Fish Entrainment and Mortality Study

A-Mill Artist Lofts Hydroelectric Project (FERC No. 14628)

Minneapolis, Minnesota

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Introduction

1.1 Background

Minneapolis Leased Housing Associates IV, Limited Partnership (Applicant), filed with the Federal Energy Regulatory Commission (FERC, or Commission) a Notice of Intent (NOI) and a Pre-Application Document (PAD) on July 28, 2014 and July 29, 2014, respectively, to seek an original license for the construction and operation of the A-Mill Artist Lofts Hydroelectric Project (Project). The Applicant is using the Commission's Alternative Licensing Process (ALP) to prepare the license application. The Project will be located in Hennepin County, in Minneapolis, Minnesota on the east bank of the Mississippi River at St. Anthony Falls. The "Falls of St. Anthony" has been the site of numerous water power developments since the first grist and lumber mills were established the early 1820's. After several decades, hydro-mechanical milling began evolving into steam powered milling and hydroelectric generation. In 1881 the Pillsbury Company illuminated the A-Mill with self-generated hydroelectric power (Anfinson 2003). The proposed Project will utilize historical Pillsbury mill race and drop shaft features to once again provide clean renewable energy to the A-Mill complex. It will consist of a single 650 kW Kaplan turbine with a hydraulic capacity of 200 cubic feet per second (cfs). The Project will be operated as a run-of-river facility, passing a relatively small proportion of total Mississippi River flow through a 1.25-inch (in) trashrack, a 5-foot (ft) diameter penstock, and a 600 rpm vertical axis Kaplan turbine.

There are two FERC-licensed hydropower projects in the immediate vicinity of the falls. The St. Anthony Falls Hydroelectric Project (FERC Project No. 2056) is owned and operated by Northern States Power Company (d.b.a. Xcel Energy); it includes the St. Anthony Falls Dam complex and the pool that it forms. The unconstructed Crown Hydroelectric Project (FERC Project No. 11175) is licensed for development at the west dam abutment adjacent to the Corps' navigation lock. A third development, the Lower St. Anthony Falls Hydroelectric Project (FERC Project No. 12451), is located approximately a half mile downstream at the Lower St. Anthony Falls Lock and Dam.

The potential for fish to be impinged on the trashrack and/or entrained through the turbine unit was assessed by the Applicant in this report. Operation of hydroelectric projects can result in the sporadic/episodic impingement and entrainment of fish. Impingement refers to the potential for fish to become trapped against the intake trashracks due to velocity conditions at the intake. Entrainment at hydroelectric projects refers to the passage of fish into the powerhouse intakes and through the turbine units. Fish passing through a turbine can be subject to the risk of injury or mortality. The number of fish impinged or entrained at a project is related to a variety of physical factors near the dam and powerhouse, such as flow rate, intake depth, intake approach velocities, trashrack spacing, and proximity to fish habitat. Biotic factors also affect entrainment, including diurnal and/or seasonal patterns of fish migration and dispersal, fish size and swimming capabilities, life history requirements, and density-dependent influences (e.g., resource availability) on fish populations in upstream habitats.

In addition, survival of turbine-entrained fish depends on the physical characteristics of the turbine system, such as head, turbine size and design, runner speed, wicket gate openings, number of runner blades, runner blade angle, gap size, and water flow through the turbine. Many of these factors can be causes of mechanical injury, and studies suggest that survival probability primarily depends on the size of the fish and type of turbine.

During the past 20 years, owners of hydroelectric facilities, mostly applicants for FERC relicensing, have conducted numerous field studies to assess impingement, entrainment, and turbine survival at many small-to-medium-sized projects. Over 50 site-specific studies of resident fish entrainment and mortality at hydroelectric sites in the United States have been performed and reported on to date. Projects studied vary by location, size, operation patterns, fish presence, impoundment characteristics, and intake features such as trashrack spacing and intake velocities. Similarly, these studies contain extensive turbine survival data for a range of turbine types and physical characteristics. In recent years, this extensive empirical database has been successfully used to conduct desktop assessments of fish impingement, entrainment, and turbine survival at many projects throughout the country. This approach is currently accepted by the FERC, as well as other federal agencies and most state fisheries agencies nationwide.

1.2 Fish Community

At least 123 fish species have been documented in the upper Mississippi River (Minneapolis Leased Housing Associates IV 2014; Xcel Energy 2005; MDNR 2009). St. Anthony Falls historically acted as a natural barrier to upstream fish movement until the Army Corps of Engineers constructed a navigation lock there in 1963. Since that time, species previously restricted by the falls (e.g., channel catfish, flathead catfish, gizzard shad, northern hog sucker, golden redhorse, and white crappie) are now found upstream of St. Anthony Falls (Xcel Energy 2005).

Great Lakes Environmental Center (GLEC 2013) conducted fish community sampling in the Upper and Lower St. Anthony Falls pools in October 2011 and July 2012. Their sampling produced a total of 6,275 fish representing 35 species and 12 families (Appendix A). Emerald shiner, bluegill, smallmouth bass, quillback, and common carp were the most abundant species collected. The game species collected included smallmouth bass, largemouth bass, black crappie, walleye, northern pike, white bass, and channel catfish.

Study Goals and Objectives

The objective of this fish entrainment and mortality study is to provide the information necessary to estimate potential project operational effects on fisheries resources in the upper Mississippi River, namely the potential for fish to become impinged or entrained at the proposed Project facilities. The general approach utilized to conduct this study is as follows:

1. Describe the physical characteristics of the proposed Project that may influence fish-related turbine entrainment, impingement, and survival;

2. Describe the species composition of the existing fish community;
3. Assess the potential for trashrack exclusion and/or impingement of the target species;
4. Provide monthly turbine entrainment rates from existing empirical data, and utilize these rates to estimate monthly turbine entrainment for the target species using existing hydrologic records or information and proposed Project operations; and
5. Calculate turbine mortality rates for the range of target species' sizes expected to become entrained, and apply these rates to the monthly entrainment estimates.

Methodology

3.1 Overview

The most current fish community data, historical hydrology, operational and structural specifications, empirical entrainment rates, intake velocity calculations, and blade strike probabilities were analyzed for a comprehensive review of fish entrainment and mortality at the Project. The following independent assessments or study phases were made to address study goals and objectives:

1. Description of factors affecting entrainment, impingement, and survival;
2. Intake velocities, trashrack exclusion, and impingement; and
3. Entrainment and turbine survival estimation.

3.2 Description of Factors Affecting Entrainment, Impingement and Survival

A general, qualitative assessment was made of factors influencing entrainment and mortality, and their occurrence at the Project. Various structural, operational, and biological (biotic and abiotic) factors generally known to influence entrainment and turbine mortality probability were identified for the Project, and are presented below. These included intake proximity to littoral zone habitats, littoral zone species abundance, and turbine type, to name a few.

3.3 Intake Velocities, Trashrack Exclusion, and Impingement

Fish impingement and intake avoidance were determined utilizing intake velocity calculations, fish burst swim speeds, and trashrack spacing for a general qualitative assessment. Average approach velocity was calculated using trashrack drawings (clear spacing) and the Project's maximum hydraulic capacity. Although not used in the entrainment estimation, available fish swim speed data in scientific literature (Appendix B) were compared with calculated intake velocities at the Project. Approach velocities were calculated by dividing the Project's hydraulic capacity by the total gross area of the intake (EPRI 2000). Approach velocities are considered to be the average water velocity measured a few inches in front of the intake screen, taken in the same direction as the general flow (EPRI 2000). Approach velocities are typically considered more critical when assessing potential for impingement/entrainment (EPRI 2000).

The exclusion assessment also involved estimating minimum fish lengths for the target fish species that would be excluded or impinged by the 1.25-in trashrack bar spacing at the Project. A scaling factor relating fish body width to total length was used for the impingement assessment phase to determine minimum sizes of the target fish species that would be physically excluded or impinged on the trashracks (Smith 1985). Entrainment rates for these species-specific sizes that cannot physically pass through the trashracks were not considered in the entrainment estimation, but instead are considered to either become impinged on or excluded (escape) by the trashracks.

3.4 Entrainment and Turbine Survival Estimation

The entrainment and turbine mortality estimation is a quantitative assessment that utilized a combination of the best available data sources, including: (1) species lists and relative composition data from the Project area (GLEC 2013); (2) Electric Power Research Institute (EPRI 1997a) empirical entrainment rates; (3) United States Geological Survey (USGS) 73-year (1940-2013) period of record hydrology; (4) Project operational and mechanical specifications; and (5) blade strike probabilities (Franke et al. 1997). The result is a monthly, seasonal, and annual estimate (number of fish) of potential entrainment and mortality for species occurring in the Project area. Trashrack exclusion findings are the only data from the other independent assessments utilized in the entrainment estimation.

3.4.1 Fish Species Composition

Fish collection data from the GLEC (2013) sampling were used to compile a list of those species occurring in the Upper and Lower St. Anthony Falls pools (Appendix A). Table 3-1 provides the fish species and relative percent composition (RC%) used to represent those communities vulnerable to entrainment at the Project. The RC% represents combined data for the upper and lower pools. Following methods previously accepted by FERC (HDR Engineering, Inc. 2014, 2013, 2012a, 2012b, 2012c), RC% for each species was incorporated into their respective entrainment and survival estimations to account for the local fishery composition. Spawning and early life stage periodicities for each of these species are provided in Appendix C.

Table 3-1. Combined catch and percent relative composition (RC%) of fish species in the Upper and Lower St. Anthony Falls pools (GLEC 2013).

Species	Number	RC%
Emerald Shiner	3,385	53.95
Bluegill	527	8.40
Smallmouth Bass	426	6.79
Quillback	423	6.74
Common Carp	354	5.64
Shorthead Redhorse	289	4.61

Table 3-1. Combined catch and percent relative composition (RC%) of fish species in the Upper and Lower St. Anthony Falls pools (GLEC 2013).

Species	Number	RC%
Freshwater Drum	265	4.22
Green Sunfish	153	2.44
Walleye	89	1.42
Channel Catfish	56	0.89
Gizzard Shad	41	0.65
Bigmouth Buffalo	40	0.64
Mimic Shiner	40	0.64
Brook Silverside	31	0.49
Black Crappie	28	0.45
Silver Redhorse	17	0.27
Spotfin Shiner	15	0.24
Northern Pike	15	0.24
Largemouth Bass	12	0.19
Golden Redhorse	10	0.16
White Sucker	10	0.16
Flathead Catfish	10	0.16
River Carpsucker	7	0.11
White Bass	7	0.11
Rock Bass	5	0.08
Pumpkinseed	5	0.08
Orangespotted Sunfish	3	0.05
White Crappie	2	0.03
Hybrid Sunfish	2	0.03
Yellow Bullhead	2	0.03
Logperch	2	0.03
Sauger	1	0.02
Blackside Darter	1	0.02
Trout-Perch	1	0.02

3.4.2 Empirical Entrainment Rate Data

An extensive literature review was conducted of entrainment studies previously completed for various hydroelectric facilities throughout the United States. Recent FERC relicensing entrainment studies (HDR Engineering, Inc. 2014, 2013, 2012a, 2012b, 2012c, 2011, 2010a, 2010b, 2010c; HDR|DTA 2010a, 2010b; GeoSyntec Consultants [GeoSyntec] 2005; Normandeau Associates Inc. [Normandeau] 2008; Normandeau 2009) have utilized desktop study approaches for such assessments, where data compiled by EPRI (1992, 1997a, 1997b) and FERC (1995a, 1995b) has most commonly been used for comparative purposes. These reports have detailed trends and correlations between fish community characteristics, entrainment rates, mortality, and passage with hydroelectric plant design and operation. Findings from field trials conducted at these projects and their transferability across the hydroelectric spectrum have eliminated the need for costly and time-consuming survival/netting studies at FERC hydroelectric projects (EPRI 1997a).

The EPRI (1997a) database provides the most robust empirical entrainment dataset from field trials conducted at 43 hydroelectric facilities east of the Mississippi River (Appendix D). Ten of the 43 projects are in Minnesota, although none are located on the mainstem Mississippi River. All studies in the database utilized full-flow tailrace netting, which according to EPRI (1997a) is the most preferred entrainment study methodology as opposed to partial-flow tailrace netting, intake gallery netting, and/or hydroacoustics.

Full-flow tailrace netting involves placing a conical net in the immediate tailrace to collect the entire discharge on a seasonal or monthly basis. Because full-flow tailrace netting did not always document all fish passing through a turbine, most of the studies adjusted the number of fish collected by the net's collection efficiency. Studies conducted at the Buzzards Roost, Gaston Shoals, Hollidays Bridge, Ninety-Nine Islands, and Saluda projects were the only ones that did not, and were excluded from this desktop analysis, as were other projects from South Carolina and Georgia. Other potential sources of error in the database include net intrusion of fish in the tailrace. Larger fish often entered the draft tube before the net was installed, thus producing entrainment rates that included fish that did not pass through the turbines. The impingement assessment described above helps to correct for these errors in eliminating those larger fish from the entrainment estimation at the Project.

The species, number (corrected for net efficiency), and size of entrained fish were documented, of which data are available for approximately 140 species and 30 species groups. The resulting 5,332 rows of entrainment collection data were compiled into a sortable spreadsheet. Each row represents fish numbers collected for one species/group at a given project in a given month, and for the following 10 size intervals: 0-2 in, 2.1-4 in, 4.1-6 in, 6.1-8 in, 8.1-10 in, 10.1-15 in, 15.1-20 in, 20.1-25 in, 25.1-30 in, and >30 in. Therefore, a total of 53,320 entrainment data points for all projects, species/groups, and size intervals combined are available. This includes data points where no fish were collected for a given size interval.

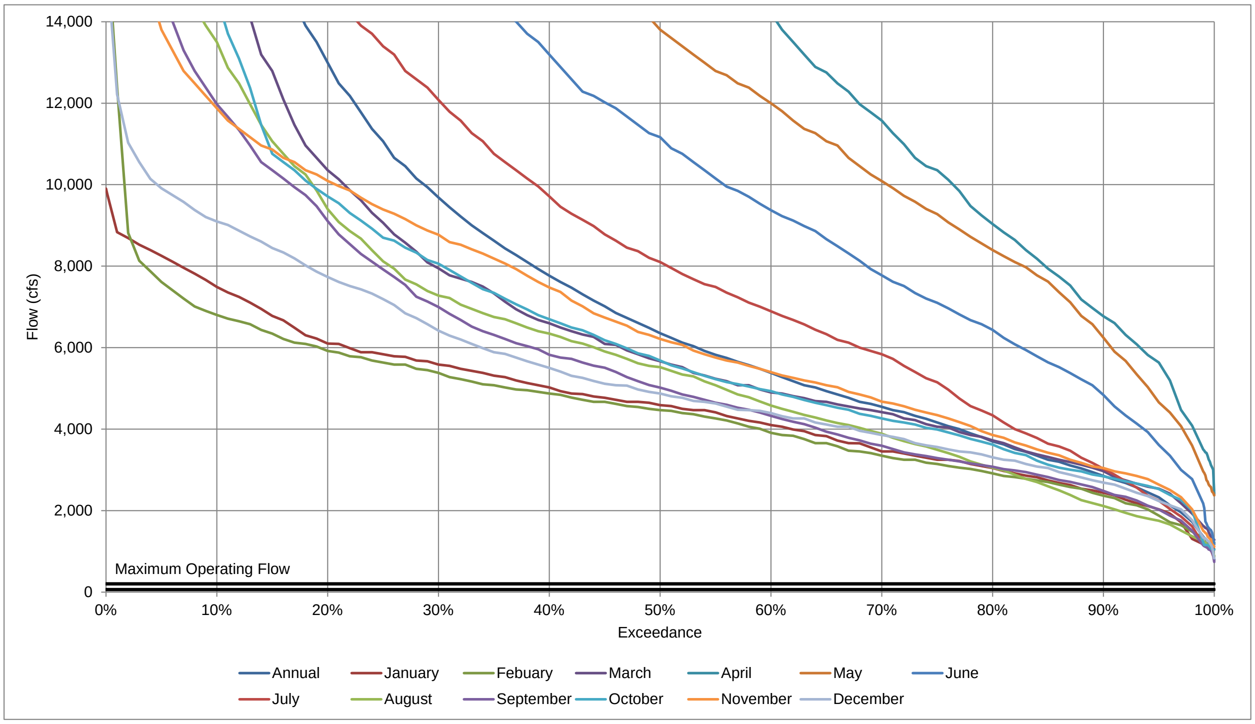
Entrainment rates (fish/hour/1,000 cfs of unit capacity) were determined for each of the 53,320 data points. Because only half of the studies in the EPRI database reported volume of water sampled, EPRI (1997a) recommended using the number of fish entrained per hour per 1,000 cfs of unit capacity. This allows for the standardization of all data and a larger sample size from which to calculate average, monthly entrainment rates for a given species/group. All of the studies in the database reported hours sampled, as well as the hydraulic capacity of the sampled units. The number of fish reported for each of the 53,320 data points was divided by the hours reported for the associated sample event, and then by the capacity of the sampled unit(s). If more than one unit was sampled, the average hydraulic capacity was used (EPRI 1997a). This value was then divided by 1,000 to obtain fish per hour per 1,000 cfs of unit capacity. In most cases, this resulted in very small numbers, where significant units were rounded to the ten thousandth decimal point.

All of the 53,320 entrainment rate data points were considered as the sample pool from which to obtain monthly rates for all species. Using the entire database is considered conducive to capturing the variability of aquatic ecosystems within and between river systems, while providing a robust database for a wide range of species, sizes, and months. Based on professional judgment, these data were filtered in the following manner in an attempt to acquire entrainment rates for all 12 months for each species: (1) only use individual species data if all months are represented (at least one data point in a given month); (2) if not all months are represented, use at least one similar species within the same genus that occupies similar habitats; (3) if this does not account for all months, use at least one similar species/group of species within the same family that occupies similar habitats; (4) use the entire family average; (5) if no data are available for a given species up to the family level, select a similar species/group of species from another family that occupies similar habitats; and (6) use partial monthly data if no comparable species is available.

3.4.3 Project Hydrology and Generation

Mississippi River flow exceedance values were obtained from United States Geological Survey (USGS) Stream Gage No. 05288500 (Highway 610 in Brooklyn Park, MN) period of record (POR) from 1940-2013 (Figure 3-1), and used to determine the hydrologic variability and amount of water available for generation. A flow proration of 1.015 was used based on the methodology in the PAD (Minneapolis Leased Housing Associates IV 2014). These data were used to determine the hydrologic variability and volume of water available for generation at the Project on a monthly basis (Appendix E). Generation amounts were determined by fitting custom lines to flow duration curves, and calculating the area under that curve (exceedance volume) that would have been available for generation. Combined with the Project’s hydraulic capacity, this resulted in projected monthly generation amounts (1,000 cfs-hours) at the Project for the POR. Dry and wet water years had the same generation amounts as the POR and were not analyzed.

Figure 3-1. Project flow exceedance for the POR (1940-2013) and operating range.



3.4.4 Turbine Specifications and Fish Survival

Turbine specifications for the Project (Table 3-2) were compiled and used to calculate blade strike probabilities and fish survival. A predictive blade strike model was used to estimate turbine survival for fish passing through the Project's turbines. The Advanced Hydro Turbine model (Franke et al. 1997) is a leading edge blade strike probability model developed by the U.S. Department of Energy program to develop more "fish-friendly" turbines. Franke et al. (1997) refined the original Von Raben Model (cited by Bell 1981) to account for the effect of tangential projection of fish length and flow angle on operating head and discharge parameters. The probability of blade strike in the model is based on several factors, including the number of runner blades, fish length, runner blade speed, turbine type, runner diameter, turbine efficiency, and total discharge.

Model predictions were made for 1-in fish length increments up to 15 in, which is the maximum length of the target species (northern pike) that could physically pass through the 1.25-in trashrack bar spacing at the Project powerhouse based on the impingement/exclusion assessment. A correlation factor (lambda) was added to each equation to account for the fact that a fish may not always lie in a plane of revolution, as well as the fact that the strike severity may vary with strike location on the fish. Von Raben (cited by Bell 1981) incorporated the correlation factor to adjust the predictive turbine strike results to more closely match empirical results. Franke et al. (1997) suggested correlation factors of 0.1 and 0.2 (i.e., 10% and 20% of strikes are lethal), based on test results using Pacific salmonids. Survival is also dependent on the location of entry into the runner for Kaplan turbines. Depending on turbine design, survival is typically lower closer to the hub due to smaller spacings. To account for this, blade strike probabilities were calculated for passage near the hub (0.4 or 40% of the hub diameter/runner diameter ratio), mid-blade (0.6 or 60% of the hub diameter/runner diameter ratio), and blade tip (1 or 100% of the hub diameter/runner diameter ratio).

Blade strike probabilities were calculated for each correlation factor with the associated model input parameters, including entry location. Survival was calculated by subtracting the predicted strike estimate from 100. Average survival rates could then be calculated from all correlation values for each of the 10 size intervals available in the EPRI (1997a) database.

The following equations (Franke et al. 1997) were used for the vertical Kaplan turbine unit at the Project under maximum turbine flow efficiency:

$$P = \lambda \frac{N \cdot L}{D} \cdot \left[\frac{\cos \alpha_a}{8 \cdot Q_{wd}} + \frac{\sin \alpha_a}{\pi \cdot \frac{r}{R}} \right]$$

$$\alpha_a = \tan^{-1} \left[\frac{\pi \cdot E_{wd} \cdot \eta}{2 \cdot Q_{wd} \cdot \frac{r}{R}} \right]$$

$$R = \frac{D}{2}$$

$$E_{wd} = \frac{g \cdot H}{(\omega \cdot D)^2}$$

$$Q_{wd} = \frac{Q}{\omega \cdot D^3}$$

$$\omega = RPM \cdot \frac{2\pi}{60}$$

$$S = 1 - P$$

Where:

P = Predicted strike
S = Predicted survival
N = Number of turbine blades
L = Fish length
D = Runner diameter
λ = Strike mortality correlation factor (lambda)
R = Radius of runner = (D/2)
r = Location along radius that a given fish enters the turbine (passage route)
η = Turbine efficiency at maximum flow rate (*Q*)
E_{wd} = Head coefficient or energy coefficient (see above equation)
Q_{wd} = Discharge coefficient (see above equation)
α_a = Angle to axial of absolute flow upstream of runner (see above equation)
g = Acceleration of gravity
H = Turbine net head
ω = Rotational speed $= RPM \cdot \frac{2\pi}{60}$
RPM = Revolutions per minute
Q = Maximum turbine flow rate

Table 3-2. Project turbine specifications.

Operating Mode	Run of River
Unit Type / Number	Kaplan / 1
Unit Orientation	Vertical
Maximum Flow (cfs)	200
Minimum Flow (cfs)	30
Runner Diameter (ft)	3.28
Hub Diameter (ft)	1.30
Runner Speed (rpm)	600
Number of Blades	4
Rated Net Head (ft)	48
Rack Spacing (in)	1.25

3.4.5 Monthly Entrainment and Survival Estimation

Monthly entrainment estimates at the Project incorporate the average monthly entrainment rate (fish/hour/1,000 cfs unit capacity), projected monthly generation (1,000 cfs-hours), RC%, and trashrack exclusion. Monthly generation amounts were multiplied by the monthly entrainment rate for each of the 10 size intervals per species. This included separate estimates for each of the 10 size intervals (as provided in the EPRI database) for each species per month. An estimate was derived for each species identified in Table 3-1. These values were then multiplied by the species RC% for a project-specific entrainment estimate. Species-specific estimates of those size intervals that could physically pass through the trashracks at the Project were summed for an overall species estimate in a given month. Monthly estimates were summed to produce seasonal estimates (Winter = December, January, February; Spring = March, April, May; Summer = June, July, August; Fall = September, October, November), and seasonal estimates were summed for an annual estimate. Entrainment estimates were derived in this fashion for the POR.

Blade strike survival results were used to estimate immediate mortality during passage through the Project's turbines. This included multiplying the average blade strike survival rate of a given size interval by each species entrainment estimate for that size interval. Survival estimates of those size intervals per species that could physically pass through the trashracks were summed for an overall species estimate in a given month. Monthly estimates were summed to produce seasonal estimates, and seasonal estimates were summed for an annual estimate.

Results and Discussion

4.1 Description of Factors Affecting Entrainment, Impingement and Survival

Table 4-1 provides a description of factors known to increase the risk of entrainment and turbine survival, and their representation at the Project. The applicant will restore the former intake into the main headrace tunnel that is located below Main Street. The intake structure is located on the left bank of the Mississippi River a short distance upstream of Northern States Power's St. Anthony Falls Hydroelectric Project. This suggests that littoral zone species, such as sunfish, may be more susceptible to entrainment than open water species, and sunfish species composition and abundance is also high in the Project area. There are no obligatory migrants or diadromous fish species in this portion of the Mississippi River that could be susceptible to entrainment. Several species may exhibit long-distance movements during spawning seasons, but these are restricted to freshwaters (potadromy) and are generally in the upstream direction. As presented in this section and documented during entrainment studies at projects in EPRI 1997a database, fish less than 8 in long typically constitute the majority of entrainment. As discussed below, on average, these size groups have an immediate survival rate of 95% through the Project's Kaplan turbines.

Table 4-1. Factors influencing fish entrainment and survival.

Factor		Influence on Entrainment/Turbine Survival[1]	Representation at the Project
Entrainment	Intake adjacent to shoreline	Near shore intakes may potentially entrain higher numbers of fish than offshore intakes due to tendency of fish to follow shorelines or orient to physical structures in shorelines.	Yes
	Intake location in littoral zone	The littoral zone (generally from the shoreline to extent of aquatic vegetation or approximately 10 ft deep) is the most productive region of a reservoir and is where most species spawn and rear their young.	Yes
	Abundant littoral zone fishes	Centrarchids and other reservoir species such as catfish that spend most of their lives in near shore habitats tend to be the most abundant species in an assemblage.	Yes
	Abundant clupeids	Entrainment rates may potentially be higher at projects where clupeids such as gizzard shad, threadfin shad, and alewife are relatively abundant.	No
	Obligatory migrants	Obligatory migrants are those species that must migrate within and between freshwater systems to fulfill certain life cycles. Depending on time of year, turbine flow can represent the majority of river flow cues while migrating downstream.	No
	Intake depth (ft at full pond)	Fish are usually more abundant in shallower portions of a reservoir year-round.	16
	Winter drawdown	Drawdowns may put fish in proximity to intakes.	No
	Normal hydraulic capacity (cfs)	Values used with respect to entrainment rate.	200
	Avg approach velocity (ft/s)	Approach velocities may correlate with intake rates, although siting may be more important. Velocities greater than fish burst swim speeds suggest potential inability to escape entrainment or impingement.	1.0
	Water quality	Poor water quality (e.g., stratification and low dissolved oxygen in the hypolimnion) may reduce fish susceptibility to entrainment	No
	Additional downstream passage routes	Sluiceways, spillways, or other bypass structures may reduce turbine entrainment by providing an alternate route of downstream passage.	Yes

Table 4-1. Factors influencing fish entrainment and survival.

Factor		Influence on Entrainment/Turbine Survival[1]	Representation at the Project
Survival	Turbine type	The size of water passage spaces relative to fish size may increase the probability of contact with structural elements. Francis runners have more closely spaced bucket/blades than Kaplan/propeller-type units.	Vertical Kaplan
	High speed (rpm)	Higher turbine speeds potentially increase the likelihood of fish contact with structural elements.	Yes
	Avg survival rates of small fish (<8 in)	More than 90% of fishes entrained at hydro projects are small. High survival rates reduce the overall impact to fish populations.	91%
	Pressurized intake tunnel	High hydrostatic pressure in a penstock at high head sites may be suddenly released as fish acclimated to a higher pressure pass from pressurized areas of deep water to tailwaters at normal hydrostatic pressure. The sudden relief from high pressure increases the potential risk to fish of decompression trauma.	No

4.2 Intake Velocities, Trashrack Exclusion and Impingement

The mean intake approach velocity at the Project was calculated by dividing the total hydraulic capacity of the unit (200 cfs) by the total gross area of the trashrack (216 square feet). This resulted in a velocity of 1.0 feet per second (ft/s). Bluegill, one of the more abundantly collected species in the Project area have burst swim speeds ranging from 1.8 ft/s to 4.3 ft/s depending on life stage (Table 4-2). This suggests that larger bluegill would likely be able to avoid impingement and entrainment. Not all of the species identified in Table 3-1 have swim speed data available in the scientific literature researched for this study. Those available for important game, rough, and forage species are provided in Appendix B and Table 4-2. Although the majority of available burst swim speeds suggest avoidance capability, fish behavior in front of an intake structure can be variable and unpredictable (Odeh 1999; Bell 1981). Individuals may volitionally follow the intake flow through the trashracks, swim against the current and hold in the forebay, actively swim in front of the intake without being entrained or impinged, dart away from the intake, and/or inadvertently become entrained/impinged due to the inability to escape.

Proportional estimates of body width to total length (scaling factor) for all species in this study are provided in Table 4-3. This proportional measurement was used to determine the minimum length of each species excluded or impinged on the trashracks. Surrogates or groups/guilds of fish were used to represent certain target species if data were not available in Smith (1985). Maximum reported sizes for each species are also included in Table 4-3.

Based on this assessment, the largest sized target species that could physically pass through the trashracks at the Project is a 15-in northern pike. A fish this large would likely be capable of avoiding entrainment unless volitional movement occurred through the intake. Only those fish with sizes greater than the minimum reported size excluded are at risk of impingement. Entrainment data for those size groups larger than the maximum reported size or minimum length excluded by the trashracks (whichever is less) were omitted from entrainment estimates.

Table 4-2. Target species burst swim speeds.

Species	Life Stage	Total Length (TL) or Fork Length (FL) (in)	Burst Swim Speed (ft/s)
Bluegill[1]	Juvenile	2.01-2.13 (TL)	1.84
	Adult	3.94-5.91 (TL)	2.44
	Adult	6.02 (TL)	4.30
Blue Sucker[2]	Adult	26.20 (TL)	19.51
Common Carp	Juvenile	6.02 (TL)	2.76-4.59
Emerald Shiner[3]	Adult	2.5 (TL)	4.00
Hybrid Catfish[4]	Juvenile	6.30-9.06 (TL)	7.88
Largemouth Bass	Juvenile	3-5 (TL)	2.32-3.28
Longnose Sucker[2]	Juvenile/Adult	3.9-16.0 (TL)	4.0-8.0
Northern Pike	Adult	4.72-24.41 (FL)	1.24-3.12
Pumpkinseed[1]	Adult	5 (TL)	2.44
Robust Redhorse[2]	Larval/Fry	0.51-0.80 (TL)	0.46-0.76
Smallmouth Bass	Fry	0.55-0.98 (TL)	<1.78
	Juvenile	3.58-3.66 (TL)	2.6-3.6
	Adult	10.3-14.9 (TL)	3.2-7.8
Spotfin Shiner[3]	Adult	2.95-3.31 (TL)	2.11-2.37
Striped Bass[5]	Fry	0.5-1.0 (TL)	0.4-1.0
	Juvenile	2.0-5.0 (TL)	1.0-5.0
Walleye[6]	Juvenile	3.15 (FL)	2.48
	Juvenile	6.30 (FL)	6.02
	Adult	13.78-22.44 (FL)	5.48-8.57
White Crappie[7]	Juvenile	3.03 (TL)	0.36-1.04
White Sucker[2]	Adult	7-15 (TL)	4.96

[1] Used to represent sunfish; [2] used to represent suckers; [3] used to represent all cyprinid species and brook silverside; [4] used to represent catfish; [5] used to represent white bass; [6] used to represent sauger; [7] used to represent crappie

Table 4-3. Estimated minimum lengths of each species excluded or impinged on the Project's trashracks (1.25-in clear spacing).

Species	Scaling Factor for Body Width[1]	Maximum Reported Size (in)[2]	Minimum Size Excluded (in)
Bigmouth Buffalo[3]	0.139	40	9
Black Crappie	0.099	21	13
Blackside Darter	0.110	4	NE
Bluegill	0.132	12	10
Brook Silverside	0.076	5	NE
Channel Catfish	0.156	40	8
Common Carp	0.162	40	8
Emerald Shiner	0.108	5	NE
Flathead Catfish[4]	0.172	60	7
Freshwater Drum	0.109	37	11
Gizzard Shad	0.105	20	12
Golden Redhorse	0.127	26	10
Green Sunfish	0.154	10	8
Hybrid Sunfish[5]	0.154	10	8
Largemouth Bass	0.134	26	9
Logperch	0.104	7	NE
Mimic Shiner	0.101	3	NE
Northern Pike	0.077	48	16
Orangespotted Sunfish[6]	0.132	4	NE
Pumpkinseed	0.124	10	NE
Quillback	0.139	26	9
River Carpsucker[3]	0.139	25	9
Rock Bass	0.156	15	8
Sauger	0.125	24	10
Shorthead Redhorse	0.130	25	10
Silver Redhorse	0.127	30	10
Smallmouth Bass	0.128	24	10
Spotfin Shiner	0.110	5	NE
Trout-Perch	0.135	5	NE
Walleye	0.125	36	10

Table 4-3. Estimated minimum lengths of each species excluded or impinged on the Project's trashracks (1.25-in clear spacing).

Species	Scaling Factor for Body Width[1]	Maximum Reported Size (in)[2]	Minimum Size Excluded (in)
White Bass	0.102	21	12
White Crappie	0.085	18	15
White Sucker	0.146	25	9
Yellow Bullhead	0.172	18	7

[1] Scaling factor expresses body width as a proportion of total length (TL) based on proportional measurements for the target/surrogate species in Smith (1985); [2] maximum reported sizes from MDNR (2014) and ODNR (2012); [3] bigmouth buffalo and river carpsucker are not represented in Smith (1985); used scaling factor of quillback; [4] flathead catfish is not represented in Smith (1985); used average scaling factor of channel catfish and white catfish; [5] used scaling factor of green sunfish to represent hybrid sunfish; [6] orangespotted sunfish is not represented in Smith (1985); used scaling factor of bluespotted sunfish; * NE = not excluded; all size classes could physically pass through trashracks based on maximum reported sizes

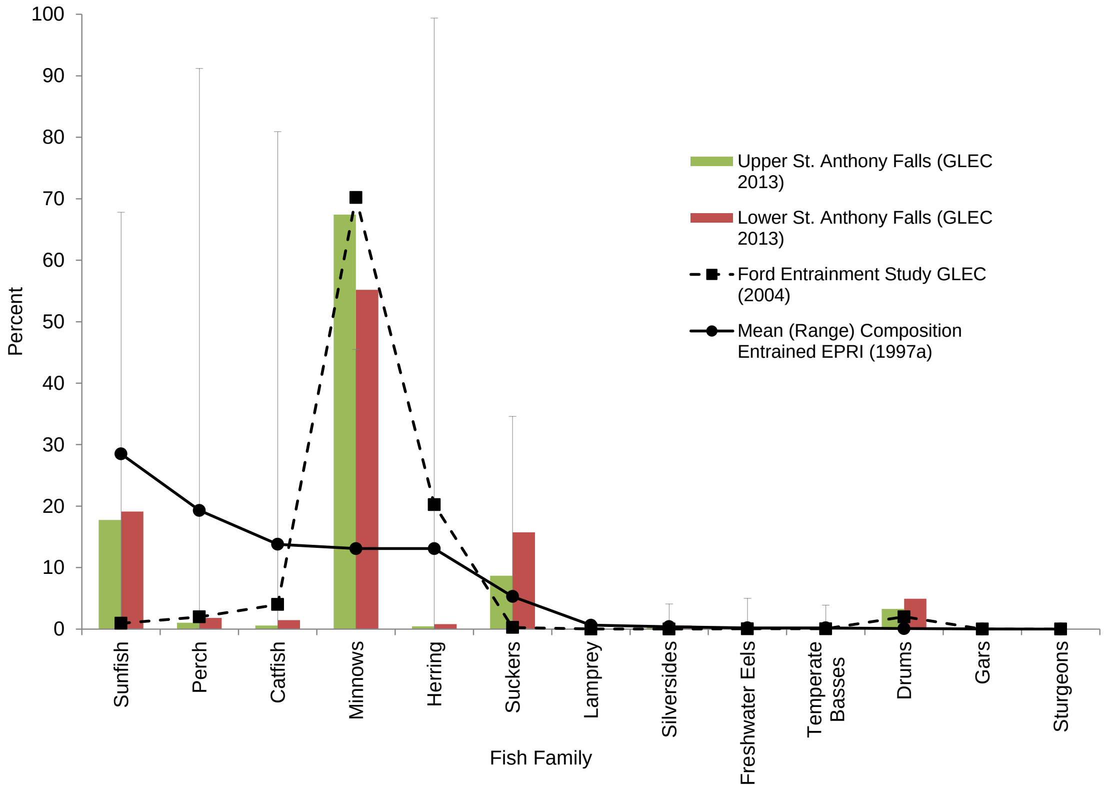
4.3 Entrainment Estimation

4.3.1 Empirical Entrainment Rate Data and Fish Composition

Average monthly entrainment rates derived from the EPRI (1997a) database for each species are provided in Appendix F. Shaded cells represent those size intervals that cannot physically pass through the Project's trashracks, and are therefore not included in the entrainment estimation. Except for gizzard shad, entrainment rates for all species generally increase in the summer and fall months, likely due to increased activity related to foraging, spring reproduction, and subsequent dispersal (GeoSyntec 2005; EPRI 1997a; Jenkins and Burkhead 1993). Fall and winter months showed the highest entrainment rates due primarily to the number of gizzard shad entrained.

Fish measuring less than 4 in long constituted the majority of fish entrainment compositions in the EPRI (1997a) database. Sunfish were the majority of species entrained at 42 of the 43 developments included in the database, representing on average 30% of the netted species compositions (Figure 4-1). Sunfish are also common in the Project area, and along with the minnow family, comprise the majority of the fish community (Figure 4-1). Estimated entrainment family compositional data at the Twin Cities (a/k/a Ford) Hydroelectric Project (GLEC 2004) are also included in Figure 4-1. Findings suggest gizzard shad and cyprinids will dominate entrainment compositions, with sunfish and catfish also making up a large majority.

Figure 4-1. Fish family composition from collections in the Upper and Lower St. Anthony Falls pools (GLEC 2013), those estimated during a desktop entrainment study at Ford Hydroelectric Project (GLEC 2004), and EPRI (1997a) data (mean and range).



4.3.2 A-Mill Generation and Entrainment Estimates

Analysis of the 73-year hydrology dataset and Project operations resulted in monthly generation amounts (1,000 cfs-hrs) for the POR (1940-2013), including the driest (1977) and wettest (2013) water years on record (Table 4-4). The total, annual generation estimated at the Project for an average water year (POR) was 1,489 (1,000 cfs-hrs). This equates to 5,361 million cubic feet (mcf) of water (Appendix E). The same amount was estimated for the dry and wet water years; therefore, it can be assumed that consistent operation of the Project, regardless of water year, will create similar entrainment potential.

Monthly generation amounts were multiplied by monthly entrainment rates for each target species and size interval, and the species' associated RC% in Table 4-1, resulting in project-specific monthly estimates of entrainment. For example, in October (for the POR) the entrainment estimate for 2.1-in to 4-in gizzard shad was calculated by the following equation:

227.28 (fish/hr/1,000 cfs) × 126 (1,000 cfs-hrs) × 0.0065 (RC%) = 200 fish (rounded to the nearest hundred)

This was performed for all size intervals of each species, in each month for the POR hydrology. Entrainment estimates up to the maximum size reported of a given species, or for only those size intervals that cannot physically pass through the trashracks (whichever is less) were summed for a species monthly entrainment estimate. This was done for each species, and then all species estimates were summed for an overall monthly entrainment estimate (Figure 4-2).

The annual average number of fish that may become entrained at the Project is estimated at approximately 2,500 (Table 4-5). The majority of the entrainment estimates are small fish less than 6-in (Figure 4-3). Gizzard shad and emerald shiner represent the majority of entrained species, and overall entrainment numbers (except for gizzard shad) generally increase from spring to fall, which is suggestive of increased activity and presence/dispersal of juveniles.

Table 4-4. Estimated Project generation flow (1,000 cfs-hrs) based on the POR hydrology.

Month	Monthly Generation (1,000 cfs-hrs)	Seasonal Generation (1,000 cfs-hrs)
December	126	
January	126	367
February	114	
March	126	
April	122	375
May	126	
June	122	
July	126	375
August	126	
September	122	
October	126	371
November	122	
Annual	1,489	

Figure 4-2. Combined monthly entrainment estimates for all species and associated generation.

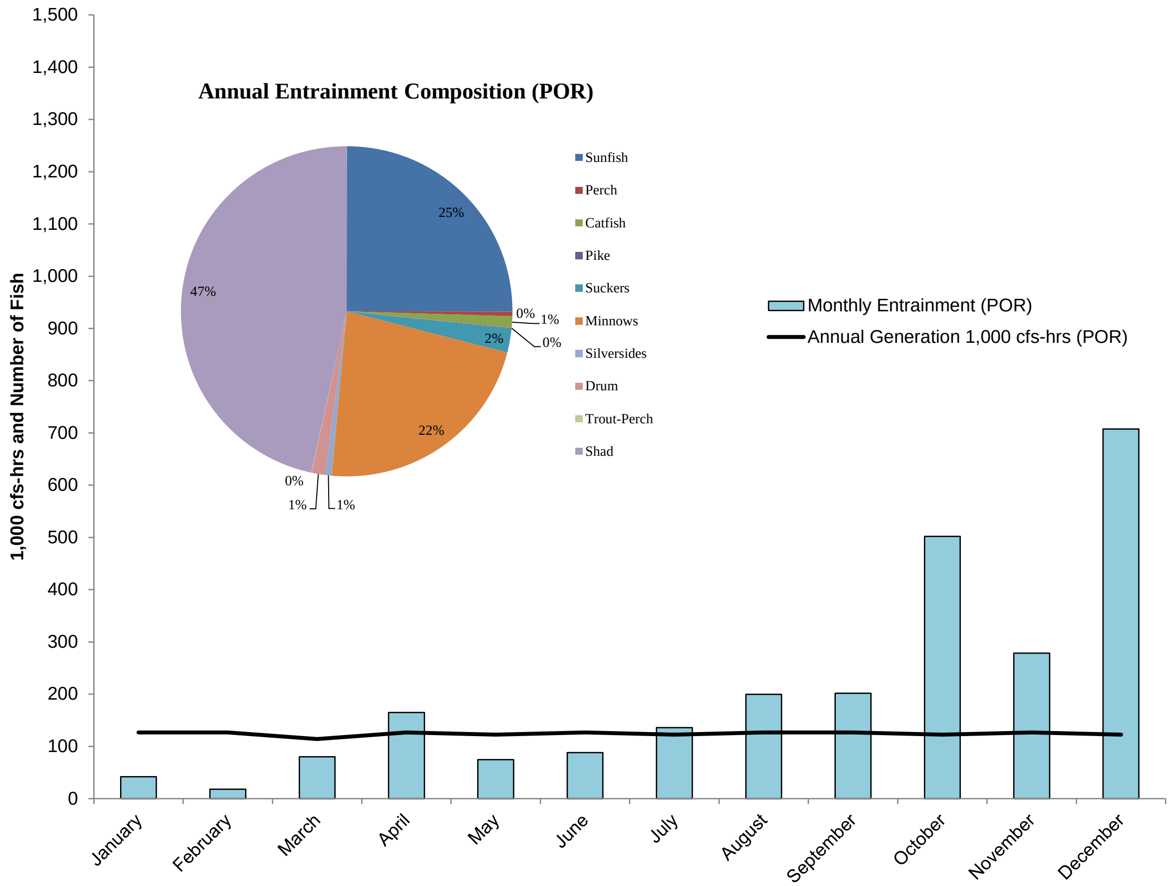
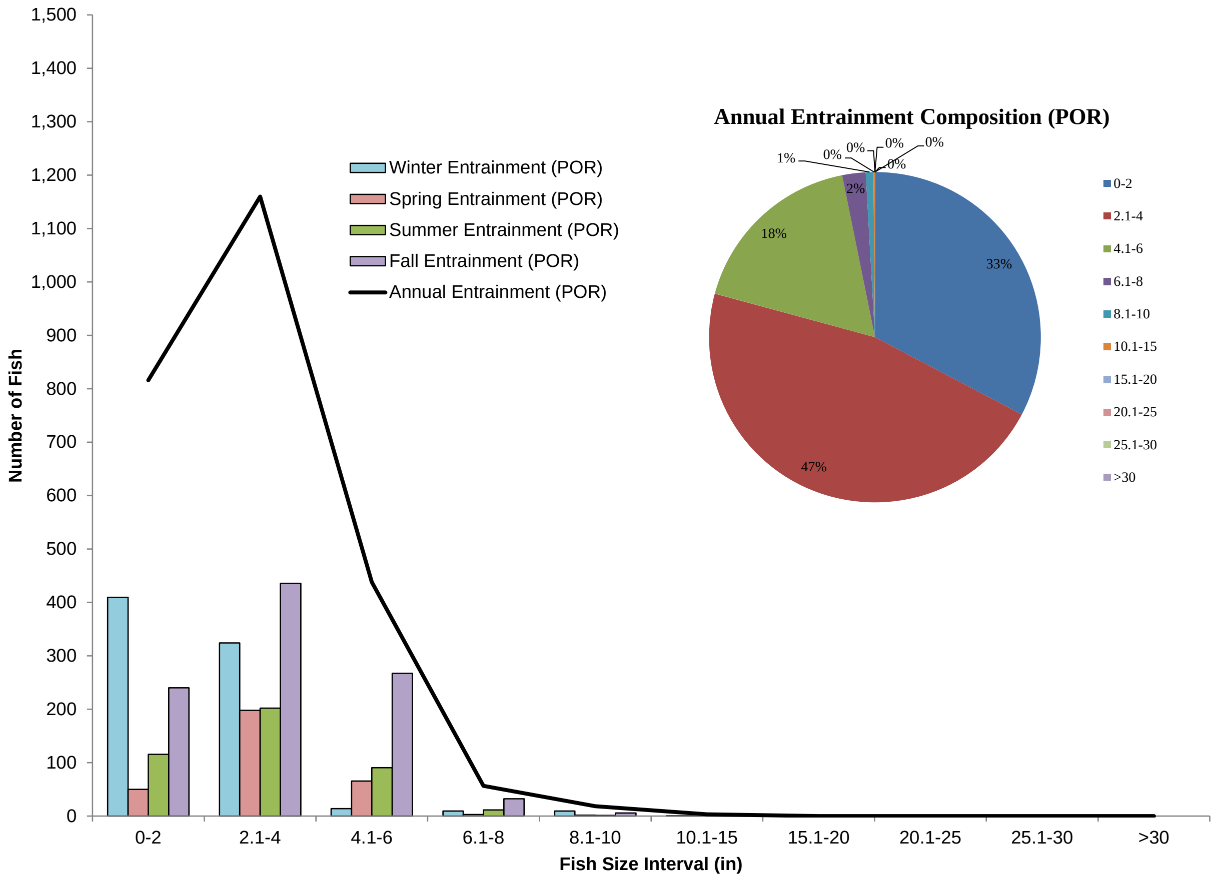


Table 4-5. Seasonal and annual entrainment estimates based on the POR (1940-2013).

Species	Winter	Spring	Summer	Fall	Annual
Gizzard Shad	705	15	50	486	1,256
Emerald Shiner	44	176	179	250	648
Bluegill	2	97	80	171	350
Green Sunfish	1	12	15	23	50
Channel Catfish	1	1	39	4	45
Smallmouth Bass	1	1	17	10	29
Quillback	9	6	2	4	20
Freshwater Drum	0	1	12	6	19
Black Crappie	1	1	4	3	9
Brook Silverside	0	0	0	8	9
Flathead Catfish	0	0	7	1	8
White Sucker	1	0	1	4	6
Walleye	0	0	4	0	5
Rock Bass	0	1	0	1	2
Shorthead Redhorse	0	0	2	1	2
Common Carp	0	0	1	0	2
Mimic Shiner	0	0	1	0	2
Bigmouth Buffalo	1	0	0	0	2
Largemouth Bass	0	0	1	0	1
Orangespotted Sunfish	0	0	0	0	1
Hybrid Sunfish	0	0	0	0	1
Pumpkinseed	0	0	0	0	1
Golden Redhorse	0	0	0	0	0
River Carpsucker	0	0	0	0	0
Yellow Bullhead	0	0	0	0	0
White Bass	0	0	0	0	0
Troutperch	0	0	0	0	0
Blackside Darter	0	0	0	0	0
Silver Redhorse	0	0	0	0	0
Logperch	0	0	0	0	0
Sauger	0	0	0	0	0
White Crappie	0	0	0	0	0
Northern Pike	0	0	0	0	0
Spotfin Shiner	0	0	0	0	0

Figure 4-3. Seasonal and annual entrainment estimates for the 10 size intervals of all species combined.



4.4 Turbine Survival Estimation

Survival of target species through the Project's turbines is expected to be high based on this analysis and the size groups of fish expected to become entrained. The majority of entrained fish are expected to be less than 6 in, and fish in this size class show relatively high immediate survival rates through the units (Figure 4-4). A total of 90 blade strike probability/survival rates were calculated for the Project (Appendix G). The maximum length used (15 in) represents the largest sized fish of the target species (northern pike) that could physically pass through the 1.25-in trashrack bar spacing.

As discussed, physical exclusion of certain size classes of target species will occur due to the 1.25-in trashrack bar spacing. An average blade strike survival rate was determined for each of the 10 size intervals analyzed in the entrainment assessment. For example, the estimated average survival rate of the 2.1- to 4-in length group of gizzard shad is 95%. This was calculated by averaging the individual blade strike survival rates for the 2- and 3-in fish length groups, correlation factors, and points of entry. It has been suggested that fish turbine mortality is more related to fish size than the type of species (Franke et al. 1997; Winchell et al. 2000); therefore, the survival rates determined for each length group was deemed transferable across species (e.g., a 4-in gizzard shad has the same survival rate as a 4-in smallmouth bass).

Analysis of several projects with Kaplan-type turbines from the EPRI (1997a) turbine passage survival database and several other empirical sources cited in Normandeau (2012) showed similar high survival (Appendix H). Fish sizes investigated ranged from 3 to 15 in. Figure 4-5 displays the immediate survival rates for these trials compared with fish length. Mean blade strike survival rates for fish from 3 to 15 in at the Project are also included. Figure 4-6 provides both datasets compared to associated project specifications. Blade strike survival estimates are comparable with empirically derived survival estimates determined at those projects with similar specifications as the Project.

Average blade strike survival rates for each size interval per species were multiplied by the species' associated monthly entrainment estimates to determine immediate turbine mortality estimates. For example, in October (for the POR) the mortality estimate for 2.1-in to 4-in gizzard shad was calculated by the following equation:

188 fish × 0.053 (average blade strike mortality rate of 2-in to 4-in fish) = 10 fish (rounded to the nearest ten)

This was performed for all size intervals of each species, in each month, and for the POR hydrology. Mortality estimates up to the maximum size reported of a given species, or for only those size intervals that cannot physically pass through the trashracks (whichever is less) were summed for a species monthly survival estimate. This was done for each species, and then all species estimates were summed for an overall monthly survival estimate (Figure 4-7).

The annual average number of fish that may experience immediate turbine-related mortality at the Project is estimated at approximately 130 (Table 4-6), which equates to an average annual survival rate of 95%. This rate is expected to be the same, regardless of water year. The majority of the mortalities are small fish less than 6 in. Entrainment mortalities will likely be the highest from fall to winter due primarily to gizzard shad entrainment (Figure 4-8).

Figure 4-4. Mean (range) immediate turbine survival rates derived from blade strike model runs for 7 of the 10 size intervals analyzed in EPRI (1997a,b), expected to become entrained at the Project.

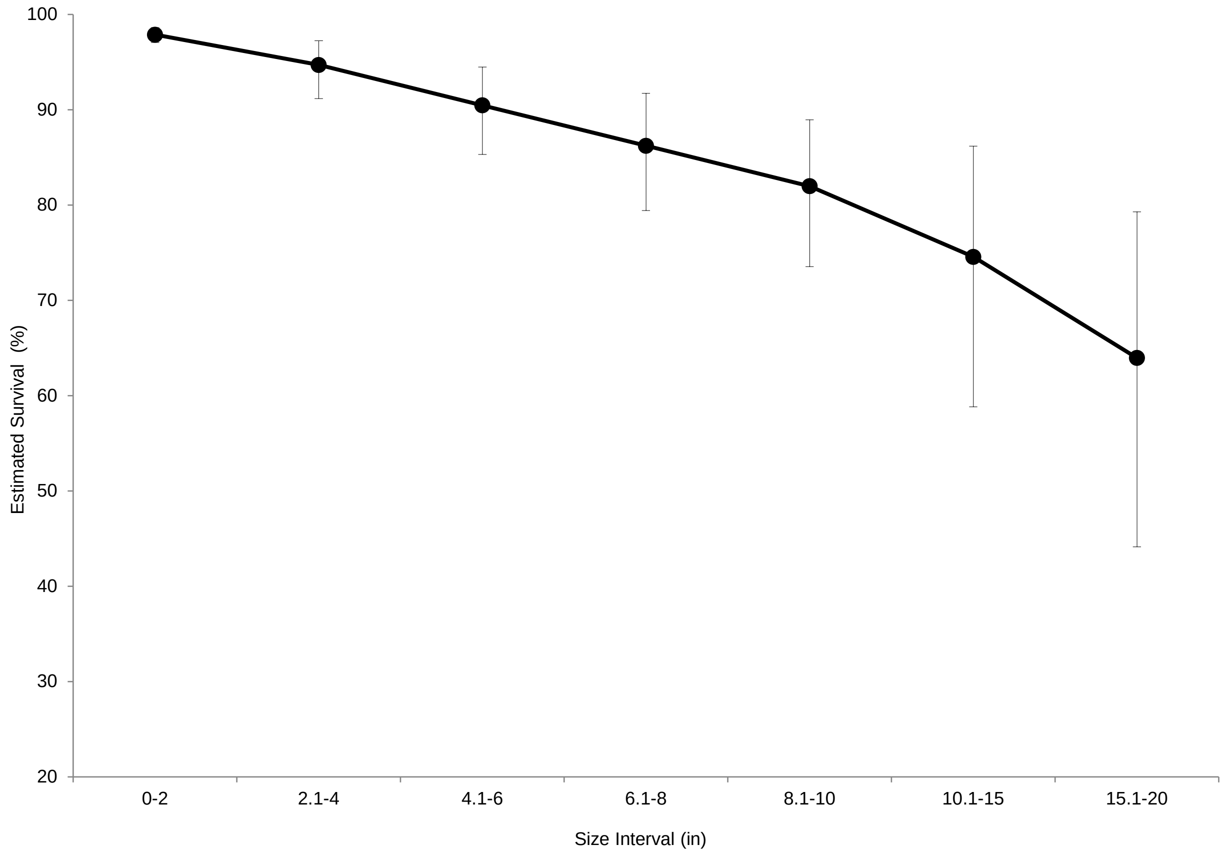
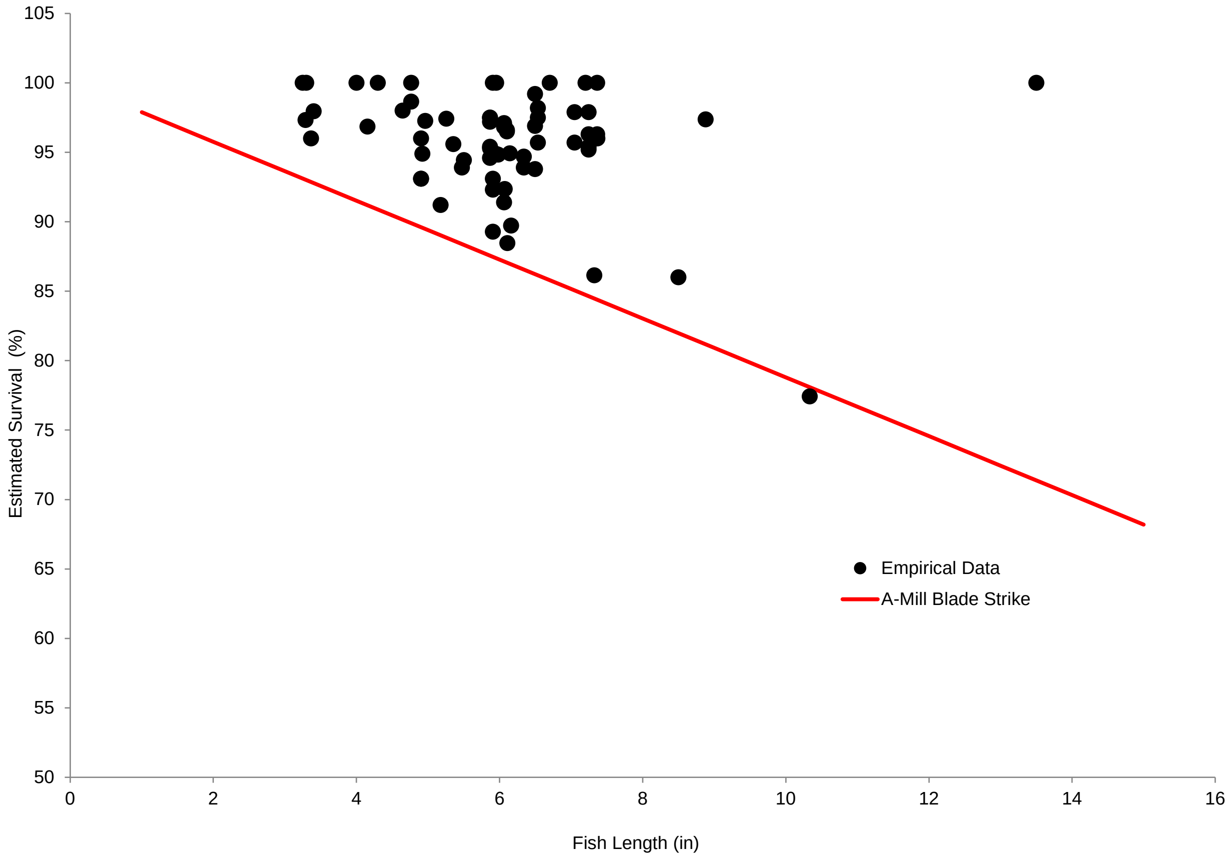
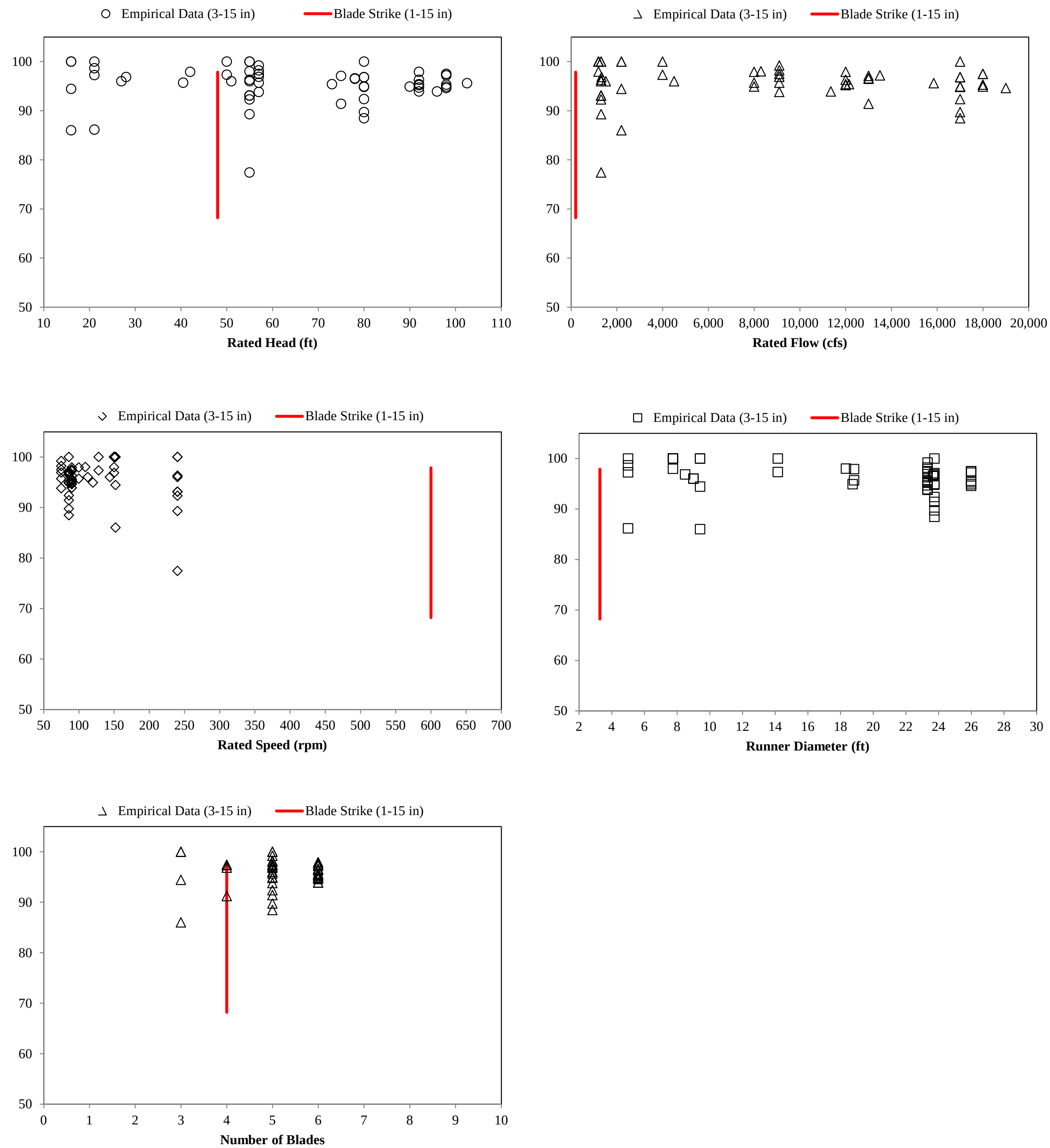


Figure 4-5. Immediate Kaplan turbine survival rates derived from empirical balloon tag studies from various soucres[1] and mean blade strike survival at the Project; fish sizes range from 3 to 15 in for the empirical data and 1 to 15 in for the blade strike.



[1] EPRI (1997a) and several sources cited in Normandeau (2012)

Figure 4-6. Immediate Kaplan turbine survival rates derived from empirical balloon tag studies from various soucres[1] and blade strike survival range at the Project compared with associated Project specifications; fish sizes range from 3 to 15 in for the empirical data and 1 to 15 in for the blade strike.



[1] EPRI (1997a) and several sources cited in Normandeau (2012)

Figure 4-7. Combined monthly mortality estimates for all species and associated generation.

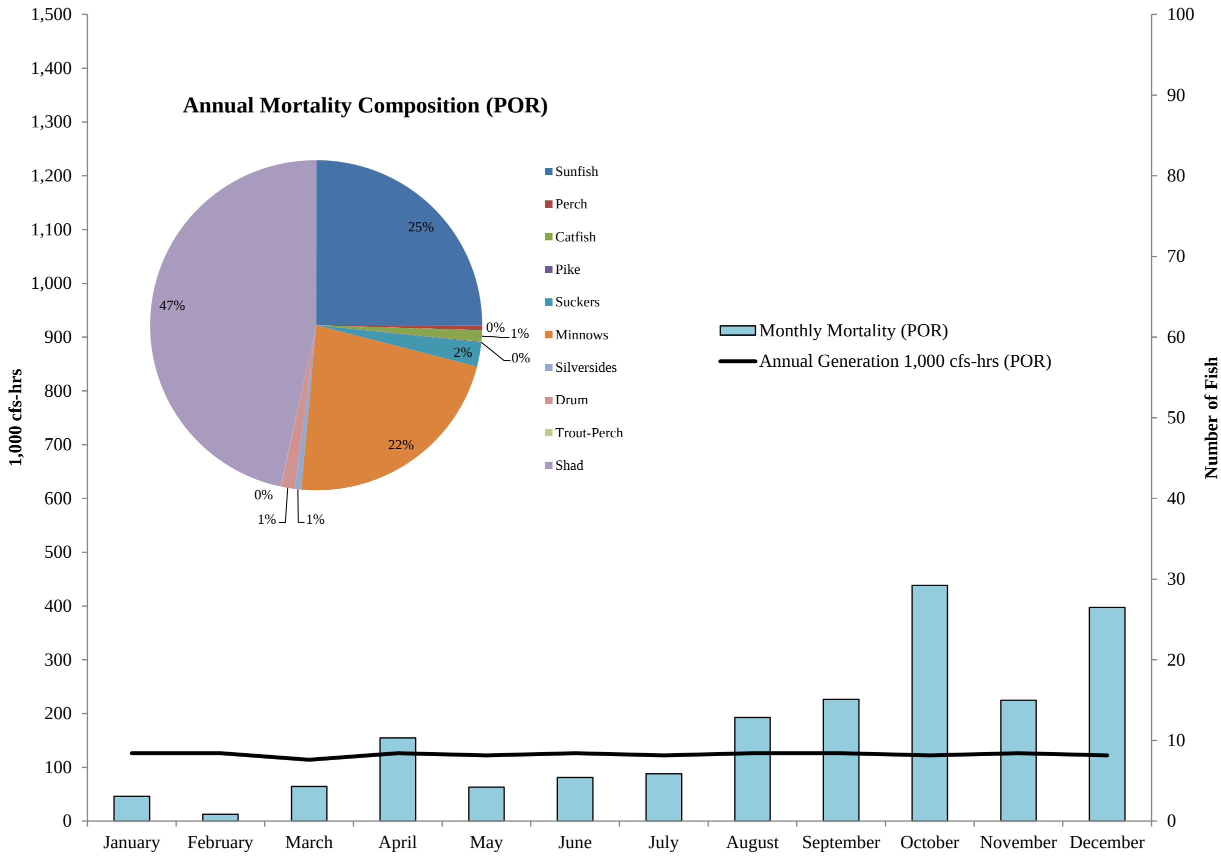
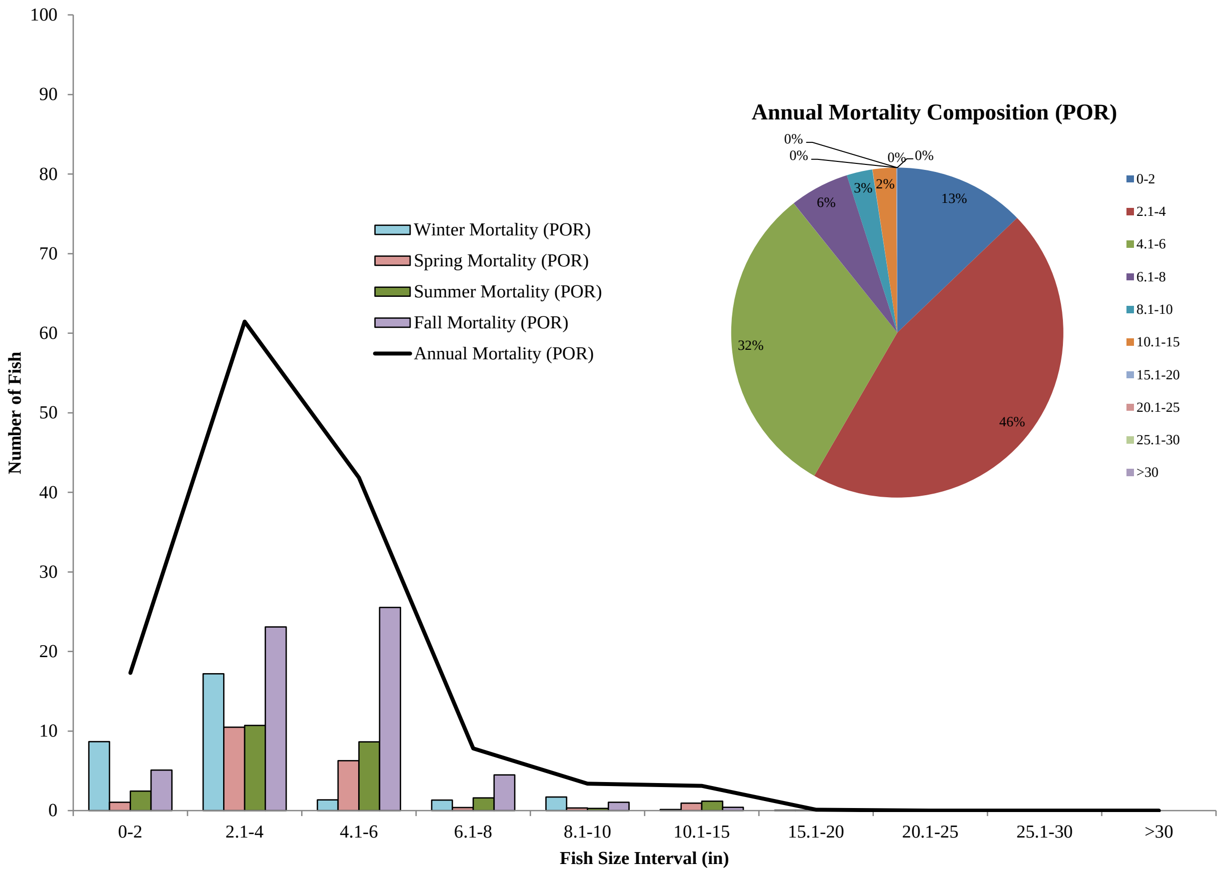


Table 4-6. Seasonal and annual mortality estimates based on the POR (1940-2013).

Species	Winter	Spring	Summer	Fall	Annual
Gizzard Shad	27	1	5	29	62
Emerald Shiner	2	8	9	10	29
Bluegill	0	7	5	14	26
Green Sunfish	0	1	1	2	4
Quillback	1	1	0	0	2
Smallmouth Bass	0	0	1	1	2
Channel Catfish	0	0	1	0	1
Freshwater Drum	0	0	1	0	1
Brook Silverside	0	0	0	1	1
White Sucker	0	0	0	0	1
Black Crappie	0	0	0	0	1
Common Carp	0	0	0	0	0
Flathead Catfish	0	0	0	0	0
Rock Bass	0	0	0	0	0
Walleye	0	0	0	0	0
Bigmouth Buffalo	0	0	0	0	0
Shorthead Redhorse	0	0	0	0	0
Orangespotted Sunfish	0	0	0	0	0
Mimic Shiner	0	0	0	0	0
Largemouth Bass	0	0	0	0	0
Hybrid Sunfish	0	0	0	0	0
Pumpkinseed	0	0	0	0	0
Golden Redhorse	0	0	0	0	0
River Carpsucker	0	0	0	0	0
White Bass	0	0	0	0	0
Troutperch	0	0	0	0	0
Yellow Bullhead	0	0	0	0	0
Blackside Darter	0	0	0	0	0
Silver Redhorse	0	0	0	0	0
Sauger	0	0	0	0	0
Logperch	0	0	0	0	0
White Crappie	0	0	0	0	0
Spotfin Shiner	0	0	0	0	0
Northern Pike	0	0	0	0	0

Figure 4-8. Seasonal and annual mortality estimates for the 10 size intervals of all species combined.



4.5 Conclusion

The proportion of Mississippi River flow to be used for generation at the Project is minor compared to that passing through other power-generating facilities or spillways at the Upper St. Anthony Falls Project. This fact, coupled with the 1.25-in trashracks and low intake velocity, suggests that most juvenile and adult fish will be excluded from entrainment. Only those smaller juveniles incapable of avoidance may become entrained, but small fish have relatively high turbine survival rates. Based on this desktop analysis, the annual average number of fish expected to become entrained at the Project is approximately 2,500. This estimate is based on species lists and relative composition data from the Project area, empirically derived entrainment rates, 73-year USGS hydrology, and the Project's hydraulic capacity and operational specifications. Turbine mortality estimates were derived using size-specific blade strike model survival rates, multiplied by the entrainment estimates for each size interval. The survival rates obtained using the blade strike model compare relatively well with empirically derived survival study findings at several projects with similar specifications. The annual average number of fish to experience immediate turbine-related mortality at the Project is approximately 130 (95% survival rate).

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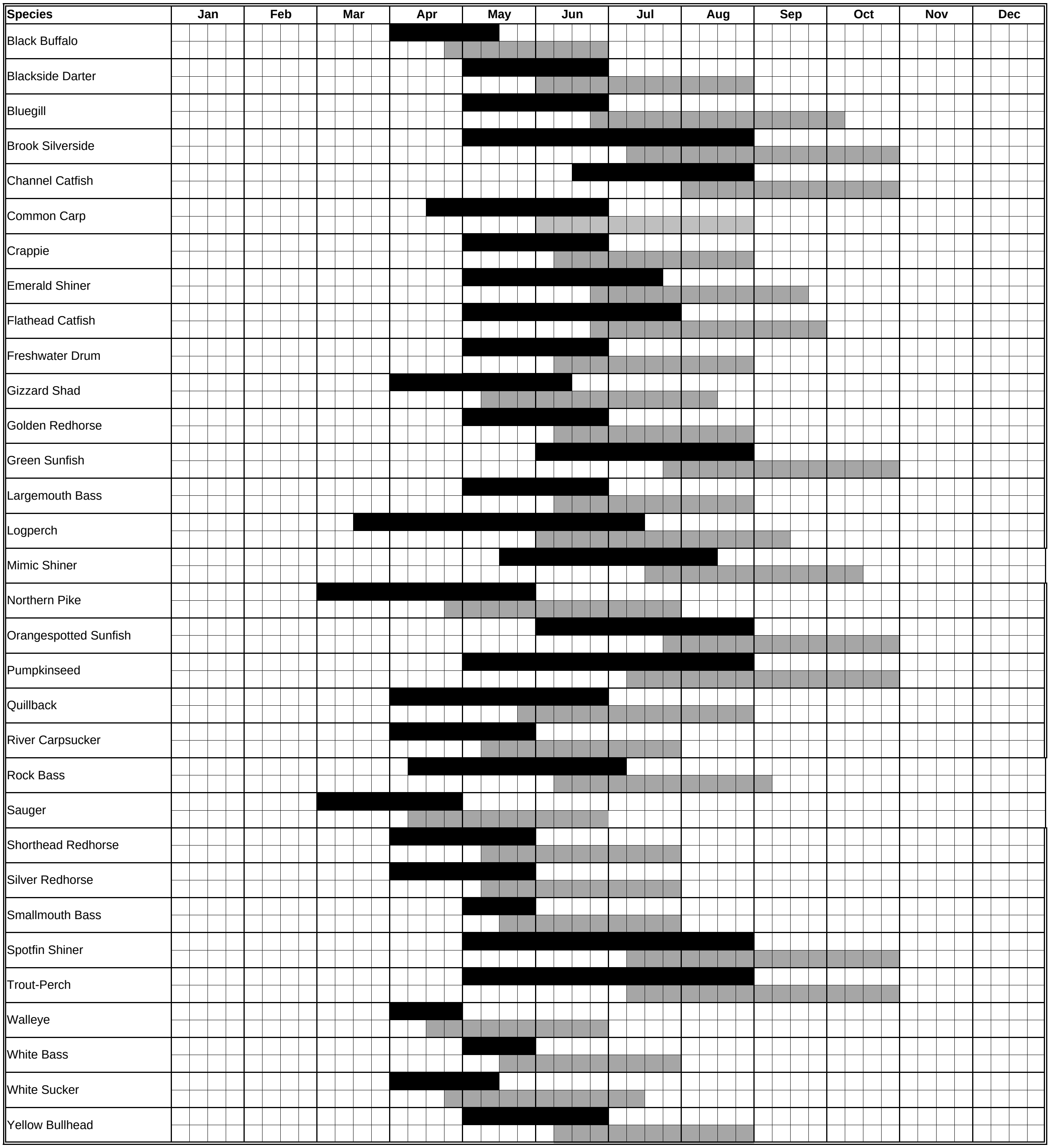
Appendix A. Fish Species Collected in the Project Area (GLEC 2013)

Common Name	Scientific Name	Upper St. Anthony Falls[a]		Lower St. Anthony Falls[a]		Combined	
		N	RC (%)	N	RC (%)	N	RC (%)
Atherinidae	**Silversides**						
Brook silverside	*Labidesthes sicculus*	10	0.37	21	0.59	31	0.49
Catostomidae	**Suckers**						
Quillback	*Carpriodes cyprinus*	123	4.54	300	8.41	423	6.74
River Carpsucker	*Carpiodes carpio*	2	0.07	5	0.14	7	0.11
Bigmouth buffalo	*Ictiobus cyprinellus*	20	0.74	20	0.56	40	0.64
Silver redhorse	*Moxostoma anisurum*	10	0.37	7	0.20	17	0.27
Golden redhorse	*Moxostoma erythrurum*	1	0.04	9	0.25	10	0.16
Shorthead redhorse	*Moxostoma macrolepidotum*	76	2.81	213	5.97	289	4.61
White sucker	*Catostmous commersoni*	3	0.11	7	0.20	10	0.16
Centrarchidae	**Sunfish**						
Rock Bass	*Ambloplites rupestris*	3	0.11	2	0.06	5	0.08
Black crappie	*Pomoxis nigromaculatus*	18	0.66	10	0.28	28	0.45
Bluegill	*Lepomis macrochirus*	204	7.54	323	9.06	527	8.40
Pumpkinseed	*Lepomis gibbosus*	1	0.04	4	0.11	5	0.08
Green sunfish	*Lepomis cyanellus*	84	3.10	69	1.93	153	2.44
Orangespotted sunfish	*Lepomis humilis*	2	0.07	1	0.03	3	0.05
Largemouth bass	*Microterus salmoides*	6	0.22	6	0.17	12	0.19
Smallmouth bass	*Micropterus dolomieu*	161	5.95	265	7.43	426	6.79
White crappie	*Pomoxis annularis*	0	0.00	2	0.06	2	0.03
Hybrid sunfish	*Lepomis* hybrid	2	0.07	0	0.00	2	0.03
Clupeidae	**Herring**						
Gizzard Shad	*Dorosoma cepedianum*	12	0.44	29	0.81	41	0.65
Cyprinidae	**Carps and Minnows**						
Common carp	*Cyprinus carpio*	170	6.28	184	5.16	354	5.64
Emerald shiner	*Notropis atherinoides*	1,634	60.36	1,751	49.09	3,385	53.95
Mimic shiner	*Notropis volucellus*	19	0.70	21	0.59	40	0.64
Spotfin shiner	*Cyprinella spiloptera*	2	0.07	13	0.36	15	0.24
Esocidae	**Pikes**						
Northern pike	*Esox lucius*	6	0.22	9	0.25	15	0.24
Ictaluridae	**North American Catfishes**						
Channel catfish	*Ictalurus punctatus*	13	0.48	43	1.21	56	0.89
Flathead catfish	*Pylodictus olivaris*	2	0.07	8	0.22	10	0.16
Yellow bullhead	*Ameiurus notatus*	1	0.04	1	0.03	2	0.03
Moronidae	**Temprate Bass**						
White Bass	*Morone chrysops*	5	0.18	2	0.06	7	0.11
Percidae	**Perch**						
Logperch	*Percina caprodes*	1	0.04	1	0.03	2	0.03
Sauger	*Sander canadensis*	1	0.04	0	0.00	1	0.02
Walleye	*Sander vitreus*	25	0.92	64	1.79	89	1.42
Blackside darter	*Percina maculata*	1	0.04	0	0.00	1	0.02
Percopsidae	**Trout-perch**						
Trout-perch	*Percopsis omiscomaycus*	0	0.00	1	0.03	1	0.02
Sciaenidae	**Drum**						
Freshwater Drum	*Aplodinotus grunniens*	89	3.29	176	4.93	265	4.22
Total		**2,707**	**100**	**3,567**	**100**	**6,274**	**100**

Appendix B. Swim Speed Data

Species	Life Stage	TL/FL (in)	Swim Speed (ft/s)			Tested Temperature (C)	Time (min)	References
			Maximum Sustained	Prolonged (P) or Critical (C)	Burst (B) or Startle (S)			
Bluegill	Juvenile	0.98-1.57	0.3-0.75			>15.5		Schuler (1968)
	Juvenile	1.54-1.73	0.48-0.52			26.1-29.4		King (1969)
	Juvenile	2.01-2.13		0.92		21		Beamish (1978)
	Adult	3.94-5.91		1.22 (C)			10	Gardner et al. (2006)
	Adult	6.02			4.3		0.15	Webb (1978)
	Adult	7.99	1.0					Deng et al. (2004)
	Adult		0.98					Drucker and Lauder (1999)
Blue Sucker	Adult	26.20		4.36	19.51			Brett 1964 cited in The University of Iowa 2010; Brainbridge 1961 cited in The University of Iowa 2011
Common Carp	Juvenile	6.02			2.76-4.59		15	Tsukamoto et al. (1975)
Emerald Shiner	Adult	2.5		2.00	4.00			Bell (1991)
Hybrid Catfish (Female Channel Catfish x Male Blue Catfish	Juvenile	6.30-9.06	1.31	3.94		19-22		Beecham et al. (2009)
Largemouth Bass	Fry	0.79-0.87		0.78-1.02 (P)		10-30		Larimore and Deuver (1968) cited in Beamish (1978)
	Juvenile	2.05-2.52	0.5	1.63 (C)		30, 15-35		Hocutt (1973)
	Juvenile	2.05-2.52		8.08L/sec		30		Hocutt (1973) - relative swim speed
	Juvenile	2.05-2.52		1.64 (C)		25		Farlinger and Beamish (1977) cited in Beamish (1978)
	Juvenile	2.24		1.01 (P)		20		Larimore and Deuver (1968) cited in Beamish (1978)
	Juvenile	2.95-3.35	1.21-1.34					Dahlberg et al. (1968) cited in Carlander (1977)
	Juvenile	3.66-5.04		1.60 (C)		15-19	2	Kolok (1991)
	Juvenile	3.66-5.04		0.92 (C)		5	2	Kolok (1991)
	Juvenile	3.94		1.15 (C)		10		Otto and Rice (1974) cited in Beamish (1978)
	Juvenile	4.02		1.50 (C)		25		Farlinger and Beamish (1977) cited in Beamish (1978)
	Juvenile	5.91	0.79			10		Beamish (1970) cited in Carlander (1977)
	Juvenile	5.91	1.57			30		Beamish (1970) cited in Carlander (1977)
	Juvenile	5.91-10.63		1.80-2.17 (P)		10-30		Beamish (1970) cited in Beamish (1978)
	Juvenile	9.84	1.51			10		Beamish (1970) cited in Carlander (1977)
	Juvenile	9.84	2.07			30		Beamish (1970) cited in Carlander (1977)
Longnose Sucker	Juvenile/Adult	3.9-16.0			4.0-8.0			Bell (1991)
Northern Pike	Adult	4.72-24.41 (FL)		0.62-1.56				Jones et al. (1974)
Pumpkinseed	Adult	5.00 (TL)		1.22		20		Brett and Sutherland (1965)
Smallmouth Bass	Fry	0.55		13-19 L/sec				Larimore and Deuver (1968)
	Fry	0.55		0.60-0.87				Larimore and Deuver (1968)
	Fry	0.79-0.98		<0.89				Larimore and Deuver (1968) cited in Carlander (1977) and Houde (1963)
	Juvenile	3.58-3.66		1.3-1.8 (C)		13-23	2	Webb (1998)
	Adult	10.3-14.9		1.6-3.9 (C)		15-20	10	Bunt et al. (1999)
Spotfin Shiner	Adult	2.95-3.31		8.60 L/sec		30		Hocutt (1973) - relative swim speed
Striped Bass	Fry	0.5-1.0			0.4-1.0			Bell (1991)
	Juvenile	2.0-5.0			1.0-5.0			
Walleye	Fry	0.47	0.16			18.3		Houde (1963)
	Fry	0.78	0.25			13.0		Houde (1963)
	Juvenile	3.15 (FL)		1.24 (C)		18.0-20.0	10	Jones et al. (1974)
	Juvenile	6.3 (FL)			6.02 (S)			Peake et al. (2000)
	Adult	13.78 (FL)			7.20 (S)			Peake et al. (2000)
	Adult	14.96 (FL)		2.74 (C)				Peake et al. (2000)
	Adult	22.44 (FL)			8.57 (S)			Peake et al. (2000)
White Crappie	Juvenile	2.17-3.94 (FL)	0.50-0.75			21.1-28.3		Schuler (1968)
	Juvenile	2.95-3.19 (FL)	0.54-0.61			24.4-26.1		King (1969)
	Juvenile	3.03	-	0.52 (C)		25	60	Smiley and Parsons (1997)
	Juvenile	3.03	-	0.18 (C)		5	60	Smiley and Parsons (1997)
White Sucker	Adult	6.69-14.57 (FL)		2.48		12-19		Hunter and Mayor (1986)

Appendix C. Spawning and Early Life Stage Periodicity



Spawning Period

Eggs and Larvae (estimated to begin two-thirds of the way through the spawning period and lasting 60 days post spawn)

Sources: MDNR 2014; ODNR 2013

Appendix D. Forty-Three Hydroelectric Projects Used in the Entrainment Assessment (EPRI 1997a)

Site Name	State	River	Reservoir		Total Plant Capacity (cfs)	Hydraulic Capacity of Sampled Units (cfs)	No. Units	Operating Mode	Avg. Velocity at Trash Rack (ft/sec)	Trash Rack Clear Spacing (in)
			Area (ac)	Volume (ac-ft)						
Belding	MI	Flat	-	-	416	416	2	-	-	2
Bond Falls	MI	W.B. Ontonagon	-	-	900	450	2	PK	-	3
Brule	WI	Brule	545	8,880	1,377	916	3	PK-partial	1	1.62
Buzzard's Roost	SC	Saluda	11,404	270,000	3,930	1,310	3	-	-	3.63
Caldron Falls	WI	Peshtigo	1,180	-	1,300	650	2	PK	-	2
Centralia	WI	Wisconsin	250	-	3,640	550	6	ROR	2.3	3.5
Colton	NY	Raquette	195	620	1,503	450	3	PK	-	2
Crowley	WI	N.F. Flambeau	422	3,539	2,400	1,200	2	ROR	1.4	2.38
E. J. West	NY	Sacandaga	25,940	792,000	5,400	5,400	2	-	-	4.5
Feeder Dam	NY	Hudson	-	-	5,000	2,000	5	PK	-	2.75
Four Mile Dam	MI	Thunder Bay	1,112	2,500	1,500	500	3	ROR	-	2
Gaston Shoals	SC	Broad	300	2,500	2,211	837	3	-	-	1.5
Grand Rapids	MI/WI	Menominee	250	-	3,870	2,216	5	ROR	-	1.75
Herrings	NY	Black	140	-	3,610	1,203	3	ROR	-	4.13
High Falls - Beaver River	NY	Beaver	145	1,058	900	300	3	-	0.7	1.81
Higley	NY	Raquette	742	4,446	2,045	2,045	3	PK	-	3.63
Hillman Dam	MI	Thunder Bay	988	1,600	270	270	1	ROR	-	3.25
Hollidays Bridge*	SC	Saluda	466	6,000	4,396	370	4	-	-	-
Johnsonville	NY	Hoosic	450	6,430	1,288	1,288	2	PK	-	2
Kleber	MI	Black	270	3,000	400	400	2	ROR	1.41	3
Lake Algonquin	NY	Sacandaga	-	-	750	750	1	-	-	1
Luray	VA	S.F. Shenandoah	-	-	1,477	369	3	ROR	-	2.75
Minetto	NY	Oswego	350	4,730	7,500	4,500	5	PULSE	2.4	2.5
Moshier	NY	Beaver	365	7,339	660	660	2	PK	-	1.5
Ninety-Nine Islands	SC	Broad	433	2,300	4,800	584	6	-	-	1.5
Ninth Street Dam	MI	Thunder Bay	9,884	2,600	1,650	550	3	ROR	-	1
Norway Point Dam	MI	Thunder Bay	10,502	3,800	1,775	575	2	ROR	-	1.69
Potato Rapids	WI	Peshtigo	288	-	1,380	500	3	ROR	-	1.75
Raymondville	NY	Raquette	50	264	1,640	1,640	1	PK	-	2.25
Richard B. Russell	GA/SC	Savannah	31,770	1,297,513	60,000	7,200	8	PK	-	8
Saluda	SC	Saluda	556	7,228	812	227	4	-	-	
Sandstone Rapids	WI	Peshtigo	150	-	1,300	650	2	PK	-	1.75
Schaghticoke	NY	Hoosic	164	1,150	1,640	1,640	4	ROR	-	2.13
Shawano	WI	Wolf	155	1,090	850	850	1	ROR	-	5
Sherman Island	NY	Hudson	305	6,960	6,600	4,950	4	PK	-	3.13
Thornapple	WI	Flambeau	295	1,000	1,400	700	2	ROR-mod	1.22	1.69
Tower	MI	Black	102	620	404	404	2	ROR	0.82	1
Townsend Dam	PA	Beaver	-	-	4,400	4,400	2	ROR	-	5.5
Twin Branch	IA	St. Joseph	1,065	-	3,200	1,200	-	ROR	-	3
Warrensburg	NY	Schroon	-	-	1,350	1,350	1	-	-	-
White Rapids	MI/WI	Menominee	435	5,155	3,994	3,994	3	PK-partial	1.9	2.5
Wisconsin River Division	WI	Wisconsin	240	1,120	5150	5,150	10	ROR	1.4	2.19
Youghiogheny	PA	Youghiogheny	2,840	149,300	1,600	1,600	2	ROR	0.7	10

Appendix E. Flow Routing and Generation Amounts

Period of Record (1940-2013)												
Month	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Additional Spill (cfs)	*4,388*	*4,266*	*5,464*	*16,649*	*13,604*	*10,965*	*7,900*	*5,322*	*4,819*	*5,484*	*6,012*	*4,672*
Minimum Spill/Bypass flow (cfs)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Turbine Flow (cfs)	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*
# Turbines	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
Median Flow (cfs)	*4,588*	*4,466*	*5,664*	*16,849*	*13,804*	*11,165*	*8,100*	*5,522*	*5,019*	*5,684*	*6,212*	*4,872*
Exceedance Volume at Maximum Operating flow	200	200	200	200	200	200	200	200	200	200	200	200
Exceedance Volume at Minimum Operating flow	30	30	30	30	30	30	30	30	30	30	30	30
Total Exceedance Volume	170	170	170	170	170	170	170	170	170	170	170	170
Percent of Possible Volume	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*
Million Cubic Feet	455	411	455	441	455	441	455	455	441	455	441	455
1,000 cfs hours	126	114	126	122	126	122	126	126	122	126	122	126
Dry Year: 1977												
Month	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Additional Spill (cfs)	*1,069*	*1,287*	*4,368*	*4,368*	*2,612*	*2,997*	*2,703*	*1,495*	*5,540*	*957*	*1,221*	*1,059*
Minimum Spill/Bypass flow (cfs)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Turbine Flow (cfs)	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*
# Turbines	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
Median Flow (cfs)	*1,269*	*1,487*	*4,568*	*4,568*	*2,812*	*3,197*	*2,903*	*1,695*	*5,740*	*1,157*	*1,421*	*1,259*
Exceedance Volume at Maximum Operating flow	200	200	200	200	200	200	200	200	200	200	200	200
Exceedance Volume at Minimum Operating flow	30	30	30	30	30	30	30	30	30	30	30	30
Total Exceedance Volume	170	170	170	170	170	170	170	170	170	170	170	170
Percent of Possible Volume	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*
Million Cubic Feet	455	411	455	441	455	441	455	455	441	455	441	455
1,000 cfs hours	126	114	126	122	126	122	126	126	122	126	122	126
Wet Year: 2013												
Month	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Additional Spill (cfs)	*3,160*	*2,886*	*3,251*	*15,837*	*26,292*	*22,079*	*14,010*	*3,698*	*3,073*	*2,175*	*2,845*	*3,738*
Minimum Spill/Bypass flow (cfs)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Turbine Flow (cfs)	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*	*200*
# Turbines	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
Median Flow (cfs)	*3,360*	*3,086*	*3,451*	*16,037*	*26,492*	*22,279*	*14,210*	*3,898*	*3,273*	*2,375*	*3,045*	*3,938*
Exceedance Volume at Maximum Operating flow	200	200	200	200	200	200	200	200	200	200	200	200
Exceedance Volume at Minimum Operating flow	30	30	30	30	30	30	30	30	30	30	30	30
Total Exceedance Volume	170	170	170	170	170	170	170	170	170	170	170	170
Percent of Possible Volume	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*	*85.0%*
Million Cubic Feet	455	411	455	441	455	441	455	455	441	455	441	455
1,000 cfs hours	126	114	126	122	126	122	126	126	122	126	122	126

Appendix F. Monthly Average Entrainment Rates (EPRI 1997a)

Appendix G. Blade Strike Results

Appendix H. Empirical Survival Results at 21 Projects and 85 Field Trials with Kaplan Turbines