Energy Resources and Bathymetry*

Numerical models for simulating tidal hydrodynamics using the Finite Volume Community Ocean Model (FVCOM) had previously been developed in each of the water bodies [6], [7], [8]. High-resolution models with validation using field measurements allowed detailed and accurate tidal resource assessments at multiple locations in each water body. Initial assessments include a review of the tidal currents and bathymetry in the three water bodies (Figs. 2 and 3). In the San Juan archipelago, four channels show sufficient tidal current velocities to warrant further investigation—San Juan Channel, Rosario Strait, Middle Channel (Cattle Point), and Spieden Channel. In Western Passage, sufficient tidal current velocities are observed in the southeastern part of Western Passage, between Cummings Cove and Eastport. In Cook Inlet, deeper waters (> 50 m) are mainly observed in the central part and the southern parts of the inlet, and locations off Anchorage, Harriet Point, and between East and West Foreland have sufficient tidal current velocities.

Table I
FRAMEWORK FOR RAPID ASSESSMENT OF POTENTIAL TIDAL ENERGY DEVELOPMENT AREAS

Step	Topic	Criteria
1	Tidal Currents & Bathymetry	• Adequate power • Depth range
2	Infrastructure for Exclusion Zones	• Ferry routes & terminals • Navigation routes • Cable crossings
3	Biological Resources, Conservation Status	• Populations at risk • Critical habitats • Marine Protected Areas • Essential fish habitats
4	Supportive Infrastructure	• Grid connection • Distance to ports
5	Regulatory Needs	• Federal & state regulations • Monitoring needs
6	Spatial Analysis	• Integration of: o Power o Exclusion zones o Information for regulatory acceptance

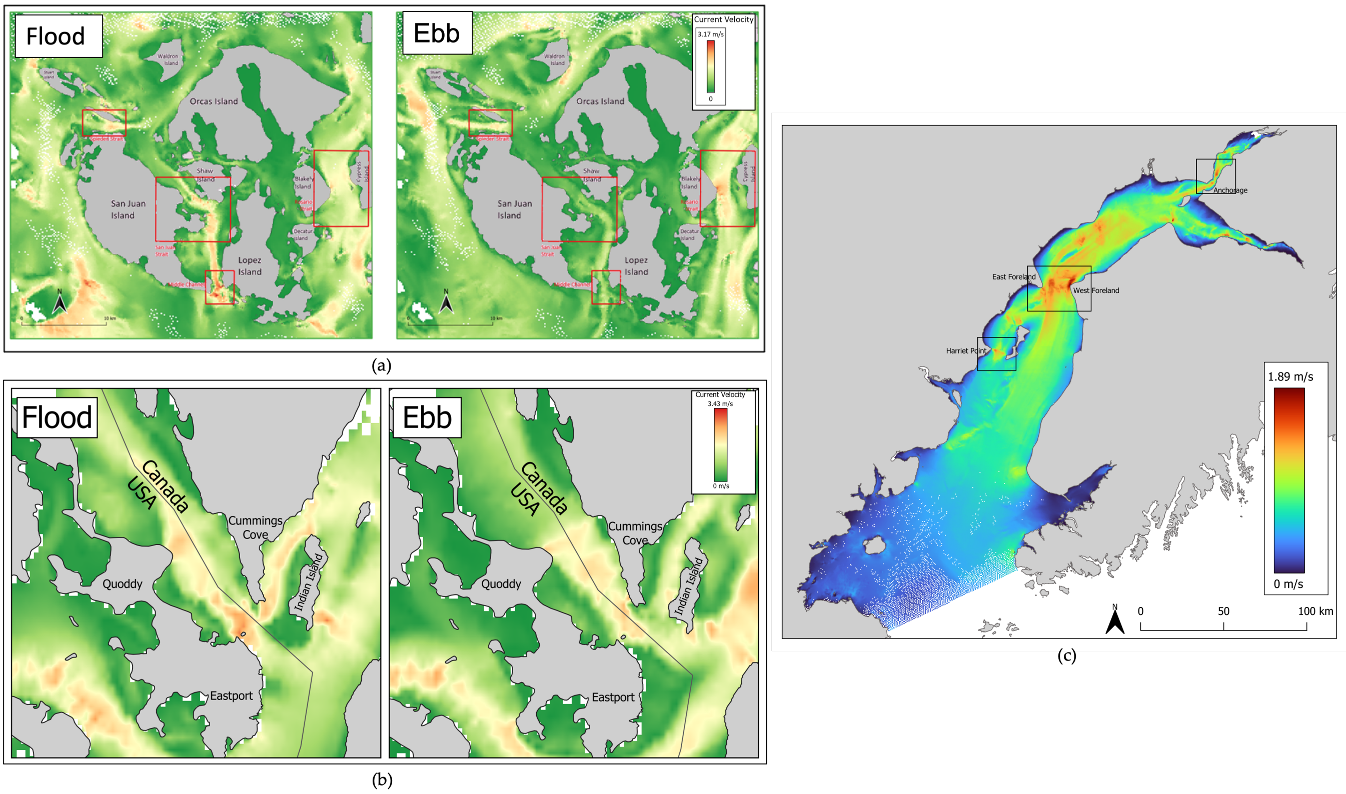

Fig. 2. Maximum current velocity during the spring tide around San Juan Islands, Washington (a) [6] and in Western Passage, Maine (b) [7]. Average yearly current velocities in Cook Inlet, Alaska (c) [8]. Red boxes in (a) and black boxes in (c) indicate locations with high current velocities.

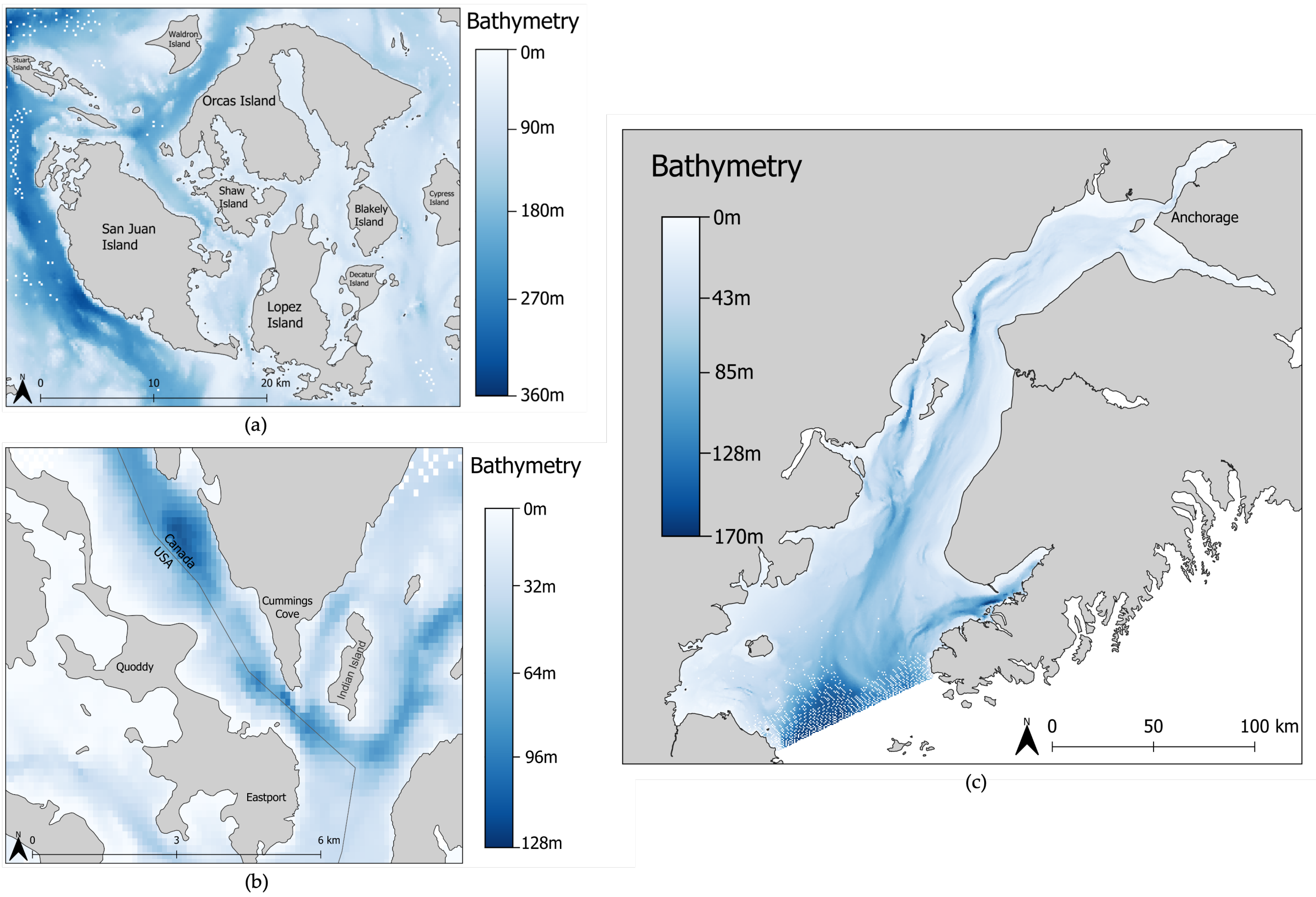

Fig 3. Bathymetric charts around San Juan Islands, Washington (a) [6], in Western Passage, Maine (b) [7], and in Cook Inlet, Alaska (c) [8].

C. *Infrastructure for Exclusion Zones*

Existing infrastructures in the water column and on the seafloor need to be considered to avoid any overlap with a tidal energy project. For example, in San Juan Islands, infrastructures that should be avoided are conduits, subsea cables, ferry terminals, and navigation routes (including ferry). Similarly in Cook Inlet, navigation routes and subsea cables are present (Fig. 4).

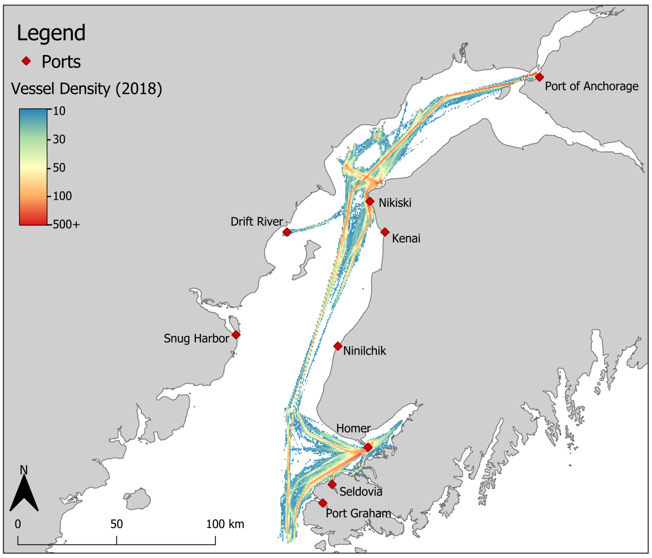

Fig 4. Density of vessels (data from 2018) and location of ports in Cook Inlet, Alaska.

D. *Biological Resources, Conservation Status*

Regulatory marine species and critical habitats are identified in the three study areas. In Western Passage, three species of fish, three marine mammals, and two sea turtles are listed (Table II).

Around San Juan Islands, several species are listed as threatened or endangered and have designated critical habitat. This is the case for the Southern resident killer whale (*Orcinus orca*), Chinook salmon (*Oncorhynchus tshawytscha*), North American green sturgeon (*Acipenser medirostris*), bocaccio (*Sebastes paucispinis*), and the Puget Sound yelloweye rockfish (*Sebastes ruberrimus*) (see Fig. 4 for bocaccio and yelloweye rockfish critical habitat).

E. *Supportive Infrastructure*

The presence of ports, distance between a port and a tidal energy project site, and location of grid connections were assessed in the three study areas. For example, nine ports are present in Cook Inlet (Fig. 5).

Table II
STATE OF FEDERAL STATUS (THREATENED, ENDANGERED) OF THE MARINE SPECIES THAT CAN POTENTIALLY OCCUR IN WESTERN PASSAGE, MAINE. DPS = DISTINCT POPULATION SEGMENT

	Threatened		Endangered	
Species	*State of Maine*	*Federal*	*State of Maine*	*Federal*
Atlantic salmon (*Salmo salar*)				X Gulf of Maine DPS
Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*)		X Gulf of Maine DPS		
Shortnose sturgeon (*Acipenser brevirostrum*)			X	X
North Atlantic right whale (*Eubalaena glacialis)*			X	X
Fin whale (*Balaenoptera physalus)*			X	X
Sei whale (*Balaenoptera borealis*)			X	X
Leatherback sea turtle (*Dermochelys coriacea)*			X	X
Loggerhead sea turtle (*Caretta caretta)*	X	X Northwest Atlantic Ocean DPS		

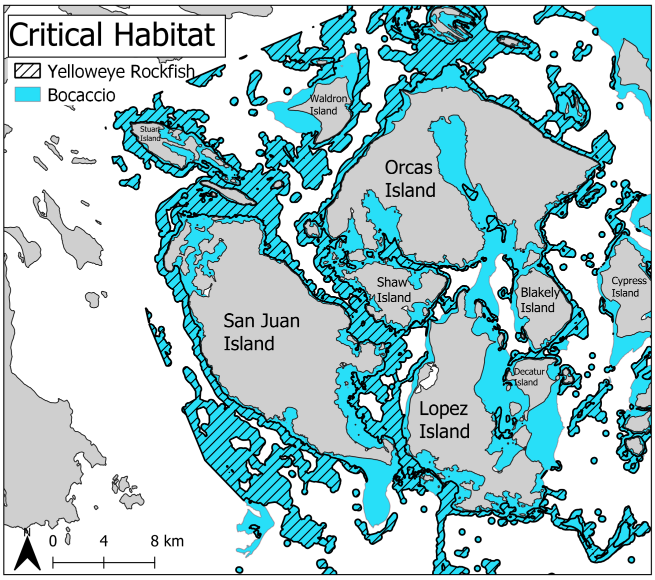

Fig 5. Critical habitat map for the endangered bocaccio and threatened yelloweye rockfish in San Juan Islands, Washington (NOAA Fisheries).

F. *Regulatory Needs*

The regulatory context applicable to tidal energy development was explored, at both the US federal level (which applies to the three water bodies) and for each of the applicable state regulatory processes for Washington, Maine, and Alaska, respectively. For each applicable regulation or law, the pertinent portion of the marine environment (or "receptor") was listed. An example is showed in Table III for San Juan Islands.

Table III

KEY FEDERAL, STATE, AND LOCAL REGULATIONS NEEDED FOR PERMITTING MARINE ENERGY DEVICES IN THE SAN JUAN ISLANDS, WASHINGTON.

Jurisdiction	Regulation	Cognizant Agency	Receptor of Concern (where applicable) / Notes
Federal	Endangered Species Act	National Oceanic and Atmospheric Administration (NOAA)-National Marine Fisheries Service (NMFS)	Marine mammals, marine and most anadromous fish
Federal	Endangered Species Act	U.S. Fish and Wildlife Service (USFWS)	Land-based and sea birds, certain species of anadromous fish, sea otters
Federal	Marine Mammal Protection Act	NOAA-NMFS	Marine mammals
Federal	Migratory Bird Treaty Act	USFWS	Migratory birds
Federal	Rivers and Harbors Act, Clean Water Act	U.S. Army Corps of Engineers	Navigation
Federal	Federal Power Act	Federal Energy Regulatory Commission (FERC)	National Environmental Policy Act process
Federal	PATON (Private Aid to Navigation)	U.S. Coast Guard	Navigation lighting and notice to mariners
State	Clean Water Act (delegated from the U.S. Environmental Protection Agency)	Washington Department of Ecology	Water quality, habitat quality, consistency with federal regulations for shorelines
State	Hydraulic Project Approval	Washington Department of Fish and Wildlife	Wildlife, habitats, includes timing for construction activities
State	Aquatic Use Authorization	Washington Department of Natural Resources	Lease of seabed in state waters
State	Various Statutes	Washington Department of Transportation	Applicable if state roadways or other assets are involved in the project
Local	Shoreline Management Act	San Juan County	Program not currently in place

G. *Spatial Analysis*

The feasibility to develop a tidal energy project in the three study areas is illustrated within Cook Inlet. The suitability was assessed through a spatial analysis that included the relevant parameters considered for such project:

- bathymetry and yearly average current velocities
- infrastructures – navigation routes, distance to ports, subsea cables
- biological resources and conservation status – species critical habitat and essential fish habitat.

Table IV describes each data layer included in the spatial analysis and the constraints for their inclusion in or exclusion from the analysis. For example, navigation routes (> 10 vessel tracks) are excluded as areas for potential tidal development in the analysis. The spatial analysis identifies suitable areas for a tidal energy project across these various parameters.

Table IV

PARAMETERS INCLUDED IN THE SPATIAL ANALYSIS AND ASSOCIATED CONSTRAINTS TO IDENTIFY SUITABLE AREAS FOR DEVELOPING A TIDAL ENERGY PROJECT IN COOK INLET, ALASKA.

Parameter	Constraint
Average annual current velocities	> 1 m/s
Bathymetry	50 – 80 m
Navigation routes > 10 vessel tracks	Entire area excluded
Distance to ports	0 – 40 km
Underwater cables	Entire area excluded (500 m buffer)
Critical habitat (Beluga whale, Northern sea otter, Stellar sea lion)	Entire area excluded
Essential fish habitat (Pacific cod, salmon, scallop, sculpin, skates, walleye pollock, rockfish, sablefish)	Entire area excluded

The spatial analysis produced a heatmap with a grid of points of approximately 0.8 km x 0.8 km in resolution. Results of the suitability for a tidal energy project in Cook Inlet are showed in Fig. 6 with higher suitability in the northern part of the inlet. The low suitability observed off the Anchorage coast can be explained by high vessel traffic, shallow bathymetry, and the presence of critical habitat for beluga whales.

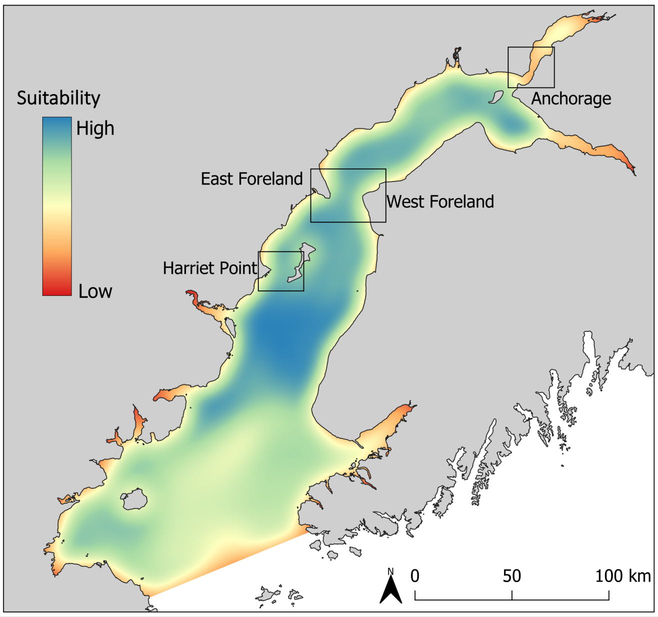

Fig 6. Heatmap of the suitability for the development of a tidal energy project in Cook Inlet, Alaska.

IV. CONCLUSION

The assessment framework to organize and apply siting and regulatory acceptance information for tidal sites in the US was successfully applied to three water bodies: San Juan Islands, Western Passage, and Cook Inlet. The application of the framework used information and data derived from publicly available databases as well as hydrodynamic models. While these information and data represent most of what is required for an assessment of regulatory permission, this type of methodology does not replace any regulatory requirements. Based on the assessment from this study, suitable areas were identified to develop potential tidal energy projects in US waters.

The framework developed to assess the three waterbodies can provide a useful starting point for assessing areas where tidal energy seems feasible. Additional studies will always be needed to provide detailed siting of projects. In addition, the regulatory structure of each nation or region where tidal devices are ready for deployment will need to be examined, along with the conservation status and infrastructure assets in each jurisdiction.

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