APPLICATION OF THE IEC TIDAL ENERGY RESOURCE ASSESSMENT AND CHARACTERIZATION TECHNICAL SPECIFICATION TO THE ROOSEVELT ISLAND TIDAL ENERGY (RITE) SITE

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INTRODUCTION

The extraction of hydrokinetic energy is the conversion of the kinetic energy of moving water into another form of energy, frequently electricity. This water motion may be in the form of waves, tides, ocean currents or river flows. In addition to the development of the technology, the successful extraction of hydrokinetic energy requires a clear understanding of physical, environmental and social aspects of the resource and their interactions with the technology. Much work over the past decade has been completed developing Technical Specifications (TS), pre-cursers to International Standards, which provide guidance and best practice methods to facilitate the development of the hydrokinetic industry in a consistent manner. The full spectrum of hydrokinetic industry stakeholders, beyond just project developers, can use these TS.

An International Electrotechnical Commission (IEC) TS was published in 2015, outlining a standardized methodology for performing a resource assessment and characterization for tidal energy [1]. The objective of this TS is to provide a consistent, systematic and acceptable methodology for computing the tidal current probability distributions. These distributions are used with the power curve of a specific technology to determine the annual energy production (AEP) of a tidal energy project. The AEP is an important measure of the opportunity for energy generation and is used to calculate the levelized cost of energy, which can be used as a measure of technology performance.

To help clarify the types of resource assessments, the IEC has defined a conceptual framework for assessing marine hydrokinetic resources [2]. The overall assessment process is considered in three stages: theoretical, technical, and practical. The theoretical resource consists of the hydrokinetic energy available for conversion without consideration of any turbine properties. In essence, this is the power within the undisturbed flow field. The technical resource is the amount of power that can be generated considering the particular technology to be utilized. This resource assessment will incorporate turbine efficiencies and interactions with the flow field and will be a fraction of the theoretical resource. Finally, the practical resource includes the additional external constraints of turbine operation such as regulatory, environmental, economic, and life cycle constraints. The practical resource will again be a fraction of the technical resource.

The TS for tidal energy resource assessments outlines two stages, feasibility (stage 1) and layout design (stage 2). Stage 1 assessments generally focus on the theoretical resource whereas stage 2 assessments focus on the technical and practical resource. The methodologies for the two stages are similar, the primary difference between the two stages being the amount of uncertainty that is allowable. The specific methodology utilized will depend on the scale of the project. For small projects, direct measurements of the currents at the proposed turbine locations may be used to estimate the velocity probability distributions directly. Alternatively, a resource assessment based on a calibrated and validated numerical model is allowable. Model calibration and validation are accomplished using in situ water level and velocity measurements.

For larger projects the use calibrated and validated numerical models are required, including the effect of energy extraction from the turbines to account for the reduction in the flow. The velocity structure at each turbine location is determined from the model in order to create the required probability distributions used to compute the AEP.

This paper presents the application of the IEC TS for a stage 1 feasibility assessment for the Roosevelt Island Tidal Energy (RITE) project in the East River, New York, NY. The intention is to provide a case study example to illustrate how this TS is applied. Following a description of the RITE project, field measurements and numerical modeling efforts are described, values of key resource statistics generated from these efforts are summarized along with other plots that describe the main tidal energy resource characteristics at the site.

THE RITE PROJECT

Verdant Power's RITE project is a multi-year initiative to install, operate, and demonstrate tidal energy turbine systems in the East Channel of the East River in New York City under a FERC Hydrokinetic Pilot Project License (FERC No. P-12611). The RITE project has been a showcase project in the United States for the marine energy sector, representing the world's first grid-connected array of tidal turbines and the first US commercial tidal Pilot license.

The East River is a 27 km long tidal strait connecting the waters of the Long Island Sound with those of the Atlantic Ocean in New York Harbor. It separates the New York City Boroughs of Manhattan and the Bronx from Brooklyn and Queens and is a saltwater conveyance passage for tidal flows. Roosevelt Island splits the East River in to two channels, the West Channel, the primary navigation channel, and the East Channel, where the RITE Project is located (Figure 1).

MEASUREMENTS

Verdant Power has collected detailed site assessment measurements, including water velocity, water depth and bathymetry, among others, for more than a decade. Bottom-mounted Acoustic Doppler Current Profilers (ADCPs) deployed at RITE are cabled to shore to provide power and real-time data transmission. Figure 2 provides representative parameters for bottom-mounted ADCP deployments at RITE. Additional hub-height Acoustic Doppler Velocimeter (ADV) data has been collected at RITE [9].

NUMERICAL MODEL

Numerical model simulations of the tidal flows within the project region use the ROMS modeling system similar to the original US national tidal energy resource assessment [3]. ROMS is a 3-dimensional, free surface, terrain-following numerical model that solves 3-D Reynolds-averaged (time-averaged based on Reynolds decomposition) Navier-Stokes (RANS) equations using hydrostatic and Boussinesq assumptions [6]. ROMS uses finite-difference approximations on a horizontal curvilinear Arakawa C grid and vertical stretched terrain-following coordinates [7]. Momentum and scalar advection and diffusive processes are solved using transport equations and an equation of state is used to compute the density field that accounts for temperature, salinity, and suspended sediment concentrations. The model is configured to run with multiple processors using distributed memory.

FIGURE 1. RITE PROJECT LOCATION.

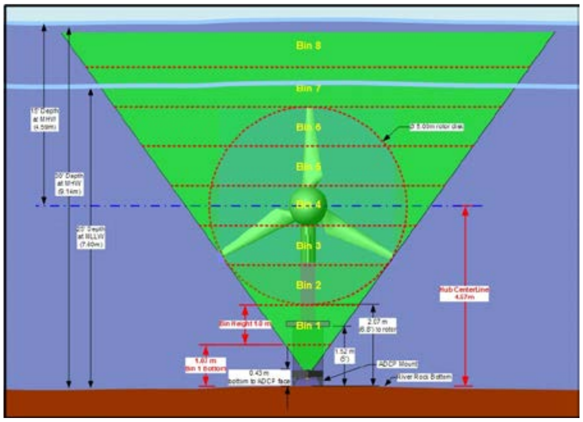

FIGURE 2. BOTTOM-MOUNTED ADCP DEPLOYMENT.

The model domain shown in Figure 3 encompasses the entire Long Island Sound, the East River and the Hudson River. The grid resolution within the East River is increased relative to Defne et al. [3] to 50m to better resolve the RITE Project site. In the simulation, the coastline data used to mask the land nodes was obtained from the National Ocean Service (NOS) Medium Resolution Coastline via the Coastline Extractor. Raw bathymetry was obtained from the NOS Hydrographic Surveys Database. The ROMS tidal forcing file is generated by interpolating the

ADCIRC tidal database (http://adcirc.org/) at the open boundary nodes of the ROMS grid. The harmonic constituents used for the forcing includes Q1, O1, K1, S2, M2, N2, K2, M4 and M6. The simulations are run for 32 days. With the rapid development of tidal currents in the model, the first 2 days are considered as model spin up and the last 30 days used for the tidal analysis. The model is calibrated by adjusting the roughness coefficient to match the water level tidal constituents from the model at all locations with those from available constituent data.

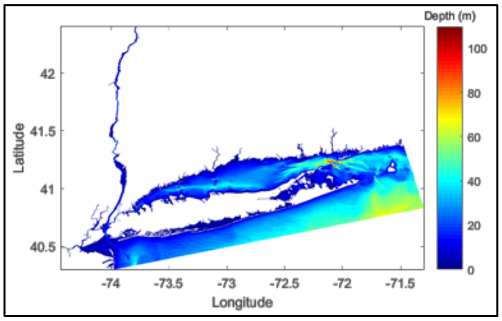

FIGURE 3. NUMERICAL MODEL DOMAIN.

RESOURCE CHARACTERIZATION

An example of the water level constituent data (amplitude and phase), and comparisons between observations and model predictions, is shown in Table 1 for a measurement location with the RITE Project site. The full comparisons include the top 20 constituents, whereas for brevity, only the top seven are shown here. Additional model calibration is done by adjusting roughness to match depth-averaged current constituents computed from the model with those computed from the ADCP data. An example for the top seven velocity constituents is shown in Table 2. This includes the current amplitude, phase and inclination. The agreement of model constituents varies, generally less than ten-percent for dominant water level and velocity constituents, e.g., M2, S2, N2, but over ten-percent for the others.

TABLE 1. WATER LEVEL CONSITITUENT COMPARISIONS BETWEEN MODEL AND MEASUREMENTS

		Amplitude (m)				Phase (deg)			
Name	T (h)	Obs	Mod	Diff	Diff (%)	Obs	Mod	Diff	Diff (min)
M2	12.42	0.569	0.590	0.021	3.67	74.57	70.29	-4.28	-8.86
S2	12.00	0.117	0.119	0.002	1.45	96.98	93.06	-3.92	-7.84
N2	12.66	0.111	0.119	0.008	7.47	59.87	50.98	-8.89	-18.76
K1	23.93	0.079	0.102	0.023	29.28	180.41	190.20	9.78	39.03
M4	6.21	0.072	0.092	0.019	26.83	157.76	157.22	-0.55	-0.57
M6	4.14	0.065	0.074	0.009	13.15	179.28	155.35	-23.93	-16.51
O1	25.82	0.047	0.063	0.015	32.63	201.33	199.67	-1.66	-7.13

TABLE 2. VELOCITY CONSITITUENT COMPARISIONS BETWEEN MODEL AND MEASUREMENTS

		Amplitude (m/s)				Inclination (deg)			Phase (deg)			
Name	T (h)	Obs	Mod	Diff	Diff (%)	Obs	Mod	Diff	Obs	Mod	Diff	Diff (min)
M2	12.42	1.98	1.89	-0.09	-4.64	61.3	58.5	-2.8	341.2	330.9	-10.3	-21.3
S2	12.00	0.31	0.30	0.00	-0.52	61.2	58.5	-2.7	14.5	1.7	-12.7	-25.5
N2	12.66	0.29	0.28	-0.02	-5.56	60.8	58.5	-2.3	330.8	317.8	-13.0	-27.3
K1	23.93	0.03	0.05	0.02	86.74	63.3	58.9	-4.5	94.7	77.4	-17.3	-69.2
M4	6.21	0.10	0.04	-0.06	-58.90	64.4	53.3	-11.1	335.6	329.0	-6.6	-6.9
M6	4.14	0.14	0.18	0.04	30.75	60.4	58.6	-1.8	127.1	95.3	-31.9	-22.0
O1	25.82	0.05	0.05	0.00	-7.58	61.1	59.0	-2.2	111.6	102.6	-9.0	-38.6

The vertical structure of the currents computed from the model and from the ADCP are compared in Figure 4. These currents span a full flood/ebb tidal cycle, although different time periods for the model and measurements, and are each averaged over a one-hour window. The model captures the vertical structure best in the lower portion of the water column where the turbines will be deployed. Both observed and measured profiles exhibit the dominant characteristics of turbulent boundary layer flows over the entire tidal range, similar to rivers current profiles [4]. Near the surface, where agreement is not as good, currents may be driven by wind-shear and complex bathymetry and secondary flow patterns that can be difficult to model. The observed profiles exhibit the *velocity-dip effect* near the free surface, which is often attributed to secondary flows [5]. The turbulence intensities for this site measured with a deployment of ADVs has previously been reported [9].

Validation of the model is done following the guidelines in the TS by computing and comparing the AEP (without the turbine power curve) computed directly from the ADCP measurements with that computed from the model. In addition, the power density from both the model and measurements are compared.

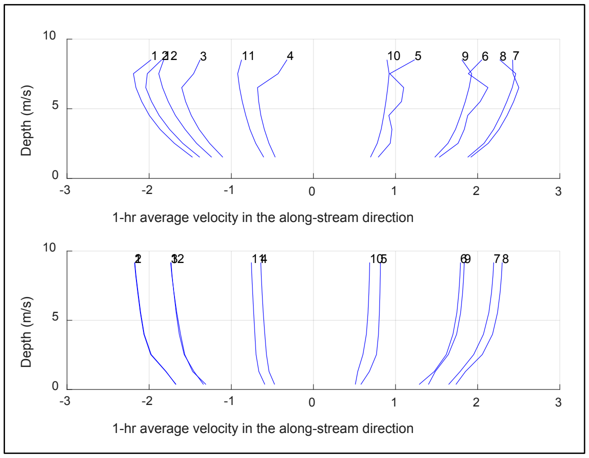

FIGURE 4. VERTICAL STRUCTURE OF 1 HOUR AVERAGED CURRENTS FROM THE ADCP (TOP) AND MODEL (BOTTOM) OVER A TIDAL CYCLE (DIFFERENT TIME PERIODS). FLOOD IS POSITIVE (TO THE NORTHEAST), EBB IS NEGATIVE (TO THE SOUTHWEST).

RESOURCE ASSESSMENT

The preliminary results include computations of the kinetic power density as well as the average annual power based on the method by Garrett and Cummins (G&C) [8], both common measures of the theoretical resource. The modeled kinetic power density of the depth averaged current is 1.9 kW/m², a sizeable increase from previous estimates (0.5 kW/m²) from Defne et al. [3]. This also compares favorably with the depth averaged power from the ADCP, 2 kW/m², as well as the previously computed power density measured by an ADV at hub height of 2.3 kW/m² [9]. The G&C estimate is 13 MW total annual average power for the combination of both channels in the East River. This is again a sizeable increase from previous estimates by Defne et al. (4 MW) demonstrating the importance of following the requirements in the TS. The licensed practical resource for the RITE project is 1 MW.

CONCLUSION The present study demonstrates the recommended methods when conducting a feasibility (stage 1) theoretical resource assessment at a tidal energy site. The numerical modeling requirements for this stage 1 assessment (increased resolution and model validation), significantly improve the accuracy of the resource estimate compared to reconnaissance level assessments. The model predicted theoretical power density and tidal constituents agree well with estimates derived from ADCP measurements.

Additional work will be done to perform the full resource assessment as outlined in the TS. The probability distributions of the velocity will be presented. In order to perform the resource assessment, the velocity must be computed for bins across the turbine-projected area as shown in Figure 2. Because the scale of the project is relatively small, either the ADCP measurements or the model may be used to compute the velocity distributions for computing the AEP. The velocities distributions within each bin can be used together with a power curve to compute the AEP for the turbine. However, the AEP without the power curve included will be presented for this work.

General comments about the usability of the technical specification will be provided. This will include highlights of aspects methodology of the TS that would need to be incorporated for larger scale projects.

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