TRANSCANADA HYDRO NORTHEAST INC.

ILP Study 23
Fish Impingement, Entrainment, and Survival Study

Final Study Report

In support of Federal Energy Regulatory Commission Relicensing of:

Wilder Hydroelectric Project (FERC Project No. 1892-026)
Bellows Falls Hydroelectric Project (FERC Project No. 1855-045)
Vernon Hydroelectric Project (FERC Project No. 1904-073)

Prepared for

TransCanada Hydro Northeast Inc.
4 Park Street, Suite 402
Concord, NH 03301

Prepared by

Normandeau Associates, Inc.
25 Nashua Road
Bedford, NH 03110

November 30, 2016

[This page intentionally left blank.]

TABLE OF CONTENTS

List of Tables

List of Abbreviations

CRASC	Connecticut River Atlantic Salmon Commission
FERC	Federal Energy Regulatory Commission
FWS	U.S. Department of the Interior – Fish and Wildlife Service
NHDES	New Hampshire Department of Environmental Services
NHFGD	New Hampshire Fish and Game Department
RSP	Revised Study Plan
TransCanada	TransCanada Hydro Northeast Inc.
VANR	Vermont Agency of Natural Resources
VY	Vermont Yankee Nuclear Power Station

1.0 INTRODUCTION

This final study report presents the findings of the Fish Impingement, Entrainment, and Survival Study (ILP Study 23) conducted in support of Federal Energy Regulatory Commission (FERC) relicensing efforts by TransCanada Hydro Northeast, Inc. (TransCanada) for the Wilder Hydroelectric Project (FERC Project No. 1892), Bellows Falls Hydroelectric Project (FERC No. 1855) and the Vernon Hydroelectric Project (FERC No. 1904).

In their study requests, the Federal Energy Regulatory Commission (FERC), New Hampshire Department of Environmental Services (NHDES), New Hampshire Fish and Game Department (NHFGD), and the Vermont Agency of Natural Resources (VANR) identified potential issues related to Wilder, Bellows Falls, and Vernon Project operations on fish impingement, entrainment, and survival. The study was conducted to assess the adequacy of the intakes at the projects to minimize fish mortality resulting from impingement and entrainment of fishes residing in the Connecticut River.

The Revised Study Plan (RSP) for this study was modified by TransCanada in its December 31, 2013 filing, based on stakeholder agreement from the Vermont Yankee (VY) technical meeting held on November 26, 2013, with the following specific change.

- Reschedule the study for late summer and fall 2015 in accordance with delayed associated studies' schedules.

The RSP was approved without modification (except to delay the study until 2015), in FERC's February 21, 2014 SPD.

This final study report makes minor corrections, revises Franke formula calculations based on stakeholder requests, and includes revisions based on stakeholder comments received by July 14, 2016 on the initial study report filed May 16, 2016, including the addition of Appendix A containing a copy of Winchell et al., 2000. Additional analyses are being conducted related to total project survival (Section 7.0) and will be reported in a supplement to this final study report.

2.0 STUDY GOALS AND OBJECTIVES

As stated in the RSP, the goal of this study was to assess the adequacy of the intakes at the projects to minimize fish mortality resulting from impingement and entrainment of fishes residing in the Connecticut River. Specific objectives were to:

- provide a description of physical characteristics of the Wilder, Bellows Falls, and Vernon Projects (including forebay characteristics, intake location and dimensions, approach velocities, and rack spacing);

- identify current routes of fish movement past each project and the risk of injury/mortality associated with each route (considering seasonality, flow direction and velocity, existing management regimes);
- analyze target species for factors that may influence vulnerability to entrainment and mortality;
- assess the potential for impingement and estimate survival rates for target species;
- assess the potential for entrainment and estimate survival rates for target species;
- estimate turbine passage survival rates;
- estimate total project survival considering all passage routes for American shad and river herring at the Vernon Project; and
- estimate total project survival considering all passage routes for American eel, Atlantic salmon, and sea lamprey at the Wilder, Bellows Falls, and Vernon Projects.

3.0 STUDY AREA

The study area includes the Wilder, Bellows Falls, and Vernon project structures as described below.

3.1 Wilder

Wilder project structures (Table 3.1-1) consist of a concrete gravity dam 1,541 feet long and 59 feet high, having a gated spillway with 6 tainter gates, 2 skimmer gates, and 4 stanchion bays; a powerhouse containing three generating units, two rated at 19,000 kW and one at 3,200 kW; transmission interconnection facilities; fish passage facilities; and appurtenant facilities.

The dam is a concrete gravity structure extending across the Connecticut River from Hartford, Vermont, to Lebanon, New Hampshire. The dam structures include an earthen embankment about 400 feet long, a non-overflow gravity concrete bulkhead wall 232 feet long, a concrete forebay intake 208 feet long, a gravity concrete spillway about 526 feet long and 59 feet in maximum height and another earthen embankment about 180 feet long. The south embankment is 13 feet in maximum height and the north embankment is primarily a natural bank to which protection has been added. The spillway portion of the dam is divided into four sections: skimmer gate, tainter gates, stanchion flashboards, and another skimmer gate. The various bays are separated by concrete piers supporting a steel and concrete bridge. The non-overflow section crest is at El. 393.

The Wilder fishway is a reinforced concrete structure with accessory electrical, mechanical, and pneumatic equipment which was designed to provide passage past the dam for migrating Atlantic salmon. Upstream migrating fish are guided to the ladder entrance by attraction water supplied from the discharge of the Unit No. 3's generator and collection channel weirs. When Unit No. 3 is not available there is a Unit No. 3 bypass to supply the attraction water. Upstream migrating fish enter the tailrace area where fish are attracted to the main entrance weir (MEW) at the northwest end of the powerhouse. A spillway entrance weir (SEW) and a turbine entrance weir (TEW) are incorporated into the south and southwest walls of the attraction water channel, respectively, for use under varying tailwater conditions. The SEW is a gated entrance slot used for fish attraction from the spillway area, where fish may congregate during high-water "spill" conditions. The TEW is a gated entrance slot which is used for fish attraction during minimum flow operation of the "continuous-flow" turbine (Unit No. 3). The entrance weirs, when used, open fully and are not modulated. The operating season for upstream passage has been determined by the schedule provided each year by the Connecticut River Atlantic Salmon Commission (CRASC) and is dependent on observed passage of adult Atlantic salmon at the Bellows Falls fishway. Prior to curtailment of the Connecticut River Atlantic Salmon restoration program, operation was also dependent on the presence of radio-tagged adult salmon.

Downstream fish passage is provided by the existing log sluiceway located between Unit No. 3 and the fish ladder entrance gallery bay and spillway. The existing sluice gate is motorized and operated locally as needed. A flow of 512 cfs is maintained continuously through the skimmer gate for downstream passage. The operating season for downstream passage has been determined by the schedule provided each year by the CRASC and is dependent on Atlantic salmon having passed upstream via the Wilder fishway.

The powerhouse superstructure is 181 feet by 50 feet by about 50 feet high and is constructed of steel frame and brick construction. The boundary line between New Hampshire and Vermont lies between Unit 1 and Unit 2. The powerhouse contains three turbine generator units, electrical equipment, a control room, machine shop, excitation equipment, emergency generator, air compressor, an overhead crane, offices, storage rooms, battery room, and appurtenant facilities.

The powerhouse contains two adjustable blade propeller type Kaplan turbines (Units 1 and 2) and a single vertical runner Francis turbine (Unit 3). Specific parameters associated with each of the turbine units at Wilder are presented in Table 3.1-2. Units 1 and 2 are protected by trash racks made of 0.5 inch stock with clear spacing of 5.0 inches. Unit 3 is protected by trash racks made of 3/8 inch stock with clear spacing of 1 5/8 inches.

Table 3.1-1. Characteristics of the Wilder impoundment and forebay structure[1].

Site Characteristic		Wilder	
Drainage Area (sq miles)		3,375	
Surface Area-Full Pond (acres)		3,100	
Gross Storage Volume (acre-feet)		34,600	
Useable Storage Volume (acre-feet)		13,350 (at 5-ft drawdown)	
Maximum Operating Pond Elevation (ft)		385.0	
Minimum Operating Pond Elevation (ft)		380.0	
Normal Operating Range (ft)		382.0-384.5	
Nominal Station Capacity (cfs)		10,700	
Intake Elevations	Unit	Units 1 & 2	Unit 3
	Top (ft)	355.0	354.0
	Bottom (ft)	324.0	324.0
Unit Intake Height (ft)		31.0	30.0
Unit Intake Width (ft)(per bay)		21.2	20.0
		Units 1 & 2	Unit 3
Number of Bays per Intake Area		2.0	1.0
Unit Intake Area (sq ft)		1314.4	600.0
Trash Rack Bars	Thickness (in)	0.5	0.375
	Clear Spacing (in)	5.0	1.625
Calculated Approach Velocity (fps)		2.2	1.4

---

[1] All elevations are in National Geodetic Vertical Datum of 1929 (NGVD 29).

Table 3.1-2. Wilder turbine characteristics.

Parameter	Wilder Turbines	
	Unit 1 and 2	Unit 3
Turbine Type	Kaplan - adjustable blade	Vertical Francis
Number blades/buckets	5	15
Max turbine discharge (cfs) [a]	5,650	825
Efficiency at max discharge [a, b]	0.796	0.738
Discharge at peak efficiency(cfs) [a, b]	3,353	745
Peak efficiency [a, b]	0.872	0.745
Discharge at typical full load (cfs)	4,400	n/a
Efficiency at typical full load [a, b]	0.857	n/a
Minimum flow from generation (cfs)	n/a	700
Efficiency at minimum flow [a, b]	n/a	0.714
Runner diameter at inlet (ft)	-	4.25
Runner diameter (ft)	15	-
Runner diameter at discharge (ft)	-	5.5
Runner height at inlet (ft)	-	2
RPM	112.5	212
Design head (ft)	49	58

a. From unit-specific power and efficiency curves used in the Operations Model Study 5 (Hatch, 2016).

b. Efficiency at approximate midpoint of normal operating range.

3.2 Bellows Falls Project Structures

Bellows Falls project structures (Table 3.2-1) consist of (1) a concrete gravity dam 643 feet long and 30 feet high, having a gated spillway with two roller gates and three stanchion flashboard bays; (2) the Bellows Falls reservoir, extending 26 miles upstream, having a surface area of 2,804 acres at normal full pond elevation of 291.63 feet msl; (3) a power canal 1,700 feet long with a forebay intake area and sluice gate; (4) a tailrace approximately 900 feet long; (5) a powerhouse containing three generating units, each rated at 13,600 kW; (6) transmission interconnection facilities; (7) fish passage facilities; and (8) appurtenant facilities.

Bellows Falls dam is a concrete gravity structure extending across the Connecticut River between Rockingham, Vermont and Walpole, New Hampshire. Virtually all of the dam structure is located in New Hampshire. It is 643 feet long with a maximum height of about 30 feet, and is divided by concrete piers into 5 bays. Two bays contain steel roller-type flood gates and the three other bays contain stanchion flashboards. A steel bridge runs the length of the dam for access and for operation of flashboards. A 25-ton gantry crane sits atop the bridge. A power canal connects the impoundment to the powerhouse. The canal is lined with paving stones stabilized by a grid of concrete grade beams and walls. The downstream end of the canal is a concrete walled forebay. The canal is 100 feet wide at the upper end, about 36 feet wide at the lower end and about 29 feet deep, and approximately 1,700 feet long including the length of the powerhouse forebay. The canal creates a natural bypassed reach between the dam and the outlet of the powerhouse tailrace. The reach is about 3,500 feet long and receives minimal water from leakage, and when conditions dictate, spill from the dam.

The upstream fishway system consists of a conventional vertical slotted weir fish ladder at the powerhouse and an upstream concrete barrier dam in the bypassed reach. The barrier dam prevents upstream migrating fish from being attracted by spillway discharge into the reach and later becoming trapped in isolated pools after spill ends. The barrier is located just upstream of the Boston and Maine railroad bridge. The fish ladder is a 920-foot long reinforced concrete structure with accessory electrical, mechanical, and pneumatic equipment that was designed to provide passage for migrating Atlantic salmon past the dam by way of the forebay and canal, a vertical distance of about 60 feet. Upstream migrating fish are attracted to the tailrace channel by flow from the turbines. Once in the tailrace area, fish are attracted to the main entrance weir at the east end of the powerhouse. Attraction water is provided by the upper three weirs containing slide gates, which open and close depending on the forebay elevation to maintain the required fish ladder flow. A skimmer gate/sluiceway is located in the forebay and is used for additional fish ladder attraction water. Water from this channel enters two diffuser openings at the fish ladder entrance.

Downstream migrating fish are attracted to the forebay sluiceway/skimmer gate by a solid, partial depth diversion boom across the canal. A small auxiliary gate located on the east side of the powerhouse is opened to direct fish that may get under the diversion boom to the sluiceway.

The powerhouse contains three turbine/generators, electrical equipment, a control room, machine shop, excitation equipment, emergency generator, air compressor, an overhead crane, offices, storage rooms, battery room, and appurtenant facilities. The powerhouse superstructure is 186 feet by 106 feet by 52 feet, and constructed of steel frame and brick. The powerhouse substructure is of reinforced concrete construction excavated into bedrock.

The concrete gravity intake is integral with the powerhouse structure with two water passages for each of the three generating units (vertical Francis turbines; Table 3.2-1). Water enters directly from the canal intake and into the scroll or wheel cases. The draft tubes discharge into the tailrace excavated partly in the bank and partly in the bed of the river. The generating units do not have draft tube gates. The scroll cases and draft tubes are formed in the concrete of the substructure which was poured on rock. The water passages for the three generating units have trash racks (4-inch clear spacing) and two headgates that can be used in any one of the three units.

Table 3.2-1. Characteristics of the Bellows Falls impoundment and forebay structures.

Site Characteristic		Bellows Falls
Drainage Area (sq miles)		5,414
Surface Area-Full Pond (acres)		2,804
Gross Storage Volume (acre-feet)		26,900
Useable Storage Volume (acre-feet)		7,476 (at 3-ft drawdown)
Maximum Operating Pond Elevation (ft)		291.6
Minimum Operating Pond Elevation (ft)		288.6
Normal Operating Range (ft)		291.4-289.6
Nominal Station Capacity (cfs)		11,400
Intake Elevations	Units	1-3
	Top (ft)	291.6
	Bottom (ft)	245.9
Unit Intake Height (ft)		45.8
Unit Intake Width (ft)(per bay)		19.4
Number of Bays per Intake Area		2.0
Unit Intake Area (sq ft)		1772.8
Trash Rack Bars	Thickness (in)	0.5
	Clear Spacing (in)	4.0
Calculated Approach Velocity (fps)		2.2

Table 3.2-2. Bellows Falls turbine characteristics.

Parameter	Bellows Falls Turbines
	Units 1 - 3
Turbine Type	Vertical Francis
Number blades/buckets	15
Max turbine discharge (cfs) [a]	3,850
Efficiency at max discharge	0.828
Discharge (cfs) at peak efficiency, also typical full load [a, b]	3,175
Peak efficiency [a, b]	0.870
Minimum flow from generation (cfs)	1,300
Efficiency at minimum flow [a, b]	0.592
Runner diameter at inlet (ft)	10.3
Runner diameter at discharge (ft)	14.4
Runner height at inlet (ft)	5.4
RPM	85.7
Design head (ft)	57
Max hydraulic capacity (cfs) [c]	3,670

a. From unit-specific power and efficiency curves used in the Operations Model Study 5 (Hatch, 2016).

b. Efficiency at midpoint of normal operating range.

c. Theoretical value at design head.

3.3 Vernon Project Structures

Vernon project structures (Table 3.3-1) consist of (1) a concrete gravity dam 956 feet long and 58 feet high, and consists of the integral powerhouse with a sluice gate block section that is about 356 feet long, and a concrete overflow spillway section about 600 feet long with 6 tainter gates, 2 hydraulic flashboard bays, 3 stanchion bays, and a sluice; (2) the Vernon reservoir, extending 26 miles upstream, having a surface area of 2,550 acres at normal full pond elevation of 220.13 feet mean sea level (msl); (3) a powerhouse containing ten generating units, with Unit Nos. 1 – 4 rated at 2,000 kW, Unit Nos. 5 – 8 rated at 4,000 kW and unit Nos. 9 – 10 rated at 4,200 kW; (4) transmission interconnection facilities; (5) fish passage facilities; and (6) appurtenant facilities.

Vernon dam is a composite overflow and non-overflow ogee type concrete gravity structure extending across the Connecticut River between Hinsdale, New Hampshire, and Vernon, Vermont. It is 956 feet long with a maximum height of 58 feet, and consists of the integral powerhouse with a sluice gate block section that is about 356 feet long, and a concrete overflow spillway section about 600 feet long. The maximum dam height is 58 feet. The spillway portion of the dam is divided into 12 bays containing, from west to east, a trash sluice, 4 tainter gates, 2 hydraulic flashboard bays, 3 stanchion bays, and 2 tainter gates. The various bays are separated by concrete piers supporting a steel and concrete bridge. A steel bridge runs the length of the dam for access and for operation of flashboards. The trash sluice is a skimmer gate which passes logs and other debris deflected away from the powerhouse by a log and ice boom in the station forebay.

The fishway is a reinforced concrete structure (ice harbor and vertical slot design) 984 feet long with accessory electrical, mechanical, and pneumatic equipment that was designed to provide passage for migrating Atlantic salmon and American shad past the dam, a vertical distance of about 35 feet. Upstream migrating fish enter the tailrace area where they are attracted to entrance weirs at the west end of the powerhouse. Attraction water to the channel entrance weirs consists of 64 cfs from the fishway flow and up to 254 cfs through a floor diffuser supplied by a 48-inch diameter pipe from the attraction water intake at the fishway exit. Fish are attracted into the fishway and "climb" by swimming through a series of 51 pools created by a sequence of overflow weirs in the lower section and by a series of vertical slot pools in the upper section.

Downstream fish passage facilities consist of a “fish pipe” that discharges about 350 cfs through the powerhouse, a second smaller “fish tube” at the Vermont end of the powerhouse that discharges about 40 cfs, and a 156-foot-long louver array that extends from the forebay to the fish pipe entrance. The louver array consists of stainless steel louver panels with 3-inch spacing between louver vanes that extend to 15 feet depth at normal pond elevation. The louver intercepts and directs downstream-migrating fish that enter the forebay from mid-river and from the east (New Hampshire) shoreline into the fish pipe. The smaller fish tube on the Vermont end of the powerhouse functions as a secondary passage route for fish that are not intercepted by the louver array and enter the western end of the forebay.

The powerhouse is integral to the dam and contains ten turbine/generators, electrical equipment, machine shop, excitation equipment, emergency generator, air compressor, an overhead crane, offices, and storage rooms. The powerhouse is approximately 356 feet long by 55 feet wide by 45 feet high, and is a reinforced concrete substructure with a structural steel and brick superstructure.

The concrete gravity intake is integral with the powerhouse structure with two water passages for Units 9 and 10 and a single water passage for Units 1 - 8. Vernon turbine Units 1-4 and 9-10 are vertical Francis units whereas Units 5-8 are vertical Kaplan units (Table 3.3-2). Water enters directly from the forebay intake and into the scroll or wheel cases. The draft tubes discharge into a short tailrace excavated partly in the bank (for Units 9 and 10) and partly in the bed of the river. The scroll cases and draft tubes are formed in the concrete of the substructure which was poured on bedrock. The water passages for Units 9 and 10 have trash racks (4-inch on center) and head gates consisting of two concrete gates with an electrically driven fixed hoist. Units 1 8 have a clear rack spacing of 1.75 inches.

Table 3.3-1. Characteristics of the Vernon impoundment and forebay structures[2].

Site Characteristic		Vernon		
Drainage Area (sq miles)		6,266		
Surface Area-Full Pond (acres)		2,550		
Gross Storage Volume (acre-feet)		40,000		
Useable Storage Volume (acre-feet)		18,300 (at 8-ft drawdown)		
Maximum Operating Pond Elevation (ft)		220.0		
Minimum Operating Pond Elevation (ft)		212.0		
Normal Operating Range (ft)		218.3-220.1		
Nominal Station Capacity (cfs)		17,100		
Intake Elevations	Unit	1-4	5-8	9-10
	Top (ft)	214.9	215.0	215.0
	Bottom (ft)	178.1	179.0	191.1
Unit Intake Height (ft)		36.8	36.0	23.9
Unit Intake Width (ft)(per bay)		20.8	20.8	21.0
Number of Bays per Intake Area		1.0	1.0	2.0
Unit Intake Area (sq ft)		764.4	748.8	1002.5
Trash Rack Bars	Thickness (in)	0.25	0.25	0.375
	Clear Spacing (in)	1.75	1.75	3.625
Calculated Approach Velocity (fps)		1.4	2.5	2.1

---

[2] All elevations are in National Geodetic Vertical Datum of 1929 (NGVD 29).

Table 3.3-2. Turbine characteristics for the Vernon Project.

Parameter	Vernon			
	Units 1-2	Units 3-4	Units 5-8	Units 9-10
Turbine Type	Vertical Francis	Vertical Francis	Vertical Kaplan	Vertical Francis
Number blades/buckets	12	13	5	12
Max turbine discharge (cfs) [a]	1,092	1,092	1,860	2,060
Efficiency at max discharge [a, b]	0.824	0.824	0.819	0.777
Discharge (cfs) at peak efficiency, also typical full load [a, b]	1,092	1,092	1,178	1,573
Peak efficiency [a, b]	0.824	0.824	0.865	0.851
Minimum flow from generation (cfs)	n/a	n/a	1,600	1,600
Efficiency at minimum flow	n/a	n/a	0.845	0.850
Runner diameter (ft)	-	-	10.2	-
Runner diameter at inlet (ft)	5.2	5.2	-	11.7
Runner diameter at discharge (ft)	8.2	8.2	-	13
Runner height at inlet (ft)	3.7	3.7	-	4.8
RPM	133.3	133.3	144	75
Design head (ft)	35	35	32	34
Max hydraulic capacity (cfs) [c]	1,465	1,465	1,800	2,035

a. From unit-specific power and efficiency curves used in the Operations Model Study 5 (Hatch, 2016).

b. Efficiency at midpoint of normal operating range.

c. Theoretical value at design head.

4.0 TARGET FISH SPECIES

4.1 Fish Community

The fish community within the Wilder, Bellows Falls, and Vernon impoundments was sampled as part of the Fish Assemblage Study (Study 10) during May-October, 2015. Sampling was conducted on a seasonal basis (Spring: May-June; Summer: July-August; Fall: September-October) and relied on a stratified random sampling design where the predetermined number of sampling locations were placed proportional to available habitat types. The percent composition of fish species sampled within the Wilder, Bellows Falls, and Vernon impoundments is presented in Table 4.1-1.

To evaluate impingement and entrainment susceptibility and effects, a group of fish species were identified for each impoundment that were considered representative of the overall fish assemblage. These target species were primarily identified based on a combination of life history strategies, their relative abundance in the impoundment community, and their trophic guild (as identified by Halliwell et al., 1999). Individual species representing greater than 1% of the fish assemblage as sampled during Study 10 were flagged for inclusion in the target species list. In the event that any major family or trophic guild was not included based on those criteria, additional species were added on an as-needed basis. Fish species within a particular family that represented a minor portion of the overall assemblage (e.g., 1-2%) were dropped if a species with similar life history characteristics, within the same family/trophic guild, and representing a larger percentage of the overall community was present.

4.1.1 Wilder Project

The target fish community for Wilder impoundment consisted of 14 species, representing 8 families. Although present in low to no abundance during Study 10 sampling, two diadromous species, American Eel and Sea Lamprey, were included based on the original stakeholder study requests. Resident species, including White Sucker, Largemouth Bass, Smallmouth Bass, Fallfish, Golden Shiner, Spottail Shiner, Northern Pike, Tessellated Darter, Walleye, and Yellow Perch were included based on their relative abundance within the Wilder impoundment fish community. Two species, Bluegill and Brown Bullhead were added to ensure completeness. Bluegill was included in the Wilder target fish community in lieu of Pumpkinseed or Rock Bass due to their similar life history characteristics and greater abundance of available swim-speed information.

4.1.2 Bellows Falls Project

The target fish community for the Bellows Falls impoundment consisted of 14 species, representing 8 families. Although present in low to no abundance during the Study 10 sampling, two diadromous species, American Eel and Sea Lamprey, were included based on the original stakeholder study requests. Resident species, including White Sucker, Bluegill, Largemouth Bass, Smallmouth Bass, Fallfish, Golden Shiner, Spottail Shiner, Tessellated Darter, and Yellow Perch were included based on their relative abundance within the Bellows Falls impoundment fish community. Three species, Northern Pike, Brown Bullhead, and Walleye were added to ensure completeness. Bluegill was included in the Bellows Falls target fish community in lieu of Pumpkinseed or Rock Bass due to their similar life history characteristics and greater abundance of available swim-speed information.

4.1.3 Vernon Project

The target fish community for the Vernon impoundment consisted of 15 species, representing 9 families. Although present in low to no abundance during the Study 10 sampling, three diadromous species, American Eel, American Shad and Sea Lamprey, were included based on the original stakeholder study requests. Resident species, including White Sucker, Bluegill, Largemouth Bass, Smallmouth Bass, Fallfish, Golden Shiner, Spottail Shiner, Tessellated Darter, and Yellow Perch were included based on their relative abundance within the Vernon impoundment fish community. Three species, Northern Pike, Brown Bullhead, and Walleye were added to ensure completeness. Bluegill was included in the Vernon target fish community in lieu of Pumpkinseed or Rock Bass due to their similar life history characteristics and greater abundance of available swim-speed information.

Table 4.1-1. Species, family, trophic guild and percent composition for fish species observed in the Wilder, Bellows Falls, and Vernon impoundments during sampling associated with Study 10. Green shading indicates target fish community selection.

Common Name	Family	Trophic Guild	Percent Composition (from Study 10)		
			Wilder	Bellows Falls	Vernon
American eel	Anguillidae	TC	0.1	0.0	0.0
White sucker	Catostomidae	GF	3.0	1.6	2.8
Black crappie	Centrarchide	TC	0.0	0.7	1.0
Bluegill	Centrarchide	GF	0.3	1.0	8.0
Largemouth bass	Centrarchide	TC	1.8	1.5	4.5
Pumpkinseed	Centrarchide	GF	0.4	1.6	2.0
Rock bass	Centrarchide	TC	13.0	6.4	4.2
Smallmouth bass	Centrarchide	TC	6.4	10.1	3.9
American shad	Clupeidae	PI	0.0	0.0	0.8
Blacknose shiner	Cyprinidae	BI	0.1	0.0	0.0
Bridle shiner	Cyprinidae	WC	0.5	0.2	0.0
Common carp	Cyprinidae	GF	0.0	0.0	0.2
Common shiner	Cyprinidae	GF	0.3	<0.1	0.0
Creek chub	Cyprinidae	GF	1.1	0.4	0.2
Cutlips minnow	Cyprinidae	BI	0.0	<0.1	0.0
Eastern silvery minnow	Cyprinidae	BH	0.2	0.0	1.8
Fallfish	Cyprinidae	GF	18.5	5.3	9.3
Golden shiner	Cyprinidae	GF	4.9	4.2	4.7
Rosyface shiner	Cyprinidae	WC	0.0	0.7	0.1
Spottail shiner	Cyprinidae	WC	15.5	49.4	38.2
Chain pickerel	Esocidae	TC	0.3	0.2	0.1

Common Name	Family	Trophic Guild	Percent Composition (from Study 10)		
			Wilder	Bellows Falls	Vernon
Northern pike	Esocidae	TC	1.4	0.5	0.6
Banded killifish	Fundilidae	WC	0.1	0.0	0.1
Brown bullhead	Ictaluridae	GF	0.1	0.4	0.1
Channel catfish	Ictaluridae	TC	0.0	0.0	0.1
Yellow bullhead	Ictaluridae	GF	0.0	<0.1	0.0
White perch	Moronidae	TC	0.0	0.0	0.4
Tessellated darter	Percidae	BI	10.2	1.9	1.9
Walleye	Percidae	TC	3.5	0.4	0.2
Yellow perch	Percidae	TC	18.6	13.1	14.2
Sea lamprey	Petromyzontidae	PF	0.0	0.3	0.8

* Halliwell et al. 1999

GF = Generalist Feeder

WC = Water Column Insectivore

BI = Benthic Insectivore

TC = Top Carnivore

PF = Parasitic Filterers

PI = Planktivorous Invertivores

4.2 Life History and Habitat Requirements

When considering the Wilder, Bellows Falls and Vernon Projects, a total of 15 target fish species were evaluated for entrainment susceptibility and effects. A general description of the habitat requirements for these species is presented below. Fish species within the same family are grouped and discussed together. A summary of key species habitat preferences is provided in Table 4.2-1 and descriptions of these habitat types are provided in Table 4.2-2.

4.2.1 Anguillidae

The American Eel is a catadromous species with the juvenile stage existing in the freshwater environment for a period of years prior to downstream migration as an adult. Reaching maturity, American Eels in the Connecticut River begin migration to the Atlantic Ocean during late summer into the fall (August through November). Spawning occurs between February and April in the Sargasso Sea. Size ranges in the Connecticut River from approximately 6 inches for juveniles migrating up-river to a maximum of 30-60 inches for out-migrating adults (Langdon et al., 2006). During the freshwater phase, eels prefer lakes, rivers, and ponds with mud or silt bottoms and can be found at a variety of depths. Eels are primarily predators, feeding on a variety of invertebrates and fish and typically are more active during night hours. Activity is restricted to the warmer months and winter is spent buried in the mud or silt.

4.2.2 Catostomidae

White Sucker was the only member of the family Catostomidae present in each of the three impoundments during Study 10. The species can attain ages in excess of 15 years and lengths up to 25 inches although typical adults range from 12-20 inches (Scott and Crossman, 1973). White Suckers accommodate a wide variety of habitats and environmental conditions. They can exist in lakes and large rivers as well as small ponds and streams. The species can be found in high and low gradient habitats and is generally tolerant of degraded environmental conditions including pollutants and siltation (Langdon et al., 2006). Larval White Sucker migrate from spawning sites about 2 weeks after hatching and exist in the upper portions of the water column where they feed on plankton and invertebrates (Langdon et al., 2006). At the length of approximately 1 inch, they relocate to benthic habitats typically feeding on algae and invertebrates (Becker, 1983).

Spawning takes place when water temperatures reach 50°F, typically between late April and June in the upper Connecticut River (Langdon et al., 2006). Adults migrate up tributaries, to higher gradient riverine sections or even along windswept regions of lakes where they utilize rocky, shallow areas with moderate current (Langdon et al., 2006). No nests are prepared and no parental care is provided for the eggs scattered along the bottom of these spawning areas.

4.2.3 Centrarchidae

Three of the target species (Largemouth Bass, Smallmouth Bass, and Bluegill) are included into Centrarchidae, the sunfish family. This family is further divided into the genus *Micropterus* (the black basses) including Largemouth and Smallmouth Bass and the genus *Lepomis* (the sunfishes) including Bluegill. In terms of body size, the black bass are the largest (commonly 10-16 inches in VT) and the sunfishes are the smallest (typically 3-8 inches). Centrarchids are found in habitats with protective cover for feeding and nesting, generally in the littoral zone (along the shoreline to about 6-20 feet) in backwaters and other off-channel habitats. Smallmouth Bass prefer clearer, cooler water than Largemouth Bass, and can be found in either still or moving water. Centrarchids are ambush predators that use vegetated water or water with other solid structure (e.g., rocks, stumps) for cover to prey on smaller fish and invertebrates. Smallmouth Bass may move from littoral areas in late fall to winter aggregations associated with cover in deep water (Langhurst and Schoenike, 1990). Largemouth Bass are generally considered to be inactive during the winter (Cooke et al., 2003).

Spawning occurs from spring, when water temperatures are near 60°F, into summer and early fall. Males construct nests in shallow water by sweeping a depression into sand or gravel, usually around brush, rocks, or logs. Target species of the centrarchid family build nests in water about one to six feet in depth. Many centrarchid species build nest in colonies with Bluegill, typically creating the highest density among the target species listed. Males guard the eggs and young until the young disperse from the nest. Generally, young centrarchids remain in shallow, protected habitats such as coves and flooded tributary mouths following cessation of parental care. High water flows which can result in a rapid drop in water temperature and excessive siltation and excessive lowering of the water level during spawning are the two most common habitat-related reasons for reproductive failure (Becker, 1983). Strong orientation to cover and preference for shallower, off-channel habitats generally limits this family of fishes to exposure to impingement and entrainment through hydroelectric projects.

4.2.4 Clupeidae

American Shad are an anadromous species with adults ascending the Connecticut River to spawn during the spring and summer before returning to the Atlantic Ocean in the fall. Adult shad in the Connecticut River average approximately 18 inches whereas out-migrating juveniles typically range from 2-4 inches (Langdon et al, 2006). Their historic upstream limit in the river is Bellows Falls so this species is not included in the set of Wilder or Bellows Falls target species. As adults, American Shad inhabit the coastal regions of the Atlantic Seaboard. Juveniles, prior to out-migration, prefer backwaters and areas associated with aquatic vegetation. Downstream migration for juvenile shad occurs in autumn of the same year as spawn. American Shad are classified as planktonic insectivores (Halliwell et al., 1999) consuming primarily aquatic invertebrates and zooplankton during their freshwater residency. Spawning migrations take place when water temperatures reach approximately 50°F with fish reaching the upper Connecticut River between mid-May and June. Spawning occurs in mid-river up to temperatures of 70°F. Eggs are fertilized as they are released and settle slowly as they are carried downstream by the current (Scott and Crossman, 1973). No parental care is given and adults begin movement back toward the Atlantic Ocean after spawning is finished.

4.2.5 Cyprinidae

Eleven species from the family Cyprinidae were captured within Wilder, Bellows Falls and Vernon impoundments during Study 10. Of those, Fallfish, Golden Shiner, and Spottail Shiner were selected as the target species to represent this family due to their relative contribution to the overall fish assemblage. Fallfish are the largest representative species (typically 4 to 12 inches) followed by Golden Shiner (3-5 inches) and then Spottail Shiner (2-3 inches). Although all three target Cyprinids inhabit lakes and large rivers, there are habitat preferences that distinguish them from each other. Fallfish prefer clear water lakes and rivers with gravel bottoms whereas Golden Shiner and Spottail Shiner are associated more with slower currents and modest to high concentrations of aquatic vegetation. Golden and Spottail Shiner tend to inhabit shallower waters (up to 12 feet in depth). Golden Shiner and Fallfish are classified as generalist feeders (Halliwell et al., 1999) eating a variety of zooplankton, aquatic invertebrates and even algae (Golden Shiner) and fish (Fallfish). Although classified as a water column feeder (Halliwell et al., 1999), Spottail Shiner generally feed on the same food items as Golden Shiner and Fallfish. Spawning periods for the target cyprinids range from spring through mid-summer with Fallfish initiating spawning the earliest (late April-May) followed by Golden Shiner and Spottail Shiner (May–August). Fallfish spawn over piles of stones or gravel bottoms in flowing water which then are covered by mounds of additional stones (Scott and Crossman, 1973). Golden Shiner broadcast spawn over beds of vegetation while Spottail Shiner are reported to aggregate for spawning at tributary mouths where they broadcast spawn over gravel bottoms (Becker, 1983).

4.2.6 Esociade

Northern Pike were selected as a target species for the three impoundments. Not native to the Connecticut River, Northern Pike were introduced and are now naturalized within the impoundments. Northern Pike can grow large, exceeding 50 inches although commonly encountered sizes in the Connecticut River are between 20-30 inches (Langdon et al., 2006). Northern Pike prefer warm to cool lakes and rivers with slow current and large amounts of aquatic vegetation. Often found in coves and bays or along shorelines during much of the year, pike have been known to move into deeper waters, especially in the heat of summer (Becker, 1983). Northern Pike are predators, ingesting essentially all prey they can swallow including small mammals, birds, fish, and invertebrates. Spawning occurs during spring just after ice out, typically when waters reach 40°F in the Connecticut River. Pike move into marshes and backwaters with shallow water where adhesive eggs are broadcast onto vegetation. No parental care is provided and eggs typically hatch in 10-14 days with young beginning feeding less than 2 weeks later (Becker, 1983).

4.2.7 Ictaluridae

Brown Bullhead was selected as a target species to represent the family Ictaluridae due to its presence in all three study impoundments. Brown bullhead typically range from 8-14 inches in length and are one of three catfish species (along with Channel Catfish and Yellow Bullhead) known to be present within the projects. Bullheads prefer warm water and usually can be found inhabiting regions near or on the bottom in depths as great as 40 feet in shallow ponds, lakes and slow moving rivers with abundant aquatic vegetation and soft bottoms. Bullheads are tolerant of conditions including low temperature, pollution, and low dissolved oxygen; and subsist on a variety of prey including aquatic invertebrates, algae, waste, fish (including eggs and larvae; Scott and Crossman, 1973). Active, especially at night, during the warmer months, Brown Bullhead often stop feeding and have been known to burrow in the bottom substrate during fall and winter months (Becker, 1983). Spawning typically occurs from late spring to late summer when water temperatures range between 69°F and 77°F (Becker, 1983). Nests are excavated into the substrate (sand, gravel, mud) often in the vicinity of aquatic vegetation or some form of structure (Becker, 1983). Nests are typically found along the shoreline in depths ranging from less than 6 inches to several feet (Scott and Crossman, 1973). Nests, and later juveniles, are guarded by one or both adults for several weeks until lengths of about two inches are attained (Scott and Crossman, 1973). Habitat preferences for this species generally limit the exposure of these fish to entrainment or impingement associated with hydroelectric projects.

4.2.8 Percidae

Three of the target species within the impoundments belong to the Percidae family, including two that fall within the subfamily Percinae (Walleye and Yellow Perch) and one within the subfamily Etheostomatinae (Tessellated Darter). Walleye are the largest of the three, typically attaining lengths of 13-20 inches followed by Yellow

Perch (typically 4-10 inches; Scott and Crossman, 1973). Tessellated Darter is the smallest, rarely attaining of a maximum length of 4.5 inches. Walleye and Yellow Perch commonly occur in lakes and rivers, occupying a variety of habitats and depths. Typically, Yellow Perch are associated with slow moving or static water bodies with abundant submerged aquatic vegetation and are active during daylight hours whereas Walleye, due to their light-sensitive tapetum lucidum, prefer more turbid environments and are more active in the shallow regions at night (Scott and Crossman, 1973). The diet of both species includes a variety of invertebrates and fish dependent on season, availability, and size (Becker, 1983). Yellow Perch and Walleye are active year round. Tessellated Darter can be found in habitats ranging from small streams to large rivers and lakes, typically over mud or sand bottom in areas of little to no current (Langdon et al., 2006).

Spawning for Yellow Perch and Walleye occurs at night during early spring after ice out. Walleye begin ascending tributaries in Vermont in April through early May when water temperatures range from 35°F-44°F. Yellow Perch typically begin spawning when temperatures reach 44°F (Langdon et al., 2006). Yellow Perch prefer slow moving or static water and spawn in the shallows at night in lakes and rivers by laying strings of eggs on vegetation or other bottom substrates. Walleye typically broadcast spawn eggs over gravel or rocky substrates along shorelines or tributary mouths although they have been recorded spawning on flooded wetland vegetation (Becker, 1983). Tessellated Darter spawn in late April to May when water temperatures are between 50°F and 59°F, creating nests under rocks (Langdon et al., 2006).

4.2.9 Petromyzontidae

Sea Lamprey are an anadromous fish species that migrate from the ocean environment into freshwater rivers and streams for the purpose of spawning. Sea Lamprey are semelparous (i.e., die following spawning) and therefore it is the juvenile form migrating out to the ocean that is potentially susceptible to impingement/entrainment at hydroelectric facilities. Adults migrate upstream during the spring to spawn when water temperatures exceed 40°C. Adults typically return to the upper Connecticut River in early June where nests are constructed over areas of flowing water with a gravel, sand, and rubble substrate in 15-20 inches of water. Nests are cleared by removing larger stones and sediments and eggs are deposited between June and July (Scott and Crossman, 1973).

Approximately 2-3 weeks after hatching, Sea Lamprey ammocoetes inhabit pools or eddies downstream of the nest in streams and large rivers where they burrow into the soft sediment and become filter feeders, consuming phytoplankton, detritus and zooplankton (Scott and Crossman, 1973). Transformation to the free-swimming juvenile stage in freshwater usually occurs between 3 to 7 years after hatching when these individuals are capable of seeking out host fish on which to feed. Downstream migration to the ocean occurs for some in October and November although the majority move during April of the following spring in conjunction with increased river flows (Scott and Crossman, 1973).

Table 4.2-1. Summary of target fish species habitat preferences (S = spawning, F = feeding, R = rearing).

Family and Species	Life Stage	Lake Habitat Zone					Activity Pattern
		Littoral	Limnetic	Lotic	Pelagic	Benthic	
Anguillidae							
American Eel	Adult						On maturity, adults migrate to ocean
	Juvenile	F		F		F	Rearing and juveniles up to one year remain at sea
Catostomidae							
White Sucker	Juvenile	F	R, F	R		F	White Sucker fry remain in spawning substrate for a month, then migrating downstream. Often found in littoral zone until growth-morphological changes initiate shift to benthic zone.
	Adult	F		F,S		F	Commonly found in shallow regions of most streams and lakes.
Centrarchidae							
Smallmouth Bass	Juvenile	F, R		F			Prefer shallow zones with hard bottom in lakes and rivers. Move off shore and deeper during winter months.
	Adult	F, S		F			
Largemouth Bass	Juvenile	F, R					Prefer shallow zones with soft bottom and vegetation or cover in lakes and slow moving rivers. Move off shore and deeper during winter months.
	Adult	F, S					
Bluegill	Juvenile	R, F					Bluegill typically inhabit warm shallow weedy ponds and similar regions in lakes and slow rivers.
	Adult	S, F	F		F		Adults migrate to deeper water during winter and midsummer
Clupeidae							
American Shad	Adult			S			Adults inhabit marine environment
	Juvenile			R, F			Juveniles spend first summer within rivers, drifting downstream to brackish water by autumn.
Cyprinidae							

Family and Species	**Life Stage**	**Lake Habitat Zone**					**Activity Pattern**
		Littoral	**Limnetic**	**Lotic**	**Pelagic**	**Benthic**	
Fallfish	Juvenile	F		F, R			Young inhabit more rapid water in upstream reaches of rivers.
	Adult	F		S, F			Abundant in gravel and rock bottomed, clear streams, rivers, and lakes. Adults more commonly found in larger pools and deeper, slower section of rivers.
Golden Shiner	Juvenile	R, F					Inhabit clear quiet weedy lakes and slow river rivers with extensive shallow water.
	Adult	S, F					
Spottail Shiner	Juvenile	F	F		F		Prefer large lakes and rivers and can be found in water up to 60 feet deep.
	Adult	S, F	F	S	F		
Esocidae							
Northern Pike	juvenile	R, F					Young remain in shallow spawning areas for several weeks after hatching
	Adult	S, F	F	F			Spawn in shallows, exists in littoral zone although adults may move to deeper water in summer
Ictaluridae							
Brown Bullhead	Juvenile	R, F					Prefer shallow, slow or still water with soft bottom and aquatic vegetation. Can be found in up to 40 feet of water. Generally inactive in winter.
	Adult	S, F				F	
Percidae							
Tessellated Darter	Juvenile	R, F		R, F		R, F	Found in flowing and still water, but prefers slower current water with sand or mud bottom.
	Adult	F, S		F, S		F, S	
Yellow Perch	Juvenile	F	R		F,R		Young hatch and exist for several weeks at the top of the water column feeding on invertebrates.
	Adult	F,S	F		F		Adults often change depth due to light or seasonal temperature changes, existing in most habitats at some point in the year.
Walleye	Juvenile	F,R	F,R				Juveniles inhabit limnetic zone until about 30 mm, then move toward littoral zone

Family and Species	**Life Stage**	**Lake Habitat Zone**					**Activity Pattern**
		Littoral	**Limnetic**	**Lotic**	**Pelagic**	**Benthic**	
	Adult	S, F		F, S	F	F	Walleye feed heavily on fish and invertebrates, moving into shallow waters during night or turbid water periods and retreating to deeper water at night and midsummer.
Petromyzontidae							
Sea Lamprey	Adult			S			Juveniles inhabit marine environment after ammocoete stage, returning to spawn in freshwater rivers with gravel and moderate current as adults
	Juvenile	F		F, R		F	Ammocoetes burrow out of nest and drift down to eddies or pools with sand or mud bottom where they burrow in and live as filter feeders.

Table 4.2-2. Description of habitat types identified in Table 4.2-1.

Littoral zone	The near shore area where sunlight penetrates to the sediment and allows aquatic plants (macrophytes) to grow. Light levels of about one percent or less of surface values usually define this depth. In most lakes this zone extends approximately 10 to 15 feet. Most of the aquatic plant life (both rooted and floating) in a pond or lake is found here because the high amount of sunlight reaching it allows for significant photosynthetic activity. Plants in this area provide a food source and substrate for algae and invertebrates, and habitat for fish and other organisms that is very different from the open water environment. This area is often highly structured with fallen trees, rocks, and roots.
Limnetic zone	The open water area of a lake where light penetrates and some photosynthesis occurs. This is typically a productive area of a lake or impoundment with some rooting and floating vegetation or plankton present.
Lotic zone	An area characterized by flowing or running water with little or no backwater (streams and rivers). The riverine reaches below Wilder, Bellows Falls and Vernon dams represent lotic habitat.
Pelagic zone	The open water, off-shore and above the bottom habitat of a lake or impoundment. The open water pelagic zone is usually a highly productive area for zooplankton and phytoplankton as well as schooling fish.
Benthic zone	The bottom areas of a lake or impoundment void of light penetration and active photosynthesis. The benthic zone can be the deepest parts of a lake or shallower areas void of sunlight or aquatic vegetation where detritus accumulates and aquatic invertebrates are present. The benthic zone can also be affected by water temperature stratification where lake turnover can affect DO levels and currents that stir up material on the bottom.

4.3 Swimming Speeds

For individuals susceptible to entrainment and impingement at water intakes, avoidance of the intakes is related to fish size and swimming performance (Castro-Santos and Haro, 2005). A literature review of swim speed information was conducted for the 15 target fish species that inhabit the Wilder, Bellows Falls, and/or Vernon impoundments. The purpose was to compare available swim performance data for these species to measured current velocity proximal to project intakes.

Three swim speed modes are generally recognized for fishes, though terminology differs slightly among authors. This document will follow the nomenclature of Beamish (1978) and swim speeds presented here are defined as follows:

- Sustained swim speed: that which can be maintained for an indefinite period (longer than 200 minutes) and does not involve fatigue;
- Prolonged swim speed: that which can last between 15 seconds and 200 minutes, and if maintained will end in fatigue; and
- Burst swim speed: that characterized by rapid movements of short duration and high speed, maintained for less than 15 seconds.

Burst swim speeds are the fastest attainable and are generally associated with fish well-being or survival (Beamish, 1978; Wardle, 1980), as they are also related to a fish's ability to capture prey, avoid predators, or in the present case, avoid water intake velocities or structural elements. Utilization of burst swim speed to avoid water intakes also implies the ability to use additional sensory mechanisms to properly detect and orient to the intake. Available stimuli near an intake, in addition to the physical structure, include factors such as turbulence, flow acceleration, pressure changes, and sound (Bell, 1991; Castro-Santos and Haro, 2005). The ability to utilize available cues to avoid intake structures or flow fields may be compromised by darkness, turbidity or reduced swimming ability at water temperatures approaching or exceeding cold water tolerances. Bell (1991) indicates that prolonged swim speed is between 0.5 and 0.7 of the burst swim speed for a fish, whereas sustained swim speed is approximately 0.15 to 0.2 of the burst swim speed. For species and/or life stages where burst speeds were unavailable, these relations were used to convert literature-available prolonged or sustained swim speeds to burst speeds for use in assessing entrainment potential relative to intake velocities.

Results of the literature review of swim performance data for the 15 target species is provided in Table 4.3-1. Swim speeds determined in the laboratory are typically measured by a distance rate (feet per second, fps) for a given fish length range or measure of length central tendency (mean or median lengths). However, in recognition of the role of fish size in swim performance, information on burst swim speed may also be expressed as fish body lengths per second (L/sec), termed "relative burst speed." Smaller fish typically have a higher relative swim speed (more body lengths per second) than larger fish, even though the absolute swim speed (fps) of larger fish is greater (Beamish, 1970).

The data listed in Table 4.3-1 include studies specifically designed to measure one or more components of swim speed or performance, as well as other studies, typically more recent, that measure swim speed in relation to one or more variables (e.g., temperature changes, dissolved oxygen levels). Where a temperature range or specific test temperature is provided, these are indicated. For others with a range provided, the maximum swim speed attained was listed along with the appropriate temperature. Where other conditions were tested, such as physically-conditioned fish versus non-conditioned fish, the data from non-conditioned fish were used as they best represent wild fish (Young and Cech, 1993). In general, the comments or clarifications provided in Table 4.3-1 identify any information deemed useful to assist interpretation of the test result.

4.3.1 Anguillidae - American Eel

Literature reported estimates of burst swim speed were available for young American Eel. Elvers (2.8-3.9 in) were found to swim at burst speeds of 2-3 fps over distances of less than 5 feet and up to 10 feet at 1 fps (McCleave, 1980). However, no estimates were available for larger juvenile (yellow) or adult (silver) American Eel. Swim speed estimates for European Eel (*Anguilla anguilla*), a species similar in morphology and behavior to American Eel, were available. Quintella et al. (2010) tested the prolonged swim speed of 29 yellow European Eel (14-21 in) and 33 silver European Eel (12.5-27.6 in) placed in a swimming tunnel submerged in a fiberglass tank. The water velocity in the swimming tunnel was adjusted from 0 to 4.9 fps for water temperatures ranging from 16.1-18.9°C (61-66°F). Prolonged swim speeds of 1.4 fps for yellow eels and 2.2 fps for silver eels were calculated. Assuming European Eel is a good surrogate for American Eel and applying Bell's percentage criteria to the prolonged swimming speeds, an estimated burst speed of 2.0-2.8 fps for yellow eels and 3.1-4.4 fps for silver eels was calculated (Table 4.3-2).

4.3.2 Catostomidae – White Sucker

Jones et al. (1974) determined a prolonged swim speed of 1.6-2.4 fps for juvenile and adult White Sucker ranging in size from 6.7-14.5 in. Applying Bell's percent criteria to these swim speeds, a burst speed ranging from 2.2-4.8 fps was estimated for juvenile White Sucker (Table 4.3-2). Haro et al. (2004) evaluated the burst swimming ability of White Sucker adults against controlled water velocities in an open-channel flume. The median distance White Sucker with a mean length of 15.4 in were able to travel was approximately 7 m (23 ft) at velocities of 11.5 fps while adults with a mean length of 15.7 in were capable of traveling approximately 3 m (9.8 ft) at 14.8 fps. This suggests large adult White Sucker should be capable of burst speeds on the order of 11.5-14.8 fps for the purpose of behavioral avoidance.

4.3.3 Centrarchidae

4.3.3.1 Bluegill

Swim speed studies of both juvenile and adult Bluegill were located. Bluegills are not considered strong swimmers, although tested juveniles oriented well to current (Schuler, 1968). Bluegill body morphology is better suited for maneuverability than for fast swim speed (Deng et al., 2004). Prolonged swim speeds of 0.33-0.82 fps were reported for young-of-year Bluegill (0.8-3.0 in) at typical summer water temperatures by Schuler (1968) and King (1969). Osied and Smith (1972) *in* Beamish (1978) found a prolonged swim speed of 0.74-0.92 fps at 70°F for young-of-year Bluegill. Adult sustained swim speed was reported at about 1.0 fps (Drucker and Lauder, 1999). The burst swim speed of adult Bluegill (6.0 in) was estimated at 4.3 fps, attained over a 9-second test period using high speed photography (Webb, 1978). However, this speed was reported as a final velocity calculated from an acceleration rate, and may represent a faster speed than might be estimated by more conventional test methods. Gardner et al. (2006) obtained a prolonged swim speed of 1.2 fps over a period of 10 minutes for Bluegill at lengths of 4-6 inches. Applying Bell's percent criteria to the calculated prolonged swimming speeds, a burst swim speed estimate of 0.5-1.7 fps was calculated for juvenile Bluegill and 1.6-4.3 fps for adult Bluegill (Table 4.3-2).

4.3.3.2 Largemouth Bass

Although a common test animal in swim speed studies, no estimates of burst swim speed for juvenile or adult Largemouth Bass were found in the literature review, perhaps because Largemouth Bass are not typically thought of as a riverine species, nor a common user of fishways, often a stimulus for burst swim speed testing. A range of studies cited in Table 4.3-1 identified prolonged swim speed for fry (0.8-0.9 in) at 0.2-1.0 fps and small juvenile Largemouth Bass (2.0-2.5 in) at 0.6-1.6 fps, within a temperature range of 50-95°F. Prolonged swim speeds for larger juveniles (3.0-4.0 in) ranged from 0.7-1.6 fps while those of juveniles 5.9-10.6 in were faster, within the range of 1.8-2.2 fps within a temperature range of 50-86°F.

Burst swim speed for juveniles would be faster than the estimates for prolonged or critical swim speed (subset of prolonged swim speed). Applying Bell's percent criteria, an estimated burst swim speed for fry (0.8-0.9 in) would be 0.2-2.0 fps and for small juvenile Largemouth Bass (2.0-2.3 in) would be 0.9-3.3 fps (Table 4.3-2). Calculated burst speeds were similar for slightly larger juveniles (3.0-5.0 in), ranging from 1.0-3.3 fps while for the larger juveniles and small adults (5.9-10.6 in) the estimated burst swim speed range is 1.1-4.5 fps. Burst swim speed for adult (≥ 11.8 in) Largemouth Bass would be expected to be faster than for the larger juveniles.

4.3.3.3 Smallmouth Bass

No studies of burst swim speed for Smallmouth Bass were located. Several studies that developed estimates of prolonged swim speed for fry (0.6-1.0 inches) ranged from 0.7-1.8 fps while the range of prolonged swim speeds for juvenile Smallmouth

Bass up to 3.7 in long was 1.3-1.8 fps (Webb, 1978). Prolonged swim speed for adult Smallmouth Bass (10.5-14.9 in) was 1.6–3.9 fps at water temperature of 59-68°F (Bunt et al., 1999). Applying Bell's percent criteria, the estimate of burst swim speed for Smallmouth Bass fry is 0.8-1.8 fps, for juvenile Smallmouth Bass is 1.9-3.6 fps, and for adult Smallmouth Bass is 2.3-7.8 fps (Table 4.3-2).

4.3.4 Clupeidae – American Shad

Literature reported estimates of burst swim speeds are available for both juvenile and adult American Shad. Bell (1991) established a burst speed of 2.5 fps for juvenile American Shad between 1.0-3.0 inches (fork length). Robbins et al. (1970) found juvenile American Shad (2.0-3.0 in) had a maximum swim speed of 1.5 fps over a three minute period. Weaver (1965) measured the time adult American Shad took to cover a certain distance within a fishway, determining a burst speed of 11.5-13.0 fps for adults. A similar burst speed (10.0-14.0 fps) was calculated by applying Bell's percentage criteria to a prolonged swim speed of 7 fps established by Bell (1991). The median distance adult American Shad (16.3 in mean fork length) entering a test flume was able to travel was 33 ft at velocities approaching 11.2 fps and 19 ft at velocities of 14.8 fps (Haro et al., 2004). Based on available data, a range for burst swim speeds for juvenile American Shad of 2.1-3.0 fps and for adult American shad of 10.0-14.8 fps was determined (Table 4.3-2).

4.3.5 Cyprinidae

4.3.5.1 Fallfish

Bell (1991) indicates that the sustained swim speed for "chub" (7.1-11.8 in) ranges from 0.7-3.6 fps; and suggests that the sustained swim speed of a fish can be estimated at 15-20% of the burst swimming speed. Based on this, an estimate of 3.3-24.1 fps was calculated for Fallfish (Table 4.3-2).

4.3.5.2 Golden Shiner

Swim speeds of Golden Shiner were evaluated for individuals as well as groups of fish ranging from 1.8-2.7 inches (Boyd and Parsons, 1998). The mean prolonged swim speed for individual fish was 0.8 fps while a group evaluation was conducted for schools of six Golden Shiner with the reported range of prolonged swimming speeds being based on the first fish to fatigue (1.0 fps) to the third (or 50% of the group) to fatigue (1.4 fps). If the range of observed prolonged swimming speeds for Golden Shiner is considered, using Bell's percent criteria, an estimate of 1.2-2.8 fps is calculated as the potential burst speed for Golden Shiner (Table 4.3-2).

4.3.5.3 Spottail Shiner

Literature reported swim speed studies for Spottail Shiner were limited to a single comparative study involving fish collected from a treatment and reference location (Goertzen et al., 2012). Spottail Shiner (2.0 in) collected from both locations had a mean measured prolonged swim speed of 0.7 fps. Applying Bell's percent criteria, an estimate of 1.0-1.5 fps was calculated as the potential burst speed for Spottail Shiner (Table 4.3-2).

4.3.6 Esocidae – Northern Pike

Swim speed estimates for Northern Pike vary by study. Jones et al. (1974) evaluated the prolonged swimming capabilities of 192 Northern Pike at 12°C (53.6°F) ranging from 4.7-24.4 inches and found the prolonged velocity (10-minute increments) to range from 0.6-1.5 fps. Applying Bell's percentage criteria to these numbers provides a burst speed of 0.8-3.0 fps. Gray (1953, as cited in Beamish, 1978) used photography to establish a maximum velocity of 6.9 fps for Northern Pike at 6.5 inches and Magnan (1928, as cited in Beamish, 1978), determined a maximum critical velocity of 4.9 fps for Northern Pike at 14.9 inches. Applying Bell's percentage criteria to these prolonged swim speeds provides estimates of calculated burst swim speeds of 9.0-13.9 fps and 6.3-9.7 fps, respectively (Table 4.3-2). Directly measured estimates of burst speed also vary greatly with Lane (1941, as cited in Beamish, 1978) determining through a hook and line study that a single Northern Pike (no length provided) had a burst speed of 11.8-14.8 fps. A study on Esox spp. of indeterminate length indicates this family, in a timed distance study, had a burst swim speed of 19.4-44.9 fps (Neill et al., personal communication in Beamish, 1978).

4.3.7 Ictaluridae – Brown Bullhead

Frick et al. (1987 in EPRI, 2000) reported a critical swim speed for juvenile Brown Bullhead (mean length of 2.0 in) of approximately 1.0 fps. Applying Bell's percent criteria, an estimated burst speed ranging from 1.5-2.1 fps was calculated for juvenile Brown Bullhead. No swim speed data was available for adult Brown Bullhead. As a result, Channel Catfish were used as a surrogate for adult bullhead. Channel Catfish are a member of the Ictaluridae family and also inhabit the project impoundments. Venn Beecham et al. (2007) determined the burst swim speed data for Channel Catfish ranging in length from 6.3-8.3 inches (FL) to be 3.9 fps (Table 4.3-2).

4.3.8 Percidae

4.3.8.1 Yellow Perch

Larval Yellow Perch (0.6-1.4 in) have been observed to maintain a prolonged swim speed of < 0.1-0.2 fps for one hour at 13°C (55.4°F) (Houde, 1969). Otto and Rice (1974, as cited in Beamish, 1978) observed larger juvenile Yellow Perch (mean length = 3.7 in) tested between 10-20°C (50-68°F) with or without an acute temperature exposure to achieve prolonged swim speeds of 0.1-1.1 fps. Rajotte and Couture (2002) calculated burst speeds of (14.9-18.0 body lengths per second) in similarly sized juvenile Yellow Perch (mean length = 3.9-4.1 in). Conversion of body lengths per second values to fps with use of the reported mean test fish lengths results in estimates of burst speed ranging from 4.8-6.2 fps. Adult Yellow Perch burst swimming speed data was not identified; however, Nelson (1989) studied the prolonged swim speeds of Yellow Perch. Although no lengths were provided, the reported range of weight for study fish (21.5-132 g) indicate the use of a range of fish sizes, including adults. Yellow Perch observed by Nelson (1989) displayed a range of prolonged swim speeds of 0.6-1.5 fps. Using the provided burst swim speeds and applying Bell's percentage criteria to prolonged swim speeds, larval Yellow Perch have an estimated burst swim speed of < 0.1-0.3 fps, juveniles (3.7-4.1 in) have a burst swim speed of 0.7-6.2 fps and larger juveniles/adults have a burst swimming speed of 1.4-3.0 fps (Table 4.3-2). The burst swim speed for adult Yellow Perch is likely a low estimate as Clay (1995) indicates that larger fish generally have a greater swim speed than smaller fish which, as indicated above, have burst speeds recorded as high as 6.2 fps.

4.3.8.2 Walleye

Houde (1969) recorded sustained swim speeds for larval Walleye fry (0.5-0.8 in) of 0.2-0.3 fps at temperatures from 55.4-64.9°F. A juvenile Walleye burst speed of 6.0 fps was calculated for individuals with a mean length of 6.3 inches (Peake et al., 2004). Jones et al. (1974) identified the critical swim speed of juvenile Walleye (mean length = 3.2 in) as 1.2 fps. The burst swim speed of adult Walleye with a body length of 13.8 inches was calculated at 7.2 fps whereas those with a body length of 22.4 inches had a calculated burst speed of 8.6 fps (Peake et al., 2004). Jones et al. (1974) identified the critical swim speed of Walleye with a mean length of 15.4 inches to be 2.8 fps. Using the criteria that sustained swim speeds are approximately 15-20% of burst speed (Bell, 1991), the burst swim speed for larval Walleye was estimated at 0.2-0.3 fps. Appling Bell's percentage criteria to the data from Jones et al. (1974) and utilizing the burst speed estimates from Peake et al. (2004), burst swim speeds for juvenile Walleye fall within the range of 1.8-6.0 fps whereas adult Walleye range from 3.9-8.6 fps (Table 4.3-2).

4.3.8.3 Tessellated Darter

There was no literature reported swim speed information identified for Tessellated Darter. As a result the Jonny Darter, a similar species, was used as a surrogate and reported swim speed information for that species included a minimum prolonged swim speed of 2.2 fps for individuals ranging in length from 1.6-3.1 inches (Gardner, 2006). Applying Bell's percentage criteria to the prolonged swim speed, a burst speed of 3.2-4.4 fps was estimated for juvenile and adult Tessellated Darter (Table 4.3-2).

4.3.9 Petromyzontidae – Sea Lamprey

Beamish (1974) determined a range of prolonged swim speed for juvenile Sea Lamprey (5.7-15.4 in) in water temperatures of 5°C, 10°C and 15°C (41, 50, and 59°F). The range of sustained swim speeds included a lower end of 0.5 fps at 5°C and an upper end of 1.4 fps at 15°C. Using a range of 0.5-1.4 fps as a range of sustained swim speeds and applying Bell's percent criteria, an estimate of 0.8-2.7 fps was calculated as the burst speed for Sea Lamprey (Table 4.3-2). Although no literature reported swim speed data for adult Sea Lamprey was identified, it is expected to be greater than that of the juveniles as critical swimming speed increases with increasing fish length (Clay, 1995).

Table 4.3-1. Literature based swimming performance data for target fish species at Wilder, Bellows Falls, and Vernon.

Species	Family	Life Stage	Body Length (inches)	Swim Speed			Literature Source	Comments
				Sustained	Prolonged	Burst		
American Eel	Anguillidae	juvenile (elver)	2..8-3.9			2.0-3.0 fps	McCleave 1980	
		juvenile (yellow)	14.0-21.0		1.4 fps		Quintella et al. 2010	U-Critical 20 min, 60.8-66.2°F
		adult (silver)	12.5-27.6		2.2 fps		Quintella et al. 2010	U-Critical 20 min, 60.8-66.2°F
White Sucker	Catostomidae	juvenile/adult	6.7		48-73 cm/s		Jones et al. 1974 (in Beamish 1978)	
		adult	15.4			11.5 fps	Haro et al. 2004	15°C, fish voluntarily navigated at V, traveled approximately 7 m at 11.5 fps
		adult	15.7			14..8 fps	Haro et al. 2004	15°C, fish voluntarily navigated at V, traveled approximately 3 m at 14.8 fps
Largemouth Bass	Centrarchidae	Fry	0.8-0.9		4.8-31.2 cm/s		Larimore and Deuver 1968 (cited in Beamish 1978)	prolonged at 5°C to 30°C, acute temperature exposure, 3 minutes at max velocity
		juvenile	2.0-2.5		30.6-50.0 cm/s		Hocutt 1973	critical speed was maximum of test from 15 to 35°C
		juvenile	2.2		18.8-30.7 cm		Larimore and Deuver 1968 (cited in Beamish 1978)	prolonged at 20°C, 3 minutes at max velocity
		juvenile	2.3	0.79 fps			Beamish 1970 in Carlander 1977	at 10°C
		juvenile	2.3	1.57 fps			Beamish 1970 in Carlander 1977	at 30°C
		juvenile	3.9	1.51 fps			Beamish 1970 in Carlander 1977	at 10°C
		juvenile	3.9	2.07 fps			Beamish 1970 in Carlander 1977	at 30°C
		juvenile	3.0	1.21-1.34 fps			Dahlberg et al. 1968 (in Carlander 1977)	
		juvenile	3.7--5.0		3.5-3.8 body lengths/s		Kolok 1991	U-crit 2 min=3.5-3.8 body lengths/sec; 15°C to 19°C- based on a graph with no detail regarding numbers.
		juvenile	3.7-5.0		2.2 body lengths/s		Kolok 1991	U-crit 2 min = 2.2 body lengths/sec; 5°C
		juvenile	3.9		35.1 cm/s		Farlinger and Beamish 1977 (cited in Beamish 1978)	critical at 25°C (60 minutes between increments (10cm/s)

Species	Family	Life Stage	Body Length (inches)	Swim Speed				
				Sustained	Prolonged	Burst	Literature Source	Comments
		juvenile	4.0		45.7 cm/s		Farlinger and Beamish 1977 (cited in Beamish 1978)	critical at 25^{o}C, 10 minutes between increments (10 cm/s)
			5..9-10.6		24-55 cm/s		Beamish 1970 (cited in Beamish 1978)	30 minutes at max velocity, 10^{o}C
			5.9-10.6		33-58 cm/s		Beamish 1970 (cited in Beamish 1978)	30 minutes at max velocity, 15^{o}C
			5.9-10.6		45-63 cm/s		Beamish 1970 (cited in Beamish 1978)	30 minutes at max velocity, 20^{o}C
			5.9-10.6		47-64 cm/s		Beamish 1970 (cited in Beamish 1978)	30 minutes at max velocity, 25^{o}C
			5.9-10.6		48-68 cm/s		Beamish 1970 (cited in Beamish 1978)	30 minutes at max velocity, 30^{o}C
			5.9-10.6		40-60 cm/s		Beamish 1970 (cited in Beamish 1978)	30 minutes at max velocity, 34^{o}C
Smallmouth Bass	Centrarchidae	Fry	0.6		13-19 Lengths/sec		Larimore and Deuver 1968, cited in Carlander 1977 and Houde 1969	relative prolonged speed
		Fry	0.6		0.60-0.87 fps		Larimore and Deuver 1968, cited in Carlander 1977 and Houde 1969	range of prolonged speed
		Fry	0.7-1.0		≤ 0.89 fps	1.78 fps	Larimore and Deuver 1968, cited in Carlander 1977 and Houde 1969	
		juvenile	3.6-3.7		1.3-1.8 fps		Webb 1978	critical swim speed, 2-,in U-crit at 55.4 to 73.4^{o}F
		adult	10.5-14.9		1.6-3.9 fps		Bunt et al. 1999	critical swim speed, U-crit-10 min at 59-68^{o}F
Bluegill	Centrarchidae	juvenile	0.8-3.0		0.33-0.83 fps		Schuler 1968, King 1969	S/max = maximum swim speed for 3 min (= Beamish prolonged), most test at ≥ 15.6^{o}C
		juvenile	1.8-2.2		22.5 cm/sec		Osied and Smith (1972) in Beamish 1978	Tested at 21^{o}C, swim time at max velocity of 31-201 min
		juvenile	2.0-2.1		28.0 cm/s		Osied and Smith (1972) in Beamish 1978	Tested at 21^{o}C
		adult	unknown	0.98 fps			Drucker and Lauder 1999	
		adult	3.9-5.9		37.05 cm/s		Gardner 2006 (MS thesis)	critical swim speed for 10 min.
		adult	6.0			4.3 fps	Webb 1978	final velocity measured after 9-sec burst over short distance

Species	Family	Life Stage	Body Length (inches)	Swim Speed				
				Sustained	**Prolonged**	**Burst**	**Literature Source**	**Comments**
Pumpkinseed	Centrarchidae		5.0		37.2 cm/sec		Brett and Sutherland 1965 (in Beamish 1978)	20^{o}C, velocity increments of 6 cm/s with 60 min intervals
American Shad	Clupeidae	juvenile	1.0-3.0		1.75 fps	2.5 fps	Bell 1991	
		juvenile	2.0-3.0		1.5 fps		Robbins et al. 1970	S/max =maximum swim speed for 3 min (=Beamish prolonged)
		adult	15.7			14.8 fps	Haro et al. 2004	over a distance of 5.9 m
		adult	15.4			11.0 fps	Haro et al. 2004	over a distance of 10.1 m
		adult		2.36-2.47 fps			Dodson and Leggett 1973	Boat speed while following sonic tagged fish, not from laboratory test
		adult			7 fps		Bell 1991	
		adult				350-402cm	Weaver 1965, (in Beamish 1978)	Timed over measured distance (fishway)
Fallfish	Cyprinidae	adult/juvenile	7.1-11.8		0.2-1.1 m/s		Bell 1991	
Golden Shiner	Cyprinidae		1.8-2..7		mean 31.7-43.4 cm/sec		Boyd and Parsons 1998	Groups of 6 fish, minimum is first fish to fatigue, maximum is 3rd fish to fatigue. Temps 21-23^{o}C, 30 minute test period.
			1.8-2.7		mean 25.6 cm/s		Boyd and Parsons 1998	individual fish (12). Temps 21-23oC, 30 minute test period.
Spottail Shiner	Cyprinidae	juvenile	2.0		22.5 cm/sec		Goertzen et al. 2012 (used MS report 2011)	Ucrit5, fish from lake downstream of uranium mill, in document 1 body length/sec approximated to 5 cm/sec
		juvenile	2.0		21.05 cm/sec		Goertzen et al. 2012 (used MS report 2011)	Ucrit5, reference lake, in document 1 body length/sec approximated to 5 cm/sec
Northern Pike	Esocidae		4.7-24.4		19-47 cm/sec		Jones et al. 1974 (in Beamish 1978)	10 min, 12^{o}C
			6.5		210 cm/sec		Gray (1953) (in Beamish 1978)	maximum velocity, no swim time increments.
			14.9		148 cm/sec		Magnan (1929)	maximum velocity, no swim time increments.
						360-450 cm/s	Lane 1941 (in Beamish 1978)	Hook and line

Species	Family	Life Stage	Body Length (inches)	Swim Speed			Literature Source	Comments
				Sustained	Prolonged	Burst		
Esox spp.	Esocidae					590-1370 cm/s	Niel et al (*per com.*) (in Beamish 1978)	25°C, timed over measured distance
Brown Bullhead	Ictaluridae	juvenile	2.0		32 cm/s		Frick et al. 1987 in Dixon 2000	17°C
Channel Catfish	Ictaluridae	juvenile	6.3-8.3	1.3	2.9 fps	3.9 fps	Beecham et al. 2007	maximum prolonged swim speed
Yellow Perch	Percidae	larval	0.6-1.4		0.6-4.6 cm/s		Houde 1969 (in Beamish 1978)	Maintained for 1 hour at 13°C
		juvenile	3.7		15.5-21.0 cm/s		Otto and Rice (1974) (in Beamish 1978)	10°C, velocity increase of 5 cm/s every 15 min
		juvenile	3.7		25.2-33.0 cm/s		Otto and Rice (1974) (in Beamish 1978)	20°C, velocity increase of 5 cm/s every 15 min
		juvenile	3.7		33.5 cm/s		Otto and Rice (1974) (in Beamish 1978)	10°C, acute temp exposure, velocity increase of 5 cm/s every 15 min
		juvenile	3.7		15.5 cm/s		Otto and Rice (1974) (in Beamish 1978)	20°C, acute temp exposure, velocity increase of 5 cm/s every 15 min
		juvenile	3.9		4.77 body lengths/sec	16.94 body lengths/sec	Rajotte and Couture 2002	fish from metal contaminated lakes, 19°C, 5 cm/s every 30 minutes till exhaustion. Burst from 9 VDC jolt
		juvenile	3.9		5.29 body lengths/sec	14.84 body lengths/sec	Rajotte and Couture 2002	fish from metal contaminated lakes, 19°C, 5 cm/s every 30 minutes till exhaustion. Burst from 9 VDC jolt
		juvenile	3.9		4.04 body lengths/sec	17.41 body lengths/sec	Rajotte and Couture 2002	fish from metal contaminated lakes, 19°C, 5 cm/s every 30 minutes till exhaustion. Burst from 9 VDC jolt
		juvenile	4.1		3.8 body lengths/sec	18.03 body lengths/sec	Rajotte and Couture 2002	fish from metal contaminated lakes, 19°C, 5 cm/s every 30 minutes till exhaustion. Burst from 9 VDC jolt
		juvenile/adult			30.2-45.5 cm/s		Nelson 1989	pH 7.8, based on mass of 21.5-132 g. 5 cm/s increments of 30 min intervals till exhaustion
		juvenile/adult			18.3-44.8 cm/s		Nelson 1989	pH 4, based on mass of 21.5-132 g. 5 cm/s increments of 30 min intervals till exhaustion
Walleye	Percidae	fry	0.5	0.16 cm/s			Houde 1969	64.9°C
		fry	0.8	0.25 cm/s			Houde 1969	55.4°C
		juvenile	3.2		38 cm/s		Jones et al. 1974	critical swim speed at 19°C for 10 min

Species	Family	Life Stage	Body Length (inches)	Swim Speed			Literature Source	Comments
				Sustained	Prolonged	Burst		
		juvenile	6.3			6.02 fps	Peake et al. 2004	fast-start or startle speed calculated from formula in Peake et al. 2000
		adult	13.8			7.2 fps	Peake et al. 2000	fast-start or startle speed calculated from formula in Peake et al. 2000
		adult	15.4		84 cm/s		Jones et al. 1974	critical swim speed at 19°C for 10 min
		adult	22.4			8.57 fps	Peake et al. 2000	fast-start or startle speed calculated from formula in Peake et al. 2000
Tessellated Darter (substitute Jonny Darter)	Etheostoma		1.6-3.1		67.76 cm/s		Gardner 2006	substitute Jonny Darter: Ucrit10, flume only achieved 70 cm/sec, which most darters achieved so not a true mean. More accurately highest achieved velocity
Sea Lamprey	Petromyzontidae		5.7-15.4		16.6-33.6 cm/sec		Beamish 1974 (in Beamish 1978)	5°C, endurance- gradually attained max velocity, maintained at max for 10 minutes
			5.7-15.4		16.8-34.7 cm/sec		Beamish 1974 (in Beamish 1978)	10°C, endurance- gradually attained max velocity, maintained at max for 10 minutes
			5.7-15.4		24.2-41.3 cm/sec		Beamish 1974 (in Beamish 1978)	15°C, endurance- gradually attained max velocity, maintained at max for 10 minutes

[This page intentionally left blank.]

Table 4.3-2. Burst swim speeds for target fish species at Wilder, Bellows Falls, and Vernon.

Family	Species	Life Stage	Species Size (in)	Burst/Startle Speed (fps)
Anguillidae	American Eel	Juvenile (elver)	2.8-3.9	2.0-3.0
		Juvenile (yellow)	14.0-21.0	2.0-2.8
		Adult (silver)	12.5-27.6	3.1-4.4
Catostomidae	White Sucker	Juvenile/Adult	6.7-14.5	2.2-4.8
		Adult	15.4-15.7	11.5-14.8
Centrarchidae	Largemouth Bass	Fry	0.8-0.9	0.2-2.0
		Juvenile	2.0-5.0	0.9-3.3
		Large Juvenile	5.9-10.6	1.1-4.5
	Smallmouth Bass	Fry	0.6-1.0	0.8-1.8
		Juvenile	3.6-3.7	1.9-3.6
		Adult	10.5-14.9	2.3-7.8
	Bluegill	Juvenile	0.8-3.0	0.5-1.7
		Adult	3.9-6.0	1.1-4.3
Clupeidae	American Shad	Juvenile	1.0-3.0	2.1-3.0
		Adult	(Unknown-16.3)	10-14.8
Cyprinidae	Fallfish	Juvenile/Adult	7.1-11.8	3.5-24.1
	Golden Shiner	Juvenile	1.8-2.7	1.2-2.8
	Spottail Shiner	Juvenile	2	1.0-1.5
Esocidae	Northern Pike	Juvenile/Adult	4.7-24.4	0.9-13.8
		Unknown	Unknown	11.8-14.8
	Esox. Sp.	Unknown	Unknown	19.4-44.9
Ictaluridae	Brown Bullhead (Channel Catfish as adult surrogate)	Juvenile	2	1.5-2.1
		Adult	6.3-8.3	3.9
Percidae	Yellow Perch	Larval	0.6-1.4	<0.1-0.3
		Juvenile	3.7-4.1	0.7-6.2
		Juvenile/Adult	Unknown	1.4-3.0+
	Walleye	Fry	0.5-0.8	0.2-0.3
		Juvenile	3.2-6.3	1.8-6.0
		Adult	13.8-22.4	3.9-8.6
	Tessellated Darter (Jonny Darter as a surrogate)	Juvenile/Adult	1.6-3.1	3.2-4.4
Petromyzontidae	Sea Lamprey	Juvenile	5.7-15.4	0.8-2.7

4.4 Project Approach Velocities

Intake or approach velocities were calculated from engineering drawings of the Wilder, Bellows Falls, and Vernon forebay structures using the velocity equation:

$Q = V * A$

Where:

Q = Flow rate (cfs)
V = Velocity (fps)
A = Area (ft^2)

To provide the most conservative estimate of entrainment, intake velocities were calculated based on the maximum turbine discharge (cfs) for each turbine type at Wilder (Table 3.1-2), Bellows Falls (Table 3.2-2), and Vernon (Table 3.3-2). Intake velocities were calculated as 2.2 fps and 1.4 fps for Units 1-2 and Unit 3 at Wilder (Table 3.1-1), 2.2 fps for Units 1-3 at Bellows Falls (Table 3.2-1), and 1.4, 2.5, and 2.1 for Units 1-4, Units 1-5, and Units 9-10 at Vernon (Table 3.3-1).

Table 4.4-1. Calculated intake velocities at Wilder, Bellows Falls, and Vernon.

Project and Unit	Max. Turbine Discharge (cfs)	Calculated Intake Velocity (fps)
Wilder Units 1 – 2	5650	2.2
Wilder Unit 3	825	1.4
Bellows Falls Units 1 – 3	3850	2.2
Vernon Units 1 – 4	1100	1.4
Vernon Units 5 – 8	1860	2.5
Vernon Units 9 - 10	2060	2.1

5.0 IMPINGEMENT AND ENTRAINMENT

5.1 Impingement

Fish impingement at a particular project can be considered a function of rack spacing. Clear spacing on trash racks at Wilder, Bellows Falls, and Vernon varies. Clear spacing on turbine trash racks at Wilder is 5.0 inches for Units 1 and 2 and 1.625 inches for Unit 3. At Bellows Falls, Units 1-3 are all shielded by trash racks with 4.0-inch clear spacing. Trash racks installed at Vernon are 1.75-inch clear spacing at Units 1-8 and 3.625-inch clear spacing at Units 9 and 10. Fish body widths for representative lengths of target fish is shown in Table 5.1-1. Representative target fish lengths from 5-40 inches were established and body width proportions in Smith (1985) were used to calculate corresponding body width.

For target species and representative lengths, there were no calculated body widths wider than the trash rack clear spacing on Units 1 and 2 at Wilder (5.0 in). Wilder Unit 3 has a narrower clear spacing (1.625 in) and as a result, most of the target species that can reach 15 inches or more in total length, have a calculated body width which may leave them vulnerable to impingement. At Bellows Falls, only Northern Pike and Walleye with a body length greater than 30 inches reached calculated body widths wider than the trash rack clear spacing at Units 1-3 (4.0 in). This observation holds true for Units 9 and 10 at Vernon, with 3.625-inch clear spacing for the trash racks. Vernon Units 1-8 have a narrower clear spacing (1.75 in) and as a result, most of the target species which can reach 15 inches or more in total length have a calculated body width which may leave them vulnerable to impingement. The rate of impingement for species/body lengths noted above at project trash racks will be a function of their ability to escape the flow field associated with the intake structures.

With the exception of the species/body sizes indicated above, target fish unable to escape the flow field of the intake structure may pass through the rack spaces rather than become impinged on any of the racks or support structures. Some fish may be unable to react normally to a flow field if injured or lethargic due to loss or reduction of swimming ability, such as can occur in cold water.

Impingement is an unlikely event for most species at Wilder and Bellows Falls due to the larger trash rack spacing found on most intakes at these sites. Vernon has a greater chance of impingement due to the smaller clear spacing (1.75 in) found on the majority of intake racks.

Table 5.1-1. Fish body widths for representative lengths of target fish at Wilder, Bellows Falls, and Vernon. Fish length-body width (BW) relationships from Smith (1985).

Target Species	Max. Adult Length[a]	Body Width (BW) for Given Total Length (TL) (in)						BW as % of TL
		TL=5	TL=10	TL=15	TL=20	TL=30	TL=40	
American Eel	45	0.2	0.4	0.6	0.8	1.1	1.5	3.8
White Sucker	25	0.9	1.8	2.7	3.6	-	-	17.8
Bluegill	10	0.8	1.7	-	-	-	-	16.8
Largemouth Bass	20+	0.8	1.7	2.5	3.3	-	-	16.5
Smallmouth Bass	20	0.8	1.6	2.4	3.2	-	-	15.8
American Shad	18	0.8	1.6	2.5	3.3	-	-	16.4
Fallfish	20	0.8	1.6	2.4	3.2	-	-	16.1
Golden Shiner	12	0.7	1.3	2	-	-	-	13
Spottail Shiner	6	0.9	-	-	-	-	-	18
Northern Pike	40+	0.8	1.6	2.4	3.2	4.8	6.4	16
Brown Bullhead	12	1	2.1	3.1	-	-	-	20.6
Yellow Perch	15	0.7	1.4	2.1	-	-	-	14.1
Walleye	34	0.8	1.5	2.3	3	4.5	-	15
Tessellated Darter	4.5	0.8	-	-	-	-	-	16.9
Sea Lamprey	36	0.4	0.8	1.2	1.6	2.3	-	7.8[b]

a. As indicated in Langdon et al., 2006.

b. Body depth was used instead of body width since body width information was not available and Lamprey are more or less cylindrical in cross section.

5.2 Entrainment

Assessing the probability of entrainment at Wilder, Bellows Falls, and Vernon included an examination of the characteristics of each project relative to life history and behavioral traits of the target species, including swim speed. Various comprehensive reviews of entrainment data (FERC, 1995; EPRI, 1997) suggest that the factors listed below will influence the potential of entrainment.

- Intake adjacent to shoreline: nearshore intakes typically entrain fish at higher rates than offshore intakes, as fish tend to follow shorelines or orient to physical structures associated with shorelines.

- Intake location in littoral zone: the littoral zone is the most productive region of an impoundment and most fish rear in the shallower littoral areas.

- Abundant littoral zone species: fish such as centrarchids that spawn, rear, and spend most of their lives in shallow near-shore waters tend to be among the most abundant species in a littoral-zone fish assemblage.

- Presence of obligatory migrants: resident fish are usually entrained inadvertently, but in relation to their use of near-intake habitats. Migrants into or out of freshwater systems must utilize a passage or exit route; turbine intakes or draft tubes provide the flow cues that migrating fish may follow into the area of turbine intakes.

- Intake depth: fish are usually more abundant in shallower portions of an impoundment throughout most of the year.

- Drawdown: drawdown of an impoundment to provide storage of winter and spring runoff, or during generation at pumped storage projects, reduces impoundment volume and may place fishes in closer proximity to water intakes. Frequent, large water fluctuations can reduce or impair available shoreline habitat.

- Hydraulic capacity: greater volumes of water passed through intakes will entrain more fish for a given entrainment rate.

- Water quality factor: poor water quality (e.g., low dissolved oxygen in the hypolimnion) in an impoundment may form a barrier and reduce fish susceptibility to entrainment.

- Approach velocity: approach velocities may positively correlate with entrainment rates, although FERC (1995) was unable to find a significant trend between entrainment rate and intake velocity.

The factors above were reviewed for generation conditions at Wilder, Bellows Falls, and Vernon (Table 5.2-1) for the existing fish community as a whole. There will obviously be individual species which may or may not conform to these generalizations due to their specific life history characteristics. At Wilder, it is likely that the primary factors reducing entrainment potential are the lack of clupeids, low numbers of obligatory migrants, relatively deep intakes (upper intake elevations are ~30 feet below the maximum operating impoundment level), and the lack of a seasonal impoundment drawdown. Approach velocities at the trash racks were estimated to be relatively low (1.4 - 2.2 fps) which will also help reduce the likelihood of entrainment. Primary factors increasing entrainment potential at Wilder may include the location of the intakes relative to the shoreline (within ~ 200 ft).

Primary factors reducing entrainment potential at Bellows Falls may include the lack of clupeids, low numbers of obligatory migrants, the lack of a seasonal impoundment drawdown and the absence of a natural shoreline adjacent to the intake structure due to the presence of the elongated power canal constructed from paving stones and concrete that do not provide suitable habitat for littoral fish species Approach velocities at the trash racks were estimated to be relatively low

(2.2 fps) which will also help reduce the likelihood of entrainment. Primary factors increasing entrainment potential at Bellows Falls includes the shallow depth of the upper intake elevations (surface level) in relation to the maximum operational impoundment level.

At Vernon, it is likely that the primary factors reducing entrainment potential are slightly reduced depth intakes (upper intake elevations are ~5 feet below the maximum operational impoundment level) and the lack of a seasonal impoundment drawdown. Approach velocities at the trash racks were estimated to be relatively low (1.4 - 2.5 fps) which will also help reduce the likelihood of entrainment. Primary factors increasing entrainment potential at Vernon may include the location of the intakes relative to the shoreline (within ~ 300 ft) as well as the large number of obligatory migrants (juvenile American Shad) upstream of the project.

Table 5.2-1. Comparison of factors that may influence entrainment of target fish species at Wilder, Bellows Falls, and Vernon.

Influencing Factors	Wilder	Bellows Falls	Vernon
Intake adjacent to shoreline	Yes	No	Yes
Intake location in littoral zone	No	No	Yes
Abundant littoral zone species	Yes	Yes	Yes
Abundant clupeids	No	No	Yes
Obligatory migrants	Few	Some	Yes
Intake depth (ft) at max/min impoundment elevation	~30	surface	~5
Approach velocity (fps)	1.4-2.2	2.2	1.4-2.5
Normal hydraulic capacity (cfs)	10,700	11,400	17,100
Seasonal impoundment drawdown	No	No	No
Water quality	No	No	No

5.2.1 Data From EPRI

In 1997, the Electric Power Research Institute (EPRI) compiled entrainment data from 43 selected sites. The compilation filtered site entrainment data through acceptability criteria such as:

- Requirement for utilization of full-flow netting;
- Sufficient data for seasonal analyses;
- Performance of net efficiency tests;
- Sufficient operational data to calculate entrainment densities; and,
- Lack of major study flaws such as net intrusion, extensive net damage, etc.

The thorough data screening enabled calculation of reliable seasonal and annual estimated entrainment rates for fishes of three size groups. For a species, the range of densities among a number of sites were used by EPRI (1997) to develop a 5-step qualitative scale of entrainment potential from Low to Moderate to High. The qualitative rating was determined within the distribution of entrainment densities by identifying "break points". A different set of "break-points" from among higher density values were used to describe entrainment potential for small fish compared to medium and large fish since small fish are more abundant in an impoundment than either medium or large fish.

The entrainment potentials shown in Table 5.2-2 represent up to 41 sites per species without regard to variations in local conditions (e.g., intake configuration, impoundment size) that may influence entrainment. Not all target species were represented in the EPRI (1997) database and as a result, Alewife and Gizzard Shad were used as surrogates for American Shad. Alewife were used as a surrogate for the small and medium fish categories due to their similar life history characteristics. Gizzard Shad entrainment potential was used for large fish (> 15 inches) as Alewife data does not exist within that size class.

Table 5.2-2. Entrainment potential for Wilder, Bellows Falls and Vernon target species as identified from other projects (EPRI, 1997).

Species/ Surrogates	No. Sites Species Present	Entrainment Potential[a]		
		Small Fish (< 8 in)	Medium Fish (8-15 in)	Large Fish (>15 in)
American Eel	9	Low	Moderate	Moderate-High
American Shad (Alewife and Gizzard Shad surrogates)	10	High	Moderate-High	Moderate
Bluegill	36	Moderate-High	Moderate	Low
Brown Bullhead	30	Moderate-High	Moderate-High	Low
Fallfish	7	Low	Low	N/A
Golden Shiner	34	Moderate-High	Low	N/A
Largemouth Bass	34	Moderate-High	Low-Moderate	Moderate
Northern Pike	22	Low-Moderate	Moderate	Moderate
Sea Lamprey	2	Low	Low	Low
Smallmouth Bass	34	Moderate	Moderate	Low
Spottail Shiner	26	Moderate-High	N/A	N/A
Tessellated Darter	10	Low-Moderate	N/A	N/A
Walleye	29	Moderate-High	Moderate-High	Low-Moderate
White Sucker	39	Moderate-High	Moderate-High	Moderate
Yellow Perch	41	High	Moderate	Low

a. N/A indicates no qualitative rating of entrainment potential (no data for fish within size range).

Most studies have shown that entrainment is highest for fish less than four inches (FERC 1995; Winchell et al., 2000). The qualitative entrainment potential of small fish entrained at other hydroelectric projects ranged from Low for American Eel, Fallfish, and Sea Lamprey, to High for American Shad (Alewife as a surrogate) and Yellow Perch. Moderate-High entrainment potential ratings (Bluegill, Brown Bullhead, Golden Shiner, Largemouth Bass, Spottail Shiner, Walleye, and White Sucker) were the most prevalent among the target species for small fish (Table 5.2-2).

In the medium (8-15 inch) size category, none of the target species entrainment potential from other hydroelectric projects were ranked as High, although four species (American Shad, Brown Bullhead, Walleye and White Sucker) were ranked as Moderate-High. All other target species within the 8-15 inch range were ranked between Moderate and Low. Though the qualitative potential for entrainment of medium (or large) fish relative to small fish may be comparable for some species, the numbers of many fish greater than eight inches that are available for entrainment are relatively low. Other than American Eel (Moderate-High), the entrainment potential among large-sized fishes (> 15 inches) considered was no higher than Moderate or less.

Bar rack clear spacing at intake structures varied among projects. At Wilder, rack clear spacing ranged from 1.625 inches (Unit 3) to 5.0 inches (Units 1-2). Bellows Falls clear rack spacing was 4.0 inches at all three units whereas Vernon clear spacing ranged from 1.75 inches (Units 1-8) to 3.625 inches (Unit 9-10). As reported in Winchell et al. (2000), little difference in fish size distributions existed for the wide range of bar rack clear spacing represented in the reviewed studies. Across all rack spacing, 94 percent of the fish entrained were less than eight inches long (Table MF5.2-3).

Table MF5.2-3. Size class composition of fish entrained at projects with the given range of bar rack spacing (as summarized in Winchell et al., 2000).

Clear Spacing (in)	N	Average Composition (%) by Size Class					Representative TransCanada Project (and Units)
		0–4 (in)	4–8 (in)	8–15 (in)	15–30 (in)	>30 (in)	
1	3	61.5	32.2	5.5	0.9	0	n/a
1.5 - 1.8	10	64.8	27.1	7.5	0.6	0	Wilder (Unit 3), Vernon (Units 1-8)
2.0 - 2.75	12	68.9	25.3	5.1	0.7	0	n/a
3.0 - 10.0	14	80.0	15.7	3.9	0.3	0	Wilder (Units 1,2), Bellows Falls (Units 1-3), Vernon (Units 9-10)
All	39	71.3	22.9	5.3	0.5	0	

5.2.2 Qualitative Assessment of Entrainment Potential

Data collected from the literature review (i.e., habitat and life history, swim speeds, and comparable hydroelectric locations as summarized in EPRI, 1997) were used to compile a qualitative assessment of the potential entrainment of target fishes at each of the three projects. The qualitative assessment used a multi-step rank from High to Medium to Low. An overall entrainment potential was given to each target species and life stage based on consideration of habitat and life history, swim speed relative to approach velocity, and data reported for other projects (Wilder, Table 5.2-4; Bellows Falls, Table 5.2-5; Vernon, Table 5.2-6).

Members of the target fish community most susceptible to entrainment are those whose life history strategies include downriver movement, and small bodied (i.e., juvenile) fish. Given those criteria, the most susceptible fish life stage/species is likely juvenile American Shad (at Vernon) which move in large schools near the center of the river channel and towards the upper portion of the water column.

Juvenile individuals of littoral fish species (i.e., Bluegill, Largemouth Bass and Smallmouth Bass) are likely more susceptible to entrainment than adults of those species due to their lesser swimming abilities. However, these species are more prevalent in shallower, shoreline habitat and would likely have a lower entrainment potential at units positioned near the center of the channel. Likewise, the preference for more nearshore habitat of forage species such as Golden and Spottail Shiner may help to offset their relatively weak swimming ability and lower their entrainment potential.

With regard to pelagic, predatory species such as Walleye and Yellow Perch, their entrainment potential may be increased while following prey species into the intake areas (e.g., during the fall out migration of juvenile American Shad at Vernon). However, adults of those species are strong swimmers and should be capable of avoiding intake velocities at the three projects. It should be noted that the ability to react to intake velocities may be reduced for injured fish or those that become lethargic due to loss or reduction of swimming ability, which can occur in cold water conditions.

Table MF5.2-4. Qualitative assessment of the entrainment potential of target fish species relative to factors evaluated in this assessment and an overall entrainment potential for the Wilder Project.

Species and Life stage	Habitat & Life History Relative to Project Characteristics	Swim Speed Relative to Approach Velocity	Other Projects (EPRI 1997)	Overall Entrainment Potential
American Eel				
Juvenile	L	M	L	M-L
Adult	H	L	H-M	H
Bluegill				
Juvenile	M	H-M	H-M	H-M
Adult	L	M-L	M-L	M-L
Brown Bullhead				
Juvenile	L	H	H-M	M-L
Adult	L	L	M-L	L
Fallfish				
Juvenile	L	L	L	L
Adult	L	L	L	L
Golden Shiner				
Juvenile	H	H-M	H-M	H-M
Adult	M	ND [a]	L	M-L
Largemouth Bass				
Juvenile	M	M-L	H-M	M
Adult	L	M-L	M-L	M-L
Northern Pike				
Juvenile	L	L	M-L	L
Adult	L	L	M-L	L
Sea Lamprey				
Juvenile	M	H-M	L	M-L
Adult	L	ND [a]	L	L
Smallmouth Bass				
Juvenile	M	H	M	M
Adult	L	M-L	M-L	M-L
Spottail Shiner				
Juvenile	H	H	H-M	H-M
Adult	M	H	H-M	H-M
Tessellated Darter				
Juvenile	L	M-L	M-L	M-L

Species and Life stage	Habitat & Life History Relative to Project Characteristics	Swim Speed Relative to Approach Velocity	Other Projects (EPRI 1997)	Overall Entrainment Potential
Adult	L	M-L	M-L	M-L
Walleye				
Juvenile	M	M-L	H-M	M
Adult	M	L	M-L	M-L
White Sucker				
Juvenile	M	M-L	H-M	M
Adult	L	L	M	M-L
Yellow Perch				
Juvenile	M	M-L	H	H-M
Adult	L	M-L	M-L	M-L

a. ND = no data

Table 5.2-5. Qualitative assessment of the entrainment potential of target fish species relative to factors evaluated in this assessment and an overall entrainment potential for the Bellows Falls Project.

Species and Life stage	Habitat & Life History Relative to Project Characteristics	Swim Speed Relative to Approach Velocity	Other Projects (EPRI 1997)	Overall Entrainment Potential
American Eel				
Juvenile	L	M	L	M-L
Adult	H	L	H-M	H
Bluegill				
Juvenile	M	H-M	H-M	H-M
Adult	L	M-L	M-L	M-L
Brown Bullhead				
Juvenile	L	H	H-M	M-L
Adult	L	L	M-L	L
Fallfish				
Juvenile	L	L	L	L
Adult	L	L	L	L
Golden Shiner				
Juvenile	H	H-M	H-M	H-M
Adult	M	ND [a]	L	M-L
Largemouth Bass				

Species and Life stage	Habitat & Life History Relative to Project Characteristics	Swim Speed Relative to Approach Velocity	Other Projects (EPRI 1997)	Overall Entrainment Potential
Juvenile	M	M-L	H-M	M
Adult	L	M-L	M-L	M-L
Northern Pike				
Juvenile	L	L	M-L	L
Adult	L	L	M-L	L
Sea Lamprey				
Juvenile	M	H-M	L	M-L
Adult	L	ND [a]	L	L
Smallmouth Bass				
Juvenile	M	H	M	M
Adult	L	H-M	M-L	M-L
Spottail Shiner				
Juvenile	H	H	H-M	H-M
Adult	M	H	H-M	H-M
Tessellated Darter				
Juvenile	L	M-L	M-L	M-L
Adult	L	M-L	M-L	M-L
Walleye				
Juvenile	M	M-L	H-M	M
Adult	M	L	M-L	M-L
White Sucker				
Juvenile	M	M-L	H-M	M
Adult	L	L	M	M-L
Yellow Perch				
Juvenile	M	M-L	H	H-M
Adult	L	M-L	M-L	M-L

a. ND = no data

Table 5.2-6. Qualitative assessment of the entrainment potential of target fish species relative to factors evaluated in this assessment and an overall entrainment potential for the Vernon Project.

Species and Life stage	Habitat & Life History Relative to Project Characteristics	Swim Speed Relative to Approach Velocity	Other Projects (EPRI 1997)	Overall Entrainment Potential
American Shad				
Juvenile	H	H-M	H	H
Adult	H-M	L	H-M	H-M
American Eel				
Juvenile	L	H-M	L	L
Adult	H	L	H-M	H
Bluegill				
Juvenile	H-M	H	H-M	H-M
Adult	L	H-M	M-L	M-L
Brown Bullhead				
Juvenile	L	H	H-M	M-L
Adult	L	L	M-L	L
Fallfish				
Juvenile	L	L	L	L
Adult	L	L	L	L
Golden Shiner				
Juvenile	H	H-M	H-M	H-M
Adult	M	ND [a]	L	M-L
Largemouth Bass				
Juvenile	M	H-M	H-M	H-M
Adult	L	H-M	M-L	M
Northern Pike				
Juvenile	L	M-L	M-L	M-L
Adult	L	L	M-L	L
Sea Lamprey				
Juvenile	M	H	L	M
Adult	L	ND [a]	L	L
Smallmouth Bass				
Juvenile	M	H-M	M	H-M
Adult	L	M-L	M-L	M-L
Spottail Shiner				
Juvenile	H	H	H-M	H-M

Species and Life stage	Habitat & Life History Relative to Project Characteristics	Swim Speed Relative to Approach Velocity	Other Projects (EPRI 1997)	Overall Entrainment Potential
Adult	M	H	H-M	H-M
Tessellated Darter				
Juvenile	L	L	M-L	L
Adult	L	L	M-L	L
Walleye				
Juvenile	M	H-M	H-M	H-M
Adult	M	L	M-L	M-L
White Sucker				
Juvenile	M	M-L	H-M	M
Adult	L	L	M	M-L
Yellow Perch				
Juvenile	M	H-M	H	H-M
Adult	L	M	M-L	M-L

a. ND = no data

6.0 ESTIMATES OF TURBINE SURVIVAL

6.1 Blade Strike Probability Using Predictive Model

Franke et al. (1997) defines the three primary risks to emigrating fish passing through the turbine environment as 1) mechanical mechanisms, 2) fluid mechanisms, and 3) pressure mechanisms. Mechanical mechanisms are primarily defined as forces on a fish's body resulting from direct contact with turbine structural components (e.g., rotating runner blades, wicket gates, stay vanes, discharge ring, draft tube, passage through gaps between the blades and hub, or at the distal end of blades or other structures placed into the water passageway). The probability of that contact is dependent on distance between blades, number of blades and fish body length. Additional sources of mechanical injury may include gap grinding, abrasion, wall strike, and mechanical chop. Fluid mechanisms are defined as shear-turbulence (the effect on fish of encountering hydraulic forces due to rapidly changing water velocities) and cavitation (injury resulting from forces on fish body due to vapor pockets imploding near fish tissue). Impacts from pressure result from fish inability to adjust from regions of high pressure immediately upstream of turbines to regions of low pressure immediately downstream of turbines.

Results from most studies indicate that mechanical related injuries are the dominant source of mortality for fish in the turbine environment at low head (< 30 m or 100 ft) projects (Franke et al., 1997). Blade strike is considered the primary mechanism of mortality when fish pass through turbines (Eicher Associates Inc., 1987; Cada, 2001) and pressure related injuries appear to be of minor secondary importance when working at low head (< 30 m or 100 ft) hydroelectric projects. In addition, Franke et al. (1997) noted that tolerance to pressure reduction is greater for physostomous fish species, defined by having a pneumatic duct connecting the air bladder to the esophagus so that gasses from the air bladder can quickly dissipate through the mouth to accommodate changing pressures. Franke et al. (1997) noted that although evidence of injuries due to fluid shear forces does exist, relative to other injury types, they are not a dominant source of mortality during turbine passage.

Given that mechanical related injuries comprise the dominant source of mortality for fish passing through low head hydroelectric projects, blade strike probabilities and the resulting estimates of turbine passage survival were calculated for the Wilder, Bellows Falls, and Vernon turbines using the Advanced Hydro Turbine model developed by Franke et al. (1997). The Franke et al. (1997) blade strike model was developed as part of the U.S. Department of Energy program to develop more “fish friendly” turbines and is a modified form of the equation originally proposed by VonRaben (Bell, 1981). Franke et al. (1997) refined the VonRaben model to consider tangential projection of the fish length and calculation of flow angles based on overall operating head and discharge parameters because most turbine passage mortality is likely caused by fish striking a blade or other component of the turbine unit. The Franke blade strike model predicts the probabilities of leading edge strikes (a possible mechanical injury source). Those strikes could result from contact between a fish body and a blade, a gap between blade and an adjacent structure, stay vane leading edge, wicket gate leading edge, or leading edge to any support pieces in the intake or draft tube.

The probability (P) of direct contact between a fish and a leading edge depends on a number of factors including the number of turbine blades (or buckets; N), fish length (L), runner blade speed (rpm), turbine type, runner diameter (D), and total discharge (Q). Additionally, a correlation function (λ) is added to the equations to account for several factors (Franke et al., 1997). Among these are that an individual fish may not lie entirely in the plane of revolution due either to internal forces within the turbine or the physical movement of the individual fish. Additionally, a length-related fraction may be applied to account for the fact that an impact on a sensitive portion of the fish body (i.e., the head) may be more damaging than an impact to a less sensitive portion (i.e., the tail) of the fish (Franke et al., 1997).

The use of the correlation factor also extends the applicability for the blade strike equations to all injury mechanisms related to the variable NL/D (number of blades*body length / runner diameter). These include both mechanical (leading edge strikes and gap grinding) and fluid mechanisms (Franke et al., 1997)[3]. As used in this analysis, the equation assumes that any strike results in immediate mortality whether the fish actually died, was injured, or not. The probability of survival predicted by this model will provide a useful perspective for fish sizes where site-specific data is not available. Turbine passage survival was calculated for a range of fish body lengths (4, 8, 15, and 30 inches) considered to be representative of Connecticut River fish species.

The blade strike probability for project Kaplan units was calculated using Equation 1:

$$P = \lambda \frac{N \cdot L}{D} \cdot \left[\frac{\cos \alpha_{\alpha}}{8\, Q_{\omega d}} + \frac{\sin \propto_a}{\pi \frac{r}{R}} \right] \qquad \text{(Equation 1)}$$

where Equation 2 was used to calculate the value of α_{α}:

$$\tan \alpha_{\alpha} = \frac{\pi \cdot E_{\omega d} \cdot \eta}{2 \cdot Q_{\omega d} \cdot \frac{r}{R}} \qquad \text{(Equation 2)}$$

The blade strike probabilities for project Francis units were calculated using Equation 3

$$P = \lambda \frac{N \cdot L}{D} \cdot \left[\frac{\sin \alpha_t \cdot \frac{B}{D_1}}{2\, Q_{\omega d}} + \frac{\cos \alpha_t}{\pi} \right] \qquad \text{(Equation 3)}$$

where Equation 4 was used to calculate the value of αt:

$$\tan(90 - \alpha_t) = \frac{2\pi E_{\omega d} \cdot \eta}{Q_{\omega d}} \cdot \frac{B}{D_1} + \frac{\pi \cdot 0.707^2}{2 Q_{\omega d}} \frac{B}{D_1} \left(\frac{D_2}{D_1} \right)^2 - 4 \cdot 0.707 \cdot \tan \beta \frac{B}{D_1} \frac{D_1}{D_2} \qquad \text{(Equation 4)}$$

and Equation 5 was used to calculate the value of tan β.

$$\tan \beta = \frac{0.707 \frac{\pi}{8}}{\xi \cdot Q_{\omega d} opt \frac{D_1}{D_2}^3} \qquad \text{(Equation 5)}$$

---

[3] The range of correlation factors presented by Franke et al. (1997) for these predictive equations is 0.1 to 0.2. To account for the variation in correlation among this range of values and turbine types, both ends of the recommended range of values were included in the Tables 6.1-1 through 6.1-3.

Input parameters for Equations 1 through 5 were defined as:

B = Runner height at inlet

D = Diameter of runner

D_1 = Diameter of runner at the inlet

D_2 = Diameter of runner at the discharge

g = Acceleration due to gravity

H = Turbine head

L = Length of fish

N = Number of turbine blades or buckets

P = Predicted strike probability

Q = Turbine discharge

Q_{opt} = Turbine discharge at best efficiency

r = Fish entry point (along blade)

R = Radius

RPM = Revolutions per minute

α_a = Angle to axial of absolute flow upstream of runner (for Kaplan and Propeller units)

α_t = Angle to tangential of absolute flow upstream of runner (for Francis units)

β = Relative flow angle at runner discharge

ξ = Ratio between Q with no exit swirl and Q_{opt} (typical value = 1.1)

λ = Strike mortality correlation factor

η = Turbine efficiency

ω = Rotational speed (calculated as: $\omega = RPM \cdot \frac{2\pi}{60}$)

$E_{\omega d}$ = Energy coefficient (calculated as: $E_{\omega \mathrm{d}} = \frac{gH}{(\omega \mathrm{d})^2}$)

$Q_{\omega d}$ = Discharge coefficient (calculated as: $Q_{\omega \mathrm{d}} = \frac{Q}{\omega \mathrm{D}^3}$)

Calculated blade strike probabilities (P) generated by leading edge strike equations for Kaplan and Francis turbines were converted into a percent survival (S) using equation 6.

$S = 100 - P$ (Equation 6)

6.1.1 Wilder Blade Strike Probabilities

Blade strike potential and estimated survival rates for the two adjustable-blade Kaplan turbines (Units 1 and 2) and the single vertical Francis turbine (Unit 3) operating at Wilder are presented in Table 6.1-1 at maximum discharge, at typical full load, at peak efficiency, and at minimum flow from generation (Unit 3 only). Survival estimates for small fish (4-8 in) under all scenarios for the Kaplan turbines ranged from approximately 85-99%, and for larger fish ranged from approximately 72-96% for 15-inch fish and approximately 44-92% for 30-inch fish. Survival estimates for small fish (4-8 in) under all scenarios for the Francis turbine ranged from approximately 72-93% and for larger fish ranged from approximately 47-75% for 15-inch fish and approximately 0-50% for 30-inch fish.

6.1.2 Bellows Falls Blade Strike Probabilities

Blade strike potential and estimated survival rates for the three vertical Francis units operating at Bellows Falls are presented in Table 6.1-2 at maximum discharge, at peak efficiency (which is also typical full load), and at minimum flow from generation. Survival estimates for small fish (4-8 in) under all scenarios ranged from approximately 87-97, and for larger fish ranged from approximately 76-89% for 15-inch fish and from approximately 52-78% for 30-inch fish.

6.1.3 Vernon Blade Strike Probabilities

Blade strike potential and estimated survival rates for the four vertical Kaplan turbines (Units 5 - 8) and the six vertical Francis turbine (Units 1 – 4, and 9 -10) operating at Vernon are presented in Table 6.1-3 at maximum discharge, at peak efficiency (which is also typical full load), and at minimum flow from generation (Units 5-8 and Unit 10 only). Survival estimates for small fish (4-8 in) under all scenarios for the Kaplan turbines ranged from approximately 78-98%, and for larger fish ranged from approximately 59-93% for 15-inch fish and approximately 17-86% for 30-inch fish. Survival estimates for small fish (4-8 in) under all scenarios for the Francis turbines ranged from approximately 80-97% and for larger fish through the Vernon Francis units ranged from approximately 62-89% for 15-inch fish and approximately 24-77% for 30-inch fish.

Table 6.1-1. Predicted survival of entrained fishes based on Franke et al. (1997) for the Wilder Kaplan and Francis turbines.

Unit	Turbine Type	Discharge Type	Discharge (cfs)	Effic. (%)	Corr. Factor	Fish Entry Point	Predicted Survival (%) by Body Length (in)			
							4	8	15	30
1 - 2	Kaplan - Adjustable Blade	Max	5,650	79.6	0.1	blade tip	96.3	92.7	86.3	72.5
						mid blade	98.8	97.6	95.5	91.0
						near hub	98.9	97.9	96.1	92.1
					0.2	blade tip	92.7	85.3	72.5	45.0
						mid blade	97.6	95.2	91.0	82.0
						near hub	97.9	95.8	92.1	84.2
		Peak Effic.	3,353	87.2	0.1	blade tip	96.3	92.6	86.1	72.2
						mid blade	98.5	97.1	94.5	89.0
						near hub	98.5	97.0	94.4	88.9
					0.2	blade tip	92.6	85.2	72.2	44.3
						mid blade	97.1	94.2	89.0	78.1
						near hub	97.0	94.1	88.9	77.8
		Typical Full Load	4,400	85.7	0.1	blade tip	96.3	92.6	86.2	72.3
						mid blade	98.7	97.3	95.0	89.9
						near hub	98.7	97.5	95.3	90.6
					0.2	blade tip	92.6	85.2	72.3	44.6
						mid blade	97.3	94.6	89.9	79.9
						near hub	97.5	95.0	90.6	81.1
3	Vertical Francis	Max	825	73.8	0.1	-	93.3	86.5	74.7	49.5
					0.2	-	86.5	73.1	49.5	0.0
		Peak Effic.	745	74.5	0.1	-	93.1	86.1	74.0	47.9
					0.2	-	86.1	72.2	47.9	0.0
		Min Flow	700	71.4	0.1	-	92.9	85.8	73.4	46.9
					0.2	-	85.8	71.7	46.9	0.0

Table 6.1-2. Predicted survival of entrained fishes based on Franke et al. (1997) for the Bellows Falls Francis turbines.

Unit	Turbine Type	Discharge Type	Discharge (cfs)	Effic. (%)	Corr. Factor	Predicted Survival (%) by Body Length (in)			
						4	8	15	30
1 - 3	Vertical Francis	Max	3,850	82.8	0.1	96.8	93.6	87.9	75.8
					0.2	93.6	87.1	75.8	51.7
		Peak Effic.	3,175	87.0	0.1	96.9	93.9	88.5	77.0
					0.2	93.9	87.7	77.0	53.9
		Min Flow	1,300	59.2	0.1	97.1	94.2	89.2	78.3
					0.2	94.2	88.4	78.3	56.6

Table 6.1-3. Predicted survival of entrained fishes based on Franke et al. (1997) for the Vernon Kaplan and Francis turbines.

Unit	Turbine Type	Discharge Type	Discharge (cfs)	Effic. (%)	Corr. Factor	Fish Entry Point	Predicted Survival (%) by Body Length (in)			
							4	8	15	30
1 - 2	Vertical Francis	Max. and Peak Effic.	1,092	82.4	0.1	-	95.4	90.7	82.6	65.1
					0.2	-	90.7	81.4	65.1	30.3
3 - 4	Vertical Francis	Max. and Peak Effic.	1,092	82.4	0.1	-	95.0	89.9	81.1	62.2
					0.2	-	89.9	79.9	62.2	24.4
5 - 8	Vertical Kaplan	Max.	1,860	81.9	0.1	blade tip	94.6	89.1	79.6	59.1
						mid blade	98.0	96.0	92.5	85.1
						near hub	98.2	96.4	93.2	86.3
					0.2	blade tip	89.1	78.2	59.1	18.3
						mid blade	96.0	92.1	85.1	70.2
						near hub	96.4	92.7	86.3	72.7

Unit	Turbine Type	Discharge Type	Discharge (cfs)	Effic. (%)	Corr. Factor	Fish Entry Point	Predicted Survival (%) by Body Length (in)			
							4	8	15	30
		Peak Effic.	1,178	86.5	0.1	blade tip	94.5	89.0	79.4	58.7
						mid blade	97.7	95.3	91.2	82.4
						near hub	97.5	95.1	90.8	81.6
					0.2	blade tip	89.0	78.0	58.7	17.4
						mid blade	95.3	90.6	82.4	64.8
						near hub	95.1	90.2	81.6	63.2
		Min. Flow	1,600	84.5	0.1	blade tip	94.5	89.1	79.5	58.9
						mid blade	97.9	95.8	92.0	84.1
						near hub	98.0	95.9	92.4	84.8
					0.2	blade tip	89.1	78.1	58.9	17.9
						mid blade	95.8	91.5	84.1	68.1
						near hub	95.9	91.9	84.8	69.5
9 - 10	Vertical Francis	Max.	2,060	77.7	0.1	-	96.3	92.7	86.3	72.5
					0.2	-	92.7	85.4	72.5	45.1
		Peak Effic.	1,573	85.1	0.1	-	96.9	93.9	88.6	77.1
					0.2	-	93.9	87.8	77.1	54.2
		Min. Flow	1,600	85.0	0.1	-	96.9	93.8	88.5	76.9
					0.2	-	93.8	87.7	76.9	53.8
9 - 10	Vertical Francis	Study 19 tested flow	1,300	83.5	0.1	-	97.2	94.3	89.3	78.7
					0.2	-	94.3	88.6	78.7	57.4

6.2 EPRI Source Data

Numerous investigations of fish turbine passage survival have been conducted, providing a considerable dataset from which a qualitative approach to assessing turbine passage survival at Wilder, Bellows Falls, and Vernon. Winchell et al. (2000) summarized turbine passage survival data reported in the EPRI (1997) database by turbine type and characteristics and by fish size, but not by species. The survival rates reported represented field tests at up to 19 turbines per size class of test fish that met specific acceptability criteria for control fish mortality (could not exceed 10%). These data are reproduced herein for axial flow (i.e., Kaplan, fixed blade propeller, bulb, and tube type) and Francis turbines (Table 6.2-1). Winchell et al. (2000) treated axial flow units rotating slower than 300 rpm and Francis units rotating slower than 250 rpm as low-speed turbines. Each of the turbine units installed at Wilder, Bellows Falls, and Vernon match those criteria.

Immediate survival rates were used for this assessment since they enabled use of a larger sample size (N). The mean rates are reported (Winchell et al., 2000) irrespective of local site conditions such as shallow or deep intakes or tailrace configuration that could affect ultimate fish survival after turbine passage. Additionally, the survival rates are reported for all species combined. More importantly, evidence suggests that fish size is more important than species per se when assessing fish survival potential (Franke et al., 1997; Winchell et al., 2000).

The EPRI dataset for single runner radial-flow Francis turbines includes survival results from 20 hydroelectric projects. The Francis turbines tested had runner speeds between 72 and 360 rpm, 14-19 buckets, hydraulic capacities between 326 and 2,450 cfs, and operating heads of 13 to 228 feet. The principal survival trend among the reviewed studies of Francis type turbines was higher survival for small fish (generally those less than 8 in) than larger fish. Survival was generally highest for smaller fish and for turbines with rotational speeds less than 250 rpm. For fish less than 8 inches, mean immediate survival rates ranged between 91.6 and 93.9% for low-speed turbines. Mean survival for large fish tested at low-speed turbines was 86.9% for fish between 8 and 12 inches and 73.2% for fish greater than 12 inches.

The EPRI dataset for axial-flow turbines includes survival results from 18 hydroelectric projects. The axial-flow turbines tested had runner speeds between 86 and 240 rpm, 3-6 blades, hydraulic capacities between 640 and 21,000 cfs, and operating heads of 16 to 98 feet. The principal survival trend among the reviewed studies of axial-flow type turbines was higher survival for small fish (generally those less than 8 inches) than larger fish. Survival was generally highest for smaller fish and for turbines with rotational speeds less than 300 rpm. For fish less than 8 inches, mean immediate survival rates ranged between 94.8 and 95.4% for low-speed axial-flow turbines. Mean survival for large fish tested at low-speed axial-flow turbines was 87.2% for fish between 8 and 12 inches and 93.4% for fish greater than 12 inches. These survival results were comparable to the calculated survival estimates for Project turbines.

Table 6.2-1. Empirical fish survival rates for representative fish sizes passing axial-flow (Kaplan) and radial-flow (Francis) turbines, from Winchell et al. (2000).

Turbine Type	Runner Speed	Hydraulic Capacity (cfs)	Fish Size (in)	Average Immediate Survival (all species)		
				Minimum	Maximum	Mean
axial-flow	<300	636-1,203	<4	94.1%	98.0%	95.4%
		636-21,000	4-8	89.8%	97.5%	94.8%
		636-2,200	8-12	77.4%	97.4%	87.2%
		1,203-2,200	>12	86.8%	100.0%	93.4%
Francis (radial-flow)	<250	440-1,600	<4	85.9%	100.0%	93.9%
		370-1,600	4-8	74.8%	100.0%	91.6%
		370-2,450	8-12	59.0%	100.0%	86.9%
		440-1,600	>12	36.1%	100.0%	73.2%

6.3 Potential Survival Through Turbines

A qualitative assessment of overall survival potential for target species based on all calculated discharge parameters at Wilder (Table 6.3-1), Bellows Falls (Table 6.3-2), and Vernon (Table 6.3-3) was developed from project survival estimates calculated using the Franke et al. (1997) model as well as data in the EPRI database. Quantitative data were converted to a qualitative ranking system, as defined by Winchell et al. (2000) where:

High (H) = 90-100%
Moderate-High (MH) = 90-95%
Moderate (M) = 85-90%
Low-Moderate (LM) = 80-85%
Low (L) = <80%

Fish size was the ranking variable, not species. Fish size has been found to be more important than species per se when assessing fish survival potential (Franke et al., 1997; Winchell et al., 2000). Survival of juvenile fish at each of the three projects was generally rated between Moderate-High and Moderate due to their smaller body sizes. The overall rating of entrainment survival for adult fish ranged from Moderate-High to Low, with fish species attaining larger size as adults (e.g., Northern Pike, Walleye, etc.) having lower overall survival ratings. Predicted survival was based on the fish size up to the next size range (i.e., a 6-inch fish would receive the highest and lowest survival rating for the 4-8 inch survival range).

Table 6.3-1. Predicted survival from EPRI (1997), calculated survival (Franke et al., 1997), and overall qualitative rating of target species that may be entrained at Wilder.

Species and Life stage	Approx. Size Range (in)	EPRI Source Data		Calculated Survival Potential		Overall Rating of Survival Potential
		% Survival by fish size	Rating by fish size[a]	% Survival by fish size	Rating by fish size[a]	
American Eel						
Juvenile	1.0-24.0	95.4-73.2	H-L	98.9-46.9	H-L	MH-M
Adult	24.0-40.0	93.4-73.2	MH-L	92.1-0.0	MH-L	M-LM
Bluegill						
Juvenile	1.0-4.0	95.4-93.9	MH	85.8-98.9	H-M	MH
Adult	4.0-8.0	94.8-91.6	MH	71.7-97.9	H-L	MH
Brown Bullhead						
Juvenile	1.0-8.0	95.4-91.6	H-MH	98.-71.7	H-L	MH
Adult	8.0-14.0	93.4-73.2	MH-L	97.9-71.7	H-L	M
Fallfish						
Juvenile	1.0-6.0	95.4-91.6	H-MH	98.9-85.8	H-M	MH
Adult	6.0-18.0	94.8-73.2	MH-L	98.9-46.9	H-L	M
Golden Shiner						
Juvenile	1.0-4.0	95.4-93.9	H-MH	98.9-85.8	H-M	MH
Adult	4.0-8.0	94.8-91.6	MH	98.9-71.7	H-L	MH
Largemouth Bass						
Juvenile	1.0-6.0	95.4-91.6	MH	98.9-71.7	H-L	MH
Adult	6.0-18.0	94.8-73.2	MH-L	98.9-46.9	H-L	M
Northern Pike						
Juvenile	1.0-16.0	95.4-73.2	H-L	98.9-46.9	H-L	M
Adult	16.0-48.0	93.4-73.2	MH-L	96.1-0.0	H-L	M-LM
Sea Lamprey						
Juvenile	6.0-24.0	94.8-73.2	MH-L	98.9-46.9	H-L	MH-M
Adult	24.0-36.0	93.4-73.2	MH-L	96.1-0.0	H-L	M-LM
Smallmouth Bass						
Juvenile	1.0-8.0	95.4-91.6	H-MH	98.9-71.7	H-L	MH
Adult	8.0-20.0	91.6-73.2	MH-L	97.9-46.9	H-L	M
Spottail Shiner						
Juvenile	1.0-2.0	95.4-93.9	H-MH	98.9-85.8	H-M	MH
Adult	2.0-4.0	95.4-93.9	H-MH	98.9-85.8	H-M	MH
Tessellated Darter						
Juvenile	1.0-2.0	95.4-93.9	H-MH	98.9-85.8	H-M	MH
Adult	2.0-4.0	95.4-93.9	H-MH	98.9-85.8	H-M	MH

Species and Life stage	Approx. Size Range (in)	EPRI Source Data		Calculated Survival Potential		Overall Rating of Survival Potential
		% Survival by fish size	Rating by fish size[a]	% Survival by fish size	Rating by fish size[a]	
Walleye						
Juvenile	1.0-16.0	95.4-73.2	H-L	98.9-46.9	H-L	M
Adult	16.0-30.0	93.4-73.2	MH-L	96.1-0.0	H-L	LM
White Sucker						
Juvenile	1.0-12.0	95.4-86.9	MH-M	98.9-71.7	H-L	MH-M
Adult	12.0-24.0	93.4-73.2	MH-L	97.9-46.9	L	M-LM
Yellow Perch						
Juvenile	1.0-8.0	95.4-91.6	H-MH	98.9-71.7	H-L	MH
Adult	8.0-12.0	87.2-86.9	M	97.9-46.9	H-L	M

a. L = Low (<80%), LM = Low-Moderate (80-85%), M = Moderate (85-90%), MH = Moderate-High (90-95%), H = High (95-100%).

Table 6.3-2. Predicted survival from EPRI (1997), calculated survival (Franke et al., 1997), and overall qualitative rating of target species that may be entrained at Bellows Falls.

Species and Life stage	Approx. Size Range (in)	EPRI Source Data		Calculated Survival Potential		Overall Rating of Survival Potential
		% Survival by fish size	Rating by fish size[a]	% Survival by fish size	Rating by fish size[a]	
American Eel						
Juvenile	1.0-24.0	93.9-73.2	MH-L	97.1-75.8	H-L	MH-M
Adult	24.0-40.0	73.2	L	75.8-51.7	L	L
Bluegill						
Juvenile	1.0-4.0	95.4-93.9	MH	97.1-93.6	H-MH	H-MH
Adult	4.0-8.0	94.8-91.6	MH	97.1-87.1	H-M	MH
Brown Bullhead						
Juvenile	1.0-8.0	93.9-91.6	MH	97.1-87.1	H-M	MH
Adult	8.0-14.0	91.6-73.2	MH-L	94.2-87.1	MH-M	M
Fallfish						
Juvenile	1.0-6.0	93.9-91.6	MH	97.1-93.6	H-MH	MH
Adult	6.0-18.0	91.6-73.2	MH-L	97.1-75.8	H-L	M-LM
Golden Shiner						
Juvenile	1.0-4.0	93.9	MH	97.1-93.6	H-MH	H-MH
Adult	4.0-8.0	91.6	MH	97.1-87.1	H-M	MH

Species and Life stage	**Approx. Size Range (in)**	**EPRI Source Data**		**Calculated Survival Potential**		**Overall Rating of Survival Potential**
		% Survival by fish size	**Rating by fish size[a]**	**% Survival by fish size**	**Rating by fish size[a]**	
Largemouth Bass						
Juvenile	1.0-6.0	95.4-91.6	MH	97.1-93.6	H-MH	MH
Adult	6.0-18.0	94.8-73.2	MH-L	97.1-75.8	H-L	MH-L
Northern Pike						
Juvenile	1.0-16.0	93.9-73.2	MH-L	97.1-75.8	H-L	MH-M
Adult	16.0-48.0	73.2	L	89.2-51.7	M-L	LM-L
Sea Lamprey						
Juvenile	6.0-24.0	91.6-73.2	MH-L	97.1-75.8	H-L	MH-L
Adult	24.0-36.0	73.2	L	89.2-51.7	M-L	L
Smallmouth Bass						
Juvenile	1.0-8.0	93.9-91.6	MH	97.1-87.1	H-M	MH
Adult	8.0-20.0	91.6-73.2	MH-L	94.2-75.8	MH-L	MH-L
Spottail Shiner						
Juvenile	1.0-2.0	93.9	MH	97.1-93.6	H-MH	H-MH
Adult	2.0-4.0	93.9	MH	97.1-93.6	H-MH	H-MH
Tessellated Darter						
Juvenile	1.0-2.0	93.9	MH	97.1-93.6	H-MH	H-MH
Adult	2.0-4.0	93.9	MH	97.1-93.6	H-MH	H-MH
Walleye						
Juvenile	1.0-16.0	93.9-73.2	MH-L	97.1-75.8	H-L	MH-M
Adult	16.0-30.0	73.2	L	89.2-51.7	M-L	LM-L
White Sucker						
Juvenile	1.0-12.0	93.9-73.2	MH-L	97.1-87.1	H-M	MH-M
Adult	12.0-24.0	73.2	L	94.2-75.8	MH-L	LM-L
Yellow Perch						
Juvenile	1.0-8.0	93.9-91.6	MH	97.1-87.1	H-M	MH
Adult	8.0-12.0	91.6-73.2	MH-L	94.2-75.8	MH-M	M

a. L = Low (<80%), LM = Low-Moderate (80-85%), M = Moderate (85-90%), MH = Moderate-High (90-95%), H = High (95-100%).

Table 6.3-3. Predicted survival from EPRI (1997), calculated survival (Franke et al., 1997), and overall qualitative rating of target species that may be entrained at Vernon.

Species and Life stage	Approx. Size Range (in)	EPRI Source Data		Calculated Survival Potential		Overall Rating of Survival Potential
		% Survival by fish size	Rating by fish size[a]	% Survival by fish size	Rating by fish size[a]	
American Eel						
Juvenile	1.0-24.0	95.4-73.2	H-L	98.2-58.7	H-L	H-L
Adult	24.0-40.0	93.4-73.2	MH-L	93.2-17.4	MH-L	MH-L
American Shad						
Juvenile	1.0-4.0	95.4-93.9	H-MH	98.2-89.0	H-M	MH
Adult	20.0-30.0	93.4-73.2	MH-L	93.2-17.4	MH-L	M-LM
Bluegill						
Juvenile	1.0-4.0	95.4-93.9	MH	98.2-89.0	H-M	MH
Adult	4.0-8.0	94.8-91.6	MH	98.2-78.0	H-L	MH-M
Brown Bullhead						
Juvenile	1.0-8.0	95.4-91.6	H-MH	98.2-78.0	H-L	MH-M
Adult	8.0-14.0	93.4-73.2	MH-L	96.4-78.0	H-L	M
Fallfish						
Juvenile	1.0-6.0	95.4-91.6	H-MH	98.2-89.0	H-M	MH
Adult	6.0-18.0	94.8-73.2	MH-L	98.2-58.7	H-L	MH-M
Golden Shiner						
Juvenile	1.0-4.0	95.4-93.9	H-MH	98.2-89.0	H-M	MH
Adult	4.0-8.0	94.8-91.6	MH	98.2-78.0	H-L	MH-M
Largemouth Bass						
Juvenile	1.0-6.0	95.4-91.6	MH	98.2-89.0	H-L	MH-M
Adult	6.0-18.0	94.8-73.2	MH-L	96.4-58.7	H-L	MH-M
Northern Pike						
Juvenile	1.0-16.0	95.4-73.2	H-L	98.2-58.7	H-L	M
Adult	16.0-48.0	93.4-73.2	MH-L	93.2-17.4	MH-L	M-LM
Sea Lamprey						
Juvenile	6.0-24.0	94.8-73.2	MH-L	98.2-58.7	H-L	M
Adult	24.0-36.0	93.4-73.2	MH-L	93.2-117.4	MH-L	M-LM
Smallmouth Bass						
Juvenile	1.0-8.0	95.4-91.6	H-MH	98.2-78.0	H-L	MH-M
Adult	8.0-20.0	91.6-73.2	MH-L	96.4-58.7	H-L	MH-M

Species and Life stage	Approx. Size Range (in)	EPRI Source Data		Calculated Survival Potential		Overall Rating of Survival Potential
		% Survival by fish size	Rating by fish size[a]	% Survival by fish size	Rating by fish size[a]	
Spottail Shiner						
Juvenile	1.0-2.0	95.4-93.9	H-MH	98.2-89.0	H-M	MH
Adult	2.0-4.0	95.4-93.9	H-MH	98.2-89.0	H-M	MH
Tessellated Darter						
Juvenile	1.0-2.0	95.4-93.9	H-MH	98.2-89.0	H-M	MH
Adult	2.0-4.0	95.4-93.9	H-MH	98.2-89.0	H-M	MH
Walleye						
Juvenile	1.0-16.0	95.4-73.2	H-L	98.2-58.7	H-L	M
Adult	16.0-30.0	93.4-73.2	MH-L	93.2-17.4	MH-L	M-LM
White Sucker						
Juvenile	1.0-12.0	95.4-86.9	MH-M	98.2-78.0	H-L	MH-M
Adult	12.0-24.0	93.4-73.2	MH-L	96.4-58.7	H-L	M-LM
Yellow Perch						
Juvenile	1.0-8.0	95.4-91.6	H-MH	98.2-78.0	H-L	MH-M
Adult	8.0-12.0	87.2-86.9	M	96.4-78.0	H-L	M

a. L = Low (<80%), LM = Low-Moderate (80-85%), M = Moderate (85-90%), MH = Moderate-High (90-95%), H = High (95-100%).

7.0 TOTAL PROJECT SURVIVAL

As stated in the FERC study request related to the assessment of fish impingement, entrainment, and survival, total project survival considering all passage routes, was to be estimated for American Eel, Atlantic Salmon, and Sea Lamprey at Wilder, Bellows Falls and Vernon, and for American Shad and river herring at Vernon.

Total project survival rates for American Eel at each of the three project locations are being estimated using data collected as part of the radio-telemetry (i.e., route selection) and Hi-Z turbine tag survival evaluations conducted on adult silver eels as part of Study 19 - American Eel Downstream Passage Assessment. Total project survival rates for American Shad at Vernon are being estimated for both the adult and juvenile life stages and relied on radio-telemetry data collected as part of the radio-telemetry (Studies 21 and 22; American Shad Telemetry at Vernon, and Downstream Migration of Juvenile American Shad at Vernon, respectively) and Hi-Z turbine tag survival evaluations conducted as part of Study 22 and during 1995 (Normandeau, 1996). As reported in the October 31, 2016 Response to Comments filing, telemetry data for Studies 19, 21, and 22 are being re-processed and revised results of downstream passage route selection used for this analysis will be reported in a Study 23 report supplement.

There is no available data related to the downstream route selection or passage survival of Sea Lamprey at Wilder, Bellows Falls, or Vernon. To date, peer-reviewed literature related to passage of Sea Lamprey has focused on upstream passage. Sea Lamprey were not among the fish species evaluated as part of the EPRI (1997) turbine passage survival database. Given the lack of available data, the total project survival of emigrating Sea Lamprey at the projects is unknown at this time.

The Atlantic Salmon Connecticut River Restoration Program was discontinued in July, 2012. As of 2016, TransCanada has been granted permission by FERC to cease operation of the downstream fish passage facilities for emigrating Atlantic Salmon smolts at their Moore, Comerford, and McIndoes developments (FERC Project # 2077) on the Connecticut River upstream of the Wilder, Bellows Falls, and Vernon project areas. Given the lack of the species presence within the project area, total station survival estimates are not provided.

As summarized in the Vernon Pre-Application Document, returns of Blueback Herring at Vernon have been low since 1981 with greater than 100 individuals recorded during only two of the 32 years summarized, and no individuals recorded since 2000. It is suspected that the total project survival for river herring would be similar to American Shad due to similar size.

8.0 LITERATURE CITED

Beamish, F.W.H. 1970. Oxygen consumption of largemouth bass, *Micropterus salmoides*, in relation to swimming speed and temperature. Canadian Journal of Zoology 48:1221-1228.

Beamish, F.W.H. 1974. Swimming performance of adult sea lamprey, Petromyzon marinus, in relation to weight and temperature. Transactions of the American Fisheries Society 103: 355-358.

Beamish, F.W.H. 1978. Swimming capacity. Pages 101-172 in W.S. Hoar and D.J. Randall, editors. Fish Physiology, Volume 7, Locomotion. Academic Press, NY.

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, WI.

Bell, M.C. 1991. Fisheries Handbook of Engineering Requirements and Biological Criteria. U.S. Army Corps of Engineers, North Pacific Division, Portland, OR.

Boyd, G. and G. Parsons. 1998. Swimming performance and behavior of golden shiner, *Notemigonus crysoleucas*, while schooling. Copeia 1998: 467-471.

Brett, J.R. amd D.B. Sutherland. 1965. Respiratory metabolism of pumpkinseed in relation to swimming speed. Journal of the Fisheries Research Board of Canada 22: 405-409.

Bunt, C.M., Katopodis, C. and McKinley, R.S. 1999. Attraction and passage efficiency of white suckers and smallmouth bass by two Denil fishways. North American Journal of Fisheries Management 19, 793–803.

Cada, G.F. 2001. The development of advanced hydroelectric turbines to improve fish passage survival. Fisheries 26: 14-23.

Carlander, K.D., 1977. Handbook of freshwater fish biology. The Iowa State University Press, Ames, Iowa.

Castro-Santos, T and A. Haro. 2005. Biomechanics and fisheries conservation. Pages 469-523, Chapter 12 in Fish Biomechanics, Volume 23. Elsevier, Inc., Atlanta, GA.

Clay, C.H. (1995) Design of Fishways and Other Fish Facilities, 2nd edn. Lewis Publishers, Boca Raton.

Cooke, S.J., E.C. Grant, J.F. Schreer, D.P. Philipp, and A.L. Devries. 2003. Low temperature cardiac response to exhaustive exercise in fish with different levels of winter quiescence. Comparative Biochemistry and Physiology, Part A, 134:157-165.

Deng, Z, M.C. Richmond, G.R. Guensch, and R.P. Mueller. 2004. Study of fish response using particle image velocimetry and high-speed, high-resolution imaging. Prepared for U.S. Department of Energy by Pacific Northwest National Laboratory, Richland, WA.

Dodson, J.J., and W. C. Leggett. 1973. Behavior of adult American shad (*Alosa sapidissima*) homing to the Connecticut River from Long Island Sound. Journal of the Fisheries Research Board of Canada 30: 1847-1860.

Drucker, E.G. and G.V. Lauder. 1999. Locomotor forces on a swimming fish; three dimensional vortex wake dynamics quantified using digital particle imaging velocimetry. Journal of Experimental Biology 202:2393-2412.

Eicher Associates, Inc. 1987. Turbine-related fish mortality: review and evaluation of studies. Research Project 2694-4. Electric Power Research Institute (EPRI), Palo Alto, CA.

EPRI (Electric Power Research Institute). 1997. Turbine entrainment and survival database-field tests. Prepared by Alden Research Laboratory, Inc. EPRI Report No. TR-108630. 13 pp. (plus two 3.5" diskettes), Palo Alto, CA.

Farlinger, S. and F.W.H. Beamish. 1977. Effects of time and velocity increments on the critical swimming speed of largemouth bass (*Micropterus salmoides*). Transactions of the American Fisheries Society 106: 436-439.

EPRI (Electric Power Research Institute). 2000. Technical evaluation of the utility of intake approach velocity as an indicator of potential adverse environmental impact under Clean Water Act Section 316(b). EPRI 1000731, Palo Alto, CA.

FERC (Federal Energy Regulatory Commission). 1995. Preliminary assessment of fish entrainment at hydropower projects, Vol. 1. A report on studies and protective measures. Report prepared by Stone & Webster Environmental Technology and Services for Office of Hydropower Licensing. Paper No. DPR-10, Washington, DC.

Franke, G.F., D.R. Webb, R.K. Fisher, Jr., D. Mathur, P.N. Hopping, P.A. March, M.R. Headrick, I.T. Laczo, Y. Ventikos, and F. Sotiropoulos. 1997. Development of environmentally advanced hydropower turbine system design concepts. Prepared for U.S. Dept. Energy, Idaho Operations Office. Contract DE-AC07-94ID13223.

Gardner, A.N., G.D. Jennings, W.F. Hunt, and J.F. Gilliam. 2006. Non-anadromous fish passage through road culverts. Paper No. 067034, Annual Meeting, American Society of Agricultural and Biological Engineers, St. Joseph, MI.

Gardner, A. N. 2006. Fish passage through road culverts. Master's Thesis, North Carolina State University.

Goertzen, M.M., D.W. Hauck, J. Phibbs, L.P. Weber, D.M. Janz. 2012. Swim performance and energy homeostasis in spottail shiner (*Notropis hudsonius*) collected downstream of a uranium mill. Ecotoxicology and Environmental Safety 75: 142-150.

Halliwell, D.B., R.W. Langdon, R.A. Daniels, J.P. Kurtenbach, and R. A. Jacobson. 1999. Classification of freshwater fish species of northeastern United States for use in the development f indicies of biological integrity, with regional applications. Pages 301-338 *in* T.P. Simon (editor) Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Raton.

Haro, A, T. Castro-Santos, J. Noreika, and M. Odeh. 2004. Swimming performance of upstream migrant fishes in open-channel flow: a new approach to predicting passage through velocity barriers. Canadian Journal of Fisheries and Aquatic Sciences 61: 1590-1601.

Hatch Ltd. 2016. ILP Study 5 – Operations Modeling Study Report. Prepared for TransCanada Hydro Northeast Inc. August 1, 2016.

Hocutt, C.H. 1973. Swimming performance of three warmwater fishes exposed to a rapid temperature change. Chesapeake Science 14: 11-16.

Houde, E.D. 1969. Sustained swimming ability of larvae of walleye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavescens*). Journal of the Fisheries Research Board of Canada 26: 1647-1659.

Jones, D.R., J.W. Kiceniuk, and O.S. Bamford. 1974. Evaluation of the swimming performance of serval fish species from the Mackenzie River. Journal of the Fisheries Research Board of Canada 31: 1641-1647.

King, L.R. 1969. Swimming speed of the channel catfish, white crappie and other warm water fishes from Conowingo Reservoir, Susquehanna River, PA, Ichthyological Associates Bulletin No. 4

Kolok, A.S. 1991. Photoperiod alters the critical swimming speed of juvenile largemouth bass, *Micropterus salmoides*, acclimated to cold water. Copeia 1991(4): 1085-1090.

Langdon, R.W., M.T. Ferguson, and K.M. Cox. 2006. Fishes of Vermont. Vermont Agency of Natural Resources. Waterbury, VT.

Langhurst, R. W., and D. L. Schoenike. 1990. Seasonal migration of smallmouth bass in the Embarrass and Wolf rivers, Wisconsin. North American Journal of Fisheries Management 10:224-227.

Larimore, R.W. and M.J. Duever. 1968. Effects of temperature acclimation of thw swimming ability of smallmouth bass fry. Transactions of the American Fisheries Society 97: 175-184.

McCleave, J.D. 1980. Swimming performance of European eel (*Anguilla anguilla* (L.)) elvers. Journal of Fish Biology 16: 445-452.

Nelson, J.A. 1989. Critical swimming speeds of yellow perch: comparison of populations from a naturally acidic lake and a circumneutral lake in acid and neutral water. Journal of Experimental Biology 145: 239-254.

Normandeau (Normandeau Associates, Inc.). 1996. Estimation of survival and injuries of juvenile American shad passage through a Francis turbine at the Vernon hydroelectric station, Connecticut River. Prepared for New England Power Company.

Oseid, D. and L.L. Smith. 1972. Swimming endurance and resistance to copper and malathion of bluegills treated by long-term exposure to sublethal levels of hydrogen sulfide. Transactions of the American Fisheries Society 101: 620-625.

Otto, R.G., and J.O. Rice. 1974. Swimming speeds of yellow perch following an abrupt change in environmental temperature. Journal of the Fisheries Research Board of Canada 31: 1731-1734.

Peake, S., R.S. McKinley, and D.A. Scruton. 2000. Swimming performance of walleye (*Stizostedion vitreum*). Canadian Journal of Zoology 78: 1686-1690.

Quintella, B.R., C.S. Mateus, J.L. Costa, I. Domingos, and P.R. Almeida. 2010. Critical swimming speed of yellow- and silver-phase European eel (*Anguilla anguilla*, L.). Journal of Applied Ichthyology 26: 432-435.

Rajotte, J.W., and P. Couture. 2002. Effects of environmental mental contamination on the condition, swimming performance, and tissue metabolic capacities of wild yellow perch (*Perca flavescens*). Canadian Journal of Fisheries and Aquatic Sciences 59: 1296-1304.

Robbins, T.W., M.S. Topping, and E.C. Raney. 1970. Study of Fishes in the Muddy Run Pumped Storage Reservoir and Connecting Waters, a Summary. Prepared for submission to the Federal Power Commission. Prepared for Philadelphia Electric Company, Philadelphia, PA.

Schuler, V.J. 1968. Progress report of swim speed study conducted on fishes of Conowingo Reservoir. Ichthyological Associate, Progress Report 1B.

Scott, W.B., and E.J. Crossman. 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada, Bulletin 184. 966 pp.

Smith, C.L. 1985. The Inland Fishes of New York State. Albany, NY. New York Department of Environmental Conservation.

Venn Beecham, R., C.D. Minchew, and G. R. Parsons. 2007. Comparative swimming performance of juvenile pond-cultured and wild-caught channel catfish. North American Journal of Fisheries Management 27: 729-734.

Wardle, C.S. 1980. Effects of temperature on the maximum swimming speed of fishes. Pages 519-531 in M.A. Ali, editor. The Environmental Physiology of Fishes. Plenum Press, NY.

Weaver, C.R. 1965. Observations of the swimming ability of adult American shad (*Alosa sapidissima*). Transactions of the American Fisheries Society 94: 382-385.

Webb, P.W. 1978. Hydrodynamics: non-scombroid fish. Pages 190-232 in W.S. Hoar and D.J. Randall, editors. Fish Physiology, Volume 7, Locomotion. Academic Press, NY

Winchell, F., S. Amaral, and D. Dixon. 2000. Hydroelectric turbine entrainment and survival database: an alternative to field studies. In: Hydrovision 2000: New Realities, New Responses. HCI Publications, Kansas City, MO.

Young, P.S. and J.J. Cech, Jr. 1993. Improved growth, swimming performance, and muscular development in exercise-conditioned young-of-the-year striped bass, *Morone saxatilis*. Canadian Journal of Fisheries and Aquatic Sciences 50:703-707.

APPENIDIX A

Copy of Winchell et al., 2000

Winchell, F., S. Amaral, and D. Dixon. 2000. Hydroelectric turbine entrainment and survival database: an alternative to field studies. In: Hydrovision 2000: New Realities, New Responses. HCI Publications, Kansas City, MO.

[This page intentionally left blank.]

Hydroelectric Turbine Entrainment and Survival Database: An Alternative to Field Studies

By Fred VVinchell, Alden Research Laboratory, Inc., Holden, Massachusetts, USA,
Steve Amaral, Alden Research Laboratory, Inc., Holden, Massachusetts, USA,
and Doug Dixon, Electric Power Research Institute, Gloucester Point, Virginia, USA

ABSTRACT

Fish entrainment and turbine survival studies have been conducted at more than 100 hydroelectric projects in the last decade. These studies have been undertaken with the primary goals of determining the number, species and sizes of fish that are entrained into hydro turbines and their rate of survival following turbine passage. A large volume of infon77ation has been generated, but it has not been readily accessible due to the limited distribution of most study reports. Also, comparing the results obtained at different sites has been complicated by differences in study and analytical techniques and the for-rnat in which the data are presented. In 1997, EPRI sponsored a study to draw together the existing data on rish entrainment and turbine passage survival into databases employing a consistent and objective format designed to facilitate the examination of trends based on project design, geographical location and other site characteristics. In some cases, this type of analysis will allow project owners and other stakeholders to estimate the likely range of impacts associated with rish entrainment and turbine passage without conducting site-speciflc studies. This paper describes the EPRI databases and some of the trends that were found in recent studies.

Background

In recent years, many studies have been conducted to evaluate the entrainment and turbine passage survival of fish at hydroelectric projects. Most of these studies have been conducted during the FERC relicensing process at the request of state or federal fisheries agencies. When most studies were initiated in the early 1990's, little was known about how many fish were being entrained at hydroelectric projects, and little information existed about the rates of turbine passage survival for fish other than juvenile salmon and trout. The recent studies not only increased the volume of information that was available, but improvements in study techniques and reporting standards produced substantial improvements in data quality. The goal of this project, sponsored by the Electric Power Research Institute, was to compile this information using a consistent and objective format that would allow users to access and evaluate the data applicable for estimating these parameters without the need for conducting site-specific studies.

Entrainment Database Development

The entrainment database includes information from 43 sites where nets were used to sample the enbre discharge from one or more hydro turbines. Detailed information was compiled in the database on the species and sizes of fish that were collected in each month at each site. In addition, the following measures of sampling effort were included: the total water volume filtered by the net, the duration that each turbine unit was sampled, and the efficiency of each net in collecting fish that passed through the turbine.

The fish length intervals chosen for the database consist of 2-inch intervals up to 10 inches, 5-inch intervals from 10 to 30 inches, and a single size class for all fish exceeding 30 inches. For each study, the raw catch data was adjusted to compensate for the measured efficiency of the sampling net in recovering fish that had passed through the turbine.

Entrainment Trends

The entrainment database includes 20 studies conducted in the Midwest (Wisconsin, Michigan, and Indiana), 16 studies conducted in the Northeast and mid-Atlantic states (New York and Pennsylvania), and 7 studies conducted in the Southeast (South Carolina, Georgia and Virginia). As shown in Table 1, the hydraulic capacity of turbines sampled in these studies ranged from 200 to 7,200 cfs. The number of hours of sampling conducted at each site varied widely, with a general trend towards greater effort in the more recent studies conducted in the Midwest and Northeast.

Table 1. Unit Size and Sampling Effort Statistics by Region

Region/Statistic	Hydraulic Capacity of Sampled Units (cfs)	Total Unit-hrs Sampled (units x hrs)	Total Volume Sampled (ft^3 x 10^6)
Midwest sites (N = 20)			
Minimum	200	261	149
Maximum	1,225	4,123	10,222
Mean	575	1,554	2,578
Northeast sites (N = 16)			
Minimum	300	608	637
Maximum	2,450	7,616	15,719
Mean	1,085	1,648	4,531
Southeast sites (N = 7)			
Minimum	227	40	31
Maximum	7,200	218	5,654
Mean	1,557	94	937

Table 2 presents the number of sites where each family of fish was represented and the average percentage of the catch that the family comprised among these sites in each region. The families Cyprinidae, Catostomidae, Ictaluridae, Centrarchidae and Percidae were represented at almost every site. In the Northeast and Southeast, the family Clupeidae was numerically dominant at most of the sites where it was represented. Other families that composed an average of more than 10% of the catch in a region included Cyprinidae (Midwest and Northeast), Ictaluridae (Midwest and Southeast), Osmeridae (Northeast), Centrarchidae (all regions), and Percidae (Midwest and Northeast).

Table 2. Taxonomic Composition of Entrainment Catch by Region

	Number of sites			Average Composition (among sites where family occurs)		
Family	Midwest (N = 20)	Northeast (N = 16)	Southeast (N = 6)	Midwest	Northeast	Southeast
Petromyzontidae (lampreys)	8	2	0	0.8%	0.1%	--
Acipenseridae (sturgeon)	2	0	0	0.1%	--	--
Lepisosteidae (gars)	3	2	1	<0.1%	<0.1%	<0.1%
Amiidae (bowfins)	4	0	0	0.2%	--	--
Hiodontidae (mooneye)	0	1	0	--	<0.1%	--
Anguillidae (eels)	1	6	1	<0.1%	1.2%	<0.1%
Clupeidae (herring)	1	4	6	<0.1%	73.4%	43.2%
Cyprinidae (carps and minnows)	20	15	6	14.5%	14.2%	6.5%
Catostomidae (suckers)	20	16	5	9.4%	1.1%	4.4%
Ictaluridae (catfishes)	20	16	6	18.4%	6.5%	16.6%
Esocidae (pikes)	18	11	0	0.9%	2.2%	--
Umbridae (mudminnows)	19	6	0	0.3%	3.0%	--
Osmeridae (smelts)	3	10	0	0.3%	10.4%	--
Salmonidae (trout and salmon)	17	14	1	0.3%	0.6%	<0.1%
Percopsidae (trout-perches)	6	2	0	1.8%	0.1%	--
Gadidae (cods)	15	1	0	0.5%	<0.1%	--
Cyrinodontidae (killifishes)	5	7	0	<0.1%	3.3%	--
Atherinidae (silversides)	3	0	0	0.6%	--	--
Gasterosteidae (sticklebacks)	15	3	0	1.3%	8.9%	--
Cottidae (sculpins)	10	3	0	0.2%	0.2%	--
Percichthyidae (temperate basses)	1	2	3	1.7%	0.6%	1.7%
Centrarchidae (sunfishes)	20	16	6	28.8%	26.6%	26.5%
Percidae (perch)	20	16	6	25.0%	20.8%	2.6%
Sciaenidae (drums)	0	2	0	--	0.1%	--

Members of the family Clupeidae (primarily alewives, threadfin shad and gizzard shad) were entrained in high numbers at several sites. Entrainment of these species tended to show strong peaks in the winter months (Figure 1). For other species, the average rate of entrainment showed a strong peak in April with secondary peaks in July and October (Figure 2). The April and July peaks were primarily small fish (<4 inches), while larger fish (4-8 inches) were more prevalent in October. In direct contrast to the Clupeid species, most of the other species were rarely entrained during the winter months.

Overall, fish less than 4 inches comprised an average of 71.3% of the entrainment catch, and fish less than 8 inches comprised an average of 94.2% of the catch (Table 3). Fish between 8 and 15 inches comprised an average of 5.3% of the catch and fish > 15 inches comprised less than 1 % of the catch. We were surprised to find' that there was little apparent difference in the size distributions reported from sites with very different trash rack spacings. As shown in Table 3, even fish larger than 15 inches were as common at sites with narrow trash rack spacings as they were at the sites with larger spacings.

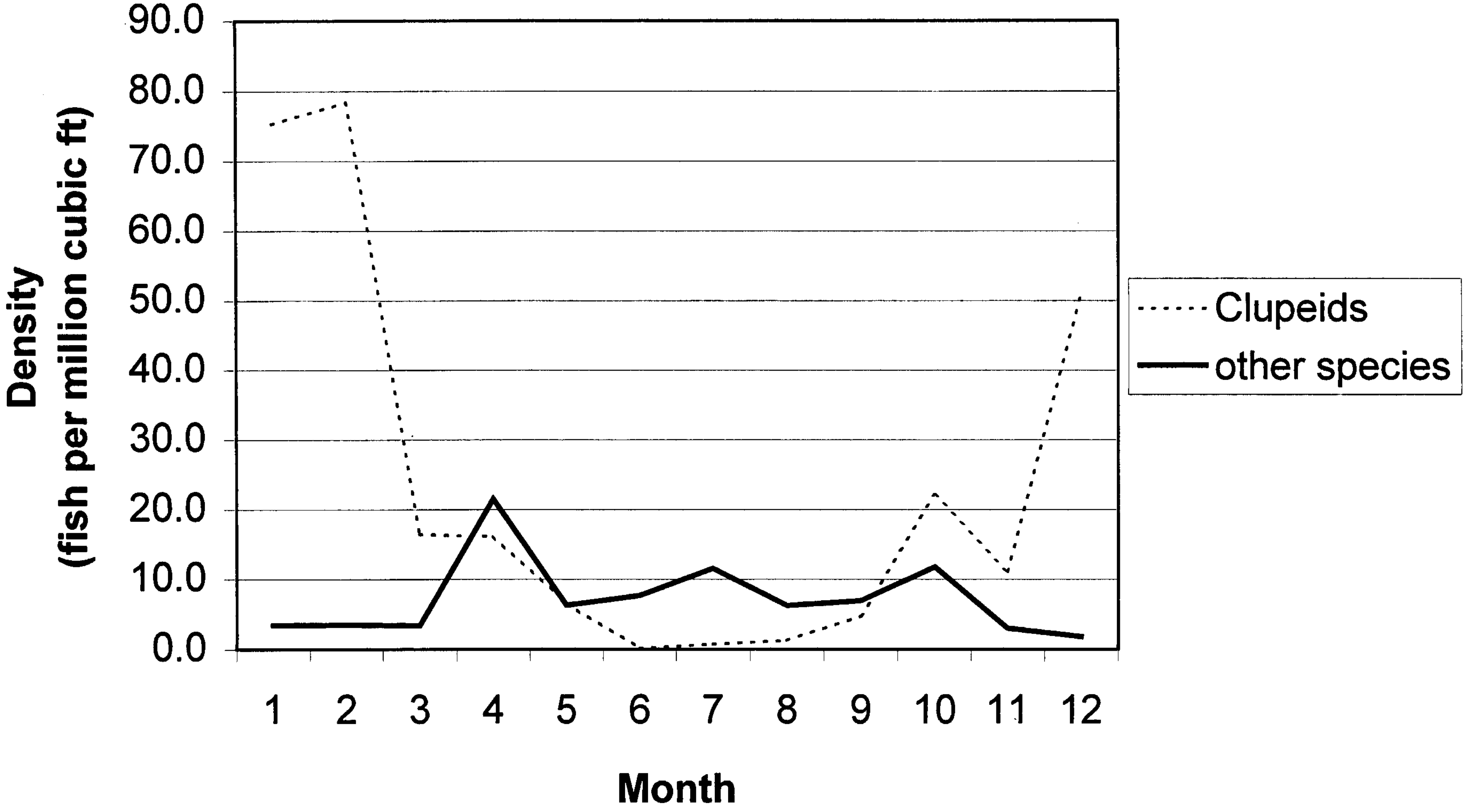
The fish size data was recompiled excluding Clupeids, whose high abundance at some sites might skew the distribution towards smaller size classes, and American eels, which may able to pass through relatively narrow-spaced racks due to their elongated and narrow body shape. Even after excluding these taxa, there was no apparent relationship between trash rack spacing and the size distribution of fish collected during entrainment sampling (Table 4). This finding suggests that many of the larger fish collected in the studies may have entered the nets from the tailrace either through gaps in the net seals or by entering the draft tubes before the nets were lowered into place. If true, the entrainment rate of larger fish may have been overestimated in some of these studies.

Survival Database Development

The turbine survival database includes data from studies conducted at 51 different turbines that used paired releases of treatment and control fish to estimate immediate and delayed survival. Treatment fish refers to fish that were subjected to turbine passage and recaptured in the tailrace. Control fish typically were released in the draft tube or tailrace discharge of the turbine being tested. Control fish were used to account for handling- and recapture-related injury and mortality in the estimation of turbine survival.

The turbine survival estimates that are presented in the database were calculated using the relative recovery rate method (Ricker 1945, 1948; Burnham et al. 1987; EPRI 1997). Data used in the survival estimate calculations are presented as well, and include the number of fish released, the number recovered, the number recovered live, and the number live at 24 and 48 hours after capture. These numbers are reported for

Figure 1. Average Monthly Entrainment for Clupeids and Other Species (average of 43 sites)



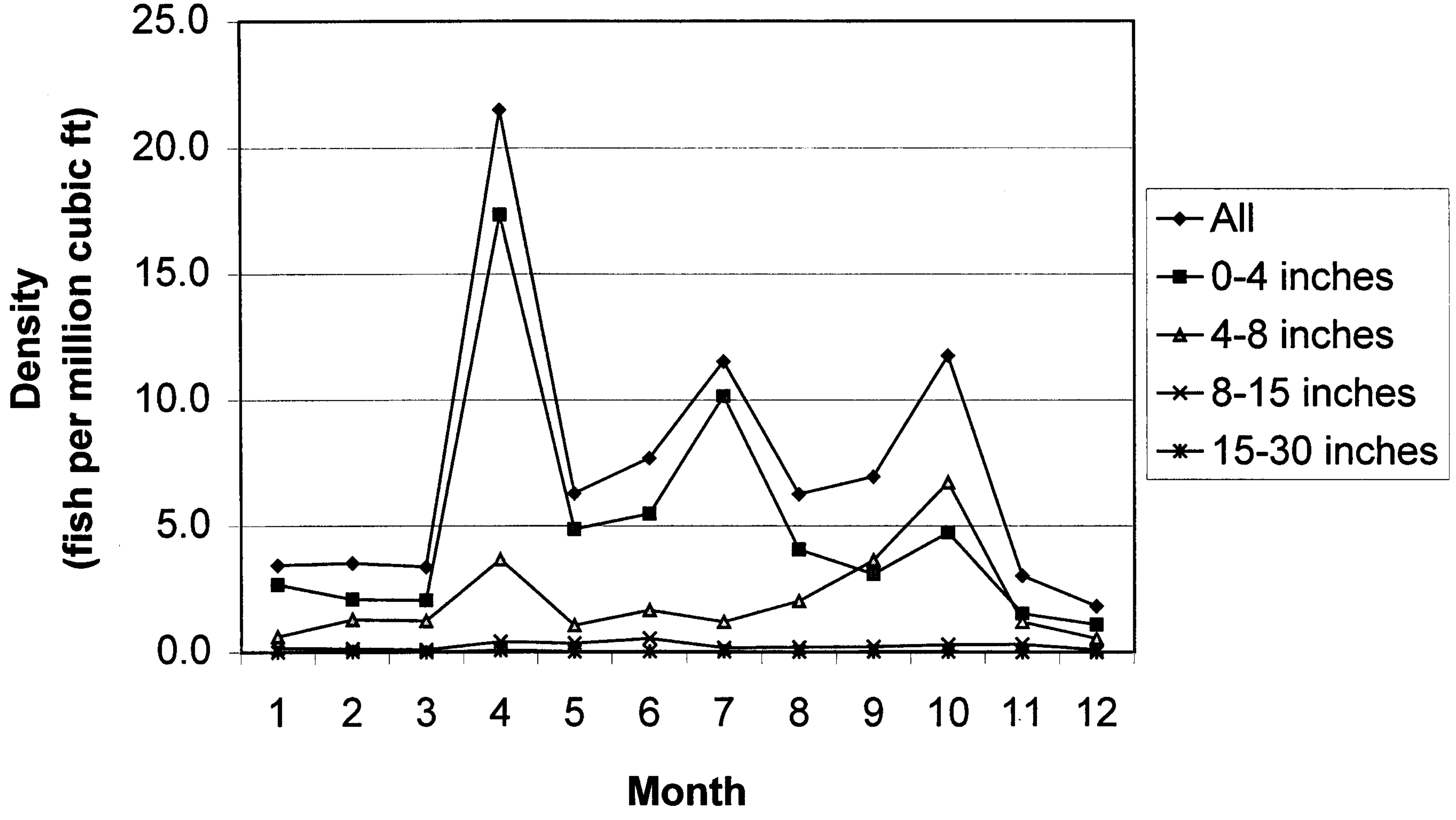


Figure 2. Average Monthly Entrainment by Size Excluding Clupeid Species (average of 43 sites)

Table 3. Size Composition of Entrainment Catch by Trash Rack Spacing[1] (all species)

Clear Spacing		Average Composition by Size Class				
(inches)	N	0-4"	4-8"	8-15"	15-30"	>30"
1	3	61.5%	32.2%	5.5%	0.9%	0.0%
1.5-1.8	10	64.8%	27.1%	7.5%	0.6%	0.0%
2-2.75	12	68.9%	25.3%	5.1%	0.7%	0.0%
3-10	14	80.0%	15.7%	3.9%	0.3%	0.0%
All	*39*	*71.3%*	*22.9%*	*5.3%*	*0.5%*	*0.0%*

[1] Excludes three sites where trash rack spacing was not known and one site where only catches of American eels were reported.

Table 4. Size Composition of Entrainment Catch by Trash Rack Spacing[1] (all species except Clupeids and American eels)

Clear Spacing		Average Composition by Size Class				
(inches)	N	0-4"	4-8"	8-15"	15-30"	>30"
1	3	61.5%	32.2%	5.5%	0.9%	0.0%
1.5-1.8	10	64.6%	27.5%	7.5%	0.5%	0.0%
2-2.75	12	73.7%	20.6%	5.4%	0.3%	0.0%
3-10	14	67.9%	24.9%	6.4%	0.7%	0.0%
All	*39*	*68.4%*	*24.8%*	*6.3%*	*0.5%*	*0.0%*

[1] Excludes three sites where trash rack spacing was not known and one site where only catches of American eels were reported.

treatment and control fish. The numbers of fish released, recovered, or live after a specified delayed mortality holding period were not reported in all studies. All available data that are required to estimate survival are included in the database.

Survival Trends

To look for survival trends, we chose to exclude data from tests where control mortality exceeded 10%. Ruggles (1992) examined the effects of experimental stress on the accuracy of turbine survival estimates, and concluded that tests with control mortality rates exceeding 10% were likely to produce unreliable estimates of turbine passage survival. In a 1997 survey of fisheries professionals experienced in studies of entrainment and turbine passage, most respondents indicated that a control mortality of 10% or less was needed to produce a reliable estimate of survival (EPRI 1997).

After the data was screened to eliminate estimates associated with high rates of control mortality, the data was examined to look for general trends. The clearest trends were associated with differences in fish size, turbine type, turbine rotational speed, and turbine size. As shown in Table 5, the database includes survival ' data for a wide range of species. No obvious differences in survival were evident between species.

Table 5. Species Represented in the Survival Database

	Species in Database with Acceptable Control Survival	
Family	Immediate control survival >90%	48-hour control survival >90%
Anguillidae (eels)	American eel	American eel
Clupeidae (herring)	alewife, American shad, blueback herring	American shad, blueback herring
Cyprinidae (carps and minnows)	golden shiner, spottail shiner	golden shiner
Catostomidae (suckers)	white sucker	white sucker
Ictaluridae (catfishes)	bullhead spp., channel catfish	bullhead spp., channel catfish
Esocidae (pikes)	grass pickerel, northern pike	grass pickerel, northern pike
Salmonidae (trout and salmon)	Atlantic salmon, chinook salmon, coho salmon, brook trout, rainbow trout	Atlantic salmon, chinook salmon, coho salmon, brook trout, rainbow trout
Percichthyidae (temperate basses)	white perch	
Centrarchidae (sunfishes)	bluegill, bluegill/green sunfish hybrids, largemouth bass, smallmouth bass, sunfish spp.	bluegill, bluegill/green sunfish hybrids, largemouth bass
Percidae (perch)	walleye, yellow perch	walleye, yellow perch
other species represented in mixed species tests	fathead minnow, creek chub, golden redhorse, shorthead redhorse, steelhead, spotted	fathead minnow, creek chub, golden redhorse, shorthead redhorse, steelhead

Table 6 shows the minimum, maximum and mean immediate survival estimated for four size classes of fish after they passed through 5 classes of turbines. N represents the number of turbines for which acceptable estimates (control survival > 90%) were available. The estimates for each turbine are an average of all accepted tests conducted using the indicated size class of fish (all species and test conditions combined).

For axial-flow turbines (Kaplan, propeller, bulb and tube turbines), the average survival rates were distinctly lower at one site than they were at all of the other axial-flow turbines in the database. This turbine had the highest rotational speed and the lowest hydraulic capacity of all of the axial-flow turbines. For other axial-flow turbines, the average immediate survival tended to fall between 90 and 98%. Average survival rates as low as 77.4% were found for large fish tested in some of the smaller turbines.

The single mixed-flow (Deriaz) turbine tested had an immediate survival rate of 97.2% for the single size class of fish evaluated.

The survival rates observed for radial-flow (Francis) turbines were generally more variable than they were for the axial-flow turbines. Survival was generally highest for smaller fish and for turbines with rotational speeds less than 250 rpm. For fish less than 200 mm, immediate survival rates averaged about 60 to 70% for higher-speed turbines, and survival ranged between 91.6 and 93.9% for lower-speed turbines. Survival was considerably lower for large fish tested at the higher speed turbines, and a similar but less pronounced trend was observed for the lower speed turbines. However, the results were quite variable between turbines and some radial-flow turbines showed high rates of survival for all sizes of fish.

Table 7 shows the results of the same analysis conducted using survival rates observed 48 hours after turbine passage. The number of data points is lower, since the latent mortality holding period in some studies did not extend to 48 hours and more tests were excluded based on low control survival (<90%). The general trends of lower survival for larger fish and for turbines with higher rotational speeds are still evident for radial turbines, while these relationships were less clear for axial-flow turbines. In general, survival at 48 hours was about 3-4% lower than immediate survival for the combinations of fish size and turbine type where immediate survival was relatively high. For turbines and fish sizes that had lower rates of immediate survival, there tended to be a greater reduction in survival over the 48 hour holding period.

Conclusions

Compiling recent information on entrainment and survival into databases using a consistent and objective format allowed for several trends to be identified. The size, species composition and seasonality of entrainment catches showed a degree of consistency both between and within regions. Trash rack spacing did not have a strong influence on the size distribution of fish represented in the entrainment catch,

Table 6. Fish Survival Rates (immediate) for Different Turbines and Sizes of Fish

Turbine Type	Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size (mm)	Average immediate Survival[1] (all species combined) N[2]	Minimum	Maximum	Mean
axial-flow[3]	<300	636-1203	<100	3	94.1%	98.0%	95.4%
"	"	636-21,000	100-199	10	89.8%	97.5%	94.8%
"	"	636-2200	200-299	5	77.4%	97.4%	87.2%
"	"	1203-2200	300+	2	86.8%	100.0%	93.4%
axial-flow	>300	530	<100	1	81.3%	81.3%	81.3%
"	"	"	100-199	1	78.0%	78.0%	78.0%
"	"	--	200-299	0	--	--	--
"	"	--	300+	0	--	--	--
mixed-flow	77	--	<100	0	--	--	--
(Deriaz)	"	9,200	100-199	1	97.2%	97.2%	97.2%
"	"	--	200-299	0	--	--	--
"	"	--	300+	0	--	--	--
radial-flow	<250	440-1,600	<100	13	85.9%	100.3%[4]	93.9%
(Francis)	"	370-1,600	100-199	19	74.8%	100.0%	91.6%
"	"	370-2,450	200-299	18	59.0%	100.0%	86.9%
"	"	440-1,600	300+	14	36.1%	100.0%	73.2%
radial-flow	>250	275-695	<100	6	31.0%	97.6%	70.1%
(Francis)	"	"	100-199	7	34.3%	82.7%	60.0%
"	"	"	200-299	7	22.8%	82.9%	39.3%
"	"	"	300+	3	3.5%	35.4%	19.1%

[1] Average of all control-adjusted estimates provided in EPRI (1997) including all species and test conditions but excluding tests with less than 90% survival of control groups.

[2] Number of turbines for which survival estimates are available.

[3] Includes Kaplan, fixed-blade propeller, bulb and tube turbines.

[4] Even with high rates of control survival, the true rate of survival may be under- or over-estimated. When the survival of treatment groups is higher than controls, the adjusted survival estimates will exceed 100%.

Table 7. Fish Survival Rates (after 48 hours) for Different Turbines and Sizes of Fish

Turbine Type	Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size (mm)	Average 48 hour Survival[1] (all species combined)			
				N[2]	Minimum	Maximum	Mean
axial-flow[3]	<300	1,203	<100	1	84.9%	84.9%	84.9%
"	"	636-21,000	100-199	8	89.8%	97.2%	93.4%
"	"	636-2,200	200-299	4	77.4%	86.4%	83.9%
"	"	1,203-2,200	300+	2	79.0%	100.0%	89.5%
axial-flow	>300	--	<100	0	--	--	--
"	"	--	100-199	0	--	--	--
"	"	--	200-299	0	--	--	--
"	"	--	300+	0	--	--	--
mixed-flow	77	--	<100	0	--	--	--
(Deriaz)	"	--	100-199	0	--	--	--
"	"	--	200-299	0	--	--	--
"	"	--	300+	0	--	--	--
radial-flow	<250	440-1,600	<100	11	80.9%	101.1%[4]	90.4%
(Francis)	"	370-2,450	100-199	17	73.7%	101.8%[4]	87.8%
"	"	440-2,450	200-299	15	47.4%	96.4%	80.4%
"	"	440-1,600	300+	13	33.8%	94.1%	66.8%
radial-flow	>250	275-695	<100	3	63.3%	86.3%	72.4%
(Francis)	"	275-695	100-199	5	16.1%	77.5%	45.9%
"	"	275-695	200-299	5	12.3%	64.5%	32.3%
"	"	275-450	300+	2	3.5%	8.4%	6.0%

[1] Average of all control-adjusted estimates provided in EPRI (1997) including all species and test conditions but excluding tests with less than 90% survival of control groups.

[2] Number of turbines for which survival estimates are available.

[3] Includes Kaplan, fixed-blade propeller, bulb and tube turbines.

[4] Even with high rates of control survival, the true rate of survival may be under- or over-estimated. When the survival of treatment groups is higher than controls, the adjusted survival estimates will exceed 100%.

suggesting that most of the larger fish may have intruded into the sampling nets from the tailrace. Excluding tests with low rates of control survival, it was found that survival rates were consistent between sites for similar-sized fish passed through turbines of similar design, rotational speed and flow capacity. Survival rates tended to be highest for small fish and for turbines with lower rotational speeds.

References

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie and K. H. Pollock. 1987. *Design and Analysis Methods for Fish Survival Experiments Based on ReleaseRecapture.* **American Fisheries Society Monograph 5.**

Electric Power Research Institute. 1997. *Guidelines for Hydro Turbine Fish Entrainment and Survival Studies.* **EPRI Report TR-1 07299. Prepared by Alden Research Laboratory, Inc.**

Ricker, W. E. 1945. *Abundance, Exploitation, and Mortality of Fishes of Two Lakes. Investigations of Indiana Lakes and* ***Streams.*** **2:345-448.**

Ricker, W. E. 1948. *Methods of Estimating Vital Statistics of Fish Populations.* **Indiana University Publications in Science Series 15.**

Ruggles, C. P. 1992. *Effects of Stress on Turbine Fish Passage Mortality Estimates.* **Canadian Technical Report Fisheries and Aquatic Sciences No. 1905:39-57.**

Authors

Fred Winchell is a senior fisheries biologist with the Alden Research Laboratory. He has authored several reviews on fish entrainment, turbine passage survival and fish protection. He is currently engaged in preparing NEPA documents on licensing actions at numerous hydroelectric facilities.

Steve Amaral is a fisheries biologist with Alden Research Laboratory. He was lead author of a 1997 EPRI guideline on methods for conducting studies of fish entrainment and survival. He is active in the evaluation of fish passage measures and the analysis of entrainment and impingement trends at cooling water intakes.

Doug Dixon is a project manager with the Electric Power Research Institute in charge of the Watershed, Ecosystem & Power Plant Water Management Environment Division.