BIOLOGICAL PERFORMANCE OF INTAKE SCREEN ALTERNATIVES TO REDUCE ANNUAL IMPINGEMENT MORTALITY AND ENTRAINMENT AT MERRIMACK STATION

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Biological Performance of Intake Screen Alternatives to Reduce Annual Impingement Mortality and Entrainment at Merrimack Station

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1.0 INTRODUCTION

As a result of the 4 December 2008 meeting between Public Service Company of New Hampshire ("PSNH"), the United States Environmental Protection Agency ("EPA") and PSNH's technical experts, Enercon Services, Inc. and Normandeau Associates, Inc., to discuss PSNH's pending application for renewal of the existing National Pollutant Discharge Elimination System permit for Merrimack Station Unit 1 and Unit 2 in Bow, New Hampshire ("Merrimack Station" or the "Station"), EPA asked PSNH to prepare and submit an enhanced conceptual cooling water intake structure ("CWIS") technology evaluation for the Station in order to augment and refine the evaluation that PSNH had provided to EPA in November 2007 in response to EPA's July 2007 information request letter under Clean Water Act ("CWA") §308 (the "§308 Response Report"). Specifically, following the December 2008 meeting, EPA asked PSNH to prepare and submit a more detailed evaluation of the following CWIS technologies: (1) seasonal deployment of narrow slot cylindrical wedgewire ("CWW") screens in Hooksett Pool connected to the Station's CWISs (Section 2.0), (2) seasonal deployment of an aquatic filter barrier ("AFB") enclosing the Station's existing CWISs (Section 3.0), and (3) installation of fine mesh traveling screens to replace the Station's existing coarse mesh traveling screens at the existing CWISs (Section 4.0).

2.0 SEASONAL OPERATION OF CYLINDRICAL WEDGEWIRE SCREENS OF DIFFERENT SLOT WIDTHS TO REDUCE ANNUAL IMPINGEMENT MORTALITY AND ENTRAINMENT AT MERRIMACK STATION

2.1 APPROACH

In support of this requested enhanced conceptual CWIS technology evaluation, Normandeau undertook additional analysis to determine the expected biological performance of seasonally deployed CWW screens of different slot sizes at Merrimack Station. For this analysis, Normandeau evaluated, individually and in combination, three technological and operational alternatives for reducing impingement mortality and entrainment abundance from baseline at the Station: (1) installation and seasonal operation of CWW screens, (2) operational flow reductions at each unit, and (3) impingement survival achievable through operation of the existing conventional traveling screens and installation and operation of a new fish return sluice.

Fish eggs and larvae were observed predominantly during the months of April through July in entrainment samples from Merrimack Station (Normandeau 2007), suggesting that installation and operation of CWW screens of an appropriate slot width during this entrainment season could provide significant annual reductions in both impingement mortality and entrainment abundance at the Station while avoiding the winter period, when the risk of screen failure is unacceptably high due to the potential for frazil ice formation. Using data from the 2005-2007 Study (Normandeau 2007), Normandeau prepared this analysis to estimate the potential monthly and annual impingement mortality and entrainment ("IM&E") reductions from the installation and seasonal operation of CWW screens at Merrimack Station. Monthly and annual reductions in impingement mortality and numbers entrained were estimated with respect to a baseline representing full flow at both units, i.e., consistent with the §308 Response Report (PSNH 2007), baseline flow was defined as 59,000 gallons per minute (“gpm”) for Unit 1 and 140,000 gpm for Unit 2, during all 365 days per year (“baseline”). The total monthly number impinged and entrained at that baseline flow was estimated from impingement rates and entrainment densities observed in the 2005-2007 Study (when a month was sampled in two years, the average of the two estimates was used).

This analysis is based on five fundamental premises supported by peer-reviewed or published technical literature relating to entrainment and impingement of fish exposed to CWW screens:

1. The ability of a CWW screen to exclude impinged and entrained fish is affected by the width of the screen’s slot openings (EPRI 1999; EPA 2004). This analysis evaluated exclusion effectiveness for screen slot widths of 1.0, 1.5 mm, 2.0 mm, 3.0 mm, 6.0 mm, and 9.0 mm using physical exclusion factors based on the limiting dimensions of the eggs and larvae of certain species representing over 90% of the total numbers impinged and entrained at the Station (as explained in the “Physical Exclusion Factors” Section 2.2.1 below).
2. Additional entrainment reduction can result from active avoidance of CWW screens by larvae too small to be physically excluded (Heuer and Tomljanovich 1978). To provide boundaries for its estimates of such entrainment reduction, This analysis evaluated CWW screen performance using three different assumptions regarding active avoidance derived from the literature (as explained in the “Wedgewire Avoidance Factors” Section 2.2.2 below).
3. All fish excluded by CWW screens escape impingement and survive (EPA 2004). CWW screens can achieve 80 to 90% or greater reduction in entrainment compared with conventional once-through systems (EPA 2004). Moreover, while screening to prevent organism entrainment may cause impingement of those organisms instead, it has been demonstrated that fish excluded by CWW screens can escape impingement and survive (Hanson *et al*. 1977, Hanson 1981, Browne *et al*. 1981, EPRI 2003). Both laboratory studies and field tests by fisheries experts have demonstrated that CWW screens allow fish larvae and juveniles to avoid impingement or escape after only a brief period of impingement. For example, most fish larvae and juveniles impinged on a CWW screen in a laboratory flume escaped and swam away after a brief period of impingement (Hanson *et al*. 1977). When CWW screens were oriented with the long axis of each cylinder parallel to the sweeping flow and the slots radial (perpendicular to the sweeping flow) in another laboratory study, striped bass larvae avoided impingement completely (EPRI 2003). Visual observations in a field test of CWW screens indicated that few fish were impinged and many fish (including 20-25 mm larvae) and invertebrates swam or hovered near the screens without being impinged (Browne *et al*. 1981). Moreover, the premise that fish excluded by CWW screens can escape impingement and survive is supported by EPA’s determination, incorporated into the Phase II §316(b) Rule (the “Phase II Rule”), that CWW screens can reduce impingement mortality by 99% or greater compared with conventional once-through screens (EPA 2004). For this reason, under the Phase II Rule, EPA pre-approved the use of CWW screens for CWISs that are located in freshwater rivers or streams and meet certain other conditions, including a maximum through-slot design velocity of 0.5 feet per second (“ft/s”) (0.15 m/s) in order to enable fish to avoid impingement (EPA 2004).
4. Total impingement mortality in months when CWW screens are not in use will include not only the mortality resulting from impingement of fish against the existing screens, as observed in the 2005-2007 Study and summarized quarterly (Normandeau 2007), but also the additional mortality of impinged fish during passage through a state-of-the-art fish return system (Con Edison 1992).

5. This analysis conservatively assumed a zero percent entrainment survival rate for the baseline scenario and all evaluated CWW screen scenarios. Zero percent entrainment survival is EPA's preferred assumption for estimating baseline and alternatives (EPA 2004). In addition, although entrainment survival rates for eggs, larvae, and juveniles entrained through 9.5-mm square mesh screens at some power stations have been shown to be substantially greater than zero (EPRI 2000), the entrainment survival rate for ichthyoplankton entrained through the existing conventional traveling screens at Merrimack Station is not sufficiently well-known to assume any survival value other than 0%.

2.2 ANALYTICAL METHODS

2.2.1 Physical Exclusion Factors

The exclusion of eggs and larvae when cooling water is withdrawn through openings that are too small for the eggs and larvae to pass through is represented in this analysis by the "physical exclusion factor" ("P_e"), which is the proportion of such organisms that would have been entrained through Merrimack Station's existing conventional traveling screens but can be excluded from the Station's cooling water by the installation and operation of CWW screens. The purpose of the physical exclusion factor is to enable estimation of the reduced number of organisms that would be entrained through CWW screens of slot widths less than the mesh openings of the existing screens:

$$E_w = (E)(1 - P_e) \qquad \text{(Equation 1)}$$

where E_w = number entrained through CWW screens,

E = number entrained through existing intake screens, and

P_e = proportion excluded by CWW screens (i.e., the physical exclusion factor).

Entrainment of the early life stages of fish depends on what sizes of them can fit through a screen's openings. For fish eggs, which are generally spherical, that is readily determined, assuming no compressibility and extrusion. If the egg diameter is larger than the width of the CWW slots, the egg will not be entrained. The estimates of P_e for larvae are based on their "limiting dimension," reflecting the fundamental assumption that a small fish attempting to avoid the screen will typically orient itself to swim directly away from the screen surface, so that if it is entrained it is drawn tail first through the mesh opening by the intake current. Therefore, the limiting dimension is not the length of the fish, but its thickness, which could be either the head or the thickest or deepest part of the body. If either the greatest width or greatest depth of the fish exceeds the slot width, the fish will usually not be entrained. Greatest body depth ("GBD") was selected to represent the limiting dimension for this evaluation because it is usually the most readily determined measurement other than total length. Although GBD might in some cases be slightly smaller than head capsule width or greatest body width, the difference would be very small, making GBD a reasonable representation of the limiting dimension of the larva.

Estimates of P_e based on egg diameter or GBD can overestimate the actual fraction excluded at the upper end of the entrainment/impingement transition size range if some eggs or larvae are compressed and forced through the screen. Estimates of P_e based on GBD can underestimate the fraction excluded at the lower end of the entrainment/impingement transition size range, because of fish that are small enough to fit through the screen tail first but are instead impinged sideways across the slots in the screen. No attempt was made to adjust for these biases because there is insufficient site-specific information available on which to base such adjustments.

P_e for larvae varies depending on the species, the size of the individual, and the slot width. This evaluation focused on taxa for which adult equivalent estimates were previously presented for Merrimack Station, representing over 90% of the total numbers impinged and entrained (Normandeau 2007): cyprinids (carp and minnow family), centrarchids (sunfish family), white sucker, and yellow perch. Estimates of P_e (Table 2-1) were based on length-frequency data for 1-mm length groups from Merrimack Station entrainment samples collected in 2006 and 2007, for nearly 300 larvae in these four taxa (Normandeau 2007). Slot widths evaluated were 1.0 mm, 1.5 mm, 2.0 mm, 3.0 mm, 6.0 mm, and 9.0 mm. The length at which the GBD of a growing larva exceeds each of the six slot widths was estimated from published larval descriptions of spottail shiner, bluegill, white sucker, and yellow perch (Auer 1982). P_e was then estimated for each taxon and month from the length frequency distribution for larvae entrained during 2006 and 2007 at Merrimack Station (Normandeau 2007):

$$P_e = \Sigma_{L=Ls,Lmax}\,(n_L) \,/\, \Sigma_{L=Lmin,Lmax}\,(n_L) \qquad \text{(Equation 2)}$$

where P_e = proportion excluded (physical exclusion factor),

Ls = smallest length class excluded by slot width *s*,

$Lmax$ = largest length class entrained by standard screens,

$Lmin$ = smallest length class entrained by standard screens, and

n_L = number of larvae measured in length class L.

Only one of the four fish taxa in the analysis, Cyprinidae, was entrained in the egg stage (Normandeau 2007). Based on the range of 1.0-1.4 mm for spottail shiner egg diameters (Jones *et al*. 1978), P_e for cyprinid eggs was estimated as one for a slot width of 1.0 mm and zero for all larger slot widths. The P_e estimates for the Merrimack Station analysis are summarized in Table 2-1.

2.2.2 Wedgewire Avoidance Factors

Proportions of larvae entrained through flat panels of wedgewire screening in a laboratory flume study were observed to be significantly lower than the proportions of the flow entrained, suggesting that some larvae have sufficient swimming ability to actively avoid being entrained through CWW screens even if they are small enough to pass through the slots of the screens (Heuer and Tomljanovich 1978). The possibility of avoidance is represented in this analysis by the “wedgewire avoidance factor” (P_a), which is the proportion of organisms that are vulnerable to entrainment but actively avoid being entrained through CWW screens. The hydrodynamic transport of organisms out of the withdrawal zone of the CWW screens by means of water currents (“sweeping flows”) is not estimated separately in this evaluation, but is included as part of the wedgewire avoidance factor. The purpose of the wedgewire avoidance factor is to combine both the avoidance ability and the limiting physical dimensions of fish larvae to estimate the proportion of larvae that would be entrained through CWW screens:

$$P_E = (1 - P_a)(1 - P_e) \qquad \text{(Equation 3)}$$

where P_E = proportion of larvae within the withdrawal zone that are entrained,

P_a = proportion of larvae within the withdrawal zone that avoid entrainment, and

P_e = proportion of larvae within the withdrawal zone that do not avoid entrainment but are physically excluded.

In field and laboratory tests of wedgewire screening, only P_E (the combined effect of P_a and P_e) can be directly observed. However, by estimating the physical exclusion factor P_e, Equation 3 can be solved for P_a to estimate wedgewire avoidance factors from these experimentally observed values of P_E:

$$P_a = 1 – [(P_E / (1–P_e)] \qquad \text{(Equation 4)}$$

where P_a = proportion of larvae within the withdrawal zone that avoid entrainment,

P_E = proportion of larvae within the withdrawal zone that are entrained, and

P_e = proportion of larvae within the withdrawal zone that do not avoid entrainment but are physically excluded.

Flume tests were conducted by Heuer and Tomljanovich (1978) to estimate the exclusion and avoidance of larvae exposed to 0.5 mm, 1.0 mm, and 2.0 mm flat wedgewire screen panels at through-slot velocities of 7.6, 15.2, and 22.9 cm/s (0.25, 0.5, and 0.75 ft/s) and sweeping velocities of 7.6, 15.2, 30.5, and 61.0 cm/s (0.25, 0.5, 0.75, 1.0, and 2.0 ft/s). For each test, a wedgewire screen panel was mounted flush with either the bottom or side of the flume, withdrawing water perpendicular to the direction of flow in the flume. In the absence of physical exclusion or active avoidance (or attraction), the expected proportion of larvae not drawn through the panel (i.e., the proportion "bypassed") was the same as the proportion of the flume's flow that was bypassed. The expected proportion of larvae bypassed was compared to the observed proportion of larvae that actually were bypassed.

The larvae in these flume test experiments were distributed uniformly both within the withdrawal zone and within the flow that bypassed the screen panel, which can be accounted for by inserting another term into Equation 3:

$$P_E = \mathbf{(1–P_b)} (1–P_a) (1–P_e) \qquad \text{(Equation 5)}$$

where P_E = proportion of larvae **within the entire flume** that were entrained,

P_b = proportion of the flume's flow that bypassed the screen panel,

P_a = proportion of larvae within the withdrawal zone that avoided entrainment, and

P_e = proportion of larvae within the withdrawal zone that did not avoid entrainment but were physically excluded.

Therefore, solving for P_a to estimate the CWW avoidance factor based on the Heuer and Tomljanovich (1978) flume tests,

$$P_a = 1 – \{ P_E / [(1–P_b) (1–P_e)] \} \qquad \text{(Equation 6)}$$

where P_a = proportion of larvae within the withdrawal zone that avoided entrainment,

P_E = proportion of larvae within the entire flume that were entrained (observed by the experimenters),

P_b = proportion of the flume's flow that bypassed the screen panel (determined by the experimenters from measurements of the flow in the flume and the flow withdrawn through the wedgewire screen panel), and

P_e = proportion of larvae within the withdrawal zone that did not avoid entrainment but were physically excluded.

CWW screens are most effective in minimizing entrainment and impingement if the sweeping velocity is at least as high as the through-slot velocity (and preferably higher). Entrainment has been observed to be generally higher for through-slot velocities of 0.30 m/s (1.0 ft/s) compared to 0.15 m/s (0.5 ft/s), and to decrease with increasing sweeping velocities (EPRI 2006). Preliminary engineering designs for CWW screens at Merrimack Station are based on a through-slot intake velocity of 0.5 ft/s (0.15 m/s) and sweeping velocities in the range of 0.15-0.30 m/s (0.5-1.0 ft/s). In early May 2009, Normandeau conducted a velocity survey using an Acoustic Doppler Current Profiler along several transects in the vicinity of the Merrimack Station CWISs. Preliminary results of this survey confirmed (at least for the flow conditions at that time) the presence of river currents of sufficient magnitude for the effective use of CWW screens. In the longitudinal (parallel to the shoreline) transect closest to the Merrimack Station CWIS with a water column depth of about 4 m (16 ft), the mean depth-averaged current speed was 0.49 m/s (1.6 ft/s), with a range 0.39-0.60 m/s (1.3-2.0 ft/s). Speeds tended to be highest closest to the surface of the water and lowest near the river bottom, so the mean or mid-column velocities and the near-bottom velocities would be most representative of the withdrawal depth of the CWW screen array because these are the expected installation depths at Merrimack Station.

For estimating wedgewire avoidance factors, the Heuer and Tomljanovich (1978) data for striped bass larvae at a through-slot velocity of 0.15 m/s (0.5 ft/s), flume velocities (representing sweeping velocities) of 0.15 and 0.30 m/s (0.5 and 1.0 ft/s), and slot widths of 1.0 and 2.0 mm from their Tables 1 and 2 were selected as representative of the CWW screen system under consideration for Merrimack Station. Striped bass provide a good representative for typically shaped larvae (neither elongated nor stout) and measurements of GBD were available for estimating P_e for striped bass (Normandeau 1987). Striped bass were tested by Heuer and Tomljanovich (1978) in two series of trials, one in April (lengths averaging 5.6 mm) and one in June (lengths averaging 5.9 mm). For larvae exposed to panels with slots 1 mm wide, the wedgewire avoidance factor (P_a) averaged 0.309 in April tests and 0.483 in June tests. For striped bass larvae exposed to panels with slots 2 mm wide, P_a averaged 0.412 in April tests and 0.755 in June tests. Each of these values was the mean of P_a for four trials, where a trial was the average of three replicate releases of about 100-200 larvae each. The overall averages by slot width for the April and June tests combined (average length 5.75 mm) were P_a=**0.396** at a slot width of 1 mm and P_a=**0.583** at a slot width if 2 mm.

In 2001 and 2002, flume testing of CWW screen entrainment and impingement was conducted by Alden Research Laboratory, Inc. (EPRI 2003). The screens were 1 ft in diameter with 0.5, 1.0, and 2.0 mm slot widths, oriented both perpendicular and parallel to the flume flow. Flume speeds were 0.08, 0.15 and 0.30 m/s (0.25, 0.5, and 1.0 ft/s) and through-slot velocities were 0.15 and 0.30 m/s (0.5 and 1.0 ft/s). Striped bass (representative of a generalized body shape) were among the species tested. Test organisms were released from a tube close to the screen at its centerline, so all would be vulnerable to entrainment or impingement (none were in the part of the flume flow that bypassed the screen, so Equation 4 above was the one applicable to these data).

Review of the EPRI (2003) results for application to the CWW screen systems designed for Merrimack Station revealed substantial extrusion of 8.9-mm striped bass larvae through 1.0-mm slots when the slot velocity was high (0.3 m/s; 1.0 ft/s) and the screens were mounted perpendicular to the flume flow, since only 15% of 8.9 mm larvae should fit through 1.0 mm slots but 67% and 68% of the larvae were entrained. Neither the slot velocity nor the screen orientation, however, is representative of the system proposed for Merrimack Station. There was little or no avoidance for the 1.0 mm CWW screen in the parallel orientation at 0.30 m/s (1.0 ft/s) flume velocity, although those three experiments did not show the extreme extrusion as when the screen was oriented perpendicularly. Because of the high slot velocity, these also are not representative of the CWW screens under consideration for Merrimack Station. Low avoidance was also seen for the 2.0 mm CWW screen in the perpendicular orientation, also not representative of the system proposed for Merrimack Station.

To best represent the system designed for Merrimack Station, this evaluation focused on the EPRI (2003) striped bass larvae experiments conducted at a slot velocity of 0.15 m/s (0.5 ft/s) through 1.0 and 2.0 mm slots in screens oriented parallel to the flow in flume velocities of 0.15 and 0.30 m/s (0.5 and 1.0 ft/s). The mean P_a for 7.0-mm striped bass larvae and 1.0-mm slot width screens was **0.706**. The mean P_a for 8.3-mm striped bass larvae and 2.0-mm slot width screens was **0.464**.

Considered together, the results of Heuer and Tomljanovich (1978) and EPRI (2003) for striped bass on 1.0 and 2.0-mm wedgewire screens suggest a consistent avoidance factor, with no indication of differences due to slot width. The size range of the striped bass larvae tested in these two studies was, however, too narrow to adequately detect any variation in avoidance behavior related to length.

Observations over a wider range of lengths for other species were obtained from a third study, a peer-reviewed and published field test of CWW screen exclusion conducted in 1982 and 1983 in a Maryland power plant intake canal by Weisberg *et al*. (1987). Their study compared densities of wild-caught larvae pumped through 1.0, 2.0, and 3.0-mm slot width CWW screens as well as through an unscreened sampling port. Bay anchovy, a good representative of a species with elongated fish larvae, was a dominant species collected in this study, and GBD measurements of bay anchovy were available for estimating P_e (Normandeau 1987). No exclusion was demonstrated for larvae ≤4 mm, but densities of bay anchovy larvae ≥5 mm were lower for all three screens than in the unscreened samples. Mean densities entrained appeared to decrease with decreasing slot width, although this pattern was not statistically significant. Within the four larger size ranges (5-7, 8-10, 11-14, and ≥15 mm total length), entrained densities were significantly lower than open port densities for 15 of the 20 combinations of size group, sampling year, and slot width.

Mean annual bay anchovy densities from Table 1 in Weisberg *et al*. (1987) were used as the basis for estimating P_E. Because of unequal sample volumes and numbers of samples in the two years of the study, as well as zero catches for some size groups and slot widths, the densities from the two years were first averaged together, weighted by total sampling volume. Next, the proportion entrained for each size group and slot width (P_E) was calculated as the ratio of entrained density to open port density to enable estimating P_a by Equation 4 using P_e estimated from GBD data (Normandeau 1987).

Bay Anchovy	1.0-mm screen	2.0-mm screen	3.0-mm screen
≤4 mm larvae	**0.000**	**0.000**	**0.000**
5-7 mm larvae	**0.427**	**0.512**	**0.438**
8-10 mm larvae	**0.860**	**0.747**	**0.662**
11-14 mm larvae	**1.000**	**0.832**	**0.769**
≥15 mm larvae	**0.874**	**0.793**	**0.839**

Negative values for P_a in the ≤4 mm length class for all three slot widths were interpreted as artifacts of low catches and set to zero, resulting in the following wedgewire avoidance factors for bay anchovy larvae estimated from the data of Weisberg *et al*. (1987):

The above estimates of wedgewire avoidance are based on a wide range of sizes for bay anchovy and a limited size range for striped bass. To evaluate the best approach to estimate behavioral avoidance factors for other species, the estimates for striped bass and bay anchovy were compared within their common size range. P_a estimates for striped bass were 0.396 and 0.583 at 5.75 mm and 0.706 at 7.0 mm, compared to bay anchovy estimates of 0.427, 0.512, and 0.438 in the 5-7 mm length range. The good agreement among values for these two species, in spite of their different body shapes, supports using a single value (or set of values) of P_a for all species in the Merrimack Station analysis. The P_a estimates for bay anchovy, the only species tested over a wide range of sizes, increase consistently with increasing size. This is consistent with the biology of fish larvae, which improve in swimming capability as they grow. Based on the similarity in avoidance between striped bass and bay anchovy of a comparable size, the increase in avoidance demonstrated by bay anchovy as they grow, and the similarity in avoidance among different slot widths tested, the 18 values highlighted in bold font above and summarized in the following table were used to fit a generalized logistic curve (SAS 2003) for estimating wedgewire avoidance as a function of length, applicable to all species in the Merrimack Station analysis. Length ranges are represented by the midpoints of the ranges, 4 mm was used to represent the ≤4 mm category, and 15 mm was used to represent the ≥15 mm category:

Reference	Species	Slot width (mm)	Total length (mm)	CWW avoidance factor (P_a)
Weisberg *et al*. (1987)	Bay anchovy	1	4	0.000
Weisberg *et al*. (1987)	Bay anchovy	2	4	0.000
Weisberg *et al*. (1987)	Bay anchovy	3	4	0.000
Heuer and Tomljanovich (1978)	Striped bass	1	5.75	0.396
Heuer and Tomljanovich (1978)	Striped bass	2	5.75	0.583
Weisberg *et al*. (1987)	Bay anchovy	1	6	0.427
Weisberg *et al*. (1987)	Bay anchovy	2	6	0.512
Weisberg *et al*. (1987)	Bay anchovy	3	6	0.438
EPRI (2003)	Striped bass	1	7.0	0.706
EPRI (2003)	Striped bass	2	8.3	0.464
Weisberg *et al*. (1987)	Bay anchovy	1	9	0.860
Weisberg *et al*. (1987)	Bay anchovy	2	9	0.747
Weisberg *et al*. (1987)	Bay anchovy	3	9	0.662
Weisberg *et al*. (1987)	Bay anchovy	1	12.5	1.000
Weisberg *et al*. (1987)	Bay anchovy	2	12.5	0.832
Weisberg *et al*. (1987)	Bay anchovy	3	12.5	0.769
Weisberg *et al*. (1987)	Bay anchovy	1	15	0.874
Weisberg *et al*. (1987)	Bay anchovy	2	15	0.793
Weisberg *et al*. (1987)	Bay anchovy	3	15	0.839

When length <4 mm, P_a was defined as zero. When length ≥4 mm, P_a was estimated by the following exponential equation (illustrated in Figure 2-1):

$$P_a = 1 - e^{[-0.275 (L - 4)]} \qquad \text{(Equation 7)}$$

where P_a = proportion of larvae within the withdrawal zone that avoid entrainment,

e = base of natural logarithms (2.71828),

L = total length (mm).

The generalized relationship between larval length and wedgewire avoidance observed for striped bass and bay anchovy larvae and predicted in Equation 7 (Figure 2-1) is consistent with the very low entrainment rates for 13.9-mm white sucker larvae and the higher entrainment rates for the smaller (6.4-6.5 mm) common carp larvae (in the cyprinid family) observed in flume tests (EPRI 2003), indicating the applicability of Equation 7 to the species entrained at Merrimack Station.

To account for the variation inherent in these experimental estimates of the CWW avoidance factor P_a as well as the uncertainty in extrapolating estimates of P_a to species, larval lengths, and slot widths that have not been adequately tested, P_a was represented three different ways in this Merrimack Station CWW screen performance evaluation. This approach provided a range of estimates for the numbers of larvae entrained for each of the CWW screen scenarios modeled. The most conservative model and one likely to underestimate the performance was based solely on physical exclusion (i.e., $P_a = 0$) as a function of the smallest body dimension as described above in Section 2.2.1. This model is considered conservative because it ignores the convincing, peer-reviewed, published scientific evidence among the three studies described above that confirms the presence of active swimming avoidance behavior by larvae exposed to CWW screens of the configuration designed for Merrimack Station. The most realistic (i.e., the most likely to occur) scenario modeled included both larval avoidance by Equation 7, which estimated avoidance increasing with larval length (e.g., about 81% of larvae avoid entrainment at a length of 10-mm, increasing to 95% avoidance at 15-mm) and physical exclusion of those larvae not avoiding the CWW screens (i.e., $P_a = f(L)$). A third and intermediate model assumed a constant, but low 30% avoidance (P_a=0.3) by all larvae without regard to length and physical exclusion of those larvae not avoiding the CWW screens. This intermediate model relies on a minimum avoidance factor of 30%, which is lower than all of those experimentally observed (see avoidance factor figure above), and will produce intermediate performance compared to the other two models. This intermediate model is based on the observation that at least 30% of larvae tested by Heuer and Tomljanovich (1978) avoided entrainment.

2.2.3 Model Input Conditions

In addition to the general approach and conditions modeled regarding about exclusion and avoidance described above, this analysis to determine the expected biological performance of seasonally deployed CWW screens of different slot sizes at Merrimack Station was based on the following criteria regarding flow rates through Merrimack Station, months of operation of CWW screens or a new state of the art fish return system, and mortality rates:

1. CWW screens are installed at both Unit 1 and Unit 2 at the Station.
2. CWW screens are not used during December through March because of the danger of clogging by frazil ice.
3. Impingement on existing screens only occurs when CWW screens are not being used.
4. In months when the new state-of-the-art fish return system is used, the existing conventional traveling screens are continuously rotated and washed.
5. The new state-of-the-art fish return system is not operated during December through March due to ice cover on Hooksett Pool requiring the discharge section to be removed to

prevent ice damage (although the existing screens are rotated and washed for debris removal whenever necessary during these months).

6. Entrainment and impingement densities (number of organisms per unit volume of intake flow) are the same as observed during the 2005-2007 Study.
7. Entrainment mortality is 100% under all scenarios.
8. Exclusion of young-of-the-year and older fish is 100% for all slot widths, because of the large size of these fish in relation to the slot widths under consideration.
9. Impingement mortality is 0% during CWW screen operation.
10. Impingement mortality rates are the same as observed during the 2005-2007 Study for months when CWW screens are not operating, based on quarterly estimates at each unit (Table 4-9 of Normandeau 2007).
11. Post-impingement mortality rates during passage through a new state-of-the-art fish return system are the same as reported by Con Edison (1992), assuming the same mortality rate (15.4%) for centrarchids and yellow perch as for white perch and the same mortality rate (0%) for spottail shiner as for golden shiner.
12. Length and body depth ranges used for common Merrimack Station larval fish taxa were:

Larval Fish Taxon	Total Length Range (mm)	Greatest Body Depth Range (mm)
White sucker	6.4-24.2	0.6-3.6
Centrarchids	4.1-13.4	0.6-2.9
Cyprinids	3.7-17.2	0.5-2.6

With respect to the evaluated scenarios calling for operational flow reductions:

1. Flow reductions were modeled by assuming operational flows would be the same as the actual flows at each unit during the 2005-2007 Study (Normandeau 2007).
2. The fish taxa analyzed were those for which adult equivalent estimates were presented in the 2005-2007 Study, representing over 90% of the total numbers impinged and entrained (Normandeau 2007).

Scenarios calling for installation of a new state-of-the-art fish return system to improve survival of fish impinged on the conventional traveling screens presently installed and operated at Merrimack Station made the following assumptions:

1. The sluice would be long enough to convey fish back into the Merrimack River at a location far enough downstream to prevent re-impingement.
2. The sluice would return impinged fish to Hooksett Pool at all water levels.
3. The sluice would be supplied with a constant flow of river water sufficient to maintain a depth of at least two inches at all locations along the length of the return sluice.
4. No modifications to the existing traveling screens (such as adding Ristroph buckets or changing the spray wash system) are necessary because of the relatively high survival observed for impinged fish washed from those existing screens when operated in a continuous wash mode (Normandeau 2007).

Entrainment reduction estimates used in the §308 Response Report and in the enhanced conceptual CWIS technology evaluation were both calculated using the same entrainment abundance estimates and the same cooling water flows (design and actual) as in the 2005-2007 Study report (Normandeau 2007). The percent reductions in entrainment due to physical exclusion alone (P_a=0) for CWW screens presented in the results Section 2.3 below are consistent with the values previously estimated for fine-mesh intake screens and presented in Table 10 in Attachment 6 of the §308 Response Report (PSNH 2007); however, they are not exactly the same, for three reasons. First, the fine-mesh entrainment reduction estimates in the §308 Response Report were presented separately for 2006 and 2007, but neither represented a full year of entrainment. To estimate annual entrainment reduction from CWW screens for purposes of the enhanced conceptual CWIS technology evaluation, Normandeau based its analysis based on a full year of entrainment, which was calculated from the April estimate from 2007, the July and August estimates from 2006, and the averages of the 2006 and 2007 estimates for May and June. Second, the fine-mesh entrainment reductions estimates presented in the §308 Response Report were estimated separately for the two scenarios of actual flow and design flow, whereas this analysis (and the enhanced conceptual CWIS technology evaluation it supports) combine the entrainment reductions due to reduced flow and CWW screen operation into a single estimate. Third, generalized physical exclusion factors were used for the §308 Response Report, whereas this analysis was refined to use factors estimated separately by taxon and month on the basis of lengths of larvae entrained at Merrimack Station.

2.3 RESULTS

The results of this analysis determined the expected biological performance of seasonally deployed CWW screens of different slot sizes at Merrimack Station, and are summarized in Table 2-2 in terms of estimated numbers and percent reductions for annual impingement mortality, annual numbers entrained, and annual adult equivalent losses for the following scenarios: (1) baseline, (2) current operation, (3) CWW screen operation during April through July and operation of a new state-of-the-art fish return system during August through November, and (4) CWW screen operation during April through November, with no fish return system operation at any time during the year.

Tables 2-3 through 2-17 present monthly breakdowns for the results summarized in Table 2-2 plus two additional scenarios: (1) no CWW screen operation at any time during the year, but operation of the existing conventional traveling screens and a new state-of-the-art fish return system during April through November and (2) CWW screen operation during April through July but no new state-of-the-art fish return system operation at any time during the year. Each scenario is tabulated for CWW screen slot widths of 1.0 mm, 1.5 mm, 2.0 mm, 3.0 mm, 6.0 mm, and 9.0 mm as well as for the three different assumptions regarding the CWW avoidance factor P_a.

The results of Normandeau's analysis show that the Phase II Rule's performance standards of a 60-90% reduction in entrainment and an 80-95% reduction in impingement mortality could be attained at Merrimack Station by installing CWW screens with any of the six slot widths evaluated (1 mm through 9 mm) at both Unit 1 and Unit 2, operating them from April through July of each year, and installing and operating a state-of-the-art fish return sluice (in combination with the existing traveling screens) during August through November. These results are based on the predictions from the most realistic model, which included both active avoidance as a function of larval length ($P_a = f(L)$) and physical exclusion for those larvae not avoiding the screens. Entrainment is reduced more for this model than would be expected based on limiting physical dimensions alone, because there is clear and convincing experimental evidence of active avoidance behavior by fish larvae that increases as the larvae grow throughout the entrainment season. The data from the three published or peer-reviewed studies described above collectively support an expectation that the percentage of fish larvae in the withdrawal zone that are entrained through CWW screens is related primarily to the length (and swimming ability) of the larvae interacting in a significant way with the slot width opening, through-slot velocity, and sweeping velocity for screens that are oriented with their long axis parallel to the sweeping flow, the narrow width of the mesh slots aligned perpendicular to the sweeping flow, and designed with a through-slot velocity of 0.5 ft/s (0.15 m/s) and a sweeping velocity greater than the through-slot velocity. The estimated reductions for the CWW screen system designed for Merrimack Station are 84% for impingement mortality at all six slot widths, and range from 73% for the 3 mm through 9 mm slot widths to 83% for the 1 mm slot width CWW screens. Reductions in adult equivalent losses for impingement mortality and entrainment combined were predicted to range from 76% for the 3 mm through 9 mm slot widths to 84% for the 1 mm slot width CWW screens.

Runs of the intermediate model ($P_a = 0.3$) indicated that the Phase II Rule's performance standards of a 60-90% reduction in entrainment and an 80-95% reduction in impingement mortality could be attained at Merrimack Station by installing either 1.0 mm or 1.5 mm slot width CWW screens at both units and operating them during April through July of each year and installing a new fish return system and operating it during August through November of each year, based on the lowest experimentally observed behavioral avoidance of 30% and physical exclusion for a portion of the remaining 70% of larvae not avoiding the screens. The estimated reductions for Merrimack Station under this scenario are 84% for impingement mortality, 79% for entrainment through 1 mm slot width CWW screens, and 64% for entrainment through 1.5 mm slot width CWW screens. Reductions in adult equivalent losses for impingement mortality and entrainment combined for this intermediate model were 81% for the 1 mm slot widths and 68% for the 1.5 mm slot width CWW screens.

Predicted reductions from the most conservative model runs, based on physical exclusion alone ($P_a = 0$), revealed that only the 1 mm slot width CWW screens achieved the impingement mortality (84%) and entrainment reduction (70%) performance standards of the Phase II Rule, if installed and operated from April through July of each year with a state-of-the-art fish return sluice (in combination with the existing traveling screens) installed and operated during August through November. This unrealistically conservative model ignores the published scientific evidence that swimming avoidance plays an increasingly important role affecting reductions in entrainment through CWW screens as larvae grow and increase in length.

These results also show similar but slightly improved performance for each of the three performance models if CWW screens are installed at both units and operated from April through November without installation or operation of a state-of-the-art fish return sluice (in combination with the existing traveling screens).

In sum, the evidence presented by Heuer and Tomljanovich (1978), Weisberg *et al*. (1987), and EPRI (2003) and expressed in the most realistic model used in this evaluation of seasonal operation of CWW screens at Merrimack Station indicates that a CWW slot width as small as 1.5 mm may not be necessary for the achievement of acceptable entrainment and impingement mortality reductions at Merrimack Station. The data presented in these peer-reviewed or published studies indicate that assuming no avoidance by actively swimming larvae is unrealistic, and assuming a constant but low 30% avoidance factor likely is unrealistically conservative for larvae longer than 5 mm. The general relationship between avoidance and length discussed in the "Wedgewire Avoidance Factors" Section 2.2.2 above did not vary greatly by species, indicating that even though the species, seasonal length distributions, and the some of the slot widths from which Equation 7 was derived were not the same as those for Merrimack Station, a similar relationship between avoidance and larval length is likely applicable to Merrimack Station. Accordingly, entrainment reductions may be acceptably high for CWW screen slots wider than 1.5 mm. In fact, based on the wedgewire avoidance factor relationship (P_a=f(L)) of Equation 7, even slots as wide as 9 mm could meet the Phase II Rule's performance standards of a 60-90% reduction in entrainment and an 80-95% reduction in impingement mortality at the Station. Under the Equation 7 estimate for avoidance increasing with larval length, the estimated reductions for both the April-July and April-November CWW screen scenarios at Merrimack Station are >80% for impingement mortality and 73% for entrainment (Table 2). Nonetheless, on-site testing in a pilot study would be prudent and is strongly recommended before final selection of a slot width for the retrofit installation of a full scale CWW screen system at Merrimack Station.

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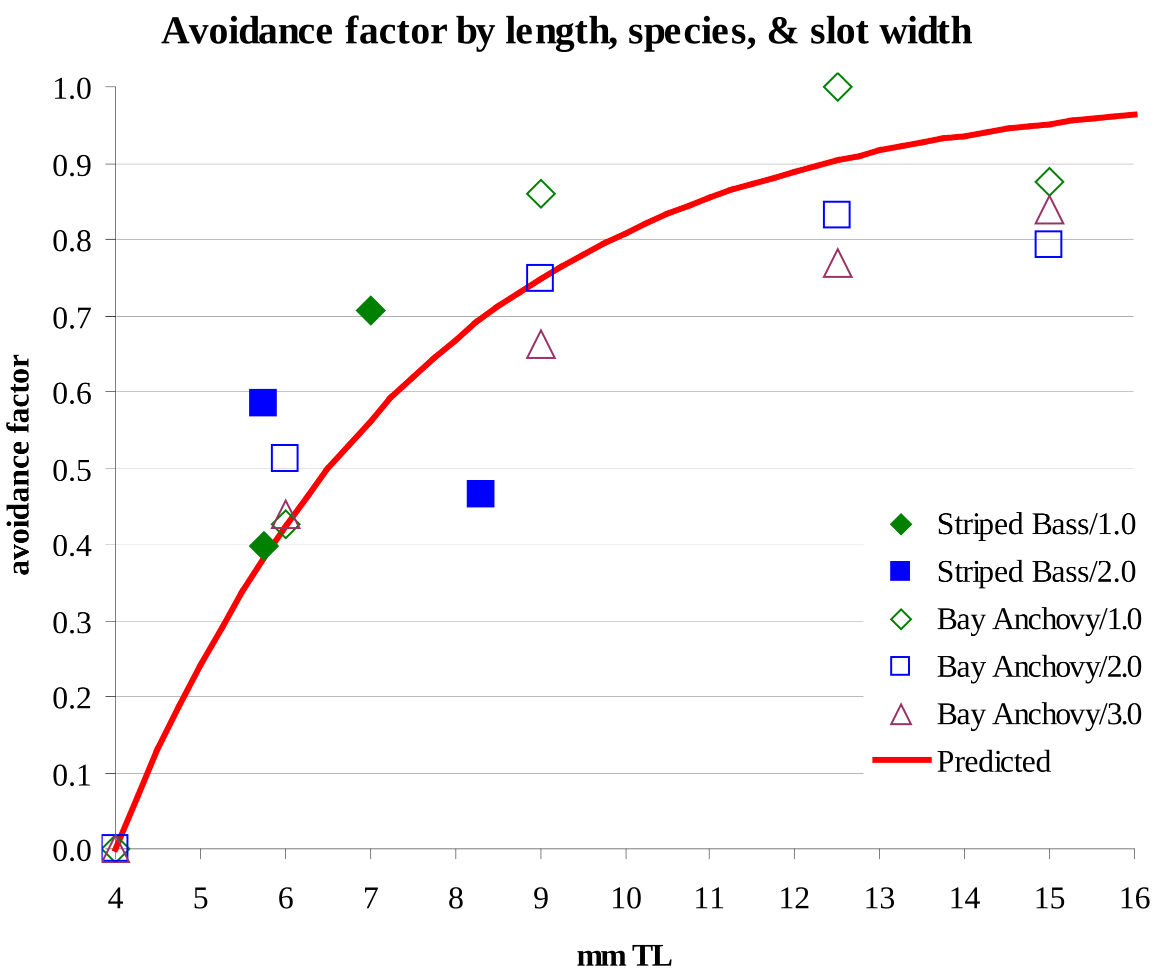

Figure 2-1. Observed and predicted relationship between length (mm total length) of striped bass or bay anchovy larvae and avoidance factor (the proportion avoiding entrainment) for cylindrical wedgewire screens with slot widths of 1.0 mm, 2.0 mm or 3.0 mm.

Table 2-1. Physical exclusion factors for the Merrimack Station CWW screen evaluation, by taxon, life stage, month, and slot width.

Taxon	Life Stage	Month	Number measured	Physical exclusion factors by slot width (mm)					
				1.0	1.5	2.0	3.0	6.0	9.0
Carp and minnow family	eggs	June	a	1.00	0.00	0.00	0.00	0.00	0.00
	larvae	May	b	0.35	0.28	0.02	0.00	0.00	0.00
		June	86	0.35	0.28	0.02	0.00	0.00	0.00
		July	7	0.14	0.14	0.14	0.00	0.00	0.00
		August	1	0.00	0.00	0.00	0.00	0.00	0.00
Sunfish family	larvae	April	1	0.00	0.00	0.00	0.00	0.00	0.00
		May	1	0.00	0.00	0.00	0.00	0.00	0.00
		June	26	0.00	0.00	0.00	0.00	0.00	0.00
		July	13	0.15	0.15	0.15	0.00	0.00	0.00
		August	3	0.00	0.00	0.00	0.00	0.00	0.00
White sucker	larvae	April	b	1.00	0.34	0.12	0.02	0.00	0.00
		May	41	1.00	0.34	0.12	0.02	0.00	0.00
		June	81	1.00	0.77	0.37	0.09	0.00	0.00
		July	1	1.00	0.00	0.00	0.00	0.00	0.00
Yellow perch	larvae	May	25	0.88	0.32	0.12	0.00	0.00	0.00
		June	3	1.00	1.00	0.33	0.00	0.00	0.00

[a] Eggs in the Merrimack samples were not measured, so exclusion factors were based on the reported egg diameter range of 1.0-1.4 mm for spottail shiner (Jones et al. 1978)

[b] None were measured in this month, so exclusion factors were based on larvae measured in the subsequent month

Explanatory Notes for Tables 2-2 through 2-17

- The “current operation” scenario reflects only the operational measure of cooling water flow reduction, without operation of either CWW screens or a new state-of-the-art fish return system at any time during the year (i.e., actual intake flows withdrawn through the existing 3/8 inch square mesh conventional traveling screens).
- “Percent reduction” is in relation to the baseline scenario.
- The three alternative assumptions for larval avoidance of CWW screens are labeled “P_a=0” for no avoidance, “P_a=0.3” for 30% of larvae avoiding, and “P_a=f(L)” for avoidance modeled as a function of larval length.
- All scenarios representing operation of CWW screens or a new state-of-the-art fish return system include the reductions in impingement mortality and entrainment resulting from operational flow reductions estimated from the actual flows during the 2005-2007 Study, compared to the baseline flow of 59,000 gpm for Unit 1 and 140,000 gpm for Unit 2.
- Adult equivalent losses are the losses resulting from both impingement and entrainment combined.

Table 2-2. Summary of annual estimates of impingement mortality, entrainment, and adult equivalent losses, with percent reductions from baseline, at Merrimack Station (Unit 1 and Unit 2 combined) for two CWW screen operating schedules and six different slot widths, under three different assumptions of larval avoidance (P_a).

Scenario	Wedgewire slot width (mm)	Performance metric	Impingement mortality	Entrainment			Adult equivalent losses		
				P_a=0	P_a=0.3	P_a=f(L)	P_a=0	P_a=0.3	P_a=f(L)
Baseline	N/A	estimated number	4,270	3,227,220	3,227,220	3,227,220	17,852	17,852	17,852
Current operation	N/A	estimated number	3,502	2,673,714	2,673,714	2,673,714	14,829	14,829	14,829
		percent reduction	**18%**	**17%**	**17%**	**17%**	**17%**	**17%**	**17%**
Wedgewire screens April through July and fish return system August through November	1.0	estimated number	673	973,954	687,216	556,914	4,588	3,402	2,883
		percent reduction	**84%**	**70%**	**79%**	**83%**	**74%**	**81%**	**84%**
	1.5	estimated number	673	1,633,157	1,148,659	675,951	7,914	5,730	3,335
		percent reduction	**84%**	**49%**	**64%**	**79%**	**56%**	**68%**	**81%**
	2.0	estimated number	673	2,261,454	1,588,467	824,210	11,128	7,980	3,975
		percent reduction	**84%**	**30%**	**51%**	**74%**	**38%**	**55%**	**78%**
	3.0	estimated number	673	2,603,229	1,827,709	881,500	14,173	10,112	4,222
		percent reduction	**84%**	**19%**	**43%**	**73%**	**21%**	**43%**	**76%**
	6.0	estimated number	673	2,673,714	1,877,049	887,096	14,619	10,424	4,257
		percent reduction	**84%**	**17%**	**42%**	**73%**	**18%**	**42%**	**76%**
	9.0	estimated number	673	2,673,714	1,877,049	887,096	14,619	10,424	4,257
		percent reduction	**84%**	**17%**	**42%**	**73%**	**18%**	**42%**	**76%**
Wedgewire screens April through November	1.0	estimated number	496	973,954	681,768	549,466	4,513	3,304	2,777
		percent reduction	**88%**	**70%**	**79%**	**83%**	**75%**	**81%**	**84%**
	1.5	estimated number	496	1,633,157	1,143,210	668,504	7,839	5,632	3,229
		percent reduction	**88%**	**49%**	**65%**	**79%**	**56%**	**68%**	**82%**
	2.0	estimated number	496	2,261,454	1,583,018	816,762	11,054	7,882	3,869
		percent reduction	**88%**	**30%**	**51%**	**75%**	**38%**	**56%**	**78%**
	3.0	estimated number	496	2,603,229	1,822,260	874,052	14,099	10,014	4,116
		percent reduction	**88%**	**19%**	**44%**	**73%**	**21%**	**44%**	**77%**
	6.0	estimated number	496	2,673,714	1,871,600	879,648	14,544	10,326	4,151
		percent reduction	**88%**	**17%**	**42%**	**73%**	**19%**	**42%**	**77%**
	9.0	estimated number	496	2,673,714	1,871,600	879,648	14,544	10,326	4,151
		percent reduction	**88%**	**17%**	**42%**	**73%**	**19%**	**42%**	**77%**

Yellow	Impingement mortality reductions that meet EPA's Phase II Rule performance standards of 80% to 95% reduction.
Green	Entrainment abundance reductions that meet EPA's Phase II Rule performance standards of 60% to 90% reduction.
Light blue	Adult equivalent losses for impingement and entrainment combined equal to or exceeding 75%.

Table 2-3. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 1.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), under the conservative assumption of no active avoidance of CWW screens by larvae.

1.0 mm, P_a=0		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	42,083	42,083	42,083
	May	802,576	677,692	677,692	45,853	45,853	45,853
	June	1,923,540	1,630,590	1,630,590	643,437	643,437	643,437
	July	345,927	287,546	287,546	224,417	224,417	224,417
	August	22,326	18,163	18,163	18,163	18,163	18,163
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**973,954**	**973,954**	**973,954**
Entrainment % reduction from baseline		0%	17%	17%	70%	70%	70%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	174	174	174
	May	3,473	2,985	2,971	94	94	94
	June	11,256	9,550	9,514	2,743	2,743	2,743
	July	1,518	1,268	1,263	943	943	943
	August	113	94	84	94	84	77
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**4,693**	**4,588**	**4,513**
Adult equivalent losses % reduction from baseline		0%	17%	18%	74%	74%	75%

Table 2-4. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 1.5-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), under the conservative assumption of no active avoidance of CWW screens by larvae.

1.5 mm, P_a=0		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	53,726	53,726	53,726
	May	802,576	677,692	677,692	456,779	456,779	456,779
	June	1,923,540	1,630,590	1,630,590	855,338	855,338	855,338
	July	345,927	287,546	287,546	249,150	249,150	249,150
	August	22,326	18,163	18,163	18,163	18,163	18,163
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**1,633,157**	**1,633,157**	**1,633,157**
Entrainment % reduction from baseline		0%	17%	17%	49%	49%	49%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	247	247	247
	May	3,473	2,985	2,971	1,976	1,976	1,976
	June	11,256	9,550	9,514	3,957	3,957	3,957
	July	1,518	1,268	1,263	1,099	1,099	1,099
	August	113	94	84	94	84	77
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**8,019**	**7,914**	**7,839**
Adult equivalent losses % reduction from baseline		0%	17%	18%	55%	56%	56%

Table 2-5. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 2.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), under the conservative assumption of no active avoidance of CWW screens by larvae.

2.0 mm, P_a=0		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	57,607	57,607	57,607
	May	802,576	677,692	677,692	598,956	598,956	598,956
	June	1,923,540	1,630,590	1,630,590	1,337,577	1,337,577	1,337,577
	July	345,927	287,546	287,546	249,150	249,150	249,150
	August	22,326	18,163	18,163	18,163	18,163	18,163
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**2,261,454**	**2,261,454**	**2,261,454**
Entrainment % reduction from baseline		0%	17%	17%	30%	30%	30%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	272	272	272
	May	3,473	2,985	2,971	2,614	2,614	2,614
	June	11,256	9,550	9,514	6,509	6,509	6,509
	July	1,518	1,268	1,263	1,099	1,099	1,099
	August	113	94	84	94	84	77
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**11,234**	**11,128**	**11,054**
Adult equivalent losses % reduction from baseline		0%	17%	18%	37%	38%	38%

Table 2-6. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 3.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), under the conservative assumption of no active avoidance of CWW screens by larvae.

3.0 mm, P_a=0		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	59,371	59,371	59,371
	May	802,576	677,692	677,692	668,947	668,947	668,947
	June	1,923,540	1,630,590	1,630,590	1,569,202	1,569,202	1,569,202
	July	345,927	287,546	287,546	287,546	287,546	287,546
	August	22,326	18,163	18,163	18,163	18,163	18,163
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**2,603,229**	**2,603,229**	**2,603,229**
Entrainment % reduction from baseline		0%	17%	17%	19%	19%	19%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	283	283	283
	May	3,473	2,985	2,971	2,903	2,903	2,903
	June	11,256	9,550	9,514	9,093	9,093	9,093
	July	1,518	1,268	1,263	1,260	1,260	1,260
	August	113	94	84	94	84	77
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**14,279**	**14,173**	**14,099**
Adult equivalent losses % reduction from baseline		0%	17%	18%	20%	21%	21%

Table 2-7. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 6.0-mm or 9.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), under the conservative assumption of no active avoidance of CWW screens by larvae.

6.0 & 9.0 mm, P_a=0		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	59,724	59,724	59,724
	May	802,576	677,692	677,692	677,692	677,692	677,692
	June	1,923,540	1,630,590	1,630,590	1,630,590	1,630,590	1,630,590
	July	345,927	287,546	287,546	287,546	287,546	287,546
	August	22,326	18,163	18,163	18,163	18,163	18,163
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**2,673,714**	**2,673,714**	**2,673,714**
Entrainment % reduction from baseline		0%	17%	17%	17%	17%	17%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	285	285	285
	May	3,473	2,985	2,971	2,958	2,958	2,958
	June	11,256	9,550	9,514	9,481	9,481	9,481
	July	1,518	1,268	1,263	1,260	1,260	1,260
	August	113	94	84	94	84	77
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**14,725**	**14,619**	**14,544**
Adult equivalent losses % reduction from baseline		0%	17%	18%	18%	18%	19%

Table 2-8. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 1.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), under the assumption that 30% of larvae actively avoid CWW screens.

1.0 mm, P_a=0.3		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	29,458	29,458	29,458
	May	802,576	677,692	677,692	32,097	32,097	32,097
	June	1,923,540	1,630,590	1,630,590	450,406	450,406	450,406
	July	345,927	287,546	287,546	157,092	157,092	157,092
	August	22,326	18,163	18,163	18,163	18,163	12,714
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**687,216**	**687,216**	**681,768**
Entrainment % reduction from baseline		0%	17%	17%	79%	79%	79%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	122	122	122
	May	3,473	2,985	2,971	66	66	66
	June	11,256	9,550	9,514	1,920	1,920	1,920
	July	1,518	1,268	1,263	660	660	660
	August	113	94	84	94	84	54
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**3,507**	**3,402**	**3,304**
Adult equivalent losses % reduction from baseline		0%	17%	18%	80%	81%	81%

Table 2-9. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 1.5-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), under the assumption that 30% of larvae actively avoid CWW screens.

1.5 mm, P_a=0.3		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	37,608	37,608	37,608
	May	802,576	677,692	677,692	319,745	319,745	319,745
	June	1,923,540	1,630,590	1,630,590	598,737	598,737	598,737
	July	345,927	287,546	287,546	174,405	174,405	174,405
	August	22,326	18,163	18,163	18,163	18,163	12,714
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**1,148,659**	**1,148,659**	**1,143,210**
Entrainment % reduction from baseline		0%	17%	17%	64%	64%	65%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	173	173	173
	May	3,473	2,985	2,971	1,383	1,383	1,383
	June	11,256	9,550	9,514	2,770	2,770	2,770
	July	1,518	1,268	1,263	769	769	769
	August	113	94	84	94	84	54
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**5,835**	**5,730**	**5,632**
Adult equivalent losses % reduction from baseline		0%	17%	18%	67%	68%	68%

Table 2-10. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 2.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), under the assumption that 30% of larvae actively avoid CWW screens.

2.0 mm, P_a=0.3		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	40,325	40,325	40,325
	May	802,576	677,692	677,692	419,269	419,269	419,269
	June	1,923,540	1,630,590	1,630,590	936,304	936,304	936,304
	July	345,927	287,546	287,546	174,405	174,405	174,405
	August	22,326	18,163	18,163	18,163	18,163	12,714
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**1,588,467**	**1,588,467**	**1,583,018**
Entrainment % reduction from baseline		0%	17%	17%	51%	51%	51%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	190	190	190
	May	3,473	2,985	2,971	1,830	1,830	1,830
	June	11,256	9,550	9,514	4,556	4,556	4,556
	July	1,518	1,268	1,263	769	769	769
	August	113	94	84	94	84	54
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**8,086**	**7,980**	**7,882**
Adult equivalent losses % reduction from baseline		0%	17%	18%	55%	55%	56%

Table 2-11. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 3.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), under the assumption that 30% of larvae actively avoid CWW screens.

3.0 mm, P_a=0.3		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	41,560	41,560	41,560
	May	802,576	677,692	677,692	468,263	468,263	468,263
	June	1,923,540	1,630,590	1,630,590	1,098,441	1,098,441	1,098,441
	July	345,927	287,546	287,546	201,282	201,282	201,282
	August	22,326	18,163	18,163	18,163	18,163	12,714
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**1,827,709**	**1,827,709**	**1,822,260**
Entrainment % reduction from baseline		0%	17%	17%	43%	43%	44%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	198	198	198
	May	3,473	2,985	2,971	2,032	2,032	2,032
	June	11,256	9,550	9,514	6,365	6,365	6,365
	July	1,518	1,268	1,263	882	882	882
	August	113	94	84	94	84	54
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**10,217**	**10,112**	**10,014**
Adult equivalent losses % reduction from baseline		0%	17%	18%	43%	43%	44%

Table 2-12. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 6.0-mm or 9.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), under the assumption that 30% of larvae actively avoid CWW screens.

6.0 & 9.0 mm, P_a=0.3		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	41,807	41,807	41,807
	May	802,576	677,692	677,692	474,384	474,384	474,384
	June	1,923,540	1,630,590	1,630,590	1,141,413	1,141,413	1,141,413
	July	345,927	287,546	287,546	201,282	201,282	201,282
	August	22,326	18,163	18,163	18,163	18,163	12,714
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**1,877,049**	**1,877,049**	**1,871,600**
Entrainment % reduction from baseline		0%	17%	17%	42%	42%	42%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	200	200	200
	May	3,473	2,985	2,971	2,071	2,071	2,071
	June	11,256	9,550	9,514	6,637	6,637	6,637
	July	1,518	1,268	1,263	882	882	882
	August	113	94	84	94	84	54
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**10,529**	**10,424**	**10,326**
Adult equivalent losses % reduction from baseline		0%	17%	18%	41%	42%	42%

Table 2-13. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 1.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), with larval avoidance modeled as increasing with length.

1.0 mm, P_a=f(L)		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	37,201	37,201	37,201
	May	802,576	677,692	677,692	20,476	20,476	20,476
	June	1,923,540	1,630,590	1,630,590	359,157	359,157	359,157
	July	345,927	287,546	287,546	121,917	121,917	121,917
	August	22,326	18,163	18,163	18,163	18,163	10,716
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**556,914**	**556,914**	**549,466**
Entrainment % reduction from baseline		0%	17%	17%	83%	83%	83%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	154	154	154
	May	3,473	2,985	2,971	55	55	55
	June	11,256	9,550	9,514	1,528	1,528	1,528
	July	1,518	1,268	1,263	512	512	512
	August	113	94	84	94	84	45
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**2,989**	**2,883**	**2,777**
Adult equivalent losses % reduction from baseline		0%	17%	18%	83%	84%	84%

Table 2-14. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 1.5-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), with larval avoidance modeled as increasing with length.

1.5 mm, P_a=f(L)		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	38,470	38,470	38,470
	May	802,576	677,692	677,692	90,252	90,252	90,252
	June	1,923,540	1,630,590	1,630,590	401,634	401,634	401,634
	July	345,927	287,546	287,546	127,432	127,432	127,432
	August	22,326	18,163	18,163	18,163	18,163	10,716
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**675,951**	**675,951**	**668,504**
Entrainment % reduction from baseline		0%	17%	17%	79%	79%	79%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	162	162	162
	May	3,473	2,985	2,971	272	272	272
	June	11,256	9,550	9,514	1,720	1,720	1,720
	July	1,518	1,268	1,263	547	547	547
	August	113	94	84	94	84	45
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**3,441**	**3,335**	**3,229**
Adult equivalent losses % reduction from baseline		0%	17%	18%	81%	81%	82%

Table 2-15. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 2.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), with larval avoidance modeled as increasing with length.

2.0 mm, P_a=f(L)		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	38,893	38,893	38,893
	May	802,576	677,692	677,692	115,622	115,622	115,622
	June	1,923,540	1,630,590	1,630,590	524,099	524,099	524,099
	July	345,927	287,546	287,546	127,432	127,432	127,432
	August	22,326	18,163	18,163	18,163	18,163	10,716
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**824,210**	**824,210**	**816,762**
Entrainment % reduction from baseline		0%	17%	17%	74%	74%	75%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	164	164	164
	May	3,473	2,985	2,971	350	350	350
	June	11,256	9,550	9,514	2,279	2,279	2,279
	July	1,518	1,268	1,263	547	547	547
	August	113	94	84	94	84	45
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**4,081**	**3,975**	**3,869**
Adult equivalent losses % reduction from baseline		0%	17%	18%	77%	78%	78%

Table 2-16. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 3.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), with larval avoidance modeled as increasing with length.

3.0 mm, P_a=f(L)		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	39,086	39,086	39,086
	May	802,576	677,692	677,692	128,625	128,625	128,625
	June	1,923,540	1,630,590	1,630,590	547,350	547,350	547,350
	July	345,927	287,546	287,546	148,276	148,276	148,276
	August	22,326	18,163	18,163	18,163	18,163	10,716
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**881,500**	**881,500**	**874,052**
Entrainment % reduction from baseline		0%	17%	17%	73%	73%	73%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	165	165	165
	May	3,473	2,985	2,971	384	384	384
	June	11,256	9,550	9,514	2,403	2,403	2,403
	July	1,518	1,268	1,263	635	635	635
	August	113	94	84	94	84	45
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**4,328**	**4,222**	**4,116**
Adult equivalent losses % reduction from baseline		0%	17%	18%	76%	76%	77%

Table 2-17. Monthly and annual estimates of impingement mortality, entrainment, and adult equivalent losses, with annual percent reductions from baseline at Merrimack Station (Unit 1 and Unit 2 combined) under various options for 6.0-mm or 9.0-mm slot width CWW screens ("WWS"), with and without replacement of the existing screenwash sluice by a state-of-the-art fish return system ("FRS"), with larval avoidance modeled as increasing with length.

6.0 & 9.0 mm, P_a=f(L)		Baseline	Current operation	FRS Apr-Nov	WWS Apr-Jul	WWS Apr-Jul, FRS Aug-Nov	WWS Apr-Nov
Estimated number killed by impingement	January	78	64	64	64	64	64
	February	70	58	58	58	58	58
	March	102	83	83	83	83	83
	April	84	28	9	0	0	0
	May	417	215	93	0	0	0
	June	2,400	2,192	1,059	0	0	0
	July	139	126	59	0	0	0
	August	16	14	7	14	7	0
	September	42	36	14	36	14	0
	October	327	204	82	204	82	0
	November	227	190	74	190	74	0
	December	369	291	291	291	291	291
	Annual	**4,270**	**3,502**	**1,892**	**940**	**673**	**496**
Impingement mortality % reduction from baseline		0%	18%	56%	78%	84%	88%
Estimated number entrained	January	0	0	0	0	0	0
	February	0	0	0	0	0	0
	March	0	0	0	0	0	0
	April	132,851	59,724	59,724	39,124	39,124	39,124
	May	802,576	677,692	677,692	129,578	129,578	129,578
	June	1,923,540	1,630,590	1,630,590	551,954	551,954	551,954
	July	345,927	287,546	287,546	148,276	148,276	148,276
	August	22,326	18,163	18,163	18,163	18,163	10,716
	September	0	0	0	0	0	0
	October	0	0	0	0	0	0
	November	0	0	0	0	0	0
	December	0	0	0	0	0	0
	Annual	**3,227,220**	**2,673,714**	**2,673,714**	**887,096**	**887,096**	**879,648**
Entrainment % reduction from baseline		0%	17%	17%	73%	73%	73%
Estimated number of adult equivalent losses	January	55	47	47	47	47	47
	February	89	73	73	73	73	73
	March	39	32	32	32	32	32
	April	668	286	286	166	166	166
	May	3,473	2,985	2,971	390	390	390
	June	11,256	9,550	9,514	2,432	2,432	2,432
	July	1,518	1,268	1,263	635	635	635
	August	113	94	84	94	84	45
	September	10	10	4	10	4	0
	October	85	64	28	64	28	0
	November	121	89	35	89	35	0
	December	424	331	331	331	331	331
	Annual	**17,852**	**14,829**	**14,668**	**4,363**	**4,257**	**4,151**
Adult equivalent losses % reduction from baseline		0%	17%	18%	76%	76%	77%

3.0 LOVETT GUNDERBOOM EFFECTIVENESS AND MESH SELECTIVITY ANALYSIS APPLIED TO MERRIMACK STATION TO ESTIMATE ANNUAL REDUCTIONS IN ENTRAINMENT ABUNDANCE AND IMPINGEMENT MORTALITY

3.1 LOVETT STATION GUNDERBOOM EVALUATION

The aquatic filter barrier ("AFB") is a relatively new fish protection technology for use at CWISs to meet CWA §316(b) performance requirements (EPA 2004). While the AFB is permeable to water, it is relatively impermeable to fish, shellfish, and ichthyoplankton and, therefore, is one of only a few technologies capable of reducing both impingement and entrainment of aquatic organisms (EPA 2004). Gunderboom has a patented full-water-depth filter curtain composed of polyethylene or polypropylene fabric panels that is supported by flotation billets at the surface of the water and anchored to the bottom of the water body (Enercon 2009). This AFB system is referred to as the Gunderboom Marine Life Exclusion System™ (Gunderboom MLES™). The Gunderboom MLES™ completely surrounds a CWIS, preventing organisms from entering the intake. Since the surface area of an MLES™ is large compared to the surface area of the intake structure's traveling screens, through-screen water velocity can be reduced to below 0.5 fps, thereby enabling even small fish and larvae to swim or drift away from the filter curtain.

A Gunderboom MLES™ was evaluated at Lovett Generating Station ("Lovett") from May through October of each year 2004, 2005, 2006 and 2007 to estimate its effectiveness in excluding fish eggs and larvae from entrainment into Lovett's CWISs (ASA 2004, 2005, 2006, 2007). Lovett, which ceased operation in 2008 and was dismantled, was located on the west bank of the Hudson River estuary just north of Stony Point, New York, 41 miles upstream from the southern tip of Manhattan in New York City. Lovett consisted of three fossil-fueled, steam electric units (Units 3, 4, and 5) having net generating capacities of 63 MWe, 197 MWe, and 202 MWe, respectively, for a total of 463 MWe for all three units combined. The once through design cooling water intake flows were 42,000 gpm for Unit 3, 104,300 gpm for Unit 4, and 112,000 gpm for Unit 5, for a total of 258,300 gpm. Cooling water for each of the three Lovett units was withdrawn from the Hudson River estuary through shoreline intakes equipped with conventional 3/8-inch mesh traveling screens. The AFB installed and tested at Lovett was made from two layers of non-woven fabric (LMS 1998) that encircled the shoreline bulkhead containing the CWISs for Unit 3, Unit 4, and Unit 5. The outer layer had 0.5 mm diameter perforations spaced on-center at 6.4 mm, and the inner layer was vented with horizontal 5.1 cm flaps spaced at 0.6 m (LMS 1998).

Effectiveness was determined by comparing the percent difference in density of entrainment-sized ichthyoplankton from pairs of pumped samples collected inside and outside of a deployed AFB enclosing the Lovett CWIS. Although the Hudson River at Lovett is estuarine, and the fish community sampled there is composed of different species than those found in the Hooksett Pool of the Merrimack River (a freshwater river impoundment) that is the source water body for Merrimack Station, the Lovett AFB study is the only "full scale" test of deployment and effectiveness of an AFB system for a power plant cooling water intake system of comparable size to Merrimack Station. Furthermore, the ichthyoplankton tested during the Lovett studies were of a comparable size range to those entrained at Merrimack Station. Therefore, the AFB system tested at Lovett was considered a surrogate for predicting the effectiveness and selectivity of a similar system if designed, installed, and operated at Merrimack Station for additional impingement and entrainment mitigation.

The four reports regarding the biological effectiveness of the AFB evaluated at Lovett (ASA 2004, 2005, 2006, and 2007) describe the sampling designs and methods specified in the project-specific Standard Operating Procedures (LMS 2005). These Standard Operating Procedures, which assured consistency of methods among years, are briefly summarized in this report. Five pairs of ichthyoplankton samples of an average volume of about 70 m^3 each were collected during two nights per week by pumping for 60-75 minutes at 200-240 gpm in the protected (from entrainment) water on the intake side of the deployed AFB and in an adjacent area outside of the AFB beginning in May and continuing through August of each year. One night was sampled every other week from early September through mid-October of each year. The samples from the intake side of the deployed AFB were considered representative of the "test" location, and the samples from the river side were considered the "control" location (5 test and 5 control samples per night). All samples were filtered through a 505 micron net suspended in a barrel sampler, preserved in 10% buffered formalin, and processed in the laboratory to indentify, enumerate, and measure the length (mm total length) of the ichthyoplankton species collected in four life stage categories: eggs, yolk sac larvae, post yolk sac larvae, and juveniles. In addition to the nighttime sampling, three pairs of daytime samples were collected one day each week from June through August. The final achieved sampling designs for each year, 2004 through 2007, were as follows:

	Sampling Dates		Number of Samples		
Year	**Start**	**End**	**Day**	**Night**	**Total**
2004	10-May	15-Oct	24	358	382
2005	28-Apr	13-Oct	24	392	416
2006	22-May	13-Oct	18	324	342
2007	27-May	15-Oct	18	320	338
2004-07	28-Apr	15-Oct	84	1,394	1,478

Post yolk sac larvae was the dominant life stage in all samples, contributing 91% (2,380) of the total ichthyoplankton collected at the control location (2,619) and 94% (17,661) of the total ichthyoplankton collected at the test location (18,730) over the four-year study.

The Lovett AFB evaluation focused on six target taxa: striped bass, white perch, river herring (alewife and blueback herring), bay anchovy, American shad, and Atlantic tomcod. However, only the first four taxa were caught in sufficient numbers to estimate the exclusion effectiveness.

The AFB system installed and operated at Lovett during 2004 through 2007 exhibited an average exclusion effectiveness of 79% for all species and life stages of ichthyoplankton combined, with inter-annual variation ranging from a low of 40% in 2004 to a high of 95% in 2007 (Table 3-1). The Lovett AFB was estimated to exclude, on average among the four years, 89% of the bay anchovy (inter-annual range 68% to 100%), 89% of the striped bass (inter-annual range 85% to 94%), 85% of the white perch (inter-annual range 62% to 97%), and 52% of the river herring (inter-annual range of -57% to 99%) over the four years of testing.

The Lovett AFB system did not exhibit size selectivity in its exclusion efficiency during 2004 through 2007. Kolmogorov-Smirnov two-sample tests (Siegel 1956; SAS 2003) of the standardized (percent) length-frequency distributions from the ichthyoplankton collected and measured from both the test and control locations were not significantly different (p>0.05) indicating no size selectivity of the AFB for all taxa combined (p>KSa = 0.9375), or for bay anchovy (p>KSa = 0.8079), striped bass (p>KSa = 0.8186), white perch (p>KSa = 0.8186), and river herring (p>KSa = 1.0000). Figure 3-1 illustrates the absence of statistically significant size selectivity by comparing the length frequency of all taxa collected and measured in one millimeter length groups from the test and control locations during the 2004 through 2007 study.

A likely explanation for the absence of significant size selectivity of the Lovett AFB is that the effective mesh opening of the non-woven outer layer (0.5 mm) was typically smaller than the smallest (i.e. "limiting") dimensions of the fish eggs and larvae exposed to entrainment at the Lovett CWIS. The table below compares the length range and greatest body depth range for bay anchovy, striped bass, white perch and river herring (taxa vulnerable to entrainment at Lovett) to the size and greatest body depth dimensions for the abundant fish larvae found at Merrimack Station during the 2005-2007 study (white sucker, centrarchids, and cyprinids), and demonstrates that all of the Merrimack fish larvae sampled during the 2005-2007 study (Normandeau 2007) and nearly all of the Lovett fish larvae were considerably larger than 0.5 mm in limiting body dimensions.

Larval Fish Taxon	**Total Length Range (mm)**	**Greatest Body Depth Range (mm)**
Bay anchovy	1.8-42	0.2-7.1
Striped bass	3.2-56	0.5-10.6
White perch	2.0-90	0.3-22
River herring	3.3-59.7	0.2-13.2
White sucker	6.4-24.2	0.6-3.6
Centrarchids	4.1-13.4	0.6-2.9
Cyprinids	3.7-17.2	0.5-2.6

As a result, ichthyoplankton appearing inside the deployed Lovett AFB and sampled at the test location would likely have originated in unfiltered water from the control location outside of the AFB that had entered by either overtopping, underflow, or by other means indicating partial failure of the deployment. Unfiltered water sampled at the test location would be expected to have the same length frequency of ichthyoplankton as water sampled at the control location, because the water did not pass through the mesh openings where size selectivity would occur. Some ichthyoplankton sampled inside the deployed AFB at Lovett may have originated from individuals trapped inside during deployment, depending on when deployment occurred relative to the onset of the spawning season (May) for most species of Hudson River fishes. When the AFB was deployed at Lovett in late April (2005) or early May (2004), which was prior to the spawning season, the first weekly samples from both inside and outside the filter barrier exhibited zero densities of ichthyoplankton. However, when the Lovett AFB was deployed during the spawning season in late May of 2006 and 2007, the first weekly samples from both inside and outside of the filter barrier contained ichthyoplankton.

The 79% overall average percent effectiveness and the absence of size selectivity both suggest that performance of the Lovett AFB is directly related to its time of deployment with respect to the local fish spawning season, the proportion of the total intake flow drawn directly through the filtration mesh, and the density of ichthyoplankton in the volume of unfiltered water drawn into the intake when deployment fails.

3.2 APPLICATION OF LOVETT AFB EVALUATION RESULTS TO MERRIMACK STATION

This analysis evaluated, individually and in combination, three technological and operational alternatives for reducing impingement mortality and entrainment abundance from baseline at Merrimack Station Unit 1 and Unit 2: (1) operational flow reductions at each unit, (2) AFB installation and seasonal operation during the observed peak entrainment period from April through July or for the entire entrainment season from April through November, and (3) impingement survival achievable by operating the existing conventional screens and installing a new fish return sluice and operating it during April through November of each year. Fish eggs and larvae were observed predominantly during the months of April through July in entrainment samples from Merrimack Station (Normandeau 2007), suggesting that installation and operation of an AFB of similar construction as the one tested at Lovett could provide significant annual reductions in both impingement mortality and entrainment abundance at Merrimack Station while avoiding periods when the risk of failure is unacceptably high, or impossible, due to ice formation in the freshwater impoundment of Hooksett Pool on the Merrimack River.

Using data from the 2005-2007 Study (Normandeau 2007), this analysis was prepared to estimate the potential annual impingement mortality and entrainment reductions from the installation and seasonal operation of an AFB to encircle Merrimack Station Unit 1 and Unit 2. Monthly and annual reductions in impingement mortality and numbers entrained were estimated with respect to a baseline representing full flow at both units, i.e., consistent with the §308 Response Report (PSNH 2007), baseline flow was defined as 59,000 gpm for Unit 1 and 140,000 gpm for Unit 2, during all 365 days per year ("baseline"). The total monthly number impinged and entrained at that baseline flow was estimated from impingement rates and entrainment densities observed in the 2005-2007 Study (when a month was sampled in two years, the average of the two estimates was used).

Flow reductions were modeled based on operational flows that were the same as the actual flows at each unit during the 2005-2007 Study (Normandeau 2007). The fish taxa analyzed were those for which adult equivalent estimates were presented in the 2005-2007 Study, representing over 90% of the total numbers impinged and entrained (Normandeau 2007). The analysis was also based on the following model conditions:

1. The AFB is 79% effective in excluding fish from impingement and entrainment during its deployment period (ASA 2004, 2005, 2006, and 2007).
2. The AFB is deployed to protect both Unit 1 and Unit 2 of Merrimack Station during the months of April through July or April through November of each year.
3. All fish excluded by the AFB escape impingement and entrainment and survive. This premise is supported by EPA's determinations, incorporated into the Phase II Rule, that (a) AFBs can reduce impingement mortality by 99% or greater compared with conventional once-through screens, and (b) AFBs can achieve 80% to 90% or greater reduction in entrainment compared with conventional once-through screens (EPA 2004).
4. Total impingement mortality during the period of AFB deployment will be based on 21% of fish entering the AFB enclosure and encountering the continuously rotated existing traveling screens, the impingement survival rates observed in the 2005-2007 Study and summarized

quarterly (Table 4-9, Normandeau 2007), plus the additional mortality of impinged fish during passage through a state-of-the-art fish return system (Con Edison 1992).

5. Total impingement mortality during the remaining open water period when the AFB is not deployed will be based on the observed impingement rates and survival as observed in the 2005-2007 Study and summarized quarterly (Table 4-9, Normandeau 2007), plus the additional mortality of impinged fish during passage through a state-of-the-art fish return system (Con Edison 1992).
6. The existing traveling screens at Merrimack Station Unit 1 and Unit 2 will be operated intermittently during the period from December through March, without the use of the state-of-the-art fish return system, due to ice cover on Hooksett Pool requiring the discharge section to be removed to prevent ice damage, resulting in 100% impingement mortality during this period.
7. Post-impingement mortality rates during passage through a state-of-the-art fish return system are the same as reported by Con Edison (1992), assuming the same mortality rate (15.4%) for centrarchids and yellow perch as for white perch and the same mortality rate (0%) for spottail shiner as for golden shiner.
8. Entrainment survival is conservatively assumed to be zero for all fish eggs and larvae not excluded from the cooling water intake flow by the deployed AFB, for the baseline scenario and for all evaluated AFB scenarios. Zero percent entrainment survival is the EPA's preferred assumption for estimating baseline and alternatives (EPA 2004). Although entrainment survival rates for eggs, larvae, and juveniles entrained through 9.5-mm square mesh screens at some power stations has been shown to be substantially greater than zero (EPRI 2000), survival rates at Merrimack Station are not sufficiently well known to assume survival values other than 0%.
9. Entrainment and impingement densities (number of organisms per unit volume of intake flow) are the same as observed during the 2005-2007 Study.

Scenarios calling for installation of a new state-of-the-art fish return system to improve survival of fish impinged on the conventional traveling screens presently installed and operated at Merrimack Station were based on the following conditions:

1. The sluice would be long enough to convey fish back into the Merrimack River at a location far enough downstream to prevent re-impingement.
2. The sluice would return impinged fish to Hooksett Pool at all water levels.
3. The sluice would be supplied with a constant flow of river water sufficient to maintain a depth of at least two inches at all locations along the length of the return sluice.
4. No modifications to the existing traveling screens (such as adding Ristroph buckets or changing the spray wash system) are necessary because of the relatively high survival observed for impinged fish washed from those existing screens when operated in a continuous wash mode (Normandeau 2007).

3.3 RESULTS

The results of the analysis are summarized in Table 3-2 for both estimated numbers and percent reductions for annual impingement mortality, annual numbers entrained, and annual adult equivalent losses (1) for current operation, (2) for the AFB deployed during April through July, with the existing traveling screens and a new state-of-the-art fish return system operating during April through November, and (3) for the AFB deployed during April through November, with the existing traveling screens and new state-of-the-art fish return system operating during April through November, but no fish return system operation at any other time during the year.

These results show that the Phase II Rule's performance standards of a 60-90% reduction in entrainment and an 80-95% reduction in impingement mortality are nearly attained at Merrimack Station by installing an AFB and operating it from April through July of each year. The estimated reduction in impingement mortality is 78%, the estimated reduction in entrainment abundance is 82%, and the estimated reduction in adult equivalent losses for impingement mortality and entrainment combined is 80% compared to the baseline. When the AFB is deployed for the entire open water period from April through November, the Phase II Rule's performance standards are satisfied for Merrimack Station, with an estimated reduction in impingement mortality of 82%, an estimated reduction in entrainment abundance of 83%, and an estimated reduction in adult equivalent losses for impingement mortality and entrainment combined of 81% compared to the baseline.

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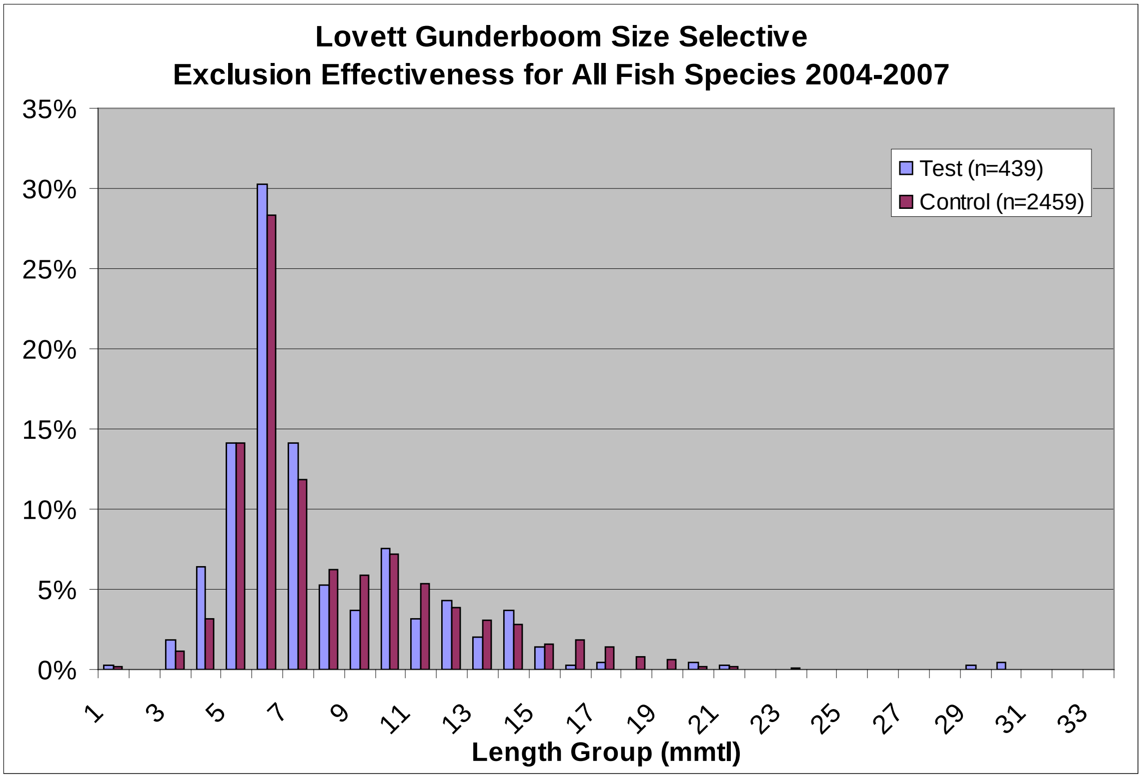

Figure 3-1. Length Frequency (one mm length groups) of all larval fish taxa combined collected by simultaneous pairs of samples taken inside (test) or outside (control) of a deployed AFB at Lovett Station on the Hudson River, New York, from May through October 2004, 2005, 2006 and 2007.

Table 3-1. Summary of annual percent exclusion effectiveness for fish larvae collected by simultaneous pairs of samples taken inside and outside of a deployed AFB at Lovett Station on the Hudson River, New York, from May through October 2004, 2005, 2006 and 2007.

Fish Taxon	Year	Percent of Catch	Percent Effectiveness
Bay Anchovy	2004	34%	68%
	2005	32%	99%
	2006	39%	89%
	2007	52%	100%
	2004-07 Mean	**39%**	**89%**
Striped Bass	2004	35%	85%
	2005	43%	94%
	2006	21%	90%
	2007	22%	88%
	2004-07 Mean	**30%**	**89%**
White Perch	2004	2%	62%
	2005	3%	97%
	2006	8%	89%
	2007	1%	92%
	2004-07 Mean	**4%**	**85%**
River Herring	2004	1%	-57%
	2005	1%	84%
	2006	4%	81%
	2007	2%	99%
	2004-07 Mean	**2%**	**52%**
All Species	2004	100%	40%
	2005	100%	92%
	2006	100%	89%
	2007	100%	95%
	2004-07 Mean	**100%**	**79%**

Table 3-2. Summary of annual estimates of impingement mortality, entrainment, and adult equivalent losses, with percent reductions from baseline, at Merrimack Station (Unit 1 and Unit 2 combined) for AFB installation and operation during April through July or April through November of each year.

Scenario	Performance Metric	Impingement Mortality	Entrainment	Adult Equivalent Losses
Baseline	estimated number	4,270	3,227,220	17,852
Current operation	estimated number	3,502	2,673,714	14,829
	percent reduction	18%	17%	17%
AFB operation Apr - Jul	estimated number	929	575,829	3,581
	percent reduction	78%	82%	80%
AFB operation Apr- Nov	estimated number	789	561,480	3,462
	percent reduction	82%	83%	81%

4.0 EVALUATION OF THE POTENTIAL FOR YEAR-ROUND OPERATION OF FINE-MESH TRAVELING SCREENS TO REDUCE IMPINGEMENT MORTALITY AND ENTRAINMENT AT MERRIMACK STATION

4.1 INTRODUCTION

One option under consideration for reducing impingement mortality and entrainment at Merrimack Station is retrofitting the existing conventional traveling screens currently installed at the Station's Unit 1 and Unit 2 CWISs with fine mesh traveling screens for year-round operation. The evaluated designs for this option consist of installation and continuous, year-round use of traveling screens with a mesh size of 1.5 mm (i.e., square openings 1.5 mm by 1.5 mm) and a designed through-mesh velocity of 0.5 ft/s or less, with or without a state-of-the-art fish return system.

Mortality of fish that would have been impinged on standard-mesh traveling screens (i.e., with 3/8-inch square openings) could be assumed to be zero if a retrofit installation were to provide sufficient screen area to maintain a through mesh velocity of 0.5 ft/s or less, on the basis of EPA's determination, incorporated into the Phase II Rule, that a facility that reduces its maximum through-screen design intake velocity to 0.5 ft/s or less is deemed to have met the Phase II Rule's impingement mortality performance standards (EPA 2004). This assumption is consistent with the expectation that the swimming capabilities of juvenile and adult fish would enable them to avoid being impinged if the intake current is less than 0.5 ft/s (EPA 2004). It is unknown, however, whether the same assumption is reasonable for fish larvae that would be entrained through standard-mesh traveling screens but retained by (i.e., impinged on) 1.5-mm-mesh traveling screens, because larvae have limited swimming capability, so they are mainly transported passively by the water currents. The best-case assumption would be that larvae would also be able to avoid impingement on such fine-mesh screens at low intake velocities, similar to juvenile and adult fish. The worst-case assumption would be that all larvae would be impinged on such fine-mesh screens. Unlike CWW Screens that rely on a sweeping flow greater than the through-slot velocity (Section 2.0), a fine-mesh retrofit of the through-flow screens in the Merrimack Station CWISs would not provide a sweeping flow. The lack of a sweeping flow would not allow larvae to avoid entrainment by escaping perpendicular to the intake flow along the fine-mesh screen's surface and out of the withdrawal zone.

Fish eggs drifting in the flow approaching the intake could not avoid impingement, however the number of fish eggs entrained at Merrimack Station is low, less than 1% of total entrainment (Normandeau 2007). Freshwater fish eggs are typically small enough to pass through a 1.5-mm mesh (Auer 1982). Therefore, impingement of eggs would not occur on 1.5-mm fine-mesh traveling screens at Merrimack Station.

Under the best-case assumption that fish larvae would be able to avoid impingement on 1.5 mm fine mesh traveling screens, limiting the through-mesh velocity to a maximum of 0.5 ft/s has the potential to reduce impingement to zero, thus reducing impingement mortality 100%. This theoretically would eliminate the need to install a state-of-the-art fish return system.

To model the worst-case assumption that larvae would not be able to avoid impingement on 1.5 mm fine mesh screens, the survival rates for the larvae impinged on such screens would need to be known to estimate the number of larvae killed by impingement. The strategy of installing fine-mesh intake screens to reduce entrainment has only recently received serious attention, primarily in response to the Phase II Rule, so the impingement survival of larvae has not yet been adequately determined. In laboratory tests of white sucker larvae impinged on fine-mesh screens, the average survival rate at an approach velocity of 0.5 ft/s was about 60% after adjusting for control survival (EPRI 2009). The mesh sizes tested were different than the 1.5-mm mesh proposed for Merrimack Station, though, and the investigators concluded that survival in a real power plant would be lower because of the effects of debris and variation in environmental conditions. The larval impingement survival rates for fine-mesh screens could be as low as zero, considering the fragility of larvae in the context of the physical stresses they could be subjected to during the screen washing process. A more optimistic assumption would be that the survival rates for larvae impinged on fine mesh would be comparable to the survival rates that have been observed for juvenile and adult fish impinged on coarse-mesh screens.

The actual survival rates for larvae impinged on 1.5 mm fine-mesh screens are likely to fall somewhere between these two scenarios. In a study comparing survival rates for fish impinged on 3.2-mm screens and 9.5-mm screens in the Hudson River estuary, impingement survival rates tended to be lower for the finer mesh screens (Normandeau 1989). The results of that study may not be directly applicable to Merrimack Station, however, because of the different mesh size and species impinged, as well as other site-specific factors. Nonetheless, it is an indication that if larvae are impinged on fine-mesh screens their survival rates could be lower than those of larger fish impinged on standard-mesh screens.

4.2 APPROACH

There are three important factors determining the effectiveness of fine-mesh traveling screens as compared to conventional mesh traveling screens: (1) the percentage of entrained fish eggs and larvae that survive entrainment through the fine-mesh screens, (2) the percentage of larvae that avoid entrainment and become impinged on the fine-mesh screens, and (3) the mortality rate of larvae formerly entrained but now impinged on the fine-mesh screens. Entrainment mortality for Merrimack Station was assumed to be 100%, following EPA's assumption in the Phase II Rule. However, the ability of larvae to avoid impingement on fine-mesh screens and their survival rate if they were to be impinged are both unknown. Therefore, three scenarios were modeled for fine-mesh screens at Merrimack Station to bound the total range of possible outcomes. In the Assumption 1 scenario, larvae entrained through coarse-mesh screens but excluded by fine-mesh screens would be able to avoid impingement due to the low through-mesh velocity (i.e., have 0% impingement mortality). In the Assumption 2 scenario, some larvae formerly entrained through coarse-mesh screens will be retained on the fine-mesh screens and experience some intermediate level of impingement mortality. In the Assumption 3 scenario, some larvae formerly entrained through coarse-mesh screens will be retained on the fine-mesh screens and experience 100% impingement mortality.

More particularly, the potential reductions in impingement mortality and entrainment from the continuous use of fine-mesh traveling screens at a maintained through-screen velocity of 0.5 ft/s at Merrimack Station were modeled under three scenarios: (1) all larvae too large to be entrained through 1.5-mm mesh screens, as well as all juvenile and adult fish, avoid impingement due to the low intake velocity of 0.5 ft/s (Assumption 1); (2) juvenile and adult fish avoid impingement due to the low intake velocity of 0.5 ft/s but larval fish are impinged and experience impingement survival rates that are comparable to previously observed impingement survival rates for juvenile and adult fish (Assumption 2); and (3) juvenile and adult fish avoid impingement due to the low intake velocity of 0.5 ft/s but larval fish are impinged and experience 100% impingement mortality (Assumption 3).

4.3 RESULTS

The resulting estimates of the three scenarios modeled are compared in Table 4-1. Under the Assumption 1 scenario (in which larvae are assumed to avoid impingement), impingement mortality would be eliminated (100% reduction), entrainment would be reduced by >99% (only a few eggs entrained), and adult equivalent losses would be reduced >99% compared to the baseline.

Under the Assumption 2 scenario (in which larvae would be impinged or entrained but some impinged larvae would survive and be returned alive to the Merrimack River), it was assumed that larval impingement survival was estimated to be 58.7%. This survival rate is the product of 69.1% survival on the screens (as observed for test fish at Merrimack Station in the 2005-2007 Study; Normandeau 2007) and 85% sluice survival observed for white perch (Con Edison 1992). Based on this estimated larval impingement survival rate, entrainment would be reduced by an estimated 49%. However, impingement mortality would be *increased* by a factor of 100. The adult equivalent losses combining both impingement mortality and entrainment would be reduced by 43% compared to the baseline.

Under the Assumption 3 scenario (in which larvae would be impinged or entrained with 100% mortality), entrainment would be reduced by 49%, adult equivalent losses would be reduced by 21%, and impingement mortality would be increased by a factor of 240.

The assumption that fine-mesh screens and a state-of-the-art fish return system would be "used continuously year-round" at Merrimack Station does not require that screen rotation and washing be continuous throughout the entire year. Continuous rotation and washing of fine-mesh screens would only be necessary under the Assumption 2 scenario (larvae are unable to avoid impingement and are subjected to <100% impingement mortality rates), and even under that scenario, continuous washing would only be necessary during the April-August seasonal occurrence of larvae. Operation of the fish return system would likewise only be necessary for the same April-August period, and only under the Assumption 2 scenario. This would avoid the difficulty of constructing and operating the fish return system in a way to enable it to function successfully without being damaged by ice during the winter, when the surface of Hooksett Pool is frozen (December-March).

The results of this analysis would apply to any intake screens with a through-mesh velocity no higher than 0.5 ft/s, a mesh size of 1.5 mm, and a state-of-the-art fish return system (such as dual-flow traveling screens or MultiDisc screens).

The use of fine mesh traveling screens (<3/8 inch open area) to replace conventional mesh traveling screens (3/8 inch open area) and achieve entrainment reductions at CWISs involves the transfer of some or all of formerly entrained fish eggs and larvae to impingement on fine mesh screens. The number of fish eggs and larvae entrained cannot be directly compared to the number impinged unless the comparisons are made within the same life stages or all life stages are converted to a common age equivalent (i.e., Age 1 or adult) using population survival models for each species and life stage. This is because fish eggs and larvae must live for a longer time to become Age 1 (or adult), and many die due to considerable natural mortality during this time period. Young-of-the-year fish of the size typically impinged on screens are nearly Age 1, and have already survived the period of high larval mortality, so many more of the young-of-the-year fish become Age 1 than larvae. The true impact to the fish populations of entrainment and impingement can only be compared by converting numbers killed by entrainment and numbers killed to impingement to an equivalent life stage and adding them together, which was done in the Merrimack Station evaluation by expressing the results in terms of adult equivalents.

In this analysis, for the Assumption 3 scenario, the annual number dead due to impingement would equal the sum of the number of fish formerly impinged on the coarse mesh screens plus the number that would have been entrained through coarse-mesh screens but are instead are impinged by the fine-mesh screens. Under the assumption of 100% entrainment mortality, the total number killed would be no different than the number currently killed by entrainment. However, by separately considering impingement mortality and number entrained (in accordance with the framework of the Phase II Rule), the reduction in number entrained has been achieved at the expense of a huge percentage increase in impingement mortality (*even though the total number killed remains the same*). The 24,000% increase in impingement mortality is a misleading artifact of the separate "percent reduction" standards for impingement mortality and entrainment, due the annual number entrained being nearly three orders of magnitude higher than the annual number impinged. The true "benefits" of replacing conventional traveling screens with fine mesh traveling screens should be determined exclusively on the reductions in adult equivalents from the sum of those fish entrained and impinged with each technology.

The percent reductions in entrainment estimated for fine-mesh screens (Table 4.1) are consistent with the values previously estimated for fine-mesh intake screens and presented in Table 10 in Attachment 6 of the §308 Response Report (PSNH 2007), however they are not exactly the same for three reasons. First, the fine-mesh entrainment reduction estimates in the §308 Response Report are presented separately for 2006 and 2007, but neither of those represents a full year of entrainment. To estimate the annual entrainment reduction from fine-mesh screens in this supplemental technology evaluation, the analysis was based on a full year of entrainment, which was calculated from the April estimate from 2007, the July and August estimates from 2006, and the averages of the 2006 and 2007 estimates for May and June. Second, the fine-mesh entrainment reductions in the §308 Response Report were estimated separately for the two scenarios of actual flow and design flow. This fine-mesh evaluation combines the entrainment reductions due to reduced flow and fine-mesh screen operation into a single estimate. Third, generalized physical exclusion factors were used for the §308 Response Report, whereas this analysis was refined to use factors estimated separately by taxon and month on the basis of lengths of larvae entrained at Merrimack Station. The entrainment reduction estimates in the §308 Response Report and in this fine-mesh screen evaluation were both calculated using the same entrainment abundance estimates and the same cooling water flows (design and actual) as in the 2005-2007 Study report (Normandeau 2007).

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Table 4-1. Estimated annual reduction from baseline in impingement mortality, entrainment, and adult equivalent losses at Merrimack Station (Unit 1 and Unit 2 combined) if each intake is equipped with new 1.5-mm fine mesh traveling screens and a state-of-the-art fish return system, under three different assumptions of avoidance and impingement mortality rate for larvae.

Scenario	Performance Metric	Impingement Mortality	Entrainment	Adult Equivalent Losses
Baseline	Estimated number	4,270	3,227,220	17,852
Assumption 1: 100% larval avoidance	Estimated number	0	3,950	2
	Percent reduction from baseline	100%	>99%	>99%
Assumption 2: 100% larval impingement with 58.7% survival	Estimated number	429,386	1,633157	7,958
	Percent reduction from baseline	-10,000%	49%	43%
Assumption 3: 100% larval impingement with 100% mortality	Estimated number	1,040,557	1,633,157	14,061
	Percent reduction from baseline	-24,000%	49%	21%

Notes:

All three scenarios for the new fine-mesh traveling screens above reflect reductions in impingement mortality and entrainment resulting from operational flow reductions estimated from the actual flows during the 2005-2007 Study, compared to the baseline flow of 59,000 gpm for Unit 1 and 140,000 gpm for Unit 2.

The negative percent reductions in impingement mortality in the Assumption 2 and Assumption 3 scenarios mean that the numbers killed by impingement were higher for the new fine-mesh traveling screens than for the baseline.

Adult equivalent losses are the combined losses from both impingement and entrainment.

Assumptions:

Densities of fish vulnerable to entrainment and impingement (number of organisms per unit volume of intake flow) are the same as observed during the 2005-2007 Study (Normandeau 2007).

New fine-mesh traveling screens (1.5-mm mesh) are installed at both units.

Juvenile and adult fish are not impinged because of intake velocity ≤0.5 ft/s.

Entrainment mortality is 100% under all scenarios.

Larvae avoid impingement on the new fine-mesh traveling screens only in the Assumption 1 scenario.

For the Assumption 2 scenario, the new fine mesh traveling screens are continuously rotated and washed and the new fish return system is operated during the April-August period when larvae could be impinged.

For the Assumption 2 scenario, the larval impingement survival rate on the new fine-mesh traveling screens is 69.1%, estimated from the impingement mortality rate observed for adult golden shiner tested on standard screens during the 2005-2007 Study (Normandeau 2007).

For the Assumption 2 scenario, the larval post-impingement survival rate during passage through a state of the art fish return system is 85%, as reported for white perch juveniles in sluice survival testing by Con Edison (1992).

For the Assumption 3 scenario, mortality of impinged larvae is 100%.