PARAMETER UPDATES TO PROBABILISTIC TIDAL TURBINE – FISH INTERACTION MODEL

Chris Tomichek
Kleinschmidt Associates
Essex, CT, USA

Jonathan Colby[1]
Verdant Power
New York, NY, USA

Mark Bevelhimer
Oak Ridge National Lab
Oak Ridge, TN, USA

Mary Ann Adonizio
Verdant Power
New York, NY USA

[1]Corresponding author: jcolby@verdantpower.com

INTRODUCTION

As part of the FERC licensing process for Verdant Power's FERC licensed Roosevelt Island Tidal Energy (RITE) Project (P-12611) in the East Channel of the East River, New York City (NYC) a Kinetic Hydropower System (KHPS)–Fish Interaction Model (KFIM) was developed. The model addresses the probabilities of fish interacting with a pilot project array of up to 30 KHPS turbines operating in the East Channel of the East River [1]. The model uses seven parameters (water velocity distribution; channel geometry; physical and operation characteristics of the turbines; and specific fish characteristics, such as size, burst swimming speed, and swimming velocity and endurance) to determine the probability of an interaction.

During the RITE demonstration, Verdant Power conducted environmental monitoring efforts required under project permits to advance the understanding of fish presence, abundance, species characterization and fish interaction with operating kinetic hydropower turbines. This monitoring involved various applications of hydroacoustic detection devices in an effort to understand fish interaction with the Verdant KHPS. As part of the start of construction and the final technology development, with partial funding from the New York State Energy Research and Development Authority (NYSERDA)[1] and the US Department of Energy[2] (DOE), following a year of preparatory work in September 2012, Verdant successfully completed an in-water test of an updated KHPS turbine rotor including composite blades and concurrently deployed a remotely aimed DIDSON system. The data collection effort resulted in over 370 hours of DIDSON video with and without the operation of a KHPS turbine being assembled and subsequently analyzed [2].

Concurrent, a stationary Acoustic Doppler Current Profiler (ADCP) also collected detailed tidal velocity measurements as the horizontal axial turbine operated. These data were collected continuously for 19 days (August 30–September 18, 2012) through multiple tidal cycles, including periods with and without the turbine in place and periods (according to water velocity conditions) when the turbine rotor was turning and when it was stationary. From August 29 through September 3, the DIDSON was put through various tests to ensure proper data collection and operation of the remote-control aiming system. Data were collected during this time, and the turbine was allowed to rotate only during flood tides. Turbine operation began during ebb tides as well as flood tides on September 4 and continued through September 7. On September 8, the turbine testing was terminated, and turbine removal was completed on September 11. The DIDSON continued to collect data aimed where the turbine had been located through September 14. Verdant has also continued the collection of telemetry data using VEMCO receivers deployed in the East and West Channels of the East River, NYC [3].

SITE CHARACTERIZATION

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

---

[1] NYSERDA Grant 20802.
[2] DOE Grant DE-FG36-08GO18168, "Improved Structure and Fabrication of Large, High-Power KHPS Rotors."

in to two channels, the West Channel, the primary navigation channel, and the East Channel, where the RITE project is located. The cross sectional areas of the two channels are roughly equal, as both channels have similar widths of approximately 240 m and depths of 10 m. The volume of water passing through both channels is equal to within approximately 5%. However, the West Channel has a slightly higher average flow speed. The introduction of KHPS technologies into the East River poses a new and somewhat unknown risk to fish populations. To characterize this risk, a basic understanding of the technologies involved, typical environmental conditions and fish behavior are factored into the analysis.

TECHNOLOGY

Hydrokinetic (HK) technologies refer to a group of devices that extract energy directly from the kinetic energy present in moving water. Some devices, such as the KHPS turbine developed by Verdant, are designed to extract energy from tidal flows in a manner similar to the way a typical wind turbine operates. The Verdant turbine is an open bladed horizontal axis, downstream rotor type whose design is such that as the flow direction changes from flood to ebb tide, the turbine passively yaws to align with the flow. The Verdant turbine, as applied to RITE, features a 5 m diameter rotor and operates at a fixed speed of 40 rpm. As such, the tip speed ratio varies from 10.5 (water velocity (V_W) = 1 m/s) to 4.2 (V_W = 2.5 m/s) and the tip speed at rated power is 5 (V_W = 2.1 m/s) which would be the optimal tip speed ratio. Since the turbine rotates at a fixed speed, the nominal tip speed is 10.5 m/s (23.5 mph).

KHPS-FISH INTERACTION MODEL (KFIM)

A 2-Dimensional (2D) probabilistic approach was developed to support the Verdant Power FERC License to determine the overall risk of strike by using a product of independent sub-probabilities. The model considered a 2D lateral cross-section of the channel at the location of the turbine and comprised seven major parameters: Probability of Blade Rotation (P1), Distribution of Water Velocity over the Tidal Cycle (P2), Fish Distribution (East vs. West Channel) (P3), Turbine Rotor Area (P4), Blade Interaction with Fish (P5), Fish Distribution Fish Distribution (At Different Velocities) (P6) and Avoidance Behavior (P7). These parameters were combined to provide the total probability of strike as shown in Eq. 1.

$$P_{Strike} = \sum_{V_W=0}^{V_{W,Max}} P1 \cdot P2 \cdot P3 \cdot P4 \cdot P5 \cdot P6 \cdot P7 \qquad (1)$$

Most of these parameters varied as a function of water velocity and were summed across all water velocities up to the maximum tidal flow ($V_{W,\ Max}$). Previously three parameters P3: Fish Distribution (East vs. West Channel), P5: Blade Interaction with Fish and P6: Fish Distribution (At Different V_W) have been updated based on data collected as part of the Tagged Species Detection Plan conducted at the RITE site [4].

UPDATED PARAMETERS FROM HYDROACOUSTICS

As part of a DOE Oak Ridge National Lab-Verdant Power grant, the DIDSON data collected in 2012 was analyzed [2]. The analysis resulted in the identification of 34,705 fish tracks, distributed as 11,641 and 4,049 during ebb and flood tides, respectively, without a turbine in place; 10,490 and 5,076 during ebb and flood tides with a non-rotating turbine; and 1,734 and 1,715 during ebb and flood tides with a rotating turbine. In addition, the distribution and trajectory of fish throughout the vicinity of the RITE site was quantified using a representative sample of hydroacoustics data collected with an array of BioSonics split beam transducers (SBTs) mounted at the RITE site from June 2007 to October 2009 during testing of an array of six tidal turbines. Data collected from nine SBTs while up to two Verdant Power Gen4 KHPS turbines were operating in the array was analyzed. These data were collected at virtually the same location and during the same time of year (September 1–14, 2008), but not the same year, as the DIDSON data. The analysis focused on the effects of proximity to turbine, tide cycle, and current speed on fish distribution, swimming direction (with or against the turbine), and swimming velocity. A total of 15,641 fish targets were analyzed and revealed that most of the fish are near shore; and nearly twice as many fish were observed away from the turbines. In addition, many more fish were seen during slack tide (with no turbine operating) than ebb and flood tides.

The primary purpose of this analysis is to provide additional data to inform parameterization of the existing KFIM. In particular, these results contributed to two model parameters: P5, blade interaction with fish passing through turbine disk,

Table 1. Revised P5 parameter values based on the proportion of fish swimming with the current for nine velocity ranges and two size classes of fish

Velocity range (m/s)	0.0–1.0	1.0–1.2	1.2–1.4	1.4–1.6	1.6–1.8	1.8–2.0	2.0–2.2	2.2–2.4	2.4–2.6
P5: L > 76 cm*	0.79	0.91	0.88	0.92	0.84	0.88	1	1	1
P5: L < 76 cm*	0.65	0.90	0.96	0.97	0.97	0.98	1	1	1

Table 2. Revised P6 parameter values based on the distribution of fish around the turbines for nine current velocity ranges and two size classes of fish

Velocity range (m/s)	0.0–1.0	1.0–1.2	1.2–1.4	1.4–1.6	1.6–1.8	1.8–2.0	2.0–2.2	2.2–2.4	2.4–2.6
P6: L > 76 cm*	0.30	0.12	0.12	0.14	0.11	0.08	0.05	0.04	0.04
P6: L < 76 cm*	0.38	0.08	0.08	0.10	0.08	0.07	0.07	0.07	0.07

*Fish size separated based on signal strength (30 dB) or about 76 cm

and P6, fish distribution at different velocities. For the P5 parameter, the results for swimming with and against the current were summarized by velocity range by fish size class (Table 1). For the P6 parameter, the distribution of fish around the turbines at different velocities was used to update the probability of finding a fish of either of two size classes at nine velocity ranges (Table 2).

P5: Probability of the blade impacting the fish

For fish that will be incident upon the rotor, parameter P5 provides the probability of the blade impacting the fish (at any point on its body). This quantity is determined only by the following:

- The speed of the fish approaching the turbine (a function of species burst speed and direction (the 80/20 rule as defined below));
- The length of the fish, generally grouped as native species size;
- The rotational speed of the turbine blades (a known constant) and
- The angle at which the fish is approaching the turbine (angle of incidence)

P5: 80/20 rule

The primary assumption included in this parameter is that a fish will move through the turbine blades by swimming at its maximum burst speed through the rotor. Based upon the body of data collected during the RITE demonstration, it may be possible to justify some additional spatial or zonal avoidance behavior. However, because no specific data are available, no additional avoidance behavior is accounted for in the present model. The speed of the fish through the rotor will therefore be given only by the species' maximum burst speed plus the water velocity.

At RITE, fish likely swim through the east channel in both directions. However, over the course of the RITE demonstration, Verdant collected information on fish movements at the RITE east channel site that support the assumption that fish will typically be swimming with the current, especially at times of high velocity. From these data we made the assumption that when the water velocity is less than the regular endurance speed for a particular species, then 80% of fish will be swimming with the current and 20% against. For times when the water velocity is greater than the regular endurance speed, all fish will be swimming with the current. We term this assumption the 80/20 rule and this parameter was examined as part of the ORNL work. The new analysis indicates that 84% of the fish swam with the current while 16% swam against it.

P5: Angle of Incidence

Previously, the angle at which the fish will approach the turbine disk was not known; therefore, it was assumed that fish will be incident upon the rotor disk from an even distribution of angles (±90°) centered on the direction of transit (upstream or downstream). As the angle of incidence for the fish moves away from the perpendicular, the effective length of the fish decreases; however, its velocity through the rotor is also reduced. New analysis indicates that a narrower angle of incidence (±15°) occurs.

P6: Fish Distribution

This fish distribution parameter was included in the KFIM for RITE to account for the transit of species within the configuration at RITE, as described earlier. For the 2010 RITE KFIM cases, in the absence of further information on fish species, the model assumed an even distribution of fish in the East River. Therefore, P6=1 for all velocities. This parameter set at 1 for each velocity was applied as an extremely conservative value, rather than representing a uniform distribution of 11% per velocity bin. The modification of this assumption is reflected in the results.

P7: Avoidance

It is difficult to suggest a quantification metric for reduction of the P7 fish avoidance behavior parameter, although the parameter could be modified to P=0.98, or similar, based on DIDSON data. Doing so would result in practically no change to the overall results but would account for the effort of observing some fish movement as a result of the presence of an operating KHPS. In this analysis, P7=1 and is unchanged.

UPDATED PARAMETERS FROM ACOUSTIC TAGS AND RECEIVERS

In addition to the updates to P5 and P6 as discussed above, Verdant was able to make an additional modification to the KFIM based on the passive telemetry study that has been ongoing since 2011. In May and August 2011, VEMCO receivers were deployed in the East Channel and West Channel respectively. Since that time, 1,167 days of data were collected in the East Channel and 1,457 days of data were collected in the West Channel. Regardless of species, 48 total fish were detected – 38 in the West Channel and 10 in the East Channel. To remove the bias of sampling duration, the average detection rate can be determined for the East Channel (3.13 detections per year) and the West Channel (9.52 detections per year). Based on these normalized numbers, the annual rate of detections is 12.65 detections per year with 75.3% of those detections occurring in the West Channel per year.

In the initial KFIM, it was assumed that fish had an equal probability of using the East or West Channel, thus P3 = 0.5. However, based on 4 years of data collection, the P3 can be updated as follows: P3=0.25.

UPDATED KFIM RESULTS

The KFIM was re-calculated for large fish (Length=104 cm) and smaller fish (Length=25cm) and included the updates to parameters P3, P5 and P6 for 1 turbine, 2 turbines, 3 turbines, 12 turbines and 30 turbines (Tables 3 and 4). In all cases the probability of a KHPS-fish interaction was reduced based on the updated information.

Table 3. Probability of strike for Atlantic sturgeon (L = 104 cm)

Case	Original Model	Updated Results
1 Turbine (T)	0.09%	0.006%
2 T	0.17%	0.01%
3 T	0.26%	0.02%
12 T	1.03%	0.07%
30 T	2.59%	0.17%

Table 4. Probability of strike for black sea bass (L = 25 cm)

Case	Original Model	Updated Results
1 Turbine (T)	0.03%	0.002%
2 T	0.07%	0.003%
3 T	0.10%	0.005%
12 T	0.39%	0.02%
30 T	0.98%	0.05%

CONCLUSIONS

Based on the review and analysis of site specific hydroacoustic data and the continued detection of acoustically tagged species that traverse the East River, three of the seven model parameters have been updated. The updated parameters are P3: Fish Distribution (East vs. West Channel), P5: Blade Interaction with Fish, and P6: Fish Distribution (At Different V_W). Data collected from environmental monitoring studies proposed by Verdant has as intended been used to refine the body of knowledge in this area and update the predictions made by the model. The method of establishing a KHPS - Fish Interaction Model using conservative assumptions, and updating the model parameters with collected monitoring data once the turbines are deployed is a sound adaptive management approach for the marine renewable energy industry to confirm environmental compatibility.

ACKOWLEDGEMENTS

The authors would like to acknowledge New York State Energy Research and

Development Authority and the US Department of Energy for their continuing support.

REFERENCES

[1] Verdant Power, LLC. 2010. Final Pilot License Application - RITE East Channel Pilot, Volume 4: RITE Monitoring of Environmental Effects (RMEE) Plans, Appendices A & B summarizing supporting fishery information, ESA, EFH.

[2] Bevelhimer, M., J. Colby, M. Adonizio, C. Tomichek and C. Scherelis. *In Press*. Informing a tidal Turbine Strike Probability Model Through Characterization of Fish Behavioral Response Using Multibeam Sonar Output. Oak Ridge National Lab Report to the US Department of Energy (DE-ACO5-00OR22725).

[3] Tomichek, C., J. Colby, M. Adonizio, M. Frisk, K. Dunton, D. Fox and A. Jordaan. 2014. Tagged Species Detection: Approach to Monitoring Marine Species at Marine Hydrokinetic Projects. Proceedings of the 2nd Marine Energy Technology Symposium, Seattle, WA.

[4] Tomichek, C., J. Colby, and M. Adonizio. 2015. Improvements to Probabilistic Tidal Turbine-Fish Interaction Model Parameters. Proceedings of the 3nd Marine Energy Technology Symposium, Washington, D.C.