ESTIMATION OF SURVIVAL OF ADULT AMERICAN SHAD PASSED THROUGH FRANCIS AND KAPLAN TURBINES

RSP 3.2

CONOWINGO HYDROELECTRIC PROJECT

FERC PROJECT NUMBER 405

Prepared for:

Exelon

Prepared by:

Normandeau Associates, Inc.

Gomez and Sullivan Engineers, P.C.

August 2012

EXECUTIVE SUMMARY

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt Conowingo Hydroelectric Project (Conowingo Project). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. FERC issued the final study plan determination for the Project on February 4, 2010, approving the revised study plan with certain modifications. FERC's study plan determination did not contain any requirements to conduct field-based entrainment and mortality studies at the Conowingo Project. On February 24, 2010, Maryland's Department of Natural Resources (MDNR) and Department of the Environment (MDE) filed a notice to initiate the formal study dispute resolution process.

On September 30, 2010, Exelon and MDNR/MDE reached an agreement regarding the February 24, 2010 study dispute notice for the Conowingo Project. Conditions of the agreement, in part, stipulated that MDNR and MDE would formally withdraw their February 24, 2010 notice, and Exelon would conduct a field-based validation study for American shad (*Alosa sapidissima*) to supplement its literature-based turbine passage survival estimates related to Conowingo RSP 3.2-Downstream Fish Passage Effectiveness Assessment. The study was to provide entrainment survival rates for juvenile American shad through a Francis unit and for adult American shad through a Francis unit and a Kaplan unit. The specific methodologies were presented in a revised study plan, developed in consultation with stakeholders.

In 2011, Exelon completed the field study to assess the injury/survival rate of juvenile American shad passing through a Francis unit turbine at the Conowingo Project. A report detailing the results of this study was submitted on January 23, 2012. In 2012, Exelon completed the field study to assess the injury/survival rate of adult American shad passing through a Francis and Kaplan unit turbine at the Conowingo Project which is the subject of this report. The objectives of the study were to estimate 1 h and 48 h post passage survival; precision (ε) of ±10%, 90% of the time, of adult shad passing these units during typical operating conditions when they are most susceptible to entrainment. Additionally, determine injury rate, type, cause, and severity.

The survival probabilities (1 and 48 h) and injury rates for adult American shad were obtained using the HI-Z Turb'N Tag (HI-Z Tag) recapture technique May 8 through 16, 2012. The adult American shad ranged in size from 330 to 590 mm (total length) with an average size approximately 450 mm. The turbine passage survival was estimated at Francis Unit 2 and Kaplan Unit 8 using 100 and 101 treatment fish

respectively, and 120 control fish were released downstream of the turbine discharge from the Fisherman's Wharf.

Recapture rates (physical retrieval of live and dead shad) were 99.0, 92.1 and 100% for Francis Unit 2, Kaplan Unit 8, and control fish, respectively. Mean recapture times of Unit 2, Unit 8, and control fish were 5.3, 7.5, and 5.2 minutes after release, respectively. The combination of high recapture rates (92-100%) and relatively high control survival (100% at 1 h and 87.6% at 48 h) provided a statistically valid survival estimate for adult American shad passing through Francis Unit 2 and Kaplan Unit 8 at the Conowingo Project.

Survival estimates differed between turbine types. The Unit 2 1 h survival was estimated at 93.0% with 90% confidence intervals (CI) of ≤±4.2%; this estimate was within the pre-specified precision (ε) of ±10%, 90% of the time (α = 0.10). The 48 h survival was 88.3% with a 90% CI of ≤±10.5%, just outside the desired precision.

The Unit 8 1 h survival was estimated at 86.3% with 90% CI of ≤±5.8%, and the 48 h estimate was 84.1% with a 90% CI of ≤±9.9%; both estimates were within the desired precision (ε) of ±10%, 90% of the time.

Malady-free rate (free of visible injuries and loss of equilibrium, and<20% scale loss per side) of recaptured adult American shad passed through Unit 2 and Unit 8 was 76.2 and 75.4%, respectively; precision (ε) was within the desired ±10%, 90% of the time. The primary injury types observed on recaptured Unit 2 fish (12.1%) and Unit 8 fish (8.6%) were damage to the gills and operculum. The incidence of severance or decapitation was higher at Unit 8 (8.6%) than at Unit 2 (1.0%). Five of the 120 control fish displayed visible injuries; three of these fish had hemorrhaged eyes. Mechanical forces alone or in combination with shear forces appeared to be the principal cause of injuries at both units (75.0% of injured fish at Unit 2 and 66.7% of injured fish at Unit 8). The majority of the maladies at both units were classified as major (57.1% of injured fish at Unit 2 and 63.0% of injured fish at Unit 8) while most of the control maladies where classified as minor (71.5% of injured fish).

Little published data on passage survival of adult American shad through Francis units could be found for comparison. Mathematically generated survival estimates ranged from 79.8-90.4% and are on the low side for 1 h (93.0%) and 48 h (88.3%) empirical estimates obtained from the present study. However, based on the high recapture rate (99%) of the fish passed through the Francis turbine, the 88.3% survival rate appears to be a realistic value.

A few studies have been conducted on adult shad passing Kaplan type turbines with 1 h survival estimates of 75.8 to 89.7% and 48 h estimates of 84.3 and 88.2%. The 48 h estimate of 84.1% for Unit 8 fish is in line with that reported (84.3%) for a similar type unit at the Safe Harbor Station. Direct survival estimates (80.4, 83.8, 84.9, and 87.8%) on similar sized adult walleye (*Sander vitreus*) and rainbow trout (*Onchorhynchus mykiss*) passed through large Kaplan type units also are close to the 48 h survival rate for Unit 8. Mathematically generated survival estimates ranged from 82.1 to 94.5%. Based on collaboration of the 48 h survival rate with other studies on adult fish, 84.1% appears to be a realistic rate for the Kaplan turbines at Conowingo.

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LIST OF ABBREVIATIONS

C	Celsius, Centigrade
cfs	cubic feet per second
CI	confidence interval
Exelon	Exelon Generation Company, LLC
FERC	Federal Energy Regulatory Commission
ft	foot/feet
gal	gallon
h	hour
in	inch
km	kilometer
lb	pound
LOE	loss of equilibrium
mm	millimeter
MDE	Maryland Department of Environment
MDNR	Maryland Department of Natural Resources
Mhz	megahertz
MW	megawatt
ppt	parts per thousand
rpm	revolutions per minute
SRAFRC	Susquehanna River Anadromous Fish Restoration Commission
WFL	Conowingo West Fish Lift

1.0 INTRODUCTION

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt Conowingo Hydroelectric Project (Conowingo Project). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. FERC issued the final study plan determination for the Project on February 4, 2010, approving the revised study plan with certain modifications. FERC's study plan determination did not contain any requirements to conduct field-based entrainment and mortality studies at the Conowingo Project. On February 24, 2010, Maryland's Department of Natural Resources (MDNR) and Department of the Environment (MDE) filed a notice to initiate the formal study dispute resolution process.

On September 30, 2010, Exelon and MDNR/MDE reached an agreement regarding the February 24, 2010 study dispute notice. The agreement stipulated, in part, that MDNR and MDE would formally withdraw their notice and that Exelon would conduct a field-based validation study for American shad (*Alosa sapidissima*) to supplement its literature-based turbine passage survival estimates related to Conowingo RSP 3.2-Downstream Fish Passage Effectiveness Assessment. The study was to provide entrainment survival rates for juvenile American shad through a Francis unit and for adult American shad through a Francis unit and a Kaplan unit. The specific methodologies were developed in a revised study plan, developed in consultation with stakeholders.

In 2011, Exelon completed the field study to assess the injury/survival rate of juvenile American shad passing through aerated Francis Unit 2 turbine at the Conowingo Project. This report was submitted to FERC on January 23, 2012. An earlier study provided survival estimates of juvenile American shad passed through Kaplan Unit 8 at Conowingo Project (RMC 1994a).

1.1 Objectives

In 2012, Exelon completed the field study to assess the injury/survival rate of adult American shad passing through a Francis and Kaplan unit turbine at the Conowingo Project. The results of this 2012 study are the subject of this report. The specific objectives of this study were to: (1) estimate survival (1 h and 48 h post passage) of adult American shad passing through a Francis and Kaplan unit at the Conowingo Project while operating at a typical discharge when adult shad are most susceptible to entrainment at the Conowingo Station; (2) determine survival estimates with a precision (ε) of ±10%, 90% of the time; and (3) determine injury rate, type, cause, and severity

1.2 Project Description

The Conowingo Dam is a large hydroelectric dam on the Lower Susquehanna River (Figure 1.1-1). Built in 1928, Conowingo Dam is a medium-height, masonry gravity-type dam. The dam is located in Maryland, spanning the Cecil and Harford county border, 9.9 miles (16 km) from the river mouth at the Chesapeake Bay, about 5 miles (8 km) south of the Pennsylvania border, and 45 miles (72 km) northeast of Baltimore. The powerhouse has a generating capacity of 573 megawatt (MW) and a hydraulic capacity of 86,000 cubic feet per second (cfs) provided by seven vertical Francis turbines (Units 1-7) and four Kaplan turbines (Units 8-11) (Table 1.1-1 and Appendix A). The Francis units have hydraulic capabilities ranging from 6,320 to 6,749 cfs. The hydraulic capabilities of the Kaplan units range from 9,352 to 9,727 cfs. The design head is 89 and 86 ft for the Francis and Kaplan units, respectively.

2.0 STUDY DESIGN

This field-based study used the HI-Z Turb'N Tag (HI-Z tag) recapture technique (Heisey *et al.*, 1992), to provide survival and injury estimates of adult American shad passed through a Francis turbine (Unit 2) and a Kaplan turbine (Unit 8) at the Conowingo Project. .

2.1 Turbine Description

There are two types of Francis turbines at the Conowingo Project in addition to two smaller Francis turbines (known as the house units) that service the Conowingo powerhouse (Table 1.1-1 and Figure 2.1-1). The Conowingo turbine fish assessment did not include testing of survival through the house units due to their small contribution to total station discharge. Additionally, the small trash bar opening (1.5 inch) on these units would deter adult American shad from being entrained. The trash bar spacing for all the other units is 5.4 inches.

Five of the seven Francis turbines (Units 1, 3, 4, 6, and 7) are equipped with conventional air venting systems. Units 2 and 5 are equipped with aeration runners. Structurally, the seven Francis units are virtually identical except that the trailing edge of the aerated blades on Units 2 and 5 is thicker. Structural features that may affect fish survival include the number of blades or buckets, clearances between buckets or blades, runner diameter, runner rotational speed, gaps between blade and hub and blade tip and discharge ring, number and orientation of wicket gates and stay vanes, and shape and thickness of the leading edge of the blades, (Amaral *et al.*, 2008; Franke *et al.*, 1997; Normandeau Associates *et al.*, 2006, 2000; Dresser *et al.*, 2006). The number of runner blades or buckets, runner speed (rpm), and runner diameter are generally considered the most important features affecting survival of turbine-passed fish.

Francis Unit 2 (aerated) was selected as the turbine for testing rather than a non aerated unit to evaluate a potentially worst case scenario for adult American shad. Unit 2 has 13 blades (buckets), a runner diameter of 203 in, 24 wicket gates, rotation speed of 81.8 rpm, and blade tip speed of 72.5 ft/s (Table 1.1-1). Typical output is 36 MW at a discharge near 6,320 cfs at a rated head of 89 ft. Fish passage through Unit 2 was tested at near-peak efficiency, the settings the unit operates at most of the time when adult American shad would be moving past the Conowingo Project. During testing, Unit 2 outputs ranged from 29.9 to 32.3 MW, average discharge was 5,063 cfs, and operational head ranged from 84.7 to 89.2 ft (Table 1.1-1 and Appendix A).

There are four mixed-flow fixed bladed Kaplan turbines units 8-11 (Figure 2.1-1). These units have six blades, runner diameter of 225 in, rotate at 120 rpm, and have 24 wicket gates (Table 1.1-1). Under a design head of 86 ft, Unit 8 has a rated output of 9,352 cfs and units 9-11 have a rated output of 9,727 cfs.

During the shad passage tests, Unit 8 had an output of 57.2 to 57.6 MW, average discharge of 8,842 cfs and operational head ranged from 83.8 to 87.1 ft (Table 1.1-1 and Appendix A). The total station discharge during the study ranged from 72,700 to 81,100 cfs (Appendix A).

2.2 Sample Size

One of the main objectives prior to the implementation of this study was the statistical determination of the number of fish to be released to obtain an estimate of turbine passage survival of adult American shad within a precision (ε) level of ± 10%, 90% of the time (α=0.10). Appendix B-1 provides the equations used to calculate sample size and precision (ε) for this study. Since the sample size is a function of the recapture rate (P_A), expected passage survival (τ) or mortality (1- τ), survival of control fish (S), and the desired precision (ε) at a given probability of significance (α), we used a range of values for these parameters to calculate potential sample sizes for various combinations of these parameters. Initially, for the present study sample size calculations, the following range of values was assumed for these parameters: recapture probabilities (P_A) of 85 to 98%; control survival: 95 to 100%; and turbine passage survival ($\hat{\tau}$) of 90 to 97% (Table 2.2-1).

Required sample sizes are shown in Table 2.2-1 for various combinations of values of the above parameters. Based on several studies on adult fish passing turbines (e.g., Heisey *et al*. 2008; Normandeau Associates 2011 and 2012; and North/South Consultants and Normandeau Associates 2009) utilizing the HI-Z tag-recapture technique, we targeted for a release of 100 treatment fish (introduced through each test turbine) accompanied by a release of 100 control fish downstream of the powerhouse to obtain a precision (ε) of ±0.10 on survival estimate at α = 0.10. This sample size was based on the potential of 95% control survival, recapture rate of 90%, and expected passage survival rates of close to 90% for the study. Because of the embedded flexibility in the HI-Z tag-recapture technique, the sample size requirements can be adjusted downwards or upwards to achieve the desired statistical precision level if the initial assumptions deviated significantly during the course of the study. In general, sample size requirements decrease with an increase in control fish survival and recapture rates (Mathur *et al*.1996a). Only precision (ε) and α level can be controlled by the investigator. A total of 100 Unit 2, 101 Unit 8 and 120 control fish were released on May 8-16, 2012 to obtain the survival estimates (Table 2.2-2).

2.3 Source of Test Fish

Approximately 350 adult American shad for this study were collected from the Conowingo West Fish Lift (WFL) and transported to tanks on the Conowingo head works and Fisherman's Wharf on May 6, 10, 11, 14, and 15, 2012. Water temperatures ranged from 17.6° C to 22.0° C (Table 2.2-2) during the study period coinciding with migration of adult American shad in the Lower Susquehanna River. Control fish were placed in 950 gal holding tanks located below the Dam at the Fisherman's Wharf, and treatment fish were placed in two 750 gal tanks located on the head works near Units 2 and 8. These circular tanks (Figure 2.3-1) were continuously supplied with ambient river water. A 50 lb block of salt was initially added to the tanks when fish were stocked and each day before fish were removed for tagging. The block of salt raised salinity in the tanks to near 5 ppt, which was gradually diluted by the ambient river water. The addition of salt to the holding pools reduced osmotic and ionic imbalances in the fish due to handling stress and minimized adverse effects of handling as clupeids are known to be extremely sensitive to handling stress (Heisey *et al*., 1992; Meinz 1978).

2.4 Fish Tagging and Release

Fish tagging, release, and recapture techniques were similar to those used to assess effects of turbine passage of adult American shad at the Safe Harbor Project (Heisey *et. al* 2008). Fish were removed from the holding pools with a rubber coated mesh dip net. (Figure 2.4-1) In order to bring the adult shad to the surface for rapid recapture, four HI-Z balloon tags were attached with a small cable tie passed through the musculature with a curved cannula needle (Figure 2.4-2). Tags were attached anterior of the dorsal and pelvic fins. A radio tag was attached in combination with one set of HI-Z tags to aid in tracking released fish. A specially designed fish restraint device aided in holding the fish while tags were attached (Figure 2.4-2). Treatment and control fish were identified by clipping the right and left fin, respectively. The radio tags were approximately 6 x 12 mm, weighing 0.5 g in air and propagated radio signals through a 27 cm thin wire antenna. The un-inflated HI-Z Tags were made of bright-colored latex 40 mm long and 15 mm wide and weighing 3.0 g. Just prior to release into the induction system (Figure 2.4-3), the HI-Z tags were activated by injecting 1-1.5 ml of catalyst (Figure 2.4-2).

Tagged fish were introduced individually into the penstock of Francis Unit 2 and Kaplan Unit 8 (treatment) by an induction apparatus (Figure 2.4-3). The induction apparatus consisted of a holding basin attached to an 8-inch discharge hose. A 3 or 4 inch trash pump supplied river water to ensure that fish were transported quickly within a continuous flow of water to the release point. The release hose was secured to the downstream side of the intake trash rack with the terminus positioned near elevation 47 ft that released fish approximately 10 ft below the elevation of the intake ceiling of Units 2 and 8 (Figures 2.4-4 and 2.4-5).

Procedures for handling, tagging, release and recapture of control fish were similar to those used for treatment fish. The control fish were released directly into the tailrace from the Fisherman's Wharf (Figure 2.4-1).

A total of 100 Unit 2, 101 Unit 8, and 120 control fish were released from May 8-16 (Table 2.2-2 and Appendix C-1). Fish showing erratic behavior or fresh external injuries and/or extensive fungal infections were rejected and not used. Because the study was conducted with shad in typical condition caught at the WFL, many fish had patchy scale loss and some had small areas of fungus around the snout and on the fins. Fish length measurements were estimated to the nearest 10 mm once placed in the restraining tube for tagging and measured again if a fish died during the 48 h delayed assessment period. Total length of Unit 2 fish ranged from 330 mm to 560 mm, with an average length of 451 mm (Figure 2.4-6). The Unit 8 fish total length ranged from 330 mm to 550 mm, with an average length of 456 mm (Figure 2.4-6). The control fish ranged in length from 320 mm to 590 mm, with an average length of 441 mm. Males were generally smaller (treatment fish ranged from 330-520 mm, average 431 mm; controls ranged from 320-540 mm, average 417 mm) than females (treatment ranged from 430- 560 mm, average 497 mm; controls ranged from 430–570 mm, average 502 mm) (Figure 2.4-7).

2.5 Recapture Methods

After release (treatment and control), the fish were tracked downstream of the Conowingo Project by two boat crews and then retrieved once buoyed to the surface by the inflated HI-Z tag. Boat crews were notified of the radio tag frequency (48 or 49 MHz) for each fish upon its release. Advanced Telemetry System receivers with a loop or a 5-element shore based Yagi antenna were utilized in tracking both treatment and control fish. Fish that failed to surface shortly after passage were monitored via radio signals for a minimum of 30 minutes.

Boat crews retrieved buoyed fish by a rubber net. Recaptured fish were placed into a 100-150 quart cooler where tags were removed. To the extent possible, fish were kept in water during recapture and examination. Each fish was immediately examined for maladies including visible injuries, scale loss >20% per side, and/or loss of equilibrium, and was assigned appropriate condition codes (Table 2.5-1 and 2.5-2). Tagging and data recording personnel were notified via a two-way radio system of each fish's recapture time and condition (Appendix D).

Recaptured fish were transported to shore and held in holding pools (900 gal) to monitor delayed (48 h) effects of tagging and turbine passage (Figure 2.4-1). The holding pools were continuously supplied with ambient river water. A 50 lb block of salt was placed in each of the delayed assessment pools daily to provide salinity near 5 ppt although the continuous flow gradually diluted the salt concentration (Heisey *et al*. 2008). Additionally, sufficient fine granular salt was also added to the fish holding coolers and transfers bucket to provide salinity near 5 ppt.

The pools were covered to prevent escapement and minimize external stressors. Mortalities in the holding pools were retrieved after 24 h and 48 h. Fish that were alive after 48 h and free of major injuries were released into the river.

2.6 Classification of Recaptured Fish

As in previous turbine passage investigations (Heisey *et al.*, 1992; Mathur *et al.*, 1994, 1996a, 1996b), the immediate post passage status of each recaptured fish and recovery of inflated tags dislodged from fish were designated as alive, dead, or unknown. The following criteria have been established to make these designations: (1) alive—recaptured alive and remaining so for 1 h; (2) alive—fish does not surface but radio signals indicate movement patterns; (3) dead—recaptured dead or dead within 1 h of release; (4) dead—only inflated dislodged tag(s) are recovered, or telemetric tracking or the manner in which inflated tags surfaced is not indicative of a live fish; and (5) unknown—no fish or dislodged tag is recaptured, and radio signals are received only briefly or not at all, and the subsequent status cannot be ascertained. Fish that moved into areas where they could not be recaptured (i.e., at rip rap along the shore, in submerged crevices, or in areas of high turbulence) and fish of unknown status were excluded from the statistical analysis. Mortalities of recaptured fish occurring after 1 h were assigned 48 h post passage effects.

2.7 Assessment of Fish Injuries

All recaptured fish were examined for types and extent of external injuries. Dead fish were also necropsied for internal injuries when there were no apparent external injuries. Additionally, all specimens alive at 48 h were closely examined for injury. The initial examination allowed detection of some injuries, such as bleeding and minor bruising that may not be evident after 48 h due to natural healing processes. Injuries were categorized by type, extent, and area of body. Fish without visible injuries that were not actively swimming or were swimming erratically at recapture were classified as having "loss of equilibrium" (LOE). This condition has been noted in most past HI-Z tag direct survival/injury studies and often disappears within 10 to 15 min after recapture if the fish is not injured (Heisey *et al*. 2008; Normandeau Associates, Inc. 2012; North/South Consultants, Inc. and Normandeau Associates, Inc. 2009). Visible injuries and LOE were categorized as minor or major (Table 2.5-2). The criteria for this determination are based primarily on Normandeau personnel field observations.

Fish without visible injuries and/or loss of equilibrium were designated "malady-free". The malady-free metric is established to provide a standard way to depict a specific passage route's effects on the condition of entrained fish (Normandeau Associates *et al*., 2006). The malady-free metric is based solely on fish physically recaptured and examined. Additionally, the malady-free metric in concert with site-specific hydraulic and physical data may provide insight into which passage conditions present safer fish passage.

2.8 Estimation of Survival and Malady-Free

The release and recapture data were analyzed by a likelihood ratio test to determine whether recapture probabilities were similar for dead (P_D) and alive (P_A) fish (Mathur *et al.* 1996a). The statistic tested the null hypothesis of the simplified model (Ho: P_A=P_D) versus the alternative generalized model (Ha: $P_A \neq P_D$). The simplified model has three parameters (P, S, τ) with three minimum sufficient statistics (a_c, a_T , d_T) while the alternative generalized model (recapture probabilities of alive and dead fish are unequal) has four parameters (P_A, P_D, S, τ) and four minimum sufficient statistics (a_c, , a_T, d_c, d_T). If homogeneity (P > 0.05) was revealed by the chi-square test, turbine passage survival can be estimated by the simplified model with increased precision. Appendix B-1 provides the definition of terms, derivation of likelihood estimates, and assumptions of the likelihood model. The maximum likelihood estimators associated with the model are:

$$\hat{\tau} = \frac{a_T R_C}{R_T a_C}$$

$$\hat{S} = \frac{R_T d_C a_C - R_C d_T a_C}{R_C d_C a_T - R_C d_T a_C}$$

$$\hat{P}_A = \frac{d_C a_T - d_T a_C}{R_T d_C - R_C d_T}$$

$$\hat{P}_D = \frac{d_C a_T - d_T a_C}{R_C a_T - R_T a_C}$$

The variance (Var) and standard error (SE) of the estimated passage mortality ($1-\hat{\tau}$) or survival ($\hat{\tau}$) are:

$$Var(1-\hat{\tau}) = Var(\hat{\tau}) = \frac{\tau}{SP_A}\left[\frac{(1-S\tau P_{A)}}{R_T} + \frac{(1-SP_A)\tau}{R_C}\right]$$

$$SE(1-\hat{\tau}) = SE(\hat{\tau}) = \sqrt{Var(1-\hat{\tau})}\ .$$

Separate survival probabilities (1 and 48 h), malady-free estimates, and their associated standard errors were estimated using the likelihood model given in Appendix B-1. The formulas are:

Survival (τ), 1 and 48 hours

Where:

$$\hat{\tau}_i = \frac{a_{Ti} R_c}{R_{Ti} a_c}$$

R_{Ti} = Number of fish released for the treatment condition
a_{Ti} = Number of fish alive for the treatment condition;
R_c = Number of control fish released;
a_c = Number of control fish alive.

Malady-Free (MF) Fish

Where:

$$MF_i = \frac{c_{Ti} R_c}{R_{Ti} c_c}$$

C_{Ti} = Total number of fish without maladies for treatment;
R_{Ti} = Number of fish recovered that were examined for maladies for treatment;
C_c = Number of control fish recovered without maladies;
R_c = Number of control fish recovered that were examined for maladies.

Since the likelihood ratio tests showed equality of P_A and P_D ($P>0.05$), survival and malady-free estimates were made using the reduced model. Appendix B-2 thru B-4 presents outputs of these analyses along with estimates of standard errors.

2.9 Assignment of Probable Sources of Injury

Limited controlled experiments (Neitzel *et al*., 2000; Pacific Northwest National Laboratory *et al*., 2001) to replicate and correlate each injury type/characteristic to a specific causative mechanism provides some indication of the cause of observed injuries in the field. Some injury symptoms can be manifested by two different sources that may lessen the probability of accurate delineation of a cause and effect relationship (Eicher Associates 1987). Only probable causal mechanisms of injury were assigned for the present investigation.

Injuries likely to be associated with direct contact of turbine runner blades or structural components are classified as mechanical and include: bruise, laceration, and severance of the fish body (Dadswell *et al*., 1986; Eicher Associates 1987). Passage through gaps between the runner blades and the hub, or at the distal end of the blades may result in a pinched body (RMC. 1994b). Injuries likely to be attributed to shear forces are decapitation, torn or flared opercula, and hemorrhaged eyes (Neitzel *et al*., 2000).

2.10 Mathematical Survival Estimates

The empirical turbine survival estimates were also compared to those obtained using the blade strike equation developed by Franke *et al*. (1997). The equation grew out of efforts by the Department of Energy (DOE) to design more "fish-friendly turbines. This comparison was conducted to provide some additional perspective on the present study survival estimates and also other study results on turbine passed adult shad. The equation to estimate survival through Kaplan Unit 8 was:

$$P = \lambda\left[\frac{N * L}{D}\right]\left[\frac{\cos\alpha_a}{8Q_{\omega d}} + \frac{\sin\alpha_a}{\pi\frac{r}{R}}\right] \text{ and}$$

$$S = 1 - P \text{ where,}$$

P = probability of strike,
λ = strike mortality correlation factor,
N = number of turbine runner blades,
L = fish length,
D = maximum turbine runner diameter,
α_a = angle to axial of absolute flow upstream of turbine runner,
$Q_{\omega d}$ = discharge coefficient ($Q/\omega D^3$),
ω = rotational speed (rpm x $2\pi/60$),
R = turbine runner radius,
r = turbine runner radius at point fish enters turbine, and
S = survival probability.

The corresponding equation (Franke *et al.* 1997) to estimate survival through Francis Unit 2 was:

$$P = \lambda\left(\frac{N * L}{D}\right)\left[\frac{\sin\alpha_t\left(\frac{B}{D_1}\right)}{2Q_{\omega d}} + \frac{\cos\alpha_t}{\pi}\right] \textit{ and}$$

$S = 1 - P$ *where,*

α_t = Angle to tangential of absolute flow upstream of runner
B = Runner height at inlet
D_1 = Diameter of runner at inlet

The equations calculate the probability (P) of blade strike by relating such turbine parameters as the number of buckets or blades, runner diameter, and runner height to fish length and operating condition. The formulas do not consider whether the turbine blades were blunt or sharp. Fish length and available passage space are the principal drivers of the output.

The average fish length and operating condition of the two units tested were entered in the calculation. Two correlation factors (λ=0.1 and 0.2) were selected for the Francis and Kaplan turbines. For the Kaplan turbines, three points of entry to the turbine, from hub to tip of blade, were also selected. The operating conditions were turbine efficiency rates of 80% and 90%. The correlation factors (lambda) used were 0.1 and 0.2; these were used to account for variability in strike potential and also to relate the output to empirical data available to the Franke study. The value of lambda in the range of 0.1 to 0.2 was determined by Franke *et al.* 1997 from Kaplan survival tests. Although the formula calculates a mortality probability, in the present context it is more conventionally used in the formula Survival (S) = 1 – P, with results expressed as a survival percentage. More details on the Franke formula estimates for fish passing the turbines at the Conowingo Project are presented in (Normandeau and Gomez and Sullivan 2012).

3.0 RESULTS

3.1 Recapture Rates

The HI-Z tag recapture technique performed satisfactorily with generally high recapture rates (physical retrieval of live and dead fish). Recapture rates for the Unit 2, Unit 8, and control fish were 99% (99 out of 100), 92.1% (93 out of 101), and 100% (120 out of 120), respectively (Table 3.1-1). Dislodged inflated HI-Z tags (without fish) were recaptured on 1 and 2 of Unit 2 and Unit 8 fish, respectively. Fish with dislodged tags were assigned a dead status for Unit 8; however the fish from Unit 2 was tracked and determined to be alive. The status on 6 (5.9%) of Unit 8 fish could not be determined. No radio signals were received on five of these fish and only a brief signal on the remaining fish; no HI-Z tags were recaptured on these fish. The very turbulent conditions and swift water downstream of Unit 8 likely contributed to these fish going undetected. These six fish were removed from the analysis.

Average recapture times (the time interval between fish release and subsequent recapture) for the Unit 2 and Unit 8 fish were 5.3 and 7.5 minutes, respectively (Figure 3.1-1). The average recapture time for control fish was 5.2 minutes (Figure 3.1-1). The longest time before recapture was 32 minutes for a Unit 2 fish. The slightly longer average recapture time for Unit 8 fish was due primarily to turbulent conditions downstream of Units 8-11, which created unsafe conditions for boat crews to quickly retrieve the buoyed fish.

3.2 Survival Estimates

The estimated immediate (1 h) survival was 93.0% (90% CI = ±4.2%) and 86.3% (90% CI = ±5.8%) at Units 2 and 8, respectively (Table 3.1-1 and Appendix B-2). Unit 2 and control fish released on 13 May were removed from the 48 h survival analysis because of unexpected mortalities (9 of 15 controls and 6 of 24 treatment fish) that occurred due to low tailwater resulting in pump failure in their delayed assessment pool. A higher percentage of the control fish (60%) died than the treatment (25%). With these adjustments, the estimated 48 h survival was 88.3% (90% CI = ±10.5%) and 84.1% (90% CI = ±9.9%) for Units 2 and 8, respectively (Table 3.1-1, Appendix B-2 and B-3).

The desired precision of ±10%, 90% of the time was attained for all survival estimates except Unit 2 48 h estimate (± 10.5%, 90% of the time) was just outside the desired precision.

3.3 Post-Passage Injury Rate, Types, and Probable Source

All control fish and 99% of Francis Unit 2 recaptured fish were examined for injuries. Ninety-three percent of Kaplan Unit 8 fish were examined post turbine passage. Some fish displayed more than one type of injury (Table 3.3-1) and Appendix C-2 and C-3). Five (4.2%) control fish sustained injuries and two displayed only loss of equilibrium at capture. The number of injured fish at Units 2 and 8 was 24 (24.2%) and 26 (28.0%), respectively. An additional four and one fish passed through these respective units displayed only loss of equilibrium.

The primary injury types observed on Unit 2 treatment fish was damage to the gills and operculum, which occurred on 12 fish (12.1%) (Table 3.3-1 and Figure 3.3-1). Eight fish (8.1%) had internal hemorrhaging, seven (7.1%) had bruising on the head, five (5.1%) had bruising or cuts on the body, and one fish was nearly decapitated. The prevalence of damage to the gills and operculum was also evident for eight (8.6%) of Unit 8 fish; however the incidence of fish being severed or decapitated eight fish, (8.6%) was much higher than at Unit 2 (Figure 3.3-1). Other injuries that occurred on more than 5% of the fish included cut or bruises to the body (6.5%). Only one fish displayed internal hemorrhaging. Five control fish had visible injuries consisting of hemorrhage to eyes (2.5%), fin (0.8%) and jaw (0.8%). Mechanical forces alone, or in combination with shear, were attributed to most observed injuries at both Unit 2 (21 of 28 or 75.0%) and Unit 8 (18 of 27 or 66.7%) passed fish (Table 3.3-2).

The mechanical injuries were likely caused by blade strike or contact with other structures within the flow path. However the incidence of more severed fish at Unit 8 indicates that mechanisms contributing to the injuries may differ for the two units. A majority of the maladies at both units (57.1% of injured fish at Unit 2 and 63.0% of injured fish at Unit 8) were classified as major, while the majority of the control injuries were minor (71.4% of injured fish, Table 3.3-2).

3.4 Malady-Free Estimates

Malady-free estimates (i.e., fish free of passage-related maladies) are presented in Table 3.4-1. Adjusting for control injuries and loss of equilibrium, the malady-free rates are 76.2% (90% CI= ±8.4%) and 75.4% (90% CI= ±8.7%) for Units 2 and 8, respectively. The precision on these estimates was within the desired ±10%, 90% of the time (α=0.10).

3.5 Comparison of Empirical and Mathematically Derived Survival Estimates

The Franke blade strike equation predicted adult survival estimates for Francis Unit 2 that ranged from 79.8 to 90.4% (Table 3.5-1). The present study 1 h estimate (93.0%) was higher than the mathematical estimate. Although the Francis unit has 13 blades that entrained adult shad may encounter, the occurrence of a small number of fish with cuts on their body indicates that the fish may have encountered the blades with less frequency and or with less force than the mathematical equation predicted.

The mathematical survival estimates for the Kaplan turbine ranged from 82.1 to 94.5% (Table 3.5-1). The 1 h estimate of 86.3% is within the range of the Franke blade strike equation values. The fact that 8% of the Unit 8 fish were severely cut indicates that this unit apparently has a greater incidence of blade strikes even though Unit 8 has fewer blades (6 blades) than Unit 2 (13 blades).

4.0 FINDINGS AND CONCLUSIONS

Two primary objectives of this field-based validation study of the Conowingo Project Francis Unit 2 (aerated) and Kaplan Unit 8 were: (1) release of a sufficient number of adult American shad through the Francis and Kaplan turbine such that the resulting survival estimate would be within ±10%, 90% of the time ($\alpha = 0.10$); and (2) determine injury rate, type, cause, and severity. Both of these objectives were met to a large extent. A release of 100 Unit 2, 101 Unit 8 fish, and 120 control fish released into the tailrace were sufficient to meet the specified precision (ε) level for all 1 and 48 h survival estimates except the 48 h estimate for Unit 2 was just outside the target (±10.5%). The 1 and 48 h survival rates were 93.0 and 88.3% at Unit 2, respectively. The 1 and 48 h rates at Unit 8 were 86.3 and 84.1%, respectively.

The turbine passage survival/injury estimates are considered valid, given use of appropriate underlying assumptions and an appropriate model to fit the data (Burnham *et al.*, 1987; Mathur *et al*., 1996a). The following assumptions, primarily related to the tag-recapture process, were fulfilled: handling, tagging, and release procedures did not differentially affect the survival rates of control and treatment groups. A potential source of bias due to non-selective retrieval of treatment and control groups was minimized by not assigning a specific boat recovery crew to recapture either treatment or control fish. However, turbulent and high flow conditions downstream of Unit 8 appeared to have affected the recapture rates of treatment fish. During the conduct of the study the large units (8-11) were operating most of the time and the station was at or near peak generation levels. No HI-Z tags were recaptured and brief or no radio signals were received on six (5.9%) of Unit 8 passed fish. Conditions were not nearly as turbulent downstream of Unit 2 and all but one fish was recaptured, and the status of this unrecaptured fish was known.

The dominant injury observed on turbine passed fish was damage to the gills and operculum (Unit 2, 12.1%; Unit 8, 8.6%); severance/decapitation was more common at Unit 8 (8.6%) than at Unit 2 (1%). Adjusted for control injuries and loss of equilibrium, the estimated malady-free rates of Units 2 and 8 passed fish were 76.2 and 75.4%, respectively; precision within ±10%, 90% of the time.

The literature is scant on passage survival estimates of adult American shad through Francis turbines. However, a handful of published studies were found on adult shad passage survival through Kaplan type turbines. Direct survival estimates were obtained on adult HI-Z tagged American shad passed through the Safe Harbor station (Heisey *et.al*. 2008) and radio tagged adult shad passed through the Hadley Falls station (Bell and Kynard 1985). Although no two turbines may be identical relative to hydraulic, structural, and mechanical characteristics, some perspective on Conowingo Kaplan Unit 8 survival can be gained from comparisons with these data (Table 4.0-1). The estimated 1 h survival of adult shad in passage through Conowingo Unit 8 (86.3%) is close to the 87.0 and 89.7% reported for Safe Harbor and higher than the 75.8% reported for Hadley Falls. The turbines tested at Safe Harbor had 5 or 7 blades; discharge ranged from 8,300 to 9,200 cfs; runner speeds of 75 and 109 rpm; operating head of 55 ft; and runner diameter of 222 and 242 in. Conowingo Unit 8 is similar in size (225 in) and discharge (8,842 cfs) to the Safe Harbor units; but differs in the number of blades (5), runner speed (120 rpm), and operating head (~86 ft). The turbines at Hadley Falls were smaller; 170 in diameter with 5 blades; discharge near 4,200 cfs; runner speed 128 rpm; and operating head of 52 ft.

Delayed survival (≤48 h) for Safe Harbor Kaplan units (88.2% and 84.3%) was also close to Conowingo Unit 8 (84.1%) (Table 4.0-1).

Beyond the few studies of Kaplan turbine survival for adult American shad, a few studies have been conducted on other species of similar size to the shad tested at Conowingo, and these studies can provide a perspective of the impact of the Conowingo turbines (Table 4.0-1). Direct turbine passage survival (48 h) of adult walleye (*Sander vitreus*) similar in size (314-653 mm, average near 450 mm) to the adult shad (330-590 mm, average near 450 mm) tested at Conowingo was 87.8% at a 5-bladed propeller unit and 80.4% at a 6 bladed propeller unit at the Kelsey Station, Nelson River, Manitoba, Canada (North/South Consultants, Inc and Normandeau Associates, Inc 2009). The units at Kelsey were larger than at Conowingo (312 in versus 225 in), slower in runner rotation rate (103 versus 120) and lower in head (56 ft versus 86 ft). Direct 48 h survival rates (84.9 and 83.8%) on similar sized (305-600 mm, average near 460 mm) adult rainbow trout (*Onchorhynchus mykiss*) passed through Kaplan type turbines at Box Canyon Project, Pend Oreille River, Washington were close to the 48 h survival rate (84.1%) at Unit 8 (Normandeau Associates Inc., 2012). The units at Box Canyon are slightly smaller than Conowingo Unit 8 (208 in versus 225 in); slightly slower (100 versus 120 rpm); and lower in head (39 ft versus 86 ft). The Box Canyon study involved a unit with 4 blades and another unit with 5 blades. Although walleye and rainbow trout are generally considered hardier than American shad, their survival rates were similar to the survival rates for Conowingo Unit 8. These results along with the results from the shad survival study at Safe Harbor support the use of the 84.1% survival rate found at Conowingo as representative of the survival for adult shad passing the Kaplan Units at the Conowingo Station.

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TABLE 1.1-1: CHARACTERISTICS OF CONOWINGO TURBINES AND OPERATIONAL CONDITIONS OF FRANCIS UNIT 2 AND KAPLAN UNIT 8 DURING ADULT SHAD PASSAGE TESTS.

Turbine Characteristics		1,3,4,6,7	2,5	8	9-11	2 House Units
Turbine Type		Francis	Francis	Kaplan	Kaplan	Francis
Rated Turbine Output (MW)		47.7	36.0*	65.0**	65.0	1.2
Hydraulic Capacity at Rated Output (cfs)		6,749	6,320*	9,352**	9,727	247
Minimum Hydraulic Capacity (cfs)		4,200	2,000	7,500	7,800	210
Design Head (ft)		89	89*	86**	86	89
Number of Buckets / Blades		13	13***	6	6	13
Runner Diameter (in)	Inlet	109.4	192.5	225	225	40.6
	Outlet	206.8	203.0			42.6
Runner Speed (rpm)		81.8	81.8	120	120	360
Blade tip speed (ft/s)		72.5	72.5	117.8	117.8	68.3
Number wicket gates		24	24	24	24	16
Runner Height (in)		72.1	72.1	108.5	108.5	15.5
Wicket gate spacing (in)		13.75	13.75	22.16	22.16	3.72
Approach Velocity (fps) (calculated)		2.5	2.4	3.5	3.7	1.4
Intake Elevation – Top (ft)		69.2	69.2	69.2	69.2	41.5
Intake Elevation – Centerline (ft)		46.8	46.8	46.8	46.8	33.6
Intake Elevation – Bottom (ft)		11.2	11.2	11.2	11.2	25.7
Trash Bar Spacing (in)		5.4	5.4	5.4	5.4	1.5

*Unit 2 parameters during testing: 29.9 to 32.3 MW, average discharge 5,063 cfs, and operational head ranged from 84.7 to 89.2 ft.
**Unit 8 parameters during testing: 57.2 to 57.6 MW, average discharge 8,842 cfs, and operational head ranged from 83.8 to 87.1 ft.
***Runners equipped with aeration system.

TABLE 2.2-1: REQUIRED SAMPLE SIZES AT VARIOUS CONTROL SURVIVAL RATES, RECAPTURE RATES (PA) AND EXPECTED PASSAGE SURVIVAL PROBABILITY ($\hat{\tau}$) OF TREATMENT FISH TO ACHIEVE A PRECISION LEVEL (ε) OF ≤ ± 0.10, 90% OF THE TIME.

	Expected Survival ($\hat{\tau}$)		
Turbine Survival	**0.90**	**0.95**	**0.97**
Control Survival			
		Recapture Rate = 0.98	
1.00	34	24	19
0.99	39	29	24
0.98	44	34	30
0.95	59	51	47
		Recapture Rate = 0.95	
1.00	49	40	36
0.99	54	45	41
0.98	59	51	47
0.95	75	68	64
		Recapture Rate = 0.90	
1.00	76	69	66
0.99	81	75	72
0.98	87	80	78
0.95	103	98	96
		Recapture Rate = 0.85	
1.00	107	102	100
0.99	112	108	106
0.98	118	114	112
0.95	135	133	132

[1] Table values also applicable for malady-free estimates.

TABLE 2.2-2: DAILY SCHEDULE OF RELEASED ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

Date	Water Temperature (°C)	Test Condition	Treatment	Control	Total
5/8	18.5	Unit 2	25	15	40
5/9	19.6	Unit 2	25	15	40
5/10	18.8	Unit 8	25	15	40
5/11	17.6 and 18.2	Unit 8	23	15	38
5/12	18.3	Unit 2	25	15	40
5/13	20.0	Unit 2	25	15	40
5/14		delayed assessment			
5/15	22.0	Unit 8	28	15	43
5/16	20.0	Unit 8	25	15	40
5/17	20.0	delayed assessment			
5/18		delayed assessment			
Total			**201**	**120**	**321**

TABLE 2.5-1: CONDITION CODES ASSIGNED TO FISH AND DISLODGED HI-Z TAGS FOR FISH PASSAGE SURVIVAL STUDIES.

Status Codes	Description		
*	Turbine/passage-related malady		
4	Damaged gill(s): hemorrhaged, torn or inverted		
5	Major scale loss, >20%		
6	Severed body or nearly severed		
7	Decapitated or nearly decapitated		
8	Damaged eye: hemorrhaged, bulged, ruptured or missing, blown pupil		
9	Damaged operculum: torn, bent, inverted, bruised, abraded		
A	No visible marks on fish		
B	Flesh tear at tag site(s)		
C	Minor scale loss, <20%		
E	Laceration(s): tear(s) on body or head (not severed)		
F	Torn isthmus		
G	Hemorrhaged, bruised head or body		
H	Loss of Equilibrium (LOE)		
J	Major		
K	Failed to enter system		
L	Fish likely preyed on (telemetry, circumstances relative to recapture)		
M	Minor		
P	Predator marks		
Q	Other information		
S	Eel study only - Functionally dead		
R	Removed from sample		
T	Trapped in the rocks/recovered from shore		
V	Fins displaced, or hemorrhaged (ripped, torn, or pulled) from origin		
W	Abrasion / Scrape		
Survival Codes			
1	Recovered alive		
2	Recovered dead		
3	Unrecovered – tag & pin only		
4	Unrecovered – no information or brief radio telemetry signal		
5	Unrecovered – trackable radio telemetry signal or other information		
Dissection Codes			
1	Shear	M	Minor
2	Mechanical	N	Heart damage, rupture, hemorrhaged
3	Pressure	O	Liver damage, rupture, hemorrhaged
4	Undetermined	R	Necropsied, no obvious injuries
5	Mechanical/Shear	S	Necropsied, internal injuries
6	Mechanical/Pressure	T	Tagging/Release
7	Shear/Pressure	U	Undetermined
B	Swim bladder ruptured or expanded	W	Head removed; i.e., otolith
D	Kidneys damaged (hemorrhaged)		
E	Broken bones obvious		
F	Hemorrhaged internally		
J	Major		
L	Organ displacement		

TABLE 2.5-2: GUIDELINES FOR MAJOR AND MINOR INJURY CLASSIFICATIONS FOR FISH PASSAGE SURVIVAL STUDIES USING THE HI-Z TAGS.

A fish with only Loss of Equilibrium (LOE) is classified as major if the fish dies within 1 hour. If it survives or dies beyond 1 hour it is classified as minor.
A fish with no visible external or internal maladies is classified as a passage related major injury if the fish dies within 1 hour. If it dies beyond 1 hour it is classified as a non passage related minor injury.
Any minor injury that leads to death within 1 hour is classified as a major injury. If it lives or dies after 1 hour it remains a minor injury.
Hemorrhaged eye: minor if less than 50%. Major if 50% or more
Deformed pupil(s) are a: major injury.
Bulged eye: major unless one eye is only slightly bulged. Minor if slight.
Bruises are size-dependent. Major if 10% or more of fish body per side. Otherwise minor.
Operculum tear at dorsal insertion is: major if it is 5 % of the fish or greater. Otherwise minor.
Operculum folded under or torn off is a major injury
Scale loss: major if 20% or more of fish per side. Otherwise minor
Scraping (damage to epidermis): major if 10% or more per side of fish. Otherwise minor.
Cuts and lacerations are generally classified as major injuries. Small flaps of skin or skinned up snouts are: minor.
Internal hemorrhage or rupture of kidney, heart or other internal organs that results in death at 1 to 48 hours is a major injury.
Multiple injuries: use the worst injury

TABLE 3.1-1: SUMMARY TAG RECAPTURE DATA AND ESTIMATED 1 AND 48 H SURVIVAL WITH 90% CONFIDENCE INTERVALS (CI) OF RELEASED ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS. PROPORTIONS ARE GIVEN IN PARENTHESES. SURVIVAL RATES ESTIMATED FROM REDUCED MODELS (SEE APPENDIX B).

	Unit 2		Unit 8		Combined Controls	
Number released	100		101		120	
Number recaptured alive	92	(0.920)	82	(0.812)	120	(1.000)
Number recaptured dead	7	(0.070)	11	(0.109)	0	(0.000)
Number assigned dead	0	(0.000)	2	(0.020)	0	(0.000)
Stationary radio signals		(0.000)		(0.000)		(0.000)
Dislodged tags*	1	(0.010)	2	(0.020)		(0.000)
Number undetermined**	0	(0.000)	6	(0.059)	0	(0.000)
Number held for 48 h		92		82	120	
1 h survival rate		0.930		0.863		
SE		0.026		0.035		
90% CI (±)		0.042		0.058		
Number alive 48 hour	58***	(0.773)	70	(0.693)	92***	(0.876)
Number died in holding	17	(0.227)	25	(0.248)	13	(0.124)
48 h survival rate		0.883		0.841		
SE		0.064		0.060		
90% CI (±)		0.105		0.099		

* One Unit 2 fish with dislodged HI-Z tag recaptured was actively tracked downstream, therefore it was counted as alive (not dead) in the analysis.

**No HI-Z tags recaptured, brief radio signal on only one of the six fish, nothing on remaining five fish. These six fish removed from analysis because high turbulent discharge and flow downstream of Kaplan units hindered their recapture.

***Due to pump failure prior to 48 h assessment, 25 treatment and 15 control fish released on May 13 are not included in 48 h analysis.

Unit 2 Survival (τ), 1 h= (93*120) / (100*120) = 0.930

$$\hat{\tau}_i = \frac{a_{Ti}F}{R_{Ti}c}$$

R_{Ti} = Number of fish released for the treatment condition (100)
a_{Ti} = Number of fish alive for the treatment condition (92+1)
R_c = Number of control fish released (120)
a_c = Number of control fish alive (120)

Unit 2 Survival (τ), 48 h= (58*105) / (75*92) = 0.883

R_{Ti} = Number of fish released for the treatment condition (75)
a_{Ti} = Number of fish alive for the treatment condition (58)
R_c = Number of control fish released (105)
a_c = Number of control fish alive (92)

Unit 8 Survival (τ), 1 h= (82*120) / ((101-6)*120) = 0.863

$$\hat{\tau}_i = \frac{a_{Ti}R}{R_{Ti}a}$$

R_{Ti} = Number of fish released for the treatment condition (101-6)[1]
a_{Ti} = Number of fish alive for the treatment condition (82)
R_c = Number of control fish released (120)
a_c = Number of control fish alive (120)

Unit 8 Survival (τ), 48 h= (70*105) / ((101-6)*92) = 0.841

R_{Ti} = Number of fish released for the treatment condition (101-6)[1]
a_{Ti} = Number of fish alive for the treatment condition (70)
R_c = Number of control fish released (105)
a_c = Number of control fish alive (92)

[1] Six fish of undetermined status subtracted from sample size

TABLE 3.3-1: SUMMARY OF VISIBLE INJURY TYPES AND INJURY RATES OBSERVED ON RECAPTURED ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS. PROPORTIONS ARE GIVEN IN PARENTHESES.

				Injury Type*						
No. Released	No. Examined	Passage Related Visibly Injured	LOE** only	Bruising/ Hemorrhaging*** on head/jaw	Hemorrhaged Eye(s)	Cut/Bruising/ Hemorrhaging on body/fins	Torn isthmus/ Damaged gills/ Torn Operculum	Major Scale Loss	Severed Body/ Decapitated	Internal Hemorrhaging
Unit 2******										
100	99 (0.990)	24 (0.242)	4 (0.040)	7 (0.071)	0 (0.000)	5 (0.051)	12 (0.121)	0 (0.000)	1 (0.010)	8 (0.081)
Unit 8										
101	93 (0.921)	26 (0.280)	1 (0.011)	2 (0.022)	4 (0.043)	6 (0.065)	8 (0.086)	2 (0.022)	8 (0.086)	1 (0.011)
Combined Controls ******										
120	120 (1.000)	5 (0.042)	2 (0.017)	1 (0.008)	3 (0.025)	1 (0.008)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)

*Some fish had multiple injury types

**loss of equilibrium (LOE)

***Some hemorrhaging noted on head and jaw, possibly due to handling and holding

****Due to pump failure prior to 48 h assessment for fish released on 13 May, only fish with maladies observed at 1 hr are included.

TABLE 3.3-2: PROBABLE SOURCES AND SEVERITY OF MALADIES OBSERVED ON RECAPTURED ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS. PROPORTIONS ARE GIVEN IN PARENTHESES.

No. of Fish Examined	Total With Maladies*	Mechanical	Mechanical/ Shear	Shear	Undetermined**	Severity	
						Minor	Major
			Unit 2***				
99	28 (0.283)	13 (0.131)	8 (0.081)	2 (0.020)	5 (0.051)	12 (0.121)	16 (0.162)
			Unit 8				
93	27 (0.290)	15 (0.161)	3 (0.032)	6 (0.065)	3 (0.032)	10 (0.108)	17 (0.183)
			Combined Controls***				
120	7 (0.058)	4 (0.033)	0 (0.000)	0 (0.000)	3 (0.025)	5 (0.042)	2 (0.017)

*Maladies include both visible injuries and LOE

**Injuries appeared to be primarily related to handling and/or holding in pool

***Due to pump failure prior to 48 h assessment for fish released on 13 May, only fish with maladies observed at 1 hr.

TABLE 3.4-1: SUMMARY MALADY DATA AND MALADY-FREE ESTIMATES FOR RECAPTURED ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS. PROPORTIONS ARE GIVEN IN PARENTHESES.

	Unit 2		Unit8		Control	
Number released	100		101		120	
Number examined for maladies	99	(0.990)	93	(0.921)	120	(1.000)
Number with passage related maladies	28	(0.283)	27	(0.290)	7	(0.058)
Visible injuries	24	(0.242)	26	(0.280)	5	(0.042)
Loss of equilibrium only	4	(0.040)	1	(0.011)	2	(0.017)
Number without passage related maladies	71	(0.717)	66	(0.710)	113	(0.942)
Without passage related maladies that died*	1	(0.010)	4	(0.043)	11	(0.092)
Malady-free rate**		0.762		0.754		
SE		0.051		0.053		
90% CI (±)		0.084		0.087		

* Fish that died >1 hr sfter recapture and had no visible external or internal injuries and did not display LOE at time of recapture.

**Due to pump failure prior to 48 h assessment for fish released on 13 May, only fish with maladies observed at 1 hr are included in malady-free estimate.

Unit 2 Malady-Free (MF) Fish = (71*120) / (99*113) = 0.762

Where:

$$MF_i = \frac{c_{Ti} R_c}{R_{Ti} c_c}$$

C_{Ti} = Total number of fish without maladies for treatment (71)
R_{Ti} = Number of fish recovered that were examined for maladies for treatment (99)
C_c = Number of control fish recovered without maladies (113)
R_c = Number of control fish recovered that were examined for maladies (120)

Unit 8 Malady-Free (MF) Fish = (66*120) / (93*113) = 0.754

Where:

$$MF_i = \frac{c_{Ti} R_c}{R_{Ti} c_c}$$

C_{Ti} = Total number of fish without maladies for treatment (66)
R_{Ti} = Number of fish recovered that were examined for maladies for treatment (93)
C_c = Number of control fish recovered without maladies (113)
R_c = Number of control fish recovered that were examined for maladies (120)

TABLE 3.5-1: PREDICTED SURVIVAL ESTIMATES FOR 18 INCH (457 MM) ADULT AMERICAN SHAD BASED ON BLADE STRIKE MODEL DEVELOPED BY FRANKE ET AL. (1997) FOR CONDITIONS TESTED (NEAR PEAK EFFICIENCY) AT FRANCIS UNIT 2 (DISCHARGE 5,055 CFS) AND KAPLAN UNIT 8 (DISCHARGE 8,843 CFS) AT THE CONOWINGO PROJECT. MAY, 2012.

Operating Efficiency	90%		80%	
Correlation Factor	0.1	0.2	0.1	0.2
Entry Point/Distance from hub center (ft.)	Kaplan Unit 8 Survival (%)			
1.9 (near hub)	91.1	82.3	91	82.1
5.6 (mid blade)	94.3	88.6	94.2	88.4
8.9 (near tip)	94.5	88.9	94.4	88.8
	Francis Unit 2 Survival (%)			
	90.4	80.8	89.9	79.8

TABLE 4.0-1: PHYSICAL AND HYDRAULIC CHARACTERISTICS OF HYDROELECTRIC DAMS FOR WHICH FRANCIS AND KAPLAN TURBINE PASSAGE SURVIVAL DATA ARE AVAILABLE FOR HI-Z TAGGED ADULT FISHES.

Station	Sampling Method	Average Length (mm/in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Survival 1 h	Survival 48 h	Sample Size	Source	Species
Box Canyon Dam, WA (existing Kaplan)	HI-Z	478/18.8	7,200	5	100	39	208	87.0	83.8	200	NAI 2012	Rainbow Trout
Box Canyon Dam, WA (new Kaplan)	HI-Z	447/17.6	8,100	4	100	39	208	86.5	84.9	200	NAI 2012	Rainbow Trout
Kelsey, Canada (existing propeller)	HI-Z	459/18.1	8,000	6	103	56	312	81.4	80.4	91	NS and NAI 2009	Walleye
Kelsey, Canada (new propeller)	HI-Z	430/16.9	11,000	5	103	56	312	87.8	87.8	99	NS and NAI 2009	Walleye
Safe Harbor, PA (mixed flow)	HI-Z	431/17.0	9,200	7	75	55	242	87.0	84.3	100	Heisey et al. 2008	American Shad
Safe Harbor, PA (Kaplan)	HI-Z	431/17.0	8,300	5	109	55	222	89.7	88.2	98	Heisey et al. 2008	American Shad
Hadley Falls, MA (Kaplan)	Radio Telem.	558/22.0	4,200	5	128	52	170	75.8	NA	36	Bell and Kynard 1985	American Shad
Conowingo, MD (Kaplan/mixed flow)	HI-Z	456/18.0	8,842	5	120	86	225	86.3	84.1	101	present study	American Shad
Conowingo, MD (Francis)	HI-Z	451/17.8	5,063	13	82	87	203	93.0	88.3	100	present study	American Shad

FIGURE 1.1-1: LOCATION OF YORK HAVEN, SAFE HARBOR, HOLTWOOD AND CONOWINGO HYDROELECTRIC STATIONS ON THE SUSQUEHANNA RIVER.

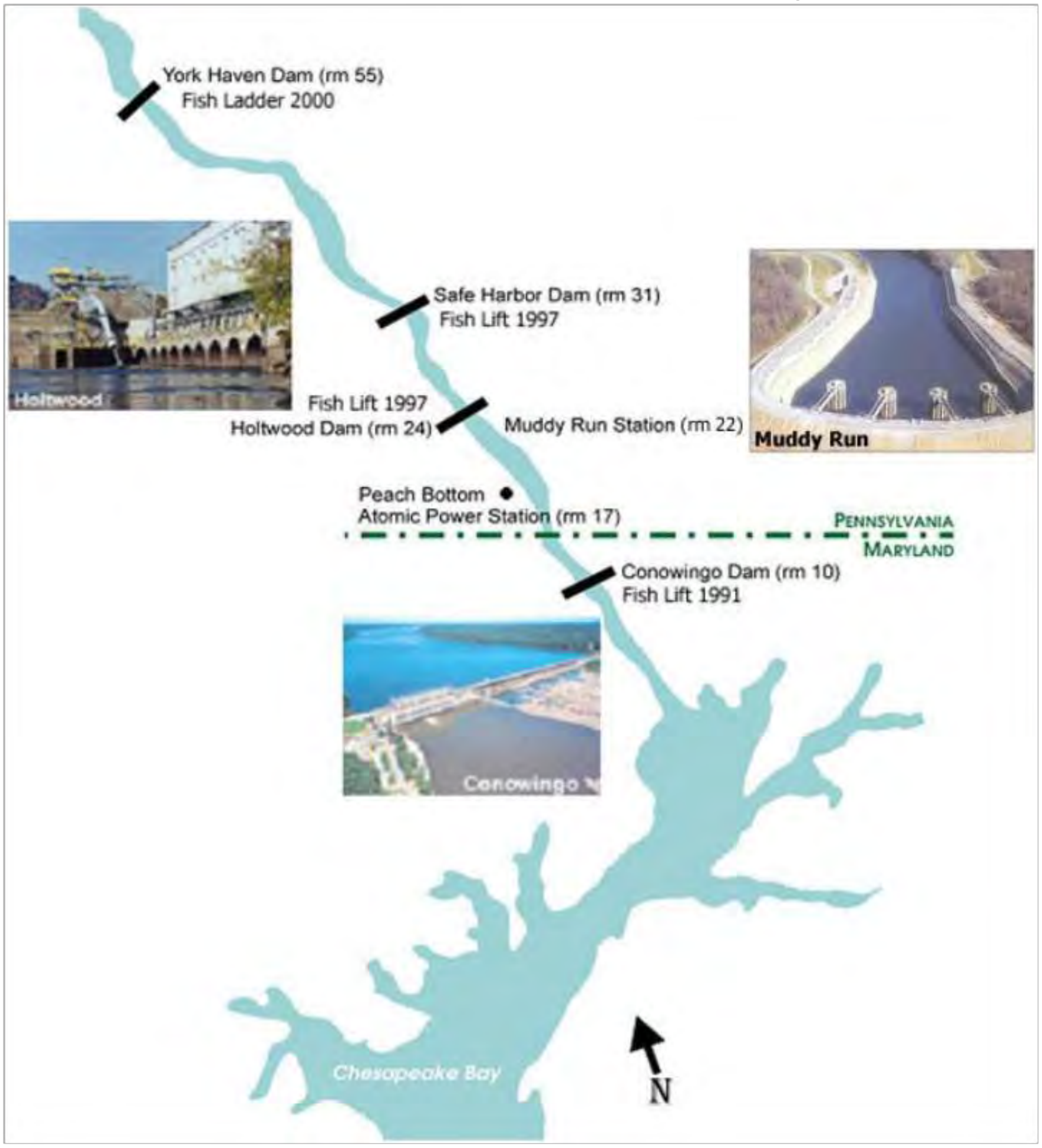

FIGURE 2.1-1: FRANCIS (TOP) AND KAPLAN/MIX-FLOW (BOTTOM) TURBINE TYPES AT CONOWINGO STATION.

FIGURE 2.3-1: FISH HOLDING TANKS AND CONTROL RELEASE SITE LOCATED AT FISHERMAN'S WHARF.

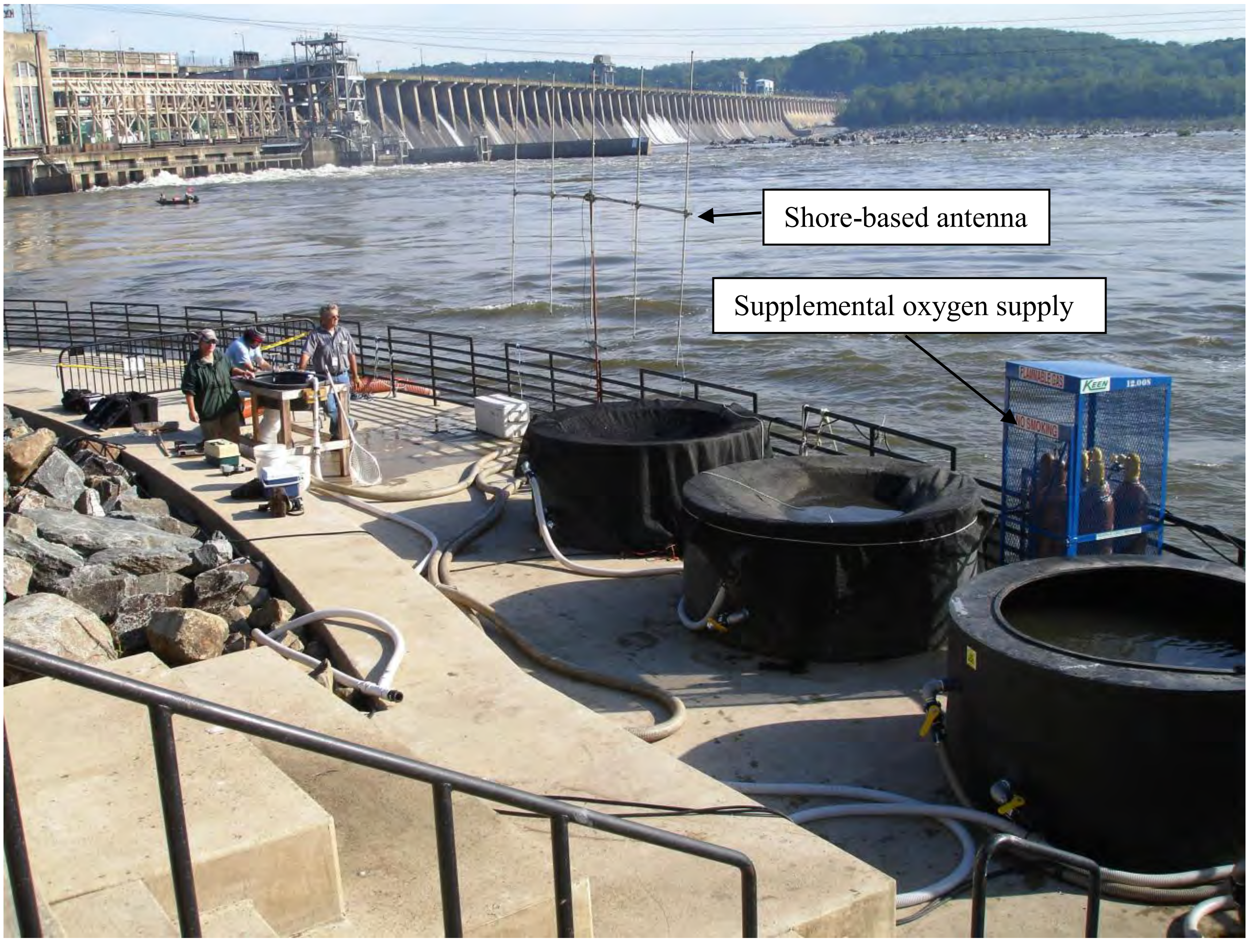

FIGURE 2.4-1: FISH NETTED BY RUBBER MESH NET FROM A HOLDING TANK PRIOR TO HI-Z TAGGING.

FIGURE 2.4-2: ADULT AMERICAN SHAD TAGGING SEQUENCE. A – PLACEMENT IN RESTRAINING DEVICE; B AND C – ATTACHING HI-Z AND RADIO TAGS WITH CANNULA AND CABLE TIE; D – ACTIVATION OF HI-Z TAGS.

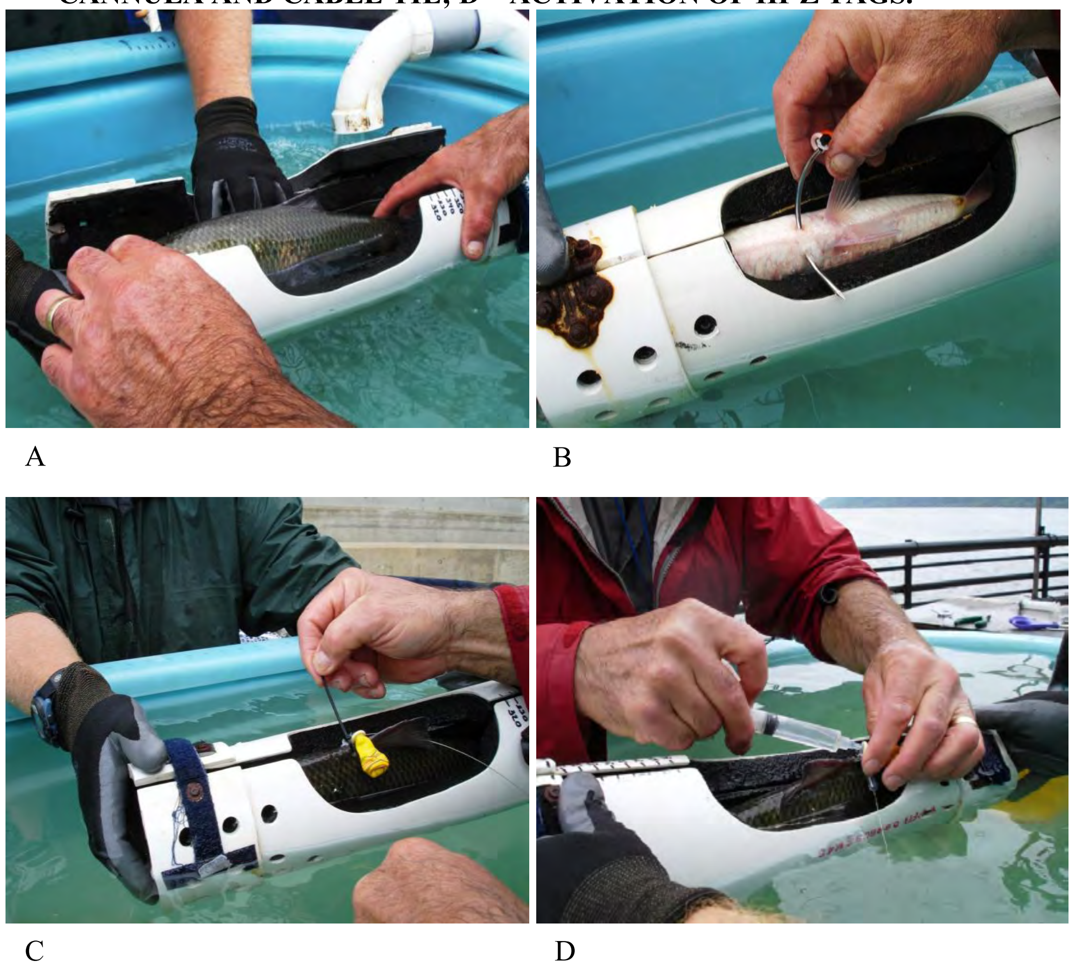

FIGURE 2.4-3: INDUCTION SYSTEM WITH DISCHARGE HOSE LOCATED ON DOWNSTREAM SIDE OF TRASH RACK.

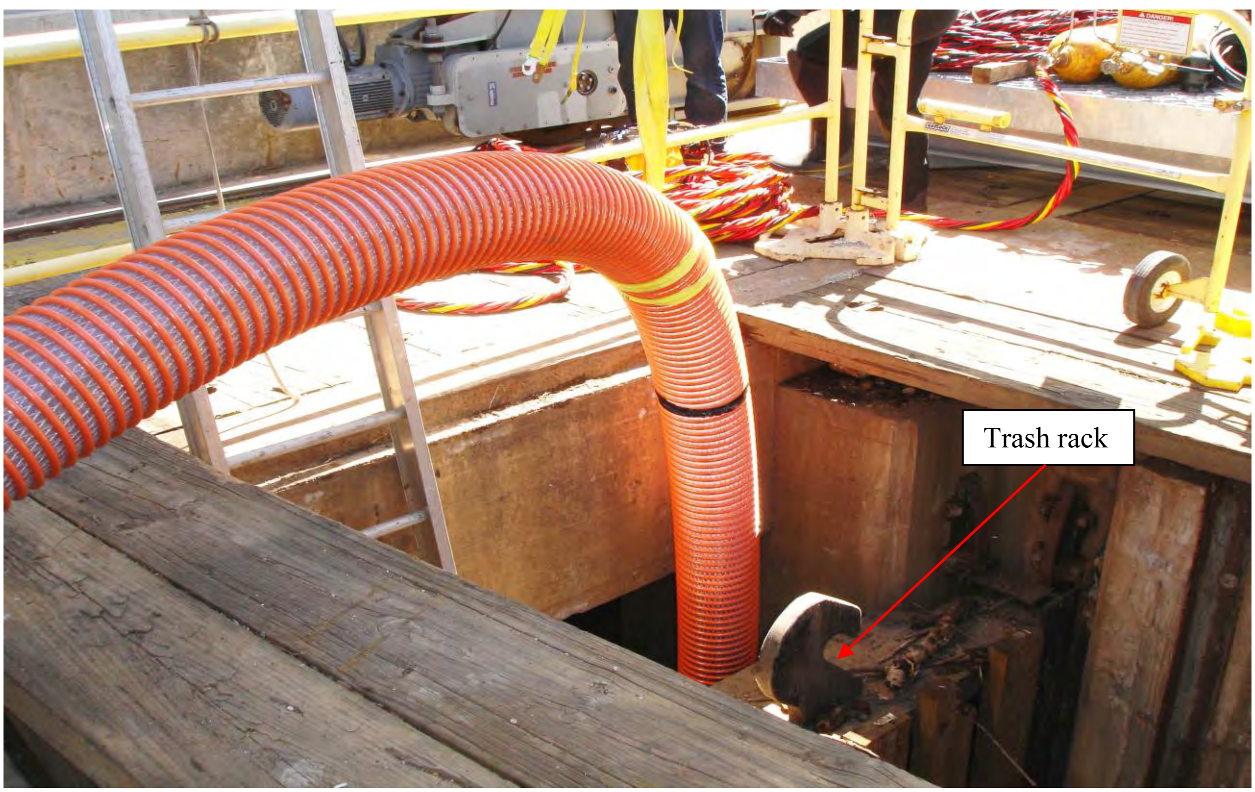

FIGURE 2.4-4: CROSS SECTION OF INTAKES FOR CONOWINGO TURBINES WITH RELEASE LOCATIONS OF ADULT SHAD JUST DOWNSTREAM OF TRASH RACKS AND APPROXIMATELY 10 FT BELOW INTAKE CEILING.

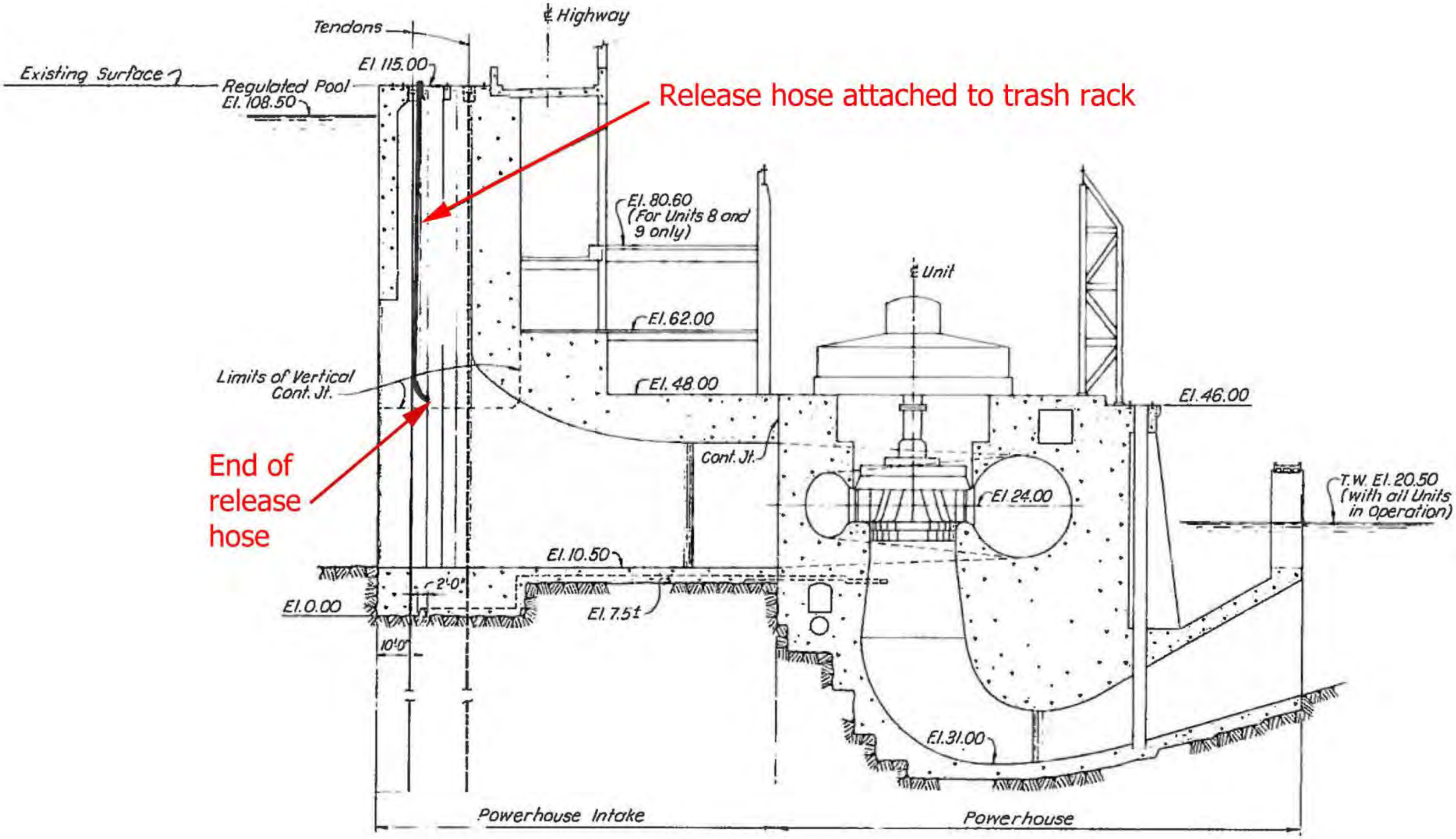

FIGURE 2.4-5: PLAN VIEW OF INTAKES FOR CONOWINGO TURBINES WITH LOCATION OF ADULT SHAD JUST DOWNSTREAM OF TRASH RACKS NEAR MIDDLE OF INTAKE AREA.

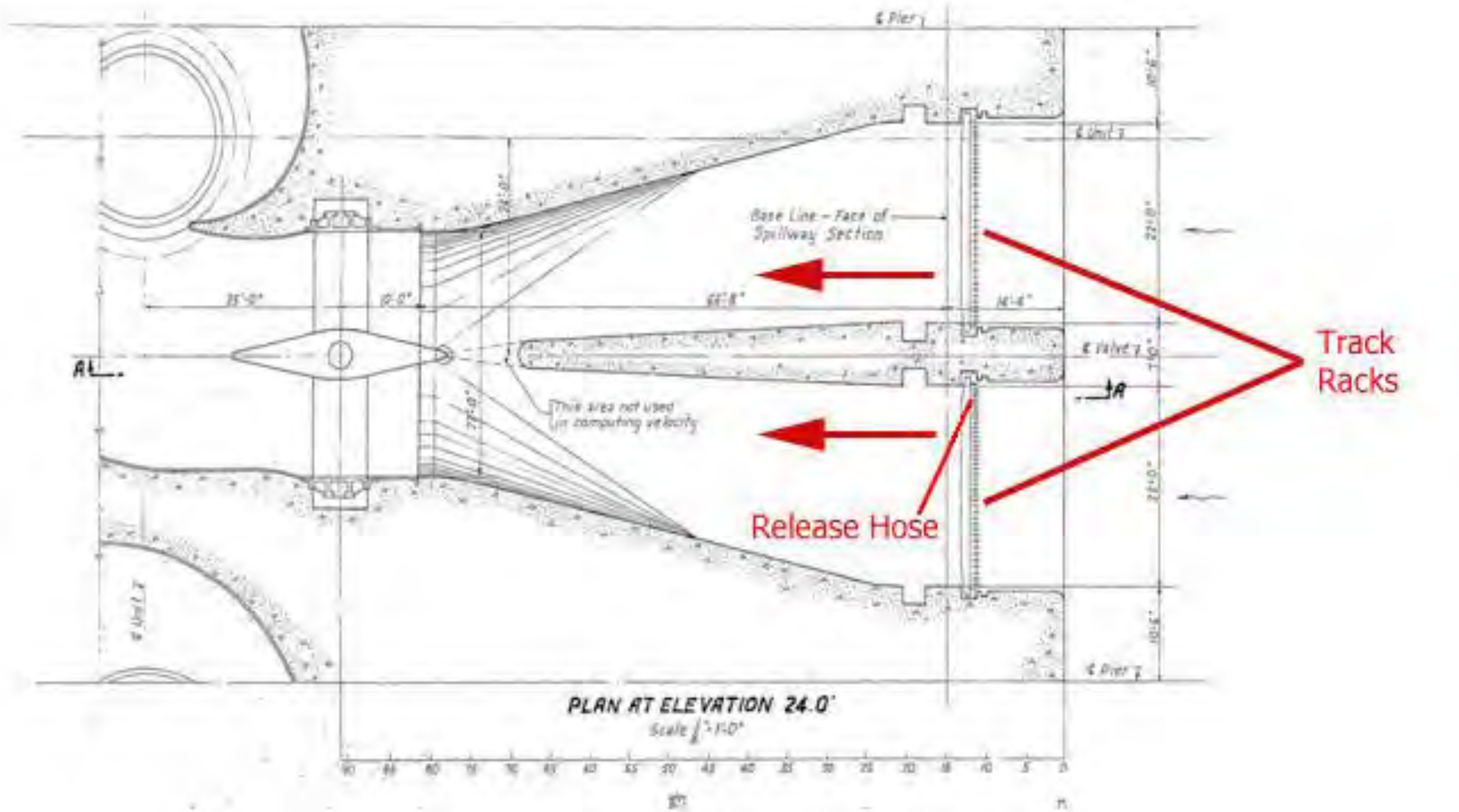

FIGURE 2.4-6: TOTAL LENGTH (MM) FREQUENCY DISTRIBUTION OF TREATMENT AND CONTROL ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROL FISH RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

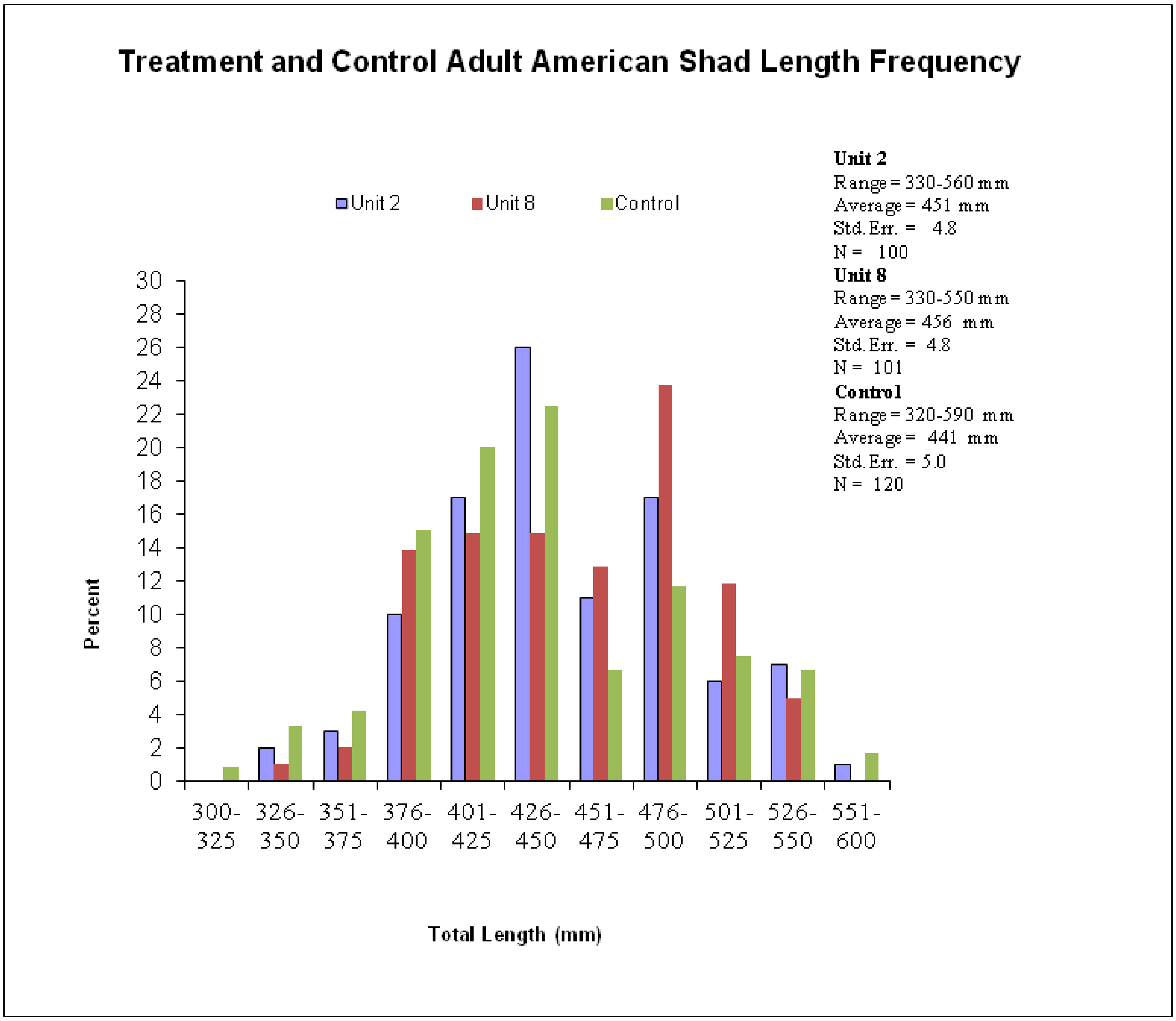

FIGURE 2.4-7: TOTAL LENGTH (MM) FREQUENCY DISTRIBUTION OF MALE AND FEMALE ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROL FISH RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

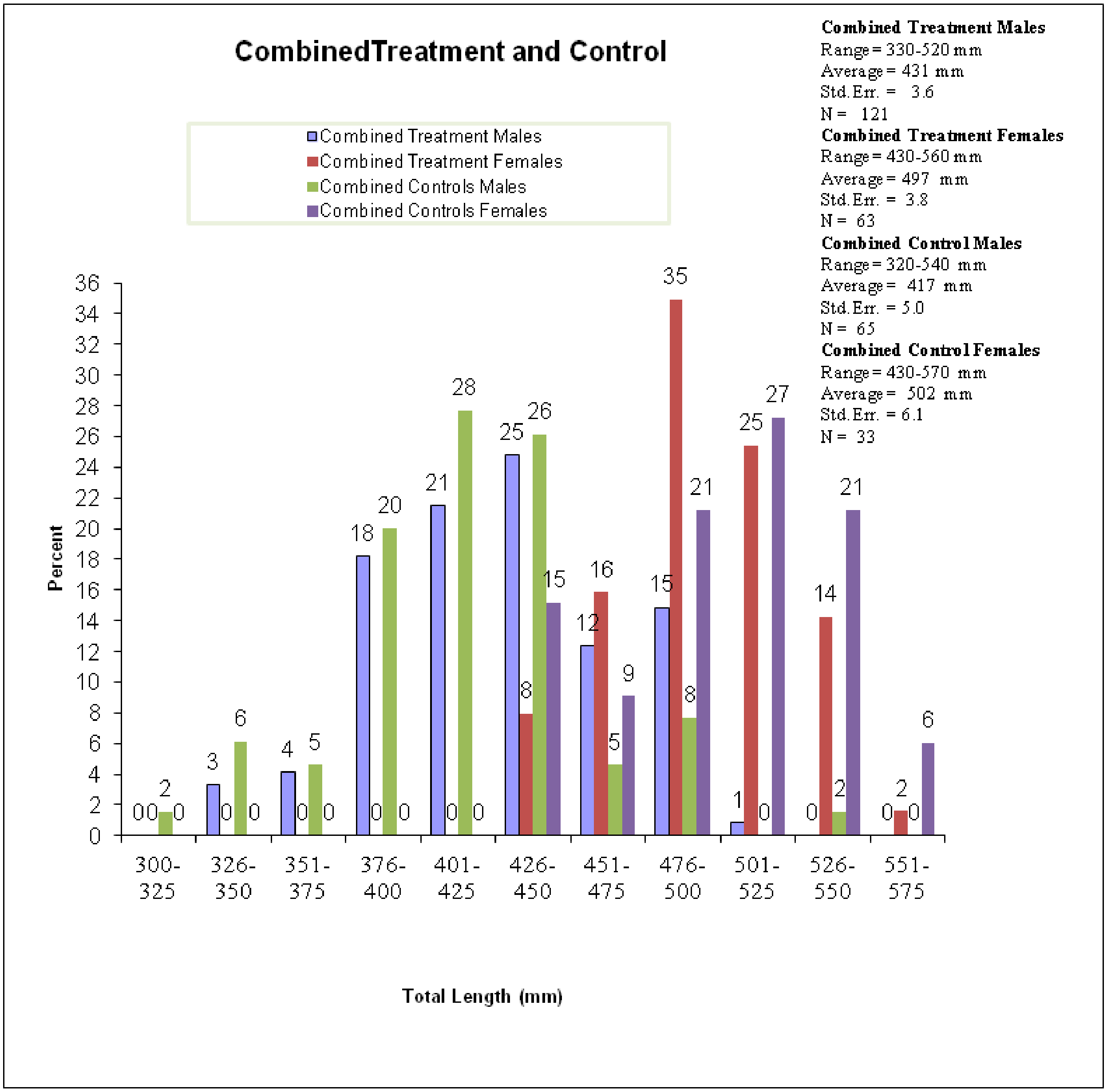

FIGURE 3.1-1: FREQUENCY DISTRIBUTION OF RETRIEVAL TIMES (MINUTES) OF TREATMENT AND CONTROL ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

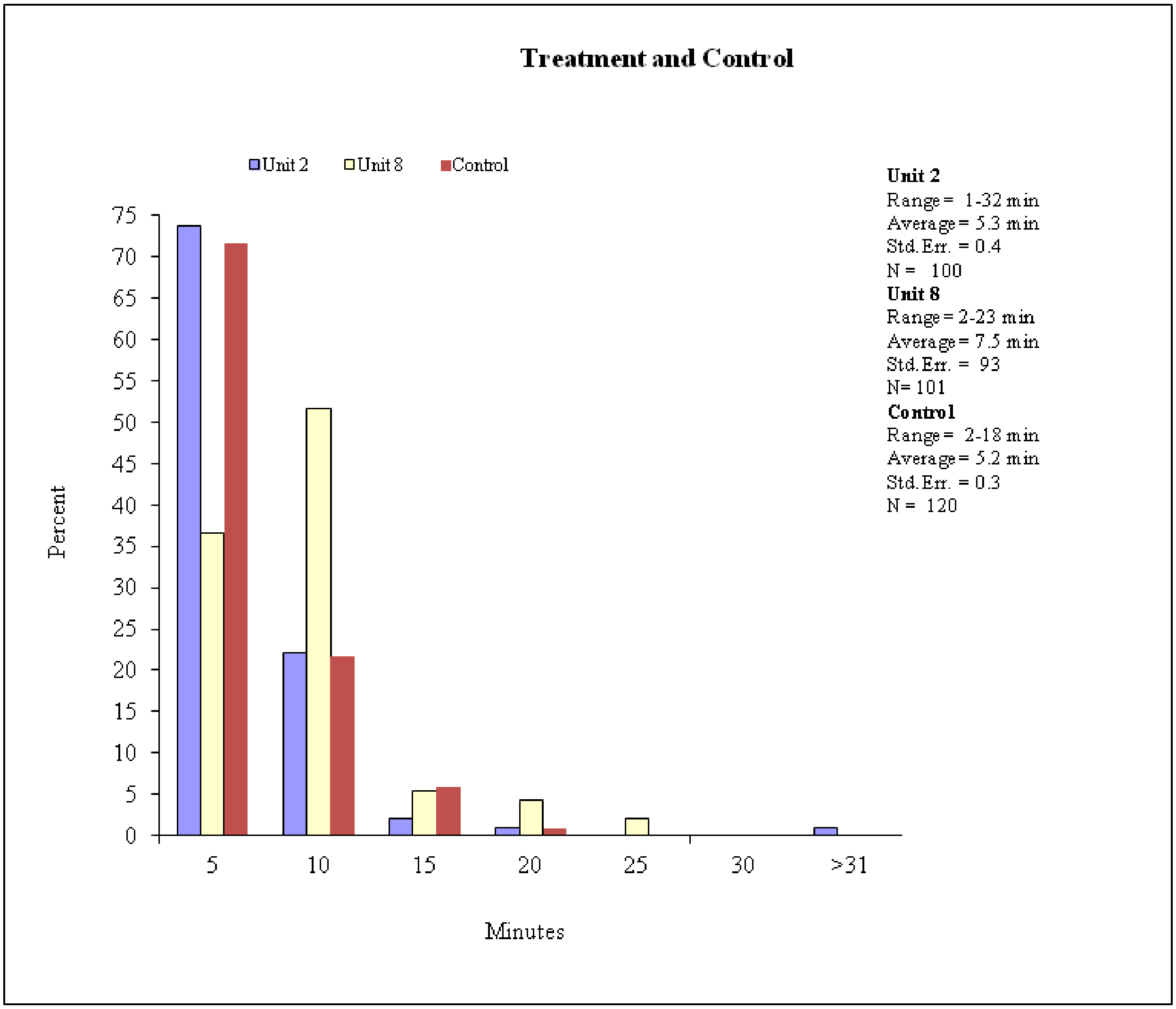

FIGURE 3.3-1: EXAMPLES OF DOMINANT INJURY TYPES OBSERVED ON ADULT AMERICAN SHAD PASSED THROUGH TURBINES AT CONOWINGO PROJECT, MAY 2012.

APPENDIX A: PROJECT PARAMETERS MEASURED DURING THE RELEASE OF ADULT AMERICAN SHAD THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

Appendix A

Project parameters measured during the release of adult American shad through Francis Unit 2 and Kaplan Unit 8, Conowingo Project, May 2012. Controls released from Fisherman's Wharf downstream of Francis units.

Time	Test / Control	Upstream water level (mNN)	Downstream Water level	Head (ft) estimation	Unit 2 discharge (cfs)*	Unit 8 discharge (cfs)*	Total Station discharge (cfs)	Power product (MW)**
Tuesday, May 8								
1000	Test	106.98	20.19	86.79	5210	NOT	75,500	401
1100	Test	106.74	20.22	86.52	5210	TESTED	75,100	400
1200	Test	106.54	20.47	86.07	5210		75,100	399
1300		106.30	20.42	85.88	5210		79,200	398
1400		106.03	21.07	84.96	5210		79,800	468
1500		105.57	20.89	84.68	5210		79,200	475
1600		105.37	20.69	84.68	5210		74,700	473
Wednesday, May 9								
0900		107.17	20.35	86.82	5190	NOT	74,300	397
1000		106.90	20.34	86.56	5190	TESTED	72,700	394
1100		106.54	20.60	85.94	5190		73,300	433
1200		106.30	20.65	85.65	5190		73,300	450
1300		106.14	20.67	85.47	5190		73,600	449
Thursday, May 10								
0800		107.27	20.89	86.38	NOT	8850	80,000	490
0900		106.96	21.03	85.93	TESTED	8850	79,200	486
1000		106.70	21.06	85.64		8850	79,600	483
1100		106.48	21.06	85.42		8850	80,000	482
1200		106.34	21.07	85.27		8850	80,000	481
1300		106.39	21.02	85.37		8850	79,600	480
Friday, May 11								
0800		106.66	20.90	85.76	NOT	8810	80,000	482
0900		106.48	21.09	85.39	TESTED	8810	79,600	482
1000		106.56	21.07	85.49		8810	79,600	482
1100		106.67	21.07	85.60		8810	79,400	481
1200		106.69	21.04	85.65		8810	79,800	483
1300		106.77	21.07	85.70		8810	79,600	483
1400		106.78	21.10	85.68		8810	79,600	483
Saturday, May 12								
0900		106.61	21.12	85.49	4900	NOT	80,000	484
1000		106.46	21.12	85.34	4900	TESTED	79,400	481
1100		106.29	21.13	85.16	4900		79,600	480
1200		106.10	21.11	84.99	4900		79,200	479
1300		105.97	21.18	84.79	4900		79,400	477
Sunday, May 13								
0800		107.95	18.79	89.16	4920	NOT	78,600	187
0900		108.00	20.93	87.07	4920	TESTED	79,800	460
1000		107.60	21.01	86.59	4920		79,600	492
1100		107.37	21.00	86.37	4920		80,000	490
1200		107.15	21.22	85.93	4920		80,200	487
1300		106.77	21.17	85.60	4920		79,600	485
Tuesday, May 15								
0900		107.69	20.58	87.11	NOT	8850	74,000	381
1000		107.27	20.44	86.83	TESTED	8850	75,100	399
1100		107.29	20.46	86.83		8850	73,300	398
1200		107.02	20.83	86.19		8850	73,600	454
1300		106.83	20.80	86.03		8850	73,100	454
1400		106.80	20.35	86.45		8850	73,300	453
1500		106.72	20.34	86.38		8850	79,200	453
Wednesday, May 16								
0900		105.02	21.24	83.78	NOT	8860	79,800	469
1000		105.29	21.27	84.02	TESTED	8860	79,600	471
1100		105.62	21.26	84.36		8860	79,600	472
1200		105.87	21.39	84.48		8860	81,100	482
1300		106.12	21.44	84.68		8860	80,900	498
1400		106.25	21.39	84.86		8860	81,100	499

*Hourly readings not available; this is average flow through unit. Discharge changes little when unit is brought online.
**MW output ranged from 29.9-32.3 MW at Unit 2 from 57.2-57.6 MW at Unit 8.

APPENDIX B-1: DERIVATION OF PRECISION, SAMPLE SIZE, AND MAXIMUM LIKELIHOOD PARAMETERS.

APPENDIX B-1

DERIVATION OF PRECISION, SAMPLE SIZE, AND MAXIMUM LIKELIHOOD PARAMETERS

A general statistical description below is given for a broad understanding for derivation of precision, sample size calculation and with likelihood model used for parameter estimation. For the sake of brevity, references within the text have been removed. However, interested readers can look up these citations in the report prepared by Normandeau Associates and Skalski (2000). Additionally, the results of statistical analyses for evaluating homogeneity in recapture and survival probabilities, and in testing hypotheses of equality in parameter estimates under the simplified (H_O:P_A=P_D) versus the most generalized model (H_A:$P_A \neq P_D$) are given.

The following terms are defined for the equations and likelihood functions which follow:

R_C	=	Number of control fish released
R_T	=	Number of treatment fish released
R	=	R_C=R_T
n	=	Number of replicate estimates $\hat{\tau}_i$ (i=1,…,n)
a_C	=	Number of control fish recaptured alive
d_C	=	Number of control fish recaptured dead
a_T	=	Number of treatment fish recaptured alive
d_T	=	Number of treatment fish recaptured dead
S	=	Probability fish survive from the release point of the controls to recapture
P_A	=	Probability an alive fish is recaptured
P_D	=	Probability a dead fish is recaptured
τ	=	Probability a treatment fish survives to the point of the control releases (*i.e.*, passage survival)
1-τ	=	Passage-related mortality.

The precision of the estimate was defined as:

$$P(-\varepsilon < \hat{\tau} - \tau < \varepsilon) = 1 - \alpha$$

or equivalently

$$P(-\varepsilon <| \hat{\tau} - \tau |< \varepsilon) = 1 - \alpha$$

where the absolute errors in estimation, *i.e.*, $|\hat{\tau} - \tau|$, is <ε (1-α) 100% of the time, $\hat{\tau}$ is the estimated passage survival, and ε is the half-width of a (1-α) 100% confidence interval for $\hat{\tau}$ or 1-$\hat{\tau}$. A precision of ±10%, 90% of the time is expressed as P($|\hat{\tau} - \tau|$<0.10)=0.90.

Using the above precision definition and assuming normality of $\hat{\tau} - \tau$, the required total sample size (R) is as follows:

$$P\left(\frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}} < Z < \frac{\varepsilon}{\sqrt{Var(\hat{\tau})}} \right) = 1 - \alpha$$

$$P\left(Z < \frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}} \right) = \alpha / 2$$

$$\Phi\left(\frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}} \right) = \alpha / 2$$

$$\frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}} = Z_{\alpha/2}$$

$$Var(\hat{\tau}) = \frac{\varepsilon^2}{Z^2_{1-\frac{\alpha}{2}}}$$

$$\frac{\tau}{SP_A}\left[\frac{(1-S\tau P_A)}{R_T} + \frac{(1-SP_A)\tau}{R_C} \right] = \frac{\varepsilon^2}{Z^2_{1-\frac{\alpha}{2}}} \ .$$

where Z is a standard normal deviate satisfying the relationship $P(Z>Z_{1-\alpha/2})=\alpha/2$, and Φ is the cumulative distribution function for a standard normal deviate.

Letting $R_C=R_T=R$, the sample size for each release is

$$R = \frac{\tau}{SP_A}\left[1 + \tau - 2S\tau P_A\right]\frac{Z^2_{1-\alpha/2}}{\varepsilon^2} \ .$$

By rearranging, this equation can be solved to predetermine the anticipated precision given the available number of fish for a study. In most previous investigations this equation has been used to calculate sample sizes because of homogeneity between trials; in the present investigation sample size was predetermined using this equation.

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Precision is defined as

$$P(|\,\bar{\hat{\tau}} - \bar{\tau}\,| < \varepsilon) = 1 - \alpha$$

$$P(-\varepsilon < \bar{\hat{\tau}} - \bar{\tau}\,| < \varepsilon) = 1 - \alpha$$

$$P\left(\frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} < t_{n-1} < \frac{\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} \right) = 1 - \alpha$$

$$P\left(t_{n-1} < \frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} \right) = \alpha / 2$$

$$\Phi\left(\frac{-\varepsilon}{Var(\bar{\hat{\tau}})} \right) = \alpha / 2$$

$$\frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} = t_{\alpha/2, n-1}$$

$$Var(\bar{\hat{\tau}}) = \frac{\varepsilon^2}{t^2_{1-\alpha/2, n-1}}$$

$$\frac{\sigma_\tau^2 + \frac{\tau}{SP_A}\left[\frac{(1 - S\tau P_A)}{R_T} + \frac{(1 - SP_A)\tau}{R_C} \right]}{n} = \frac{\varepsilon^2}{t^2_{1-\alpha/2, n-1}}$$

where σ_τ^2=natural variation in passage-related survival.

Now letting $R_T=R_C$

$$\frac{\sigma_\tau^2 + \frac{\tau}{SP_A}\left[\frac{(1 - S\tau P_A)}{R} + \frac{(1 - SP_A)\tau}{R} \right]}{n} = \frac{\varepsilon^2}{t^2_{1-\alpha/2, n-1}}$$

which must be iteratively solved for n given R. Or R given n where

$$R = \frac{\frac{\tau}{SP_A}\left[(1 - S\tau P_A) + (1 - SP_A)\tau \right]}{\left[\frac{n\varepsilon^2}{t^2_{1-\alpha/2, n-1}} - \sigma_\tau^2 \right]}$$

$$R = \frac{\frac{\tau(1+\tau)}{SP_A}}{\left[\frac{n\varepsilon^2}{t^2_{1-\alpha/2, n-1}} - \sigma_\tau^2 \right]}$$

$$R = \frac{\tau(1+\tau)}{SP_A}\left[\frac{t^2_{1-\alpha/2, n-1}}{n\varepsilon^2 - \sigma_\tau^2 t^2_{1-\alpha/2, n-1}} \right].$$

The joint likelihood for the passage-related mortality is:

$$L\ (S,\ \tau,\ P_A,\ P_D \mid R_C,\ R_T,\ a_C,\ a_T,\ d_C,\ d_T)=$$

$$\binom{R_C}{a_c d_C}(SP_A)^{a_C}((1-S)P_D)^{d_C}(1-SP_A-(1-S)P_D)^{R_C-a_C-d_C}$$

$$\times\binom{R_T}{a_T d_T}(S\tau P_A)^{a_T}((1-S\tau)P_D)^{d_T}(1-S\tau P_A-(1-S\tau)P_D)^{R_T-a_T-d_T}\ .$$

The likelihood model is based on the following assumptions: (1) fate of each fish is independent, (2) the control and treatment fish come from the same population of inference and share that same survival probability, (3) all alive fish have the same probability, P_A, of recapture, (4) all dead fish have the same probability, P_D, of recapture, and (5) passage survival (τ) and survival (S) to the recapture point are conditionally independent. The likelihood model has four parameters (P_A, P_D, S, τ) and four minimum sufficient statistics (a_C, d_C, a_T, d_T).

Likelihood models is based on the following assumptions: (a) the fate of each fish is independent; (b) the control and treatment fish come from the same population of inference and share the same natural survival probability, S; (c) all alive fish have the same probability, P_A, of recapture; (d) all dead fish have the same probability, P_D, of recapture; and (e) passage survival (τ) and natural survival (S) to the recapture point are conditionally independent.

The estimators associated with the likelihood model are:

$$\hat{\tau}=\frac{a_T R_C}{R_T a_C}$$

$$\hat{S}=\frac{R_T d_C a_C - R_C d_T a_C}{R_C d_C a_T - R_C d_T a_C}$$

$$\hat{P}_A=\frac{d_C a_T - d_T a_C}{R_T d_C - R_C d_T}$$

$$\hat{P}_D=\frac{d_C a_T - d_T a_C}{R_C a_T - R_T a_C}\ .$$

The variance (Var) and standard error (SE) of the estimated passage mortality ($1-\hat{\tau}$) or survival ($\hat{\tau}$) are:

$$Var(1-\hat{\tau})=Var(\hat{\tau})=\frac{\tau}{SP_A}\left[\frac{(1-S\tau P_{A)}}{R_T}+\frac{(1-SP_A)\tau}{R_C}\right]$$

$$SE(1-\hat{\tau})=SE(\hat{\tau})=\sqrt{Var(1-\hat{\tau})}\ .$$

APPENDIX B-2: ONE HOUR SURVIVAL ESTIMATES FOR ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8 AT CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED INTO THE TAILRACE DOWNSTREAM FROM FRANCIS UNITS AT FISHERMAN'S WHARF. CONTROL FISH RELEASED 120, 120 ALIVE AND 0 DEAD; UNIT 2: 100 RELEASED, 93 ALIVE, 7 DEAD; UNIT 8: 101 RELEASED, 82 ALIVE, 11 DEAD, 2 ASSIGNED DEAD, AND 6 UNDETERMINED.

Appendix B-2

One hour survival estimates for adult American shad, passed through Francis Unit 2 and Kaplan Unit 8 of the Conowingo Project, May 2012. Controls released into the tailrace downstream of Fisherman's Wharf.
Control fish released 120, 120 alive 0 dead; Unit 2: 100 released, 93 alive, 7 dead; Unit 8: 95, released, 11 dead, 2 assigned dead.

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RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival*
Pa =	1.0	N/A	Live recovery probability*
Pd =	1.0	N/A	Dead recovery probability*
S2 =	0.9300	(0.0255)	Unit 2 survival
S3 =	0.8632	(0.0353)	Unit 8 survival

* **--** Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.

log-likelihood : -63.2869

Tau = 0.9300 (0.0255) Unit 2/Control ratio
Tau = 0.8632 (0.0353) Unit 8/Control ratio

Z statistic for the equality of equal turbine survivals: 1.5358

Compare with quantiles of the normal distribution:

	1-tailed	2-tailed
For significance level 0.10:	1.2816	1.6449
For significance level 0.05:	1.6449	1.9600
For significance level 0.01:	2.3263	2.5758

Variance-Covariance matrix for estimated probabilities:

0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00065100	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	0.00124333

Confidence intervals:

	Unit 2 Tau	Unit 8 Tau
90 percent:	(0.8880, 0.9720)	(0.8052, 0.9212)
95 percent:	(0.8800, 0.9800)	(0.7940, 0.9323)
99 percent:	(0.8643, 0.9957)	(0.7724, 0.9540)

===

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival*
Pa = Pd	1.0	N/A	Recovery probability*
S2 =	0.9300	(0.0255)	Unit 2 survival
S3 =	0.8632	(0.0353)	Unit 8 survival

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.

log-likelihood : -63.2869

Tau = 0.9300 (0.0255) Unit 2/Control ratio
Tau = 0.8632 (0.0353) Unit 8/Control ratio

Z statistic for the equality of equal turbine survivals: 1.5358

Compare with quantiles of the normal distribution:

	1-tailed	2-tailed
For significance level 0.10:	1.2816	1.6449
For significance level 0.05:	1.6449	1.9600
For significance level 0.01:	2.3263	2.5758

Variance-Covariance matrix for estimated probabilities:

0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00065100	0.00000000
0.00000000	0.00000000	0.00000000	0.00124333

Confidence intervals:

	Unit 2 Tau	Unit 8 Tau
90 percent:	(0.8880, 0.9720)	(0.8052, 0.9212)
95 percent:	(0.8800, 0.9800)	(0.7940, 0.9323)
99 percent:	(0.8643, 0.9957)	(0.7724, 0.9540)

===

Likelihood ratio statistic for equality of recovery probabilities: -0.0001

Compare with quantiles of the chi-squared distribution with 1 d.f.:

For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

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APPENDIX B-3: FORTY-EIGHT HOUR SURVIVAL ESTIMATES FOR ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8 AT CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED INTO THE TAILRACE DOWNSTREAM FROM FRANCIS UNITS AT FISHERMAN'S WHARF. CONTROL FISH RELEASED 105, 92 ALIVE AND 13 DEAD; UNIT 2: 75 RELEASED, 58 ALIVE, 17 DEAD; UNIT 8: 101 RELEASED, 70 ALIVE, 25 DEAD, AND 6 UNDETERMINED. DUE TO PUMP FAILURE PRIOR TO 48 H ASSESSMENT, FISH RELEASED FOR UNIT 2 TESTING ON 13 MAY ARE NOT INCLUDED IN 48 H ANALYSIS.

Appendix B-3

Forty-eight hour survival estimates for adult American shad passed through Francis Unit 2 and Kaplan Unit 8 at Conowingo Project, May 2012. Controls released into the tailrace downstream of Fisherman's Wharf.

Control fish: 105 released, 92 alive, 13 dead: Unit 2: 75 released 58 alive 17 dead: Unit 8: 95 released, 70 alive, 25 dead.

===

RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	0.8762	(0.0321)	Control group survival
Pa =	1.0	N/A	Live recovery probability*
Pd =	1.0	N/A	Dead recovery probability*
S2 =	0.7733	(0.0483)	Unit 2 survival
S3 =	0.7368	(0.0452)	Unit 8 survival

* **--** Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.

log-likelihood : -134.2100

Tau = 0.8826 (0.0640) Unit 2/Control ratio
Tau = 0.8410 (0.0601) Unit 8/Control ratio

Z statistic for the equality of equal turbine survivals: 0.4745

Compare with quantiles of the normal distribution:

	1-tailed	2-tailed
For significance level 0.10:	1.2816	1.6449
For significance level 0.05:	1.6449	1.9600
For significance level 0.01:	2.3263	2.5758

Variance-Covariance matrix for estimated probabilities:

0.00103315	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00233718	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	0.00204111

Confidence intervals:

	Unit 2 Tau	Unit 8 Tau
90 percent:	(0.7774, 0.9878)	(0.7421, 0.9398)
95 percent:	(0.7572, 1.0080)	(0.7232, 0.9587)
99 percent:	(0.7179, 1.0473)	(0.6862, 0.9957)

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	0.8762	(0.0321)	Control group survival
Pa = Pd	1.0	N/A	Recovery probability*
S2 =	0.7733	(0.0483)	Unit 2 survival
S3 =	0.7368	(0.0452)	Unit 8 survival

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.

log-likelihood : -134.2100

Tau = 0.8826 (0.0640) Unit 2/Control ratio
Tau = 0.8410 (0.0601) Unit 8/Control ratio

Z statistic for the equality of equal turbine survivals: 0.4745

Compare with quantiles of the normal distribution:

	1-tailed	2-tailed
For significance level 0.10:	1.2816	1.6449
For significance level 0.05:	1.6449	1.9600
For significance level 0.01:	2.3263	2.5758

Variance-Covariance matrix for estimated probabilities:

0.00103315	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00233718	0.00000000
0.00000000	0.00000000	0.00000000	0.00204111

Confidence intervals:

	Unit 2 Tau	Unit 8 Tau
90 percent:	(0.7774, 0.9878)	(0.7421, 0.9398)
95 percent:	(0.7572, 1.0080)	(0.7232, 0.9587)
99 percent:	(0.7179, 1.0473)	(0.6862, 0.9957)

==

Likelihood ratio statistic for equality of recovery probabilities: 0.0000

Compare with quantiles of the chi-squared distribution with 1 d.f.:

For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

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APPENDIX B-4: MALADY-FREE RATES FOR ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8 AT CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED INTO THE TAILRACE DOWNSTREAM FROM FRANCIS UNITS AT FISHERMAN'S WHARF. CONTROL FISH EXAMINED: 120, 113 NO MALADIES AND 7 WITH MALADIES; UNIT 2: 99 EXAMINED, 71 NO MALADIES AND 28 WITH MALADIES; UNIT 8: 93 EXAMINED, 66 NO MALADIES AND 27 WITH MALADIES. DUE TO PUMP FAILURE PRIOR TO 48 H ASSESSMENT, ONLY THE FISH OBSERVED WITH MALADIES AT CAPTURE ARE INCLUDED IN THE MALADY-FREE ESTIMATES FOR FISH RELEASED THROUGH UNIT 2 ON 13 MAY.

Appendix B-4

Malady-free rates for adult American shad passed through Francis Unit 2 and Kaplan Unit 8 at Conowingo Project, May 2012. Controls released into the tailrace downstream of Fisherman's Wharf. Control fish examined: 120, 113 no maladies and 7 with maladies; Unit 2: 99 examined, 71 no maladies and 28 with maladies; Unit 8: 93 examined, 66 no maladies and 27 with maladies. Due to pump failure prior to 48 h assessment for fish released through Unit 2 on 13 May, only fish observed with maladies at capture are included in the malady-free estimate.

RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	0.9417	(0.0214)	Control group
Pa =	1.0	N/A	Live recovery probability*
Pd =	1.0	N/A	Dead recovery probability*
S2 =	0.7172	(0.0453)	Unit 2
S3 =	0.7097	(0.0471)	Unit 8

* -- Because of contraints in the data set, this probability is assumed equal to 1.0; not estimated.
log-likelihood : -141.6746

Tau = 0.7616 (0.0511) Unit 2/Control ratio
Tau = 0.7536 (0.0528) Unit 8/Control ratio

Z statistic for the equality of equal turbine values: 0.1085

Compare with quantiles of the normal distribution:

	1-tailed	2-tailed
For significance level 0.10:	1.2816	1.6449
For significance level 0.05:	1.6449	1.9600
For significance level 0.01:	2.3263	2.5758

Variance-Covariance matrix for estimated probabilities:

0.00045778	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00204885	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000	0.00221548

Confidence intervals:

	Unit 2 Tau	Unit 8 Tau
90 percent:	(0.6776, 0.8456)	(0.6667, 0.8405)
95 percent:	(0.6615, 0.8617)	(0.6501, 0.8572)
99 percent:	(0.6300, 0.8932)	(0.6176, 0.8897)

===

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

estim. std.err.

S1 = 0.9417 (0.0214) Control group
Pa = Pd 1.0 N/A Recovery probability*
S2 = 0.7172 (0.0453) Unit 2
S3 = 0.7097 (0.0471) Unit 8

* **--** Because of contraints in the data set, this probability is assumed equal to 1.0; not estimated.
log-likelihood : -141.6746

Tau = 0.7616 (0.0511) Unit 2/Control ratio
Tau = 0.7536 (0.0528) Unit 8/Control ratio

Z statistic for the equality of equal turbine values: 0.1083

Compare with quantiles of the normal distribution:

	1-tailed	2-tailed
For significance level 0.10:	1.2816	1.6449
For significance level 0.05:	1.6449	1.9600
For significance level 0.01:	2.3263	2.5758

Variance-Covariance matrix for estimated probabilities:

0.00045776	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00204885	0.00000000
0.00000000	0.00000000	0.00000000	0.00221543

Confidence intervals:

	Unit 2 Tau	Unit 8 Tau
90 percent:	(0.6776, 0.8456)	(0.6667, 0.8406)
95 percent:	(0.6615, 0.8617)	(0.6501, 0.8572)
99 percent:	(0.6300, 0.8931)	(0.6176, 0.8897)

==
Likelihood ratio statistic for equality of recovery probabilities: 0.0000

Compare with quantiles of the chi-squared distribution with 1 d.f.:

For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

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APPENDIX C-1: DAILY TAG RECAPTURE DATA FOR ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

Appendix Table C-1

Daily tag recapture data for adult American shad passed through Francis Unit 2 and Kaplan Unit 8, Conowingo Project, May 2012. Controls released from Fisherman's Wharf downstream of Francis units.

	5/8	5/9	5/10	5/11	5/12	5/13	5/15	5/16	Totals
Unit 2									
Number released	25	25			25	25			**100**
Number alive	24	22			22	24			**92**
Number recovered dead	1	2			3	1			**7**
Assigned dead	0	0			0	0			**0**
Dislodged tags	0	1*			0	0			**1***
Stationary radio signals	0	0			0	0			**0**
Undetermined	0	0			0	0			**0**
Held and Alive 1 h	24	22			22	24			**92**
Alive 24 h	20	21			20	18**			**79**
Alive 48 h	19	19			20	18**			**76**
Unit 8									
Number released			25	23			28	25	**101**
Number alive			18	16			24	24	**82**
Number recovered dead			4	4			2	1	**11**
Assigned dead			1	1			0	0	**2**
Dislodged tags			1	1			0	0	**2**
Stationary radio signals			0	0			0	0	**0**
Undetermined***			2	2			2	0	**6**
Held and Alive 1 h			18	16			24	24	**82**
Alive 24 h			18	15			20	20	**73**
Alive 48 h			18	15			19	18	**70**
Control									
Number released	15	15	15	15	15	15	15	15	**120**
Number alive	15	15	15	15	15	15	15	15	**120**
Number recovered dead	0	0	0	0	0	0	0	0	**0**
Assigned dead	0	0	0	0	0	0	0	0	**0**
Dislodged tags	0	0	0	0	0	0	0	0	**0**
Stationary radio signals	0	0	0	0	0	0	0	0	**0**
Undetermined	0	0	0	0	0	0	0	0	**0**
Held and Alive 1 h	15	15	15	15	15	15	15	15	**120**
Alive 24 h	14	14	13	15	14	6**	11	15	**102**
Alive 48 h	14	13	13	15	13	6**	9	15	**98**

* Fish with dislodged tags was actively tracked downriver, therefore it was presummed alive for the analysis

** Due to pump failure prior to 48 h assessment, fish released on 13 May are not included in 48 h analysis

*** Fish of undetermined status removed from analysis. High turbulent discharge amd flow downstream of large units hindered their recapture

APPENDIX C-2: DAILY MALADY DATA FOR ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

Appendix Table C-2

Daily malady data for adult American shad passed through Francis Unit 2 and Kaplan Unit 8, Conowingo Project, May 2012. Controls released from Fisherman's Wharf downstream of Francis units.

	5/8	5/9	5/10	5/11	5/12	5/13	5/15	5/16	Totals
Unit 2									
Number released	25	25			25	25			**100**
Number examined	25	24			25	25			**99**
Passage related maladies*	7	8			7	6			**28**
Visible injuries	6	7			6	5			**24**
Loss of equilibrium only	1	1			1	1			**4**
Without maladies	18	16			18	19			**71**
Without maladies that died	1	0			0	0			**1**
Unit 8									
Number released			25	23			28	25	**101**
Number examined			22	20			26	25	**93**
Passage related maladies			7	5			7	8	**27**
Visible injuries			7	5			7	7	**26**
Loss of equilibrium only			0	0			0	1	**1**
Without maladies			15	15			19	16	**65**
Without maladies that died			0	1			3	0	**4**
Control									
Number released	15	15	15	15	15	15	15	15	**120**
Number examined	15	15	15	15	15	15	15	15	**120**
Passage related maladies*	0	4	0	0	0	1	1	1	**7**
Visible injuries	0	4	0	0	0	0	1	0	**5**
Loss of equilibrium only	0	0	0	0	0	1	0	1	**2**
Without maladies	15	11	15	15	15	14	14	14	**113**
Without maladies that died	1	1	2	0	2	0	5	0	**11**

*Due to pump failure prior to 48 h assessment, only fish with maladies observed at 1 hr released on May 13 are included.

APPENDIX C-3: INCIDENCE OF MALADIES, INCLUDING INJURY, SCALE LOSS, AND TEMPORARY LOSS OF EQUILIBRIUM (LOE) OBSERVED ON ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY, 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

Appendix Table C-3

Incidence of maladies, including injury, scale loss, and temporary loss of equilibrium (LOE) observed on adult American shad passed through Francis Unit 2 and Kaplan Unit 8, Conowingo Project, May 2012. Controls released from Fisherman's Wharf downstream of Francis units.

Date	Test Lot	Fish ID	Live/Dead	Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
Control**								
5/8/12	1	31	dead 24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/9/12	2	4	dead 24h	Damaged eye: both hemorrhaged: Hemorrhaged snout; Necropsied, no obvious internal injuries	Yes*	Yes	Major	Mechanical
5/9/12	2	6	alive 48h	Hemorrhaged caudal fin	Yes*	No	Minor	Mechanical
5/9/12	2	7	alive 48h	Hemorrhaged lower jaw (minor)	Yes*	No	Minor	Mechanical
5/9/12	2	10	alive 48h	Damaged eyes: both hemorrhaged (left minor, right major	Yes*	No	Major	Mechanical
5/9/12	2	11	dead 48h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/10/12	3	28	dead 24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/10/12	3	40	dead 24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/12/12	5	38	dead 48h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/12/12	5	40	dead 24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/13/12	6	2	alive 48h	LOE	Yes*	No	Minor	Undetermined
5/15/12	7	26	dead 24h	No visible marks on fish	No	No	Minor	Undetermined
5/15/12	7	27	dead 24h	Damaged eye: both eyes minor hemorrhaged; Necropsied, no obvious internal injuries	Yes*	Yes	Minor	Undetermined
5/15/12	7	29	dead 24h	Major scale loss, > 20% per side noted pre release	No	No	Minor	Undetermined
5/15/12	7	30	dead 24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/15/12	7	32	dead 48h	No visible marks on fish	No	No	Minor	Undetermined
5/15/12	7	36	dead 48h	No visible marks on fish	No	No	Minor	Undetermined
5/16/12	8	35	alive 48h	LOE	Yes*	No	Minor	Undetermined
* Maladies attributed to tagging, handling and/or holding								
Unit 2 Turbine**								
5/8/12	1	1	dead 24h	Laceration: cut on body at dorsal area; Necropsied, no obvious internal injuries	Yes	No	Minor	Mechanical
5/8/12	1	4	dead 1h	LOE; Damaged operculum: slight tear; Laceration, hemorrhaged on left side of head; Damaged gill: hemorrhaged; Necropsied, no obvious internal injuries	Yes	Yes	Major	Mechanical
5/8/12	1	9	alive 48h	Hemorrhaged snout (Minor)	Yes	No	Minor	Undetermined
5/8/12	1	14	dead 24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/8/12	1	15	dead 48h	Hemorrhaged body behind right operculum; Hemorrhaged internally	Yes	Yes	Major	Mechanical
5/8/12	1	16	alive 48h	Damaged operculum: minor scrape right side	Yes	No	Minor	Mechanical
5/8/12	1	17	dead 24h	LOE; Necropsied, no obvious injuries	Yes	No	Minor	Undetermined
5/8/12	1	18	dead 24h	No visible marks on fish; Hemorrhaged internally	Yes	Yes	Major	Undetermined
5/9/12	2	20	dead 24h	Damaged gill: hemorrhaged left; Damaged operculum: slight right tear; Hemorrhaged internally; Kidneys damaged (hemorrhaged)	Yes	Yes	Major	Shear/Mechanical
5/9/12	2	22	alive 48h	Hemorrhaged upper and lower jaws	Yes	No	Minor	Undetermined
5/9/12	2	26	dead 1h	Nearly decapited; Laceration: between anal and pectoral fins; Damaged operculum: torn right; Necropsied, no obvious injuries	Yes	Yes	Major	Mechanical
5/9/12	2	28	alive 48h	LOE; Minor scrape on tail	Yes	No	Minor	Mechanical
5/9/12	2	29	alive 48h	Hemorrhaged on snout	Yes	No	Minor	Mechanical
5/9/12	2	31	dead 48h	LOE; Necropsied, no obvious injuries	Yes	No	Minor	Undetermined
5/9/12	2	32	dead 1h	LOE; Damaged operculum: torn right, Damaged gill: hemorrhaged right side; Hemorrhaged internally	Yes	Yes	Major	Shear/Mechanical
5/9/12	2	35	dead 48h	Hemorrhaged, right side of body; Necropsied, no obvious	Yes	No	Minor	Mechanical
5/12/12	5	2	alive 48h	LOE	Yes	No	Minor	Undetermined
5/12/12	5	3	dead 1h	Bruised head; LOE; Necropsied, no obvious injuries	Yes	No	Major	Mechanical
5/12/12	5	4	dead 24h	Damaged operculum: left torn; LOE; Damaged gill: hemorrhaged; Hemorrhaged internally	Yes	No	Major	Shear/Mechanical
5/12/12	5	10	dead 1h	Damaged gill: hemorrhaged; LOE; Hemorrhaged internally	Yes	Yes	Major	Shear/Mechanical
5/12/12	5	13	dead 1h	Damaged operculum: left torn; Hemorrhaged internally	Yes	Yes	Major	Shear/Mechanical
5/12/12	5	22	dead 24h	Damaged gill: hemorrhaged; Hemorrhaged internally	Yes	No	Major	Shear/Mechanical
5/12/12	5	25	alive 48h	Damaged gill: right hemorrhaged	Yes	No	Major	Shear/Mechanical
5/13/12	6	19	alive 48h	Damaged gill: left hemorrhaged	Yes	No	Major	Shear
5/13/12	6	21	alive 48h	LOE	Yes	No	Minor	Mechanical
5/13/12	6	23	dead 24h	LOE; Abraison, bruise on top of head, behind eye; Necropsied, no obvious internal injuries	Yes	Yes	Major	Mechanical
5/13/12	6	27	dead 24h	LOE; Hemorrhaged internally around liver	Yes	Yes	Major	Shear/Mechanical
5/13/12	6	31	alive 48h	Small bruise on top of head	Yes	No	Minor	Mechanical
5/13/12	6	33	dead 1h	Damaged operculum: right torn; Flesh tear at tag site; Damaged gill: hemorrhaged; Necropsied, no obvious injuries	Yes	Yes	Major	Shear
Unit 8 Turbine								
5/10/12	3	1	dead 1h	LOE; Damaged gills: hemorrhaged; Damaged eye: hemorrhaged right; Bruised tail; Hemorrhaged internally, ruptured heart	Yes	Yes	Major	Shear/Mechanical
5/10/12	3	7	alive 48h	Hemorrhaged and cut on snout	Yes	No	Minor	Mechanical
5/10/12	3	13	dead 1h	Decapitated	Yes	Yes	Major	Mechanical
5/10/12	3	16	dead 1h	LOE; Damaged operculum: scraped left; Damaged eye: hemorrhaged left;	Yes	Yes	Major	Shear/Mechanical
5/10/12	3	20	alive 48h	Hemorrhaged at mouth	Yes	No	Minor	Undetermined
5/10/12	3	22	dead 1h	Severed body	Yes	Yes	Major	Mechanical
5/10/12	3	23	alive 48h	Hemorrhaged around anal fin	Yes	No	Minor	Undetermined
5/11/12	4	28	dead 24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/11/12	4	32	alive 48h	Abrasion left side (minor)	Yes	No	Minor	Mechanical
5/11/12	4	33	dead 1h	Severed body	Yes	Yes	Major	Mechanical
5/11/12	4	34	dead 1h	Severed body towards tail	Yes	Yes	Major	Mechanical
5/11/12	4	36	dead 1h	Severed body	Yes	Yes	Major	Mechanical
5/11/12	4	39	dead 1h	Nearly decapited; Torn isthmus; Damaged eye: left missing	Yes	No	Major	Shear
5/15/12	7	1	dead 48h	No visible marks on fish	No	No	Minor	Undetermined
5/15/12	7	2	dead 1h	Decapitated	Yes	Yes	Major	Mechanical
5/15/12	7	5	alive 48h	LOE; Damaged operculum: torn right	Yes	No	Minor	Shear
5/15/12	7	6	alive 48h	Damaged operculum: minor hemorrhaged right	Yes	No	Minor	Mechanical
5/15/12	7	7	alive 48h	Scrape right side length of body	Yes	No	Major	Mechanical
5/15/12	7	8	dead 24h	LOE; Hemorrhaged under skin on head	Yes	No	Major	Mechanical
5/15/12	7	12	dead 1h	Damaged gill: hemorrhaged left	Yes	No	Major	Shear/Mechanical
5/15/12	7	17	dead 24h	Damaged eyes: both hemorrhaged	Yes	No	Major	Shear
5/15/12	7	24	dead 24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/15/12	7	41	dead 24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
5/16/12	8	1	dead 24h	Hemorrhaged on top of head; Major scale loss, > 20% per side	Yes	No	Major	Mechanical
5/16/12	8	3	dead 1h	Severed body	Yes	Yes	Major	Mechanical
5/16/12	8	5	dead 48h	Damaged eye: hemorrhaged left	Yes	No	Minor	Shear
5/16/12	8	8	dead 24h	Noted pre-release condition of patchy scale loss both sides with minor hemorraghing	No	No	Minor	Undetermined
5/16/12	8	9	dead 48h	LOE	Yes	No	Minor	Undetermined
5/16/12	8	11	alive 48h	Torn isthmus	Yes	No	Minor	Shear
5/16/12	8	12	dead 24h	Damaged operculum: right hemorrhaged and dented	Yes	No	Major	Mechanical
5/16/12	8	21	dead 24h	Major scale loss, > 20% per side	Yes	No	Major	Mechanical
5/16/12	8	22	alive 48h	Damaged operculum: left small tear	Yes	No	Minor	Shear

*Due to pump failure prior to 48 h assessment, only fish with maladies observed at 1 hr released on May 13 are included.

APPENDIX D: SHORT TERM PASSAGE SURVIVAL DATA FOR ADULT AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 2 AND KAPLAN UNIT 8, CONOWINGO PROJECT, MAY 2012. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS. DESCRIPTION OF CODES ARE PRESENTED IN TABLE 2.6-1.

Appendix D

Short term passage survival data for recaptured adult American shad passed through Francis Unit 2 and Kaplan Unit 8, Conowingo Project, May 2012. Controls released from Fisherman's Wharf downstream of Francis units. Description of codes are presented in Table 2.6-1.

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Time Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	Status Codes 2	Status Codes 3	Status Codes 4
8-May-12		**Testlot 1**			**Water temp = 18.5°C**					
				Unit 2						
1	560	10:34	10:38	*4*	4	1	*	E		
2	420	10:42	10:47	*5*	4	1	A			
3	410	10:46	10:50	*4*	4	1	A			
4	450	10:50	10:55	*5*	4	2	*	H		9
5	420	10:55	10:56	*1*	4	1	A			
6	510	11:15	11:34	*19*	4	1	A			
7	540	11:19	11:31	*12*	2	1	A			
8	530	11:40	11:43	*3*	4	1	A			
9	440	11:44	11:46	*2*	4	1	*	G		
10	500	11:46	11:50	*4*	4	1	A			
11	410	11:55	11:59	*4*	4	1	A			
12	410	11:59	12:05	*6*	4	1	A			
13	450	12:05	12:08	*3*	4	1	A			
14	460	12:09	12:14	*5*	4	1	A			
15	430	12:12	12:15	*3*	4	1	*	G		
16	420	12:16	12:20	*4*	4	1	*	9		
17	455	12:20	12:25	*5*	4	1	*	H		
18	550	12:25	12:28	*3*	4	1	A	*		
19	540	12:30	12:35	*5*	4	1	A			
20	400	12:36	12:40	*4*	4	1	A			
21	440	12:41	12:45	*4*	4	1	A			
22	390	12:46	12:50	*4*	4	1	A			
23	430	12:50	12:54	*4*	4	1	A			
24	480	12:54	12:56	*2*	4	1	A			
25	450	12:59	13:03	*4*	4	1	A			
8-May-12		**Testlot 1**			**Water temp = 18.5°C**					
				Control						
26	470	15:40	15:46	*6*	4	1	A			
27	400	15:45	15:48	*3*	4	1	A			
28	430	15:50	15:56	*6*	4	1	A			
29	360	15:56	16:00	*4*	4	1	A			
30	420	16:05	16:10	*5*	4	1	A			
31	340	16:10	16:14	*4*	4	1	A			
32	500	16:15	16:20	*5*	4	1	A			
33	440	16:20	16:24	*4*	4	1	A			
34	470	16:24	16:26	*2*	4	1	A			
35	490	16:29	16:33	*4*	4	1	A			
36	360	16:33	16:35	*2*	3	1	A			
37	410	16:38	16:40	*2*	4	1	A			
38	380	16:41	16:45	*4*	3	1	A			
39	430	16:47	16:50	*3*	4	1	A			
40	430	16:51	16:55	*4*	4	1	A			
9-May-12		**Testlot 2**			**Water temp = 19.6°C**					
				Unit 2						
16	430	11:50	11:55	*5*	4	1	A			
17	440	11:56	11:59	*3*	4	1	A			
18	460	12:00	12:05	*5*	4	1	A			
19	430	12:05	12:10	*5*	4	1	A			
20	530	12:09	12:14	*5*	4	1	*	A		
21	420	12:12	12:15	*3*	4	1			A	
22	520	12:16	12:21	*5*	4	1	*	G		
23	510	12:20	12:23	*3*	4	1	A			
24	400	12:23	12:26	*3*	4	1	A			
25	370	12:25	12:29	*4*	4	1	A			
26	490	12:30	12:35	*5*	4	2	*	7		
27	370	12:33	12:35	*2*	3	1	A			
28	490	12:36	12:40	*4*	4	1	*	H	W	
29	420	12:39	12:41	*2*	4	1	*	G		
30	440	12:41	12:46	*5*	3	1	B			
31	500	12:45	12:50	*5*	4	1	*	H		
32	400	12:49	12:55	*6*	3	2	*	H		
33	430	12:52			3	3				

17	440	11:56	11:59	*3*	4	1	A		
18	460	12:00	12:05	*5*	4	1	A		
19	430	12:05	12:10	*5*	4	1	A		
20	530	12:09	12:14	*5*	4	1	*	A	
21	420	12:12	12:15	*3*	4	1			A
22	520	12:16	12:21	*5*	4	1	*	G	
23	510	12:20	12:23	*3*	4	1	A		
24	400	12:23	12:26	*3*	4	1	A		
34	470	12:58	13:01	*3*	4	1	A		
35	430	13:01	13:09	*8*	4	1	*	G	
36	500	13:15	13:19	*4*	4	1	A		
37	500	13:20	13:22	*2*	4	1	A		
38	450	13:22	13:29	*7*	2	1	H	B	
39	420	13:25	13:31	*6*	4	1	A		
40	500	13:39	13:43	*4*	3	1	A		
9-May-12	**Testlot 2**				**Water temp = 19.6°C**				
				Control					
1	430	9:30	9:34	*4*	4	1	A		
2	410	9:33	9:36	*3*	4	1	A		
3	420	9:36	9:40	*4*	4	1	A		
4	370	9:41	9:48	*7*	4	1	A		
5	400	9:45	9:49	*4*	4	1	A		
6	420	9:49	9:52	*3*	4	1	*	G	
7	400	9:52	9:55	*3*	4	1	*	G	
8	410	9:56	9:59	*3*	4	1	A		
9	380	10:00	10:03	*3*	4	1	A		
10	480	10:05	10:09	*4*	3	1	*	8	
11	490	10:09	10:11	*2*	4	1	A		
12	430	10:11	10:15	*4*	4	1	A		
13	470	10:15	10:20	*5*	4	1	A		
14	440	10:19	10:21	*2*	4	1	A		
15	400	10:22	10:28	*6*	4	1	A		
10-May-12	**Testlot 3**				**Water temp = 18.8°C**				
				Unit 8					
1	450	8:46	8:56	*10*	4	2	*	H	
2	450	8:51	9:00	*9*	4	1	A		
3	410	8:56	9:01	*5*	4	1	A		
4	430	9:06	9:14	*8*	4	1	T	A	
5	420	9:10	9:19	*9*	4	1	T	A	
6	460	9:20	9:25	*5*	4	1	A		
7	450	9:26	9:31	*5*	4	1	*	G	
8	420	9:31	9:35	*4*	4	1	A		
9	390	9:35	9:38	*3*	4	1	A		
10	470	9:50			0	4			
11	500	9:55	9:57	*2*	4	1	A		
12	410	10:01	10:09	*8*	4	1	A		
13	400	10:13	10:21	*8*	4	2	*	7	
14	410	10:25	10:33	*8*	2	1	B	H	
15	500	10:30	10:35	*5*	4	1	A		
16	500	10:35	10:40	*5*	4	2	*	H	
17	390	10:40			2	3			
18	400	10:43	10:49	*6*	4	1	A		
19	510	10:50			0	4			
20	480	11:01	11:05	*4*	4	1	*	G	
21	480	11:10	11:20	*10*	2	1	H	B	
22	410	11:22	11:31	*9*	3	2	*	7	
23	480	11:26	11:33	*7*	4	1	*	G	
24	440	11:33	11:39	*6*	4	1	T	A	
25	410	11:37	11:45	*8*	4	1	A		
10-May-12	**Testlot 3**				**Water temp = 18.8°C**				
				Control					
26	530	12:35	12:39	*4*	4	1	A		
27	540	12:40	12:45	*5*	4	1	A		
28	590	12:45	12:50	*5*	4	1	A		
29	420	12:50	12:55	*5*	4	1	A		
30	410	12:55	12:59	*4*	4	1	A		
31	400	12:58	13:00	*2*	4	1	A		
32	420	13:02	13:06	*4*	4	1	A		
33	430	13:05	13:08	*3*	4	1	A		
34	430	13:08	13:11	*3*	4	1	A		
35	480	13:14	13:18	*4*	4	1	A		
36	500	13:15	13:20	*5*	4	1	A		
37	380	13:20	13:24	*4*	4	1	A		
38	450	13:24	13:27	*3*	4	1	A		
39	450	13:25	13:30	*5*	4	1	A		
40	510	13:30	13:35	*5*	4	1	A		
11-May-12	**Testlot 4**				**Water temp = 18.2°C**				

17	440	11:56	11:59	*3*	4	1	A		
18	460	12:00	12:05	*5*	4	1	A		
19	430	12:05	12:10	*5*	4	1	A		
20	530	12:09	12:14	*5*	4	1	*	A	
21	420	12:12	12:15	*3*	4	1			A
22	520	12:16	12:21	*5*	4	1	*	G	
23	510	12:20	12:23	*3*	4	1	A		
24	400	12:23	12:26	*3*	4	1	A		
				Unit 8					
16	400	11:01	11:05	*4*	4	1	A		
17	480	11:05	11:15	*10*	4	1	A		
18	460	11:10	11:12	*2*	4	1	A		
19	420	11:18	11:21	*3*	4	1	A		
20	410	11:20	11:25	*5*	4	1	A		
21	490	11:25	11:28	*3*	4	1	A		
22	350	11:28	11:55	*27*	4	1	T	H	R
23	460	11:31	11:40	*9*	4	1	A		
24	460	11:38	11:46	*8*	4	1	A		
25	480	11:45	11:55	*10*	4	1	A		
26	450	11:50	12:03	*13*	4	1	A		
27	430	12:05	12:10	*5*	4	1	A		
28	410	12:14	12:19	*5*	4	1	A		
29	390	12:20	12:29	*9*	4	1	A		
30	400	12:26			0	4			
31	520	12:25	12:44	*19*	4	1	A		
32	520	12:52	12:55	*3*	4	1	*	W	
33	500	12:55	13:00	*5*	2	2	*	6	
34	480	13:00	13:08	*8*	4	2	*	6	
35	530	13:04			1	3			
36	380	13:10	13:20	*10*	4	2	*	6	
37	480	13:25			0	5	R		
38	500	13:50	13:55	*5*	4	1	A		
39	380	13:55	14:00	*5*	4	2	*	7	
40	390	14:00			0	4			
11-May-12		**Testlot 4**			**Water temp = 18.2°C**				
				Control					
1	320	8:47	8:52	*5*	3	1	A		
2	360	8:50	8:55	*5*	3	1	A		
3	510	8:55	8:58	*3*	4	1	A		
4	440	8:58	9:01	*3*	4	1	A		
5	510	9:02	9:05	*3*	4	1	A		
6	380	9:05	9:09	*4*	4	1	A		
7	400	9:09	9:11	*2*	4	1	A		
8	450	9:11	9:15	*4*	4	1	A		
9	410	9:15	9:19	*4*	4	1	A		
10	410	9:20	9:25	*5*	4	1	A		
11	480	9:25	9:31	*6*	4	1	A		
12	480	9:28	9:34	*6*	4	1	A		
13	340	9:34	9:38	*4*	4	1	A		
14	470	9:36	9:41	*5*	4	1	A		
15	400	9:40	9:46	*6*	4	1	A		
12-May-12		**Testlot 5**			**Water temp = 18.3°C**				
				Unit 2					
1	410	9:15	9:24	*9*	4	1	A		
2	420	9:18	9:50	*32*	4	1	*	H	
3	410	9:27	9:32	*5*	4	2	*	G	H
4	460	9:35	9:50	*15*	4	1	*	9	H
5	430	9:57	10:02	*5*	4	1	A		
6	450	10:01	10:05	*4*	4	1	A		
7	480	10:09	10:15	*6*	4	1	A		
8	430	10:13	10:20	*7*	4	1	A		
9	420	10:17	10:22	*5*	4	1	A		
10	480	10:24	10:27	*3*	4	2	*	4	H
11	510	10:28	10:38	*10*	4	1	A		
12	490	10:31	10:40	*9*	4	1	A		
13	490	10:40	10:44	*4*	4	2	*	A	
14	440	10:43	10:45	*2*	4	1	A		
15	410	10:48	10:52	*4*	4	1	A		
16	520	10:52	10:59	*7*	4	1	A		
17	460	10:56	11:01	*5*	4	1	A		
18	530	11:03	11:09	*6*	4	1	A		
19	340	11:06	11:12	*6*	3	1	A		
20	440	11:10	11:16	*6*	4	1	A		
21	420	11:20	11:26	*6*	4	1	A		
22	490	11:24	11:29	*5*	4	1	A	*	
23	430	11:32	11:35	*3*	4	1	A		
24	430	11:36	11:41	*5*	4	1	A		

17	440	11:56	11:59	3	4	1	A			
18	460	12:00	12:05	5	4	1	A			
19	430	12:05	12:10	5	4	1	A			
20	530	12:09	12:14	5	4	1	*	A		
21	420	12:12	12:15	3	4	1			A	
22	520	12:16	12:21	5	4	1	*	G		
23	510	12:20	12:23	3	4	1	A			
24	400	12:23	12:26	3	4	1	A			
25	450	11:39	11:44	5	4	1	*	4		
12-May-12		**Testlot 5**			**Water temp =**	**18.3°C**				
				Control						
26	420	12:38	12:41	3	4	1	A			
27	450	12:43	12:46	3	4	1	A			
28	410	12:45	12:49	4	4	1	A			
29	410	12:52	12:54	2	4	1	A			
30	480	12:57	13:02	5	4	1	A			
31	410	13:02	13:05	3	4	1	A			
32	500	13:06	13:10	4	4	1	A			
33	450	13:10	13:15	5	4	1	A			
34	440	13:14	13:17	3	4	1	A			
35	470	13:19	13:24	5	4	1	A			
36	470	13:23	13:29	6	4	1	A			
37	410	13:28	13:34	6	4	1	A			
38	450	13:33	13:38	5	4	1	A			
39	510	13:39	13:46	7	4	1	A			
40	380	13:44	13:48	4	4	1	A			
13-May-12		**Testlot 6**			**Water temp =**	**20.0°C**				
				Unit 2						
16	370	11:11	11:18	7	4	1	A			
17	520	11:15	11:21	6	4	1	A		R	
18	500	11:23	11:29	6	4	1	A		R	
19	380	11:29	11:34	5	4	1	*	4		
20	410	11:32	11:38	6	4	1	A			
21	400	11:37	11:41	4	4	1	*	H		
22	500	11:41	11:46	5	4	1	A			
23	100	11:45	11:49	4	4	1	*	H		
24	330	11:51	11:55	4	4	1	A			
25	470	11:59	12:02	3	4	1	A		R	
26	430	11:59	12:03	4	4	1	A			
27	470	12:09	12:12	3	4	1	*	H		
28	450	12:13	12:23	10	4	1	A			
29	400	12:17	12:22	5	4	1	A			
30	460	12:26	12:31	5	4	1	A			
31	480	12:29	12:35	6	4	1	*	G		
32	400	12:34	12:38	4	4	1	A			
33	390	12:40	12:47	7	2	2	*	9	B	
34	420	12:49	12:54	5	4	1			A	
35	500	12:54	12:58	4	4	1	A			
36	550	12:58	13:03	5	3	1	A	R		
37	470	13:02	13:07	5	4	1	A			
38	470	13:06	13:10	4	4	1	A			
39	460	13:10	13:13	3	4	1	A			
40	430	13:15	13:20	5	4	1	A		R	
13-May-12		**Testlot 6**			**Water temp =**	**20.0°C**				
				Control						
1	510	8:27	8:40	13	4	1	A	R		
2	420	8:31	8:40	9	4	1	*	H		
3	430	8:44	8:50	6	4	1	A			
4	560	8:48	8:59	11	4	1	A	R		
5	340	8:53	8:57	4	4	1	A			
6	330	9:00	9:06	6	4	1	A	R		
7	530	9:04	9:12	8	4	1	A	R		
8	520	9:08	9:18	10	4	1	A			R
9	540	9:17	9:22	5	4	1	*	H	R	
10	410	9:22	9:27	5	4	1	A			
11	430	9:26	9:31	5	4	1	A			
12	520	9:31	9:39	8	4	1	A		R	
13	550	9:35	9:53	18	4	1	*	H	R	
14	410	9:47	9:53	6	4	1	A			
15	530	9:56	10:10	14	4	1	*	H	R	
15-May-12		**Testlot 7**			**Water temp =**	**22.0°C**				
				Unit 8						
1	400	9:15	9:21	6	4	1	A			
2	510	9:19	9:40	21	1	2	*	7		
3	460	9:24	9:30	6	4	1	A			
4	540	9:34	9:50	16	4	1	A			
5	490	9:45	9:56	11	4	1	*	H	9	

17	440	11:56	11:59	*3*	4	1	A			
18	460	12:00	12:05	*5*	4	1	A			
19	430	12:05	12:10	*5*	4	1	A			
20	530	12:09	12:14	*5*	4	1	*	A		
21	420	12:12	12:15	*3*	4	1			A	
22	520	12:16	12:21	*5*	4	1	*	G		
23	510	12:20	12:23	*3*	4	1	A			
24	400	12:23	12:26	*3*	4	1	A			
6	430	9:54	10:03	*9*	4	1	*	9		
7	520	9:59	10:06	*7*	4	1	*	W		
8	500	10:07	10:14	*7*	4	1	*	H		
9	500	10:11	10:14	*3*	4	1	A			
10	500	10:17			0	4				
11	520	10:21			0	4				
12	510	11:14	11:24	*10*	4	2	*	4		
13	550	11:18	11:23	*5*	4	1	A			
14	420	11:25	11:31	*6*	4	1	A			
15	470	11:30	11:38	*8*	4	1	A			
16	500	11:35	11:39	*4*	4	1	A			
17	480	11:42	11:59	*17*	4	1	A			*
18	420	11:46	12:09	*23*	2	1	T	B		
19	420	12:04	12:17	*13*	4	1	T	A		
20	520	12:09	12:16	*7*	4	1	A			
21	450	12:20	12:28	*8*	4	1	A			
22	460	12:25	12:41	*16*	4	1	A			
23	410	12:31	12:42	*11*	4	1	A			
24	450	12:44	12:54	*10*	4	1	A			
25	450	12:48	12:55	*7*	4	1	A			
41	360	13:00	13:09	*9*	4	1	A			
42	530	13:06	13:15	*9*	4	1	A			
43	390	13:12	13:22	*10*	4	1	A			
15-May-12		**Testlot 7**			**Water temp = 22.0°C**					
				Control						
26	540	14:26	14:33	*7*	4	1	A			
27	410	14:30	14:35	*5*	4	1	A			*
28	450	14:37	14:41	*4*	4	1	A			
29	490	14:42	14:46	*4*	4	1	A			
30	540	14:47	14:53	*6*	4	1	A			
31	430	14:52	14:56	*4*	4	1	A			
32	480	14:57	15:03	*6*	4	1	A			
33	380	15:01	15:09	*8*	4	1	A			
34	440	15:06	15:10	*4*	4	1	A			
35	420	15:13	15:18	*5*	4	1	A			
36	400	15:16	15:21	*5*	4	1	A			
37	410	15:20	15:23	*3*	4	1	A			
38	430	15:24	15:36	*12*	4	1	A			
39	370	15:29	15:42	*13*	4	1	A			
40	430	15:35	15:43	*8*	4	1	A			
16-May-12		**Testlot 8**			**Water temp = 20.0°C**					
				Unit 8						
1	510	9:12	9:18	*6*	4	1	*	G		
2	510	9:16	9:20	*4*	4	1	A			
3	450	9:21	9:30	*9*	4	2	*	6		
4	330	9:25	9:29	*4*	4	1	A			
5	460	9:32	9:39	*7*	4	1	*	8		
6	490	9:36	9:45	*9*	4	1	A			
7	440	9:42	9:47	*5*	4	1	A			
8	520	9:51	9:56	*5*	4	1	A			
9	490	9:54	9:57	*3*	4	1	*	H		
10	520	9:59	10:07	*8*	4	1	A			
11	460	10:03	10:08	*5*	4	1	*	F		
12	460	10:10	10:13	*3*	4	1	*	9		
13	470	10:18	10:21	*3*	4	1	A			
14	490	10:21	10:28	*7*	4	1	A			
15	380	10:42	10:49	*7*	4	1	A			
16	490	10:45	10:52	*7*	4	1	A			
17	440	10:52	10:59	*7*	4	1	A			
18	380	10:56	11:00	*4*	4	1	A			
19	410	11:02	11:06	*4*	4	1	A			
20	370	11:06	11:12	*6*	4	1	A			
21	540	11:09	11:17	*8*	4	1	A		*	
22	490	11:16	11:27	*11*	4	1	*	9		
23	480	11:21	11:25	*4*	4	1	A			
24	470	11:29	11:35	*6*	4	1	A			
25	450	11:31	11:41	*10*	4	1	T	H		
16-May-12		**Testlot 8**			**Water temp = 20.0°C**					
				Control						

17	440	11:56	11:59	*3*	4	1	A		
18	460	12:00	12:05	*5*	4	1	A		
19	430	12:05	12:10	*5*	4	1	A		
20	530	12:09	12:14	*5*	4	1	*	A	
21	420	12:12	12:15	*3*	4	1			A
22	520	12:16	12:21	*5*	4	1	*	G	
23	510	12:20	12:23	*3*	4	1	A		
24	400	12:23	12:26	*3*	4	1	A		
26	400	12:43	12:48	*5*	4	1	A		
27	380	12:46	12:50	*4*	4	1	A		
28	420	12:52	12:55	*3*	4	1	A		
29	520	12:56	13:09	*13*	4	1	A		
30	500	13:00	13:08	*8*	4	1	A		
31	470	13:12	13:21	*9*	4	1	A		
32	450	13:15	13:22	*7*	4	1	A		
33	410	13:24	13:30	*6*	4	1	A		
34	430	13:29	13:33	*4*	4	1	A		
35	510	13:34	13:47	*13*	4	1	*	H	
36	390	13:37	13:42	*5*	4	1	A		
37	460	13:47	13:52	*5*	4	1	A		
38	480	13:51	13:54	*3*	4	1	A		
39	400	13:56	14:00	*4*	4	1	A		
40	430	13:59	14:04	*5*	4	1	A		

FINAL STUDY REPORT
ESTIMATION OF SURVIVAL OF JUVENILE AMERICAN SHAD PASSED THROUGH FRANCIS TURBINES

RSP 3.2

CONOWINGO HYDROELECTRIC PROJECT

FERC PROJECT NUMBER 405

Prepared for:

Prepared by:

Normandeau Associates, Inc.

Gomez and Sullivan Engineers, P.C.

August 2012

EXECUTIVE SUMMARY

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt Conowingo Hydroelectric Project (Conowingo Project). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. FERC issued the final study plan determination for the Project on February 4, 2010, approving the revised study plan with certain modifications. FERC's study plan determination did not contain any requirements to conduct field-based entrainment and mortality studies at the Conowingo Project. On February 24, 2010, Maryland's Department of Natural Resources (MDNR) and Department of the Environment (MDE) filed a notice to initiate the formal study dispute resolution process.

On September 30, 2010, Exelon and MDNR/MDE reached an agreement regarding the February 24, 2010 study dispute notice for the Conowingo Project. Conditions of the agreement, in part, stipulated that MDNR and MDE would formally withdraw their February 24, 2010 notice, and Exelon would conduct a field-based validation study for American shad (*Alosa sapidissima*) to supplement its literature-based turbine passage survival estimates related to Conowingo RSP 3.2-Downstream Fish Passage Effectiveness Assessment, which was filed with FERC on March 31, 2011. The study would provide entrainment survival rates for juvenile American shad through a Francis unit and for adult American shad through a Francis unit and a Kaplan unit. The specific methodologies were developed in a revised study plan, developed in consultation with stakeholders.

An initial study report (ISR) was filed on January 23, 2012, containing Exelon's 2011 study findings. The deadline for formal comments on the ISR including requested study plan modifications was April 23, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the ISR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

In 2011, Exelon completed the field study to assess the injury/survival rate of juvenile American shad passing through a Francis unit turbine at the Conowingo Project, which is the subject of this report. The survival probabilities (1 and 48 h) and injury rates for juvenile American shad were obtained using the HI-Z Turb'N Tag (HI-Z Tag) recapture technique between October 10-15, 2011. The juvenile American shad ranged in size from 106 to 142 mm (total length) with an average size of 119 mm. The effects of turbine passage at Unit 5 was assessed with 138 treatment fish and 76 control fish released downstream of the turbine discharge.

Recapture rates (physical retrieval of live and dead shad) were 88.4 and 97.4% for treatment and control fish, respectively. Mean recapture times of treatment and control fish were 5.2 and 3.7 minutes after release, respectively. The combination of high recapture rates (treatment 88.4% and control 97.4%) and control survival (89.5%) provided a statistically valid survival estimate for juvenile American shad passing through the aerated Francis Unit 5 at the Conowingo Project.

The turbine passage survival was estimated at 89.9% with 90% confidence intervals of $\leq \pm$ 5.5% well below the desired precision (ε) of ±10%, 90% of the time ($\alpha = 0.10$).

Malady-free rate (free of visible injuries, >20% scale loss per side and loss of equilibrium) of recaptured juvenile American shad passed through Unit 5 was 93.3%. Of the fish examined upon retrieval, and at 48 h post passage, 14% (17 out of 122) of the treatment fish displayed visible injuries and 9.5% (7 out of 74) of the control fish also displayed visible injuries. At least three of the seventeen and five of the seven injuries to the treatment and control fish, respectively were attributed to handling and/or holding rather than to turbine passage. The prominent injury observed was hemorrhaging on the head and snout.

Although data on passage survival of juvenile American shad for relatively large Francis units are scant in literature, the estimated survival for Francis Unit 5 is within that reported for similar sized Francis units (≥ 3,000 cfs, runner diameter >110 in, buckets 13-17).

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LIST OF ABBREVIATIONS

C	Celsius, Centigrade
cfs	cubic feet per second
CI	confidence interval
FERC	Federal Energy Regulatory Commission
ft	foot/feet
gal	gallon
h	hour
in	inch
km	kilometer
lb	pound
LOE	loss of equilibrium
mm	millimeter
MDE	Maryland Department of Environment
MDNR	Maryland Department of Natural Resources
Mhz	megahertz
MW	megawatt
ppt	parts per thousand
rpm	revolutions per minute
SRAFRC	Susquehanna River Anadromous Fish Restoration Commission

1.0 INTRODUCTION

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt Conowingo Hydroelectric Project (Conowingo Project). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. FERC issued the final study plan determination for the Project on February 4, 2010, approving the revised study plan with certain modifications. FERC's study plan determination did not contain any requirements to conduct field-based entrainment and mortality studies at the Conowingo Project. On February 24, 2010, Maryland's Department of Natural Resources (MDNR) and Department of the Environment (MDE) filed a notice to initiate the formal study dispute resolution process.

On September 30, 2010, Exelon and MDNR/MDE reached an agreement regarding the February 24, 2010 study dispute notice. The agreement stipulated, in part, that MDNR and MDE would formally withdraw their notice and that Exelon would conduct a field-based validation study for American shad (*Alosa sapidissima*) to supplement its literature-based turbine passage survival estimates related to Conowingo RSP 3.2-Downstream Fish Passage Effectiveness Assessment, which was filed with FERC on March 31, 2011. The study would provide entrainment survival rates for juvenile American shad through a Francis unit and for adult American shad through a Francis unit and a Kaplan unit. The specific methodologies were developed in a revised study plan, developed in consultation with stakeholders.

This field-based study, using the HI-Z Turb'N Tag (HI-Z tag) recapture technique (Heisey *et al.*, 1992), was designed to provide survival and injury estimates of juvenile American shad passed through a Francis turbine at Conowingo Project. An earlier study provided survival estimates of juvenile American shad passed through Kaplan Unit 8 at Conowingo Project (RMC 1994).

An initial study report (ISR) was filed on January 23, 2012, containing Exelon's 2011 study findings. The deadline for formal comments on the ISR including requested study plan modifications was April 23, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the ISR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

1.1 Project Description

The Conowingo Dam is a large hydroelectric dam on the Lower Susquehanna River (Figure 1.1-1). Built in 1928, Conowingo Dam is classified as a medium-height, masonry gravity-type dam. The dam is located in Maryland, spanning the Cecil and Harford county border, 9.9 miles (16 km) from the river mouth at the Chesapeake Bay, about 5 miles (8 km) south of the Pennsylvania border, and 45 miles (72 km) northeast of Baltimore. The powerhouse has a generating capacity of 573 megawatt (MW) and a hydraulic capacity of 86,000 cubic feet per second (cfs) provided by seven vertical Francis turbines (Units 1-7) and four Kaplan turbines (Units 8-11) (Table 1.1-1 and Appendix A). The Francis units have hydraulic capabilities ranging from 6,320 to 6,749 cfs. The hydraulic capabilities of the Kaplan units range from 9,352 to 9,727 cfs. The design head is 89 and 86 ft for the Francis and Kaplan units, respectively.

2.0 Study Design

2.1 Objectives

The specific objectives of the study were to: (1) estimate survival (1 h and 48 h post passage) of juvenile American shad passing through a Francis unit at the Conowingo Project while operating at a typical discharge; (2) determine survival estimates with a precision of ± 10%, 90% of the time; and (3) determine injury rate, type, cause, and severity.

2.2 Turbine Description

There are two types of Francis turbines at the Conowingo Project in addition to two smaller Francis turbines (known as the house units) that service the Conowingo powerhouse (Table 1.1-1). The Conowingo turbine fish assessment did not include testing of survival through the house units due to their small contribution to total station discharge. Additionally, the small trash bar opening (1.5 inch) on those units could deter juvenile American shad from being entrained. The trash bar spacing for all the other units is 5.4 inches.

Five of the seven Francis turbines (Units 1, 3, 4, 6, and 7) are equipped with conventional air venting systems. Units 2 and 5 are equipped with aeration runners. Structurally the seven Francis units are virtually identical except that the trailing edge of the aerated blades on Units 2 and 5 is thicker. Structural features that may affect fish survival include the number of blades or buckets, clearances between buckets or blades, differences in runner diameter or speed, gaps between blade and hub and blade tip and discharge ring, number and orientation of wicket gates and stay vanes, and shape and thickness of the leading edge of the blades, (Amaral *et al.*, 2008; Franke *et al.*, 1997; Normandeau Associates *et al.*, 1996, 2000; Dresser *et al.*, 2006). The number of runner blades or buckets, runner speed (rpm), and runner diameter are generally considered the most important features affecting survival of turbine passed fish.

Francis Unit 5 (aerated) was selected as the turbine for testing rather than a non aerated unit to evaluate a potentially worst case scenario for juvenile American shad. Unit 5 has 13 blades (buckets), a runner diameter of 203 in, 24 wicket gates, and blade tip speed of 72.5 ft/s (Table 1.1-1). Typical output is 36 MW at a discharge near 6,320 cfs at a rated head of 89 ft. Fish passage through Unit 5 was tested at near-peak efficiency, the settings the unit operates at most of the time when juvenile American shad would be moving past the Conowingo Project. During testing, Unit 5 outputs ranged from 33 to 36 MW, average discharge was 5,080 cfs, and operational head ranged from 85 to 91 ft (Table 1.1-1 and Appendix A).

2.3 Sample Size

One of the main objectives prior to the implementation of this study was the statistical determination of the number of fish to be released to obtain an estimate of turbine passage survival of juvenile American shad within a precision (ε) level of ± 10%, 90% of the time (α=0.10). Appendix B-1 provides the equations used to calculate sample size and precision (ε) for this study. Since the sample size is a function of the recapture rate (P_A), expected passage survival (τ) or mortality (1- τ), survival of control fish (S), and the desired precision (ε) at a given probability of significance (α), we used a range of values for these parameters to calculate potential sample sizes for various combinations of these parameters. Initially, for the present study sample size calculations, the following range of values was assumed for these parameters: recapture probabilities (P_A) of 85 to 98%; control survival: 95 to 100%; and turbine passage survival of 90 to 97%.

Required sample sizes are shown in Table 2.3-1 for various combinations of values of the above parameters. Based on several studies on juvenile clupeids (e.g., Heisey *et al*. 1992; Mathur *et al.* 1994,1996) utilizing the HI-Z tag-recapture technique, we targeted for a release of 150 treatment fish (introduced through the test turbine) accompanied by a release of 75 control fish downstream of the powerhouse to obtain a precision (ε) of ± 0.10 on survival estimate at α = 0.10. This sample size assumes 95% control survival, a recapture rate of 85%, and expected passage survival rates of close to 90% for the study. Because of the embedded flexibility in the HI-Z tag-recapture technique, the sample size requirements can be adjusted downwards or upwards to achieve the desired statistical precision level if the initial assumptions deviated significantly during the course of the study. In general, sample size requirements decrease with an increase in control fish survival and recapture rates (Mathur *et al.*1996a). Only precision (ε) and α level can be controlled by the investigator. A total of 138 treatment and 76 control fish were released on October 11-13, 2011 to obtain these estimates (Table 2.3-2).

2.4 Source of Test Fish

Approximately 500 juvenile American shad for this study were transported from the MDNR Manning Fish Hatchery on October 4, 2011. Fish were initially stocked in a 950 gal tank at the Muddy Run Project which was supplied with ambient river water and then transferred (October 7) to Conowingo Dam. Water temperatures ranged from 16.1°C to 16.4°C during the study period coinciding with emigration of juvenile American shad in the Lower Susquehanna River (SRAFRC Annual Reports 1991-2006). Control fish were placed in 600 gal holding tanks located below the Dam, at the Fishermans Wharf, and treatment fish were placed in two 600 gal tanks located on the head works near Unit 5. These circular tanks (Figure 2.4-1) were continuously supplied with ambient river water. A 50 lb block of salt was initially added to the tanks when fish were stocked and before fish were removed for tagging. The block of salt raised salinity in the tanks to near 5 ppt, which was gradually diluted by the ambient river water. Sufficient fine granular salt was also added to the tagging tub and fish transfers bucket to provide salinity near 5 ppt. The addition of salt to the holding pools reduced osmotic and ionic imbalances in the fish due to handling stress and minimized adverse effects of handling as clupeids are known to be extremely sensitive to handling stress (Heisey *et al*., 1992; Meinz 1978).

2.5 Fish Tagging and Release

Fish tagging, release, and recapture techniques were similar to those used in numerous other studies including those at the Conowingo Project (Heisey *et al*., 1992, 2008; RMC 1994; Normandeau Associates 1996). Each fish was corralled in the holding tank with a fine mesh seine net (Figure 2.5-1) and then removed while in water by a brailer (Figure 2.5-2). Each fish was fitted with a miniature radio transmitter and a HI-Z Tag (Figure 2.5-3). The radio tags were approximately 6 x 12 mm, weighing 0.5 g in air and propagated radio signals through a 27 cm thin wire antenna. The un-inflated HI-Z Tags were made of bright-colored latex 30 mm long and 10 mm wide and weighing 1.7 g. Tags were attached to the fish by a single stainless steel pin through the dorsal musculature near the insertion of the dorsal fin. The pin was inserted with a modified ear piercing gun and secured by a small plastic disc (Heisey *et al*., 1992; RMC 1994). Just prior to release into the induction system (Figure 2.5-4), the HI-Z tags were activated by injecting 1-1.5 ml of catalyst (Figure 2.5-5).

Tagged fish were introduced individually into the penstock of Unit 5 (treatment) by an induction apparatus (Figures 2.5-4 and 2.5-6). The induction apparatus consisted of a holding basin attached to a 4-inch discharge hose. A 3 or 4 inch trash pump supplied river water to ensure that fish were transported quickly within a continuous flow of water to the release point. The release hose was secured to the downstream side of the intake trash rack with the terminus positioned near elevation 48 ft that released fish approximately10 ft below the elevation of the intake ceiling of Unit. 5 (Figure 2.5-6).

Procedures for handling, tagging, release and recapture of control fish were similar to those used for treatment fish. The control fish were released directly into the tailrace from the Fisherman's Wharf (Figure 2.4-1).

A pretest was conducted on October 10, releasing five treatment and five control juvenile American shad to ensure the induction system was working well and to identify potential fish recapture issues. Data from this pretest was not included in the survival estimation for this study. A total of 148 treatment and 78 control fish were released on October 11-13 (Table 2.3-2 and Appendix C-1). However, some of these fish had to be removed from the analysis (10 treatment and 2 control fish) due to unrecoverable conditions (in turbulent areas, entrapment, in rip-rap), and tag failure.

Thus, the effective sample size for survival estimation was 138 treatment (passed through Francis Unit 5) and 76 control fish (released downstream from the Fisherman's Wharf).

Fish showing erratic behavior or external injuries and/or fungal infections were rejected and not used. Fish length measurements were only taken on recaptured fish and measured at the 48 h assessment period. The treatment fish ranged in total length from 106 mm to 140 mm, with an average length of 119 mm (Figure 2.5-7). The control fish ranged in length from 107 mm to 142 mm, with an average length of 118 mm.

2.6 Recapture Methods

After release (treatment and control), the fish were tracked downstream of the Conowingo Project by two boat crews and then retrieved once buoyed to the surface by the inflated HI Z tag (Figure 2.6-1). Boat crews were notified of the radio tag frequency (48 or 49 MHz) for each fish upon its release. Advanced Telemetry System receivers with a loop or a 5-element Yagi antenna were utilized in tracking both treatment and control fish. Fish that failed to surface shortly after passage were monitored via radio signals for a minimum of 30 minutes.

Boat crews retrieved buoyed fish by a net with a water sanctuary or water brailer to reduce handling and stress. Recaptured fish were placed into a 4 gal pail where tags were removed. To the extent possible, fish were kept in water during recapture and examination. Each fish was immediately examined for maladies including visible injuries, scale loss >20% per side, and/or loss of equilibrium, and were assigned appropriate condition codes (Table 2.6-1 and 2.6-2). Tagging and data recording personnel were notified via a two-way radio system of each fish's recapture time and condition (Appendix D).

Recaptured fish were transported to shore and held in holding pools (600 and 900 gal) to monitor delayed (48 h) effects of tagging and turbine passage (Figure 2.4-1). The holding pools were continuously supplied with ambient river water. A 50 lb block of salt was placed in each of the pools to initially provide salinity near 5 ppt although the continuous flow gradually diluted the salt concentration. Additionally sufficient fine granular salt was also added to the fish transfers bucket to provide salinity near 5 ppt.

The pools were covered to prevent escapement and minimize external stressors. To further minimize handling stress, all measurements were taken at the end of the 48 h assessment period or at the time of mortality. Mortalities in the holding pools were retrieved after 24 h and 48 h. Fish that were alive after 48 h and free of major injuries were released into the river.

2.7 Classification of Recaptured Fish

As in previous turbine passage investigations (Heisey *et al.*, 1992; Mathur *et al.*, 1994, 1996a, 1996b), the immediate post passage status of each recaptured fish and recovery of inflated tags dislodged from fish were designated as alive, dead, or unknown. The following criteria have been established to make these designations: (1) alive—recaptured alive and remaining so for 1 h; (2) alive—fish does not surface but radio signals indicate movement patterns; (3) dead—recaptured dead or dead within 1 h of release; (4) dead—only inflated dislodged tag(s) are recovered, or telemetric tracking or the manner in which inflated tags surfaced is not indicative of a live fish; and (5) unknown—no fish or dislodged tag is recaptured, or radio signals are received only briefly, and the subsequent status cannot be ascertained. Fish that moved into areas where they could not be recaptured (i.e., at rip rap along the shore, in submerged crevices, or in areas of high turbulence) were excluded from the statistical analysis. Mortalities of recaptured fish occurring after 1 h were assigned 48 h post passage status effects, although the fish were observed at approximately 12 h intervals during the interim.

2.8 Assessment of Fish Injuries

All recaptured fish were examined for types and extent of external injuries. Dead fish were also necropsied for internal injuries when there were no apparent external injuries. Additionally, all specimens alive at 48 h were closely examined for injury. The initial examination allowed detection of some injuries, such as bleeding and minor bruising that may not be evident after 48 h due to natural healing processes. Injuries were categorized by type, extent, and area of body. Fish without visible injuries that were not actively swimming or were swimming erratically at recapture were classified as having "loss of equilibrium" (LOE). This condition has been noted in most past HI-Z tag direct survival/injury studies and often disappears within 10 to 15 min after recapture if the fish is not injured. Visible injuries and LOE were categorized as minor or major (Table 2.6-2). The criteria for this determination are based primarily on Normandeau personnel field observations.

Fish without visible injuries and/or loss of equilibrium were designated "malady-free". The malady-free metric is established to provide a standard way to depict a specific passage route's effects on the condition of entrained fish (Normandeau Associates *et al.*, 2006). The malady-free metric is based solely on fish physically recaptured and examined. Additionally, the malady-free metric in concert with site-specific hydraulic and physical data may provide insight into which passage conditions and locations present safer fish passage.

2.9 Estimation of Survival and Malady-Free

The release and recapture data were analyzed by a likelihood ratio test to determine whether recapture probabilities were similar for dead (P_D) and alive (P_A) fish (Mathur *et al*. 1996). The statistic tested the null hypothesis of the simplified model (Ho: P_A=P_D) versus the alternative generalized model (Ha: $P_A \neq P_D$). The simplified model has three parameters (P, S, τ) with three minimum sufficient statistics (a_c, a_T , d_T) while the alternative generalized model (recapture probabilities of alive and dead fish are unequal) has four parameters (P_A, P_D, S, τ) and four minimum sufficient statistics (a_c, , a_T, d_c, d_T). If homogeneity (P > 0.05) was revealed by the chi-square test, turbine passage survival can be estimated by the simplified model with increased precision. Appendix B-1 provides the definition of terms, derivation of likelihood estimates, and assumptions of the likelihood model. The maximum likelihood estimators associated with the model are:

$$\hat{\tau} = \frac{a_T R_C}{R_T a_C}$$

$$\hat{S} = \frac{R_T d_C a_C - R_C d_T a_C}{R_C d_C a_T - R_C d_T a_C}$$

$$\hat{P}_A = \frac{d_C a_T - d_T a_C}{R_T d_C - R_C d_T}$$

$$\hat{P}_D = \frac{d_C a_T - d_T a_C}{R_C a_T - R_T a_C}$$

The variance (Var) and standard error (SE) of the estimated passage mortality ($1-\hat{\tau}$) or survival ($\hat{\tau}$) are:

$$Var(1-\hat{\tau}) = Var(\hat{\tau}) = \frac{\tau}{SP_A}\left[\frac{(1-S\tau P_{A)}}{R_T} + \frac{(1-SP_A)\tau}{R_C}\right]$$

$$SE(1-\hat{\tau}) = SE(\hat{\tau}) = \sqrt{Var(1-\hat{\tau})} \; .$$

Separate survival probabilities (1 and 48 h), malady-free estimates, and their associated standard errors were estimated using the likelihood model given in Appendix B-1. The formulas are:

Survival (τ), 1 and 48 hours

Where:

$$\hat{\tau}_i = \frac{a_{Ti}I}{R_{Ti}c}$$

R_{Ti} = Number of fish released for the treatment condition
a_{Ti} = Number of fish alive for the treatment condition;
R_c = Number of control fish released;
a_c = Number of control fish alive.

Malady-Free (MF) Fish

Where:

$$MF_i = \frac{c_{Ti}R_c}{R_{Ti}c_c}$$

C_{Ti} = Total number of fish without maladies for treatment;
R_{Ti} = Number of fish recovered that were examined for maladies for treatment;
C_c = Number of control fish recovered without maladies;
R_c = Number of control fish recovered that were examined for maladies.

Since the likelihood ratio tests showed equality of P_A and P_D ($P>0.05$), survival and malady-free estimates were made using the reduced model. Appendix B-1 presents outputs of these analyses along with estimates of standard errors.

2.10 Assignment of Probable Sources of Injury

Limited controlled experiments (Neitzel *et al*., 2000; Pacific Northwest National Laboratory *et al*., 2001) to replicate and correlate each injury type/characteristic to a specific causative mechanism provides some indication of the cause of observed injuries in the field. Some injury symptoms can be manifested by two different sources that may lessen the probability of accurate delineation of a cause and effect relationship (Eicher Associates 1987). Only probable causal mechanisms of injury were assigned for the present investigation.

Injuries likely to be associated with direct contact of turbine runner blades or structural components are classified as mechanical and include: bruise, laceration, and severance of the fish body (Dadswell *et al*., 1986; Eicher Associates 1987). Passage through gaps between the runner blades and the hub, or at the distal end of the blades may result in a pinched body. Injuries likely to be attributed to shear forces are decapitation, torn or flared opercula, and hemorrhaged eyes (Neitzel *et al*., 2000).

3.0 Results

3.1 Recapture Rates

The HI-Z tag recapture technique performed satisfactorily with generally high recapture rates (physical retrieval of live and dead fish). Recapture rates for the treatment and control fish were 88.4% (122 out of 138) and 97.4% (74 out of 76), respectively (Table 3.1-1). Dislodged inflated HI-Z tags (without fish) were recaptured on five (3.6%) treatment fish. The status of two (1.4%) treatment fish could not be determined. Fish with dislodged tags were assigned a dead status. The two unrecaptured control fish were assigned a 1 h mortality status (Table 3.1-1). Six of the control fish died during the 48 h delayed assessment period resulting in a control survival of 89.5%

3.2 Recapture Times

Recapture times (the time interval between fish release and subsequent recapture) for the treatment fish passed through Unit 5 was 5.2 minutes. The average recapture time for control fish was 3.7 minutes. The longest time before recapture was 20 minutes for a treatment fish (Figure 3.1-1). The difference in recapture times between the treatment (5.2 min) and control (3.7 min) was due primarily to boating condition in immediate tailrace.

3.3 Survival Estimates

Because the likelihood ratio statistic detected equality in recovery probabilities of alive (P_A) and dead (P_D) fish ($P_A = P_D$), survival estimates derived from the reduced model were used (Table 3.1-1 and Appendix B-2). The estimated immediate (1 h) survival was 89.9% (90% CI = 84.1-95.7%). The estimated 48 h was 91.2% (90% CI = 83.1-100.0%). Since the 48 h survival cannot exceed the estimated 1 h survival, the study survival was established at 89.9%. The slightly higher estimated 48 h survival resulted from a slightly higher loss of control fish relative to the treatment group held for 48 h assessment (Appendix B-2 and B-3). This situation is not uncommon, particularly in turbine passage studies on juvenile clupeids (Mathur *et al*. 1996b).

3.4 Post-Passage Injury Rate, Types, and Probable Source

All of the 122 post turbine passage recaptured treatment fish (88.4%) were examined for injuries. Of the 122 fish, 103 fish (84.5%) had no visible injuries or loss of equilibrium (LOE). A total of 17 (13.9%) of the treatment fish had visible injuries and another two (1.6%) displayed only loss of equilibrium (LOE) (Table 3.4-1 and Appendix C-2 through C-4). Some fish displayed more than one type of injury.

The primary injury type observed on treatment fish was hemorrhaging on the head and snout, which occurred on 15 fish (12.3%). Five fish (4.1%) displayed >20% scale loss per side. Four fish (3.3%) had damaged eyes. Three fish (2.5%) had damaged operculum.

All but two of the 76 control fish released were examined (97.4%) and seven (9.5%) had injuries. Five control fish (6.8%) had hemorrhaging around the head and snout, which was attributed to the sensitivity of American shad when handling or holding. At least three of the treatment fish displayed similar type hemorrhaging around the head and snout, which was also likely due to handling and holding in pools, and not due to turbine passage (Figure 3.4-1). The remaining two control fish (2.7%) had major scale loss and LOE at recapture (Appendix C-4).

Mechanical forces alone, or in combination with shear, were attributed to most observed injuries (13 of 19 or 68%) on the turbine passed fish displaying injuries (Table 3.4-2). The mechanical injuries were likely caused by blade strike or contact with other structures within the flow path. A majority of the maladies (12 of 19 or 63%) inflicted during turbine passage were classified as minor. All dead fish (treatment and controls) were necopsied and no internal injuries were observed.

3.5 Malady-Free Estimates

Malady-free estimates (i.e., fish free of passage-related maladies) are presented in Table 3.5-1. Malady-free estimate rates were adjusted by any maladies incurred by control fish. The malady-free estimate for recaptured fish was 93.3% with a 90% CI of ± 8.3%. The desired precision (within ± 10%, 90% of the time) on the malady-free estimates was met.

4.0 FINDINGS AND CONCLUSIONS

Two primary objectives of this field-based validation study of the Conowingo Project Francis Unit 5 (aerated) were: (1) corroboration of literature derived survival estimates of small sized fish (Conowingo RSP 3.2-Downstream Fish Passage Effectiveness Assessment); and (2) release of a sufficient number of juvenile American shad through the turbine such that the resulting survival estimate would be within < ± 10%, 90% of the time (α = 0.10). Both of these objectives were met. A release of 138 treatment fish through the Francis Unit 5 and 76 control fish released into the tailrace were sufficient to meet the specified precision (ε) level. The 90% (α = 0.10) confidence limits on the estimated survival (89.9%) of turbine Unit 5 fish were within < ± 5.5%.

The turbine passage survival/injury estimates can be considered valid, given use of appropriate underlying assumptions and an appropriate model to fit the data (Burnham *et al.*, 1987; Mathur et al,. 1996a). The following factors, primarily related to the tag-recapture process, were assumed valid: handling, tagging, and release procedures did not differentially affect the survival rates of control and treatment groups; and both the treatment and control groups were exposed to similar tailrace conditions. A potential source of bias due to non-selective retrieval of treatment and control groups was minimized by not assigning a specific boat recovery crew to recapture either treatment or control fish.

Adjusted for injury rates of control group, the estimated malady-free rate of turbine-passed fish was 93.3%. The dominant injury observed was hemorrhaging in the head and snout, some of which was attributed to handling and holding in the pools.

Even though literature is scant on passage survival estimates of juvenile clupeids (American shad and river herrings) through Francis turbines and no two turbines may be identical relative to hydraulic, structural, and mechanical characteristics, some perspective on Conowingo Francis Unit 5 survival can be gained from comparisons with the available data (Table 4.0-1). The estimated 1 h survival of juvenile shad in passage through Conowingo Francis Unit 5 (89.9%) is virtually identical (89.4 and 90.5%) to that for the two turbines with single runners and 13 to 16 buckets at the Holtwood Station (Normandeau Associates 1997; RMC 1992). However, Conowingo Unit 5 survival is lower than that reported (94.7%) for the Vernon Project on the Connecticut River. A portion of this noted difference may be due to a relatively smaller sized fish (92 mm) used at Vernon versus 119 mm long fish used at the Conowingo Project. Because of small runner diameter (narrower water passage), greater number of buckets, and dual vertical runner at York Haven, the lowest shad survival (77.1%) was reported at this project (Normandeau Associates 2001). A test of a double runner turbine at Holtwood yielded a 1 h survival rate of 83.5%.

The probability of fish contact with structural components increases as the number of these components increases (Franke *et al.* 1997).

The survival (89.9%) and malady-free (93.3%) rates of juvenile American shad passed through the Francis turbine at the Conowingo Project was lower than that obtained at the larger Kaplan Unit 8 at the Conowingo Project (RMC 1994). In that study the 1 and 48 h direct survival estimates of juvenile American shad (100-149 mm fork length) passed through Unit 8 were 94.9 and 92.9%, respectively. In that study, a total of 95 treatment and 100 control fish were recaptured and examined for visible injuries, scale loss and loss of equilibrium (maladies). Eight (8.4%) of the treatment fish and nine (9.0%) of the control fish had maladies and when adjusted for controls, the malady-free rate for the Kaplan turbine passed fish was 100%. The Kaplan units are larger than the Francis units (runner diameter 225 in versus 203 in) and have fewer blades (6 versus 13), which likely account for the better survival and lower injury rate.

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TABLE 1.1-1: CHARACTERISTICS OF CONOWINGO TURBINES AND OPERATIONAL CONDITIONS OF UNIT 5 DURING JUVENILE SHAD PASSAGE TESTS.

Turbine Characteristics		1,3,4,6,7	2,5	8	9-11	2 House Units
Turbine Type		Francis	Francis	Kaplan	Kaplan	Francis
Rated Turbine Output (MW)		47.7	36.0*	65.0	65.0	1.2
Hydraulic Capacity at Rated Output (cfs)		6,749	6,320*	9,352	9,727	247
Minimum Hydraulic Capacity (cfs)		4,200	2,000	7,500	7,800	210
Design Head (ft)		89	89*	86	86	89
Number of Buckets / Blades		13	13	6	6	13
Runner Diameter (in)	Inlet	109.4	192.5	225	225	40.6
	Outlet	206.8	203.0			42.6
Runner Speed (rpm)		81.8	81.8	120	120	360
Blade tip speed (ft/s)		72.5	72.5	117.8	117.8	68.3
Number wicket gates		24	24	24	24	16
Runner Height (in)		72.1	72.1	108.5	108.5	15.5
Wicket gate spacing (in)		13.75	13.75	22.16	22.16	3.72
Approach Velocity (fps) (calculated)		2.5	2.4	3.5	3.7	1.4
Intake Elevation – Top (ft)		69.2	69.2	69.2	69.2	41.5
Trash Bar Spacing (in)		5.4	5.4	5.4	5.4	1.5

* Unit 5 parameters during testing: 33 to 36 MW, average discharge 5,080 cfs, and operational head ranged from 85 to 91 ft.

TABLE 2.3-1: REQUIRED SAMPLE SIZES AT VARIOUS CONTROL SURVIVAL RATES, RECAPTURE RATES AND EXPECTED PASSAGE SURVIVAL PROBABILITY OF TREATMENT FISH TO ACHIEVE A PRECISION LEVEL (ε) OF ≤ ± 0.10, 90% OF THE TIME.

	Expected Survival ($\hat{\tau}$)		
Turbine Survival	**0.90**	**0.95**	**0.97**
Control Survival			
		Recapture Rate = 0.98	
1.00	34	24	19
0.99	39	29	24
0.98	44	34	30
0.95	59	51	47
		Recapture Rate = 0.95	
1.00	49	40	36
0.99	54	45	41
0.98	59	51	47
0.95	75	68	64
		Recapture Rate = 0.90	
1.00	76	69	66
0.99	81	75	72
0.98	87	80	78
0.95	103	98	96
		Recapture Rate = 0.85	
1.00	107	102	100
0.99	112	108	106
0.98	118	114	112
0.95	135	133	132

[1] Table values also applicable for malady-free estimates.

TABLE 2.3-2: DAILY SCHEDULE OF RELEASED JUVENILE AMERICAN SHAD, PASSED THROUGH FRANCIS UNIT 5, CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

Date		Treatment	Control	Total Used in Analysis	Actual Release*
Oct 10	Pretest	(5)	(5)	0	(10)
Oct 11		44	26	70	74
Oct 12		54	25	79	84
Oct 13		40	25	65	68
Oct 14	delayed assessment				
Oct 15	delayed assessment				
Total		**138**	**76**	**214**	**226**

*Fish (10 treatment, 2 controls) removed from analysis due to unrecoverable conditions; pre-test fish (10) not included in analysis.

TABLE 2.6-1: CONDITION CODES ASSIGNED TO FISH AND DISLODGED HI-Z TAGS FOR FISH PASSAGE SURVIVAL STUDIES.

Status Codes	Description		
*	Turbine/passage-related malady		
4	Damaged gill(s): hemorrhaged, torn or inverted		
5	Major scale loss, >20%		
6	Severed body or nearly severed		
7	Decapitated or nearly decapitated		
8	Damaged eye: hemorrhaged, bulged, ruptured or missing, blown pupil		
9	Damaged operculum: torn, bent, inverted, bruised, abraded		
A	No visible marks on fish		
B	Flesh tear at tag site(s)		
C	Minor scale loss, <20%		
E	Laceration(s): tear(s) on body or head (not severed)		
F	Torn isthmus		
G	Hemorrhaged, bruised head or body		
H	Loss of Equilibrium (LOE)		
J	Major		
K	Failed to enter system		
L	Fish likely preyed on (telemetry, circumstances relative to recapture)		
M	Minor		
P	Predator marks		
Q	Other information		
S	Eel study only - Functionally dead		
R	Removed from sample		
T	Trapped in the rocks/recovered from shore		
V	Fins displaced, or hemorrhaged (ripped, torn, or pulled) from origin		
W	Abrasion / Scrape		
Survival Codes			
1	Recovered alive		
2	Recovered dead		
3	Unrecovered – tag & pin only		
4	Unrecovered – no information or brief radio telemetry signal		
5	Unrecovered – trackable radio telemetry signal or other information		
Dissection Codes			
1	Shear	M	Minor
2	Mechanical	N	Heart damage, rupture, hemorrhaged
3	Pressure	O	Liver damage, rupture, hemorrhaged
4	Undetermined	R	Necropsied, no obvious injuries
5	Mechanical/Shear	S	Necropsied, internal injuries
6	Mechanical/Pressure	T	Tagging/Release
7	Shear/Pressure	U	Undetermined
B	Swim bladder ruptured or expanded	W	Head removed; i.e., otolith
D	Kidneys damaged (hemorrhaged)		
E	Broken bones obvious		
F	Hemorrhaged internally		
J	Major		
L	Organ displacement		

TABLE 2.6-2: GUIDELINES FOR MAJOR AND MINOR INJURY CLASSIFICATIONS FOR FISH PASSAGE SURVIVAL STUDIES USING THE HI-Z TAGS.

A fish with only Loss of Equilibrium (LOE) is classified as major if the fish dies within 1 hour. If it survives or dies beyond 1 hour it is classified as minor.
A fish with no visible external or internal maladies is classified as a passage related major injury if the fish dies within 1 hour. If it dies beyond 1 hour it is classified as a non passage related minor injury.
Any minor injury that leads to death within 1 hour is classified as a major injury. If it lives or dies after 1 hour it remains a minor injury.
Hemorrhaged eye: minor if less than 50%. Major if 50% or more
Deformed pupil(s) are a: major injury.
Bulged eye: major unless one eye is only slightly bulged. Minor if slight.
Bruises are size-dependent. Major if 10% or more of fish body per side. Otherwise minor.
Operculum tear at dorsal insertion is: major if it is 5 % of the fish or greater. Otherwise minor.
Operculum folded under or torn off is a major injury
Scale loss: major if 20% or more of fish per side. Otherwise minor
Scraping (damage to epidermis): major if 10% or more per side of fish. Otherwise minor.
Cuts and lacerations are generally classified as major injuries. Small flaps of skin or skinned up snouts are: minor.
Internal hemorrhage or rupture of kidney, heart or other internal organs that results in death at 1 to 48 hours is a major injury.
Multiple injuries: use the worst injury

TABLE 3.1-1: SUMMARY TAG RECAPTURE DATA AND ESTIMATED 1 AND 48 H SURVIVAL WITH 90% CONFIDENCE INTERVALS (CI) OF RELEASED JUVENILE AMERICAN SHAD PASSED THROUGH FRANCIS UNIT 5, CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS. PROPORTIONS ARE GIVEN IN PARENTHESES. SURVIVAL RATES ESTIMATED FROM REDUCED MODEL (SEE APPENDIX B).

	Treatment		Control	
Number released	138		76	
Number recaptured alive	119	(0.862)	74	(0.974)
Number recapture dead	3	(0.022)	0	(0.000)
Number assigned dead	14	(0.101)	2	(0.026)
Stationary radio signals	9	(0.065)	1	(0.013)
Dislodged tags	5	(0.036)	1	(0.013)
Number undetermined (fish not used in survival calculation)	2	(0.014)	0	(0.000)
Number held for 48 h	119		74	
1 h survival rate	0.899			
SE	0.034			
90% CI (±)	0.055			
Number alive 48 hour	111		68	(0.895)
Number died in holding	8		6	
48 h survival rate	0.912			
SE	0.052			
90% CI (±)	0.085			

Survival (τ), 1 h= (119*76) / ((138-2)*74) = 0.899

$$\hat{\tau}_i = \frac{a_{Ti}R}{R_{Ti}a}$$

R_{Ti} = Number of fish released for the treatment condition (138-2=136)[A]
a_{Ti} = Number of fish alive for the treatment condition (119)
R_c = Number of control fish released (76)
a_c = Number of control fish alive (74)

Survival (τ), 48 h= (111*76) / ((138-2)*68) = 0.912[B]

R_{Ti} = Number of fish released for the treatment condition (138-2=136)
a_{Ti} = Number of fish alive for the treatment condition (111)
R_c = Number of control fish released (76)
a_c = Number of control fish alive (68)

[A] The fate of 2 fish could not be determined; these fish were not included in the survival calculations, but were included in probability of recapture calculations.
[B] Survival rate established at 0.899 because 48 h survival estimate cannot exceed 1 h estimate. This resulted from a higher proportional loss of control fish (6 of 74) relative to the treatment group (8 of 119) held for 48 h assessment.

TABLE 3.4-1: SUMMARY OF VISIBLE INJURY TYPES AND INJURY RATES OBSERVED ON RECAPTURED JUVENILE AMERICAN SHAD, PASSED THROUGH UNIT 5 AND CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS AT CONOWINGO DAM, OCTOBER 2011. PROPORTIONS ARE GIVEN IN PARENTHESES.

				Injury Type*			
No. Released	No. Examined	Passage Related Visibly Injured	LOE** only	Bruising/ Hemorraging*** on head/jaw	Hemorraged Eye	Torn Operculum	Major Scale Loss
Treatment							
138	122 (0.884)	17 (0.139)	2 (0.016)	15 (0.123)	4 (0.033)	3 (0.025)	5 (0.041)
Control							
76	74 (0.974)	7 (0.095)	0 (0.000)	5 (0.068)	0 (0.000)	0 (0.000)	2 (0.027)

*Some fish had multiple injury types

**loss of equilibrium (LOE)

***Some hemorraging noted on head and jaw, likely due to handling and holding

TABLE 3.4-2: PROBABLE SOURCES AND SEVERITY OF MALADIES OBSERVED ON RECAPTURED JUVENILE AMERICAN SHAD, PASSED THROUGH UNIT 5, CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS. PROPORTIONS ARE GIVEN IN PARENTHESES.

No. of Fish Examined	Total With Maladies*	Mechanical	Mechanical/ Shear	Undetermined**	Severity	
					Minor	Major
			Treatment			
122	19 (0.156)	9 (0.074)	4 (0.033)	6 (0.049)	12 (0.098)	7 (0.057)
			Controls			
74	7 (0.095)	0 (0.000)	0 (0.000)	7 (0.095)	7 (0.095)	0 (0.000)

*Maladies include both visible injuries and LOE

**Injuries appeared to be primarily related to handling and/or holding in pool

TABLE 3.5-1: SUMMARY MALADY DATA AND MALADY-FREE ESTIMATES FOR RECAPTURED JUVENILE AMERICAN SHAD, PASSED THROUGH UNIT 5, CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS. PROPORTIONS ARE GIVEN IN PARENTHESES.

	Treatment		Control	
Number released	138		76	
Number examined for maladies	122	(0.884)	74	(0.974)
Number with passage related maladies	19	(0.156)	7	(0.095)
Visible injuries	17	(0.139)	7	(0.095)
Loss of equilibrium only	2	(0.016)	0	(0.000)
Number without passage related maladies	103	(0.844)	67	(0.905)
Without passage related maladies that died	2	(0.016)	1	(0.014)
Malady-free rate*	0.933			
SE	0.050			
90% CI (±)	0.083			

*Treatment malady-free rate is adjusted for controls.

Malady-Free (MF) Fish = (103*74) / (122*67) = 0.933

Where:

$$MF_i = \frac{c_{Ti} R_c}{R_{Ti} c_c}$$

C_{Ti} = Total number of fish without maladies for treatment (103)
R_{Ti} = Number of fish recovered that were examined for maladies for treatment (122)
C_c = Number of control fish recovered without maladies (67)
R_c = Number of control fish recovered that were examined for maladies (74)

TABLE 4.0-1: PHYSICAL AND HYDRAULIC CHARACTERISTICS OF HYDROELECTRIC DAMS FOR WHICH FRANCIS TURBINE PASSAGE SURVIVAL DATA ARE AVAILABLE FOR HI-Z TAGGED JUVENILE AMERICAN SHAD.

Station	State	Study Year	River	Average Size (mm)	Unit No. Tested	Turbine Type	No. of Buckets	Runner Speed (rpm)	Runner Dia. (in)	Test Discharge (cfs)	Project Head (ft)	Sample Size	1 h Survival	Source
Holtwood Dam	PA	1991	Susquehanna	125	10	single runner	16	94.7	164	3,500	51	100	0.894	RMC (1992)
Holtwood Dam	PA	1991	Susquehanna	125	3	double runner	17	102.8	112	3,500	51	100	0.835	RMC (1992)
Holtwood Dam	PA	1997	Susquehanna	119	9	single runner	13	94.7	164	3,000	51	40	0.905	NAI (1997)
Vernon	VT/NH	1995	Connecticut	92		single runner	15	74.0	156	1,834	34	153	0.947	NAI (1996)
York Haven	PA	2000	Susquehanna	114	7	dual vert. runner	18	84.0	78	850	23	94	0.771	NAI (2001)
Conowingo	MD	2011	Susquehanna	119	5	single/vented	13	81.8	203	5,080	89	138	0.899	NAI (Present Study)

FIGURE 1.1-1: LOCATION OF YORK HAVEN, SAFE HARBOR, HOLTWOOD AND CONOWINGO HYDROELECTRIC STATIONS ON THE SUSQUEHANNA RIVER.

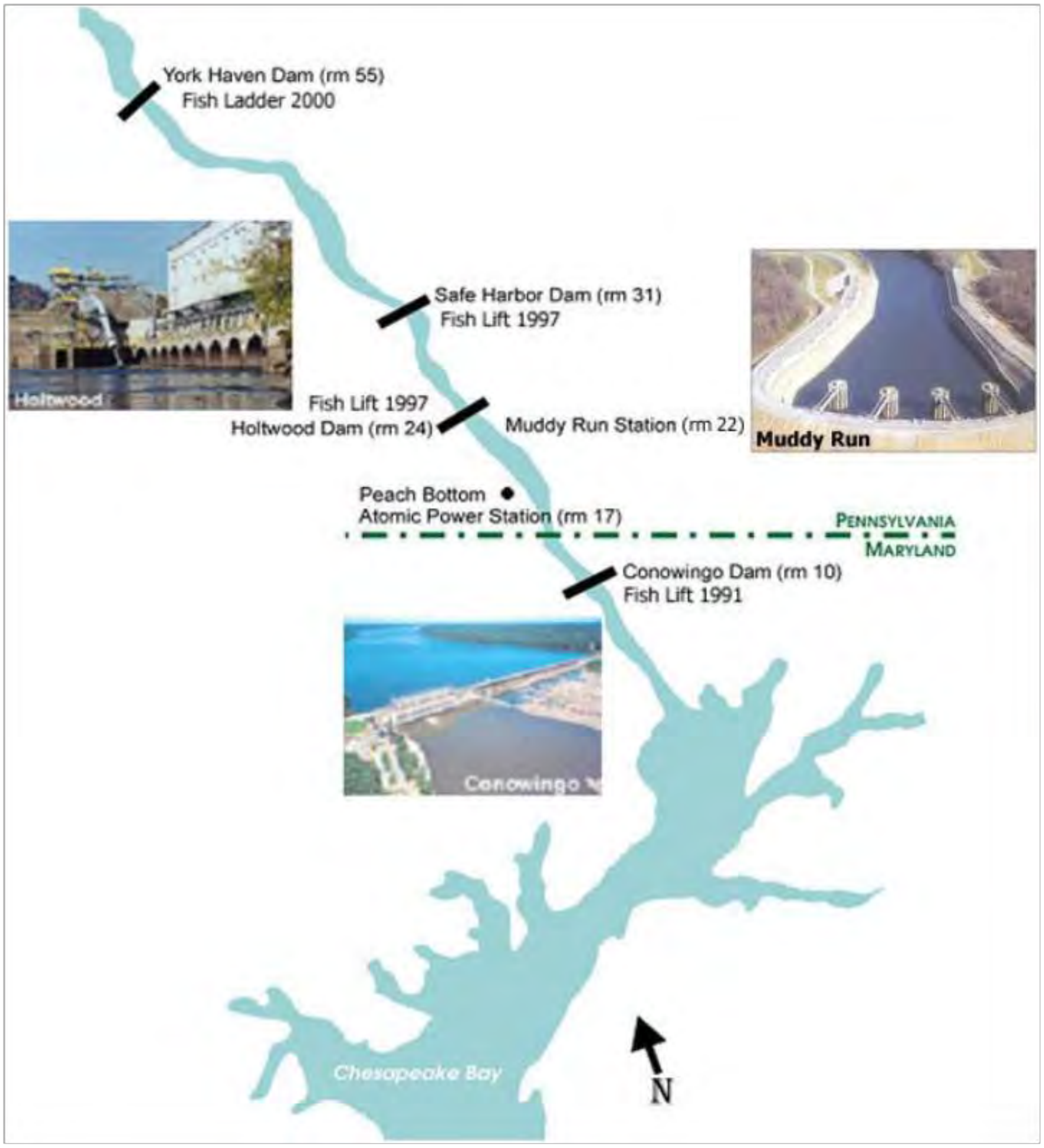


FIGURE 2.4-1: FISH HOLDING TANKS LOCATED AT FISHERMAN'S WHARF CONTROL RELEASE SITE.

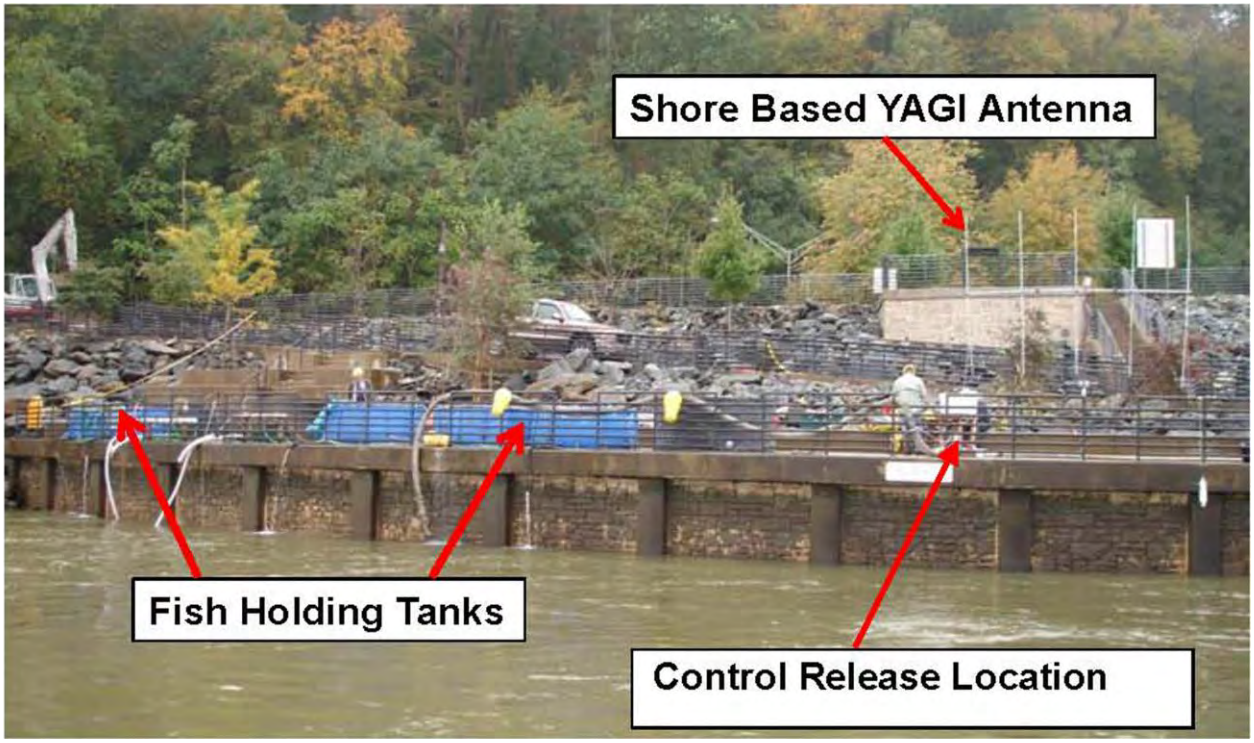


FIGURE 2.5-1: TREATMENT AND CONTROL FISH CORRALLED BY FINE MESH NET IN A HOLDING TANK.

FIGURE 2.5-2: JUVENILE AMERICAN SHAD SELECTED BY WATER BRAILER FOR PASSAGE TEST.

FIGURE 2.5-3: JUVENILE AMERICAN SHAD WITH UNINFLATED HI-Z TAG AND RADIO TAG.

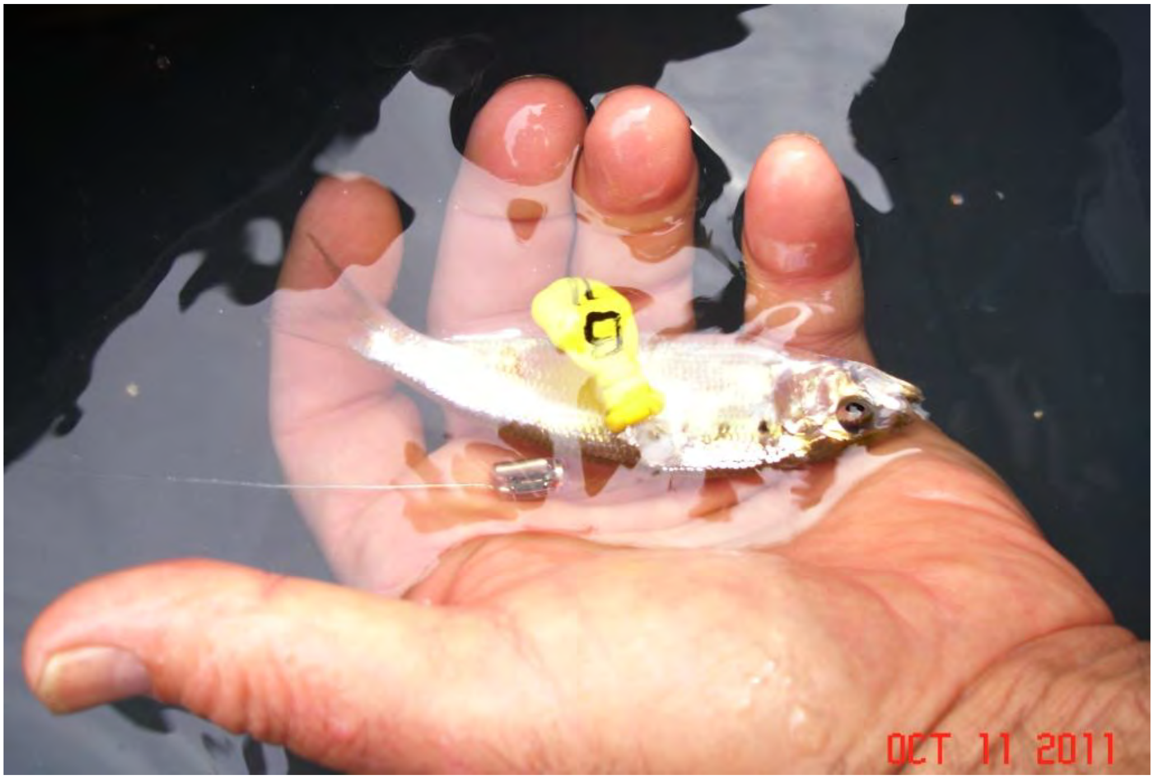


FIGURE 2.5-4: INDUCTION SYSTEM WITH DISCHARGE HOSE.

FIGURE 2.5-5: ACTIVATION OF HI-Z TAG PRIOR TO RELEASE.

FIGURE 2.5-6: CROSS SECTION OF FRANCIS UNIT 5 WITH TREATMENT FISH RELEASE POINT AT CONOWINGO PROJECT, OCTOBER 2011.

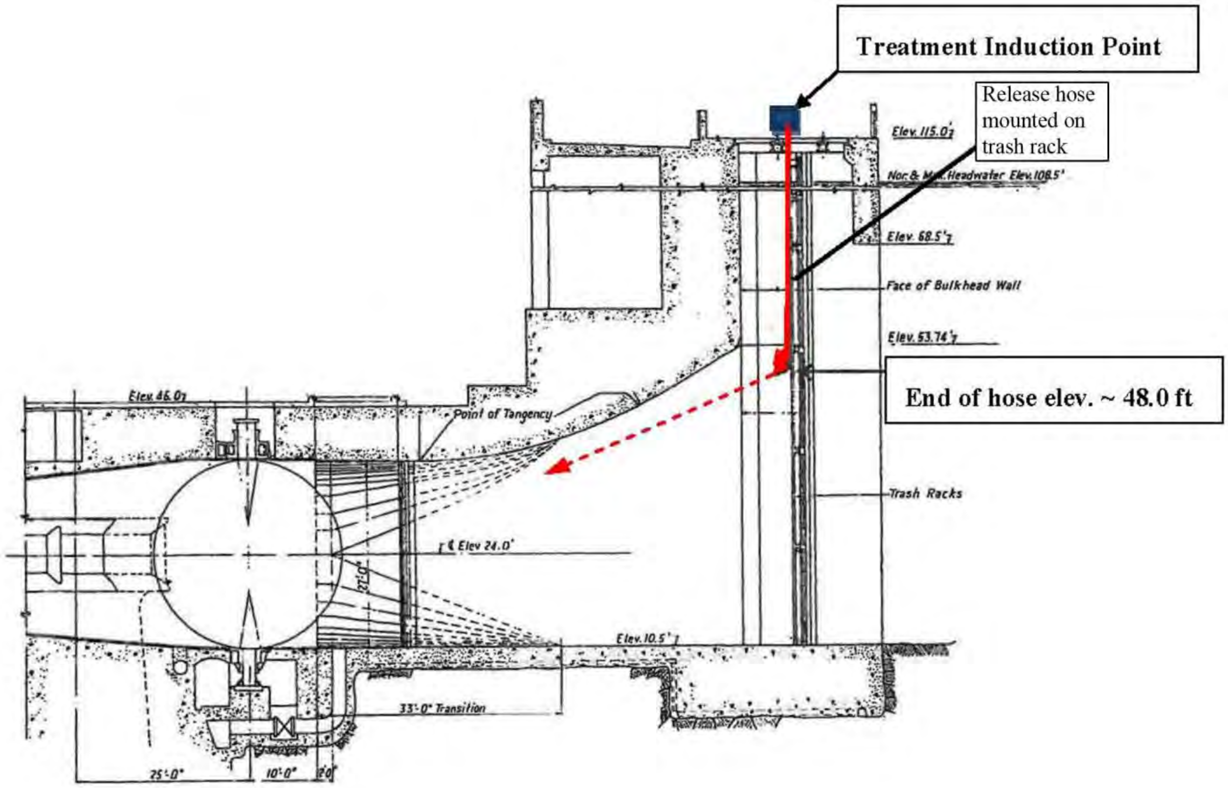


FIGURE 2.5-7: TOTAL LENGTH (MM) FREQUENCY DISTRIBUTION OF TREATMENT AND CONTROL ON RECAPTURED JUVENILE AMERICAN SHAD PASSED THROUGH UNIT 5, CONOWINGO PROJECT, OCTOBER 2011. CONTROL FISH RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

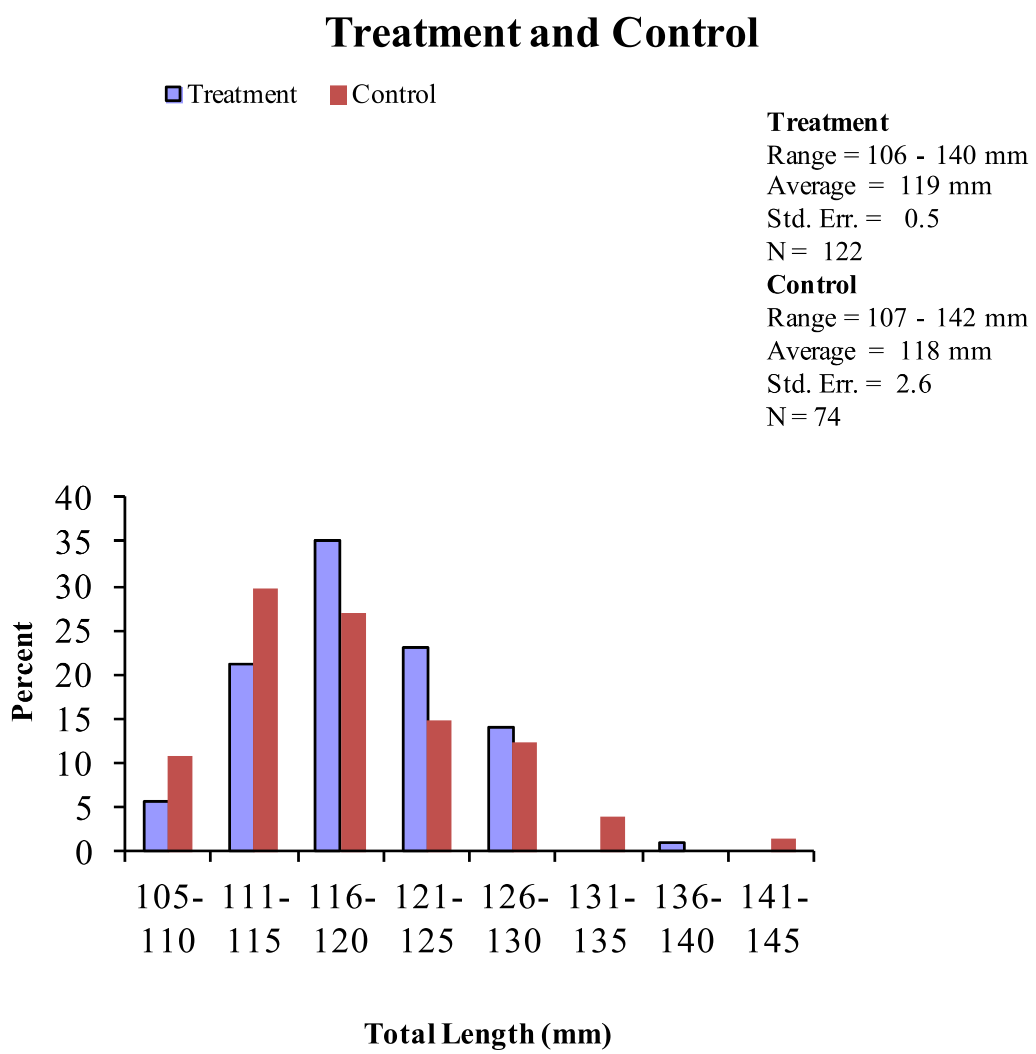


FIGURE 2.6-1: POST-PASSAGE BUOYED JUVENILE AMERICAN SHAD RETRIEVED BY WATER SANCTUARY NET OR WATER BRAILER.

FIGURE 3.1-1: FREQUENCY DISTRIBUTION OF RETRIEVAL TIMES (MINUTES) OF TREATMENT AND CONTROL OF RELEASED JUVENILE AMERICAN SHAD, PASSED THROUGH UNIT 5, CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

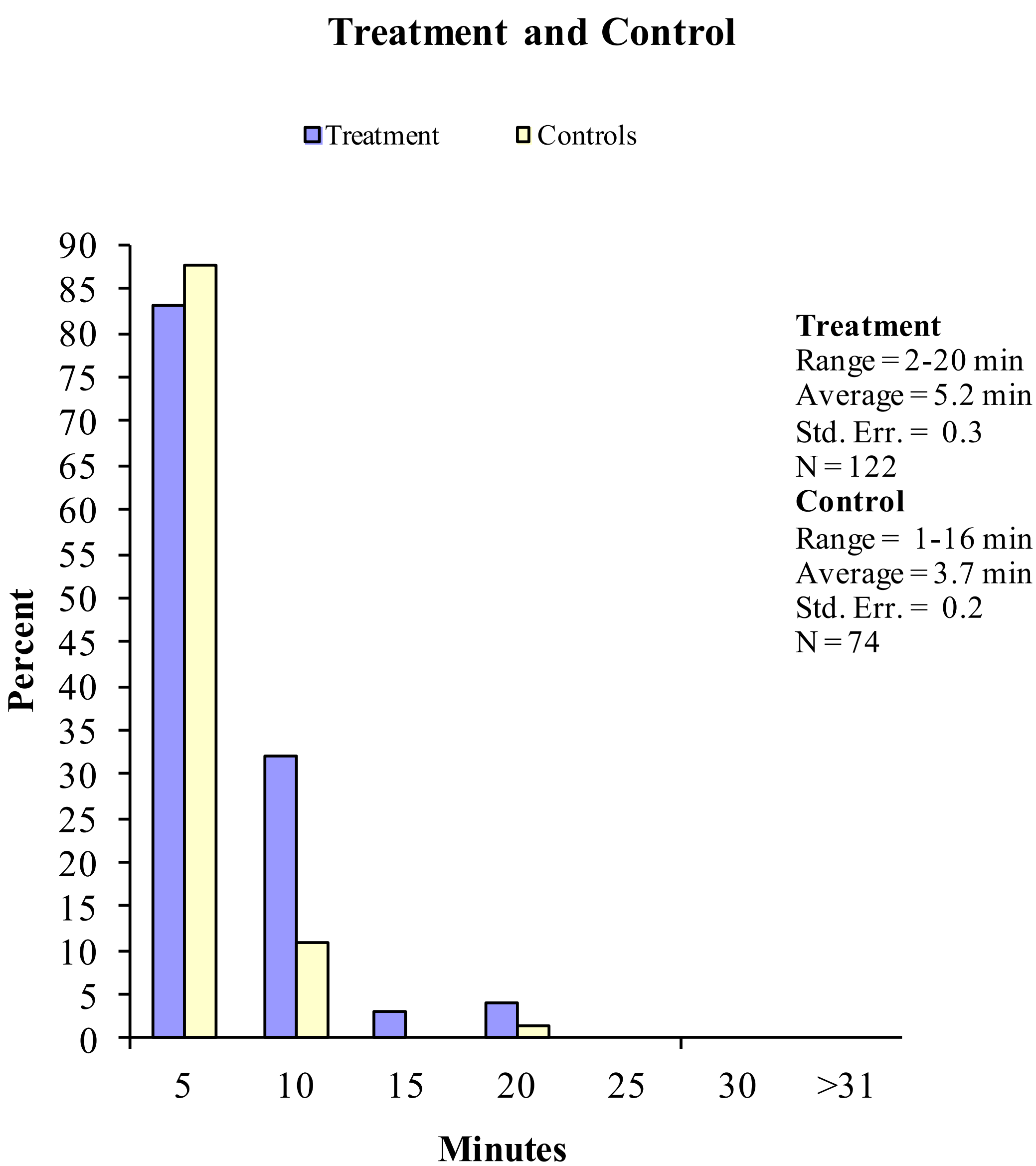
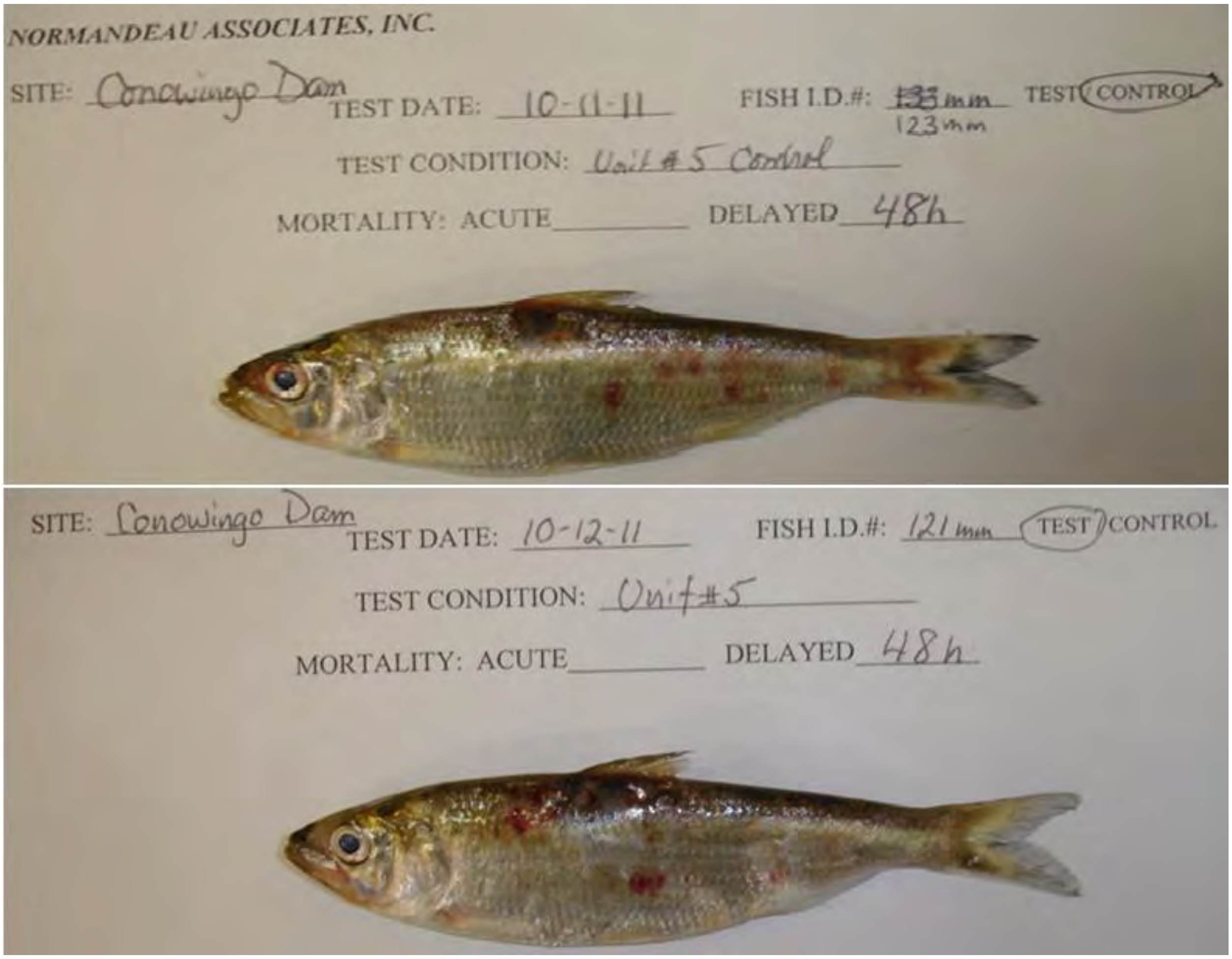


FIGURE 3.4-1: TREATMENT AND CONTROL FISH WITH REDNESS AROUND THE HEAD AND SNOUT LIKELY DUE TO HANDLING AND HOLDING.



APPENDIX A: PROJECT PARAMETERS MEASURED FOR RELEASED JUVENILE AMERICAN SHAD, PASSED THROUGH UNIT 5, CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS. WICKET GATE WAS SET AT 71% FOR UNIT 5.

Appendix A

Station parameters measured for released juvenile American shad, passed through Unit 5, Conowingo Dam, October 2011. Controls released from fisherman's wharf downstream of Francis units. Wicket gate was set at 71% for Unit 5.

Time	Test / Control	Upstream water level (mNN)	Down stream Water level	Head (m) estimation	Unit 5 discharge (cfs)*	Total Station discharge (cfs)	Power product (MW)
Tuesday 11 October							
0900	Control	108.06	17.46	90.60	4995	32151 CFS	219
0930	Control	107.54	20.80	86.74	4995	76857 CFS	
1000	Control	107.52	21.05	86.47	4995	76318 CFS	459
1030	Control	107.50	21.06	86.44	4995	76303 CFS	
1100	Control	107.13	21.23	85.90	4995	78364 CFS	491
1130	Control	107.04	21.24	85.80	4995	77628 CFS	
1200	Test	106.94	21.16	85.78	4995	77586 CFS	498
1230	Test	106.73	21.16	85.57	4995	77605 CFS	
1300	Test	106.61	21.12	85.49	4995	77470 CFS	490
1330	Test	106.50	21.12	85.38	4995	77525 CFS	
1400	Test	106.30	21.11	85.19	4995	77394 CFS	489
1430	Test	106.21	21.11	85.10	4995	77282 CFS	
1500	Test	106.09	21.11	84.98	4995	77263 CFS	486
1530	Test	105.94	21.11	84.83	4995	77215 CFS	
1600		105.79	21.12	84.67	4995	77157 CFS	484
Wednesday 12 October							
1000	Test	108.56	17.36	91.20	4965	31034 CFS	214
1030	Test	108.40	20.77	87.63	4965	77211 CFS	
1100	Test	108.41	19.91	88.50	4965	74588 CFS	442
1130	Test	108.30	19.95	88.35	4965	74386 CFS	
1200	Test	107.94	19.97	87.97	4965	74461 CFS	497
1230	Test	107.84	21.09	86.75	4965	77010 CFS	
1300	Test	107.72	21.09	86.63	4965	76969 CFS	494
1330	Test	107.51	21.09	86.42	4965	76380 CFS	
1400	Test	107.39	21.07	86.32	4965	75454 CFS	491
1430	Test	107.29	21.08	86.21	4965	76308 CFS	
1500	Control	107.18	21.09	86.09	4965	76361 CFS	489
1530	Control	107.11	21.09	86.02	4965	76335 CFS	
1600	Control	107.05	21.13	85.92	4965	76710 CFS	487
1630	Control	106.96	21.08	85.88	4965	76779 CFS	
1700	Control	106.95	21.07	85.88	4965	76771 CFS	487
Thursday 13 October							
0900		108.04	17.53	90.60	5257	32282 CFS	220
0930	Control	107.81	17.52	86.74	5257	32239 CFS	
1000	Control	107.94	17.52	86.47	5257	32293 CFS	221
1030	Control	107.53	20.57	86.44	5257	76690 CFS	
1100	Control	107.43	20.99	85.90	5257	76107 CFS	424
1130	Control	107.43	21.06	85.80	5257	76128 CFS	
1200		106.97	21.06	85.78	5257	76447 CFS	488
1230	Test	106.89	21.05	85.57	5257	76513 CFS	
1300	Test	106.83	21.03	85.49	5257	76545 CFS	485
1330	Test	106.53	21.04	85.38	5257	76348 CFS	
1400	Test	106.45	21.04	85.19	5257	76315 CFS	482
1430	Test	106.36	21.03	85.10	5257	76388 CFS	
1500	Test	106.22	21.04	84.98	5257	76327 CFS	480
1530	Test	106.19	21.03	84.83	5257	76302 CFS	
1600	Test	106.18	21.05	84.67	5257	76345 CFS	479
1630	Test	106.13	21.03	0.00	5257	76158 CFS	
1700	Test	106.05	21.03	91.20	5257	76212 CFS	478

*Hourly readings not available; this is average flow through unit. Discharge changes little when unit is brought online, but ranged from 33-36 MW.

APPENDIX B-1: DERIVATION OF PRECISION, SAMPLE SIZE, AND MAXIMUM LIKELIHOOD PARAMETERS.

APPENDIX B-1

DERIVATION OF PRECISION, SAMPLE SIZE, AND MAXIMUM LIKELIHOOD PARAMETERS

A general statistical description below is given for a broad understanding for derivation of precision, sample size calculation and with likelihood model used for parameter estimation. For the sake of brevity, references within the text have been removed. However, interested readers can look up these citations in the report prepared by Normandeau Associates and Skalski (2000). Additionally, the results of statistical analyses for evaluating homogeneity in recapture and survival probabilities, and in testing hypotheses of equality in parameter estimates under the simplified ($H_O:P_A=P_D$) versus the most generalized model ($H_A:P_A \neq P_D$) are given.

The following terms are defined for the equations and likelihood functions which follow:

R_C	=	Number of control fish released
R_T	=	Number of treatment fish released
R	=	$R_C=R_T$
n	=	Number of replicate estimates $\hat{\tau}_i$ (i=1,…,n)
a_C	=	Number of control fish recaptured alive
d_C	=	Number of control fish recaptured dead
a_T	=	Number of treatment fish recaptured alive
d_T	=	Number of treatment fish recaptured dead
S	=	Probability fish survive from the release point of the controls to recapture
P_A	=	Probability an alive fish is recaptured
P_D	=	Probability a dead fish is recaptured
τ	=	Probability a treatment fish survives to the point of the control releases (*i.e.*, passage survival)
$1-\tau$	=	Passage-related mortality.

The precision of the estimate was defined as:

$$P(-\varepsilon < \hat{\tau} - \tau < \varepsilon) = 1 - \alpha$$

or equivalently

$$P(-\varepsilon <| \hat{\tau} - \tau |< \varepsilon) = 1 - \alpha$$

where the absolute errors in estimation, *i.e.*, $|\hat{\tau} - \tau|$, is $<\varepsilon$ $(1-\alpha)$ 100% of the time, $\hat{\tau}$ is the estimated passage survival, and ε is the half-width of a $(1-\alpha)$ 100% confidence interval for $\hat{\tau}$ or $1-\hat{\tau}$. A precision of ±10%, 90% of the time is expressed as $P(|\hat{\tau} - \tau|<0.10)=0.90$.

Using the above precision definition and assuming normality of $\hat{\tau} - \tau$, the required total sample size (R) is as follows:

$$P\left(\frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}} < Z < \frac{\varepsilon}{\sqrt{Var(\hat{\tau})}} \right) = 1 - \alpha$$

$$P\left(Z < \frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}}\right) = \alpha / 2$$

$$\Phi\left(\frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}}\right) = \alpha / 2$$

$$\frac{-\varepsilon}{\sqrt{Var(\hat{\tau})}} = Z_{\alpha/2}$$

$$Var(\hat{\tau}) = \frac{\varepsilon^2}{Z^2_{1-\frac{\alpha}{2}}}$$

$$\frac{\tau}{SP_A}\left[\frac{(1-S\tau P_A)}{R_T} + \frac{(1-SP_A)\tau}{R_C}\right] = \frac{\varepsilon^2}{Z^2_{1-\frac{\alpha}{2}}} \ .$$

where Z is a standard normal deviate satisfying the relationship $P(Z>Z_{1-\alpha/2})=\alpha/2$, and Φ is the cumulative distribution function for a standard normal deviate.

Letting $R_C=R_T=R$, the sample size for each release is

$$R = \frac{\tau}{SP_A}\left[1+\tau-2S\tau P_A\right]\frac{Z^2_{1-\alpha/2}}{\varepsilon^2} \ .$$

By rearranging, this equation can be solved to predetermine the anticipated precision given the available number of fish for a study. In most previous investigations this equation has been used to calculate sample sizes because of homogeneity between trials; in the present investigation sample size was predetermined using this equation.

.

Precision is defined as

$$P(|\,\bar{\hat{\tau}} - \bar{\tau}\,| < \varepsilon) = 1-\alpha$$

$$P(-\varepsilon < \bar{\hat{\tau}} - \bar{\tau}\,| < \varepsilon) = 1-\alpha$$

$$P\left(\frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} < t_{n-1} < \frac{\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}}\right) = 1-\alpha$$

$$P\left(t_{n-1} < \frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}}\right) = \alpha/2$$

$$\Phi\left(\frac{-\varepsilon}{Var(\bar{\hat{\tau}})}\right) = \alpha/2$$

$$\frac{-\varepsilon}{\sqrt{Var(\bar{\hat{\tau}})}} = t_{\alpha/2,n-1}$$

$$Var(\bar{\hat{\tau}}) = \frac{\varepsilon^2}{t^2_{1-\alpha/2,n-1}}$$

$$\frac{\sigma_\tau^2 + \frac{\tau}{SP_A}\left[\frac{(1-S\tau P_A)}{R_T} + \frac{(1-SP_A)\tau}{R_C}\right]}{n} = \frac{\varepsilon^2}{t^2_{1-\alpha/2,n-1}}$$

where σ_τ^2=natural variation in passage-related survival.

Now letting R_T=R_C

$$\frac{\sigma_\tau^2 + \frac{\tau}{SP_A}\left[\frac{(1-S\tau P_A)}{R} + \frac{(1-SP_A)\tau}{R}\right]}{n} = \frac{\varepsilon^2}{t^2_{1-\alpha/2,n-1}}$$

which must be iteratively solved for n given R. Or R given n where

$$R = \frac{\frac{\tau}{SP_A}\left[(1-S\tau P_A) + (1-SP_A)\tau\right]}{\left[\frac{n\varepsilon^2}{t^2_{1-\alpha/2,n-1}} - \sigma_\tau^2\right]}$$

$$R = \frac{\frac{\tau(1+\tau)}{SP_A}}{\left[\frac{n\varepsilon^2}{t^2_{1-\alpha/2,n-1}} - \sigma_\tau^2\right]}$$

$$R = \frac{\tau(1+\tau)}{SP_A}\left[\frac{t^2_{1-\alpha/2,n-1}}{n\varepsilon^2 - \sigma_\tau^2 t^2_{1-\alpha/2,n-1}}\right].$$

The joint likelihood for the passage-related mortality is:

$$L\ (S,\ \tau,\ P_A,\ P_D \mid R_C,\ R_T,\ a_C,\ a_T,\ d_C,\ d_T)=$$

$$\binom{R_C}{a_c d_C}(SP_A)^{a_C}((1-S)P_D)^{d_C}(1-SP_A-(1-S)P_D)^{R_C-a_C-d_C}$$

$$\times\binom{R_T}{a_T d_T}(S\tau P_A)^{a_T}((1-S\tau)P_D)^{d_T}(1-S\tau P_A-(1-S\tau)P_D)^{R_T-a_T-d_T}\ .$$

The likelihood model is based on the following assumptions: (1) fate of each fish is independent, (2) the control and treatment fish come from the same population of inference and share that same survival probability, (3) all alive fish have the same probability, P_A, of recapture, (4) all dead fish have the same probability, P_D, of recapture, and (5) passage survival (τ) and survival (S) to the recapture point are conditionally independent. The likelihood model has four parameters (P_A, P_D, S, τ) and four minimum sufficient statistics (a_C, d_C, a_T, d_T).

Likelihood models is based on the following assumptions: (a) the fate of each fish is independent; (b) the control and treatment fish come from the same population of inference and share the same natural survival probability, S; (c) all alive fish have the same probability, P_A, of recapture; (d) all dead fish have the same probability, P_D, of recapture; and (e) passage survival (τ) and natural survival (S) to the recapture point are conditionally independent.

The estimators associated with the likelihood model are:

$$\hat{\tau}=\frac{a_T R_C}{R_T a_C}$$

$$\hat{S}=\frac{R_T d_C a_C - R_C d_T a_C}{R_C d_C a_T - R_C d_T a_C}$$

$$\hat{P}_A=\frac{d_C a_T - d_T a_C}{R_T d_C - R_C d_T}$$

$$\hat{P}_D=\frac{d_C a_T - d_T a_C}{R_C a_T - R_T a_C}\ .$$

The variance (Var) and standard error (SE) of the estimated passage mortality ($1-\hat{\tau}$) or survival ($\hat{\tau}$) are:

$$Var(1-\hat{\tau})=Var(\hat{\tau})=\frac{\tau}{SP_A}\left[\frac{(1-S\tau P_{A)}}{R_T}+\frac{(1-SP_A)\tau}{R_C}\right]$$

$$SE(1-\hat{\tau})=SE(\hat{\tau})=\sqrt{Var(1-\hat{\tau})}\ .$$

APPENDIX B-2: ONE HOUR SURVIVAL ESTIMATES FOR JUVENILE AMERICAN SHAD, PASSED THROUGH CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED INTO THE TAILRACE DOWNSTREAM OF FISHERMAN'S WHARF. CONTROL FISH RELEASED 76, 74 ALIVE AND 2 DEAD; TREATMENT: 138 RELEASED, 119 ALIVE, 17 ASSIGNED DEAD, AND 2 UNDETERMINED.

Appendix B-2

One hour survival estimates for juvenile American shad, passed through Conowingo Dam, October 2011. Controls released into the tailrace downstream of fisherman's wharf. Control fish released 76, 74 alive and 2 dead; Treatment: 138 released, 119 alive and 17 assigned dead.

RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)
estim. std.err.
S = 0.9737 (0.0184) Control group survival
Pa = 1.0 N/A Live recovery probability*
Pd = 0.9048 (0.0641) Dead recovery probability
Tau = 0.8856 (0.0344) Treatment survival
1-Tau = 0.1144 (0.0344) Treatment mortality

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
log-likelihood : -71.153931

Variance-Covariance matrix for estimated probabilities:
0.00034 -0.00000 -0.00031
-0.00000 0.00410 0.00000
-0.00031 0.00000 0.00119

Profile likelihood intervals:

	Treatment survival	Treatment mortality
90 percent:	(0.8272, 0.9446)	(0.0554, 0.1728)
95 percent:	(0.8154, 0.9574)	(0.0426, 0.1846)
99 percent:	(0.7916, 0.9850)	(0.0150, 0.2084)

==
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)
estim. std.err.
S = 0.9737 (0.0184) Control group survival
Pa = Pd 0.9907 (0.0066) Recovery probability
Tau = 0.8986 (0.0337) Treatment survival
1-Tau = 0.1014 (0.0337) Treatment mortality

log-likelihood : -71.825647

Variance-Covariance matrix for estimated probabilities:
0.00034 -0.00000 -0.00031
-0.00000 0.00004 0.00000
-0.00031 0.00000 0.00114

Profile likelihood intervals:

	Treatment survival	Treatment mortality
90 percent:	(0.8414, 0.9568)	(0.0432, 0.1586)
95 percent:	(0.8298, 0.9696)	(0.0304, 0.1702)
99 percent:	(0.8064, 0.9973)	(0.0027, 0.1936)

==

Likelihood ratio statistic for equality of recovery probabilities: 1.343432
Compare with quantiles of the chi-squared distribution with 1 d.f.:
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

APPENDIX B-3: FORTY-EIGHT HOUR SURVIVAL ESTIMATES FOR JUVENILE AMERICAN SHAD, PASSED THROUGH CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED INTO THE TAILRACE DOWNSTREAM OF FISHERMAN'S WHARF. CONTROL FISH RELEASED 76, 68 ALIVE AND 8 DEAD; TREATMENT: 138 RELEASED, 111 ALIVE, 25 ASSIGNED DEAD, AND 2 UNDETERMINED.

Appendix B-3

Forty-eight hour survival estimates for juvenile American shad, passed through Conowingo Dam, October 2011. Controls released into the tailrace downstream of fisherman's wharf.
Control fish released 76, 68 alive and 8 dead; Treatment: 138 released, 111 alive and 25 assigned dead.

RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)

estim. std.err.
S = 0.8947 (0.0352) Control group survival
Pa = 1.0 N/A Live recovery probability*
Pd = 0.9429 (0.0392) Dead recovery probability
Tau = 0.8990 (0.0517) Treatment survival
1-Tau = 0.1010 (0.0517) Treatment mortality

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
log-likelihood : -101.455377

Variance-Covariance matrix for estimated probabilities:
0.00124 0.00000 -0.00125
0.00000 0.00154 0.00000
-0.00125 0.00000 0.00268

Profile likelihood intervals:

	Treatment survival	Treatment mortality
90 percent:	(0.8177, 0.9925)	(0.0075, 0.1823)
95 percent:	(0.8025, 1.0000)	(0.0000, 0.1975)
99 percent:	(0.7729, 1.0000)	(0.0000, 0.2271)

===
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

estim. std.err.
S = 0.8947 (0.0352) Control group survival
Pa = Pd 0.9907 (0.0066) Recovery probability
Tau = 0.9122 (0.0516) Treatment survival
1-Tau = 0.0878 (0.0516) Treatment mortality
log-likelihood : -101.801277

Variance-Covariance matrix for estimated probabilities:
0.00124 0.00000 -0.00126
0.00000 0.00004 -0.00000
-0.00126 -0.00000 0.00267

Profile likelihood intervals:

	Treatment survival	Treatment mortality
90 percent:	(0.8311, 1.0000)	(0.0000, 0.1689)
95 percent:	(0.8160, 1.0000)	(0.0000, 0.1840)
99 percent:	(0.7865, 1.0000)	(0.0000, 0.2135)

===

Likelihood ratio statistic for equality of recovery probabilities: 0.691800
Compare with quantiles of the chi-squared distribution with 1 d.f.:
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

APPENDIX B-4: MALADY-FREE RATES FOR JUVENILE AMERICAN SHAD, PASSED THROUGH CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED INTO THE TAILRACE DOWNSTREAM OF FISHERMAN'S WHARF. CONTROL FISH EXAMINED: 74, 67 ALIVE NO MALADIES AND 7 WITH MALADIES; TREATMENT: 122 EXAMINED, 103 ALIVE NO MALADIES AND 19 WITH MALADIES.

Appendix B-4

Malady-free rates for juvenile American shad, passed through Conowingo Dam, October 2011. Controls released into the tailrace downstream of fisherman's wharf. Control fish examined: 74, 67 alive no maladies and 7 with maladies; Treatment: 122 examined, 103 alive no maladies and 19 with maladies.

RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)
estim. std.err.
S = 0.9054 (0.0340) Control group survival
Pa = 1.0 N/A Live recovery probability*
Pd = 1.0 N/A Dead recovery probability*
Tau = 0.9325 (0.0504) Treatment survival
1-Tau = 0.0675 (0.0504) Treatment mortality

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
log-likelihood : -75.934181

Variance-Covariance matrix for estimated probabilities:
0.00116 -0.00119
-0.00119 0.00254

Profile likelihood intervals:

	Treatment survival	Treatment mortality
90 percent:	(0.8527, 1.0000)	(0.0000, 0.1473)
95 percent:	(0.8376, 1.0000)	(0.0000, 0.1624)
99 percent:	(0.8079, 1.0000)	(0.0000, 0.1921)

===
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)
estim. std.err.
S = 0.9054 (0.0340) Control group survival
Pa = Pd 1.0 N/A Recovery probability*
Tau = 0.9325 (0.0504) Treatment survival
1-Tau = 0.0675 (0.0504) Treatment mortality

* -- Because of constraints in the data set, this probability is assumed equal to 1.0; not estimated.
log-likelihood : -75.934181

Variance-Covariance matrix for estimated probabilities:
0.00116 -0.00119
-0.00119 0.00254

Profile likelihood intervals:

	Treatment survival	Treatment mortality
90 percent:	(0.8527, 1.0000)	(0.0000, 0.1473)
95 percent:	(0.8376, 1.0000)	(0.0000, 0.1624)
99 percent:	(0.8079, 1.0000)	(0.0000, 0.1921)

===

Likelihood ratio statistic for equality of recovery probabilities: 0.000000
Compare with quantiles of the chi-squared distribution with 1 d.f.:
For significance level 0.10: 2.706
For significance level 0.05: 3.841
For significance level 0.01: 6.635

APPENDIX C-1: DAILY TAG RECAPTURE DATA FOR RELEASED JUVENILE AMERICAN SHAD, PASSED THROUGH UNIT 5, CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

Appendix Table C-1

Daily tag-recapture data for released juvenile American shad, passed through Unit 5, Conowingo Dam, October 2011. Controls released from fisherman's wharf downstream of Francis units.

	10/11	10/12	10/13	Totals
Treatment				
Number released	44	54	40	**138**
Number alive	39	46	34	**119**
Number recovered dead	0	2	1	**3**
Assigned dead	5	6	3	**14**
Dislodged tags	2	5	2	**9**
Stationary radio signals	3	1	1	**5**
Undetermined	0	0	2	**2**
Held and Alive 1 h	39	46	34	**119**
Alive 24 h	39	45	34	**118**
Alive 48 h	36	44	31	**111**
Control				
Number released	26	25	25	**76**
Number alive	25	25	24	**74**
Number recovered dead	0	0	0	**0**
Assigned dead	1	0	1	**2**
Dislodged tags	1	--	0	**1**
Stationary radio signals	0	--	1	**1**
Undetermined	0	0	0	**0**
Held and Alive 1 h	25	25	24	**74**
Alive 24 h	24	25	23	**72**
Alive 48 h	23	23	22	**68**

APPENDIX C-2: DAILY MALADY DATA FOR RELEASED JUVENILE AMERICAN SHAD, PASSED THROUGH UNIT 5, CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

Appendix Table C-2

Daily malady data for released juvenile American shad, passed through Unit 5, Conowingo Dam, October 2011. Controls released from fisherman's wharf downstream of Francis units.

	10/11	10/12	10/13	Totals
Treatment				
Number released	44	54	40	**138**
Number examined	39	48	35	**122**
Passage related maladies	4	8	7	**19**
Visible injuries	3	8	6	**17**
Loss of equilibrium only	1	--	1	**2**
Without maladies	35	40	28	**103**
Without maladies that died	2	--	--	**2**
Control				
Number released	26	25	25	**76**
Number examined	25	25	24	**74**
Passage related maladies	2	2	3	**7**
Visible injuries	2	2	3	**7**
Loss of equilibrium only	--	--	--	**0**
Without maladies	23	23	21	**67**
Without maladies that died	1	--	--	**1**

APPENDIX C-3: SUMMARY OF ALIVE AT 48 H AND MALADY-FREE DATA FOR RECAPTURED JUVENILE AMERICAN SHAD, PASSED THROUGH UNIT 5, CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

Appendix Table C-3

Summary of alive at 48 h and malady-free data for recaptured juvenile American shad, passed through Unit 5, Conowingo Dam, October 2011. Controls released from fisherman's wharf downstream of Francis units.

	Treatment	Control
Number released	138	76
Number examined for injuries	122	74
Alive and malady free	103	67
With maladies, or died	19	7
Number assigned dead* (*)	14 (4)	2(1)
Undetermined	0	2

* (*) Fish likely preyed upon

APPENDIX C-4: INCIDENCE OF MALADIES, INCLUDING INJURY, SCALE LOSS, AND TEMPORARY LOSS OF EQUILIBRIUM (LOE) OBSERVED ON RELEASED JUVENILE AMERICAN SHAD PASSED THROUGH UNIT 5 AT CONOWINGO DAM, OCTOBER, 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS.

Appendix Table C-4

Incidence of maladies, including injury, scale loss, and temporary loss of equilibrium (LOE) observed on released juvenile American shad passed through Unit 5 at Conowingo Dam, October, 2011. Controls released from fisherman's wharf downstream of Francis units.

Date	Test Lot	Fish Length ID	Live/Dead	Maladies	Passage Malady*	Photo	Malady Cause	Probable Status
Control								
10/11/11	2	123	dead 48h	Necropsied, no obvious external or internal injuries	No	Yes	Undetermined	
10/11/11	2	125	dead 24h	LOE at recovery; Major scale loss, > 20% right side; Necropsied, no obvious internal injuries	Yes	Yes	Undetermined	Minor
10/11/11	2	114	alive 48h	Hemorrhaged on top of head and behind eye; Necropsied, no obvious internal injuries	Yes	Yes	Undetermined	Minor
10/12/11	3	119	dead 48h	LOE at recovery; Major scale loss, > 20% both sides; Necropsied, no obvious internal injuries	Yes	Yes	Undetermined	Minor
10/12/11	3	116	dead 48h	Hemorrhaged head behind eye and lower jaw; Necropsied, no obvious internal injuries	Yes	Yes	Undetermined	Minor
10/13/11	4	118	alive 48h	Hemorrhaged head in front of eye; Necropsied, no obvious internal injuries	Yes	Yes	Undetermined	Minor
10/13/11	4	129	dead 24h	Hemorrhaged lower jaw; Necropsied, no obvious internal injuries	Yes	Yes	Undetermined	Minor
10/13/11	4	126	dead 48h	Hemorrhaged lower jaw; Necropsied, no obvious internal injuries	Yes	Yes	Undetermined	Minor
Unit 5								
10/11/11	2	127	dead 48h	Damaged right eye: hemorrhaged; LOE at recovery; Major scale loss, right side of head and caudal area; Hemorrhaged on top of head; Necropsied, no obvious external or internal injuries	Yes	Yes	Mechanical	Major
10/11/11	2	128	dead 48h	Necropsied, no obvious external or internal injuries	No	Yes	Undetermined	
10/11/11	2	129	alive 48h	Hemorrhaged on top of head and snout; Necropsied, no obvious internal injuries	Yes	Yes	Undetermined	Minor
10/11/11	2	117	alive 48h	Hemorrhaged on top of head; Major scale loss, left shoulder; Necropsied, no obvious internal injuries	Yes	Yes	Mechanical	Major
10/11/11	2	123	dead 48h	Necropsied, no obvious internal injuries	No	Yes	Undetermined	Minor
10/11/11	2	118	alive 48h	Slight hemorrhage on head in front of right eye; LOE; Necropsied, no obvious internal injuries	Yes	Yes	Mechanical	Minor
10/12/11	3	121	dead 48h	Hemorrhaged snout; Bruised behind head; Necropsied, no obvious internal injuries	Yes	Yes	Mechanical	Minor
10/12/11	3	125	dead 1h	Bruised head; Necropsied, no obvious internal injuries	Yes	Yes	Mechanical	Major

Date	Test Lot	Fish Length ID	Live/Dead	Maladies	Passage Malady*	Photo	Malady Cause	Probable Status
10/12/11	3	120	alive 48h	Damaged right operculum and hemorrhaged on head; LOE	Yes	No	Mechanical/Shear	Minor
10/12/11	3	114	alive 48h	LOE	Yes	No	Undetermined	Minor
10/12/11	3	120	alive 48h	LOE; Major scale loss right side	Yes	No	Mechanical	Major
10/12/11	3	130	dead 24h	Flesh tear at tag site; Major scale loss both sides; Necropsied, no obvious internal injuries	Yes	Yes	Undetermined	Major
10/12/11	3	122	alive 48h	Hemorrhaged head in front of both eyes	Yes	No	Mechanical	Minor
10/12/11	3	117	dead 1h	Damaged right operculum: scale loss; Damaged both eyes: hemorrhaged; Bruised on top of head; Necropsied, no obvious internal injuries	Yes	Yes	Mechanical/Shear	Major
10/13/11	4	120	alive 48h	Hemorrhaged head and jaw; LOE; Necropsied, no obvious internal injuries	Yes	Yes	Undetermined	Minor
10/13/11	4	127	alive 48h	LOE	Yes	No	Undetermined	Minor
10/13/11	4	128	dead 1h	Hemorrhaged head; Damaged right eye: hemorrhaged; Damaged right gill/operculum: hemorrhaged; Necropsied, no obvious internal injuries	Yes	Yes	Mechanical/Shear	Major
10/13/11	4	120	dead 48h	LOE at recovery; Hemorrhaged/torn lower jaw; Necropsied, no obvious internal injuries	Yes	Yes	Shear	Minor
10/13/11	4	120	dead 24h	Hemorrhaged on snout tip; Necropsied, no obvious internal injuries	Yes	Yes	Mechanical	Minor
10/13/11	4	122	alive 48h	Slight hemorrhage on damaged jaw	Yes	No	Mechanical	Minor
10/13/11	4	109	dead 48h	Damaged right eye: hemorrhaged; Slight hemorrhage on lower jaw; LOE at recovery; Necropsied, no obvious internal injuries	Yes	Yes	Mechanical/Shear	Minor

*Fish with passage related visible injuries and loss of equilibrium

**Fish had hemorrhaging/redness around head and snout that was likely due to handling/holding

APPENDIX D: SHORT TERM PASSAGE SURVIVAL DATA FOR RECAPTURED JUVENILE AMERICAN SHAD, PASSED THROUGH UNIT 5, CONOWINGO DAM, OCTOBER 2011. CONTROLS RELEASED FROM FISHERMAN'S WHARF DOWNSTREAM OF FRANCIS UNITS. DESCRIPTION OF CODES AND DETAILS ON INJURED FISH ARE PRESENTED IN TABLE 2.6-2.

APPENDIX D

Short term passage survival data for recaptured juvenile American shad, passed through Unit 5, Conowingo Dam, October 2011. Controls released from fisherman's wharf downstream of Francis units.

Description of codes and details on injured fish are presented in Table .

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Time Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	Status Codes 2	Status Codes 3	Status Codes 4
11-Oct-11		**Testlot 2**			**Water temp = 16.1°C**					
				Treatment						
B1		12:21	12:23	*2*	1	1	A			
B2		12:22	12:28	*6*	1	1	A			
B3		12:23	12:27	*4*	1	1	A			
B4		12:26	12:30	*4*	1	1	*	8	H	
B5		12:30	12:33	*3*	1	1	A			
B6		12:31	12:48	*17*	1	1	A			
B7		12:33	12:37	*4*	1	1	A			
B8	128	12:35	12:38	*3*	1	1	W			
B9		12:52	13:10	*18*	1	1	A			
B10		12:54			1	3	R			
B11		12:55			0	5	L			
B12		13:27	13:43	*16*	1	1	A			
B13		13:29	13:35	*6*	1	1	A			
B14		13:37	13:39	*2*	1	1	A			
B15		13:41	13:44	*3*	1	1	A			
B16		13:45	13:52	*7*	1	1	A			
B17		13:51			0	5	L			
B18		13:54	13:56	*2*	1	1	A			
B19		13:59	14:05	*6*	1	1	A			
B20		14:15			1	3				
B21		14:32			1	3				
B22		14:35	14:40	*5*	1	1	*	G		
B23		14:41	14:50	*9*	1	1	A			
B24		14:42	14:50	*8*	1	1	A			
B25		14:51			1	3	R			
B26		14:56	15:02	*6*	1	1	A			
B27		15:00	15:03	*3*	1	1	A			
B28		15:03	15:07	*4*	1	1	A			
B29		15:04	15:08	*4*	1	1	A			
B30		15:08	15:11	*3*	1	1	A			
B31		15:09	15:13	*4*	1	1	A			
B32		15:13	15:17	*4*	1	1	A			
B33		15:14	15:18	*4*	1	1	A	*		
B34		15:18	15:22	*4*	1	1	A			
B35		15:19	15:24	*5*	1	1	A			
B36		15:23			1	3	R			
B37	110	15:25	15:32	*7*	1	1	A			
B38		15:30	15:32	*2*	1	1	A			
B39		15:33	15:38	*5*	1	1	A			
B40		15:34	15:41	*7*	1	1	A			
B41		15:39	15:43	*4*	1	1	A			
B42		15:43	15:46	*3*	1	1	A			

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
B43		15:44	15:54	*10*	1	1	A			
B44		15:47	15:50	*3*	1	1	A			
B45		15:51	15:57	*6*	1	1	*	G	H	
B46		15:54	15:58	*4*	1	1	A			
B47		15:58			0	5				
11-Oct-11	**Testlot 2**				**Water temp = 16.1°C**					
				Control						
C1		9:26	9:35	*9*	1	1	A			
C2		9:28	9:30	*2*	1	1	A			
C3		9:32			0	5	R	T		
C4		9:37	9:40	*3*	1	1	A			
C5		9:34	9:50	*16*	1	1	A			
C6		9:50	9:51	*1*	1	1	A			
C7	105	9:51	9:55	*4*	1	1	A			
C8		9:59	10:01	*2*	1	1	A			
C9		10:01	10:04	*3*	1	1	A			
C10		10:03			1	3				
C11		10:05	10:09	*4*	1	1	A			
C12		10:10	10:12	*2*	1	1	A			
C13		10:12	10:14	*2*	1	1	A			
C14		10:20	10:22	*2*	1	1	A			
C15		10:21	10:24	*3*	1	1	A			
C16		10:23	10:25	*2*	1	1	A			
C17	123	10:26	10:30	*4*	1	1	A			
C18		10:27	10:30	*3*	1	1	A			
C19		10:31	10:34	*3*	1	1	A			
C20		10:33	10:36	*3*	1	1	A			
C21		10:36	10:39	*3*	1	1	A			
C22	125	10:41	10:43	*2*	1	1	*	H	5	
C23		10:42	10:44	*2*	1	1	A			
C24		10:48	10:50	*2*	1	1	A			
C25		10:49	10:51	*2*	1	1	A			
C26		10:53	10:56	*3*	1	1	A			
C27		10:54	10:56	*2*	1	1	A	*		
12-Oct-11	**Testlot 3**				**Water temp = 16.2°C**					
				Treatment						
A1		10:00	10:08	*8*	1	1	A			
A2		10:17	10:20	*3*	1	1	A			
A3		10:18	10:23	*5*	1	1	A			
A4		10:21	10:24	*3*	1	1	A			
A5		10:24			0	5				
A6		10:25	10:29	*4*	1	1	A			
A7		10:30	10:36	*6*	1	1	A			
A8		10:41	10:45	*4*	1	1	A			
A9		10:42	10:53	*11*	1	1	A			
A10		11:00	11:04	*4*	1	1	A			
A11		11:01	11:04	*3*	1	1	A			
A12		11:06	11:09	*3*	1	1	A			
A13		11:06	11:10	*4*	1	1	A			
A14		11:11			1	3				
A15	121	11:11	11:20	*9*	1	1	*	G		

Fish ID	Total Length (mm)	Time			No. HI-Z tags recovered	Survival Code	Status Codes			
		Re-leased	Re-covered	Minutes at large			1	2	3	4
A16		11:17	11:20	3	1	1	A			
A17		11:21	11:30	9	1	1	A			
A18		11:22	11:26	4	1	1	A			
A19		11:27	11:31	4	1	1	A			
A20		11:31	11:34	3	1	1	A			
A21		11:32	11:36	4	1	1	A			
A22		11:35	11:44	9	1	1	A			
A23		11:40	11:43	3	1	1	A			
A24		11:44	11:48	4	1	1	A			
A25		11:45	11:50	5	1	1	A			
A26		11:49	11:54	5	1	1	A			
A27		11:51	11:55	4	1	1	A			
A28		11:55			1	3				
A29		11:57			1	3				
A30		11:59	12:01	2	1	1	A			
A31		12:32	12:43	11	1	1	A			
A32		12:33	12:38	5	1	1	A			
A33		12:40	12:43	3	1	1	A			
A34		12:43	12:46	3	1	1	A			
A35		12:46	12:49	3	1	1	A			
A36	125	12:47	12:57	10	1	2	*	H	G	
A37		12:52	12:57	5	1	1	*	9	G	H
A38		12:54	13:01	7	1	1	*	H		
A39		12:57	13:03	6	1	1	A			
A40		13:02	13:08	6	1	1	*	5	H	
A41		13:03			0	5	R			
A42		13:07	13:20	13	1	1	A			
A43		13:18	13:21	3	1	1	A			
A44		13:22			0	5	R			
A45		13:31	13:40	9	1	1	A			
A46	130	13:41	13:45	4	1	1	*	B		
A47		13:47	13:49	2	1	1	A			
A48		13:51	13:54	3	1	1	*	G		
A49		13:57			1	3				
A50		13:58	14:01	3	1	1	A			
A51		14:01			1	3	R			
A52		14:02	14:05	3	1	1	A			
A53		14:06	14:08	2	1	1	A			
A54		14:10			1	3				
A55		14:15			1	3	R			
A56		14:19	14:25	6	1	1	A			
A57		14:20	14:24	4	1	1	A			
A58	117	14:23	14:30	7	1	2	J	*	8	9
12-Oct-11		**Testlot 3**			**Water temp = 16.2°C**					
				Control						
C2		15:17	15:22	5	1	1	A			
C1		15:16			0	5	T	R		
C3	119	15:22	15:27	5	1	1	H	*		
C4		15:29	15:34	5	1	1	A			
C5		15:32	15:37	5	1	1	A			
C6		15:35	15:38	3	1	1	A			
C7	116	15:38	15:42	4	1	1	A	*		

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
C8		15:41	15:44	*3*	1	1	A			
C9		15:45	15:47	*2*	1	1	A			
C10		15:46	15:49	*3*	1	1	A			
C11		15:48	15:53	*5*	1	1	A			
C12		15:51	15:58	*7*	1	1	A			
C13		15:55	15:59	*4*	1	1	A			
C14		16:00	16:03	*3*	1	1	A			
C15		16:00	16:04	*4*	1	1	A			
C16		16:06	16:12	*6*	1	1	A			
C17		16:07	16:10	*3*	1	1	A			
C18		16:10	16:13	*3*	1	1	A			
C19		16:13	16:20	*7*	1	1	A			
C20		16:15	16:19	*4*	1	1	A			
C21		16:20	16:24	*4*	1	1	A			
C22		16:27	16:31	*4*	1	1	A			
C23		16:29	16:32	*3*	1	1	A			
C24		16:33	16:35	*2*	1	1	A			
C25		16:34	16:39	*5*	1	1	A			
C26		16:36	16:38	*2*	1	1	A			
13-Oct-11		**Testlot 4**			**Water temp = 16.4°C**					
				Treatment						
A1		12:39	12:43	*4*	1	1	A			
A2		12:41	12:45	*4*	1	1	A			
A3		12:46	12:49	*3*	1	1	A			
A4	120	12:47	12:50	*3*	1	1	*	G	H	
A5		12:50			1	3				
A6		12:53			0	4				
A7		13:05	13:09	*4*	1	1	*	H		
A8		13:08	13:11	*3*	1	1	A			
A9		13:08	13:11	*3*	1	1	A			
A10		13:11	13:16	*5*	1	1	A			
A11	128	13:15	13:19	*4*	1	2	9	*	G	8
A12		13:17	13:25	*8*	1	1	A			
A13		13:21	13:27	*6*	1	1	A			
A14		13:27	13:35	*8*	1	1	A			
A15		13:28	13:35	*7*	1	1	A			
A16		13:36			1	3	L			
A17		13:37	13:39	*2*	1	1	A			
A18	120	13:43	13:48	*5*	1	1	*	H	E	
A19		13:50	13:57	*7*	1	1	A			
A20		13:58	14:04	*6*	1	1	A			
A21		14:09			0	5	L			
A22	120	14:45	14:49	*4*	1	1	*	G		
A23		14:51	14:54	*3*	1	1	A			
A24		14:54	14:57	*3*	1	1	A			
A25		14:56			0	5	R			
A26		14:58			0	4				
A27		15:07	15:13	*6*	1	1	*	G		
A28		15:15	15:25	*10*	1	1	A			
A29		15:22	15:25	*3*	1	1	A			
A30		15:25	15:29	*4*	1	1	A			
A31		15:27	15:30	*3*	1	1	A			

Fish ID	Total Length (mm)	Time Re-leased	Time Re-covered	Time Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	2	3	4
A32		15:30			0	5	R			
A33		15:31	15:34	*3*	1	1	A			
A34	109	15:37	15:42	*5*	1	1	*	8	G	H
A35		15:47	15:52	*5*	1	1	A			
A36		15:50	15:56	*6*	1	1	A			
A37		15:53	15:56	*3*	1	1	A			
A38		15:57	15:59	*2*	1	1	A			
A39		15:58	16:01	*3*	1	1	A			
A40		16:00	16:20	*20*	1	1	A			
A41		16:01			0	4	R			
A42		16:24	16:27	*3*	1	1	A			
A43		16:25	16:29	*4*	1	1	A			
13-Oct-11		**Testlot 4**			**Water temp = 16.4°C**					
				Control						
C1		9:36	9:40	*4*	1	1	A			
C2		9:37	9:40	*3*	1	1	A			
C3		9:40	9:47	*7*	1	1	A			
C4		9:41	9:47	*6*	1	1	A			
C5		9:50	9:54	*4*	1	1	A			
C6		9:51			0	5	L			
C7		9:52	9:55	*3*	1	1	A			
C8		9:52	9:59	*7*	1	1	A			
C9	118	10:04	10:08	*4*	1	1	A	*		
C10		10:04	10:11	*7*	1	1	A			
C11		10:24	10:25	*1*	1	1	A			
C12	129	10:25	10:28	*3*	1	1	A	*		
C13		10:26	10:29	*3*	1	1	A			
C14		10:27	10:31	*4*	1	1	A			
C15		10:37	10:39	*2*	1	1	A			
C16		10:37	10:41	*4*	1	1	A			
C17		10:41	10:43	*2*	1	1	A			
C18	126	10:42	10:45	*3*	1	1	A	*		
C19		10:47	10:51	*4*	1	1	A			
C20		10:51	10:54	*3*	1	1	A			
C21		10:53	10:56	*3*	1	1	A			
C22		10:54	10:57	*3*	1	1	A			
C23		11:01	11:04	*3*	1	1	A			
C24		11:01	11:04	*3*	1	1	A			
C25		11:02	11:05	*3*	1	1	A			

FINAL STUDY REPORT
DOWNSTREAM FISH PASSAGE EFFECTIVENESS ASSESSMENT
RSP 3.2

CONOWINGO HYDROELECTRIC PROJECT

FERC PROJECT NUMBER 405

Prepared for:

Exelon

Prepared by:

Normandeau Associates, Inc.

Gomez and Sullivan Engineers, P.C.

August 2012

EXECUTIVE SUMMARY

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt Conowingo Hydroelectric Project (Conowingo Project). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. FERC issued the final study plan determination for the Conowingo Project on February 4, 2010, approving the revised study plan with certain modifications.

FERC's final study plan determination required Exelon to conduct an assessment of impingement and entrainment of target fish species relative to the downstream fish passage effectiveness study. The objectives of this study are to: 1) provide estimates of entrainment and impingement potential and survival for the three turbine types at the Conowingo Project for the fish species of interest using existing data, and 2) describe downstream fish passage measures already in place.

An initial study report (ISR) was filed on March 31, 2011, containing Exelon's 2010 study findings. A meeting was held on August 23 and 24, 2011 with resource agencies and interested members of the public. Formal comments on the ISR including requested study plan modifications were filed with FERC on March 21, 2012 by several resource agencies and interested members of the public. Exelon filed responses to the ISR comments with FERC on April 20, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the ISR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

Entrainment is the passage of fish through water intakes (FERC 1995). In the case of hydropower developments, such as the Conowingo Project, fish entrained in the intakes are passed through a penstock and turbine, and discharged to the tailwater downstream. Factors that determine the potential for entrainment at a hydropower project include the size and depth of the intakes, the hydraulic capacity and configuration of the turbines, the velocity of water as it enters the intake relative to fish swim speeds, the location of the intake relative to fish habitat, and the characteristics of fish species present in the reservoir. Entrainment of fish at a hydropower project does not necessarily result in injury to the fish. Depending upon the characteristics of the individual units, fish survival rates through turbines can be very high. Some of the factors that determine survival rates include the type of turbine, the number of blades, the blade spacing and the rotation speed of the turbine. This study examines both entrainment potential and survival at the Conowingo Project.

A fish entrainment evaluation was conducted utilizing historic data for Conowingo Pond, existing literature, life history information, and data on fish entrainment at other hydroelectric projects for eight species of management interest at the Conowingo Project. The fish species considered in the evaluation were those identified by Exelon and Project stakeholders as important management species and included both resident fish: bluegill (*Lepomis macrochirus*), channel catfish (*Ictalurus punctatus*), gizzard shad (*Dorosoma cepedianum*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), and walleye (*Sander vitreus*); and diadromous fish: American eel (*Anguilla rostrata*) and American shad (*Alosa sapidissima*).

The survival assessment was also based on an extensive review of literature and existing data and considered the important physical characteristics of the units, as well as the biological characteristics of the various fish species. Some of the important factors considered in this portion of the assessment included turbine type, turbine speed and intake characteristics.

The Conowingo Project is located at river mile 10 on the Susquehanna River. It is the most downstream of five hydroelectric projects located on the Lower Susquehanna River. Below Conowingo Dam the Susquehanna River flows approximately 10 miles before entering Chesapeake Bay. The impounded reservoir, Conowingo Pond, is approximately 14 miles long, with a surface area of 9,000 acres. The Conowingo Pond serves many diverse uses including hydropower generation, water supply, industrial cooling water, recreational activities and various environmental resources. The resident fishes of Conowingo Pond are common warm-water species that are found in ponds, lakes, and reservoirs from the southeastern U.S. to Canada. Sampling conducted between 1996 and 1999 revealed that species composition of the resident fish community has changed little since 1966, except for some specific fish introductions from downstream of the Conowingo Dam. The gizzard shad, spottail shiner, spotfin shiner and bluntnose minnow are common forage species. Green sunfish, pumpkinseed, bluegill, and white crappie are important pan fishes. The common game fishes include channel catfish, smallmouth bass, largemouth bass, and walleye (Normandeau 1998, 1999, 2000).

The Project operates thirteen turbine generators of generally three types: four large, mixed-flow, fixed blade Kaplan units with hydraulic capacities in excess of 9,000 cfs; seven Francis units with hydraulic capacities around 6,500 cfs; and two small house turbines with Francis runners, passing up to 247 cfs. The larger (primary) units are used to generate power for distribution; the small house units supply power to the station and provide “black-start” capability.

Overall, the results of the entrainment study indicate that the potential for impact to fishes due to entrainment and turbine passage at the Conowingo Project is moderate to moderate-high, principally due to the abundance of gizzard shad, the presence of the anadromous species American shad, and the potential for entrainment of catadromous American eel. Young gizzard shad (1.5 to 4 inches), as well as young bluegill (< 4 inches), typically form the bulk of entrainment catches where they are abundant in hydropower reservoirs (FERC 1995). In Conowingo Pond young gizzard shad form dense, large, open-water schools that typically move downstream out of the Pond in the fall. These fish are also susceptible to torpor due to cold water temperatures. As a result, entrainment of gizzard shad tends to be episodic due to their schooling behavior and more prevalent during fall and winter. American shad and silver American eel must move past the Project to complete their emigration to the sea and are therefore subject to entrainment. Adult American shad move downstream in the spring after spawning, and juvenile American shad and adult American eel emigrate in the fall.

Entrainment potential is low for the remaining target species due to characteristics of the Project combined with habit preferences and life history traits of the fish. The Project intake bays for the primary units are deep (intake ceiling is 40 feet below normal full pond) and intake flow velocities calculated at the face of the intake structure are moderate, ranging from 2.4 to 3.7 fps. Entrainment through the house units is expected to lower than through the primary units because of their small hydraulic capacity, very deep intake (67.7 feet below normal full pond) and intake flow velocity of 1.4 fps.

Channel catfish is a benthic species, walleye is a pelagic predator, and three target species are littoral zone fishes: bluegill, largemouth bass and smallmouth bass. The deep intakes are remote to the shallow water areas where the littoral species are found, and large juvenile and adult life stages of channel catfish and walleye have burst swim speeds greater than intake flow velocities. Small juveniles that are not strong swimmers are more susceptible to entrainment, as are walleye or other piscivorous species chasing prey, such as gizzard shad, proximal to the intake structure.

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). Overall, survival through the Kaplan turbines was rated the highest, followed closely by the large Francis turbines. Fish passage through the small Francis house units was rated relatively low for most fish sizes. For the smaller juveniles that are more likely to be entrained, estimated survival through the Kaplan and larger Francis units is expected to be greater than 90%. Survival is estimated to be Moderate-High (95-90%) to Low (<80%) for large adult American shad and adult American eel passing the Kaplan units, and Moderate (90-85%) to Low when passing the Francis units.

Existing downstream passage routes include turbine passage and spillage. Turbine survival studies of juvenile and adult American shad passed through the unit 8 Kaplan turbine resulted in 94.9% and 86.3% survival, respectively under a "worst-case" operational scenario. Survival for juvenile and adult shad passing Francis turbines was 89.9% and 93.0%, respectively, under a "worst-case" scenario. These results compare reasonably well with survival estimates for similar sized fish summarized from the EPRI database (Winchell *et al.* 2000), other tests of similar Francis and Kaplan turbines, and calculated survival using the blade-strike equation (Franke *et al.* 1997).

Silver eels will pass through Project turbines or via spillage during their emigration. USFWS (2012) analyzed silver eel migrations past Conowingo Dam in 2011. Based on 88 tagged silver eels released in upper Conowingo Pond above the Muddy Run Pumped Storage Project, 79 eels (89.8%) were detected at receivers downstream of Conowingo Dam. As these eels were detected several miles below the Dam, USFWS concluded that these 79 eels successfully migrated past the Dam and out of the Susquehanna River. Since spillage occurred for a number of days during which eels were outmigrating, it was not possible to determine which eels passed the Dam through spillage or turbine passage. The remaining nine eels were not detected below the Dam so it is not known if they remained in the Pond, migrated after the end of the monitoring (late December, did not survive passage through the turbines or over the spillway, or the tags or tag battery failed, or the tags were damaged in turbine or spillway passage).

The Conowingo Pond supports a diverse assemblage of fishes and a healthy multi-species sport fishery supported by natural reproduction. The overall entrainment and turbine mortality effect of the Project on resident fishes is expected to be moderate for gizzard shad and low for all other target species. Entrained resident fishes would comprise mostly prey species such gizzard shad, a very prolific species in Conowingo Pond. Predators such as walleye may be entrained as smaller juveniles, but older, larger fish are most likely to avoid entrainment through better swimming ability. The survival of the mostly small fish that would be expected to pass through the turbines would be expected to be high based on model calculations and evidence accumulated elsewhere for similar turbines and similar-sized fishes.

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LIST OF ABBREVIATIONS

Agencies

DOE	Department of Energy
FERC	Federal Energy Regulatory Commission
MDE	Maryland Department of Environment
MDNR	Maryland Department of Natural Resources
PBAPS	Peach Bottom Atomic Power Station
PFBC	Pennsylvania Fish and Boat Commission
SRBC	Susquehanna River Basin Commission
USGS	United States Geological Survey
USFWS	United States Fish and Wildlife Service

Units of Measure

cfs	cubic feet per second
El.	elevation
F	Fahrenheit
h	hour
in	inch
fps	feet per second
ft	feet
MGD	million gallons per day
MW	megawatt
NGVD	National Geodetic Vertical Datum
rpm	revolutions per minute
sq ft	square feet

Regulatory

CWA	Clean Water Act

Environmental

BW	body width
DO	dissolved oxygen
FL	fork length
SL	standard length
TL	total length

Miscellaneous

EPRI	Electric Power Research Institute
FPA	Federal Power Act
ILP	Integrated Licensing Process

1.0 INTRODUCTION

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt (MW) Conowingo Hydroelectric Project (Project). Exelon is applying for license renewal using the FERC's Integrated Licensing Process (ILP). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014.

As required by the ILP, Exelon filed their Pre-Application Document (PAD) and Notice of Intent (NOI) with FERC on March 12, 2009. On June 11 and 12, 2009, a site visit and two scoping meetings were held at the Project for resource agencies and interested members of the public. Following these meetings, formal study requests were filed with FERC by several resource agencies. Many of these study requests were included in Exelon's Proposed Study Plan (PSP), which was filed on August 24, 2009. On September 22 and 23, 2009, Exelon held a meeting with resource agencies and interested members of the public to discuss the PSP.

Formal comments on the PSP were filed with FERC on November 22, 2009 by Commission staff and several resource agencies. Exelon filed a Revised Study Plan (RSP) for the Project on December 22, 2009. FERC issued the final study plan determination for the Project on February 4, 2010, approving the RSP with certain modifications. One of the modifications pertained to the downstream fish passage effectiveness study (RSP 3.2); FERC stated that the on-site turbine mortality testing component of the study (Tasks 4 and 5) was not required because sufficient information was available in existing literature to assess the issue. On May 20, 2010 FERC issued an order granting rehearing in response to a dispute filed by the Maryland Department of Natural Resources, Power Plant Research Program (MDNR) and Maryland Department of the Environment (MDE) on February 24, 2010, and a joint request for rehearing filed on March 8, 2010. One of the studies in dispute was RSP 3.2; MDE requested that the on-site turbine mortality testing be restored to the study plan. A three member Study Dispute Resolution Panel (Panel) convened on August 3, 2010, and held a dispute panel meeting and technical conference with MDNR, MDE and other stakeholders on August 31, 2010. On September 9, 2010 FERC issued findings and recommendations of the study dispute resolution panel. The Panel recommended restoring the field-based validation type study to RSP 3.2 as described in the RSP with application to American shad only. On September 30, 2010, Exelon submitted to FERC a Notice of Settlement and Request to Withdraw Study Dispute. Exelon settled with MDE and MDNR agreeing to conduct the field-based validation study for American shad only in order to supplement its literature-based turbine passage survival estimates.

The subject of this report is the final study plan determination requirement for Exelon to conduct an assessment of impingement and entrainment of target fish species relative to the downstream fish passage effectiveness study. The objectives of this study are to: 1) provide estimates of entrainment and impingement potential and survival for the three turbine types at Conowingo for the fish species of management interest using existing data, and 2) describe downstream fish passage measures already in place. The target fish species are American eel (*Anguilla rostrata*), American shad (*Alosa sapidissima*), bluegill (*Lepomis macrochirus*), channel catfish (*Ictalurus punctatus*), gizzard shad (*Dorosoma cepedianum*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), and walleye (*Sander vitreus*).

In addition, the results of the field-validation studies for juvenile and adult American shad are discussed. The turbine-passage studies provide entrainment survival rates for juvenile shad through a Francis unit and for adult shad through a Francis unit and a Kaplan/mixed flow unit.

An initial study report (ISR) was filed on March 31, 2011, containing Exelon's 2010 study findings. A meeting was held on August 23 and 24, 2011 with resource agencies and interested members of the public. Formal comments on the ISR including requested study plan modifications were filed with FERC on March 21, 2012 by several resource agencies and interested members of the public. Exelon filed responses to the ISR comments with FERC on April 20, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the ISR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

2.0 STUDY APPROACH

This report addresses the likelihood of impingement, entrainment, and turbine mortality at the Conowingo Project within a comprehensive review of relevant biological and physical factors at the Project. The overall approach to this assessment is to review existing literature relative to the species of management interest and evaluate the potential for impingement, entrainment, and turbine mortality of these fishes relative to Project facilities and structures using the following four literature based tasks:

1. Review swim speed and intake avoidance behavior literature for the fish species of management interest and compare with approach velocity at the Project intake structures.
2. Review existing evidence of impingement and entrainment associated with the current operating regime.
3. Review other projects of similar design for impingement, entrainment and mortality rates, and perform a comparative analysis to the Conowingo Project.

4. Use a predictive model to estimate the probability of survival for a range of fish lengths passed through each type of turbine at the Project.

This report also includes an estimate of the magnitude of fallback of adult American shad through the turbines. Fallback is defined as passage downstream through Conowingo Dam after a fish has passed upstream of the Dam. Measured variables that might affect fallback (e.g., number and type of turbines operating, river flow, water temperature) at the time of fallback are also provided.

3.0 CONOWINGO PROJECT

3.1. Project Location

The Conowingo Project is located on the Susquehanna River in Pennsylvania and Maryland, and has a total drainage area of 27,510 square miles. Conowingo Dam (Figure 3.1-1) is located at river mile 10 connecting Cecil and Harford counties Maryland, as is the lowermost six miles of the Project reservoir, Conowingo Pond. The remaining eight miles of Conowingo Pond are located in Pennsylvania, within York and Lancaster counties (Figure 3.1-2).

The Susquehanna River begins at Lake Otsego in Cooperstown, New York and flows for 444 miles before reaching the Chesapeake Bay. Numerous tributaries feed directly into Conowingo Pond, of which Muddy Creek, Broad Creek, Peters Creek, Conowingo Creek and Fishing Creek are the largest.

The Conowingo Project is the most downstream of the five hydroelectric projects located on the Lower Susquehanna River. The upstream projects (York Haven, Safe Harbor, Holtwood, and Muddy Run) are located at river miles 56, 32, 24, and 22, respectively. The Susquehanna River is navigable by large vessels to Port Deposit, Maryland, located four miles downstream of the dam. The Susquehanna River below Conowingo Dam flows approximately 10 miles before entering Chesapeake Bay. The non-tidal portion of the Susquehanna River encompasses approximately 3.5 miles of river length, from Conowingo Dam downstream to the mouth of Deer Creek (a tributary), which is the approximate natural upstream limit of tidal influence. The Chesapeake Bay stretches about 200 miles from the Susquehanna River in the north to the Atlantic Ocean in the south. Much of the bay is quite shallow. At the point where the Susquehanna River flows into the bay, the average river depth is 30 feet.

3.2. Project Description

3.2.1.Conowingo Pond

The Conowingo Pond (Pond) is generally maintained at or near full pool elevation of 109.2 feet (National Geodetic Vertical Datum of 1929 [NGVD]), with a surface area of 9,000 acres and a design storage capacity of 310,000 acre-feet, of which 71,000 acre-feet are usable storage. The Conowingo Pond serves many diverse uses including hydropower generation, water supply, industrial cooling water, recreational activities and various environmental resources. Relative to hydropower generation, the Conowingo Pond serves as the lower reservoir for the 800-MW Muddy Run Pumped Storage Project (Muddy Run Project), located 12 miles upstream of the Conowingo Dam. It also serves as the source of cooling water for the 2,186 MW Peach Bottom Atomic Power Station (PBAPS), located approximately seven miles upstream of the Conowingo Dam. The Muddy Run Project has a maximum pumping capacity of 28,000 cfs, while PBAPS has a maximum withdrawal capacity of 2,230 MGD (3,450 cfs). Conowingo Pond is used as a public water supply source, with the City of Baltimore and Chester Water Authority (CWA) having permitted withdrawals of 250 MGD (387 cfs) and 30 MGD (46 cfs), respectively.

The allowable range of water level fluctuation in Conowingo Pond per the Conowingo FERC license is El. 101.2 to 110.2 NGVD. Maximum depth is about 100 feet near the turbine intake structure at Conowingo Dam and in deep pools in the upper portion of the Pond; average depth is about 20 feet. Conowingo Pond has approximately 35 miles of shoreline and a width varying from about 0.5 to 1.3 miles. Much of the Pond is characterized by a flat narrow shoreline followed by steep slopes rising above and falling below the waterline. The Norfolk Southern railroad embankment dominates the eastern shoreline of Conowingo Pond. Exposed vertical banks on this side of the river reach about 20 feet above water level. An abandoned and collapsing Susquehanna and Tidewater Canal towpath berm dominates the western shoreline below the Pennsylvania Fish and Boat Commission boat launch opposite the Muddy Run powerhouse (SRBC 2006).

For the purpose of this report, Conowingo Pond will be discussed in terms of upper, middle and lower sections. Upper Conowingo Pond is a reach approximately three miles long bounded by Holtwood Dam upstream and Hennery Island downstream. The upper reach is characterized by potholes, deep holes and channels carved into the bedrock, and rugged island rock formations. Alluvial tails, created as the river deposited sediments immediately downstream of the islands are also visible. The majority of the upper section is relatively shallow (6.5 to 20 feet), and the river bed just below the Holtwood Dam is often exposed. However, a few potholes and deep holes of up to almost 100 feet deep occur along the eastern shoreline of Conowingo Pond in the vicinity of the Muddy Run powerhouse which is located approximately 0.5 miles upstream of Hennery Island. Shallow littoral areas are common in the uppermost-section below Holtwood Dam and along the western shoreline of the Pond, particularly where tributaries enter the Pond. Riverine conditions occur just below the Holtwood Dam. The Pond ranges in width from about 0.5 to 1.0 mile in the upper section.

Below Hennery Island, the river channel broadens significantly to a lentic environment with greater average depths (>20 feet) and lower water velocities that characterize the middle and lower sections of Conowingo Pond. The middle section is a five-mile reach that encompasses the widest part of the Pond, ranging from about 1.0 to 1.3 miles. PBAPS is located on the western shore about mid-reach of the middle section; across from it, near the eastern shore is Mount Johnson Island, the only bedrock island found below the upper section of the Pond. The lower section of the Pond is a six- mile reach bounded by the Conowingo Dam to the south. The width of the lower section is fairly uniform at just under one mile (URDC 1993). Water depth is greatest at the Dam, reaching up to 98 feet. Littoral habitat in the middle and lower sections occurs primarily where tributaries enter the Pond. Much of the remaining shoreline is narrow, followed by steep slopes rising above and falling below the waterline.

Thermal stratification, typically characteristic of many temperate lakes and reservoirs, has not been observed in Conowingo Pond since environmental monitoring began in 1966. However, during the summertime, generally at water temperatures exceeding 75°F and river flows less than 12,000 cfs, the lower third of the Pond, particularly in the deeper areas near the dam, experiences dissolved oxygen stratification. This stratification usually is not strong or stable and quickly breaks down during periods of heavy rain or high wind events (Normandeau 2005).

A 1999 United States Geological Survey (USGS) evaluation of long-term data concluded that water quality and ecological conditions for aquatic life in the lower Susquehanna River were improving (Takita and Edwards 1999). Water quality studies in Conowingo Pond indicated that overall fluctuations in the concentrations of most chemical and physical parameters coincided with variations in natural river inflow (Philadelphia Electric Company 1975) and that the Pond acted as a sink for organic and inorganic material of upstream origin (RMC 1985).

Relative to dissolved oxygen (DO), Whaley (1960) noted vertical stratification in DO in the lower Conowingo Pond. Although variations among years occur, surface DO levels in the Pond are highest in winter (12-15 mg/l), decline through spring to seasonal lows during summer (5-7 mg/l), and then increase through fall. The general pattern of seasonal variation has remained the same throughout the years of study (1968-1991). DO levels in the water column remain relatively well mixed throughout most of the year; variations at depth occur in summer, particularly in the deeper waters in the lower Pond near Conowingo Dam. When stratified, primarily in July-September, differences in DO between surface and bottom of up to 9 mg/l may occur. Significant stratification of DO rarely occurs in other months or at locations in the more shallow areas of the Pond (RMC Environmental Services 1985a, 1985b; Normandeau 1998-2000).

Results of long-term monitoring studies conducted within Conowingo Pond indicate that water temperature generally follows a seasonal pattern of variation typical for temperate waters. Water temperatures are lowest in the winter (typically 32-40°F), increase in spring (45-65°F) to seasonal highs (at or near 80-86°F) in summer and then decline in the fall (70-40°F). Temperatures throughout the water column in the upper, shallower areas of the Pond remain relatively well mixed throughout the year; differences in temperature between the surface and bottom are usually less than 1°F (Whaley 1960; RMC Environmental Services 1985a, 1985b; Normandeau 1998-2000). Long term monitoring of water temperature at the MD-PA state line relative to PBAPS heated water effluent showed that the respective allowable water temperature standards were met. Analysis of data from 1956–1999 indicates that the range in water temperature at Conowingo Dam was similar to the temperature ranges of the inflow values measured at Holtwood (Normandeau 2000).

3.2.2. Hydroelectric Facilities

The Conowingo Dam is a concrete gravity dam with a maximum height of approximately 94 feet and a total length of 4,648 feet. The dam consists of four distinct sections from east to west: a 1,190-foot long non-overflow gravity section with an elevation of 115.7 feet; an ogee shaped spillway, the major portion of which is 2,250 feet long with a crest elevation of 86.7 feet and the minor portion of which is 135 feet long with a crest elevation of 98.7 feet; an intake-powerhouse section 950 feet long; and a 100-foot-long abutment section. The tailrace and spillway sections of the dam are separated by a dividing wall extending 300 feet downstream of the powerhouse. The dam and powerhouse also support U.S. Highway Route No. 1.

Flow over the ogee spillway sections is controlled by 50 stony-type crest gates and two regulating gates. Each of the crest gates has a discharge capacity of 16,000 cfs at a reservoir elevation of 109.2 feet NGVD. The two regulating gates have a discharge capacity of 4,000 cfs per gate at a reservoir elevation of 109.2 feet NGVD.

Maximum hydraulic capacity of the Conowingo powerhouse is 86,000 cfs. The Project includes 11 turbine generators that produce electricity for distribution and two small house turbines that provide station service and "black-start" capability. Enclosed within the powerhouse and located closest to the west shoreline are the two house units followed by units 1 through 7. Units 8 through 11 are an outdoor type of construction with no superstructure surrounding them. Units 1-7 are Francis-type single runner hydraulic turbines, operating at 81.8 revolutions per minute (rpm) (Table 3.2.2-1). Under a design head of 89 feet, units 1, 3, 4, 6 and 7 have a rated output of 6,749 cfs, and units 2 and 5 have a rated output of

6,320 cfs. Units 8-11 are mixed-flow fixed-blade Kaplan turbines that operate at 120 rpm. Under a design head of 86 feet, unit 8 has a rated output of 9,352 cfs and units 9-11 have a rated output of 9,727 cfs. The small house units are Francis turbines that operate at 360 rpm with a rated output of 247 cfs under a design head of 89 feet; typically, only one house unit is operated at a time.

The Kaplan turbine runners at the Conowingo Project (Figure 3.2.2-1) are propeller-type turbines that have six fixed blades. The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate. Water is directed tangentially through the adjustable wicket gate and spirals on to the propeller shaped runner, causing it to spin. The outlet is a specially shaped draft tube that helps decelerate the water and recover kinetic energy. Variable geometry of the wicket gate and turbine blades allows efficient operation for a range of flow conditions. A cross section composite for Kaplan units 8-11 is provided in Figure 3.2.2-2.

The Francis turbine runners at the Conowingo Project (Figure 3.2.2-3) consist of 13 vertically arranged, curved, fixed metal blades. Water under high to moderately high pressure flows down through the blades and makes the turbine spin. Water flow from the intakes is delivered to the turbine through the penstock and is controlled by adjustable wicket gates (24 wicket gates on units 1-7 and 16 wicket gates on the two house units) that surround the runner. Index testing determines the best wicket gate setting (percent opening, or most efficient setting) to deliver the optimum output. Water exits the turbine through a draft tube (or tubes) to the tailrace. A cross section composite for Francis units 1-7 is provided in Figure 3.2.2-4.

The submerged intakes for the eleven units (two intake bays per unit) are 58 feet high by 23 feet wide and extend from 40 to 98 feet below normal full pond (Table 3.2.2-2). Each unit is screened by bar racks with clear spacing of 5.375 inches. The single intake bay for the two house units is 15.8 feet high by 23 feet wide and extends from 67.7 to 75.5 feet below normal full pond. A multi-purpose gantry crane, installed in 2007 to replace a stationary crane, is used as a trash rake. Intake bay approach velocity for each turbine was estimated from a Project velocity diagram. Estimated approach velocity at the face of the intake structure ranged from 2.4 – 2.5fps for units 1 and 7, 3.5 - 3.7 fps for units 9 through 11; and 1.4 fps for the house units (Table 3.2.2-1).

Under Article 15 of its existing license, Exelon was required to construct reasonable facilities for the protection of fish. Pursuant to a settlement agreement on water quality and fish passage approved by FERC on January 24, 1989, Exelon operates two fish lifts at the Conowingo Project (FERC 1989). The West Lift, adjacent to the west shoreline, is operated for American shad egg production and other research purposes. The newer East Lift, which uses regulating gate bays for attraction flow, is used primarily to pass American shad and other migratory fishes during the April through June migration season.

3.3. Project Operation

The Conowingo Project is characterized as a modified run-of-river hydroelectric facility in that limited active storage is available owing to reservoir size and the relatively small allowable variation in headwater level. Safe Harbor Corporation's operation of Safe Harbor Dam, a peaking facility located 24 miles upstream, primarily determines the operation of the Conowingo Project in terms of energy generation timing. Maximum hydraulic capacity of Safe Harbor Dam (110,000 cfs) is more than that of the Conowingo powerhouse (86,000 cfs). There is approximately a two-hour lag time for the arrival of water released at Safe Harbor to reach Conowingo.

The Conowingo Project license allows for the Conowingo Pond to normally fluctuate between elevation 101.2 to 110.2 NGVD. The following factors also influence the management of water levels within the Conowingo Pond:

- The Conowingo Pond must be maintained at an elevation of 107.2 feet on weekends between Memorial Day and Labor Day to meet recreational needs;
- The Muddy Run Project cannot operate its pumps below elevation 104.7 feet due to cavitation;
- PBAPS begins experiencing cooling problems when the elevation of the Pond drops to 104.2 feet;
- The CWA cannot withdraw water below elevation 100.5 feet;
- The Nuclear Regulatory Commission license for PBAPS requires the plant to shut down completely at 99.2 feet; and
- The City of Baltimore cannot withdraw water below elevation 91.5 feet.

A minimum flow regime below Conowingo Dam was formally established with the signing of a settlement agreement in 1989 with several federal and state resource agencies (FERC 1989). The established minimum flow regime below Conowingo Dam is the following:

March 1 – March 31	3,500 cfs or natural river flow, whichever is less
April 1 – April 30	10,000 cfs or natural river flow, whichever is less
May 1 – May 31	7,500 cfs or natural river flow, whichever is less
June 1 – September 14	5,000 cfs or natural river flow, whichever is less

September 15 – November 30	3,500 cfs or natural river flow, whichever is less
December 1 – February 28	3,500 cfs intermittent (maximum six hours off followed by an equal amount on)

The natural river flow is the discharge measured at the Susquehanna River at Marietta USGS gage (No. 01576000). The Marietta USGS gage is located approximately 35 miles upstream of Conowingo Dam above the Safe Harbor Dam.

3.3.1. Downstream Passage

Volitional downstream passage of American shad and other migratory fishes approaching Conowingo Dam is normally via turbines. Preferential operation of the Kaplan turbines (units 8-11) is implemented upon request by the Susquehanna River Technical Committee (SRTC) during the juvenile shad emigration period between 1700 and 2300 hours in October through November. The preferential operational scheme was developed based on a site-specific turbine survival study of American shad tested at unit 8 in 1993 (RMC 1994). Although turbine passage survival studies of clupeids have also been conducted at upstream hydroelectric dams (*e.g.*, Safe Harbor, Holtwood), similar studies have not been conducted on resident species on the Susquehanna River.

A review of the optimization of the preferential downstream passage strategy has been compiled; it is summarized briefly here. The original preferential turbine operational strategy for Conowingo Dam was developed as a flexible operational strategy to maximize the survival of emigrating young American shad and other clupeids at about 95%. Development of the strategy incorporated the understanding that downstream transport of juvenile alosids through large sized turbines, particularly the Kaplan type units at the Conowingo Project, was a viable method because survival of juveniles in passage through Kaplan type turbines was higher (95-98%) than through Francis turbines (average about 90%) or through non-turbine passage routes. Additionally, the incremental gain in survival by construction of a bypass was too small relative to the cost of installation given an assumed bypass effectiveness of 70%. A site-specific passage survival estimate (94.9% through Kaplan turbine unit 8 at Conowingo Dam), natural river flows, diel movements of juvenile shad and emigration season from the literature, and actual Conowingo Station operations (1981-1991) were incorporated in derivation of the strategy, which was preferential operation of Kaplan turbines during the times and season of peak emigration (1700 – 2300 hours in October and November) to achieve juvenile passage survival ≥95%. This strategy was accepted by the regulatory agencies and approved by FERC.

The effects on passage survival were assessed by evaluating actual turbine operations in the context of assumed turbine survival rates and total Project discharge. Duration and frequency of operation of each Conowingo turbine unit was assessed during the periods of peak emigration of juvenile American shad, assumed to be 1700-2300 hours in October and November, for the years 2005 and 2006 when river flows were ≤30,000 cfs. The assessment resulted in a finding that the Francis turbines were operated an average of 57% of the hours between 1700-2300 hours in October and November 2005 and October 2006 when river flows were ≤ 30,000 cfs (river flows continuously exceeded 30,000 cfs in November 2006). To estimate turbine survival, an estimated loss matrix (turbine mortality) was derived for all combinations of Kaplan units 8-11, assuming conservative survival rates of 95% through Kaplan turbines and 92% survival through Francis turbines (about 1% lower than averages calculated from recent studies (Winchell *et al.* 2000) on juvenile clupeids). Using the actual operational data, weighted for duration (hours) each turbine operated, Project specific survival estimates of 93.4% and 93.7% in 2005 and 2006, respectively were calculated, about 1.6 % and 1.4 % lower than if all passage occurred through Kaplan turbines (95%).

4.0 FISH SPECIES

4.1. Fish Species Present

The fish community in Conowingo Pond has been intensively studied for over 40 years due to the presence of the several power plants located on the impoundment. The resident fishes of Conowingo Pond are for the most part common warm-water species that are found in ponds, lakes, and reservoirs from the southeastern U.S. to Canada. The Pond has been identified as one of the most diverse freshwater fisheries in Maryland, with a highly productive forage base that is likely responsible for the excellent condition and abundance of gamefish, particularly walleye (MDNR 2006). Sampling conducted between 1996 and 1999 revealed that species composition of the resident fish community has changed little since 1966, except for some specific fish introductions from downstream of the Conowingo Dam. More than 50 species were taken in the Pond and tributary streams during this four-year period. The spottail shiner, spotfin shiner, bluntnose minnow, and tessellated darter are common forage species. Green sunfish, pumpkinseed, bluegill, and white crappie are important pan fishes. The common game fishes include channel catfish, smallmouth bass, largemouth bass, and walleye (Normandeau 1998, 1999, 2000). Several other species have arrived in Conowingo Pond via downstream dispersal. Examples include mimic shiner, banded darter, and, more recently, non-native, predacious flathead catfish (see Muddy Run RSP 3.4 for additional detail).

One significant change in the fish community was the increase in relative abundance in the 1970's and 1980's of gizzard shad, which was inadvertently stocked into Conowingo Pond in 1972 (Philadelphia

Electric Company 1975). Gizzard shad is now ranked among the most dominant species in the Pond. Large numbers of gizzard shad are lifted into Conowingo Pond every spring from the lower river, along with the lesser numbers of American shad, and are likely to remain an important part of the ecosystem. Gizzard shad juveniles may be out-competing other species in Conowingo Pond (*e.g.*, white crappie) for food (Normandeau 2000). In 2005, more than 305,000 gizzard shad (81% of the total catch) were passed to Conowingo Pond via the East Lift (SRAFRC 2006).

Conowingo Pond is well known for its smallmouth bass and largemouth bass recreational fishery, and also provides angling opportunities for walleye. Local and regional fishing clubs and organizations utilize Conowingo Pond for fishing tournaments from spring through fall. There is no commercial fishery in the Pond.

Game fish and forage fish abundance in lower Conowingo Pond was examined by MDNR using night electrofishing in October 2005 (MDNR 2006). Walleye were the most abundant gamefish species collected followed by largemouth bass. Both walleye and largemouth bass stocks were considered healthy and indicative of stable recruitment (MDNR 2006). Green sunfish and bluegill were the dominant panfish species. Overall forage fish abundance was high. The dominant forage species was gizzard shad, but residualized alewife were also abundant. Since alewife are not normally passed into Conowingo Pond by the East Fish Lift, recruitment may come from upstream sources (*e.g.*, Raystown Lake in central Pennsylvania).

Agency fisheries management activities in Conowingo Pond include fish stocking by MDNR (walleye, tiger muskellunge) and Pennsylvania Fish and Boat Commission (PFBC) (striped bass fingerlings). In addition, agencies are closely monitoring the Susquehanna River smallmouth bass population due to recent summer fish kills of juveniles, mainly young of year. During 2005, 2007, and 2008 smallmouth bass juveniles acquired bacterial infections believed to reduce year class recruitment (USGS, PFBC and PPL Corporation 2009). The infections, observed from collections taken above Holtwood Dam, appeared to occur during extended periods of warm water temperatures and low river flows.

The Chesapeake logperch (*Percina bimaculata*), a species found in Conowingo Pond, is listed as threatened in Maryland (Ashton and Near 2010). The Conowingo Pond is not an important or critical habitat for any other special status species listed by the States of Pennsylvania and Maryland or the federal government.

4.2. Life History and Habitat Requirements of Target Species

In evaluating entrainment susceptibility and effects, the eight target species (American eel, American shad, bluegill, channel catfish, gizzard shad, largemouth bass, smallmouth bass, and walleye) were considered separately. Following are brief accounts for each of the eight target species, with emphasis on their distribution in Conowingo Pond.

4.2.1. American Eel

Between 1957 and 1980, elver-stage (juvenile) American eels (from 23,000 to 6,000,000 individuals) were stocked annually in the Susquehanna River upriver of the hydroelectric dams (ASMFC 2000). Approximately 2,500 juvenile eels were stocked above Safe Harbor Dam in June 1983 (RMC 1985, unpublished report). American eels were commonly caught in the Susquehanna River in PBAPS-related studies during the 1970s but were absent from catches during the most recent PBAPS studies during 1996-1999. Since volitional passage via the Conowingo Dam East Fish Lift began in 1997, annual passage numbers of juvenile American eel at the Conowingo Dam have been negligible. Presently, the population of eels, both juvenile and adults, in the Conowingo Pond appears to be quite small.

The American eel supports a commercial fishery along the Atlantic Coast. Available harvest data from Maine to Florida indicate that the American eel harvest has declined since the mid-1970s. Atlantic Coast eel populations, including those in the Susquehanna River drainage, are currently managed by an Interstate Fisheries Management Plan for American eel (ASMFC 2000). The Susquehanna River Anadromous Fish Restoration Cooperative (SRAFRC), comprised of state and federal resource agencies, issued a 2010 Migratory Fish Management and Restoration Plan for the Susquehanna River Basin. The plan provides for the restoration of American eels to their historical habitats above dams (SRAFRC 2010).

The American eel is the only catadromous species present on the Atlantic Coast. It is found from the tip of Greenland to the Caribbean and Venezuela in coastal and marine habitats. Its life cycle is complex and poorly understood, and typically includes oceanic, estuarine, and freshwater (riverine) phases. American eel spawn in the winter and early spring in the Sargasso Sea. Fecundity has been reported to range from 0.5 to 4.0 million eggs per female (ASMFC 2000). Adult American eel die after spawning. Following the egg stage, the American eel succeeds from the larval (leptocephalus) stage to the glass eel, elver, yellow eel, and finally to the sexually mature stage known as silver eel. There is a period of migration within each of the aforementioned life stages. In the Chesapeake Bay region, yellow eel mature to the silver eel phase in 8 to 24 years (ASMFC 2000).

The yellow and silver eel stages are more susceptible to entrainment at the Conowingo Project than are elvers. Virtually all elver-stage eels (typically less than 6 inches) reaching the Conowingo Dam do not pass. Larger juveniles (yellow eels) attaining Conowingo Pond via the East Fish Lift may migrate through the Conowingo Pond on their way to upstream tributaries and some may remain in Conowingo Pond. Elvers that are manually transported upstream to tributaries (*e.g.,* by recent USFWS studies) could move upstream or downstream as yellow eels and possibly pass by the Conowingo Project. Yellow eels may spend 8-24 years in freshwater above the Conowingo Dam. The home range of juvenile eels has been found to be relatively small, ranging from about 0.05 acres in a Massachusetts salt marsh (Ford and Mercer 1986), 0.3 miles to 3 miles in Louisiana and West Virginia freshwater streams (Gunning and Shoop 1962; Goodwin 1999), and up to 162 acres in Lake Champlain, Vermont (LaBar and Facey 1983).

Mature eels (silver phase) emigrate downstream to spawning grounds in the Sargasso Sea. The silver eel life stage begins after a lengthy period as a yellow eel. Between the time of beginning the downstream migration and leaving the estuary for the open ocean, yellow eel begin to metamorphose into the adult silver eel phase, which is better suited for ocean migration (ASMFS 2000). Maturing eels begin the spawning migration in late summer and fall in the Mid-Atlantic region (USFWS 1987). Emigrating eels are most active at night and may occupy a variety of depths. Haro *et al.* (2000) monitored eels approaching the Cabot hydroelectric station, located on the Connecticut River, and found that eels occupied a variety of depths while in the forebay but spent the greater proportion of time at or near the bottom (33 feet), occasionally venturing to the surface. In a test flume under lighted conditions, Adam and Schwevers (1997) and Adam *et al.* (1997) reported that European eels occupied different water depths depending on flow velocity. At lower velocities (less than 0.6 feet per second) eels drifted close to the bottom, and at higher velocities (greater than 1.6 feet per second) eels exhibited an active downstream movement generally in the upper two-thirds of the water column.

The size and age of silver eels can vary greatly depending on sex and geographic location. On average, mature female American eels are larger than mature males. Males begin spawning migrations when they are 10 to 15 inches in length, while females begin when they reach 15 to more than 40 inches. Growth continues for a period of time during migration so that eels passing through the Conowingo Pond from upstream locations are likely to be larger than eels just beginning emigration.

Silver eels emigrating from locations upstream of the Conowingo Dam are susceptible to entrainment at the Project. Adult eels are likely to be in the upper two-thirds of the water column as they approach the dam and could pass via spill if a spill event was occurring.

Renewed elver transplants to selected drainages above Conowingo Dam began in 2008. Elvers (approximately 17,500) were transplanted by USFWS to the Conestoga River drainage above Holtwood Dam in 2008 and to Conowingo Creek drainage (tributary to Conowingo Pond) in 2009. Survivors may eventually pass into Conowingo Pond over the next decade or more as elvers or as adult eel outmigrants.

4.2.2. American Shad

The Conowingo Dam West Fish Lift has been operated during anadromous spawning migration since 1972 as part of a cooperative private, state, and federal effort to restore American shad to the upper Susquehanna River. Early goals of the West Fish Lift operation were to determine if adult American shad could be attracted to and collected from below the Conowingo Dam and transported upriver. Subsequently, upon operation of the East Fish Lift in 1997, the goal of the West Fish Lift was to monitor shad populations below Conowingo Dam and provide as many American shad as needed for studies to aid their restoration. Early West Fish Lift annual passage numbers were low until a peak of more than 2,000 American shad passed in 1982. Shad passage via the East Fish Lift began in 1991, when fish were trucked upstream. Trucking ended and volitional passage began in 1997, and passage numbers climbed to just under 200,000 fish in 2001 (Normandeau 2008). More recently, shad catches have declined with just over 29,000 American shad passed into Conowingo Pond in 2009 (SRAFRC 2010). Currently, restoration efforts also include fry stocking above the Conowingo Pond. The number of fry stocked varies annually and is largely dependent on shad fry raised from fertilized eggs obtained from out-of-basin sources.

Adult American shad are the largest anadromous fish of the clupeid family, reaching maximum lengths of about 30 inches. Adults begin migrating to upstream spawning areas in the spring when water temperatures reach about 60-65°F. American shad pass the Conowingo fish lifts from about mid-April through early-June and, traverse Conowingo Pond in the upper water column. After spawning, a portion, estimated at up to 49% in the Susquehanna River (ASMFC 2007), return to the sea.

Over much of their range, downstream movement of juveniles to the sea is triggered by a decrease in water temperature below 65°F or 68°F, increase in river flow, or a combination of both factors, and typically occurs in the fall. Peaks in seaward migrations of juveniles in the Chesapeake Bay region occur from late October to late November when water temperatures are below 59°F. Average length prior to the fall migration is about 2.5 to 5 inches. Size at age is generally greater for females than males, and greater in northern stocks than southern stocks (Klauda *et al.* 1991).

Adult American shad returning to the sea after spawning and juvenile American shad are obligatory downstream migrants that must pass the Conowingo Project to continue their natural life cycle. Adults pass the Project from mid-April through June. Juvenile American shad emigrating downstream are susceptible to entrainment at the Conowingo Project from about October through November.

4.2.3. Bluegill

Bluegill represents one of the most abundant species in Conowingo Pond. It is an important panfish caught and harvested in Conowingo Pond (RMC 1979). A 1978 creel survey found bluegill comprised 17% of the numerical catch in Conowingo Pond, ranking third after white crappie and channel catfish.

Bluegill is primarily a littoral zone resident, typically found in backwaters and other off-channel habitats, usually associated with in-water cover of some type. Spawning is protracted, occurring from May through at least August, and nests are constructed in shallows on sand or gravel. Upon leaving nests, bluegill larvae migrate to limnetic surface waters, returning to littoral areas at approximately 1 inch in length (Werner 1967). Young are planktivores (Jenkins and Burkhead 1993; Werner 1969) and also provide forage for game species. In Conowingo Pond juvenile and adult bluegill abundance would likely be highest at the back of coves where shallow littoral habitat is most common. The bluegill preference for shallow littoral habitats would tend to isolate most young and adult stages from the deep intake structure at the dam.

4.2.4. Channel Catfish

Channel catfish spawn in the spring after water temperatures attain 70°F and build sheltered nests or nests associated with cover (Jenkins and Burkhead 1993; Smith 1985). Eggs and larvae are brooded by the male. Young disperse from schools to available habitats when about 1 inch long (Becker 1983). Channel catfish are generally benthic, they feed mostly on zooplankton and insects when smaller, become more piscivorous as adults (Mathur 1971; Ichthyological Associates 1976), and are most active at night, preferring areas with clean bottoms of sand, rubble or gravel. Growth in channel catfish is relatively slow. It is a relatively long-lived fish that may attain up to 13 years and more than 24 inches in Conowingo Pond. However, comparatively few fish larger than 12 inches or older than 6-8 years old have been taken during field studies.

Spawning areas in Conowingo Pond are widely distributed, with larval and young fish taken in greatest numbers in areas where there is moderate current. In the middle section of Conowingo Pond, larval and young are more common in the current along the west shore (Robbins *et al.* 1970).

Channel catfish are commonly taken by bottom trawling at stations near PBAPS. Sampling by multiple gear types in June-October 1999 showed channel catfish was the third most abundant species (9.9% of all fish combined); most were collected by bottom trawl (Normandeau 2000). Channel catfish is a popular sport fish in Conowingo Pond, and is caught more often in the upper reach of the Pond (RMC 1979). Tagging studies showed no seasonal or other extensive movement of channel catfish in Conowingo Pond (RMC 1979).

FERC (1995) noted the tendency for channel catfish relative abundance in entrainment samples to generally exceed their relative abundance in impoundment populations. The benthic nature of the channel catfish makes it susceptible to entrainment at the deep intake structures at the Conowingo Project. Channel catfish are often taken in samples from the cooling water strainers at the Project turbines that are collected in October and November, indicating entrainment of this species occurs at the Project.

4.2.5. Gizzard Shad

The gizzard shad inhabits fresh and brackish waters in the United States. Its range extends throughout the Mississippi and Great Lakes drainages to about as far north as the St. Lawrence River; from southern New York along the Atlantic Coast to the Gulf of Mexico; and west through the Gulf Coast States to the portions of New Mexico and Colorado east of the Continental Divide (Williamson and Nelson 1985). Although most gizzard shad complete their entire life cycle in fresh water, some enter brackish bays and estuaries along the Atlantic and Gulf Coasts and occasionally enter marine waters. The gizzard shad is essentially an open water, schooling species, living at or near the surface; however, they have been collected at depths of up to 100 feet.

Larval gizzard shad eat mainly protozoans, rotifers and crustaceans; young fish also feed on zooplankton; and larger fish consume detritus, phytoplankton, zooplankton and insect larvae (Williamson and Nelson 1985). At about 1 inch in length, gizzard shad lose their larval teeth, become deeper-bodied, develop a muscular gizzard, and become filter feeders. Gizzard shad can grow to 22.5 inches long and 4.4 pounds. Reproductive maturity normally is reached in two or three years at mean total lengths of 10 to 14 inches (Williamson and Nelson 1985).

Gizzard shad was inadvertently introduced to the Conowingo Pond 1972 and has become one of the most abundant fish species in the Pond. Gizzard shad is a highly prolific species that represents an important component of a rich forage base in Conowingo Pond. Young gizzard shad are the principal forage for several predatory species, including smallmouth bass, largemouth bass, channel catfish and walleye.

It is typically found in the upper 50 feet of the water column. Gizzard shad spawn throughout spring and summer in inshore areas, tributary coves, and in open water. Gizzard shad may become moribund as water temperatures decline below 56°F and succumb at about 38°F. Young gizzard shad typically pass downstream out of reservoirs during fall and early winter and their tendency to become moribund as their lower temperature threshold is approached furthers their susceptibility to entrainment. As a result, entrainment of gizzard shad tends to peak in the fall and winter in reservoirs where they are abundant (FERC 1995).

4.2.6. Largemouth bass

The largemouth bass is native to the eastern United States, excluding the northeastern states and has been introduced throughout the United States. Largemouth bass mature and spawn in as early as one year near the southern limit of its range, in 3-5 years in northern regions, and may live up to 15 years. Larval largemouth bass feed mainly on microcrustaceans and small insects, juveniles consume mostly insects and small fish, and adults feed primarily on fish and crayfish (Stuber *et al.* 1982). Adults generally feed near vegetation within shallow areas.

Largemouth bass live in shallow vegetated habitats, preferring warm, clear water with no noticeable current and do not tolerate excessive turbidity and siltation. Largemouth bass spawn in spring when water temperature reaches 53.5-60° F and build nests in shallow, littoral zone habitats typically associated with cover objects. Adults guard the young after hatching, and young bass remain in shallow, protected habitats such as coves and flooded tributary mouths following cessation of parental care. Adults typically establish home ranges during the summer into fall. Largemouth bass are generally considered inactive during winter (Cooke *et al.* 2003). In the Conowingo Pond largemouth bass are more commonly found in the lower reaches (Robbins *et al.* 1970). Strong orientation to cover and preference for shallower, off-channel habitats generally limits largemouth bass exposure to entrainment through water intakes.

4.2.7. Smallmouth Bass

Conowingo Pond is well known for its smallmouth bass recreational fishery. In Conowingo Pond smallmouth bass formed 13% of the reported recreational harvest in 1978, and nearly 25% of the total weight of fishes harvested (RMC 1979). Smallmouth bass are primarily caught by boating anglers in upper Conowingo Pond during the peak harvest months of May and June (RMC 1979). Smallmouth bass were the most common game fish species taken by night electrofishing in upper Conowingo Pond during 1986 (RMC 1987). Smallmouth bass (juvenile and adult) represented 14.0-19.9% of the shoreline fish community.

Smallmouth bass spawn in spring and build nests associated with littoral zone cover, and guard their young after hatching. Young bass remain in shallow, protected habitats following cessation of parental care. After spawning, adult smallmouth bass may move about within a variable-sized home range up to perhaps one acre (Savitz *et al.* 1993) in summer. Smallmouth bass may move from littoral areas in late fall to winter aggregations associated with cover in deep water (Langhurst and Schoenike 1990).

The smallmouth bass preference for shallow littoral habitats would tend to isolate most young smallmouth bass, typically the life stage most vulnerable to entrainment, from the relatively deep intake structures located in Conowingo Pond.

4.2.8. Walleye

Walleye are a popular sport fish but are sought by a comparatively small proportion of Conowingo Pond anglers. A 1978 creel survey found that walleye made up 0.9% of the recreational catch, 1.7% by weight (RMC 1979). Walleye were the most abundant game fish collected by MDNR during their October 2005 electrofishing surveys conducted in the lower Pond. All walleye collected were in excellent condition, and walleye abundance and growth was described as remarkable (MDNR 2006).

The walleye is native to freshwater rivers and lakes of Canada and the United States, with rare occurrences in brackish water (Scott and Crossman 1973). In the United States, its native range occurs primarily in drainages east of the Rocky Mountains and west of the Appalachians; however, it has been widely introduced into reservoirs outside its native range (McMahon *et al.* 1984).

Walleye live at least 17 years in cool northern waters and mature within two to eight years (Scott and Crossman 1973). Walleye fry eat zooplankton and aquatic insects and start feeding on fish at 0.5 to 1.0 inches in length. The diet of juvenile and adult walleye consists primarily of fish, but aquatic invertebrates, particularly mayfly larvae and crayfish, may be locally or seasonally important (McMahon *et al.* 1984).

Walleye spawn in spring during periods of rapid warming and spawning usually occurs at water temperatures of 43-50°F (Scott and Crossman 1973). Adults migrate to tributary streams or upper portions of rivers in late winter or early spring to lay eggs over gravel and rock in water about 3 to10 feet deep. Preferred spawning habitats are shallow shoreline areas, shoals and riffles with rocky substrate and good water circulation from wave action or currents (McMahon *et al.* 1984). Spawning activity occurs at night and is often concentrated within a few days. Eggs are broadcast freely over the substrate and fall into cracks and crevices (Scott and Crossman 1973). Walleye do not provide any parental care.

Walleye are sensitive to light, prefer depths in the 10-30 foot range, and seek out cover for shade, concealment and orientation. Dispersal of naturally produced young walleye (≤2 inches) downstream occurs at many reservoirs (FERC 1995). Walleye movement out of reservoirs is also common in late fall and winter, often accompanied by increased inflows (FERC 1995; Jernejcic 1986). Little is known of walleye movement patterns in Conowingo Pond, as determined either by fish collection efforts or by angling results. Based on generalized movement patters in other reservoirs, walleye likely move upstream to the upper portions of Conowingo Pond in late winter. Larger walleye may follow stressed prey such as cold-stressed gizzard shad to deeper reservoir areas thereby increasing susceptibility to entrainment into intakes at the Project (RMC and Harza 1992).

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). Normandeau conducted a literature review of swim speed information for the eight target fish species that inhabit the Conowingo Project area. The purpose was to compare available swim performance data for these species to calculated measurements of current velocity proximal to Project intakes.

Three swim speed modes are generally recognized for fishes, though terminology differs slightly among authors. Following the nomenclature of Beamish (1978), sustained swim speed is that which can be maintained for an indefinite period (longer than 200 minutes) and does not involve fatigue; prolonged swim speed can last between 15 seconds and 200 minutes and if maintained will end in fatigue; and burst swim speed is characterized by rapid movements of short duration and high speed, maintained for less than 15 seconds. Laboratory testing of prolonged swim speeds for specific time intervals, frequently related to an expected or required time to pass through fishways or culverts, results in estimates of critical swim speed (U) accompanied by a time stamp (*e.g.*, Ucrit2 = maximum prolonged speed for 2 minutes). Burst or sprint swim speeds (also startle, fast-start, or dart) 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.

Results of the literature review of swim performance data for the eight target species is provided in Table 4.3-1. Two trends are identifiable for a given species; the absolute swimming speed of larger juveniles or adult fish is faster than smaller juveniles, and swim speed for several species appears maximized at approximately 68-86°F, typical late spring to fall ambient water temperatures. A reduction in swimming ability of 50% may occur at water temperatures outside a preferred range (ASCE 1995).

Swim speeds determined in the laboratory are typically measured by a distance rate (feet per second) 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 (feet per second) of larger fish is greater (Beamish 1970).

The data listed in Table 4.3-1 include studies specifically designed to measure one or more component 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). Few studies were noted that tested fish with an objective of developing a water intake design, or tested vs. intake design criteria (*e.g.*, Hocutt 1973). In general, the comments or clarifications provided in Table 4.3-1 identify any information deemed useful to assist interpretation of the test result.

Among the three swim speed modes, burst swim speed is harder to quantify in a laboratory, thus, fewer burst swim speed studies with adequate sample sizes are available (Castro-Santos and Haro 2005). Based on a review of existing data, Bell (1991) suggested that prolonged speeds ("sustained" in Bell's terminology) are approximately 50 to 70 percent of the burst ("darting" in Bell's terminology) speed, and that sustained ("cruising" in Bell's terminology) speeds are 15 to 20 percent of the burst speed. Using Bell's estimates, burst speed for each of the target species can be estimated from prolonged swim speeds found in the literature. Bell's percentage calculations are only used when estimates of burst speeds were not found in the literature.

The swim speed of a number of species of fish in Conowingo Pond was tested in 1968 by Ichthyological Associates (Schuler 1968; King 1969; Robbins *et al.* 1970). The results were used to provide recommendations for maximum cooling water intake velocity for the PBAPS. A stationary circular sluiceway described by MacLeod (1967) was used to determine "maximum swimming speed," defined as the steady speed that a fish maintains for three minutes in a current slightly in excess of the fish's maximum swimming ability. This swim speed corresponds to Beamish's prolonged swim speed.

4.3.1. American Eel

Burst swim speed estimates were found for young American eel. Elvers 2.8 to 3.9 inches long 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).

No estimates were found for yellow or silver American eel. However, swim speed estimates were found for yellow and silver European eel (*Anguilla anguilla*), a species similar in morphology and behavior to American eel. Following the test method of Brett (1964), Quintella *et al.* (2010) tested the prolonged swim speed of 29 yellow eels (14 to 21 inches total length [TL]) and 33 silver eels (12.5 to 27.5 inches TL) placed in a swimming tunnel submerged in a fiberglass tank. The water velocity in the swimming tunnel was adjustable from 0 to 4.9 fps and water temperature ranged from 61 to 66°F throughout the experiment. Prolonged swim speed was 1.4 fps for yellow eels and 2.2 fps for silver eels. Applying Bell's percentage calculation and assuming European eel swim speeds are similar to American eel swim speeds, an estimate of burst swim speed for yellow American eel is 2.0-2.8 fps and 3.1-4.4 fps for silver American eel.

4.3.2. American Shad

Estimates of burst swim speed were found for adult and juvenile American shad. Bell (1991) reported a prolonged swim speed of 1.75 fps and burst swim speed of 2.5 fps for juvenile American shad (1.0-3.0 inches fork length (FL)). Prolonged swim speed for young (2-3 inches FL) American shad in Conowingo Pond was reported by Robbins et al. (1970) to be 1.5 fps.

Weaver (in Beamish 1978) measured the swim speed of American shad passing a fishway and reported speeds of 11.5 to 13.0 fps. Beamish regarded this as a burst swim speed. The size of the fish monitored was not given; however it is probably that American shad swimming through a fishway were adults. Dodson and Leggett (1973) estimated swim speeds of 2.36 to 2.47 fps for 43 adult American shad (lengths not given) tracked in Long Island Sound during 1970 and 1971. Ultrasonic telemetry was used to analyze the minute-to-minute behavior of shad in response to various environmental variables. We interpreted this value to be an estimate of sustained swim speed for adult American shad.

4.3.3. 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 to 0.82 fps were reported for young of year bluegill at typical summer water temperatures by Schuler (1968) and King (1969). Beamish (1978) found a prolonged swim speed of 0.92 fps at 70°F for young of year bluegill. Applying Bell's percent criteria, a burst swim speed estimate of 0.5-1.8 fps was calculated for juvenile bluegill.

Adult sustained swim speed was reported at about 1.0 fps (Drucker and Lauder 1999; Deng et al. 2004). The burst swim speed of adult bluegill 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 critical swim speed (subset of prolonged swim speed) of 1.22 fps over a period of 10 minutes. Applying Bell's percent criteria results in an estimated burst speed of 1.7-2.4 fps.

4.3.4. Channel Catfish

Schuler (1968) and King (1969) reported a maximum swim speed (= prolonged) for juvenile channel catfish less than 4 inches FL of approximately 1.0 fps. A critical swim speed (subset of prolonged swim speed) estimated for juvenile channel catfish 5.5 to 6.0 inches TL was 2.0 fps (Hocutt 1973). Comparing the swim speed of wild and hatchery juvenile channel catfish, Venn Beecham et al. (2007) obtained a sustained swim speed of 1.3 fps, prolonged swim speed of 2.9 fps and burst swim speed of 3.9 fps for wild channel catfish 6.3-8.3 inches standard length (SL). No swim speed studies were found for adult channel catfish.

4.3.5. Gizzard Shad

We located no estimates of burst swim speed for either juvenile or adult gizzard shad. Entrance current velocities in the West Fish Lift have been measured historically and provide a perspective on swim speed of gizzard shad. Measured current velocities of 7 fps (Buchanan 1975) represented no barrier to adult gizzard shad (estimated TL = 9.8-13.8 inches) passage into the fish lift entrance. We interpreted that this value represents a minimum burst swim speed for adult gizzard shad. A burst swim speed estimate for juvenile gizzard shad would likely be less than 7 fps, based upon information in Table 4.3-1 and trends for other species tested.

Two behavioral factors related to gizzard shad must also be acknowledged. First, gizzard shad are a schooling species. Schooling behavior confers enhanced survival (through presumably better swimming ability) as opposed to swimming as individuals (Boyd and Parsons 1998). Because of this schooling behavior, gizzard shad are prone to entrainment in large numbers. Second, gizzard shad are affected by low water temperatures (Williamson and Nelson 1985). During cold winters gizzard shad become increasingly moribund as water temperatures decline below 56°F, and die-offs of juveniles and adults occur at or below 38°F. Thus, the swimming ability of either life stage, and the ability to avoid entrainment, may be compromised during colder winters.

4.3.6. Largemouth Bass

Although a common test animal in swim speed studies, we located no estimates of burst swim speed for either life stage of largemouth bass, perhaps because largemouth bass are not typically thought of as riverine 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 small juvenile largemouth bass (2-4 inches TL) of approximately 1.0-1.6 fps, within a temperature range of 50-95°F. Prolonged swim speeds of large juveniles to perhaps small adults (6-10.6 inches TL) were faster, within the range of 1.8-2.2 fps.

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 small juvenile largemouth bass (2-4 inches TL) is in the range of 1.4-3.2 fps. For larger juveniles and small adults (6-10.6 inches TL) the estimated burst swim speed range is 2.6-4.4 fps. Burst swim speed for adult (*e.g.*, ≥ 12 inches) largemouth bass would be expected to be faster than for the larger juveniles.

4.3.7. Smallmouth Bass

No studies of burst swim speed for smallmouth bass were located. Several studies that developed estimates of prolonged swim speed for fry were identified and reported in Table 4.3-1. A maximum critical swim speed (subset of prolonged swim speed) for juvenile smallmouth bass up to 3.7 inches long was 1.8 fps (Webb 1978). A maximum critical swim speed estimated for adult smallmouth bass up to 15 inches TL was 3.9 fps (Bunt et al. 1999). Applying Bell's percent criteria, an estimate of burst swim speed for juvenile smallmouth bass is 1.9-3.6 fps and 2.3-7.8 fps for adult smallmouth bass.

4.3.8. Walleye

Walleye swim speed information was comparatively abundant for sizes ranging from fry (0.5-0.8 inches TL) to large adults (22.5 inches FL). However, burst swim speed data or estimates were available only for adults and juveniles larger than 6.3 inches FL (Table 4.3-1).

Peake et al. (2000) tested the burst swim speed of walleye by startling (tail-touching) individuals in a holding tank and measuring their movement rate by video. The term "fast-start performance" was assumed synonymous with burst swim speed, and was found to increase linearly with fish size. The estimates of burst swim speed was 6.02 fps for 6.3-inch FL walleye, 7.2 fps for 13.8-inch FL fish, and 8.57 fps for 22.5-inch FL walleye; these speeds were calculated from the regression equation "speed (meters/second) = 1.53 + 1.90*(fish FL in meters)".

Since loss of small juvenile walleye due to entrainment is more probable than loss of adults (due to the considerable swim speeds of adult walleye), information from Bell (1991) may be applied to data for walleye fry (Houde 1969) to develop an estimate of burst swim capability for very small walleye approximating fingerling size. Bell (1991) estimated that a fish's cruising (= Beamish's "sustained") speed may be 15-20% of the dart (burst) swim speed. Houde (1969) reported a sustained swim speed of 0.25 fps for 0.8-inch TL walleye. Thus, an estimate of fingerling burst swim speed is 1.25-1.7 fps.

5.0 IMPINGEMENT AND ENTRAINMENT INFORMATION

This section of the report provides information relative to the four Kaplan units (units 8 – 11) and the seven large Francis units (units 1 – 7). Information is also provided for the two small house (Francis) units.

5.1. Impingement

Impingement refers to the entrapment of fish on bar racks or a screening device located near the outer part of the intake structure as water is passed through the intake structure to the turbine. Impingement on the bar racks is an unlikely event at units 1-11 based upon the relationship of fish length to body width for target species as shown in Table 5.1-1. Representative target fish lengths from 5-40 inches were established, and body-width proportions in Smith (1985) used to calculate corresponding body width. For target species and representative lengths, only large (30 inch) channel catfish had calculated body widths (6.1 inches) wider than the 5.375 inch trash rack spacing at units 1-11. Except for large adult channel catfish, target fish species unable to escape the flow field of the intake structure could pass through the rack spaces rather than become impinged on 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.

Bar rack spacing (1.5 inches) on the house units is smaller than at the primary units; however flow velocity is low, 1.4 fps. Fry and most small juvenile bluegill that lack the swimming ability to avoid intake flows would be small enough to pass through the racks. Juvenile and adult stages of the remaining target species have burst swim speeds sufficient to overcome intake flow velocities at these units. However, as stated above some fish may be unable to react normally to a flow field if injured or lethargic due to loss or reduction of swimming ability.

5.2. Entrainment

5.2.1. Factors Affecting Entrainment

Assessing the probability of entrainment at the Conowingo Project included an examination of the characteristics of the Project relative to life history and behavioral traits of the target species. These factors and various comprehensive reviews of entrainment data (FERC 1995; EPRI 1997) suggest that the factors listed below will influence the risk of entrainment.

- Intake adjacent to shoreline - Nearshore intakes typically entrain fishes at higher rates than offshore intakes, as fish tend to follow shorelines or orient to physical structure associated with shorelines.
- Intake location in littoral zone - The littoral zone is the most productive region of a reservoir and most fish rear in the shallower littoral areas.
- Abundant littoral zone species - Fishes 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 fish assemblage.
- Abundant clupeids - Entrainment rates trend highest at projects with clupeids such as gizzard shad and threadfin shad.
- Presence of obligatory migrants - Resident fishes are usually entrained inadvertently but relative to their use of near-intake habitats. Migrants into or out of freshwater systems must locate a passage or exit route and turbine intakes or draft tubes provide the flow cues used by migrating fish.
- Intake depth - Fish are usually more abundant in shallower portions of a reservoir throughout most of the year.
- Hydraulic capacity - More water passed through intakes will entrain more fish for a given entrainment rate.

- 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 listed above were reviewed for the Conowingo Project. Factors reducing entrainment potential include the location of the intake structure well below the littoral zone and the relatively low intake velocity (Table 5.2.1-1). Unit 1 is the closest large unit to the shoreline. It is located approximately 150 feet from shore which minimizes the potential for entrainment of littoral zone fish at the large units. The house units are located nearer to shore; however, these units are small (1.2 MW), low-flow (245 cfs) and deep-set (67.7 foot depth) units which should minimize the potential for entrainment of littoral zone fishes. Additionally, suitable littoral habitat is limited. The western shoreline in the vicinity of the Dam drops off quickly due to the steep slope of the embankment, resulting in minimal shallow habitat near the dam.

Factors that may increase entrainment potential include a high abundance of gizzard shad, a primary forage fish in the Project area, the high hydraulic capacity of the Project when operated at full capacity (86,000 cfs), and the presence of migratory species that are obligated to move downstream of the Project during their life cycle.

5.2.1.1 Habitat Use

Provided in Table 5.2.1.1-1 is a summary of the life history traits and habitat requirements of the target species as they relate to factors affecting entrainment at the Conowingo Project. Of the eight target species, three are members of the family Centrarchidae (bluegill, largemouth bass and smallmouth bass). These species spend most of their life in the littoral zone, above the 40 foot ceiling depth of the intake structure for units 1-11, and the 68 foot ceiling depth of the intake structure for the house units. Their exposure to the Project's deep water intake structure is minimized by their preference for back cove, shallow areas associated with cover and substrate. Adult smallmouth bass move to deeper water after spawning where individuals in the vicinity of the dam may be susceptible to entrainment.

Life history and habitat preferences of gizzard shad, channel catfish and walleye suggest susceptibility to entrainment. The abundance of gizzard shad in the pelagic zone and the proclivity of juveniles to follow higher fall flows increases the potential for entrainment at the Conowingo Project. Channel catfish, the only benthic target species, spends most of its life near the bottom of the water column where flow velocity to the turbines is strong. Walleye are pelagic, roaming to depths of about 30 feet, but may swim deeper seeking out cool, deep water during summer, or deep-water refuge during winter. The susceptibility of adult walleye is reduced in late winter through early spring when they move to upstream spawning areas.

Two of the target species found in Conowingo Pond are obligatory migrants; American eel and American shad. Juvenile or yellow American eel may reside in a location for many years before migrating downstream as an adult or silver eel. As a resident, yellow eel have relatively small home ranges and only yellow eels in the lower Pond in the vicinity of the Project may be exposed to the Conowingo turbines. Adult eel are susceptible to entrainment during their seaward migration and would be found in Conowingo Pond from about September through November. Yellow and silver eel are found throughout the water column, increasing their susceptibility to entrainment through the deep intake bays

Adult and juvenile American shad are primarily found in the upper water column; however they follow flow cues during downstream migration and pass the Project either through the turbines or during spillage, which may occur in early spring and sporadically in fall. Adult shad move through the Pond from April through June; juveniles migrate downstream in the fall, from about October through November.

5.2.1.2 Swimming Speeds vs. Intake Velocity

Another factor affecting the entrainment potential of resident target species and life stages is swimming performance. For those species and life stages susceptible to entrainment due to life history traits and habitat requirements, the potential for entrainment can be assessed by comparing swim speeds of targeted species to intake velocity. A primary assumption is that non-migratory species/life stages most vulnerable to entrainment are weak swimmers (inability to escape intake velocity) relative to prevailing flow field. This assessment does not include adult eel and juvenile and adult American shad as they are obligatory migrants that are entrained when they migrate downstream.

Table 5.2.1.2-1 shows calculated approach velocities at the Conowingo Project compared to measured or estimated representative burst swim speeds for the target fishes (see Section 4.3, Table 4.3-1). Flow velocities were calculated from a Project drawing velocity curve (Figure 5.2.1.2-1) computed for a cross sectional area of a typical intake structure and an intake flow of 5,300 cfs. Rated flow for the primary turbines (units 1-11) is greater than 5,300 cfs, therefore, the one-to-one ratio of flow (cfs) to area (sq ft) was used to estimate intake flow velocity for each unit. Velocities calculated at the face of the intake pier ranged from about 1.4 fps for the intake bay supplying the small house units, 2.4 to 2.5 fps for the Francis turbines (units 1 through 7) and 3.5 to 3.7 fps for the Kaplan turbines (units 8 through 11) (see Table 3.2.2-1).

The potential for entrainment at the two house units, the turbines nearest the shoreline, is low because approach velocity is low relative to the burst speed of the target species. Only very small bluegill, largemouth bass fry, and walleye fry had swim speeds less than the velocities at these units. The swim speed of all other target species and life stages exceeded these velocities.

The review of fish swimming ability relative to the Francis and Kaplan turbines identified the juvenile period as the life stage most vulnerable to entrainment for most resident target species However, by mid-to-late summer, larger juveniles of these species would be capable of escaping intake velocities, particularly at the Francis units. The exceptions would likely be limited to small juvenile eel and bluegill in the vicinity of the dam. Larger juveniles and adults in the vicinity of the intakes have the swimming ability to avoid intake flow velocities.

Swim performance for several target species, including juvenile smallmouth bass and juvenile largemouth bass was poorer in colder water, as detailed in Table 4.3-1. Other species such as gizzard shad become lethargic or succumb at low water temperatures. In either instance, reduction or loss of swimming ability and the behavioral response necessary to avoid intake flows can lead to increased episodes of fish entrainment.

6.0 ENTRAINMENT ANALYSIS

6.1. Data From EPRI

In 1997, the Electric Power Research Institute (EPRI) compiled entrainment data from 43 selected hydroelectric sites. The sites represented in the EPRI database are listed in Table 6.1-1. Project data in Table 3.2.2-1 were compared to comparable project data available in the EPRI (1997) database to provide some perspective on the potential for entrainment at the Conowingo Project. Based on total plant capacity, the Conowingo Project is larger than the 43 sites reviewed by EPRI. The Richard B. Russell pump-storage project is the most similar relative to total plant capacity at 60,000 cfs. Additionally, the average capacity (7,200 cfs) of the unit sampled at the Richard B. Russell project is the most comparable to the primary units at the Conowingo Project (6,320 – 9,727 cfs). However, it is not a conventional hydroelectric project like Conowingo; it is a pump-storage project. Energy is generated when water from an upper reservoir is passed through turbine generators and released to a lower reservoir; water is pumped back to the upper reservoir to be used for generation. Most (31) of the sampled units in the EPRI database discharged less than 1,000 cfs; five are in the range of the house units (200-300 cfs).

Trash rack spacing for the 43 projects examined by EPRI (1997) is also listed in Table 6.1-1. Most projects (all but three) had rack spacing narrower than the 5.375-inch spacing of the Francis and Kaplan units at the Conowingo Project; six had rack spacing equal to or narrower than the 1.5-inch spacing of the house units. However, a subsequent examination of rack spacing and fish entrainment catch performed on EPRI (1997) data by Winchell *et al.* (2000) found that rack clear spacing had little effect on fish entrainment, particularly on the size of fish entrained (Table 6.1-2). Across all rack spacing, 94% of the fish entrained were less than eight inches long.

The EPRI (1997) analysis examined fish entrainment data for sites including turbines of both Francis and Kaplan/propeller configurations. 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 (*e.g.,* net intrusion, extensive net damage).

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 a reservoir than either medium or large fish (Table 6.1-3).

The entrainment potentials shown in Table 6.1-4 represent up to 36 sites per species without regard to variations in local conditions (*e.g.*, intake configuration, reservoir size) that may influence entrainment. All entrainment tests reviewed by EPRI (1997) that included the target species were used to classify entrainment potential. In general, this selection resulted in the same or slightly higher entrainment potential ratings for the three class-sizes of the target species compared to culling the selection for attributes of test projects similar to the Conowingo Project, such as reservoir size or turbine unit average capacity. The qualitative entrainment potentials derived in this step were used in combination with site specific variables of the Conowingo Project and the target species to assess qualitative entrainment potential at Conowingo, as discussed in Section 6.2.

Entrainment densities and associated entrainment potential for American shad was not available. Empirical data collected at the Project are reviewed to assess entrainment of American shad moving downstream out of Conowingo Pond in Section 6.2.

Most studies have shown that entrainment is highest for fish less than four inches (FERC 1995; Winchell *et al.* 2000). This applies particularly to resident species. Gizzard shad generally have the highest potential for entrainment in reservoirs where they are abundant with entrainment peaks occurring in either the fall or winter, typically when they become lethargic due to cold water temperatures. The potential for entrainment of small bluegill, channel catfish, largemouth bass and walleye was Moderate-High. Entrainment density for these species tended to be higher in summer (EPRI 1997), suggesting dispersal of young as the primary factor. Smallmouth bass entrainment risk also was highest in summer, although the overall risk was rated as Moderate. The young of each of these species, particularly the centrarchids, are considered primarily littoral zone inhabitants.

For medium sized resident fishes (> 8-15 inches), qualitative entrainment densities decreased for bluegill and largemouth bass and remained the same for gizzard shad, smallmouth bass and walleye. 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 fishes greater than eight inches that are available for entrainment are relatively low.

The entrainment potential among all resident large-sized fishes (> 15 inches) considered was no more than Moderate. For bluegill, fish greater than 15 inches are rare. The swimming ability of adults of the other resident target species (see Section 4.3) would be expected to preclude entrainment at the prevailing approach velocities.

Entrainment potential for American eel increased with increased size, as would be expected based on life history traits. Small American eel (elvers) migrate upstream and, therefore, are not frequently entrained by conventional hydropower projects. Yellow eels residing near the dam have moderate potential of entrainment. Adult American eel follow downstream river flows as they emigrate and, therefore, have high potential for entrainment through conventional projects located across the entire river.

6.2. Site Specific Entrainment Data

In support of an American shad restoration program, Exelon collects annual samples from each of the turbines' turbine-bearing cooling water strainer during October to December. The cooling water is directed to the turbine-bearing via a pipe in the penstock wall located downstream of the trash rack. These collections provided data on the seasonality of the juvenile American shad emigration, as well as specimens given to the PFBC for otolith analysis, which compares the overall contribution of hatchery and wild fish. These strainer samples also include species other than shad, and thereby provide limited data on the composition of species entrained. Data were available for a seven year period from 2001 through 2008; the number of samples collected each year ranged from 11 to 16. All of the target species except American eel were collected over the seven years, but not all species were collected in each year (Normandeau 2001 through 2008). Gizzard shad represented over 99.4% of the sample collection and bluegill, channel catfish, American shad, walleye, smallmouth bass, and largemouth bass were also collected. While these collections were not designed to quantify species composition of entrained fish, they provide some characterization of entrainment during the fall season.

An assessment of the magnitude of fallback exhibited by radio tagged adult American shad was assessed by reviewing three study reports of adult American shad telemetry: Normandeau 2001, Normandeau and Gomez and Sullivan 2009, and Normandeau and Gomez and Sullivan 2010. Fallback is defined as passage downstream through Conowingo Dam after a fish is established upstream of the Dam. Typically, length of time is the defining variable influencing falling back. The 2001 study included fish which were in Conowingo Pond and passed back downstream within 24 hours. The 2009 report used a 48 hour time frame. The 2010 study differs in that fish were released downstream of the dam, not upstream in the Pond as was done for the 2001 and 2008 studies. Consequently, numbers passing upstream in 2010 were much reduced from numbers released into the pond in 2001 and 2008. Numbers of radio tagged shad in Conowingo Pond totaled 203 in 2001, 303 in 2008, and 22 in 2010 (Tables 6.2-1 through 6.2-3).

Fallback of radio tagged shad in 2001 was just 2.5% (5 of 203). Three of these fish spent less than one hour in the pond before passing back downstream; another spent 3.5 hours and the third fish spent just over 23 hours in the pond before passing downstream of Conowingo Dam. The study conducted in 2008 found that 29 of the 303 (9.6%) radio tagged shad released into the pond fell back within 48 hours (Table 6.2-2). This result may be misleading since four of the shad were detected only once during the study, at the exit flume of the fish lift. There was no evidence that they passed downstream and were probably included to provide a conservative estimate of fallback. Times in the pond before fallback ranged from 2 minutes to just less than two days; average and median times were 8 hours 37 minutes and 44 minutes, respectively. The ultimate fate of these shad, *i.e.*, seriously injured, dead, or alive after passage cannot be accessed. The monitoring configurations for 2001 and 2008 included surveillance only in the immediate tailrace and/or exit flumes of the fishlifts to fulfill a study objective of identifying fallback and (presumed) post-spawning downstream passage. Monitoring stations were not configured downstream to determine ultimate fate.

Fish were radio tagged and released below Conowingo Dam for the 2010 American shad study. A total of 40 shad passed upstream into Conowingo Pool. Of these, only one fell back within five hours but then re-entered the fish lift and passed back upstream in less than 24 hours (fish 54-208, Table 6.2-3); fallback for these 40 fish was virtually nil since fish 54-208 did pass back upstream. Twenty-three of these 40 shad were known to have passed downstream after spending some amount of time in Conowingo Pond; 22 of these 23 had known detection times in the Conowingo tailrace. Excluding the five hours fish 54-208 was initially in the pond, these fish spent from just less than four days to just more than thirty-three days upstream of Conowingo Dam. The mean amount of time fish spent upstream was just greater than twenty one days and median time was just less than twenty two days. The fate of the radio tagged shad passing downstream of Conowingo is discussed in RSP 3.5. Summarizing, 23 of the 40 (57.5%) radio tagged shad with successful upstream passage of Conowingo Dam eventually re-entered the tailrace via the turbines. Fifteen of those passing downstream via turbines were believed alive at last detection. Signals from the other eight shad became stationary after passing downstream and were considered dead.

Concurrent with the 2010 American shad study at Conowingo, a similar study of adult American shad migration was conducted farther upstream. A subset of American shad collected in the Safe Harbor fish lift were equipped with radio tags, released back to the fish lift, and monitored through Lake Clarke to a location just upstream of the York Haven dam. Of the 180 tagged shad released, six regurgitated their tags before exiting the fish lift and six fell back downstream of the Safe Harbor dam within 48 hours. Six fish from the Conowingo study passed the Safe Harbor dam and were included in the study, providing a total of 174 test fish. The fate of the six fish that fell back is unknown; monitoring stations were not configured to assess the fate of fallback fish (*i.e.,* fish passing downstream through the Safe Harbor project within 48 hours of release). Of the 174 test fish, 14 (2%) were detected passing downstream of Conowingo Dam (Table 6.2-4). Six of those (42.9%) were deemed alive after passage. Table 6.2-4 delineates project operations at times of passage and probable passage routes for those individuals (Normandeau and HDR/DTA 2011).

6.3. Potential Entrainment at the Conowingo Project

Data collected from the literature review and limited site-specific data for the Conowingo Project were used to compile a qualitative assessment of the potential entrainment of target fishes at the Project (Table 6.3-1). The qualitative assessment used a five-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 in EPRI (1997) for other projects.

Overall entrainment potential was determined to be Low for resident adult bluegill, largemouth bass, smallmouth bass, and walleye. The burst swim speeds of these species life stages are sufficient to overcome intake velocities, while habitat preferences tend to preclude them from the intake area. Habitat preferences of adult channel catfish and gizzard shad could place them in proximity to the intake structures; the entrainment potential for these fish was Moderate. Burst swim speed data were not found for adult channel catfish and largemouth bass; however, swim speeds are likely to be similar or greater than that of juveniles, suggesting that these fishes could avoid intake velocities under normal conditions.

Entrainment potential for juvenile target species ranged from Low-Moderate for walleye to High for gizzard shad. Juvenile bluegill, largemouth bass, and smallmouth bass received a rating of Moderate, and channel catfish entrainment potential was deemed Moderate-High. Walleye spawning generally occurs in the upper sections of the Pond where young are not susceptible to entrainment at the Conowingo Project. Juvenile walleye are fast swimming piscivores with swim speeds in excess of intake velocities; however entrainment could occur while chasing prey in the vicinity of the intakes. Juvenile bluegill and young largemouth bass and smallmouth bass are found in littoral habitat but have burst swim speeds in the mid-range of intake velocities. Of these species bluegill is the most abundant in the Pond and the weakest swimmer, thus more likely to be entrained. Burst swim speeds for juvenile bluegill ranged from 0.7-1.8 fps. Bluegill juveniles found in fall strainer collection, indicating that fall entrainment of at least young of year juveniles bluegill occurs. Juvenile smallmouth and largemouth bass have burst swim speeds just below the higher intake velocities calculated at the intake structure; some individuals of both species were found in fall strainer collections.

Juvenile channel catfish were considered to have a Moderate-High entrainment potential because of their benthic habitat requirement and slow burst swim speed relative to the calculated intake velocity. Juvenile gizzard shad had the highest overall entrainment potential due to their abundance in Conowingo Pond, schooling behavior, and their proclivity to move downstream in the fall. Juvenile gizzard shad were the primary species collected in the turbine-bearing cooling water strainers.

6.3.1. Migratory Species

Overall entrainment potential for juvenile American eel in Conowingo Pond was considered to be Moderate-High for yellow eels in the near vicinity of the intake structure, Low for juvenile eels in other areas of the Conowingo Pond, and High for silver eels (Table 6.3-1). Yellow eels were considered to have lower entrainment potential than silver eels because of their residence status. Yellow eels with a home range in the upper and middle .Pond are less likely to be in the vicinity of the intake structure, whereas yellow eels in the lower Pond, near the intake structure could be entrained because they are found throughout the water column, including near the bottom where the intake structures are located, and their burst swim speed is slower than the calculated intake velocity. Entrainment potential of silver eels was considered High because they follow flow cues during their downstream migration.

The overall entrainment rating for juvenile and adult American shad was High. Adult American shad that do not succumb after spawning will migrate back downstream to the ocean. Juvenile shad migrate through Conowingo Pond to the ocean in the fall.

7.0 ESTIMATES OF SURVIVAL

Factors that can influence fish survival during turbine passage include:

- Turbine type - Among factors related to passage survival, the size of water passage spaces available relative to fish size influences susceptibility to contact with structural elements. Francis runners have more closely spaced buckets/blades than Kaplan/propeller runners and thus spaces available for passage are smaller. This is particularly relevant for larger-sized fish passing Francis turbines.

- Turbine speed - Higher speed (rpm's) increase the likelihood of fish contact with structural elements.

Additionally, researchers have found that more than 90% of fishes entrained at hydro projects are small (EPRI 1997). High survival of small fish (< 8 in) reduces the overall impact of entrainment to fish populations. Factors influencing the passage survival of entrained fish are summarized with respect to the Conowingo Project in Table 7.0-1.

7.1. Empirical Estimates of Turbine Passage Survival

Empirical estimates of turbine passage survival for American shad passing the Conowingo Project have been developed. Both the Kaplan and Francis turbines were tested, and each was tested with adult and juvenile shad.

The earliest test of turbine passage survival occurred in the fall of 1993 on juvenile American shad passed through the unit 8 Kaplan turbine (RMC 1994). The unit 8 Kaplan turbine has 6 blades, a runner diameter of 225 inches, 24 wicket gates, and a blade tip speed of 117.8 feet per second. Typical output is 65MW at a discharge near 9,352 cfs at a rated head of 86 feet. The study was conducted when the turbine was operating with a wicket gate opening of 55-56% (approximately 8,000 cfs) to simulate a “worst case” scenario; survival of fishes is reported to be lower at inefficient turbine operation (Bell 1981, Eicher Associates 1987). The optimum operating efficiency (93%) of the unit is reached at a wicket gate opening of approximately 75-80%. Study fish were collected from the inner forebay of the Holtwood Hydroelectric Station. They ranged in length from 4 to 6 inches (fork length) and were considered representative of the emigrating population. Treatment (N=108) and control (N=108) fish were tagged with HI-Z Turb'N Tags (HI-Z Tag) and released individually through an induction apparatus into the penstock of Unit 8 (treatment fish) or to an area between the discharge "boil" of unit's 8 and 7 (control fish). Details of the tag, release and recapture technique are given in Heisey et al. (1992).

The survival of juvenile American shad was high. The short-term (1 hour) survival was estimated at 94.9% (95% CI=86.2-100%) (RMC 1994). The longer term (48 hour) survival was estimated at 92.9% (95% CI=83.9-100%) (RMC 1994). Differences in survival of treatment and control fish were not significant (P>0.05) at 1-hour and 48-hours.

All recaptured fish (live and dead) were carefully examined for type and location of injury, scale loss and unusual behavior. Only one treatment fish was severed and appeared to have suffered a lethal direct strike from a turbine blade or other structural component. Some fish (11 treatment, 10 control) had scale loss which was attributed to tagging and recapture procedures. Other infrequently observed injuries included lacerations (2 treatment, 1 control) and bruises (1 treatment, 3 control). These injuries were lethal to only two of the treatment fish during the long-term (48 hour) assessment period. All live fish (both treatment and control) were in good condition at the end of 48 hours.

In 2011 the HI-Z Tag recapture technique was used to test survival and injury rates of juvenile shad passed through a Francis turbine at the Conowingo Project. The unit 5 Francis turbine, one of two Francis units equipped with aeration runners, was selected for testing rather than a non-aerated unit to evaluate a potentially worst case scenario. Unit 5 has 13 blades (buckets), a runner diameter of 203 inches, 24 wicket gates, and blade tip speed of 72.5 feet per second (see Table 3.2.2-1). Typical output is 36 MW at a discharge near 6,320 cfs at a rated head of 89 feet. Tests were conducted from October 10-15, at near-peak efficiency, the typical operating mode in autumn when juvenile American shad move past the Conowingo Project. During testing, output from the unit 5 Francis turbine ranged from 33 to 36 MW, average discharge was 5,080 cfs, and operational head ranged from 85 to 91 feet (Normandeau and Gomez and Sullivan 2012a).

Juvenile American shad grown at the MDNR Manning Fish Hatchery were used as test fish and ranged in length from 4.2 to 5.6 inches (total length) with an average length of 4.7 inches. The effects of turbine passage at the unit 5 Francis turbine was assessed with 138 treatment fish and 76 control fish. Control fish were released downstream of the turbine discharge.

Recapture rates (physical retrieval of live and dead shad) were 88.4 and 97.4% for treatment and control fish, respectively. A combination of high recapture rates and control survival (89.5%) provided a statistically valid survival estimate for juvenile American shad passing through the aerated unit 5 Francis turbine at the Conowingo Project. Turbine passage survival was estimated at 89.9% with 90% confidence intervals of ≤ ± 5.5% (90% CI≤ ± 5.5%), well below the desired precision (ε) of ±10%, 90% of the time (α = 0.10). Malady-free rate (free of visible injuries, >20% scale loss per side and loss of equilibrium) was 93.3%. Of the fish examined upon retrieval, and at 48 hour post passage, 14% (17 out of 122) of the treatment fish displayed visible injuries and 9.5% (7 out of 74) of the control fish displayed visible injuries. At least three of the seventeen and five of the seven injuries to the treatment and control fish, respectively, were attributed to handling and/or holding rather than to turbine passage. The prominent injury observed was hemorrhaging on the head and snout (Normandeau and Gomez and Sullivan 2012a).

Adult American shad were tested in 2012 to estimate passage survival through the unit 2 Francis turbine and unit 8 Kaplan turbine (Normandeau and Gomez and Sullivan 2012b). The unit 2 Francis turbine is identical to the unit 5 Francis turbine tested in 2011. Unit 2 was tested in 2012 because unit 5 was scheduled to be out of service during the testing period. As in the juvenile shad studies, survival probabilities (1 and 48 hour) and injury rates were obtained using the HI-Z Tag recapture technique. Descriptions of the Francis and Kaplan turbines tested are as detailed above and in Table 3.2.2-1. Fish passage through each unit was tested at near-peak efficiency, the typical operating mode in spring and summer when adult American shad move past the Conowingo Project. The study occurred from May 8-16, 2012. During testing, output from the Francis turbine ranged from 29.9 to 32.3 MW, average discharge was 5,055 cfs, and operational head ranged from 84.3 to 89.2 feet. Output from the Kaplan turbine ranged from 57.2 to 57.6 MW, average discharge was 8,843 cfs, and operational head ranged from 83.6 to 89.5 feet (Normandeau and Gomez and Sullivan 2012b).

Adult American shad captured in the Conowingo West Fish Lift Facility were used for the study; they ranged in length from 12.5 to 23.2 inches (total length) with an average length of 17.6 inches. The effect of turbine passage was assessed with 100 treatment fish passed through the Francis turbine, 101 passed through the Kaplan turbine and 120 control fish released downstream of the turbine discharge.

Recapture rates (physical retrieval of live and dead shad) were 99, 92, and 100% for fish tested at the Francis and Kaplan turbines, and control fish, respectively. Mean recapture times were 5.3, 7.5, and 5.2

minutes after release for the Francis, Kaplan, and control fish respectively. The combination of high recapture rates (Francis 99%, Kaplan 92%, and control 100%) and 1 hour control survival (100%) provided a statistically valid survival estimate for adult American shad passing through the aerated unit 2 Francis turbine and unit 8 Kaplan turbine at the Conowingo Project.

For the aerated Francis turbine, the 1 hour survival probability for adult American shad was estimated at 93.0% (90% CI = ±4.2%); the 48 hour survival probability was estimated at 88.3% (90% CI≤ ± 10.5%), just above the desired precision desired precision (ε) of ±10%, 90% of the time (α = 0.10)). The malady-free rate (free of visible injuries, >20% scale loss per side and loss of equilibrium) of recaptured test fish was 76.2%. Of the fish examined upon retrieval and at 48 hour post passage, 24.2% (24 out of 99) of the treatment fish displayed visible injuries and 4.2% (5 out of 120) of the control fish displayed visible injuries. The observed injuries on at least four of the twenty-four treatment fish and all of the five control fish were attributed to handling and/or holding rather than to turbine passage. The prominent injury observed was torn operculum and isthmuses (Normandeau and Gomez and Sullivan 2012b).

For the Kaplan turbine test, the passage status of 6 (5.9%) test fish could not be determined. After passage through the turbine the HI-Z tags on these fish were not recovered, and only one of the six radio tags was detected but only briefly; no HI-Z tags were recaptured on these fish. During testing of the Kaplan unit turbine the Conowingo station was operating at peak to near-peak generation creating a strong flow in the tailwater and turbulent conditions. The undetected fish likely moved downstream before being retrieved. These six fish were removed from the analysis.

The 1 hour survival probability for adult American shad passed through the Kaplan turbine was estimated at 86.3% (90% CI ≤ ± 5.8%), and 48 hour survival was estimated at 84.1% (90% CI ≤ ± 9.9%). Malady-free rate (free of visible injuries, >20% scale loss per side and loss of equilibrium) of recaptured adult American shad passed through the unit 8 Kaplan turbine was 75.4%. Of the fish examined upon retrieval, and at 48 hours post passage, 28.0% (26 out of 93) of the treatment fish displayed visible injuries. Injuries on at least one of the twenty-seven treatment fish were attributed to handling and/or holding rather than to turbine passage. The prominent injury observed was torn operculum and isthmus along with decapitated and severed bodies (Normandeau and Gomez and Sullivan 2012b).

7.1.1. 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 the Conowingo Project was developed. Winchell et al. (2000) summarized turbine passage survival data reported in the EPRI

(1997) database by turbine type and characteristics and fish size. 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 the Francis and Kaplan type turbine used at the Conowingo Project (Table 7.1.1-1). The Conowingo Project contains seven Francis turbines that rotate at 81.8 rpm and contain 13 buckets; two small Francis turbines that rotate at 360 rpm and contain 13 buckets; and four Kaplan fixed-blade turbines that rotate at 120 rpm and contain 6 blades. Winchell et al. (2000) treated units that rotate slower than 250 rpm as low-speed turbines.

Immediate survival rates were used for this assessment since they enabled use of a larger sample size (N). The mean rates are reported 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. 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 principal survival trend among the reviewed studies of Francis and Kaplan 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 low rotational speeds, less than 250 rpm for the Francis units tested and less than 300 rpm for the Kaplan units tested. For fish less than 8 inches, mean immediate survival rates ranged between 91.6 and 93.9% for the Francis turbines and between 94.8 and 95.4% for the Kaplan turbines tested. Mean survival for fish between 8 and 12 inches was 86.9% for Francis turbines and 87.2% for Kaplan units tested. Mean survival for large fish ranged from 73.2% for fish greater than 12 inches at the Francis units and 93.4% for the Kaplan units tested.

Seven Francis turbines with high rotational speed (>250 rpm) and low capacity (275–695 cfs), in the range of the Conowingo house turbines, were tested. Survival rates for the units tested were low, ranging from 70.1% for fish less than 4 inches to 19.1% for fish greater than 12 inches.

7.1.2. Expanded Survival Database

Since publication of the EPRI (1997) database, numerous studies of turbine passage survival have been conducted for Kaplan and Francis turbines. A review of the expanded dataset offers a second analysis for comparison with the Conowingo Project turbines. The current dataset for Kaplan turbines includes survival results from 150 tests conducted on 40 turbines at 34 projects (Appendix A, Table 1). Sampling methods included discharge netting, float tag, HI-Z Turb'N Tag, and radio telemetry. This dataset was reviewed for turbines similar to the Kaplan units at the Conowingo Project; turbines selected from the dataset had a runner speed less than 250 rpm, 5-7 blades, and hydraulic capacity between 1,000-15,000 cfs. The list of selected studies included 75 tests conducted on 23 turbines at 21 projects (Table 7.1.2-1).

Survival ranged from 63% - 100%, and averaged 94%. Survival less than 85% resulted for six tests, all of which tested large fish ranging in size from 18 to 39 inches. Averaged survival for small fish (less than 8 inches) was 96.2% (N=60 tests), for medium sized fish (8-15 inches) was 91.7% (N=7 tests), and for large fish (greater than 15 inches) was 79.2% (N=8).

American eel were tested through three turbines at three projects. The average length of fish tested ranged from 25-39 inches and survival was 63%, 76.1% and 84% (Table 7.1.2-2). American shad were tested at three projects, including Conowingo (unit 8), Safe Harbor, PA (units 7 and 8), and Hadley Falls, MA (Table 7.1.2-2). Seven tests were conducted with juvenile shad and three tests were conducted with adult shad. Survival for juvenile shad ranged from 89.1% to 100% (average 96.6%). Survival of adults ranged from 78.2% to 90% (average 85.1%). Survival at the Safe Harbor Project, the second dam upstream of the Conowingo Project, averaged 98.2% for juveniles and 88.5% for adults.

The current dataset for Francis turbines includes survival results from 287 tests conducted on 55 turbines at 49 projects (Appendix A, Table 2). Sampling methods included discharge netting, float tag, HI-Z TurbN'Tag, and fyke netting. A list of turbines similar to the Francis units 1-7 at the Conowingo Project was compiles; turbines selected had a runner speed less than 150 rpm, 13-16 blades, and hydraulic capacity between 1,000 and 7,000 cfs (Table 7.1.2-3). The list included 55 tests conducted on nine turbines at nine projects.

Survival values ranged from 16% - 100% and averaged between 77.3% and 79.8%. A range is given for the average in this review of Francis turbine survival tests because the results for six tests at the Shasta Project in California were given as a range. Averages calculated for this assessment include both the low and high results from that project. Averaged survival for small fish (less than 8 inches) was 78.0% – 79.9% (N=39 tests), for medium sized fish (8-15 inches) was 76.0%-81.3% (N=13 tests), and for large fish (greater than 15 inches) was 72.3% (N=3).

American eel were tested through two turbines at two of the selected projects. Fish tested ranged in size from 24.6-35.0 inches and survival was 94.0% and 84.2% (Table 7.1.2-4). American shad were tested at two projects - Vernon, NH/VT and Holtwood, PA (unit 10), the project just upstream of Conowingo (Table 7.1.2-4). Both tests were conducted with juvenile shad; survival was 94.7% at Vernon and 89.4% at Holtwood.

The database of Francis turbines was reviewed for turbines similar to the small Francis house units at the Conowingo Project; turbines selected had a runner speed between 226 and 519 rpm, 12-15 blades, and hydraulic capacity between 275 and 675 cfs (Table 7.1.2-5). The list of selected projects included 37 tests conducted on five turbines at five projects.

Survival results for these five units were variable, but generally low. Survival ranged from 2.7% to 100% and averaged 63.8%. Average survival for small fish (less than 8 inches) was 74.5% (N=24 tests) and for medium sized fish (8-15 inches) was 38.4% (N=11 tests). No larger fish were tested at these units, however, fish size was not reported for two of the tests. American eel and American shad were not tested at these units. Survival through these units reflects their high rotational speed relative to turbine size (runner diameter) and the relatively high number of buckets, creating less area for fish to pass through.

7.1.3. Passage Survival Studies on the Susquehanna River

Survival of American shad passed through turbines at projects upstream of Conowingo has been tested. While many of the turbines tested were not similar to the Conowingo turbines, and therefore were not reviewed in Section 7.1.2. A review of passage survival from upstream projects is provided here. Juvenile shad (average total length of 4.5 inches) were tested at two Francis turbines (units 3 and 10) at the Holtwood Project, just upstream of the Conowingo Project. Estimated short-term (1 hour) survival was 83.5% and 89.4% for units 3 and 10 respectively (RMC 1992) (Table 7.1.3-1). At the Safe Harbor Project, juvenile shad were tested at two Kaplan-type turbines, unit 7 and unit 8. Unit 8 is a venting turbine that was tested under vented mode and unvented operating mode. Estimated short-term survival was 98.0% at unit 7, 97.8% at unit 8 when not venting, and 98.9% at unit 8 when venting (Heisey et al. 1992). Estimated survival of adult American shad at the Safe Harbor Project was 90.0% and 87.0% at units 7 and 8 respectively. At the York Haven Project, estimated survival of juvenile shad passing a Francis turbine was 77.1%, and 92.7% for shad passing a Kaplan unit (Normandeau 2000).

Estimated survival of juvenile American shad passing turbines at the Conowingo Project was compared to two of three upstream projects. The short-term survival estimate for juvenile shad passing the Kaplan turbine at the Conowingo Project was 94.9% (Table 7.1.3-1). This rate compares to juvenile shad survival rates (short-term) of 97.8 – 98.9% at Safe Harbor and 92.7% at York Haven.

USFWS (2012) analyzed silver eel migrations past Conowingo Dam in 2011. Based on 88 tagged silver eels released in upper Conowingo Pond above the Muddy Run Pumped Storage Project, 79 eels (89.8%) were detected at receivers downstream of Conowingo Dam. As these eels were detected several miles below the Dam, USFWS concluded that these 79 eels successfully migrated past the Dam and out of the

Susquehanna River. Since spillage occurred for a number of days during which eels were outmigrating, it was not possible to determine whether eels passed the Dam through spillage or turbine passage. The remaining nine eels were not detected below the Dam so it is not known if they remained in the Pond, migrated after the end of the monitoring (late December, did not survive passage through the turbines or over the spillway , or the tags or tag battery failed, or the tags were damaged in turbine or spillway passage.

7.2. Predicted Survival

A final analysis of turbine survival was made using the formula developed by Franke et al. (1997). The formula grew out of efforts by the Department of Energy (DOE) to design more "fish-friendly" turbines. The formula developed by Franke et al. (1997) to estimate survival through a Kaplan turbine and used to predict survival at the four Kaplan turbines at the Conowingo Project was:

$$P = \lambda \left[\frac{N * L}{D} \right] \left[\frac{\cos \alpha_a}{8 Q_{\omega d}} + \frac{\sin \alpha_a}{\pi \frac{r}{R}} \right] \textit{ and}$$

$$S = 1 - P \textit{ where,}$$

P = probability of strike,
λ = strike mortality correlation factor,
N = number of turbine runner blades,
L = fish length,
D = maximum turbine runner diameter,
α_a = angle to axial of absolute flow upstream of turbine runner,
$Q_{\omega d}$ = discharge coefficient ($Q/\omega D^3$),
ω = rotational speed (rpm x $2\pi/60$),
R = turbine runner radius,
r = turbine runner radius at point fish enters turbine, and
S = survival probability.

The formula developed by Franke et al. (1997) to estimate survival through a Francis turbine and used to predict survival at the seven large Francis turbines and the two small Francis (house) units at the Conowingo Project was:

$$P = \lambda \left(\frac{N * L}{D} \right) \left[\frac{\sin \alpha_t \left(\frac{B}{D_1} \right)}{2 Q_{\omega d}} + \frac{\cos \alpha_t}{\pi} \right] \textit{ and}$$

$$S = 1 - P \textit{ where,}$$

α_t = Angle to tangential of absolute flow upstream of runner
B = Runner height at inlet
D_1 = Diameter of runner at inlet

The formulas calculate the probability (P) of blade strike by relating such turbine parameters as the number of buckets or blades, runner diameter, and runner height to fish length and operating condition (see Table 3.2.2-1 for turbine parameters). The formulas do not consider whether the turbine blades were blunt or sharp. Fish length and available passage space are the principal drivers of the output. For estimates of survival at Conowingo, five representative fish lengths, two operating conditions, and two correlation factors were selected for the Francis and Kaplan turbines. For the Kaplan turbines, three points of entry to the turbine, from hub to tip of blade, were also selected. The operating conditions were turbine efficiency rates of 80% and 90%. The correlation factors (lambda) used were 0.10 and 0.20; these are used to account for variability in strike potential and also to relate the output to empirical data available to the Franke study. The value of lambda in the range of 0.1 to 0.2 was determined by Franke et al. (1997) from Kaplan survival tests. Although the formula calculates a probability, in the present context it is more conventionally used in the formula Survival (S) = 1 – P, with results expressed as a survival percentage.

In developing the formula, Franke et al. (1997) considered previous works that calculated turbine strike probability and new information developed by the authors. Existing empirical data were used to validate the model for conventional hydro projects. A thorough discussion of the derivation and application of the formulas is provided in Franke et al. (1997).

Survival estimates were highest for the Kaplan units (Tables 7.2-1 and 7.2-2). Survival predictions between the two types of Kaplan turbines were very similar; therefore they are discussed as a group. Predicted survival for all fish sizes was greatest at the highest operating efficiency, low correlation factor, and the farthest distance from the hub of the runner nearer the tip of the blade. Survival estimates for fish sizes less than eight inches, representing most of the juvenile target species, ranged from about 92.1% to 98.9%. For adult target species up to 30 inches, survival predictions ranged from 70.3% to 91.1%. For large eels (greater than 3 feet), survival estimates ranged from 60.2% to 88.1%.

Survival predictions for the two types of large Francis turbines (units 1-7) were slightly lower than for the Kaplan units. The survival estimates for the two types of Francis units are very similar and are reviewed as a group. Predicted survival for all fish sizes was greatest at the highest operating efficiency and lowest correlation factor. Survival estimates for fish sizes less than eight inches, representing most of the juvenile target species, ranged from about 91.4% to 97.9%; this is very similar to survival predictions for small fish passing the Kaplan turbines. For adult target species up to 30 inches, survival predictions ranged from 67.9% to 84.6%. For large eels (greater than 3 feet), survival estimates ranged from 59.0% to 79.5%. At the Beauharnois project in Quebec, Canada, turbine passage survival of American eel with an average length of 35 inches was tested at a Francis turbine similar to the Conowingo turbines. The Beauharnois turbine had a low speed (75 rpm vs. 81.8 rpm at Conowingo), the same number of buckets (13), and a low head of 79 feet, vs. 89 feet at Conowingo. Immediate survival (survival after 1 hour) for American eel at Beauharnois was 84.2% (Desrochers 1995); this value was greater than survival predicted by Franke et als' formula for large (40 inch) eels. Survival through the Conowingo Project is expected to be at least as high, considering the similarities of the projects.

7.3. Potential Survival Through Turbines at the Conowingo Project

A qualitative assessment of overall survival potential for target species passing the units at the Conowingo Project was developed from data in the EPRI database, results from additional survival studies, and survival estimates calculated using the Franke *et al.* (1997) model. Quantitative data from the three data sets were converted to a qualitative ranking system where:

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

An overall rating of survival potential for each species and turbine type at the Conowingo Project was assigned based on qualitative summary of the datasets relative to life stage size for each target species. Fish size was the ranking variable as 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). Overall, survival through a Kaplan turbine was rated the highest, followed closely by the large Francis turbines (units 1-7) (Tables 7.3-1 and 7.3-2). Fish passage survival through the small Francis house units was rated relatively low for most fish sizes (Table 7.3-3).

Survival of juvenile fish passing the Kaplan turbines was rated High for American shad, bluegill, channel catfish, and smallmouth bass; High to Moderate for juvenile gizzard shad, largemouth bass; and walleye; and High to Low for yellow eel. The rating for yellow eel spanned the range of survival potential because of the eel's range of size during the yellow phase. Survival for adult life stages ranged from High to Moderate for bluegill and smallmouth bass, High to Low for channel catfish; Moderate-High to Low-

Moderate for gizzard shad and largemouth bass; and Moderate-High to Low for American eel, American shad and walleye, the largest of the adult life stages.

Passage survival through the Francis units 1-7 was rated High for juvenile bluegill, Moderate-High for juvenile American shad; High to Moderate-High for juvenile channel catfish and smallmouth bass; High to Moderate for juvenile gizzard shad, largemouth bass and walleye, and High to Low for yellow American eel. The rating for yellow eel spanned the range of survival potential because of the eel's range of size during the yellow phase. Overall survival ratings were lower for adult stages of the target fishes passing Francis units 1-7. Adult bluegill and smallmouth bass were rated Moderate-High to Low-Moderate; adult American shad, American eel, channel catfish, gizzard shad, and largemouth bass were rated Moderate-High to Low; and adult walleye were rated Moderate to Low.

For juveniles passing the house turbines, passage survival potential was Moderate-High for bluegill, Moderate for American shad, Moderate-High to Low-Moderate for channel catfish and smallmouth bass, and Moderate-High to Low for American eel, gizzard shad, largemouth bass, and walleye. For adult life stage, bluegill and channel catfish had the highest survival potential at Moderate-High to Low, smallmouth bass rated Moderate to Low and the remainder (American eel, American shad, gizzard shad, largemouth bass, and walleye) received a survival potential rating of Low.

7.4. Assessment of Mortality

Survival of small fish (<8 inches) entrained through the Kaplan turbines is predicted to be quite high. Survival of small fish through Francis units 1-7 is also expected to be high, although lower than the Kaplan units. Survival potential through the small house units is lower than the larger Kaplan and Francis units and decreases substantially for fish greater than about 12 inches.

These predictions are fairly consistent with survival data from numerous investigations of fish passage survival at other hydroelectric projects. Site-specific data of turbine survival through the Conowingo Project is available only for American shad (juvenile and adult) passing through a Kaplan turbine and a large aerated Francis turbine. Short-term (1 hour) survival for juvenile shad passing the unit 8 Kaplan turbine was 94.9% under a "worst-case" scenario. This result compares well with survival estimates for similar sized fish summarized from the EPRI database (94.8% average for fish 4-8 inches long) (Winchell *et al.* 2000), other tests of similar Kaplan turbines (100%-89.7% for fish 4-8 inches long), juvenile shad passed through Kaplan units at Safe Harbor on the Susquehanna River (97.8% - 98.9%), and calculated survival using the blade-strike equation (98.8%-92.1% for fish 4-8 inches long) (Franke *et al.* 1997).

Short-term (1 hour) survival for adult shad (average 17.6 inches long) passing the unit 8 Kaplan turbine was 86.3%. This result is in the upper range of test results (63.0 – 93.7%) from other hydro projects with Kaplan turbines similar to those at Conowingo that tested fish 10 inches and longer. The Franke *et al.* blade strike equation estimates of survival for the unit 8 Kaplan turbine ranged from 82.4 to 94.7% for fish 18 inches long. The empirical 1 hour estimate of 86.3% is within the range of the Franke blade strike equation values. Eight percent of the fish that were passed through the unit 8 Kaplan turbine were severely cut, indicating that although this unit has less blades (6) than the unit 2 Francis turbine (13) a strike event could be quite severe.

Short-term (1 hour) survival for juvenile shad (average 4.7 inches long) passing the Francis turbine was 89.9% under a "worst-case" scenario. This result compares well with survival estimates for similar sized fish passing Francis turbines similar to the large Francis units at Conowingo summarized from the EPRI database (91.6% average for fish 4-8 inches long), and for the similar, single runner turbine at the Holtwood Station (89.4%) (Normandeau Associates 1997). The Conowingo unit 5 Francis turbine survival estimate is near the lower range of calculated survival using the blade-strike equation (97.9%-91.3% for fish 4-8 inches long) (Franke *et al.* 1997). However, estimated survival through the Conowingo Francis turbine is lower than that reported (94.7%) for the similar Vernon Project on the Connecticut River. A portion of this noted difference may be due to a relatively smaller sized fish (3.6 inches) used at Vernon versus the 4.7 inch long fish used at the Conowingo Project.

Short-term (1 hour) survival for adult shad (average 17.6 inches long) passing the unit 2 Francis turbine was 93.0%. This result is on the high end of test results (38.7 – 95.6%) from other hydro projects with Francis turbines similar to those at Conowingo that tested fish 10 inches and longer. Empirical results were higher than the Franke blade strike equation predicted survival estimates of fish 18 inches long for the Francis unit 2 turbine (80.7 to 90.8%). Although the Francis unit has 13 blades that entrained adult shad can encounter, the empirical test found a small number of fish with cuts on their body, indicating that fish may have encountered the blades with less frequency and or with less force than the mathematical equation predicted.

8.0 CONCLUSION

The Conowingo Pond supports a diverse assemblage of fishes and a healthy multi-species sport fishery supported by natural reproduction. Recently, the MDNR reported that bass stocks in the lower portion of Conowingo Pond were considered healthy and indicative of stable recruitment (MDNR 2006). The condition of largemouth bass was reported as excellent. The average relative weight (an index of fish condition) of largemouth bass collected during 2010 was 109 (Normandeau and Gomez and Sullivan

Engineers, 2012c). Relative weight in the range of 95-100 is considered suitable for largemouth bass populations (Wege and Anderson 1978). The most abundant gamefish encountered during an electrofishing survey in the lower Pond was walleye. All walleye collected were in excellent physical condition and displayed rapid growth (MDNR 2006). The mean lengths at age calculated for walleye collected in Conowingo Pond in 2010 (Normandeau and Gomez and Sullivan Engineers, 2012c) were above average when compared to other populations throughout North America reported by Quist et al. (2003) and greater than populations in northeastern states reported in Carlander (1997). Overall, the effect of the Project on the target species will vary based on the life history of each species. For resident species that reside in the littoral zone, the effect of the entrainment at the Project is expected to be limited. For resident species that are pelagic for some or all of their life, the potential for entrainment is greater. American shad and American eel must move past the Project to complete their life cycle so they will be entrained through the Project turbines. The potential for entrainment through the Project for the target species is discussed in the following paragraphs. This discussion focuses on the four Kaplan and seven large Francis units. The effects of the two small house units is minimal due to their low volume, closer spacing of the trash racks, and approach velocity compared to the other units; only one of the two house units is typically in operation.

Generally, entrainment of resident fishes is expected to be moderate for gizzard shad and low for all other target species. The movement of resident species that reside in the littoral zone throughout their life is limited; individuals in the upper, middle, and most of the lower sections of the Pond are not likely to be entrained. Entrainment potential for these resident species in the vicinity of the power dam is minimized due to site and Project characteristics including deep intake bays (40 feet below normal full pond for units 1-11, and 67.7 feet for the house units), low intake velocities at the face of the intake structure (ranging from approximately 3.7 fps for the large Kaplan units to 1.4 fps for the small house units), and minimal littoral zone habitat. While the Project powerhouse is located near the west shoreline, the relatively steep shoreline embankment provides limited littoral habitat. Some small individuals may be entrained as swim-speed information coupled with engineering calculations of intake velocity flows suggest small juvenile fishes (those less than 8 inches long) are the vulnerable to entrainment. Larger juvenile and adult stages of the resident species possess the swimming ability to avoid velocities near the intakes. The survival of small fish entrained would be expected to be high based on model calculations and evidence accumulated elsewhere for similar turbines and similar-sized fishes.

Swim speed information coupled with engineering calculations of intake velocity flows suggest small juvenile fishes (those less than 8 inches long) are the most vulnerable to entrainment. Larger juvenile and adult stages of the resident species possess the swimming ability to avoid velocities near the intakes.

Entrained resident fishes would comprise mostly prey species such gizzard shad, a very prolific species in Conowingo Pond. Entrainment of young centrarchids such as bluegill and smallmouth bass is moderated by intake separation from shoreline littoral areas where they are typically most abundant. Predators such as walleye may be entrained as smaller juveniles, but older, larger fish are most likely to avoid entrainment through better swimming ability. The survival of the mostly small fish passing through the turbines would be expected to be high based on model calculations and evidence accumulated elsewhere for similar turbines and similar-sized fishes.

Some individuals of resident fishes may have a greater potential for entrainment. The benthic and pelagic habitat of channel catfish and walleye, respectively, increase their susceptibility to entrainment by proximity. However, except for juveniles less than about 6 inches, both species have burst swim speed sufficient to overcome intake flow velocities. Young bluegill (< 4 inches) have been reported to be entrained where they are abundant in hydroelectric reservoirs (FERC 1995). Entrainment of some juvenile bluegill was found in strainer collections at the Project.

Entrainment potential of gizzard shad at the Conowingo Project is rated Moderate to Moderate-High. Young gizzard shad (1.5 to 4 inches) typically form the bulk of entrainment catches where they are abundant in hydropower reservoirs (FERC 1995). Entrainment of juvenile gizzard shad is evidenced by strainer collections. Young gizzard shad form dense, large, open-water schools and in Conowingo Pond are susceptible due to cold water temperatures. As a result, entrainment of gizzard shad tends to be episodic due to their schooling behavior, and more prevalent during fall and winter when they tend to move downstream. Natural movements of gizzard shad may also increase the risk of entrainment to those predatory species utilizing shad as prey. Young gizzard shad in fall and winter, including those stressed by cold water, may move to deeper waters of the reservoir seeking warmer water. Movements to the lower portions of the reservoir may increase the exposure of the predatory fishes such as walleye that follow schools of these forage species to water proximal to the intakes, thus increasing the risk of entrainment. Smaller juvenile walleye may be entrained, but older, larger fish are most likely to avoid entrainment through better swimming ability. The survival of small fish entrained at the Project is expected to be high based on model calculations and evidence accumulated elsewhere for similar turbines and similar-sized fishes.

American shad must move past the Project to complete their emigration to the sea. Juvenile shad migrate to the Atlantic Ocean in the fall (October – November) and some adults leave the Susquehanna River in spring. Existing downstream passage routes include turbine passage and spillage. Turbine survival studies of juvenile and adult American shad passed through the unit 8 Kaplan turbine resulted in 94.9% and

86.3% survival, respectively under a "worst-case" operational scenario. Survival for juvenile and adult shad passing Francis turbines was 89.9% and 93.0%, respectively, under a "worst-case" scenario. These results compare reasonably well with survival estimates for similar sized fish summarized from the EPRI database (Winchell *et al.* 2000), other tests of similar Francis and Kaplan turbines, and calculated survival using the blade-strike equation (Franke *et al.* 1997).

American eel is a catadromous species that enters freshwater as a juvenile, resides in freshwater for a number of years as a yellow eel, and migrates to the sea as a silver adult. As a result of this life history, American eel is a species with a resident stage and a migratory stage. During its residence in Conowingo Pond, individuals typically reside throughout the Pond with a limited home range. With this limited range, only yellow eel in the lower Pond in the vicinity of the dam are susceptible to entrainment. Survival of entrained individuals will depend on size. Survival of smaller individuals is expected to be high (95 – 100 %). Silver eels will pass through Project turbines or via spillage during their emigration. USFWS (2012) analyzed silver eel migrations past Conowingo Dam in 2011. Based on 88 tagged silver eels released in upper Conowingo Pond above the Muddy Run Pumped Storage Project, 79 eels (89.8%) were detected at receivers downstream of Conowingo Dam. As these eels were detected several miles below the Dam, USFWS concluded that these 79 eels successfully migrated past the Dam and out of the Susquehanna River. Since spillage occurred for a number of days during which eels were outmigrating, it was not possible to determine which eels passed the Dam through spillage or turbine passage. The remaining nine eels were not detected below the Dam so it is not known if they remained in the Pond, migrated after the end of the monitoring (late December, did not survive passage through the turbines or over the spillway , or the tags or tag battery failed, or the tags were damaged in turbine or spillway passage).

TABLE 3.2.2-1: CHARACTERISTICS OF THE CONOWINGO PROJECT TURBINES.

Site / Turbine Characteristic		1,3,4,6,7	2,5	8	9-11	2 House Units
Turbine Type		Francis	Francis	Kaplan (Mixed Flow)	Kaplan (Mixed Flow)	Francis
Rated Turbine Output (MW)		47.7	36.0	65.0	65.0	1.2
Hydraulic Capacity at Rated Output (cfs)		6,749	6,320	9,352	9,727	247
Minimum Hydraulic Capacity (cfs)		4,200	2,000	7,500	7,800	210
Design Head (ft)		89	89	86	86	89
Number of Buckets / Blades		13	13	6	6	13
Runner Diameter (in)	Inlet	109.4	192.5	225	225	40.6
	Outlet (Francis)	206.8	203.0			42.6
Runner Speed (rpm)		81.8	81.8	120	120	360
Blade tip speed (ft/s)		72.5	72.5	117.8	117.8	68.3
No. wicket gates		24	24	24	24	16
Runner Height (in)		72.1	72.1	108.5	108.5	15.5
Wicket gate spacing (in)		13.75	13.75	22.16	22.16	3.72
Approach Velocity (fps) (calculated)		2.5	2.4	3.5	3.7	1.4

TABLE 3.2.2-2: CHARACTERISTICS OF THE CONOWINGO PROJECT RESERVOIR AND TURBINE INTAKE STRUCTURE.

Site Characteristic		Units 1-11	2 House Units
Surface Area-Full Pond (acres)		9,000	
Maximum / Mean Reservoir Depth (ft)		~100 / 20	
Normal Full Pond Elevation[1] (ft)		109.2	
Licensed Minimum Pond Elevation (ft)		101.2	
Licensed Maximum Pond Elevation (ft)		110.2	
Intake Elevations	Top (ft)	69.2	41.5
	CL (ft)	46.8	33.6
	Bottom (ft)	11.2	25.7
Unit Intake Width (ft)		23 per bay, 2 bays per unit	23
Unit Intake Area (sq ft)		1334 per bay, 2 bays per unit	361 1 bay for both units
Trash Rack Bars	Thickness (in)	0.625	0.5
	Height (in)	24	24
	Clear Spacing (in)	5.375	1.5

1. All elevations are NGVD 1929

TABLE 4.3-1: LITERATURE BASED SWIMMING PERFORMANCE DATA FOR TARGET SPECIES IN THE CONOWINGO PROJECT (TL = TOTAL LENGTH, FL = FORK LENGTH, SL = STRAIGHT LENGTH).

Species	Life Stage	Fish Size (in)	Swim Speed (fps)			Literature Source, Comments and Clarification
			Sustained	Prolonged	Burst	
American eel	Juvenile (elver)	2.8-3.9 TL	-	-	2.0 - 3.0	McCleave 1980
European eel (surrogate for American eel)	Adult (yellow)	14.0-21.0 TL	-	1.4	-	Quintella *et al*. 2010; U-crit 20 min, 60.8-66.2 F
	Adult (silver)	12.5-27.6 TL	-	2.2	-	Quintella *et al*. 2010; U-crit 20 min, 60.8-66.2 F
American shad	Juvenile	2.0-3.0 FL	-	1.5	-	Robbins *et al.* (1970); S/max= maximum swim speed for 3 min (= Beamish's prolonged)
	Juvenile	1.0-3.0 FL		1.75	2.5	Bell 1991
	Adult	unknown	2.36 - 2.47	-	-	Dodson and Leggett 1973; boat speed while following sonic tagged fish, not from laboratory test
	Adult	unknown	-	7	-	Bell 1991
	Adult	unknown	-	-	11.5 - 13.5	Weaver 1965, in Beamish 1978.

Table 4.3-1 Continued:

Species	Life Stage	Fish Size (in)	Swim Speed (fps)			Literature Source, Comments and Clarification
			Sustained	Prolonged	Burst	
Bluegill	Juvenile	0.8-3.0 FL	-	0.33 - 0.82	-	Schuler 1968, King 1969; S/max= maximum swim speed for 3 min (= Beamish's prolonged), most tests ≥ 60F
	Juvenile	2.0-2.1 FL	-	0.92	-	Beamish 1978; tested at 69.8F
	Adult	8.0 TL	1	-	-	Deng *et al*. 2004
	Adult	unknown	0.98	-	-	Drucker and Lauder 1999
	Adult	3.9-5.9 TL	-	1.22	-	Gardner *et al*. 2006; critical swim speed for 10-min
	Adult	6.0 TL	-	-	4.3	Webb 1978; final velocity measured after 9-sec burst over short distance
Channel catfish	Juvenile	5.5-6.0 TL	-	2	-	Hocutt 1973; polynomial regression at 80.6-87.8F
	Juvenile	0.78-3.5 FL	-	0.8 – 1.17	-	Schuler 1968, King 1969; S/max= maximum swim speed for 3 min (= Beamish's prolonged), 79-85F
	Juvenile	6.3–8.3 SL	1.3	2.9	3.9	Venn Beecham *et al*. 2007; 66-70F
Gizzard shad	Juvenile	unknown	2.8	-	-	Williamson and Nelson 1985; maximum water velocity at Habitat Suitability Index = 0.1 (swim speed estimated from HIS curve)
	Adult	9.8-13.8 TL	-	-	7.0	Buchanan 1975; able to enter Conowingo fish lift at this velocity

Table 4.3-1 Continued:

Species	Life Stage	Fish Size (in)	Swim Speed (fps)			Literature Source, Comments and Clarification
			Sustained	Prolonged	Burst	
Largemouth bass	Fry	0.8-0.9 TL		0.78 to 1.02		Larimore and Deuver 1968 (cited in Beamish 1978); prolonged at 50 to 86 F.
	Juvenile	2.0-2.5 TL	0.50	1.63		Hocutt 1973; at 86 F; critical speed was maximum of tests from 59-95 F.
	Juvenile	2.0-2.5 TL		1.64		Farlinger and Beamish 1977 (cited in Beamish 1978); critical at 77 F
	Juvenile	2.2 TL		1.01		Larimore and Deuver 1968 (cited in Beamish 1978); prolonged at 68 F
	Juvenile	3.0-3.3 TL	1.21 to 1.34			Dahlberg *et al.* 1968 in Carlander 1977
	Juvenile	3.7-5.0 TL		3.5-3.8 body lengths/s		Kolok 1991; U-crit 2 min at 59-66 F (=1.1-1.6 fps)
	Juvenile	3.7-5.0 TL		2.2 body lengths/s		Kolok 1991; U-crit 2 min at 41 F (=0.7-0.9 fps)
	Juvenile	4.0 FL		1.50		Farlinger and Beamish 1977 (cited in Beamish 1978); critical at 77 F
	Juvenile	3.9 TL		1.15		Otto and Rice 1974 (cited in Beamish 1978); critical at 50 F
	Large juvenile	5.9 TL	0.79 to1.57			Beamish 1970 in Carlander 1977, tested at 50-86 F
	Large Juvenile	5.9-10.6 TL		1.80 to 2.17		Beamish 1970 (cited in Beamish 1978); prolonged at 50 to 86 F
	Large Juvenile	9.8 TL	1.51 to 2.07			Beamish 1970 in Carlander 1977, tested at 50-86 F

Table 4.3-1 Continued:

Species	Life Stage	Fish Size	Swim Speed (fps)	Literature Source, Comments and

		(in)	Sustained	Prolonged	Burst	Clarification
Smallmouth bass	Fry	0.7-1.0 TL	-	≤0.89	-	Larimore and Deuver 1968, cited in Carlander 1977 and Houde 1969
	Fry	0.6 TL	-	13-19 Lengths/sec	-	Larimore and Deuver, 1968 cited in Carlander 1977 and Houde 1969; relative prolonged speed
	Fry	0.6 TL	-	0.60-0.87	-	Larimore and Deuver 1968, cited in Carlander 1977 and Houde 1969; range of prolonged speed
	Juvenile	3.6-3.7 TL	-	1.3 to 1.8	-	Webb 1978; critical swim speed, 2-min U-crit at 55.4 to73.4F
	Adult	10.5-14.9 TL	-	1.6 to 3.9	-	Bunt *et al*. 1999; critical swim speed, U-crit-10 min at 59to 68F

Table 4.3-1 Continued:

Species	Life Stage	Fish Size (in)	Swim Speed (fps)			Literature Source, Comments and Clarification
			Sustained	Prolonged	Burst	
Walleye	Fry	0.5 TL	0.16	-	-	Houde 1969; 64.94F
	Fry	0.8 TL	0.25	-	-	Houde 1969; 55.4F
	Juvenile	3.1 FL	-	1.24	-	Jones *et al*. 1974; critical swim speed at 64.4 to 68F for 10 min
	Juvenile	6.3 FL	-	-	6.02	Fast-start or startle speed calculated from formula in Peake *et al*. 2004
	Adult	15.0 FL	-	2.74	-	Jones *et al*. 1974; critical swim speed at 64.8 to 68F for 10 min
	Adult	13.8 FL	-	-	7.2	Fast-start or startle speed calculated from formula in Peake *et al*. 2000
	Adult	22.5 FL	-	-	8.57	Fast-start or startle speed calculated from formula in Peake *et al*. 2000

TABLE 5.1-1: FISH BODY WIDTHS FOR MAXIMUM LENGTHS OF TARGET FISH IN THE CONOWINGO PROJECT. FISH TOTAL LENGTH (TL)-BODY WIDTH (BW) RELATIONSHIPS FROM SMITH (1985).

Target Species	Maximum Length (in)	Body Width (BW) for Given Total Length (TL) (in)							BW as % of TL
		TL=5	TL=10	TL=15	TL=20	TL=25	TL=30	TL=40	
American eel	40	NA	0.4	0.6	0.8	1.0	1.1	1.5	3.8
American shad	30	0.8	1.6	2.5	3.3	4.1	4.9	NA	16.4
Bluegill	16	0.8	1.7	2.5	NA	NA	NA	NA	16.8
Channel catfish	30	1.0	2.0	3.0	4.1	5.1	6.1	NA	20.3
Gizzard shad	20	0.7	1.3	1.9	2.6	NA	NA	NA	13.0
Largemouth bass	25	0.8	1.7	2.5	3.3	4.1	NA	NA	16.5
Smallmouth bass	12	0.8	1.6	2.4	NA	NA	NA	NA	15.8
Walleye	30	0.8	1.5	2.3	3.0	3.8	4.5	NA	15.0

TABLE 5.2.1-1: COMPARISON OF FACTORS THAT MAY INFLUENCE ENTRAINMENT OF TARGET FISHES AT THE CONOWINGO PROJECT.

Influencing Factors	
Intake adjacent to shoreline	Yes
Intake located in littoral zone	No
Abundant littoral zone fishes (no. species)	Yes
Abundant littoral zone fishes (no. individuals)	Yes
Abundant clupeids	Yes
Obligatory migrants	Yes
Depth to intake (ft)	40
Normal hydraulic capacity (cfs)	86,000
Approach velocity (fps, normal operation)	2.5 - 3.7 (primary units) 1.4 (house units)

Table 5.2.1.1-1: Target species life history traits and activity patterns relative to factors affcting entrainment potential at the Muddy Run Project.

Species and Life Stage	Approximate Size Range (inches)	Time-Frame in Lower Pond	Activity Pattern
American eel Yellow Silver	 4.0 – 30.0 15.0 – 40.0	 Potentially all year Sept – Nov	Nocturnal, found throughout the water column, yellow eel have relatively small home ranges (up to ~150 acres), silver eel migrate downstream in fall.
American shad Juvenile Adult	 3.2 – 4.3 15.0 – 30.0	 Oct – Nov April – June	Adults migrate in the upper water column, juveniles may make diel vertical migrations, spending daylight hours near the bottom and evening near the surface; pelagic zone.
Bluegill Juvenile Adult	 0.39 – 2.5 2.5 – 16.0	 All year All year	Larvae migrate to limnetic surface waters, return to littoral zone areas at ~1 inch, juveniles and adults primarily littoral zone.
Channel catfish Juvenile Adult	 0.5 – 4.0 4.0 – 30.0	 All year All year	Primarily nocturnal and benthic.
Gizzard shad Juvenile Adult	 1.0 – 10.0 10.0 – 22.5	 All year All year	Pelagic, upper 50 feet of water column, young may pass downstream out of the Pond in fall and early winter, become lethargic at lower temperatures.
Largemouth bass Juvenile Adult	 2.0 – 10.0 10.0 – 25.0	 All year All year	Primarily found in shallow littoral zone, small summer and fall home range, relatively inactive in winter.
Smallmouth bass Juvenile Adult	 1.0 – 5.0 5.0 – 12.0	 All year All year	Primarily found in shallow littoral zone, adults move to deeper water after spawning, small home range.
Walleye Juvenile Adult	 1.0 – 12.5 12.5 – 30.0	 All year April – Dec	Adults likely move to upper reaches of the Pond in late winter to spawn and return to middle and lower reaches in early spring, primarily found in pelagic zone.

TABLE 5.2.1.2-1: CALCULATED APPROACH VELOCITY AT THE CONOWINGO PROJECT TRASH RACKS, COMPARED WITH FISH BURST SWIM SPEEDS.

Velocity Estimate Type	Approach Velocity (fps)
Engineering drawing-at face of intake structure	Kaplan – 3.5 to 3.7 Francis - 2.4 to 2.5 House – 1.4

Species	Life Stage	Fish Size (in)	Burst Swim Speed[1] (fps)
American eel European eel surrogate	Juvenile	2.8 - 3.9 TL	2.0 – 3.0
	Adult - yellow	14.0 - 21.2 TL	2.8
	Adult - silver	12.5 - 27.6 TL	4.4
American Shad	Juvenile	1.0 – 3.0 FL	2.5
	Adult	13.8 - 20.1 FL	14.7
Bluegill	Juvenile	0.8 – 3.0 FL	0.7 - 1.8
	Adult	6.0 TL	4.3
Channel catfish	Juvenile	6.3 - 8.3 SL	3.9
Gizzard shad	Adult	9.8-13.8 TL	8.0
Largemouth bass	Fry	0.8-0.9 TL	1.6 – 2.0
	Juvenile	2.0-3.9 TL	2.0 – 3.3
	Large juvenile	5.9-10.6 TL	3.6 – 4.3
Smallmouth bass	Juvenile	3.6 - 3.7 TL	2.6 - 3.6
	Adult	10.5 - 14.9 TL	3.2 - 7.8
Walleye	Fry	<1.0 TL	1.25
	Juvenile	3.1 FL	2.5
	Juvenile	6.3 FL	6.0
	Large juvenile	12.5 FL	11.0
	Adult	13.8 - 22.5 FL	7.2 - 8.6

1 Burst swim speeds are derived from Table 4.3-1. For species life stages where burst swim speed was not available in Table 4.3-1, it was calculated from prolonged swim speed where prolonged = 50% of burst swim speed (Bell 1991) and is italicized.

TABLE 6.1-1. LOCATION, HYDRAULIC CAPACITY AND TRASH RACK SPACING OF 43 HYDROELECTRIC PROJECTS INCLUDED IN THE EPRI (1997) ENTRAINMENT DATABASE REVIEW.

Site Name	State	River	Total Plant Capacity (cfs)	Average Capacity of Sampled Units (cfs)	Clear Trash Rack Spacing (in)
Belding	MI	Flat	416	208	2
Bond Falls	MI	W.B. Ontonagon	900	450	3
Brule	WI	Brule	1,377	458	1.62
Buzzard's Roost	SC	Saluda	3,930	1,310	3.625
Caldron Falls	WI	Peshtigo	1,300	650	2
Centralia	WI	Wisconsin	3,640	550	3.5
Colton	NY	Raquette	1,503	450	2
Crowley	WI	N.F. Flambeau	2,400	1,200	2.375
E. J. West	NY	Sacandaga	5,400	2,450	4.5
Feeder Dam	NY	Hudson	5,000	1,000	2.75
Four Mile Dam	MI	Thunder Bay	1,500	500	2
Gaston Shoals	SC	Broad	2,211	837	1.5
Grand Rapids	MI/WI	Menominee	3,870	739	1.75
Herrings	NY	Black	3,610	1,203	4.125
High Falls	NY	Beaver	900	300	1.81
Higley	NY	Raquette	2,045	682	3.63
Hillman Dam	MI	Thunder Bay	270	270	3.25
Hollidays Bridge	SC	Saluda	4,396	370	unknown
Johnsonville	NY	Hoosic	1,288	644	2
Kleber	MI	Black	400	200	3
Lake Algonquin	NY	Sacandaga	750	750	1
Luray	VA	S.F. Shenandoah	1,477	369	2.75
Minetto	NY	Oswego	7,500	1,500	2.5
Moshier	NY	Beaver	660	330	1.5
Ninety-Nine Islands	SC	Broad	4,800	584	1.5
Ninth Street Dam	MI	Thunder Bay	1,650	550	1
Norway Point Dam	MI	Thunder Bay	1,775	575	1.69
Potato Rapids	WI	Peshtigo	1,380	500	1.75
Raymondville	NY	Raquette	1,640	1,640	2.25
Richard B. Russell	GA/SC	Savannah	60,000	7,200	8
Saluda	SC	Saluda	812	227	unknown
Sandstone Rapids	WI	Peshtigo	1,300	650	1.75

Table 6.1-1 Continued:

Site Name	State	River	Total Plant Capacity (cfs)	Average Capacity of Sampled Units (cfs)	Clear Trash Rack Spacing (in)
Schaghticoke	NY	Hoosic	1,640	410	2.125
Shawano	WI	Wolf	850	850	5
Sherman Island	NY	Hudson	6,600	1,650	3.125
Thornapple	WI	Flambeau	1,400	700	1.69
Tower	MI	Black	404	202	1
Townsend Dam	PA	Beaver	4,400	2,200	5.5
Twin Branch	IA	St. Joseph	3,200	600	3
Warrensburg	NY	Schroon	1,350	1,350	unknown
White Rapids	MI/WI	Menominee	3,994	1,225	2.5
Wisconsin River Division	WI	Wisconsin	5,150	431	2.19
Youghiogheny	PA	Youghiogheny	1,600	800	10

TABLE 6.1-2: SIZE CLASS COMPOSITION OF FISH ENTRAINED AT PROJECTS WITH THE GIVEN RANGE OF BAR RACK SPACING, FROM WINCHELL *ET AL.* (2000).

Clear Spacing (in)	N	Average Composition (%) by Size Class					Representative Development
		0–4 (in)	4–8 (in)	8– 5 (in)	15– 0 (in)	>30 (in)	
1	3	61.5	32.2	5.5	0.9	0	
1.5 - 1.8	10	64.8	27.1	7.5	0.6	0	Conowingo Project House Units (rack clear spacing = 1.5)
2.0 - 2.75	12	68.9	25.3	5.1	0.7	0	
3.0 - 10.0	14	80.0	15.7	3.9	0.3	0	Conowingo Project Units 1-11 (rack clear spacing = 5.375)
All	39	71.3	22.9	5.3	0.5	0	

TABLE 6.1-3: FIVE STEP QUALITATIVE RATING OF EPRI (1997) ENTRAINMENT DATA AS A MEASURE OF FISH PER MILLION CUBIC FEET OF WATER.

Qualitative Rating	Fish size		
	<8 inches	8-15 inches	>15 inches
High	>1.0	>0.1	>0.1
Moderate-High	0.9999 - 0.1000	0.0999 – 0.0100	0.0999 - 0.0100
Moderate	0.0999 - 0.0300	0.0099 - 0.0025	0.0099 - 0.0030
Low-Moderate	0.0299 – 0.0100	0.0024 – 0.0010	0.0029 - 0.0010
Low	<0.0099	<0.0009	<0.0009

TABLE 6.1-4: ENTRAINMENT POTENTIAL FOR SELECT SPECIES, GROUPED BY FISH SIZE, IDENTIFIED FROM PROJECTS REVIEWED BY EPRI (1997). SELECTED SPECIES REPRESENT THE CONOWINGO PROJECT TARGET SPECIES.

Species/ Surrogates	No. Sites Species Present	Qualitative Rating of Entrainment Potential		
		Small Fish (< 8 in)	Medium Fish (8-15 in)	Large Fish (>15 in)
American eel	9	Low	Moderate	Moderate-High
American shad	0	--	--	--
Bluegill	36	Moderate-High	Moderate	Low
Channel catfish	18	Moderate-High	Moderate-High	Low-Moderate
Gizzard shad	10	High	High	Moderate
Largemouth bass	34	Moderate-High	Low-Moderate	Moderate
Smallmouth bass	34	Moderate	Moderate	Low
Walleye	29	Moderate-High	Moderate-High	Low-Moderate

TABLE 6.2-1: SUMMARY OF ADULT AMERICAN SHAD FALLBACK AFTER PASSAGE UPSTREAM OF CONOWINGO DAM, 2001.

Fish ID	Release		Last Detection at Dam		Downstream Passage		Elapsed Time in Pond	Turbines Operating	Flow CFS	Water Temperature (^oF)
	Date	Time	Date	Time	Date	Time	Hour			
5-83	5/17/01	16:00	5/18/01	8:35	5/18/01	12:07	3.53	3,7	9,830	19.7
6-63	5/17/01	16:00	5/17/01	17:33	5/17/01	18:26	0.88	7,9,10	15,190	21.0
6-73	5/17/01	16:00	5/18/01	8:45	5/18/01	9:42	0.95	3,7	9,830	19.7
6-76	5/17/01	16:00	5/18/01	15:47	5/18/01	16:05	0.30	3,7	9,830	19.7
6-56	5/17/01	16:00	5/24/01	8:37	5/25/01	7:39	23.03	3,7	13,270	19.8
						Minimum	0.30			
Number		5				Median	0.95			
Available		203				Mean	5.74			
Fallback		2.46%				S.D.	9.75			
						Maximum	23.03			

TABLE 6.2-2: SUMMARY OF ADULT AMERICAN SHAD FALLBACK AFTER PASSAGE UPSTREAM OF CONOWINGO DAM, 2008.

Fish ID	Release		Last Detection at Dam		Downstream Passage		Elapsed Time in Pond	Turbines Operating	Flow CFS	Water Temperature (^oF)
	Date	Time	Date	Time	Date	Time	Hour			
26-20	4/22/08	10:30	4/22/08	14:00	4/23/08	19:02	29.03	3,4,5,6,8,9,10	55,300	62.1
1-59	4/24/08	16:00	4/24/08	17:07	4/26/08	12:34	43.45	5,6	12,600	67.0
54-82	4/24/08	16:00	4/25/08	10:13	4/25/08	11:54	1.68	3,4,5,6	27,800	65.8
54-85	4/24/08	16:00	4/24/08	17:46	4/24/08	18:33	0.79	3,4,5,6,9	36,800	63.8
8-9	5/4/08	9:10	5/4/08	11:13	5/5/08	22:17	-	-	-	60.8
26-31	5/4/08	9:10					0.30	All	79,600	
26-35	5/4/08	9:10	5/5/08	8:45	5/5/08	9:04	-	All	79,600	60.8
26-40	5/4/08	9:10					0.04	5,7	9,430	
54-91	5/4/08	9:10	5/4/08	9:03	5/4/08	9:06	35.06	4,5,6,7,11	39,100	59.7
26-50	5/5/08	9:00					-			
54-12	5/5/08	9:00	5/6/08	13:10	5/7/08	8:56	0.13	3,4,5,6,9,10	46,800	64.2
54-16	5/5/08	9:00					19.76	All	79,800	
8-7	5/5/08	9:00	5/9/08	13:44	5/10/08	2:22	-			64.9
8-14	5/5/08	9:00	5/8/08	14:46	5/8/08	14:48	0.20	3,4,5,6,9,10	46,800	65.2
26-51	5/5/08	9:00	5/9/08	9:14	5/9/08	9:22	0.03	All	80,200	65.5
62-23	5/5/08	9:00	5/9/08	9:17	5/9/08	9:29	12.65	5,6	8,850	65.5
1-74	5/9/08	9:15					-	3,4,5,6,8,9,10,11	58,700	
1-77	5/9/08	9:15					-	3,4,5,6,8,9,10,11	58,600	
1-94	5/9/08	9:15					-			

Table 6.2-2: Continued

Fish ID	Release		Last Detection at Dam		Downstream Passage		Elapsed Time in Pond	Turbines Operating	Flow CFS	Water Temperature (^oF)
	Date	Time	Date	Time	Date	Time	Hour			
1-98	5/9/08	9:15	5/9/08	15:41	5/10/08	0:14	8.55	5,6	11,700	64.9
1-13	5/26/08	12:15	5/28/08	9:18	5/28/08	9:39	0.35	3,7,9	47,200	67.9
26-75	5/26/08	12:15	5/28/08	11:20	5/28/08	11:35	0.24	1,3,4,6,7,9,10	60,700	67.9
1-25	5/27/08	9:00					-	4,5,6,7,8	35,500	
1-26	5/27/08	9:00					-	4,5,6,7,8	65,300	
26-85	5/27/08	9:00					-	4,5,6,7,8	47,800	
26-87	5/27/08	9:00	5/27/08	9:17	5/27/08	9:42	0.41	4,5,6,7,8	35,400	65.7
1-31	5/30/08	13:15	5/31/08	5:45	5/31/08	6:27	0.69	5,7	9,060	71.1
1-38	5/30/08	13:15					-	All	76,600	
26-97	5/30/08	13:15					1.99			71.1
						Minimum	0.03			
Number		29				Median	0.74			
Available		303				Mean	8.63			
Fallback		9.57%				S.D.	13.83			
						Maximum	43.45			

TABLE 6.2-3: SUMMARY OF AMERICAN SHAD FALLBACK AFTER PASSAGE UPSTREAM OF CONOWINGO DAM 2010.

Fish ID	Release		Last Detection at Dam		Downstream Passage		Elapsed Time in Pond	Turbines Operating	Flow CFS	Water Temperature (^oF)
	Date	Time	Date	Time	Date	Time	Hour			
54-194	4/20/10	13:09	5/3/10	16:13	6/2/10	17:00	720.79	1,2,3,4,5,6,7,8,9,11	62,490	81.68
54-198	4/20/10	13:36	5/7/10	16:40	5/30/10	16:49	552.16	2,5,6,7,8,9,11	58,270	76.64
54-199	4/20/10	13:52	5/7/106	18:46	5/23/10	11:11	376.42	2,5,6,7,8,9	34,677	66.56
54-201	4/20/10	14:08	4/30/10	10:12	5/24/10	17:47	583.58	2,3,4,5,6,7,8,9,11	58,748	
54-202	4/20/10	14:12	5/5/10	15:30	6/6/10	15:00	767.51	2,5,6,7,8	34,093	82.04
54-203	4/20/10	14:16	5/6/10	11:34	5/24/10	21:13	441.65	2,3,4,5,6,7,8,9,11	58,748	68.54
54-207	4/20/10	14:41	5/7/10	17:59	6/1/10	13:29	595.50	2,3,4,5,6,7,8,9,11	59,389	77.9
21-112	4/22/10	11:44	5/8/10	8:55	6/2/10	19:24	610.49	2,5,6,7,8,9	32,600	80.24
21-114	4/22/10	12:03	5/8/10	11:29	5/28/10	15:53	484.41	2,3,4,5,6,7,8,9	46,209	66.92
21-121	4/22/10	13:11	5/7/10	18:38	5/12/10	20:58	507.18	2,3,4,5,6,7,8,9	46,209	72.86
21-122	4/22/10	13:20	5/8/10	11:30	5/31/10	15:50	122.34	All	80,733	65.84
21-123	4/22/10	13:21	5/23/10	15:10	6/3/10	8:13	556.34	2,5,6,7,8	35,387	76.1
21-124	4/22/10	13:26	5/8/10	12:48	6/2/10	12:25	257.06	2,5	7,138	78.98
21-127	4/22/10	13:34	5/7/10	14:20	5/26/10	18:24	599.61	2,5,6,7,8,9	30,815	78.44
21-135	4/22/10	12:56	5/7/10	12:46	5/28/10	15:57	460.06	All	78,256	74.66
21-132	4/28/10	11:35	5/8/106	10:46	5/23/10	9:32	358.78	2,5,6,7,8,9	33,514	72.86
54-208	4/28/10	11:35	5/11/10	15:25	5/11/10	20:25	5.00	2,3,4,5,6,7,8,9	45,518	66.2
54-208	4/28/10	11:35	5/12/10	18:12	6/4/10	11:15	545.05	5,6	7,192	
54-168	5/7/10	10:15	5/12/10	12:42	6/1/10	15:09	482.45	1,2,3,4,5,6,7,8,9,11	65,512	78.8
21-149	5/10/10	12:34	5/17/10	13:40	6/19/10	18:12	524.90	4,5,6,7,8,9,11	47,328	80.06

Table 6.2-3: Continued

Fish ID	Release		Last Detection at Dam		Downstream Passage		Elapsed Time in Pond	Turbines Operating	Flow CFS	Water Temperature (°F)
	Date	Time	Date	Time	Date	Time	Hour			
21-170	5/10/10	15:05	5/12/10	17:51	6/11/10	19:14	796.54	2,4,5,7,8	NA	80.6
21-174	5/10/10	11:17	5/12/10	15:06	6/3/10	12:00	721.39	2,3,4,5,6,7,8,9,10,11	71,450	79.16
21-171	5/12/10	11:40	5/24/10	11:55	5/28/10	9:14	93.32	2,5,6,7,8	12,508	86.18
						Minimum	3.89			
Number		1				Median	22.29			
Available		22				Mean	21.13			
Fallback		4.55%				S.D.	7.67			

TABLE 6.2-4: DISPOSITION OF AMERICAN SHAD DETECTED PASSING THE CONOWINGO DAM AFTER RELEASE IN THE SAFE HARBOR DAM FISHLIFT, 2010.

Fish ID		Dropback		Probable passage route*	Units operating at time of passage	Final	
Ch	Code	Date	Time			Location	Disposition
40	108	5/26/2010	21:57	Unit 2	Units 2,5	1/4 mile Upstream of I-95 Bridge, West Shoreline	Dead (not from turbines)
40	113	5/27/2010	6:53	Unit 2	Units 2,5,8,9,10,11	West Channel Off Downstream Tip of Rowland Is.	Dead (possibly turbine related)
40	118	5/16/2010	10:42	Unknown	Unit 5	Conowingo Small Units - Unit 5	Dead (possibly turbine related)
40	138	5/24/2010	14:39	Unit 2	Units 2,5,6,7,8	Recovered Tag only, 300 yds upstream of Lee's Ferry	Dead (possibly turbine related)
40	154	5/13/2010	21:20	Unit 2	Units 2,5	Conowingo Small Units - Unit 5	Dead (possibly turbine related)
40	155	5/19/2010	20:55	Unit 2, 3, or 4	Units 2,3,4,5,6,7,8,9,11	Tomes Landing	Alive
40	163	5/12/2010	7:06	Unit 1, 2, or 3	Full House	Lapidum	Alive
40	166	6/2/2010	19:33	Unit 5	Units 2,5	Lapidum	Alive
40	175	6/5/2010	10:44	Unit 5 or 6	Units 5,6	Lapidum	Alive
40	183	6/22/2010	3:30	Unit 5, 6, or 7	Units 1,2,3,4,5,6,7,8,9,11	Conowingo Small Units - Unit 5	Dead (possibly turbine related)
58	78	5/19/2010	18:16	Unit 9 or 11	Units 2,3,4,5,6,7,8,9,11	Lapidum	Alive
58	99	5/31/2010	1:54	Unit 5	Units 2,5	Lapidum	Alive
58	117	6/15/2010	9:23	Unit 6 or 7	Units 2,3,4,5,6,7	Conowingo Small Units - Unit 7	Dead (possibly turbine related)
58	118	6/13/2010	22:03	Unknown	Unknown	Rowland Island West	Dead (possibly turbine related)

* Based on signal strength

TABLE 6.3-1: QUALITATIVE ASSESSMENT OF THE ENTRAINMENT POTENTIAL OF TARGET SPECIES AT THE CONOWINGO PROJECT.

Species and Life Stage	Habitat & Life History Relative to Project Characteristics	Swim Speed Relative to Approach Velocity	Other Projects[1] (EPRI)	Overall Entrainment Potential[2]
American eel				
Yellow (home range throughout Pond and beyond the vicinity of the Project)	Low	High	Moderate	Low
Yellow (home range in lower Pond in the vicinity of Project)	Moderate	High	Moderate	Moderate-High
Silver	High	Low	Moderate-High	High
American shad				
Juvenile	High	Moderate	(no data available)	High
Adult	High	Low	(no data available)	High
Bluegill				
Juvenile	Low-Moderate	High	Moderate-High	Moderate
Adult	Low-Moderate	Low	Moderate	Low-Moderate
Channel catfish				
Juvenile	Moderate-High	Low-Moderate	Moderate-High	Moderate-High
Adult	Moderate-High	(no data available)	Moderate	Moderate
Gizzard shad				
Juvenile	High	(no data available)	High	High
Adult	Low-Moderate	Low	Moderate-High	Moderate
Largemouth bass				
Juvenile	Low-Moderate	Low-Moderate	Moderate-High	Moderate
Adult	Low-Moderate	(no data available)	Moderate	Low-Moderate
Smallmouth bass				
Juvenile	Low-Moderate	Moderate	Moderate	Moderate
Adult	Moderate	Low	Low-Moderate	Low
Walleye				
Juvenile	Low	Low-Moderate	Moderate-High	Low-Moderate
Adult	Low	Low	Low-Moderate	Low

[1] When fish size ranges in EPRI (1997) did not correspond to fish sizes in Table 5.2-1, ratings were averaged for the given life stage.
[2] See Section 6.3 for a discussion on how this ranking was developed.

TABLE 7.0-1: COMPARISON OF FACTORS THAT MAY INFLUENCE SURVIVAL RATES AT THE CONOWINGO PROJECT.

Site / Turbine Characteristic	1,3,4,6,7	2,5	8	9-11	2 House Units
Turbine Type	Francis	Francis	Kaplan (Mixed Flow)	Kaplan (Mixed Flow)	Francis
High turbine speed (rpm)	No	No	No	No	Yes
Survival rates of small fish (<8 in)	High	High	High	High	Low

TABLE 7.1.1-1: EMPIRICAL FISH SURVIVAL RATES FOR REPRESENTATIVE FISH SIZES PASSING FRANCIS AND KAPLAN TURBINES, FROM WINCHELL *ET AL.* (2000).

Turbine Type	Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size (in)	N[1]	Average Immediate Survival All Species (%)			Survival Potential	Representative Units
					Minimum	Maximum	Mean		
Kaplan	<300	636-1,203	<4	3	94.1	98.0	95.4	High	
		636-21,000	4-8	10	89.8	97.5	94.8	High	Units 8-11
		636-2,200	8-12	5	77.4	97.5	87.2	Moderate	
		1,203-2,200	>12	2	86.8	100	93.4	High	
Francis	<250	440-1,600	<4	13	85.9	100	93.9	High	
		370-1,600	4-8	19	74.8	100	91.6	High	
		370-2,450	8-12	18	59.0	100	86.9	Moderate	Units 1-7 (higher capacity)[2]
		440-1,600	>12	14	36.1	100	73.2	Low	
Francis	>250	275-695	<4	6	31.0	97.6	70.1	Low	House units
		275-695	4-8	7	34.3	82.7	60.0	Low	
		275-695	8-12	7	22.8	82.9	39.3	Low	
		275-695	>12	3	3.5	35.4	19.1	Low	

[1] Number of turbines for which survival estimates were available.
2 Francis units 1-7 have a higher hydraulic capacity than the units tested and reported in the EPRI database.

TABLE 7.1.2-1: SURVIVAL DATA AND PHYSICAL AND HYDRAULIC CHARACTERISTICS OF HYDROELECTRIC DAMS EQUIPPED WITH KAPLAN AND PROPELLER TYPE TURBINES DEEMED SIMILAR TO THE KAPLAN TURBINES AT THE CONOWINGO PROJECT.

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Bar Mills, ME	HI-Z Turb'N Tag	Atlantic Salmon	8	1,560	5	120	22	134	70.2	93.6
Bonneville, OR, U. 5, Hub	HI-Z Turb'N Tag	Chinook Salmon	6	7,000	5	75	57	280	91.7	100.9
Bonneville, OR, U. 5, Hub	HI-Z Turb'N Tag	Chinook Salmon	7	10,500	5	75	57	280	91.7	96.8
Bonneville, OR, U. 5, Hub	HI-Z Turb'N Tag	Chinook Salmon	7	12,000	5	75	57	280	91.7	100.3
Bonneville, OR, U. 5, Hub	HI-Z Turb'N Tag	Chinook Salmon	7	6,200	5	75	57	280	91.7	98.6
Bonneville, OR, U. 5, Mid	HI-Z Turb'N Tag	Chinook Salmon	6	7,000	5	75	57	280	91.7	95.9
Bonneville, OR, U. 5, Mid	HI-Z Turb'N Tag	Chinook Salmon	6	10,500	5	75	57	280	91.7	98.6
Bonneville, OR, U. 5, Mid	HI-Z Turb'N Tag	Chinook Salmon	6	6,200	5	75	57	280	91.7	96.4
Bonneville, OR, U. 5, Mid	HI-Z Turb'N Tag	Chinook Salmon	6	12,000	5	75	57	280	91.7	96.8
Bonneville, OR, U. 5, Tip	HI-Z Turb'N Tag	Chinook Salmon	6	7,000	5	75	57	280	91.7	93.3
Bonneville, OR, U. 5, Tip	HI-Z Turb'N Tag	Chinook Salmon	6	12,000	5	75	57	280	91.7	90.9
Bonneville, OR, U. 5, Tip	HI-Z Turb'N Tag	Chinook Salmon	6	6,200	5	75	57	280	91.7	94.7
Bonneville, OR, U. 5, Tip	HI-Z Turb'N Tag	Chinook Salmon	7	10,500	5	75	57	280	91.7	96.3
Bonneville, OR, U. 6, Hub	HI-Z Turb'N Tag	Chinook Salmon	6	7,000	5	75	57	280	91.7	97.4
Bonneville, OR, U. 6, Hub	HI-Z Turb'N Tag	Chinook Salmon	7	12,000	5	75	57	280	91.7	98.0
Bonneville, OR, U. 6, Hub	HI-Z Turb'N Tag	Chinook Salmon	7	6,200	5	75	57	280	91.7	98.6
Bonneville, OR, U. 6, Hub	HI-Z Turb'N Tag	Chinook Salmon	7	10,500	5	75	57	280	91.7	98.6
Bonneville, OR, U. 6, Mid	HI-Z Turb'N Tag	Chinook Salmon	6	7,000	5	75	57	280	91.7	96.3
Bonneville, OR, U. 6, Mid	HI-Z Turb'N Tag	Chinook Salmon	6	10,500	5	75	57	280	91.7	97.7
Bonneville, OR, U. 6, Mid	HI-Z Turb'N Tag	Chinook Salmon	7	12,000	5	75	57	280	91.7	97.7
Bonneville, OR, U. 6, Mid	HI-Z Turb'N Tag	Chinook Salmon	7	6,200	5	75	57	280	91.7	98.3
Bonneville, OR, U. 6, Tip	HI-Z Turb'N Tag	Chinook Salmon	6	7,000	5	75	57	280	91.7	94.9
Bonneville, OR, U. 6, Tip	HI-Z Turb'N Tag	Chinook Salmon	6	6,200	5	75	57	280	91.7	95.5

Table 7.1.2-1: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Bonneville, OR, U. 6, Tip	HI-Z Turb'N Tag	Chinook Salmon	6	12,000	5	75	57	280	91.7	94.7
Bonneville, OR, U. 6, Tip	HI-Z Turb'N Tag	Chinook Salmon	7	10,500	5	75	57	280	91.7	97.7
Cliff, Ireland	HI-Z Turb'N Tag	Atlantic Salmon	5	2,610	5	115	33	169	84.8	92.3
Conowingo, MD	HI-Z Turb'N Tag	American Shad	5	8,000	6	120	90	225	117.9	94.9
Cowlitz, WA	HI-Z Turb'N Tag	Coho Salmon	6	3,150	5	150	87.5	179	117.2	97.3
Crescent, NY	HI-Z Turb'N Tag	Blueback Herring	4	1,520	5	144	27	108	67.9	96.0
Feeder Dam, NY	Full discharge netting	Bluegill	4	1,040	6	120	15.5	115	60.2	97.3
Feeder Dam, NY	Full discharge netting	Bluegill	5	1,040	6	120	17	115	60.2	92.3
Feeder Dam, NY	Full discharge netting	Brown trout	8	1,040	6	120	21	115	60.2	86.4
Feeder Dam, NY	Full discharge netting	Golden shiner	3	1,040	6	120	22	115	60.2	96.8
Feeder Dam, NY	Full discharge netting	Largemouth bass	3	1,040	6	120	18	115	60.2	98.0
Feeder Dam, NY	Full discharge netting	Largemouth bass	7	1,040	6	120	19	115	60.2	90.0
Feeder Dam, NY	Full discharge netting	Largemouth bass	11	1,040	6	120	20	115	60.2	86.8
Greenup Dam, OH	Radio Telemetry	Sauger	9	11,866	5	90	30	240	94.3	85.4
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	3	4,200	5	150	52	156	102.1	89.1
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	3	4,200	5	128	52	170	95.0	97.3
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	3	1,550	5	128	52	170	95.0	100.0
Hadley Falls, MA	Radio Telemetry	American Shad	22	4,200	5	128	52	170	95.0	78.2
Hadley Falls, MA	Radio Telemetry	Atlantic salmon	11	4,200	5	128	52	170	95.0	93.7
Kelsey Generating Sta., MB	HI-Z Turb'N Tag	Northern pike	26	8,000	6	102.9	56.1	311.8	76.4	74.2
Kelsey Generating Sta., MB	HI-Z Turb'N Tag	Walleye	18	8,000	6	102.9	56.1	311.8	76.4	81.4
la centrale de Beauharnois, Quebec, Canada	Float tag	American eel	35	9,275	6	94.7	79	249	102.9	76.1
Lowell, MA	HI-Z Turb'N Tag	Atlantic Salmon	8	3,616	5	120	39	148	77.5	100.0
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	6	13,500	6	90	98	312	122.6	97.2
McNary Dam, WA	HI-Z Turb'N Tag	Chinook salmon	6	12,000	6	85.7	71-75	280	104.7	94.1

Table 7.1.2-1: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
McNary Dam, WA	HI-Z Turb'N Tag	Chinook salmon	6	7,700	6	85.7	71-73	280	104.7	94.4
McNary Dam, WA	HI-Z Turb'N Tag	Chinook salmon	6	12,000	6	85.7	71-73	280	104.7	95.8
McNary Dam, WA	HI-Z Turb'N Tag	Chinook salmon	6	13,400	6	85.7	72-74	280	104.7	98.7
Priest Rapids, WA (10ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6	15,000	6	85.7	78	284	106.2	94.9
Priest Rapids, WA (10ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6	11,000	6	85.7	78	284	106.2	98.3
Priest Rapids, WA (10ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6	9,000	6	85.7	78	284	106.2	98.6
Priest Rapids, WA (30ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6	15,000	6	85.7	78	284	106.2	96.1
Priest Rapids, WA (30ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6	11,000	6	85.7	78	284	106.2	96.7
Priest Rapids, WA (30ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6	9,000	6	85.7	78	284	106.2	97.1
Raymondville, NY	Full discharge netting	American eel	25	1,640	6	120	21	131	68.6	63.0
Robert Moses Station, NY	HI-Z Turb'N Tag	American eel	39	9,000	6	94.7	81	240	99.2	84.0
Rocky Reach, WA (10',U. 5)	HI-Z Turb'N Tag	Chinook Salmon	7	14,000	6	90	92	280	110.0	97.3
Rocky Reach, WA (10',U. 6)	HI-Z Turb'N Tag	Chinook Salmon	7	14,000	6	90	92	280	110.0	94.2
Rocky Reach, WA (30',U. 5)	HI-Z Turb'N Tag	Chinook Salmon	7	14,000	6	90	92	280	110.0	94.4
Rocky Reach, WA (30',U. 6)	HI-Z Turb'N Tag	Chinook Salmon	7	14,000	6	90	92	280	110.0	95.8
Safe Harbor, PA (Unit 7)	HI-Z Turb'N Tag	American Shad	5	8,300	5	109	55	222	105.6	98.0
Safe Harbor, PA (Unit 7)	HI-Z Turb'N Tag	American Shad	17	8,300	5	109	55	222	105.6	90.0
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	5	9,200	7	75	55	242	79.2	97.8
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	5	9,200	7	75	55	242	79.2	98.9
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	17	9,200	7	75	55	242	79.2	87.0
Wanapum, WA (10ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6	9,000	5	85.7	75	285	106.6	89.7
Wanapum, WA (10ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6	11,000	5	85.7	75	285	106.6	92.4
Wanapum, WA (10ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6	15,000	5	85.7	75	285	106.6	94.8
Wanapum, WA (30ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6	9,000	5	85.7	75	285	106.6	94.9

Table 7.1.2-1: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Wanapum, WA (30ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6	11,000	5	85.7	75	285	106.6	96.8
Wanapum, WA (30ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6	15,000	5	85.7	75	285	106.6	100.0
Wilder, VT-NH	HI-Z Turb'N Tag	Atlantic Salmon	8	4,500	5	112.5	51	180	88.4	96.0

TABLE 7.1.2-2: SURVIVAL DATA FOR AMERICAN EEL AND AMERICAN SHAD TESTED AT HYDROELECTRIC PROJECTS EQUIPPED WITH KAPLAN AND PROPELLER TYPE TURBINES SIMILAR TO THE KAPLAN TURBINES AT THE CONOWINGO PROJECT.

AMERICAN EEL

Station	Sampling Method	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Raymondville, NY	Full discharge netting	25	1,640	6	120	21	131	68.6	63.0
la centrale de Beauharnois, Quebec, Canada	Float tag	35	9,275	6	94.7	79	249	102.9	76.1
Robert Moses Station, NY	HI-Z Turb'N Tag	39	9,000	6	94.7	81	240	99.2	84.0

AMERICAN SHAD

Station	Sampling Method	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Hadley Falls, MA	HI-Z Turb'N Tag	3	4,200	5	150	52	156	102.1	89.1
Hadley Falls, MA	HI-Z Turb'N Tag	3	4,200	5	128	52	170	95.0	97.3
Hadley Falls, MA	HI-Z Turb'N Tag	3	1,550	5	128	52	170	95.0	100.0
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	5	9,200	7	75	55	242	79.2	97.8
Safe Harbor, PA (Unit 7)	HI-Z Turb'N Tag	5	8,300	5	109	55	222	105.6	98.0
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	5	9,200	7	75	55	242	79.2	98.9
Conowingo, MD	HI-Z Turb'N Tag	5	8,000	6	120	90	225	117.9	94.9
Conowingo, MD	HI-Z Turb'N Tag	17.6	8,843	6	120	90	225	117.9	86.3
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	17	9,200	7	75	55	242	79.2	87.0
Safe Harbor, PA (Unit 7)	HI-Z Turb'N Tag	17	8,300	5	109	55	222	105.6	90.0
Hadley Falls, MA	Radio Telemetry	22	4,200	5	128	52	170	95.0	78.2

TABLE 7.1.2-3: SURVIVAL DATA AND PHYSICAL AND HYDRAULIC CHARACTERISTICS OF HYDROELECTRIC DAMS EQUIPPED WITH FRANCIS TURBINES DEEMED SIMILAR TO THE FRANCIS TURBINES, UNITS 1-7 AT THE CONOWINGO PROJECT.

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 hr)
Alcona, MI	Full dschrg netting	Bluegill	4.6	1660	16	90	43	8.33	90.2
Alcona, MI	Full dschrg netting	Bluegill	6.7	1661	16	90	43	8.33	84.1
Alcona, MI	Full dschrg netting	Gold./Common Shiner	4.5	1662	16	90	43	8.33	80.9
Alcona, MI	Full dschrg netting	Gold./Common Shiner	6.1	1663	16	90	43	8.33	84.7
Alcona, MI	Full dschrg netting	Grass Pickerel	9.3	1664	16	90	43	8.33	86.7
Alcona, MI	Full dschrg netting	Northern Pike	13.9	1665	16	90	43	8.33	51.2
Alcona, MI	Full dschrg netting	Rainbow Trout	4.3	1666	16	90	43	8.33	100
Alcona, MI	Full dschrg netting	Rainbow Trout	12.5	1667	16	90	43	8.33	89.4
Alcona, MI	Full dschrg netting	Spottail Shiner	4.6	1668	16	90	43	8.33	59.5
Alcona, MI	Full dschrg netting	Walleye	6.4	1669	16	90	43	8.33	16.4
Alcona, MI	Full dschrg netting	Walleye	15.2	1670	16	90	43	8.33	38.7
Alcona, MI	Full dschrg netting	White Sucker	7.1	1671	16	90	43	8.33	94.4
Alcona, MI	Full dschrg netting	White Sucker	11.4	1672	16	90	43	8.33	90.4
Alcona, MI	Full dschrg netting	Yellow Perch	4.2	1673	16	90	43	8.33	65.1
Alcona, MI	Full dschrg netting	Yellow Perch	7.3	1674	16	90	43	8.33	55.1
E. J. West, NY	Full dschrg netting	Soft Ray	6.9	2,700	15	113	63	10.92	71.3
E. J. West, NY	Full dschrg netting	Centrarchid	6.9	2,700	15	113	63	10.92	85.5
E. J. West, NY	Full dschrg netting	Salmonid	6.9	2,700	15	113	63	10.92	90.6
E. J. West, NY	Full dschrg netting	Soft Ray	<4	2,700	15	113	63	10.92	32.3
E. J. West, NY	Full dschrg netting	Percid	<4	2,700	15	113	63	10.92	56.1
E. J. West, NY	Full dschrg netting	Salmonid	<4	2,700	15	113	63	10.92	65.2
E. J. West, NY	Full dschrg netting	Centrarchid	<4	2,700	15	113	63	10.92	71.7
E. J. West, NY	Full dschrg netting	Centrarchid	>10	2,700	15	113	63	10.92	59.8
E. J. West, NY	Full dschrg netting	Soft Ray	>10	2,700	15	113	63	10.92	67.5

Table 7.1.2-3: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 hr)
E. J. West, NY	Full dschrg netting	Salmonid	>10	2,700	15	113	63	10.92	95.6
Holtwood, PA (U10/single runner)	Balloon tag	American Shad	4.9	3,500	16	94.7	62	12.46	89.4
la centrale Beauharnois, QE	Float tag	American eel	35.0	7,000	13	75	79	17.67	84.2
Mayfield, WA	Balloon tag	Coho salmon	5.9	2,800	15	138.5	182	12.42	97.2
Mayfield, WA	Balloon tag	Steelhead	7.4	2,800	15	138.5	182	12.42	97.1
Mayfield, WA	Balloon tag	Coho salmon	5.9	2,800	16	138.5	182	13.13	87.6
Mayfield, WA	Balloon tag	Steelhead	7.5	2,800	16	138.5	182	13.13	88.4
Minetto, NY	Full dschrg netting	Centrarchid	6.9	1,500	16	72	17	11.58	83
Minetto, NY	Full dschrg netting	Percid	6.9	1,500	16	72	17	11.58	86
Minetto, NY	Full dschrg netting	Salmonids	6.9	1,500	16	72	17	11.58	91
Minetto, NY	Full dschrg netting	Soft Ray	6.9	1,500	16	72	17	11.58	94
Minetto, NY	Full dschrg netting	American Eel	24.6	1,500	16	72	17	11.58	94
Minetto, NY	Full dschrg netting	Centrarchid	<4	1,500	16	72	17	11.58	62
Minetto, NY	Full dschrg netting	Percid	<4	1,500	16	72	17	11.58	80
Minetto, NY	Full dschrg netting	Soft Ray	<4	1,500	16	72	17	11.58	82
Minetto, NY	Full dschrg netting	Salmonids	<4	1,500	16	72	17	11.58	92
Minetto, NY	Full dschrg netting	Centrarchid	>10	1,500	16	72	17	11.58	84
Minetto, NY	Full dschrg netting	Soft Ray	>10	1,500	16	72	17	11.58	84
Minetto, NY	Full dschrg netting	Salmonids	>10	1,500	16	72	17	11.58	92
Shasta, CA (January)	Full dschrg netting	Chinook Salmon	4.0	3,200	15	138.5	380	15.33	54.8 - 72.1
Shasta, CA (January)	Full dschrg netting	Steelhead	6.0	3,200	15	138.5	380	15.33	75.4 - 89.3
Shasta, CA (January)	Full dschrg netting	Rainbow Trout	10.0	3,200	15	138.5	380	15.33	53.1 - 71.2

Table 7.1.2-3: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 hr)
Shasta, CA (November)	Full dschrg netting	Chinook Salmon	4.0	3,200	15	138.5	380	15.33	61.7 - 84.5
Shasta, CA (November)	Full dschrg netting	Steelhead	6.0	3,200	15	138.5	380	15.33	50.5 - 69.2
Shasta, CA (November)	Full dschrg netting	Rainbow Trout	10.0	3,200	15	138.5	380	15.33	39.6 - 90.5
Stevens Creek, SC	Balloon tag	Bluegill	4.8	1,000	14	75	28	11.25	95.4
Stevens Creek, SC	Balloon tag	Spotted Sucker/ Yellow Perch	6.5	1,000	14	75	28	11.25	98.3
Stevens Creek, SC	Balloon tag	Blueback Herring	8.0	1,000	14	75	28	11.25	95.3
Vernon, VT/NH	Balloon tag	Atlantic salmon	5.6	1,280	14	133	34	5.20	85.1
Vernon, VT/NH	Balloon tag	American Shad	3.7	1,834	15	74	34	13.00	94.7
Vernon, VT/NH	Balloon tag	Atlantic salmon	6.1	1,834	15	74	34	13.00	97.4

TABLE 7.1.2-4: SURVIVAL DATA FOR AMERICAN EEL AND AMERICAN SHAD TESTED AT HYDROELECTRIC PROJECTS EQUIPPED WITH FRANCIS TYPE TURBINES SIMILAR TO THE FRANCIS TURBINES (UNITS 1-7) AT THE CONOWINGO PROJECT.

AMERICAN EEL

Station	Sampling Method	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Percent Survival (1 h)
Minetto, NY	Full dschrg netting	24.6	1,500	16	72	17	11.58	94
la centrale Beauharnois, QE	Float tag	35.0	7,000	13	75	79	17.67	84.2

AMERICAN SHAD

Station	Sampling Method	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Percent Survival (1 h)
Vernon, VT/NH	Balloon tag	3.7	1,834	15	74	34	13.00	94.7
Holtwood, PA(U10/single runner)	Balloon tag	4.9	3,500	16	94.7	62	12.46	89.4
Conowingo, MD (Unit 5)	Balloon tag	4.7	5,080	13	81.8	89	16	89.9
Conowingo, MD (Unit 2)	Balloon tag	17.6	5,055	13	81.8	89	16	93.0

TABLE 7.1.2-5: SURVIVAL DATA AND PHYSICAL AND HYDRAULIC CHARACTERISTICS OF HYDROELECTRIC DAMS EQUIPPED WITH FRANCIS TYPE TURBINES DEEMED SIMILAR TO THE HOUSE UNITS AT THE CONOWINGO PROJECT.

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Centrarchiforms	3.0	650	15	226	80	6.00	100
Caldron Falls, WI (Unit 1)	Full dschrg netting	Centrarchiforms	5.0	650	15	226	80	6.00	98.2
Caldron Falls, WI (Unit 1)	Full dschrg netting	Centrarchiforms	7.0	650	15	226	80	6.00	86.8
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	3.0	650	15	226	80	6.00	80.3
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	5.0	650	15	226	80	6.00	84.8
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	7.0	650	15	226	80	6.00	70.3
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	9.0	650	15	226	80	6.00	64.3
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	11.5	650	15	226	80	6.00	59.5
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	>11.5	650	15	226	80	6.00	35.5
High Falls (Unit 5)	Full dschrg netting	Centrarchiforms	3.0	275	12	358	83	3.25	85.5
High Falls (Unit 5)	Full dschrg netting	Centrarchiforms	5.0	275	12	358	83	3.25	78.1
High Falls (Unit 5)	Full dschrg netting	Centrarchiforms	7.0	275	12	358	83	3.25	58.9
High Falls (Unit 5)	Full dschrg netting	Fusiforms	3.0	275	12	358	83	3.25	87.8
High Falls (Unit 5)	Full dschrg netting	Fusiforms	5.0	275	12	358	83	3.25	67.9
High Falls (Unit 5)	Full dschrg netting	Fusiforms	7.0	275	12	358	83	3.25	48.4
High Falls (Unit 5)	Full dschrg netting	Fusiforms	9.0	275	12	358	83	3.25	46.2
High Falls (Unit 5)	Full dschrg netting	Fusiforms	11.5	275	12	358	83	3.25	20.1
High Falls (Unit 5)	Full dschrg netting	Fusiforms	>11.5	275	12	358	83	3.25	2.7
Higley, NY	Full dschrg netting	Centrarchid	<4	675	13	257	46	4.00	81
Higley, NY	Full dschrg netting	Centrarchid	6.9	675	13	257	46	4.00	14
Higley, NY	Full dschrg netting	Centrarchid	>10	675	13	257	46	4.00	17
Higley, NY	Full dschrg netting	Percid	<4	675	13	257	46	4.00	59
Higley, NY	Full dschrg netting	Percid	>10	675	13	257	46	4.00	40
Higley, NY	Full dschrg netting	Salmonid	<4	675	13	257	46	4.00	70
Higley, NY	Full dschrg netting	Salmonid	6.9	675	13	257	46	4.00	44
Higley, NY	Full dschrg netting	Salmonid	>10	675	13	257	46	4.00	61

Table 7.1.2-5: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Higley, NY	Full dschrg netting	Soft Ray	<4	675	13	257	46	4.00	60
Higley, NY	Full dschrg netting	Soft Ray	6.9	675	13	257	46	4.00	72
Higley, NY	Full dschrg netting	Soft Ray	>10	675	13	257	46	4.00	40
Lequille, NS	Full dschrg netting	Atlantic salmon		350	13	519	387	4.50	52
Pricket, MI	Full dschrg netting	Bluegill	2.0	326	15	257	54	4.46	97.7
Pricket, MI	Full dschrg netting	Bluegill	4.0	326	15	257	54	4.46	92.5
Pricket, MI	Full dschrg netting	Bluegill	>5	326	15	257	54	4.46	85.7
Pricket, MI	Full dschrg netting	Golden Shiner	<4	326	15	257	54	4.46	93.9
Pricket, MI	Full dschrg netting	Mixed resident		326	15	257	54	4.46	97.8
Pricket, MI	Full dschrg netting	White Sucker	6.5	326	15	257	54	4.46	70.8
Pricket, MI	Full dschrg netting	White Sucker	>10	326	15	257	54	4.46	35.7

7.1.3-1: ESTIMATED SURVIVAL RESULTS FOR AMERICAN SHAD TESTED AT HYRDOELECTRIC PROJECTS ON THE SUSQUEHANNA RIVER.

Station	Life Stage Tested	Turbine Type	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Percent Survival (1 h)
Conowingo, MD	Juvenile	Kaplan	8,000	6	120	90	225	94.9
Conowingo, MD	Adult	Kaplan	8,843	6	120	90	225	86.3
York Haven, PA (Unit 3)	Juvenile	Kaplan	1,100	4	200	21	93	92.7
Safe Harbor, PA (Unit 7)	Juvenile	Kaplan	8,300	5	109	55	222	98.0
Safe Harbor, PA (Unit 8)	Juvenile	Kaplan	9,200	7	75	55	242	97.8
Safe Harbor, PA (Unit 8)	Juvenile	Kaplan	9,200	7	75	55	242	98.9
Safe Harbor, PA (Unit 7)	Adult	Kaplan	8,300	5	109	55	222	90.0
Safe Harbor, PA (Unit 8)	Adult	Kaplan	9,200	7	75	55	242	87.0
Conowingo, MD	Juvenile	Francis	5,080	13	81.8	89	225	89.9
Conowingo, MD	Adult	Francis	5,055	13	81.8	89	225	93.0
Holtwood, PA(U10/single runner)	Juvenile	Francis	3,500	16	94.7	62	12.46	89.4
Holtwood, PA (U3/double runner)	Juvenile	Francis	3,500	17	102.8	62	9.33	83.5
York Haven, PA (Unit 7)	Juvenile	Francis	850	18	84	23	6.5	77.1

TABLE 7.2-1: PREDICTED SURVIVAL OF ENTRAINED FISHES BASED ON THE BLADE STRIKE FORMULA DEVELOPED BY FRANKE ET AL. (1997) FOR CONOWINGO PROJECT, FRANCIS TURBINES.

Turbines	Discharge (cfs)	Operating Efficiency	Correlation Factor	Survival Estimate (%)					
				Fish Length (in)					
				4	8	12	18	30	40
Units 1,3,4,6,7	6,749	90%	0.1	97.95	95.90	93.85	90.78	84.64	79.51
			0.2	95.90	91.81	87.71	81.56	69.27	59.03
		80%	0.1	97.93	95.85	93.78	90.67	84.45	79.26
			0.2	95.85	91.70	87.56	81.33	68.89	58.52
Units 2,5	6,320	90%	0.1	97.95	95.90	93.85	90.78	84.63	79.51
			0.2	95.90	91.80	87.71	81.56	69.26	59.02
		80%	0.1	97.86	95.72	93.57	90.36	83.94	78.58
			0.2	95.72	91.43	87.15	80.72	67.87	57.16
House Units	247	90%	0.1	90.69	81.39	72.08	58.12	30.19	6.93
			0.2	81.39	62.77	44.16	16.23	0	0
		80%	0.1	90.22	80.45	70.67	56.01	26.68	2.24
			0.2	80.45	60.89	41.34	12.01	0	0

TABLE 7.2-2: PREDICTED SURVIVAL OF ENTRAINED FISHES BASED ON THE BLADE STRIKE FORMULA DEVELOPED BY FRANKE *ET AL.* (1997) FOR CONOWINGO PROJECT, KAPLAN TURBINES.

Unit 8

Discharge (cfs)	Operating Efficiency	Point of Entry (ft from hub center)	Correlation Factor	Survival Estimate (%) Fish Length (in) 4	8	12	18	30	40
9,352	90%	1.9	0.1	98.04	96.08	94.13	91.19	85.31	80.42
			0.2	96.08	92.17	88.25	82.38	70.63	60.84
		5.6	0.1	98.77	97.55	96.32	94.48	90.80	87.73
			0.2	97.55	95.09	92.64	88.95	81.59	75.45
		8.9	0.1	98.82	97.63	96.45	94.67	91.12	88.17
			0.2	97.63	95.27	92.90	89.35	82.25	76.33
	80%	1.9	0.1	98.02	96.04	94.06	91.10	85.16	80.21
			0.2	96.04	92.08	88.13	82.19	70.32	60.42
		5.6	0.1	98.75	97.50	96.24	94.37	90.61	87.48
			0.2	97.50	94.99	92.49	88.73	81.22	74.96
		8.9	0.1	98.80	97.60	96.40	94.60	91.00	88.00
			0.2	97.60	95.20	92.80	89.20	82.00	76.00

Table 7.2-2 Continued:

Units 9, 10 and 11

Discharge (cfs)	Operating Efficiency	Point of Entry (ft from hub center)	Correlation Factor	Survival Estimate (%) Fish Length (in) 4	8	12	18	30	40
9,727	90%	1.9	0.1	98.05	96.10	94.15	91.22	85.37	80.49
			0.2	96.10	92.20	88.30	82.44	70.74	60.99
		5.6	0.1	98.80	97.59	96.39	94.58	90.97	87.96
			0.2	97.59	95.18	92.78	89.16	81.94	75.92
		8.9	0.1	98.85	97.70	96.55	94.82	91.37	88.49
			0.2	97.70	95.40	93.09	89.64	82.74	76.98
	80%	1.9	0.1	98.03	96.06	94.09	91.14	85.23	80.31
			0.2	96.06	92.12	88.18	82.28	70.46	60.61
		5.6	0.1	98.77	97.55	96.32	94.48	90.81	87.74
			0.2	97.55	95.10	92.65	88.97	81.62	75.49
		8.9	0.1	98.83	97.67	96.50	94.76	91.26	88.35
			0.2	97.67	95.34	93.01	89.51	82.52	76.70

TABLE 7.3-1: PREDICTED SURVIVAL FROM EPRI (1997), THE EXPANDED SURVIVAL DATABASE, CALCULATED SURVIVAL (FRANKE *ET AL.* 1997), AND OVERALL QUALITATIVE RATING OF SURVIVAL FOR TARGET SPECIES THAT MAY BE ENTRAINED THROUGH THE KAPLAN TURBINES AT THE CONOWINGO PROJECT.

Species and Life Stage	Approximate Size Range (inches)	EPRI Source Data		Expanded Survival Data		Calculated Survival Potential		Overall Rating of Survival Potential
		% Survival by fish size	Rating by fish size1	% Survival by fish size	Rating by fish size	% Survival by fish size	Rating by fish size	
American eel								
Yellow	4.0 – 30.0	95.4 - 87.2	H-M	100 - 63.0	H-L	98.8 – 70.3	H-L	H-L
Silver	15.0 – 40.0	93.4	MH	90.0 - 63.0	MH-L	96.4 – 60.4	H-L	MH-L
American shad								
Juvenile	3.2 – 4.3	95.4	H	100 – 89.1	H-L	98.8 – 96	H	H
Adult	15.0 – 30.0	93.4	MH	93.7 – 63	MH-L	96.4 – 70.3	H-L	MH-L
Bluegill								
Juvenile	0.39 – 2.5	95.4	H	No data available	--	98.8 – 96	H	H
Adult	2.5 – 16	95.4 – 87.2	H-M	100 – 85.4	H-M	98.8 – 82.2	H-LM	H-M
Channel catfish								
Juvenile	0.5– 4.0	95.4	H	100 – 89.1	H-M	98.8 – 96	H	H
Adult	4.0 – 30.0	95.4 – 87.2	H-M	100 – 63	H-L	98.8 – 70.3	H-L	H-L
Gizzard shad								
Juvenile	1.0 – 10.0	95.4	H-M	100 – 85.4	H-M	98.8 – 88.1	H-M	H-M
Adult	10.0 – 22.5	95.7 – 87.2	H-M	93.7 – 78.2	MH-L	96.4 – 82.2	H-LM	MH-LM
Largemouth bass								
Juvenile	2.0 – 10.0	95.4 – 87.2	H-M	100 – 85.4	H-M	98.8 – 88.1	H-M	H-M
Adult	10.0 – 25.0	93.4 – 87.2	MH-M	93.7 – 63	MH-L	96.4 – 82.2	H-LM	MH-LM
Smallmouth bass								
Juvenile	1.0 – 5.0	95.4 – 94.8	H-MH	100 – 89.1	H-M	98.8 – 96	H	H
Adult	5.0 – 12.0	94.8 – 87.2	MH-M	100 – 85.4	H-M	98.8 – 88.1	H-M	H-M
Walleye								
Juvenile	1.0 – 12.5	95.4 – 87.2	H-M	100 – 85.4	H-M	98.8 – 88.1	H-M	H-M
Adult	12.5 – 30.0	93.4 – 87.2	MH-M	90 – 63	M-L	96.4 – 70.3	M-L	MH-L

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

TABLE 7.3-2: PREDICTED SURVIVAL FROM EPRI (1997), THE EXPANDED SURVIVAL DATABASE, CALCULATED SURVIVAL (FRANKE *ET AL.* 1997), AND OVERALL QUALITATIVE RATING OF SURVIVAL FOR TARGET SPECIES THAT MAY BE ENTRAINED THROUGH THE FRANCIS TURBINES (UNITS 1-7) AT THE CONOWINGO PROJECT.

Species and Life Stage	Approximate Size Range (inches)	EPRI Source Data		Expanded Survival Table		Calculated Survival Potential		Overall Rating of Survival Potential
		% Survival by fish size	Rating by fish size[1]	% Survival by fish size	Rating by fish size	% Survival by fish size	Rating by fish size	
American eel								
Yellow	4.0 – 30.0	91.6 – 73.2	MH-L	100 – 16.4	H-L	97.9 – 67.9	H-L	H-L
Silver	15.0 – 40.0	86.9 – 73.2	M-L	95.6 – 38.7	H-L	93.8 – 57.2	MH-L	MH-L
American shad								
Juvenile	3.2 – 4.3	93.9	MH	100 – 32.3	H-L	97.9 – 95.7	H	MH
Adult	15.0 – 30.0	86.9 – 73.2	M-L	94 – 38.7	MH-L	93.8 – 67.9	MH-L	MH-L
Bluegill								
Juvenile	0.39 – 2.5	93.9	MH	94.7	MH	97.9 – 95.7	H	H
Adult	2.5 – 16	93.9 – 73.2	MH-L	100 – 16.4	H-L	97.9 – 80.7	H-LM	MH-LM
Channel catfish								
Juvenile	0.5– 4.0	93.9	MH	100 – 32.3	H-L	97.9 – 95.7	H	H-MH
Adult	4.0 – 30.0	93.9 – 73.2	MH-L	100 – 16.4	H-L	97.9 – 67.9	H-L	MH-L
Gizzard shad								
Juvenile	1.0 – 10.0	93.9 – 86.9	MH-M	100 – 16.4	H-L	97.9 – 87.1	H-M	H-M
Adult	10.0 – 22.5	86.9 – 73.2	M-L	95.6 – 38.7	H-L	93.8 – 67.9	MH-L	MH-L
Largemouth bass								
Juvenile	2.0 – 10.0	93.9 – 86.9	MH-M	100 – 16.4	H-L	97.9 – 87.1	H-M	H-M
Adult	10.0 – 25.0	86.9 – 73.2	M-L	95.6 – 38.7	H-L	93.8 – 67.9	MH-L	MH-L
Smallmouth bass								
Juvenile	1.0 – 5.0	93.9 – 91.6	MH	100 – 32.3	H-L	97.9 – 95.7	H	H-MH
Adult	5.0 – 12.0	93.9 – 86.9	MH-M	98.9 – 16.4	H-L	97.9 – 87.1	H-M	MH-LM
Walleye								
Juvenile	1.0 – 12.5	93.9 – 86.9	MH-M	100 – 86.9	H-M	97.9 – 87.1	H-M	H-M
Adult	12.5 – 30.0	86.9 – 73.2	M-L	94 – 38.7	MH-L	93.8 – 67.9	MH-L	M-L

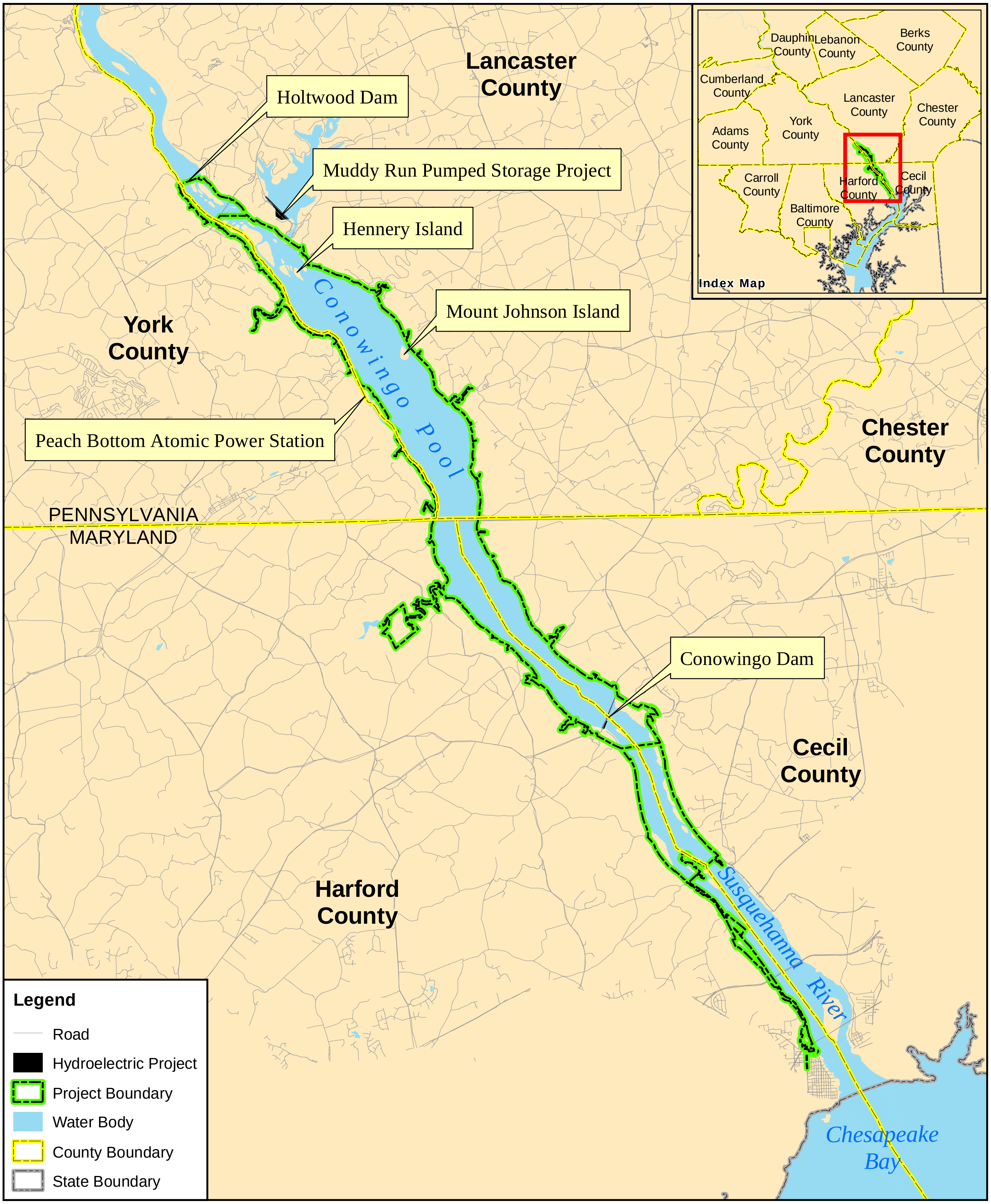
1 L=Low (<80%), LM=Low-Moderate (85-80%), M=Moderate (90-85%), MH= Moderate-High (95-90%), H=High (100-95%)

TABLE 7.3-3: PREDICTED SURVIVAL FROM EPRI (1997), THE EXPANDED SURVIVAL DATABASE, CALCULATED SURVIVAL (FRANKE *ET AL.* 1997), AND OVERALL QUALITATIVE RATING OF SURVIVAL FOR TARGET SPECIES THAT MAY BE ENTRAINED THROUGH THE FRANCIS HOUSE TURBINES AT THE CONOWINGO PROJECT.

Species and Life Stage	Approximate Size Range (inches)	EPRI Source Data		Expanded Survival Table		Calculated Survival Potential		Overall Rating of Survival Potential
		% Survival by fish size	Rating by fish size[1]	% Survival by fish size[2]	Rating by fish size	% Survival by fish size	Rating by fish size	
American eel								
Yellow	4.0 – 30.0	70.1 – 19.1	L	100 – 2.7	H-L	90.7 – 0	MH-L	MH-L
Silver	15.0 – 40.0	19.1	L	not tested	--	72.1 – 0	L	L
American shad								
Juvenile	3.2 – 4.3	70.1	L	100 – 59	H-L	90.7 – 80.4	MH-LM	M
Adult	15.0 – 30.0	19.1	L	not tested	--	72.1 – 0	L	L
Bluegill								
Juvenile	0.39 – 2.5	70.1	L	97.7	H	90.7 – 80.4	MH-LM	MH
Adult	2.5 – 16	70.1 – 19.1	L	100 – 2.7	H-L	90.7 – 12.0	MH-L	MH-L
Channel catfish								
Juvenile	0.5– 4.0	70.1	L	100 – 59	H-L	90.7 – 80.4	MH-LM	MH-LM
Adult	4.0 – 30.0	60 – 19.1	L	98.2 – 2.27	H-L	90.7 – 12.0	MH-L	MH-L
Gizzard shad								
Juvenile	1.0 – 10.0	70.1 – 39.3	L	100 – 14	H-L	90.7 – 41.3	MH-L	MH-L
Adult	10.0 – 22.5	39.3 – 19.1	L	61 – 2.7	L	72.1 – 12.0	L	L
Largemouth bass								
Juvenile	2.0 – 10.0	70.1 – 39.3	L	100 – 14	H-L	90.7 – 41.3	MH-L	MH-L
Adult	10.0 – 25.0	39.3 – 19.1	L	61 – 2.7	L	72.1 – 0	L	L
Smallmouth bass								
Juvenile	1.0 – 5.0	70.1 – 60	L	100 – 59	H-L	90.7 – 80.4	MH-LM	MH-LM
Adult	5.0 – 12.0	60 – 39.3	L	98.2 – 2.7	H-L	80.4 – 43.3	LM-L	M-L
Walleye								
Juvenile	1.0 – 12.5	70.1 – 39.3	L	100 – 2.7	H-L	90.7 – 41.3	MH-L	MH-L
Adult	12.5 – 30.0	39.3 – 19.1	L	not tested	--	72.1 – 0	L	L

1 L=Low (<80%), LM=Low-Moderate (85-80%), M=Moderate (90-85%), MH= Moderate-High (95-90%), H=High (100-95%)
2 Large fish were not tested; test fish size range was 2.0 – 11.5 inches.

FIGURE 3.1-1: CONOWINGO HYDROELECTRIC PROJECT.



EXELON GENERATION COMPANY, LLC

CONOWINGO HYDROELECTRIC PROJECT
FERC PROJECT NO. 405

1 inch = 3 miles

N

0 1.5 3 6 Miles

Figure 3.1-2:
Conowingo Hydroelectric Project Location Map

Data Source: ESRI; Exelon; PA Chesapeake Bay Program; PA State University - Environmental Resources Research Institute; USGS National Hydrography Dataset.

FIGURE 3.2.2-1: KAPLAN TYPE TURBINE RUNNER

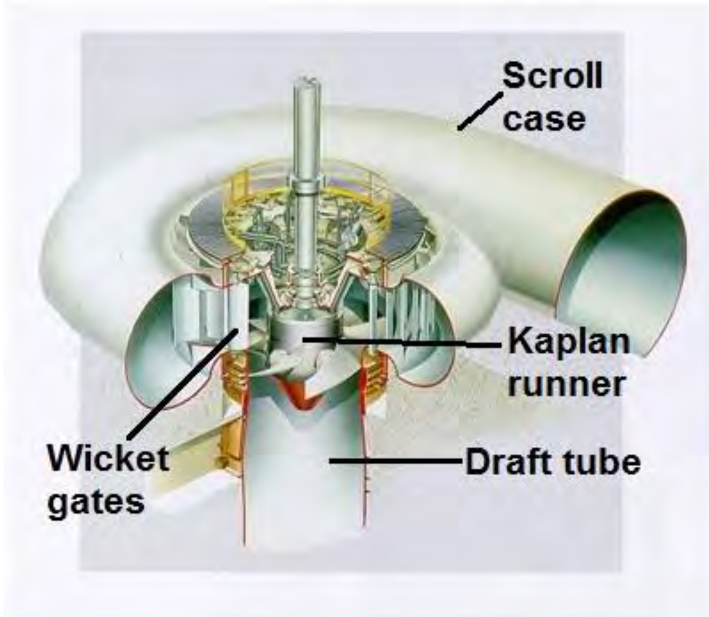


Image of a typical Kaplan turbine.

Photograph of a Kaplan runner at the Conowingo Project.

FIGURE 3.2.2-2: CROSS SECTION COMPOSITE OF THE KAPLAN UNITS 8-11 AT THE CONOWINGO PROJECT

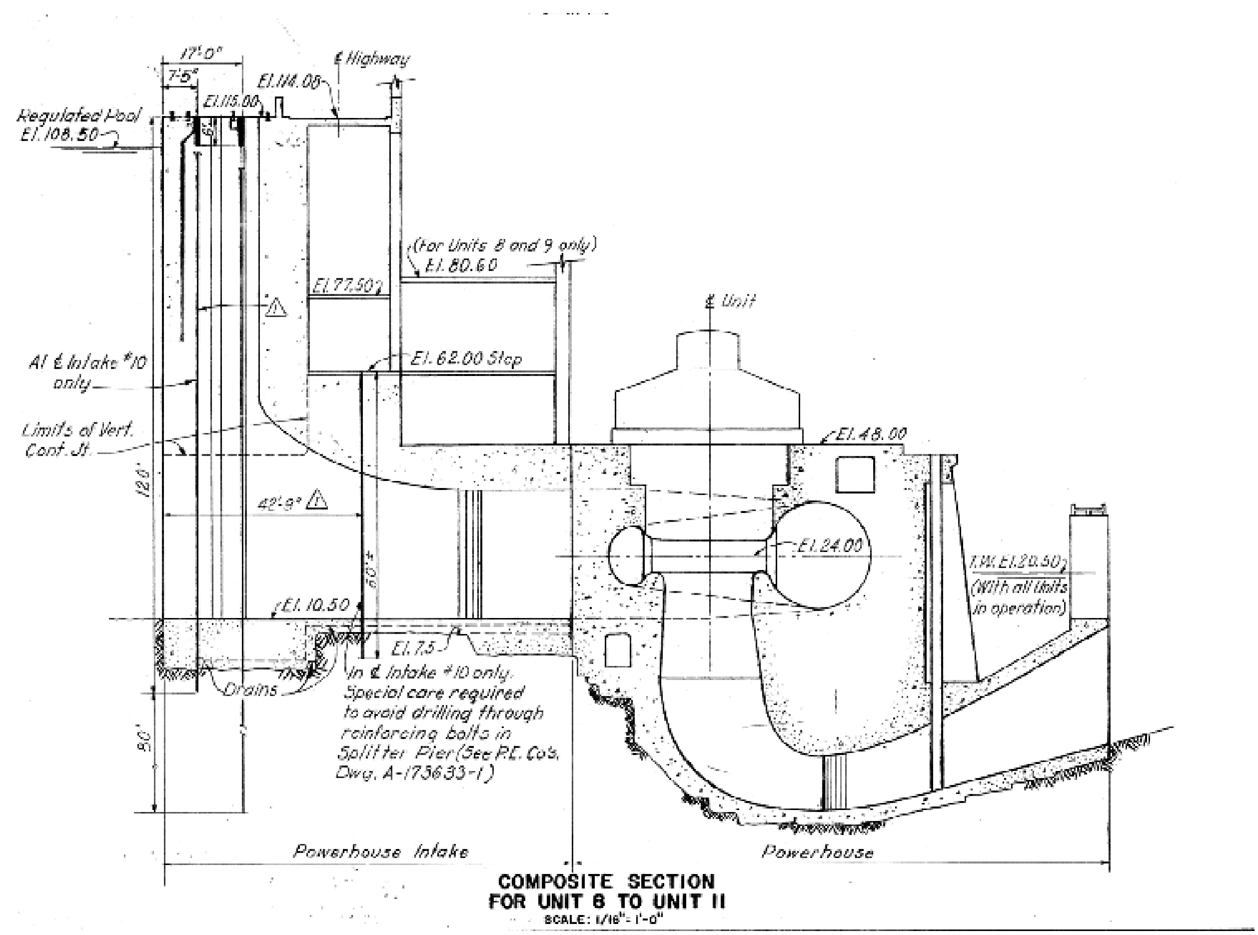


FIGURE 3.2.2-3: FRANCIS TYPE TURBINE RUNNER

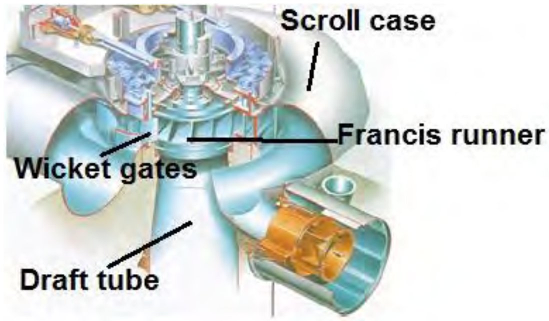
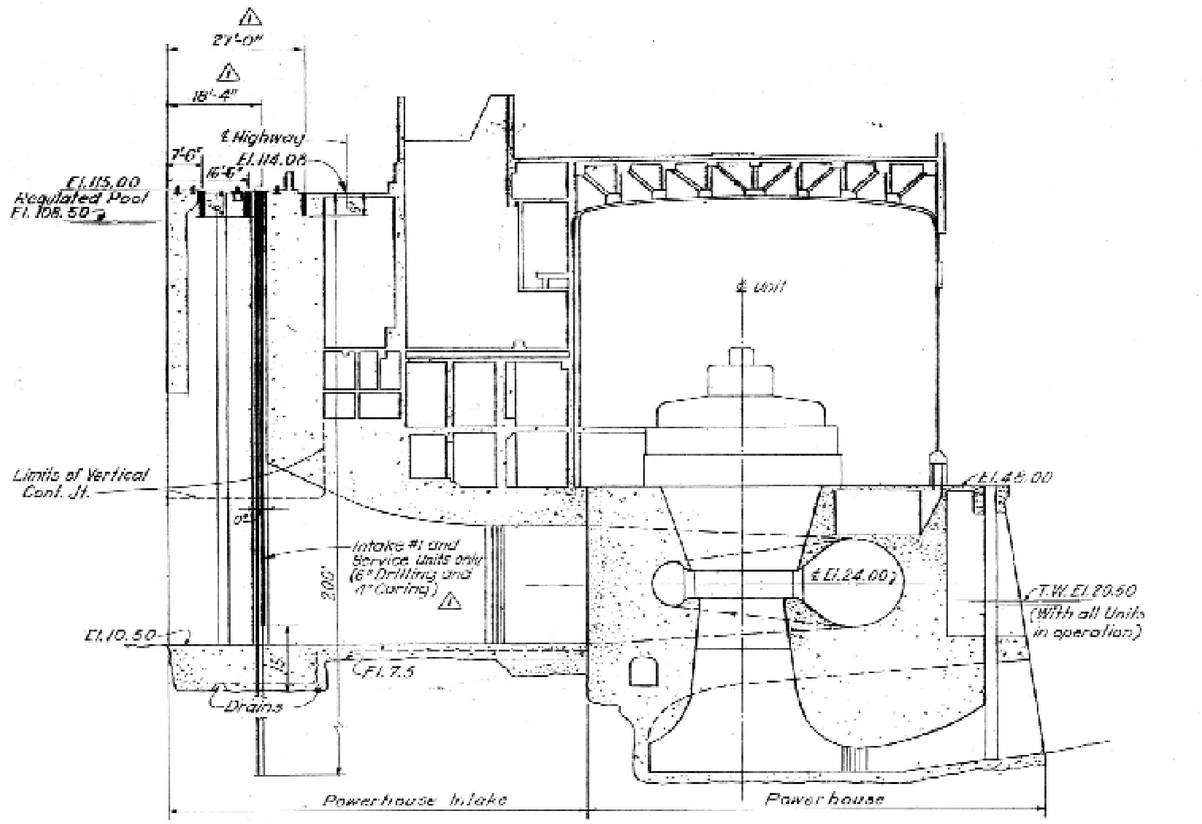


Image of typical Francis turbine showing the scroll case, wicket gates, and draft tube.

Photograph of a Francis runner from the Conowingo Project.

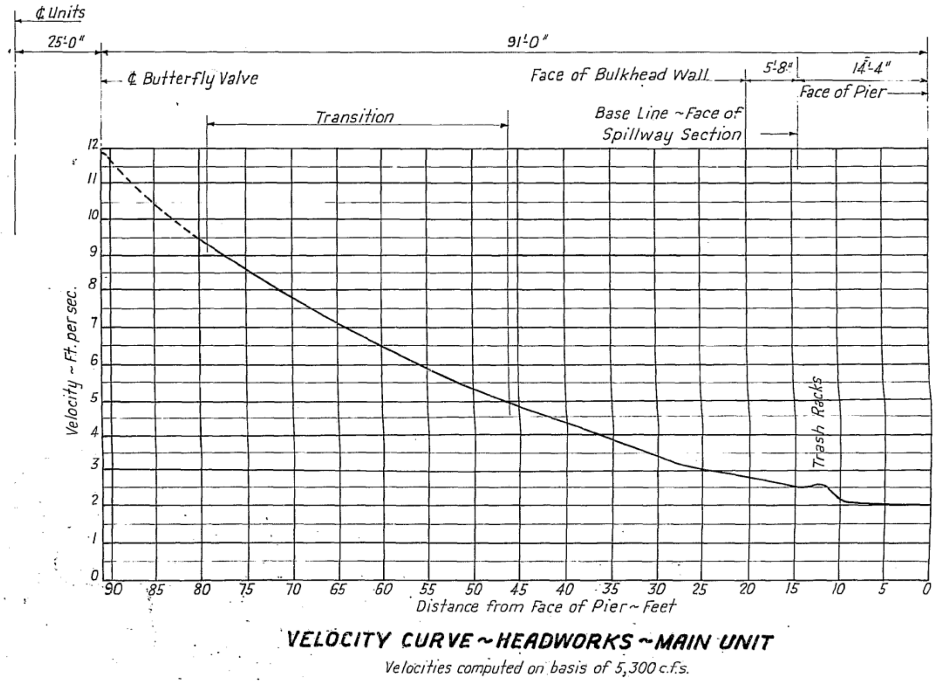
Clear picture of a typical Francis runner.

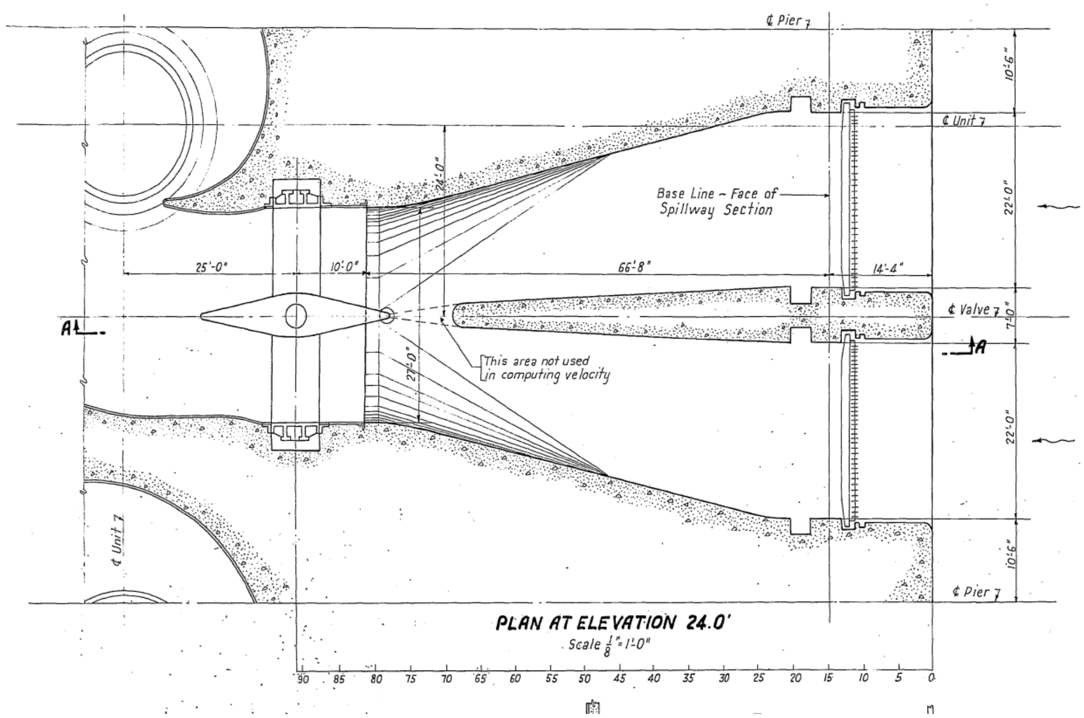
FIGURE 3.2.2-4: CROSS SECTION COMPOSITE OF THE FRANCIS UNITS 1-7 AT THE CONOWINGO PROJECT



COMPOSITE SECTION
FOR UNIT 1 TO UNIT 7
SCALE: 1/16" = 1'-0"

FIGURE 5.2.1.2-1: INTAKE FLOW VELOCITY CURVE FROM PROJECT DRAWING F110463





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APPENDIX A-PHYSICAL AND HYDRAULIC CHARACTERISTICS OF HYDROELECTRIC DAMS EQUIPPED WITH KAPLAN, PROPELLER, AND FRANCIS TYPE TURBINES FOR WHICH SURVIVAL DATA (DIRECT EFFECTS) WERE DEEMED USABLE.

APPENDIX A. TABLE 1: PHYSICAL AND HYDRAULIC CHARACTERISTICS OF HYDROELECTRIC DAMS EQUIPPED WITH KAPLAN AND PROPELLER TYPE TURBINES FOR WHICH SURVIVAL DATA (DIRECT EFFECTS) WERE DEEMED USABLE.

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Bar Mills, ME	HI-Z Turb'N Tag	Atlantic Salmon	7.9	960	5	120	22	134	70.2	88.0
Bar Mills, ME	HI-Z Turb'N Tag	Atlantic Salmon	8.2	1,560	5	120	22	134	70.2	93.6
Big Cliff, OR (1964)	Full discharge netting	Chinook Salmon	3.9	2,510	6	163.6	71	148	105.7	89.7
Big Cliff, OR (1964)	Full discharge netting	Chinook Salmon	3.9	1,854	6	163.6	91	148	105.7	91.1
Big Cliff, OR (1964)	Full discharge netting	Chinook Salmon	3.9	2,509	6	163.6	81	148	105.7	94.5
Big Cliff, OR (1966)	Full discharge netting	Chinook Salmon	3.9	2,509	6	163.6	81	148	105.7	89.8
Big Cliff, OR (1966)	Full discharge netting	Chinook Salmon	3.9	2,510	6	163.6	71	148	105.7	90.6
Big Cliff, OR (1966)	Full discharge netting	Chinook Salmon	3.9	1,854	6	163.6	91	148	105.7	92.2
Big Cliff, OR (1967)	Full discharge netting	Steelhead	6.0	2,510	6	163.6	71	148	105.7	90.4
Bonneville, OR, U. 5, Hub	HI-Z Turb'N Tag	Chinook Salmon	6.6	10,500	5	75	57	280	91.7	96.8
Bonneville, OR, U. 5, Hub	HI-Z Turb'N Tag	Chinook Salmon	6.8	6,200	5	75	57	280	91.7	98.6
Bonneville, OR, U. 5, Hub	HI-Z Turb'N Tag	Chinook Salmon	6.7	12,000	5	75	57	280	91.7	100.3
Bonneville, OR, U. 5, Hub	HI-Z Turb'N Tag	Chinook Salmon	6.5	7,000	5	75	57	280	91.7	100.9
Bonneville, OR, U. 5, Mid	HI-Z Turb'N Tag	Chinook Salmon	6.3	7,000	5	75	57	280	91.7	95.9
Bonneville, OR, U. 5, Mid	HI-Z Turb'N Tag	Chinook Salmon	6.5	6,200	5	75	57	280	91.7	96.4
Bonneville, OR, U. 5, Mid	HI-Z Turb'N Tag	Chinook Salmon	6.5	12,000	5	75	57	280	91.7	96.8
Bonneville, OR, U. 5, Mid	HI-Z Turb'N Tag	Chinook Salmon	6.5	10,500	5	75	57	280	91.7	98.6
Bonneville, OR, U. 5, Tip	HI-Z Turb'N Tag	Chinook Salmon	6.3	12,000	5	75	57	280	91.7	90.9
Bonneville, OR, U. 5, Tip	HI-Z Turb'N Tag	Chinook Salmon	6.3	7,000	5	75	57	280	91.7	93.3
Bonneville, OR, U. 5, Tip	HI-Z Turb'N Tag	Chinook Salmon	6.5	6,200	5	75	57	280	91.7	94.7
Bonneville, OR, U. 5, Tip	HI-Z Turb'N Tag	Chinook Salmon	6.6	10,500	5	75	57	280	91.7	96.3
Bonneville, OR, U. 6, Hub	HI-Z Turb'N Tag	Chinook Salmon	6.5	7,000	5	75	57	280	91.7	97.4
Bonneville, OR, U. 6, Hub	HI-Z Turb'N Tag	Chinook Salmon	6.7	12,000	5	75	57	280	91.7	98.0
Bonneville, OR, U. 6, Hub	HI-Z Turb'N Tag	Chinook Salmon	6.8	6,200	5	75	57	280	91.7	98.6
Bonneville, OR, U. 6, Hub	HI-Z Turb'N Tag	Chinook Salmon	6.8	10,500	5	75	57	280	91.7	98.6
Bonneville, OR, U. 6, Mid	HI-Z Turb'N Tag	Chinook Salmon	6.4	7,000	5	75	57	280	91.7	96.3
Bonneville, OR, U. 6, Mid	HI-Z Turb'N Tag	Chinook Salmon	6.4	10,500	5	75	57	280	91.7	97.7

Appendix A: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Bonneville, OR, U. 6, Tip	HI-Z Turb'N Tag	Chinook Salmon	6.5	12,000	5	75	57	280	91.7	94.7
Bonneville, OR, U. 6, Tip	HI-Z Turb'N Tag	Chinook Salmon	6.3	7,000	5	75	57	280	91.7	94.9
Bonneville, OR, U. 6, Tip	HI-Z Turb'N Tag	Chinook Salmon	6.4	6,200	5	75	57	280	91.7	95.5
Bonneville, OR, U. 6, Tip	HI-Z Turb'N Tag	Chinook Salmon	6.5	10,500	5	75	57	280	91.7	97.7
Cathaleen's Falls, Ireland	HI-Z Turb'N Tag	Atlantic Salmon	5.4	2,650	5	187	93	152	124.1	89.3
Chalk Hill, MI-WI	HI-Z Turb'N Tag	W. Sucker/R. Trout	4.7	1,330	4	150	29	102	66.8	91.0
Chalk Hill, MI-WI	HI-Z Turb'N Tag	Bluegill	4.1	1,330	4	150	29	102	66.8	97.0
Chalk Hill, MI-WI	HI-Z Turb'N Tag	W. Sucker/R. Trout	10.3	1,330	4	150	29	102	66.8	97.0
Chalk Hill, MI-WI	HI-Z Turb'N Tag	Bluegill	6.0	1,330	4	150	29	102	66.8	98.0
Cliff, Ireland	HI-Z Turb'N Tag	Atlantic Salmon	5.4	2,610	5	115	33	169	84.8	92.3
Conowingo, MD	HI-Z Turb'N Tag	American Shad	4.9	8,000	6	120	90	225	117.9	94.9
Cowlitz, WA	HI-Z Turb'N Tag	Coho Salmon	6.1	3,150	5	150	87.5	179	117.2	97.3
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	10.9	200	4	229	21	69	69.0	81.0
Craggy Dam, NC	HI-Z Turb'N Tag	Bluegill	6.1	200	4	229	21	69	69.0	86.0
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	7.1	200	4	229	21	69	69.0	90.0
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	7.1	600	4	229	21	69	69.0	93.0
Craggy Dam, NC	HI-Z Turb'N Tag	Channel Catfish	10.9	600	4	229	21	69	69.0	93.0
Craggy Dam, NC	HI-Z Turb'N Tag	Bluegill	3.9	200	4	229	21	69	69.0	96.0
Crescent, NY	HI-Z Turb'N Tag	Blueback Herring	3.6	1,520	5	144	27	108	67.9	96.0
Essex,MA (bulb turbine)		Atlantic Salmon	11.3	4,400	3	128.6	26	157.5	88.4	98.0
Feeder Dam, NY	Full discharge netting	Brown trout	8.1	1,040	6	120	21	115	60.2	86.4
Feeder Dam, NY	Full discharge netting	Largemouth bass	11.5	1,040	6	120	20	115	60.2	86.8
Feeder Dam, NY	Full discharge netting	Largemouth bass	7.5	1,040	6	120	19	115	60.2	90.0
Feeder Dam, NY	Full discharge netting	Bluegill	5.1	1,040	6	120	17	115	60.2	92.3
Feeder Dam, NY	Full discharge netting	Golden shiner	3.5	1,040	6	120	22	115	60.2	96.8
Feeder Dam, NY	Full discharge netting	Bluegill	3.6	1,040	6	120	15.5	115	60.2	97.3
Feeder Dam, NY	Full discharge netting	Largemouth bass	3.5	1,040	6	120	18	115	60.2	98.0
Foster, OR (tests combined)	Full discharge netting	Chinook Salmon	4.7	800	6	257	86	100	112.2	82.1
Foster, OR (tests combined)	Full discharge netting	Chinook Salmon	4.7	800	6	257	110	100	112.2	91.2

Appendix A : Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Foster, OR (tests combined)	Full discharge netting	Chinook Salmon	4.7	800	6	257	101	100	112.2	92.7
Greenup Dam, OH	Radio Telemetry	Sauger	9.1	11,866	5	90	30	240	94.3	85.4
Hadley Falls, MA	Radio Telemetry	American Shad	22.0	4,200	5	128	52	170	95.0	78.2
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	3.2	4,200	5	150	52	156	102.1	89.1
Hadley Falls, MA	Radio Telemetry	Atlantic salmon	11.2	4,200	5	128	52	170	95.0	93.7
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	3.2	4,200	5	128	52	170	95.0	97.3
Hadley Falls, MA	HI-Z Turb'N Tag	American Shad	3.2	1,550	5	128	52	170	95.0	100.0
Herrings, NY	Full discharge netting	Soft ray	9.8	1,200	4	138	19	113	68.1	85.1
Herrings, NY	Full discharge netting	Salmonids	6.9	1,200	4	138	19	113	68.1	87.5
Herrings, NY	Full discharge netting	Salmonids	3.9	1,200	4	138	19	113	68.1	90.0
Herrings, NY	Full discharge netting	Percid	3.9	1,200	4	138	19	113	68.1	91.1
Herrings, NY	Full discharge netting	Soft ray	6.9	1,200	4	138	19	113	68.1	91.7
Herrings, NY	Full discharge netting	Centrarchid	9.8	1,200	4	138	19	113	68.1	92.5
Herrings, NY	Full discharge netting	Clupeids	3.9	1,200	4	138	19	113	68.1	92.8
Herrings, NY	Full discharge netting	Centrarchid	9.8	1,200	4	138	19	113	68.1	93.2
Herrings, NY	Full discharge netting	Percid	3.9	1,200	4	138	19	113	68.1	94.9
Herrings, NY	Full discharge netting	Centrarchid	3.9	1,200	4	138	19	113	68.1	95.0
Herrings, NY	Full discharge netting	Salmonids	3.9	1,200	4	138	19	113	68.1	95.5
Herrings, NY	Full discharge netting	Percid	9.8	1,200	4	138	19	113	68.1	96.2
Herrings, NY	Full discharge netting	Salmonids	9.8	1,200	4	138	19	113	68.1	96.2
Herrings, NY	Full discharge netting	Centrarchid	6.9	1,200	4	138	19	113	68.1	96.4
Herrings, NY	Full discharge netting	Centrarchid	6.9	1,200	4	138	19	113	68.1	97.3
Herrings, NY	Full discharge netting	Soft ray	3.9	1,200	4	138	19	113	68.1	97.5
Herrings, NY	Full discharge netting	Percid	6.9	1,200	4	138	19	113	68.1	98.2
Herrings, NY	Full discharge netting	Centrarchid	3.9	1,200	4	138	19	113	68.1	98.3
Herrings, NY	Full discharge netting	Salmonids	9.8	1,200	4	138	19	113	68.1	98.6
Herrings, NY	Full discharge netting	Salmonids	6.9	1,200	4	138	19	113	68.1	98.7
Kelsey Generating Sta., MB	HI-Z Turb'N Tag	Northern pike	26.0	8,000	6	102.9	56.1	311.8	76.4	74.200
Kelsey Generating Sta., MB	HI-Z Turb'N Tag	Walleye	17.6	8,000	6	102.9	56.1	311.8	76.4	81.400
Kelsey Generating Sta., MB	HI-Z Turb'N Tag	Northern pike adult	23.4	11	5	102.9				83.0

Appendix A: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Kelsey Generating Sta., MB	HI-Z Turb'N Tag	Walleye	16.9	11	5	102.9				87.8
Kelsey Generating Sta., MB	HI-Z Turb'N Tag	Northern pike sub adult	15.5	11	5	102.9				88.9
la centrale de Beauharnois, Quebec, Canada	Float tag	American eel	34.7	9,275	6	94.7	79	249	102.9	76.1
Lowell, MA	HI-Z Turb'N Tag	Atlantic Salmon	8.0	3,616	5	120	39	148	77.5	100.0
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	5.3	21,000	6	90	98	312	122.6	94.6
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	5.8	19,000	6	90	98	312	122.6	94.6
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	5.9	18,000	6	90	98	312	122.6	94.9
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	5.9	18,000	6	90	98	312	122.6	95.3
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	5.8	13,500	6	90	98	312	122.6	97.2
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	5.9	18,000	6	90	98	312	122.6	97.5
Lower Granite, WA	HI-Z Turb'N Tag	Chinook Salmon	5.9	18,000	6	90	98	312	122.6	97.5
McIndoes, NH	HI-Z Turb'N Tag	Atlantic Salmon	8.1	1,600	4	150	26	120	78.6	96.1
McIndoes, NH	HI-Z Turb'N Tag	Atlantic Salmon	8.2	800	4	150	26	120	78.6	100.0
McNary Dam, WA	HI-Z Turb'N Tag	Chinook salmon	5.5	12,000	6	85.7	71-75	280	104.7	94.1
McNary Dam, WA	HI-Z Turb'N Tag	Chinook salmon	6.0	7,700	6	85.7	71-73	280	104.7	94.4
McNary Dam, WA	HI-Z Turb'N Tag	Chinook salmon	5.5	16,600	6	85.7	71-75	280	104.7	94.6
McNary Dam, WA	HI-Z Turb'N Tag	Chinook salmon	6.0	16,600	6	85.7	72-73	280	104.7	94.9
McNary Dam, WA	HI-Z Turb'N Tag	Chinook salmon	6.0	12,000	6	85.7	71-73	280	104.7	95.8
McNary Dam, WA	HI-Z Turb'N Tag	Chinook salmon	6.0	13,400	6	85.7	72-74	280	104.7	98.7
Priest Rapids, WA (10ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6.1	15,000	6	85.7	78	284	106.2	94.9
Priest Rapids, WA (10ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6.1	17,000	6	85.7	78	284	106.2	95.6
Priest Rapids, WA (10ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6.1	11,000	6	85.7	78	284	106.2	98.3
Priest Rapids, WA (10ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6.1	9,000	6	85.7	78	284	106.2	98.6
Priest Rapids, WA (30ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6.1	15,000	6	85.7	78	284	106.2	96.1
Priest Rapids, WA (30ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6.1	17,000	6	85.7	78	284	106.2	96.1
Priest Rapids, WA (30ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6.1	11,000	6	85.7	78	284	106.2	96.7
Priest Rapids, WA (30ft, Unit 8)	HI-Z Turb'N Tag	Chinook Salmon	6.1	9,000	6	85.7	78	284	106.2	97.1
Raymondville, NY	Full discharge netting	American eel	24.6	1,640	6	120	21	131	68.6	63.0

Appendix A: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Robert Moses Station, NY	HI-Z Turb'N Tag	American eel	39.4	9,000	6	94.7	81	240	99.2	84.0
Rock Island, WA (bulb turbine)	HI-Z Turb'N Tag	Chinook Salmon	7.0	17,000	4	85.7	40	276	103.2	96.1
Rock Island, WA (PH 1, U 4)	HI-Z Turb'N Tag	Chinook Salmon	7.0	17,000	6	100	45	226	98.7	95.0
Rock Island, WA (PH 1, U 5)	HI-Z Turb'N Tag	Chinook Salmon	7.0	17,000	6	100	45	226	98.7	96.8
Rocky Reach, WA (10',U. 3)	HI-Z Turb'N Tag	Chinook Salmon	6.3	16,000	6	90	92	280	110.0	93.9
Rocky Reach, WA (10',U. 5)	HI-Z Turb'N Tag	Chinook Salmon	7.2	14,000	6	90	92	280	110.0	97.3
Rocky Reach, WA (10',U. 6)	HI-Z Turb'N Tag	Chinook Salmon	7.2	14,000	6	90	92	280	110.0	94.2
Rocky Reach, WA (10',U. 8)	HI-Z Turb'N Tag	Chinook Salmon	4.5	20,000	5	85.7	92	311	116.3	96.9
Rocky Reach, WA (30',U. 3)	HI-Z Turb'N Tag	Chinook Salmon	6.3	16,000	6	90	92	280	110.0	94.7
Rocky Reach, WA (30',U. 5)	HI-Z Turb'N Tag	Chinook Salmon	7.2	14,000	6	90	92	280	110.0	94.4
Rocky Reach, WA (30',U. 6)	HI-Z Turb'N Tag	Chinook Salmon	7.2	14,000	6	90	92	280	110.0	95.8
Safe Harbor, PA (Unit 7)	HI-Z Turb'N Tag	American Shad	16.7	8,300	5	109	55	222	105.6	90.0
Safe Harbor, PA (Unit 7)	HI-Z Turb'N Tag	American Shad	4.6	8,300	5	109	55	222	105.6	98.0
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	16.7	9,200	7	75	55	242	79.2	87.0
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	4.6	9,200	7	75	55	242	79.2	97.8
Safe Harbor, PA (Unit 8)	HI-Z Turb'N Tag	American Shad	4.6	9,200	7	75	55	242	79.2	98.9
T. W. Sullivan, OR	HI-Z Turb'N Tag	Chinook Salmon	6.5	390	6	242	45.5	69	72.9	84.8
T. W. Sullivan, OR	HI-Z Turb'N Tag	Steelhead	8.9	390	6	242	45.5	69	72.9	85.1
Townsend Dam, PA (bulb turbine)	HI-Z Turb'N Tag	Largemouth Bass	8.5	800	3	152	16	113	75.0	86.0
Townsend Dam, PA (bulb turbine)	HI-Z Turb'N Tag	Rainbow Trout	13.5	800	3	152	16	113	75.0	86.5
Townsend Dam, PA (bulb turbine)	HI-Z Turb'N Tag	Rainbow Trout	5.5	800	3	152	16	113	75.0	94.4
Townsend Dam, PA (bulb turbine)	HI-Z Turb'N Tag	Largemouth Bass	8.5	1,500	3	152	16	113	75.0	96.8
Townsend Dam, PA (bulb turbine)	HI-Z Turb'N Tag	Largemouth Bass	4.0	800	3	152	16	113	75.0	100.0
Townsend Dam, PA (bulb turbine)	HI-Z Turb'N Tag	Rainbow Trout	5.5	1,500	3	152	16	113	75.0	100.0
Wanapum, WA (10ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6.1	17,000	5	85.7	75	285	106.6	88.5
Wanapum, WA (10ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6.1	9,000	5	85.7	75	285	106.6	89.7

Appendix A: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	No. of Blades	Runner Speed (rpm)	Head (ft)	Runner Dia. (in)	Peripheral Velocity (fps)	Percent Survival (1 h)
Wanapum, WA (10ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6.1	11,000	5	85.7	75	285	106.6	92.4
Wanapum, WA (10ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6.1	15,000	5	85.7	75	285	106.6	94.8
Wanapum, WA (30ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6.1	9,000	5	85.7	75	285	106.6	94.9
Wanapum, WA (30ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6.1	11,000	5	85.7	75	285	106.6	96.8
Wanapum, WA (30ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6.1	17,000	5	85.7	75	285	106.6	96.8
Wanapum, WA (30ft, Unit 9)	HI-Z Turb'N Tag	Coho Salmon	6.1	15,000	5	85.7	75	285	106.6	100.0
Wilder, VT-NH	HI-Z Turb'N Tag	Atlantic Salmon	7.5	4,500	5	112.5	51	180	88.4	96.0
York Haven, PA, Unit 9	HI-Z Turb'N Tag	American Shad	4.6	1,100	4	200	21	93	81.2	92.7

APPENDIX A. TABLE 2: PHYSICAL AND HYDRAULIC CHARACTERISTICS OF HYDROELECTRIC DAMS EQUIPPED WITH FRANCIS TYPE TURBINES FOR WHICH SURVIVAL DATA (DIRECT EFFECTS) WERE DEEMED USABLE.

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Alcona, MI	Full dschrg netting	Yellow Perch	4.2	1673	16	90	43	8.33	65.1
Alcona, MI	Full dschrg netting	Rainbow Trout	4.3	1666	16	90	43	8.33	100
Alcona, MI	Full dschrg netting	Gold./Common Shiner	4.5	1662	16	90	43	8.33	80.9
Alcona, MI	Full dschrg netting	Spottail Shiner	4.6	1668	16	90	43	8.33	59.5
Alcona, MI	Full dschrg netting	Bluegill	4.6	1660	16	90	43	8.33	90.2
Alcona, MI	Full dschrg netting	Gold./Common Shiner	6.1	1663	16	90	43	8.33	84.7
Alcona, MI	Full dschrg netting	Walleye	6.4	1669	16	90	43	8.33	16.4
Alcona, MI	Full dschrg netting	Bluegill	6.7	1661	16	90	43	8.33	84.1
Alcona, MI	Full dschrg netting	White Sucker	7.1	1671	16	90	43	8.33	94.4
Alcona, MI	Full dschrg netting	Yellow Perch	7.3	1674	16	90	43	8.33	55.1
Alcona, MI	Full dschrg netting	Grass Pickerel	9.3	1664	16	90	43	8.33	86.7
Alcona, MI	Full dschrg netting	White Sucker	11.4	1672	16	90	43	8.33	90.4
Alcona, MI	Full dschrg netting	Rainbow Trout	12.5	1667	16	90	43	8.33	89.4
Alcona, MI	Full dschrg netting	Northern Pike	13.9	1665	16	90	43	8.33	51.2
Alcona, MI	Full dschrg netting	Walleye	15.2	1670	16	90	43	8.33	38.7
Baker, WA	Fyke net	Sockeye salmon		550	19	300	250	5.00	64
Baker, WA	Fyke net	Coho salmon		550	19	300	250	5.00	72
Bond Falls, MI	Full dschrg netting	Golden Shiner	2.8	450	-	300	210	-	77.9
Bond Falls, MI	Full dschrg netting	Yellow Perch	4.0	450	-	300	210	-	79.5
Bond Falls, MI	Full dschrg netting	Bluegill	4.5	450	-	300	210	-	81.7
Bond Falls, MI	Full dschrg netting	Rainbow Trout	8.3	450	-	300	210	-	83.8
Buchanan, MI	Full dschrg netting	Steelhead trout	16.5	220	-	-	-	-	79.4
Buchanan, MI	Full dschrg netting	Chinook salmon	16.5	100	-	-	-	-	79.6

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	3.0	650	15	226	80	6.00	80.3
Caldron Falls, WI (Unit 1)	Full dschrg netting	Centrarchiforms	3.0	650	15	226	80	6.00	100
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	5.0	650	15	226	80	6.00	84.8
Caldron Falls, WI (Unit 1)	Full dschrg netting	Centrarchiforms	5.0	650	15	226	80	6.00	98.2
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	7.0	650	15	226	80	6.00	70.3
Caldron Falls, WI (Unit 1)	Full dschrg netting	Centrarchiforms	7.0	650	15	226	80	6.00	86.8
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	9.0	650	15	226	80	6.00	64.3
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	11.5	650	15	226	80	6.00	59.5
Caldron Falls, WI (Unit 1)	Full dschrg netting	Fusiforms	>11.5	650	15	226	80	6.00	35.5
Centralia, WI	Full dschrg netting	resident	<4	variable	15	90	15.5	2.33	64
Centralia, WI (Unit 1)	Full dschrg netting	Bluegill	4.9	510	15	90	20	2.33	98.2
Centralia, WI (Unit 1)	Full dschrg netting	Bluegill	6.9	510	15	90	20	2.33	86.8
Centralia, WI (Unit 2)	Full dschrg netting	White Sucker	4.9	510	15	90	20	2.33	97.9
Colton, NY	Full dschrg netting	Soft Ray	3.9	497	19	360	265	4.92	75
Colton, NY	Full dschrg netting	Centrarchid	6.9	497	19	360	265	4.92	1
Colton, NY	Full dschrg netting	Percid	6.9	497	19	360	265	4.92	14
Colton, NY	Full dschrg netting	Salmonid	6.9	497	19	360	265	4.92	31
Colton, NY	Full dschrg netting	Soft Ray	6.9	497	19	360	265	4.92	47
Colton, NY	Full dschrg netting	Centrarchid	<4	497	19	360	265	4.92	3
Colton, NY	Full dschrg netting	Percid	<4	497	19	360	265	4.92	65

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Colton, NY	Full dschrg netting	Salmonid	<4	497	19	360	265	4.92	68
Colton, NY	Full dschrg netting	Centrarchid	>10	497	19	360	265	4.92	0
Colton, NY	Full dschrg netting	Salmonid	>10	497	19	360	265	4.92	7
Colton, NY	Full dschrg netting	Percid	>10	497	19	360	265	4.92	17
Colton, NY	Full dschrg netting	Soft Ray	>10	497	19	360	265	4.92	17
Columbia, SC	Balloon tag	Sunfishes	4.2	833	14	164	28	5.33	95.9
Columbia, SC	Balloon tag	Blueback herring	5.5	833	14	164	28	5.33	92.7
Columbia, SC	Balloon tag	Channel catfish	5.6	833	14	164	28	5.33	93.6
Crown Zellerbach, OR (Unit 20)*	Full dschrg netting	Steelhead trout		411	-	277	39	-	69.4
Crown Zellerbach, OR (Unit 20)*	Full dschrg netting	Chinook salmon		411	-	277	39	-	71.6
Crown Zellerbach, OR (Unit 21)*	Full dschrg netting	Steelhead trout		521	-	255	42.8	-	80
Crown Zellerbach, OR (Unit 21)*	Full dschrg netting	Chinook salmon		521	-	255	42.8	-	81.2
Cushman Plant 2 (1960)	Full dschrg netting	Salmonids	2.3	800	17	300	450	6.92	44.6-77.3
Cushman Plant 2 (1961)	Full dschrg netting	Silver Salmon	3.5	800	17	300	450	6.92	34.5 - 72
Cushman Plant 2 (1961)	Full dschrg netting	Steelhead	5.0	800	17	300	450	6.92	33.8 - 51.9
E. J. West, NY	Full dschrg netting	Soft Ray	6.9	2,700	15	113	63	10.92	71.3
E. J. West, NY	Full dschrg netting	Centrarchid	6.9	2,700	15	113	63	10.92	85.5
E. J. West, NY	Full dschrg netting	Salmonid	6.9	2,700	15	113	63	10.92	90.6
E. J. West, NY	Full dschrg netting	Soft Ray	<4	2,700	15	113	63	10.92	32.3
E. J. West, NY	Full dschrg netting	Percid	<4	2,700	15	113	63	10.92	56.1
E. J. West, NY	Full dschrg netting	Salmonid	<4	2,700	15	113	63	10.92	65.2

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
E. J. West, NY	Full dschrg netting	Centrarchid	<4	2,700	15	113	63	10.92	71.7
E. J. West, NY	Full dschrg netting	Centrarchid	>10	2,700	15	113	63	10.92	59.8
E. J. West, NY	Full dschrg netting	Soft Ray	>10	2,700	15	113	63	10.92	67.5
E. J. West, NY	Full dschrg netting	Salmonid	>10	2,700	15	113	63	10.92	95.6
Elwha, WA	Partial netting	Chinook salmon		500	-	300	104	4.90	100
Faraday, OR	Partial netting	Chinook salmon		500	-	360	120	3.30	50
Finch Pruyn, NY (Unit 4)	Balloon tag	Smallmouth Bass	7.5	708	15	225	46	3.00	95
Finch Pruyn, NY (Unit 4)	Balloon tag	Smallmouth Bass	8.3	708	15	225	46	3.00	91
Finch Pruyn, NY (Unit 4)	Balloon tag	Smallmouth Bass	10.7	708	15	225	46	3.00	93
Finch Pruyn, NY (Unit 5)	Balloon tag	Smallmouth Bass	7.5	836	15	225	46	3.00	94
Finch Pruyn, NY (Unit 5)	Balloon tag	Smallmouth Bass	8.3	836	15	225	46	3.00	91
Finch Pruyn, NY (Unit 5)	Balloon tag	Smallmouth Bass	10.7	836	15	225	46	3.00	71
Five Channels, MI	Full dschrg netting	Yellow Perch	4.2	1,167	16	150	36	4.58	72.7
Five Channels, MI	Full dschrg netting	Rainbow Trout	4.3	1,167	16	150	36	4.58	95.8
Five Channels, MI	Full dschrg netting	Gold./Common Shiner	4.5	1,167	16	150	36	4.58	81.8
Five Channels, MI	Full dschrg netting	Spottail Shiner	4.6	1,167	16	150	36	4.58	36.4
Five Channels, MI	Full dschrg netting	Bluegill	4.6	1,167	16	150	36	4.58	93.6
Five Channels, MI	Full dschrg netting	Gold./Common Shiner	6.1	1,167	16	150	36	4.58	85.5
Five Channels, MI	Full dschrg netting	Walleye	6.4	1,167	16	150	36	4.58	71.2
Five Channels, MI	Full dschrg netting	Bluegill	6.7	1,167	16	150	36	4.58	89.2
Five Channels, MI	Full dschrg netting	White Sucker	7.1	1,167	16	150	36	4.58	88.6

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Five Channels, MI	Full dschrg netting	Yellow Perch	7.3	1,167	16	150	36	4.58	77.1
Five Channels, MI	Full dschrg netting	White Sucker	11.4	1,167	16	150	36	4.58	71.4
Five Channels, MI	Full dschrg netting	Rainbow Trout	12.5	1,167	16	150	36	4.58	70
Five Channels, MI	Full dschrg netting	Northern Pike	13.9	1,167	16	150	36	4.58	91.3
Five Channels, MI	Full dschrg netting	Walleye	15.2	1,167	16	150	36	4.58	76.7
Glines, WA	Partial netting	Silver salmon		1500	-	225	194	7.70	69.6
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	Bluegill	3.0	645	15	90	28	4.83	96.7
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	3.0	645	15	90	28	4.83	100
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	Bluegill	5.0	645	15	90	28	4.83	100
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	5.0	645	15	90	28	4.83	100
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	Bluegill	7.0	645	15	90	28	4.83	94.9
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	7.0	645	15	90	28	4.83	94.9
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	9.0	645	15	90	28	4.83	93.7
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	11.5	645	15	90	28	4.83	90.4
Grand Rapids, WI (U 1,2,4 comb)	Full dschrg netting	White Sucker	>11.5	645	15	90	28	4.83	80.5
Hardy, MI (Unit 2)	Full dschrg netting	Yellow Perch	4.2	510	16	163.6	100	6.98	83.1
Hardy, MI (Unit 2)	Full dschrg netting	Rainbow Trout	4.3	510	16	163.6	100	6.98	71.4
Hardy, MI (Unit 2)	Full dschrg netting	Gold./Common Shiner	4.5	510	16	163.6	100	6.98	85.5
Hardy, MI (Unit 2)	Full dschrg netting	Largemouth Bass	4.6	510	16	163.6	100	6.98	76.2
Hardy, MI (Unit 2)	Full dschrg netting	Bluegill	4.6	510	16	163.6	100	6.98	89.5

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Hardy, MI (Unit 2)	Full dschrg netting	Gold./Common Shiner	6.1	510	16	163.6	100	6.98	88.7
Hardy, MI (Unit 2)	Full dschrg netting	Bluegill	6.7	510	16	163.6	100	6.98	91.5
Hardy, MI (Unit 2)	Full dschrg netting	White Sucker	7.1	510	16	163.6	100	6.98	76.9
Hardy, MI (Unit 2)	Full dschrg netting	Yellow Perch	7.3	510	16	163.6	100	6.98	95.5
Hardy, MI (Unit 2)	Full dschrg netting	White Sucker	11.4	510	16	163.6	100	6.98	64.5
Hardy, MI (Unit 2)	Full dschrg netting	Rainbow Trout	12.5	510	16	163.6	100	6.98	68.6
Hardy, MI (Unit 2)	Full dschrg netting	Northern Pike	13.9	510	16	163.6	100	6.98	76
Hardy, MI (Unit 2)	Full dschrg netting	Walleye	15.2	510	16	163.6	100	6.98	77.3
High Falls (Unit 5)	Full dschrg netting	Centrarchiforms	3.0	275	12	358	83	3.25	85.5
High Falls (Unit 5)	Full dschrg netting	Fusiforms	3.0	275	12	358	83	3.25	87.8
High Falls (Unit 5)	Full dschrg netting	Fusiforms	5.0	275	12	358	83	3.25	67.9
High Falls (Unit 5)	Full dschrg netting	Centrarchiforms	5.0	275	12	358	83	3.25	78.1
High Falls (Unit 5)	Full dschrg netting	Fusiforms	7.0	275	12	358	83	3.25	48.4
High Falls (Unit 5)	Full dschrg netting	Centrarchiforms	7.0	275	12	358	83	3.25	58.9
High Falls (Unit 5)	Full dschrg netting	Fusiforms	9.0	275	12	358	83	3.25	46.2
High Falls (Unit 5)	Full dschrg netting	Fusiforms	11.5	275	12	358	83	3.25	20.1
High Falls (Unit 5)	Full dschrg netting	Fusiforms	>11.5	275	12	358	83	3.25	2.7
Higley, NY	Full dschrg netting	Centrarchid	6.9	675	13	257	46	4.00	14
Higley, NY	Full dschrg netting	Salmonid	6.9	675	13	257	46	4.00	44
Higley, NY	Full dschrg netting	Soft Ray	6.9	675	13	257	46	4.00	72
Higley, NY	Full dschrg netting	Percid	<4	675	13	257	46	4.00	59
Higley, NY	Full dschrg netting	Soft Ray	<4	675	13	257	46	4.00	60
Higley, NY	Full dschrg netting	Salmonid	<4	675	13	257	46	4.00	70
Higley, NY	Full dschrg netting	Centrarchid	<4	675	13	257	46	4.00	81
Higley, NY	Full dschrg netting	Centrarchid	>10	675	13	257	46	4.00	17

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Higley, NY	Full dschrg netting	Percid	>10	675	13	257	46	4.00	40
Higley, NY	Full dschrg netting	Soft Ray	>10	675	13	257	46	4.00	40
Higley, NY	Full dschrg netting	Salmonid	>10	675	13	257	46	4.00	61
Hoist, MI	Full dschrg netting	Bluegill	2.6	300	-	360	142	-	19.7
Hoist, MI	Full dschrg netting	Brown Trout	3.3	300	-	360	142	-	45.1
Hoist, MI	Full dschrg netting	Bluegill	4.5	300	-	360	142	-	75
Hoist, MI	Full dschrg netting	Brook Trout	5.3	300	-	360	142	-	43
Hoist, MI	Full dschrg netting	Brown Trout	8.7	300	-	360	142	-	22.8
Holtwood, PA (U3/double runner)	Balloon tag	American Shad	4.9	3,500	17	102.8	62	9.33	83.5
Holtwood, PA(U10/single runner)	Balloon tag	American Shad	4.9	3,500	16	94.7	62	12.46	89.4
la centrale Beauharnois, QE	Float tag	American eel	35.0	7,000	13	75	79	17.67	84.2
Leaburg, OR	Full dschrg netting	Rainbow trout		1100	-	225	89	7.50	95.2
Lequille, NS	Full dschrg netting	Atlantic salmon		350	13	519	387	4.50	52
Luray, VA	Full dschrg netting	American Eel	33.6	369	12	164	16	5.17	99
Mayfield, WA	Balloon tag	Coho salmon	5.9	2,800	16	138.5	182	13.13	87.6
Mayfield, WA	Balloon tag	Coho salmon	5.9	2,800	15	138.5	182	12.42	97.2
Mayfield, WA	Balloon tag	Steelhead	7.4	2,800	15	138.5	182	12.42	97.1
Mayfield, WA	Balloon tag	Steelhead	7.5	2,800	16	138.5	182	13.13	88.4
McClure, MI	Full dschrg netting	Resident spp.		155	-	600	424	-	-
Minetto, NY	Full dschrg netting	Centrarchid	6.9	1,500	16	72	17	11.58	83
Minetto, NY	Full dschrg netting	Percid	6.9	1,500	16	72	17	11.58	86
Minetto, NY	Full dschrg netting	Salmonids	6.9	1,500	16	72	17	11.58	91
Minetto, NY	Full dschrg netting	Soft Ray	6.9	1,500	16	72	17	11.58	94

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Minetto, NY	Full dschrg netting	American Eel	24.6	1,500	16	72	17	11.58	94
Minetto, NY	Full dschrg netting	Centrarchid	<4	1,500	16	72	17	11.58	62
Minetto, NY	Full dschrg netting	Percid	<4	1,500	16	72	17	11.58	80
Minetto, NY	Full dschrg netting	Soft Ray	<4	1,500	16	72	17	11.58	82
Minetto, NY	Full dschrg netting	Salmonids	<4	1,500	16	72	17	11.58	92
Minetto, NY	Full dschrg netting	Alewife	<4	-	-	-	-	-	80
Minetto, NY	Full dschrg netting	Centrarchid	>10	1,500	16	72	17	11.58	84
Minetto, NY	Full dschrg netting	Soft Ray	>10	1,500	16	72	17	11.58	84
Minetto, NY	Full dschrg netting	Salmonids	>10	1,500	16	72	17	11.58	92
North Fork, OR	Partial netting	Coho salmon		2500	-	139	136	9.67	74
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	3.0	460	15	100	13	6.67	94
Peshtigo, WI (Unit 4)	Full dschrg netting	Centrarchiforms	3.0	460	15	100	13	6.67	100
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	5.0	460	15	100	13	6.67	93.7
Peshtigo, WI (Unit 4)	Full dschrg netting	Centrarchiforms	5.0	460	15	100	13	6.67	98.9
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	7.0	460	15	100	13	6.67	96.6
Peshtigo, WI (Unit 4)	Full dschrg netting	Centrarchiforms	7.0	460	15	100	13	6.67	100
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	9.0	460	15	100	13	6.67	95.4
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	11.5	460	15	100	13	6.67	85.5
Peshtigo, WI (Unit 4)	Full dschrg netting	Fusiforms	>11.5	460	15	100	13	6.67	82.8

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	3.0	500	15	123	17	7.00	89.2
Potato Rapids, WI (Unit 1)	Full dschrg netting	Centrarchiforms	3.0	500	15	123	17	7.00	100
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	5.0	500	15	123	17	7.00	76.5
Potato Rapids, WI (Unit 1)	Full dschrg netting	Centrarchiforms	5.0	500	15	123	17	7.00	84.7
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	7.0	500	15	123	17	7.00	68.4
Potato Rapids, WI (Unit 1)	Full dschrg netting	Centrarchiforms	7.0	500	15	123	17	7.00	83
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	9.0	500	15	123	17	7.00	61.1
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	11.5	500	15	123	17	7.00	53.3
Potato Rapids, WI (Unit 1)	Full dschrg netting	Fusiforms	>11.5	500	15	123	17	7.00	34.5
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	3.0	440	15	135	17	6.67	84.5
Potato Rapids, WI (Unit 2)	Full dschrg netting	Centrarchiforms	3.0	500	15	123	17	7.00	93.4
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	5.0	440	15	135	17	6.67	61.7
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	7.0	440	15	135	17	6.67	75.1
Potato Rapids, WI (Unit 2)	Full dschrg netting	Centrarchiforms	7.0	440	15	135	17	6.67	91.4
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	9.0	440	15	135	17	6.67	61

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	11.5	440	15	135	17	6.67	57.8
Potato Rapids, WI (Unit 2)	Full dschrg netting	Fusiforms	>11.5	440	15	135	17	6.67	48.2
Pricket, MI	Full dschrg netting	Bluegill	2.0	326	15	257	54	4.46	97.7
Pricket, MI	Full dschrg netting	Bluegill	4.0	326	15	257	54	4.46	92.5
Pricket, MI	Full dschrg netting	White Sucker	6.5	326	15	257	54	4.46	70.8
Pricket, MI	Full dschrg netting	Mixed resident		326	15	257	54	4.46	97.8
Pricket, MI	Full dschrg netting	Golden Shiner	<4	326	15	257	54	4.46	93.9
Pricket, MI	Full dschrg netting	Bluegill	>5	326	15	257	54	4.46	85.7
Pricket, MI	Full dschrg netting	White Sucker	>10	326	15	257	54	4.46	35.7
Publishers, OR (1960)**	Full dschrg netting	Chinook salmon		275	-	255	40	-	87.4
Publishers, OR (1960)**	Full dschrg netting	Steelhead trout		275	-	255	40	-	87.9
Publishers, OR (1961)**	Full dschrg netting	Steelhead trout		275	-	255	40	-	84.5
Publishers, OR (1961)**	Full dschrg netting	Chinook salmon		275	-	255	40	-	87.1
Puntledge, BC	Floating net	Salmon	1.4	-	-	277	340	7.10	67.4
Puntledge, BC	Floating net	Kamploops	1.8	-	-	277	340	7.10	71.2
Puntledge, BC	Floating net	Kamploops	2.7	-	-	277	340	7.10	72.5
Puntledge, BC	Floating net	Steelhead trout	4.9	-	-	277	340	7.10	58.1
Rogers, MI (Units 1 & 2)	Full dschrg netting	Yellow Perch	4.2	383	15	150	39	5.00	91.8
Rogers, MI (Units 1 & 2)	Full dschrg netting	Rainbow Trout	4.3	383	15	150	39	5.00	89.9
Rogers, MI (Units 1 & 2)	Full dschrg netting	Spottail Shiner	4.6	383	15	150	39	5.00	73.5

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Rogers, MI (Units 1 & 2)	Full dschrg netting	Largemouth Bass	4.6	383	15	150	39	5.00	77.4
Rogers, MI (Units 1 & 2)	Full dschrg netting	Bluegill	4.6	383	15	150	39	5.00	96
Rogers, MI (Units 1 & 2)	Full dschrg netting	Gold./Common Shiner	6.1	383	15	150	39	5.00	92.5
Rogers, MI (Units 1 & 2)	Full dschrg netting	Bluegill	6.7	383	15	150	39	5.00	85.2
Rogers, MI (Units 1 & 2)	Full dschrg netting	White Sucker	7.1	383	15	150	39	5.00	91.2
Rogers, MI (Units 1 & 2)	Full dschrg netting	White Sucker	11.4	383	15	150	39	5.00	88.1
Rogers, MI (Units 1 & 2)	Full dschrg netting	Rainbow Trout	12.5	383	15	150	39	5.00	61.2
Rogers, MI (Units 1 & 2)	Full dschrg netting	Northern Pike	13.9	383	15	150	39	5.00	83.4
Rogers, MI (Units 1 & 2)	Full dschrg netting	Walleye	15.2	383	15	150	39	5.00	86.2
Ruskin, BC	Fyke netting dwnstrm	Sockeye Salmon	3.4	4,000	-	120	130	12.42	89.5
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	3.0	650	15	150	42	7.25	64.9
Sandstone Rapids,WI	Full dschrg netting	Centrarchiforms	3.0	650	15	150	42	7.25	97
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	5.0	650	15	150	42	7.25	75
Sandstone Rapids,WI	Full dschrg netting	Centrarchiforms	5.0	650	15	150	42	7.25	80.7
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	7.0	650	15	150	42	7.25	76
Sandstone Rapids,WI	Full dschrg netting	Centrarchiforms	7.0	650	15	150	42	7.25	79.9
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	9.0	650	15	150	42	7.25	69.8
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	11.5	650	15	150	42	7.25	58.4
Sandstone Rapids,WI	Full dschrg netting	Fusiforms	>11.5	650	15	150	42	7.25	47.1

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Schaghiticoke, NY	Full dschrg netting	Soft ray	6.9	410	17	300	143	6.67	17
Schaghiticoke, NY	Full dschrg netting	Salmonid	6.9	410	17	300	143	6.67	27
Schaghiticoke, NY	Full dschrg netting	Percid	6.9	410	17	300	143	6.67	39
Schaghiticoke, NY	Full dschrg netting	Centrarchid	6.9	410	17	300	143	6.67	59
Schaghiticoke, NY	Full dschrg netting	Centrarchid	<4	410	17	300	143	6.67	27
Schaghiticoke, NY	Full dschrg netting	Salmonid	<4	410	17	300	143	6.67	56
Schaghiticoke, NY	Full dschrg netting	Soft ray	<4	410	17	300	143	6.67	60
Schaghiticoke, NY	Full dschrg netting	Percid	<4	410	17	300	143	6.67	68
Schaghiticoke, NY	Full dschrg netting	Centrarchid	>10	410	17	300	143	6.67	7
Schaghiticoke, NY	Full dschrg netting	Salmonid	>10	410	17	300	143	6.67	11
Schaghiticoke, NY	Full dschrg netting	Soft ray	>10	410	17	300	143	6.67	22
Seton Creek, BC	Fyke net in tailrace	Sockeye Salmon	3.4	4,500	-	120	142	12.00	90.8
Shasta, CA (January)	Full dschrg netting	Chinook Salmon	4.0	3,200	15	138.5	380	15.33	54.8 - 72.1
Shasta, CA (January)	Full dschrg netting	Steelhead	6.0	3,200	15	138.5	380	15.33	75.4 - 89.3
Shasta, CA (January)	Full dschrg netting	Rainbow Trout	10.0	3,200	15	138.5	380	15.33	53.1 - 71.2
Shasta, CA (November)	Full dschrg netting	Chinook Salmon	4.0	3,200	15	138.5	380	15.33	61.7 - 84.5
Shasta, CA (November)	Full dschrg netting	Steelhead	6.0	3,200	15	138.5	380	15.33	50.5 - 69.2
Shasta, CA (November)	Full dschrg netting	Rainbow Trout	10.0	3,200	15	138.5	380	15.33	39.6 - 90.5
Stevens Creek, SC	Balloon tag	Bluegill	4.8	1,000	14	75	28	11.25	95.4
Stevens Creek, SC	Balloon tag	Spotted Sucker/Y. Perch	6.5	1,000	14	75	28	11.25	98.3
Stevens Creek, SC	Balloon tag	Blueback Herring	8.0	1,000	14	75	28	11.25	95.3
T. W. Sullivan, OR	Discharge netting	Steelhead trout		-	-	242	41	-	74.1
T. W. Sullivan, OR	Discharge netting	Chinook salmon		260	-	242	41	-	85.7

Appendix A Table 2: Continued

Station	Sampling Method	Species Tested	Avg. Fish Length (in)	Turbine Flow (cfs)	Number of Buckets	Runner Speed (rpm)	Head (ft)	Runner Dia. (ft)	Est. Percent Survival (1 h)
Vernon, VT/NH	Balloon tag	American Shad	3.7	1,834	15	74	34	13.00	94.7
Vernon, VT/NH	Balloon tag	Atlantic salmon	5.6	1,280	14	133	34	5.20	85.1
Vernon, VT/NH	Balloon tag	Atlantic salmon	6.1	1,834	15	74	34	13.00	97.4
White Rapids, WI	Balloon tag	Bluegill	3.5	900	14	100	29	11.17	95
White Rapids, WI	Balloon tag	White Sucker	4.4	900	14	100	29	11.17	100
White Rapids, WI	Balloon tag	Bluegill	6.1	900	14	100	29	11.17	100
White Rapids, WI	Balloon tag	White Sucker	8.0	900	14	100	29	11.17	93
York Haven, PA	Balloon tag	American shad	4.5	850	18	84	23	6.5	77.1
Youghiogheny, PA	Full dschrg netting	Alewife	2.0	750	-	-	120	-	0.1
Youghiogheny, PA	Full dschrg netting	Walleye	14.8	750	-	-	120	-	39.5
Youghiogheny, PA	Full dschrg netting	Crappies		750	-	-	120	-	0.2
Youghiogheny, PA	Full dschrg netting	Rock bass		750	-	-	120	-	4
Youghiogheny, PA	Full dschrg netting	Yellow perch		750	-	-	120	-	7
Youghiogheny, PA	Full dschrg netting	White sucker		750	-	-	120	-	9.5

* Decommissioned.
** Presently Blue Heron Development.
*** Composite number of fish introduced and their recapture rates; November tests - test=91.0% and control=73.8%, January tests - test=72% and control=66%.