Laboratory Evaluation of Fish Survival and Behavior Associated with Hydrokinetic Turbines

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BACKGROUND

The Electric Power Research Institute (EPRI) received funding from the U.S. Department of Energy (DOE) to conduct desktop and laboratory studies examining potential impacts of hydrokinetic turbines on fish. These studies included: (1) a review of biological criteria developed for conventional hydro turbines to determine applicability to hydrokinetic designs; (2) development of theoretical strike probability and mortality models for hydrokinetic turbines; and (3) flume studies designed to evaluate turbine passage survival and fish behavior associated with hydrokinetic turbines. The laboratory evaluations with fish and operating turbines were conducted at Alden Research Laboratory, Inc. and the USGS Conte Anadromous Fish Research Laboratory. Laboratory flume testing allowed for highly controlled evaluations with the ability to closely monitor fish movements and behavior and to recover and examine all fish that passed downstream through or around a turbine. This information will be used verify the theoretical models of strike probability and mortality, as well as provide insight into whether fish behavior patterns will be altered in the presence of an operating turbine.

STUDY GOALS AND OBJECTIVES

The primary goal of flume testing was to provide project developers, regulators, and resource agencies with the data and information they need to make informed decisions on the potential impacts of hydrokinetic turbines on local and migratory fish populations. To achieve this goal, the study objectives:

- Estimate injury and survival rates for fish that pass through the blade sweep of each turbine type
- Describe the behavior of fish approaching and passing through selected hydrokinetic turbine designs

STUDY PARAMETERS

Turbine Passage Survival Testing

- Two turbine designs: Lucid Spherical Turbine (LST) and Welka UPG
- Rainbow trout and largemouth bass (tested with Welka UPG only)
- Two size groups: 100-150 mm and 225-275 mm
- Two approach Velocities: 5 and 7 ft/s
- 5 replicate trials for each set of test conditions
- 100 treatment and 100 control fish per trial; released 12 in from turbine
- Each test group uniquely marked (combination of fin location and photonic dye color)
- 48-hr delayed mortality post-test holding period
- Turbine Passage Survival = S_t/S_c ; where S_t is survival of fish passing through turbine and S_c is survival of control fish (released downstream of turbine)

Behavioral Tests

- Same species, size classes, and approach velocities used for survival tests
- Three trials for each set of test conditions
- 100 fish per trial; released about 25 ft upstream from turbine
- Video observations of fish behavior ass they approach and pass downstream of turbine

TEST FACILITY DESIGN & OPERATION

Biological testing with each turbine was conducted in Alden's large flume fish testing facility. The test flume has a concrete floor about 10 ft below the top of the side walls. Located beneath this floor at the downstream end of the flume are two 5.5-ft diameter bow-thrusters (400 hp each) capable of pumping up to 500 cfs through the test channel with the assistance of turning vanes at both ends (i.e., flume water is circulated vertically at either end of the flume). The flume length is approximately 80 ft with a total width of 20 ft and maximum water depth of about 8 ft. To achieve higher velocities for testing with hydrokinetic turbines, temporary walls were installed to constrict the flume width to 8 ft. The hydrokinetic turbines were installed at the downstream end of this narrowed flume section. To minimize flow separation and turbulence, the entrance to the narrowed section had rounded walls. The flume is equipped with a side-mounted Acoustic Doppler Current Profiler (ADCP) to measure water velocities and determine flow rates.

TURBINE DESIGNS EVALUATED

LUCID SPHERICAL TURBINE (LST)

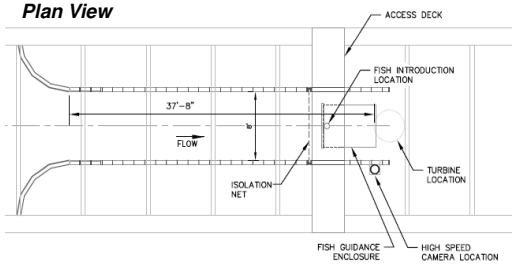
- Cross-flow design
- 4 blades
- Diameter: 3.75 ft
- Rotational speed = 64 – 127 rpm
- Approach velocity = 5 – 10 ft/s
- Blade thickness: 0.75 in

WELKA UPG

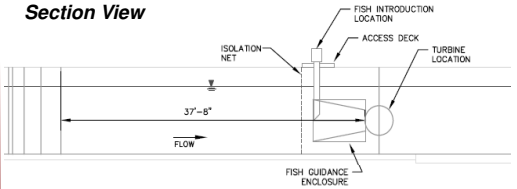
- Ducted axial-flow design
- 3 blades
- Diameter: 5 ft
- Rotational speed: 15 – 35 rpm
- Approach velocity: 3 – 10 ft/s
- Blade thickness: 2.5 in

TEST FACILITY

Plan View



Section View



RESULTS

The following is a summary of the results from the biological testing with the LST:

- Survival rates of rainbow trout encountering the LST were greater than 99% for both size classes and velocities tested, with the exception of 250-mm fish evaluated at the higher velocity, for which total survival was 98.4% (Table 1). These survival rates represent fish that passed downstream by actively avoiding entrainment and those that were entrained through the operating unit.
- Injury and scale loss rates for rainbow trout encountering the LST were negligible based on the rates observed for control fish released downstream of the turbine (i.e., most injury and scale loss was attributed to pre-test condition of fish and/or handling and testing procedures, not passage around or through the turbine).
- Despite exiting the release system within 250 to 300 mm (about 10 to 12 inches) of the upstream face of the turbine blade sweep, observations from underwater video demonstrated that many treatment fish actively avoided entrainment through the LST by swimming to the sides, top, or bottom of the operating turbine. Also, at both approach velocities, the larger trout were able to maintain position immediately upstream of the turbine after exiting the release tube and detecting the turbine (Figure 1).
- A review of the underwater video indicated between 83 and 94% of rainbow trout avoided passage through the turbine in this manner.
- Observations of blade strikes indicated fish were not stunned or severely injured. Most strikes occurred in the caudal (tail) region and elicited avoidance reactions.
- Behavioral tests indicated that most, if not all, fish moving downstream in the test channel did not encounter the turbine either through active avoidance or downstream movement along the channel walls or floor.

The following is a summary of the results from biological testing with the Welka UPG:

- Turbine passage survival for the two size groups of rainbow trout and largemouth bass evaluated at both approach velocities were greater than 99.5% (Tables 2 and 3).
- Based on control fish data, observed injury and scale loss for turbine-passed fish was primarily attributed to the pre-test condition of fish and/or handling and testing procedures.
- Neither of the two species or size groups were observed being struck by blades and appeared to be able to readily avoid the blades as they passed through the turbine (Figure 2).
- Behavioral tests indicated that most, if not all, rainbow trout and largemouth bass moving downstream in the test channel did not encounter the turbine either due to active avoidance or downstream movement along the channel walls or floor.

TABLE 1. *Turbine passage survival estimates for rainbow trout evaluated with the Lucid Spherical Turbine. Survival rates above 100% resulted when control mortality was greater than treatment mortality.*

Mean Fork Length (mm)	Approach Velocity (ft/s)	Immediate Survival (1 hr) (%) ± 95% CI	Total Survival (1 hr + 48 hr) (%) ± 95% CI
161	5	99.78 ± 0.43	99.77 ± 0.73
138	7	100.40 ±0.80	100.40 ± 0.80
250	5	99.43 ± 1.18	99.03 ± 1.30
249	7	99.60 ± 0.55	98.40 ± 1.10

TABLE 2. *Turbine passage survival estimates for rainbow trout evaluated with the Welka UPG turbine. Survival rates above 100% resulted when control mortality was greater than treatment mortality.*

Mean Fork Length (mm)	Approach Velocity (ft/s)	Immediate Survival (1 hr) (%) ± 95% CI	Total Survival (1 hr + 48 hr) (%) ± 95% CI
125	5	100.87 ± 1.21	100.87 ± 1.35
124	7	100.00 ± 0.00	100.00 ± 0.00
230	5	101.57 ± 1.33	101.57 ± 1.33
248	7	99.40 ± 0.68	99.40 ± 0.68

TABLE 3. *Turbine passage survival estimates for largemouth bass evaluated with the Welka UPG turbine. Survival rates above 100% resulted when control mortality was greater than treatment mortality.*

Mean Fork Length (mm)	Approach Velocity (ft/s)	Immediate Survival (1 hr) (%) ± 95% CI	Total Survival (1 hr + 48 hr) (%) ± 95% CI
125	5	100.21 ± 0.69	99.81 ± 0.89
124	7	100.00 ± 0.00	100.00 ± 0.56
238	5	100.84 ± 1.27	102.93 ± 2.94
246	7	100.00 ± 0.00	99.60 ± 0.56

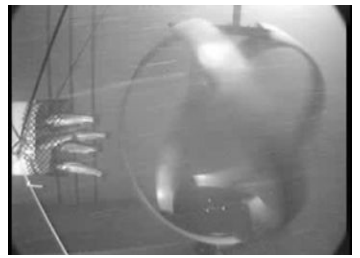


FIGURE 1. *Rainbow trout holding Position immediately upstream of the LST at an approach velocity of 5 ft/s.*

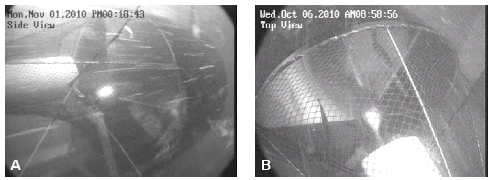


FIGURE 2. *Largemouth bass passing through the Welka UPG turbine without being struck by a blade.*

CONCLUSION

The information and data developed from this study has resulted in a better understanding of the interactions between fish and hydrokinetic turbines for two general design types (vertical cross-flow and ducted axial flow). The ability to apply the study results to other turbines will depend, in part, on differences in design and operation (e.g., blade shape and spacing, number of blades, rotational speeds) compared to the two turbines we evaluated. Regardless of turbine differences, the observations of fish behavior, particularly avoidance at a very close distance to moving blades, provide strong evidence as to how fish are likely to react when approaching a wide range of hydrokinetic turbine designs in the field.

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