AR-1192

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February 27, 2012

U.S. Environmental Protection Agency
Office of Ecosystem Protection
Attn: Mr. John Paul King
5 Post Office Square, Suite 100 (OEP06-1)
Boston, MA 02109-3912

Attention Comments on NPDES Permit No: NH0001465

SUBJECT: **Comments on the Draft 316(b) Requirements in "Clean Water Act NPDES Permit Determinations for Thermal the Discharge and Cooling Water Intake Structures at Merrimack Station in Bow, New Hampshire" – Permit Number NH0001465**

Dear Mr. King:

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass. EPRI does not advocate any regulatory or policy action, our objective is simply to document the technical implications or the scientific/engineering information that supports such actions. With this understanding and objective in mind, we submit our technical comments on the Merrimack Generating Station's Draft NPDES Permit (Permit Number NH0001465.

In addition to EPRI's technical comments (Attached), EPRI also provides a video clip referenced in the comments that we believe EPA Region 1 will find of use as part of developing the final Merrimack Generating Station Final NPDES Permit. Should you have questions regarding these comments I can be contacted at 571-226-0614.

Sincerely,

David E. Bailey
Sr. Project Manager
Fish Protection Research

Comments on the Draft 316(b) Requirements in "Clean Water Act NPDES Permit Determinations for Thermal the Discharge and Cooling Water Intake Structures at Merrimack Station in Bow, New Hampshire"

Introduction

The EPA Region 1 issued a draft NPDES Permit for the Merrimack Station (Merrimack) in Bow, New Hampshire. The draft permit includes Best Professional Judgment (BPJ) requirements for compliance with Section 316(b) of the Clean Water Act. Public Service New Hampshire (PSNH) requested that the Electric Power Research Institute (EPRI) conduct a technical review of the 316(b) requirements and their basis as described in the fact sheet and a document titled "Clean Water Act NPDES Permitting Determinations for the Thermal Discharge and Cooling Water Intake Structures at Merrimack Station in Bow, New Hampshire" (Attachment D). EPRI provides a number of general comments followed by specific comments on the permit and supporting documents.

Comments:

EPRI's review of the documents has identified a number of technical errors relative to the description of existing conditions at Merrimack as well as in the analysis of alternative fish protection technologies and operational measures. Additionally, new information not previously considered relative to these technologies, is provided for consideration. Our comments focus on five primary topics that include:

1. Characterization of Merrimack's Cooling Water Intake Structure (CWIS) and Current Levels of Impingement and Entrainment
2. Potential Use and Performance of Narrow-slot Wedgewire Screens
3. Requirements for Modified Travelling Screens to Reduce Impingement and Entrainment
4. Technologies Not Considered for Merrimack
5. Potential Benefits of Reducing Impingement and Entrainment in the Hooksett Pool

While the technical comments primarily focus on the analysis provided in the Attachment D thermal and cooling water intake structure (CWIS) evaluation but also include the permit and factsheet.

Characterization of Merrimack's Cooling Water Intake Structure and Current Levels of Impingement and Entrainment

EPRI has a number of comments on the EPA's description of current levels of impingement and entrainment mortality and associated assumptions. These comments are as follows:

- The EPA Region 1 assumed 100% mortality for all entrained organisms. The Federal EPA made a similar assumption in the remanded Phase II Rule for existing generating stations and the proposed rule for existing facilities. However, under the Phase II Rule, facilities could conduct entrainment survival studies for the purpose of quantification of the benefits of technologies and are free to conduct such studies under EPA's proposed rule for existing facilities although such studies would need to be peer reviewed and approved by the NPDES permitting authority. EPRI submitted into the public record during the proposed rule comment period, EPRI Technical Report 1019025 titled <u>Entrainment Survival: Status of Technical Issues and Role in Best</u>

Technology Available (BTA) Selection. This report provided information to address the technical issues raised by the EPA for not considering entrainment survival when quantifying current levels of entrainment. It is highly likely that such studies would find significant entrainment survival for reasons that include:

  - The dominant entrained species at Merrimack that include white sucker (42%), bluegill (11.5%) and yellow perch (7.9%) and together make up 61% of the entrainment are all considered hardier species and less subject to entrainment mortality.
  - Approximately 90% of the entrainment consisted of post yolk-sac larvae that are hardier than the more fragile earliest larval stages such as yolk-sac larvae (6.2% of entrainment).
  - The majority of the entrainment takes place in May and June when water temperatures are cooler and the temperature and exposure duration are less likely to cause mortality.

- The EPA points out that the adult equivalent analysis does not consider the entrained eggs and larvae are a food source for many species and their loss represent losses to the overall energy budget and food web. However, due to the very small size of those organisms, the amount of biomass associated with the entrainment losses is fairly trivial and the technical basis for this concern is not clear.
- On page 269 of Attachment D, the last Para before 11.4.2c the text states that "fish may have to endure sudden exposure to high water temperatures" and "Because the heated water is drawn from the circulation pumps, fish impinged on the screens may also be exposed to biocides such as chlorine….". Since the hypochlorite injection points are located downstream of the traveling screens and the direction of flow is away from the traveling screens, it is not clear how impinged fish would be exposed to harmful levels of biocides such as chlorine except when a small amount of warm water is re-circulated to the intake in winter to prevent icing. Further, as EPA is aware, chlorine use is tightly controlled by both concentration (0.2 mg/l) and duration (two hours per day) limits. Relative to exposure to high water temperatures, while the relatively small amounts of warm water are re-circulated to the intakes during the coldest period of the winter to prevent ice blockage, given the relative dilution ratios, there is no evidence to support that impinged fish are forced to "endure sudden exposure to high water temperatures"
- Also on page 269 in section 11.4.2c of Attachment D the first sentence states "As rotating traveling screen panels emerge from water laden with fish and debris, a power spray was system clears the material from the screens." Based on year 1 and year 2 impingement results reported in 11.2.2b2, impingement averaged 19 fish/day (less than one per hour) for year 1 and 3.5 fish/day (about 1 fish ever 8 hours) in year two. These levels of impingement do not support that Merrimack screens are "laden with fish". Based on the available data if screens are laden with fish it is likely an unusual occurrence of relatively short duration.
- On page 269 in the last paragraph carried and over to page 270 of Attachment D, EPA points out that on approximately 8.4 days during the winter, one traveling screen and one pump of Unit 2 are shut down due to frazil ice. EPA stated that "by not operating both screens, 100% of the screen wash flow is directed at the operating traveling screens". This statement is incorrect as there is no change in screenwash pressure when only one pump is in operation. The screen spraywash pressure remains constant regardless of how many pumps are in operation.

Additionally, EPRI points out that under this condition it should also be noted that operating with only one intake pump not only reduces the overall intake flow by half but also results in a roughly proportional reduction in the maximum through screen design velocity. Thus during this operating condition risk of impingement mortality is decreased rather than increased.

- On page 270, 11.4.2d of Attachment D the first sentence states "Power plants that utilize once-through cooling typically power spray fish and debris off their traveling screens into some form of fish return system which transports the fish and in some cases debris as well back to aquatic habitat from which they were withdrawn." Currently there is no way, except manually, to separate fish from debris and therefore screenwash water return systems do not distinguish between fish and debris. In fish friendly traveling screen systems with low pressure spraywash, both fish and debris end up in the fish return. However, some types of debris that cling to screens may be removed by the high pressure spray designed to remove debris and wash it into a separate debris return system.

Potential Use and Performance of Narrow-slot Wedgewire Screens

Narrow-slot wedgewire screens completely exclude impingeable sized organisms and their through screen design velocity of 0.5 fps meets the criteria for impingement mortality reduction compliance in both the remanded Phase II Rule and the newly proposed rule for existing facilities. EPRI studies (some jointly funded by EPA) have also demonstrated that narrow slot wedge-wire screens can be very effective in reducing entrainment. Based on entrainment studies conducted at Merrimack, the potential period for entrainment in the Hooksett pool is from April through August. Thus it would only be necessary to use this type of exclusion device during that period. However, they could also be deployed prior to or after that period, except for the period when there is risk of frazil ice.

Attachment D discusses potential issues and concerns in terms of wedgewire screen physical deployment as a result of their space requirements, as well as for blockage as a result of debris and biofouling. One of the major advantages of wedgewire screens is the flexibility to accommodate a variety of deployment options. This would include flexibility for deployment in the Hooksett Reservoir. These options include:

- A variety of module sizes (smaller sizes would be required due to water depth)
- Mounting options (modules could be deployed from a submerged pipe or could be mounted on a bulkhead in the river).
- Debris and fouling control options (either automatic compressed air release or mechanical cleaning, in addition to manual cleaning)

In terms of performance, the EPA has suggested that narrow-slot wedgewire screens would not function properly during the period when entrainment occurs due to lack of adequate sweeping velocity. The effectiveness of narrow-slot wedgewire screens was tested at Alden Research Laboratory with video cameras used to video tape the effect on small objects used to simulate fish eggs introduced into the water above the screens. EPRI provides a video clip to point out there is little tendency for impingement, even in the absence of flow that occurred during these tests. Given that most of the entrainment at Merrimack is larvae with some swimming ability, use of such screens would be expected to significantly reduce entrainment. The video clip provided was tested at a maximum through screen design velocity of 0.25 fps. In Virginia, use of narrow-slot wedgewire screens was proposed for fish protection as part of a project to withdrawal potable water from the King William Reservoir. Objections were raised to the wedgewire screen technology saying the technology would not work effectively due to lack of a sweeping current in the reservoir. In that case, the dominant flow in the reservoir would be the flow through the wedgewire screen intake. However, the Judge hearing this case dismissed those claims after viewing the video.

At the 2011 American Fisheries Society 316(b) session a paper was presented on larval avoidance of wedgewire screens (Attachment A). This Laboratory study conducted testing on over 300,000 larvae in addition to test beads to evaluate the exclusion effectiveness of slot size relative to fish larvae. Exclusion was first estimated based on larval fish size (i.e. could they physically pass through the 2 mm and 3 mm slot widths tested). Results of actual testing demonstrated that the avoidance of the larvae was significantly greater than would be predicated based on slot size alone. The EPA Region 1 states in Attachment D screen retention studies found that screen mesh sizes of 0.5 mm would be necessary to achieve a high level of larval exclusion. However, due to the small number of eggs and the size of entrainable life stages at Merrimack there is a strong likelihood that larger slot sizes proposed by PSNH could be highly effective in reducing entrainment mortality

EPRI points out that the issues of concern raised by EPA, that include both engineering, operational and performance issues, could be evaluated by conducting a pilot study to verify the necessary slot size needed for Merrimack. EPRI provides additional specific comments on Attachment D relative to wedgewire screens as follows:

- On page 278, the first full paragraph, Appendix D expresses concern over the proposed use of a 1.5 mm slot size since smaller larvae might pass through this slot size. Relative to slot size, EPRI agrees that EPA is correct that larger sizes exclude fewer larvae numerically. However, in the case of Merrimack, the smaller early life stages of the dominant species entrained make up a very small portion of the total entrainment. Further, due to the significantly higher natural mortality rates of the very early life stages they contribute significantly less to the equivalent adult entrainment loss. The result of the small percentage of early life stage larvae and significantly higher natural mortality is that the larger slot size use at Merrimack has the potential to achieve a relatively high overall performance and achieve a significant reduction in equivalent adult losses and other entrainment impact measures. This could be easily tested in a pilot study such as the joint study conducted by EPRI and EPA on wedgewire screen performance.
- On page 278 in the last paragraph which continues onto page 279, Appendix D raises the issue of potential mortality due to larvae contact with the screens. The text states that eggs are fragile and the larvae are even more so. EPRI included white sucker as a test species in laboratory studies on the performance of fine mesh modified traveling screens (EPRI Technical Report 1019027). Study results found that once larvae began to develop musculature the white sucker and other test species had impingement survival rates, that when adjusted for control mortality, were in excess of 80% and in some cases up to 90%. Similar results were found for bluegill and bass, other dominant entrained species at Merrimack. The stress of impingement on the fine mesh screens at much higher velocities than would occur with the proposed wedgewire screens, combined with the smooth texture of the wedgewire suggest that mortality as a result of incidental contact of some larvae with the cylindrical wedgewire screen modules is a not likely to be a significant issue at Merrimack.
- On page 279 in the last paragraph and continuing on to page 280, Attachment D speculates that the wedgewire screens would attenuate water current and based on a study by Niles and Hartman (2009) could attract larvae to the low velocity areas in the immediate vicinity of the

cylindrical wedgewire screens. However, larval fish large enough to swim to and reside in these low velocity areas would not be expected to be vulnerable to entrainment in those areas and would likely avoid impingement with the low through screen velocities passing through the screens. Therefore the relevance of this paragraph relative to the use of narrow-slot wedgewire screens at Merrimack is not clear.

Use of Modified Travelling Screens with a Fish Return System

EPRI provides comments on two topics discussed in Attachment D to the permits:

- Rejecting use of fine mesh travelling screens to reduce entrainment and
- Requirements for use of modified traveling screens to reduce impingement

Comments on each of these two topics are provided.

Use of Modified Finemesh Travelling Screens with a Fish Return System at Merrimack to Reduce Entrainment

Attachment D on page 284 in the last paragraph that are carried over to page 285, dismisses use of Ristroph modified traveling screens with a fish return as BTA. This is based on the belief that larvae would not survive impingement and lack of data on species relevant for Merrimack. Last Sentence – The rainbow smelt is not representative of potential survival rates for species at Merrimack. EPRI over the past couple of years have conducted finemesh screen tests on a number of the dominant entrained species at Merrimack (EPRI Technical Report 1019027 titled Laboratory Evaluation of Fine-mesh Traveling Water Screens. Species tested in this study included larval tests on both white sucker and bluegill and noted fairly high survival rates once the larvae began to develop musculature (around 12 mm in total length). Since Potentially high survival technology has the potential to achieve a significant reduction in entrainment mortality and could prove to be the most cost effective alternative technology. This could be confirmed with a site specific pilot study that would be allowed under the proposed rule planned to be issued by July of this year. The referenced study included side by side testing of Ristroph, Geiger and Hydrolox finemesh screens and all three screens were found to be comparable in performance.

Requirements for Use of Modified Traveling Screens with a Fish Return System to Reduce Impingement Mortality

On page 270 of Attachment D in section 11.4.2d the second paragraph express concerns over the design of the fish return in terms of the material makeup of the pipe and sharp turns. EPRI submitted Technical Report 1021372 into the public record during the proposed rule comment period. This report provides the results of studies EPRI conducted on design factors and their associated relationship to fish mortality associated with modified traveling screens. The report focuses on larval and juvenile life stages but is relevant to the issue since they are more fragile than larger sized fish. The results found that sharp turns did not adversely impact fish, nor did drop height unless it was excessive.

Appendix D, on page 282 in the first paragraph, states that replacing the existing traveling screens with modified traveling screens with fish buckets would not change the existing through screen velocity. This statement is incorrect, since the buckets themselves obstruct flow and reduce the amount of open screen area for cooling water flow. Any such reduction in open surface area with result in increase velocity through the remaining open area

Alternative Fish Protection Technologies Not Considered in the Evaluation

EPRI points out that there are alternative fish protection options to reduce entrainment mortality that were not considered in Attachment D. Two examples are discussed:

1. Use of Modular Inclined Screen (MIS) – The MIS consists of a large flat wedgewire screen plate inserted at a 15% angle (horizontal) into the intake tunnel or pipe through which cooling water is withdrawn. Cooling water passes through the plate to the condenser while fish and debris are drawn up along the plate to a separate intake pipe where they are returned back to the source waterbody to a suitable location. In the case of Merrimack that would be downstream of the CWIS. The fish return pipe uses a fish friendly pump to draw the fish and debris into the return system pipe and transport them back to the source waterbody. The advantages of this system are 1) they require significantly less space, since they do not require the low through screen velocity of cylindrical wedgewire systems and 2) fish are not impinged as they are with modified traveling screen systems. Larval and adult fish may contact the inclined screen plate as they pass along it to the opening of the fish return system, however, EPRI believes that based on the hardier species entrained and impinged at Merrimack, the MIS has potential to achieve good fish protection performance. Pilot study testing would be needed to confirm that. EPRI laboratory testing of this technology was conducted with a 2 mm slot width with good results but such testing could be done at a 1.5 mm slot width. A more detailed discussion of this technology can be found in EPRI Technical Report 1014934 titled Fish Protection at Cooling Water Intake Structures: A Technical Reference Manual.
2. Use of Combinations of Technologies – Attachment D does not appear to consider combinations of technologies and operational measures that could be used to reduce impingement and entrainment. For example, it may be possible to reduce the cooling water flow and intake velocity by modifying the cooling water pumps with variable speed drives at night when there is generally a reduction in power demand. For many species entrainment rates tend to be higher during the night. This change could be combined with use of modified finemesh traveling screens and a fish return system to improve the overall performance of that technology for both impingement and entrainment protection. Similarly, Narrow slot cylindrical wedgewire screens could be used during the period when entrainable life stages are present in combination with variable speed drives and use of modified traveling screens with a fish return system could be employed during other periods of the year to achieve an overall high level of fish protection.

Potential Benefits of Reducing Impingement and Entrainment in the Hooksett Pool

EPRI, in response to the Supreme Court decision in April, 2009, initiated a study to provide technical information to inform the EPA's 316(b) Rulemaking on the benefits of retrofitting existing once-through cooled facilities with closed-cycle cooling. The methods EPRI used in that study were essentially the same methods used by the EPA to estimate the commercial and recreational economic benefit of reducing impingement and entrainment for the Phase II and Proposed Rule for existing facilities. In that study benefit evaluations were conducted on over 30 facilities that included the Merrimack Generating Station, in addition to acquiring existing benefit valuation estimates from over 30 additional facilities. In addition, EPRI developed an impingement and entrainment database containing summary results of current impingement and entrainment data collected for compliance under the Phase II Rule and Merrimack data is included in that database.

The EPRI impingement and entrainment database (EPRI Technical Report 1019861) contains a summary of the total impingement and entrainment estimates from 166 facilities or 39% of the entire population of existing Phase II facilities for impingement and 90 facilities or 21% of the Phase II facilities for entrainment. For impingement, Merrimack was ranked number 136 (average annual impingement estimated to be 3,811) or in the bottom 18%. The total annual impingement from the bottom 30 facilities accounted for only 0.02% of the impingement for all 166 facilities. For entrainment, Merrimack was listed number 75 (average annual entrainment estimated to be 3,018,989 fish, mostly larvae) of the 90 facilities that provided entrainment data or the bottom 17%. The entrainment losses from those 16 facilities made up 0.04% of the entrainment losses from all 90 facilities that provided entrainment data. More information about EPRI's impingement and entrainment database can be found EPRI Technical Report 1019861.

In Section 12.5.2 of Attachment D a discussion is provided of the costs and benefits of reducing entrainment. In this Section the EPA Region 1 points out there is no commercial fishery. However, the text does qualitatively discuss the existence of a recreational fishery. EPA did not estimate the economic benefit of reducing entrainment with closed-cycle cooling explaining it required a specialized expertise and resources not available to the agency. However, as discussed EPRI did evaluate those benefits as part of its study of the national benefits of using closed-cycle cooling as BTA. The basic method follows methods used by the federal EPA in the Phase II and existing facility rulemaking. Following is a summary of the estimating procedure:

- 11 species including black crappie, bluegill, brown bullhead, largemouth bass, pumpkinseed Rainbow smelt, smallmouth bass, spottail shiner, white sucker, yellow bullhead and yellow perch as the target species. These 11 species made up 91.9% of the annual entrainment and 89.4% of the annual impingement. As the EPA noted, most of the entrainment was made up of 3 species that included white sucker, spottail shiner and bluegill and over 75% of the impingement consisted of bluegill (55.6%), spottail shiner (8.3%), black crappie (6.7%) and largemouth bass (5.3%).

- It was noted that no federally listed threatened or endangered species and no state listed rare species or species of special concern were identified in entrainment or impingement sampling.

- For species of commercial and/or recreational importance, the equivalent yield to the fishery was estimated to compute the yield if these target species not been impinged or entrained. For species that serve as forage for recreationally important species (ex. Spottail shiner), the production of biomass available as food for higher trophic levels that would have been expected if the impingement and entrainment losses had not occurred. For both estimates the methods used were consistent with those used by USEPA in the Phase II (USEPA 2004b) and Phase III (USEPA 2006) rulemakings.

- Assignment of age categories for impinged and entrained organisms considered life table information, natural mortality rates, fishing mortality rates (number of fish caught), fishing vulnerability rates (size at which fish are vulnerable to harvest for the target species) and weight at the beginning of each age category.

A detailed description of the methods can be found in Attachment A to these comments. Using these methods the estimated annual equivalent fishery yield loss is 410 lbs/yr with 313 lbs/yr due to the entrainment loss and 97 lbs/yr due to the impingement loss. The production foregone loss is estimated to be 2,382 lbs/yr with 2,160 lbs/yr due to entrainment and 222 lbs/yr due to impingement. Based on these losses the estimated economic value of the losses to the fishery is $1,321/yr. Of that value $900/yr is the annual entrainment benefit, while $429/yr is the annual impingement reduction benefit. There were a total of 65 site-specific benefit estimates acquired or generated as part of this EPRI study. The median entrainment reduction benefit for the 65 was $8,547/yr. Reducing Merrimack's entrainment to the level that would be achieved through use of closed-cycle cooling is therefore an order of magnitude less than the median value for these 65 facilities.

There were 28 facilities for which there were both a site-specific capital cost estimate to retrofit with closed-cycle cooling. For these 28 facilities a comparison was made based on the annual benefit to reduce entrainment, since for 316(b) that is what is driving the decision that cooling towers are needed as BTA. For those 28 facilities the cost-benefit ratios ranged from costs that were 51X greater than the benefit to costs that were 357,416X the entrainment reduction benefit. Merrimack's annualized capital cost estimate was 5,302X the benefit and overall it ranked 21 out of 28 in terms of the biggest ratio difference. The median ratio was 2,096, so the Merrimack's ratio was double that. Note these numbers are based on the capital cost to retrofit only and do not include the heat rate penalty, energy penalty (fans and pump operation) nor lost revenue from extended downtime.

The estimates are compared to the social costs identified by the EPA that are presented in Table 12-3. The annualized cost for EPA's selected option (Option 3 requiring a retrofit of Units 1 and 2 with closed-cycle cooling) is listed as $14.6 million/year. This cost would be

11,052 times greater than the annual benefit for both impingement and entrainment mortality reduction and 16,222 times the benefit for entrainment mortality reduction.

This evaluation does not include any estimate for non-use value such as value individuals may place on the resource that cannot be monetized. For example, knowing the community structure and function of the resource has not been altered. However, in this case the community and structure of the Merrimack River fishery was significantly altered when the decision was made to change it from a free flowing river to a series of impoundments with dams serving to impede migration of fish to freely move up and down the river. However, there are contingent valuation methods used to monetize non-use values. EPRI choose not to use such methods as they tend to be very subjective. If used, those same methods can be used to monetize the environmental and social impacts of cooling towers. Attachment D does provide a qualitative discussion of those impacts and EPRI Technical Report 1022760 focuses on that topic and was provided to EPA during the comment period of the existing facility proposed Rule. The result is to the extent non-use economic values are considered relative to impingement and entrainment losses, their net value is offset by the potential environmental and social disbenefits of cooling towers that include fine, particulate emissions, drift impacts to terrestrial vegetation and wildlife, noise, public safety due to increased icing and fogging and aesthetics due to the size and height of cooling towers and their associated vapor plumes.

As discussed on page 236 of Attachment D monetized benefit of reducing both impingement and entrainment with closed-cycle cooling are now available for evaluation to the agency's longstanding use of the wholly disproportionate cost test.

References:

- Closed-Cycle Cooling System Retrofit Study: Capital and Performance Cost Estimates. EPRI Technical Report 1022491, January 2011
- Evaluation of the National Financial and Economic Impacts of a Closed-Cycle Cooling Retrofit Requirement. EPRI Technical Report 1022751, July 2011
- Maintaining Electrical System Reliability under a Closed-Cycle Cooling Retrofit Requirement. EPRI Technical Report 1023174, July 2011
- Net Environmental and Social Effects of Retrofitting Power Plants with Once-Through Cooling to Closed-Cycle Cooling. EPRI Technical Report 1022760, July 2011.
- National Benefits of a Closed-Cycle Cooling Retrofit Requirement. EPRI Technical Report 1023401. July 2011
- Closed-cycle Cooling Retrofit Research Program Results Summary. EPRI Technical Report 1023453, July 2011

- EPRI 2011, National and Regional Summary of Impingement and Entrainment of Fish and Shellfish based on an Industry Survey of Clean Water Act §316(b) Characterization Studies. Technical Report 1019861, July 2011
- Laboratory Evaluation of Fine-mesh Traveling Water Screens. EPRI Technical Report 1019027, December 2010.
- Evaluation of Factors Affecting Juvenile and Larval Fish Survival in Fish Return Systems at Cooling Water Intakes. EPRI Technical Report 1021372, December 2010.
- Entrainment Survival: Status of Technical Issues and Role in Best Technology Available (BTA) Selection. EPRI Technical Report 1019025, December 2009
- Laboratory Evaluation of Modified Ristroph Traveling Screens for Protecting Fish at Cooling Water Intakes. EPRI Report 1013238, June 2006.

ESTIMATES OF THE ECONOMIC VALUE OF ENTRAINMENT AND IMPINGEMENT LOSSES:

MERRIMACK GENERATING STATION

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REPORT SUMMARY

This report provides estimates of the economic value of fish entrained and impinged at a cooling water intake structure withdrawing cooling water from a river in the northeastern United States. Merrimack was designated Facility No. 363NM7V in the study. Also included are estimates of the potential economic benefits of installing cooling towers at this facility. The information presented herein is designed for permit applicants, environmental staff, and facility managers seeking to increase their understanding of the economic value of fish entrained or impinged at these intakes for comparison to the costs of installing cooling towers that could reduce entrainment and impingement mortality.

Background

The United States Environmental Protection Agency (USEPA) promulgated Phase II §316(b) regulations for existing power producing facilities on 9 July 2004. The Rule contained national performance requirements based, in part, on reducing fish and shellfish impingement mortality at cooling water intake structures. However, this rule also allowed a facility to demonstrate that it meets site-specific standards set in lieu of the national standards because of implementation costs "significantly" greater than the economic value of derived benefits. To meet this standard, the applicant was required to submit a report (namely, a Benefits Valuation Study) that estimates the costs and economic value of the benefits that would result from implementation of intake and operational alternatives that could be implemented at the site.

As a result of a challenge by a variety of petitioners, the United States Court of Appeals for the Second Circuit rejected use of this cost-benefit test as a means for compliance with §316(b). Following the Second Circuit's decision, USEPA suspended the Phase II rule on 9 July 2007. In December 2008, the U.S. Supreme Court agreed to review the Second Circuit Court's decision relative to the remand of the cost-benefit component of the original Phase II Rule. In March 2008, the U.S. Supreme Court overturned the Second Circuit Court's decision and determined that EPA had the authority to use a comparison of costs and benefits in marking BTA determinations under §316(b).

Objectives

This report provides estimates of the economic value of fish entrained and impinged at a single once-through steam electric facility (Merrimack) located along a river which flows into the Atlantic Ocean. Access by anadromous fish to the site is blocked by a number of dams. Also included are estimate of the annual economic benefits that could accrue through the installation of cooling towers at this facility. These estimates can then be compared to the costs of cooling tower installation and operation as part of a cost-benefit evaluation.

Approach

Entrainment and impingement monitoring data collected at Merrimack from 2005 to 2007 was used to estimate the entrainment and impingement at this facility. These estimates were combined with published information on life history parameters and from commercial and sport fishing valuation surveys to estimate the economic value of the total annual entrainment and impingement of fish. These economic values were estimated using technically sound methods

consistent with that used by the USEPA in the original §316(b) Phase II and the Phase III rulemaking.

Results

This valuation used entrainment and impingement estimates for 11 target fish taxa: rainbow smelt, spottail shiner, white sucker, yellow bullhead, brown bullhead, bluegill, pumpkinseed, smallmouth bass, largemouth bass, black crappie, and yellow perch. These taxa comprised more than 91 percent of the total entrainment and more than 89 percent of total impingement at Merrimack. The results for these 11 species were then scaled up to reflect the benefits associated with all species entrained and impinged. These economic values were calculated assuming 100 percent entrainment and impingement mortality.

In order to assign an economic value to the fish entrained or impinged, estimates of annual entrainment and impingement were converted to a biological measure that can then be assigned a monetary value. For this assessment, the losses were converted to estimated equivalent fishery yield using the Equivalent Yield Model and to equivalent biomass production using the Production Foregone Model.

The monetary value of these entrained and impinged fish was calculated using standard resource economics methodologies that are consistent with those used by USEPA in the Phase II and Phase III rulemaking. Following this approach, annual economic values of the fish entrained or impinged was $1,421 at Merrimack. Most (>63 percent) of this was attributed to entrainment. Installation of cooling towers at Merrimack would yield an annual economic benefit of $1,321 through reductions in entrainment and impingement.

To address uncertainty in these estimates of annual economic value, two additional approached were used. First, where possible, a quantitative evaluation of uncertainty was conducted including both a sensitivity analysis and a Monte Carlo analysis. Sensitivity analysis revealed that uncertainties in natural mortality rates followed by recreational price per pound had the greatest effect on annual economic value estimates. Based on Monte Carlo analysis, it appears that actual annual economic value is unlikely (<3 percent chance) to be more than twice the best estimates based on most probable input values. Second, a qualitative assessment of other sources of uncertainty revealed that annual variability in entrainment and impingement could yield wide ranges in economic value estimates. Other factors likely to contribute significant uncertainty include entrainment and impingement survival and the existence of density dependence.

EPRI Perspective

Energy producers, federal and state resource agencies and regulators, and the public will find this report a valuable reference for understanding the concepts and process used to assign economic value to reductions in impingement that can result from application of intake and operational alternatives for their cooling water systems.

Keywords

Clean Water Act §316(b)
Cooling water intake structures
Fisheries
Economic benefit analysis
Environmental impact assessment

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INTRODUCTION

Under the Clean Water Act (CWA) §316(b), a National Pollutant Discharge Elimination System (NPDES) permit applicant must demonstrate that the location, design, construction and capacity of its cooling water intake structure reflects the Best Technology Available (BTA) for minimizing adverse environmental impact. The primary impacts of concern under §316(b) are entrainment of smaller aquatic organisms into the cooling water system and impingement of larger organisms onto traveling screens in the cooling water intake. The specific objective of this report is to estimate the benefit of reducing impingement and entrainment equivalent to a level achievable should this facility, located on a river in the northeastern United States, retrofit its once through cooled units with closed-cycle cooling. This study is part of a large EPRI Research Program to inform the EPA §316(b) rulemaking on the implications of designating closed-cycle cooling as Best Technology Available (BTA) for cooling water intake structures.

REGULATORY BACKGROUND

On 9 July 2004, the U.S. Environmental Protection Agency (USEPA) promulgated a Phase II Rule implementing CWA §316(b) (USEPA 2004a). This rule applied to existing electric generating facilities having cooling water intake structures (CWIS) with a design capacity of at least 50 million gallons per day (MGD) and that use 25 percent or more of the water withdrawn for cooling purposes. Compliance with the Phase II Rule was based on achieving national performance standards for impingement mortality and entrainment reduction set by the USEPA on the basis of facility location (i.e., waterbody type) and capacity utilization (i.e., in excess of 15 percent). As part of this rulemaking, USEPA included an option for a less stringent compliance if the facility can demonstrate that the costs of complying with the national performance standard are "significantly greater" then the benefits of reduced entrainment and impingement (Cost-Benefit Test). In addition, USEPA compared the national costs and benefits of their proposed Phase II as part of the rulemaking effort (USEPA 2004b).

Many provisions of this Phase II Rule were challenged by a variety of petitioners. On 25 January 2007, the United States Court of Appeals for the Second Circuit ruled on these petitions. Among other decisions, the Court rejected use of the cost-benefit test as a means for compliance with §316(b). As a result of the Second Circuit’s decision, USEPA suspended the Phase II rule on 9 July 2007. In December 2008, the U.S. Supreme Court agreed to review the Second Circuit Court’s decision relative to the remand of the cost-benefit component of the original Phase II Rule. In March 2009, the U.S. Supreme Court overturned the Second Circuit Court’s decision and determined that USEPA had the authority to use a comparison of costs and benefits in making BTA determinations under §316(b).

In June 2006, USEPA promulgated a Phase III rule further implementing CWA §316(b). This Phase III rule applies to new offshore and coastal oil and gas extraction facilities that have a design intake capacity of greater than 2 MGD. As part of the Phase III rulemaking effort, USEPA also compared the national costs and benefits of their proposed rule using methods virtually identical to that of the Phase II rule but with updated input data (USEPA 2006).

This report provides estimates of the equivalent fishery yield and economic value of fish entrained and impinged at the cooling water intake structures as well as other environmental benefit considerations relative to impingement and entrainment losses. This estimate then can be compared to the costs of closed cycle cooling retrofits or other fish protection alternatives for §316(b) compliance. Economic benefit estimating methods used in this report are consistent with those actually used by USEPA in their regional assessment of the Phase II (USEPA 2004b) and Phase III rules (USEPA 2006). All facilities in the EPRI Closed-cycle Cooling Research Program are assigned unique alpha-numeric designators. The designator assigned to the facility evaluated in this report is 363NM7V.

REPORT ORGANIZATION

Chapter 2 of this report provides background information on the facility evaluated, describes the selection of "Target Species", and provides estimates of annual entrainment and impingement for each Target Species. Chapter 3 describes how the annual entrainment and impingement estimates were converted to a biological currency used to determine economic benefits (Equivalent Losses). Chapter 4 then describes the economic benefits valuation process while Chapter 5 provides the results of the Uncertainty Analysis. Finally, Appendix A provides additional information on methods and data used in Chapter 3.

2

ANNUAL ENTRAINMENT AND IMPINGEMENT ESTIMATES AND TARGET SPECIES SELECTION

This chapter provides a description of the facility and an overview of the methods used to estimate annual entrainment and impingement that formed the basis for the economic valuation. In addition, this chpater briefly discusses the species of fish that were selected to be the basis for this valuation.

THE SELECTED FACILITY

Merrimack is a generating station consisting of two generating units, Unit 1 and Unit 2. Unit 1 has a net capacity of 120 MW and Unit 2, 350 MW. Capacity utilization ranges from 86 to 97 percent for Unit 1 and 79to 84 percent for Unit 2. The facility design cooling water flow is 285.6 MGD. Mean total cooling water flow summed over both units during 316(b) studies from June 2005 to June 2007 was 216 MGD. The facility is located on a freshwater river in the northeastern United States from which it draws cooling water. The location is on a pool above a dam. The facility has a shoreline intake with standard 3/8-inch traveling screens.

ANNUAL ENTRAINMENT AND IMPINGEMENT ESTIMATES

Estimates of the annual entrainment and impingement that formed the basis for this assessment were developed from an impingement and entrainment monitoring program conducted at the facility during 2005-2007. A brief summary of the methods and results of this monitoring program are provided below.

Entrainment Monitoring

Entrainment monitoring was conducted in 2006 and 2007. During 2006, entrainment sampling was conducted at both Units 1 and 2 from late-May through mid-September. The scheduled sampling was weekly from late May through August (15 sampling weeks) and bi-weekly during the first half of September (one sampling week). Sampling was restarted during early April of 2007 and continued through June 2007. The scheduled sampling was biweekly from early April to mid May (four sampling weeks) and weekly during the remainder of the 2007 period (nine sampling weeks). Entrainment sampling was not conducted at an individual unit on days when one or both of the two circulating pumps were not operating. On each sampling day, one daytime sample and one nighttime sample were collected.

Entrainment survival studies were attempted, however no fish eggs or larvae were collected (egg and larval densities were apparently too low) and this attempt was not pursued.

Entrainment samples were collected through a 0.300-mm mesh plankton net suspended over a barrel sampler located outside of the pump houses at Units 1 and 2. Water was supplied to each sampler from a 3-inch raw-water tap drawing unchlorinated ambient cooling water from the condenser supply line. Flow was calculated for each sample using a timed volumetric method to ensure that a sample volume of at least 100 m^3 was filtered and collected.

Samples were preserved in 10 percent buffered-formalin and stored until processing in the laboratory. Water temperature, conductivity and dissolved oxygen were recorded for each entrainment sample.

Preserved entrainment samples were processed in a biological laboratory. Entrainment samples were manually sorted and eggs and larvae were identified to the lowest distinguishable taxon and enumerated. Samples with high abundances were subsampled in the laboratory using a plankton splitter such that a minimum of 200 eggs and larvae were analyzed. If numbers of eggs and larvae were low but the amount of detritus in the sample was high (more than 400 ml settled volume) then a maximum of one-half of the sample was sorted. Counts were made of the following life stages: eggs, yolk-sac larvae, post-yolk-sac larvae, and juveniles. The total length to the nearest 0.1 mm was measured for up to 30 individuals of each ichthyoplankton life stage (except eggs) per sample. If more than 30 ichthyoplankton larvae were present in a sample, a random selection of 30 specimens was measured.

Identification of fish eggs and larvae is difficult and some taxa were left unidentified or were identified only to the family level.[1] For the purposes of the economic evaluation, unidentified taxa were assigned to specific taxa based on the relative abundance of taxa that could be identified and on the relative abundance of fish species in impingement samples.[2] Estimates of entrainment per unit volume sampled for each species were scaled up to annual estimates of total entrainment using actual cooling water flow at the facility (Table 2-1).

Impingement Monitoring

Impingement sampling was conducted at the Unit 1 and Unit 2 intakes beginning on 29 June 2005 and continuing for two years through 28 June 2007. Impingement sampling was conducted one day per week from late-June 2005 through mid-December of 2005 (25 sampling weeks), from mid-March of 2006 through November of 2006 (34 sampling weeks), and from mid-March of 2007 through the end of June 2007 (15 sampling weeks). During the intervening time periods, 24-hour impingement samples were collected one day evey other week (14 sampling weeks). Weekly impingement sampling consisted of one 24-hour sample followed by one 6-day sample, and biweekly sampling consisted of one 24-hour sample followed by one 13-day sample. The 24-hour impingement samples are considered the primary sampling units, and "long interval" samples of six or 13 days are considered secondary sampling units that were useful in obtaining a full species list.

Impingement sampling was conducted by placing a basket in the screen wash sluiceway of Unit 1 and Unit 2 to catch all fish and debris washed off of the operating traveling screens during the sampling interval. The basket mesh was constructed from the same mesh as the traveling

[1] Some eggs and larvae were not identified. In such cases, species was assigned based on relative abundance of identified species and relative abundance in impingement samples.

[2] Spottail shiner spp. indicates spottail shiner and related minnow species. Bluegill spp. indicates bluegill and related sunfish species.

screens, i.e., standard 3/8-inch square stainless-steel wire. The baskets were placed in sampling position and removed using a davit and chain fall installed and operated specifically for impingement sampling.

Water quality parameters were recorded at both the Unit 1 and Unit 2 intakes. Temperature, dissolved oxygen, and conductivity were measured using calibrated electronic meters at the water's surface.

Impingement collection efficiency was determined during one 24-hour sampling period in each month to adjust each 24-hour sample for fish that are lost between the time they are impinged on the operating intake screens and their collection in the sampling device. A lot of 100 stained dead fish, representative of the species and size range that had been observed in impingement samples during the previous sampling events, was introduced immediately in front of a randomly selected operating intake screen at each unit. Fish for release were placed in an injection tank located on the deck of each unit's CWIS and flushed through a flexible 3-inch hose with running water. The discharge end of the hose released test fish at mid-depth below the surface and immediately in front of a stationary screen near the mid-point of the 24-hour collection interval. Collection efficiency test fish were recovered during the next screen wash for each unit.

Stained fish were removed from debris the following day. The number of stained fish subsequently recovered in the collection device at the end of the sampling period, divided by the number released, represents the impingement collection efficiency for that period. These impingement collection efficiency factors were applied to other 24-hour impingement collections from each period centered on the date of the collection efficiency test. Collection efficiency adjustments were not applied to the "long interval" samples.

Impingement survival studies also were conducted but these were for planning purposes to estimate what survival might be if a fish return system were installed in the future.

Impinged fish and debris were taken in fresh condition to the processing trailer located on-site at the facility and were analyzed immediately. All fish were identified to species and enumerated. A maximum of 50 individuals per species per sample were measured to the nearest millimeter total length and weighed to the nearest gram. Any individual fish that could not be identified to species in the field was taken to the laboratory for taxonomic identification by microscopic examination.

Estimates of weekly or bi-weekly impingement at the facility used in this assessment were computed from counts per unit circulator pump flow (adjusted for sampling efficiency) using actual circulator flow during the weekly or bi-weekly. The initial weekly and biweekly estimates were interpolated to mean monthly estimates, which were summed to provide an annual estimate. All impinged organisms were assumed to be killed. Monthly and annual estimates of total impingement mortality for each species that was collected are provided in Table 2-2.

SELECTION OF TARGET SPECIES

It is not practical or necessary to consider all species impinged in an economic valuation study. Sufficient information does not exist to conduct the assessment for some species and many of the species found in entrainment and impingement monitoring are found in very small numbers. Therefore, economic assessments are typically conducted using a subset of species, which for this assessment are called "Target Species". Target Species are most commonly selected to include contributors to all economic benefits categories including recreational and, where appropriate, commercial fishing as well as forage species and to be representative of the total species list entrained and impinged. In addition, ideally these Target Species should account for a large portion of total annual entrainment and impingement at the facility being addressed.

Based on a careful review of the annual entrainment and impingement estimates, 11 fish species were selected to be the focus of this economic valuation:

- Rainbow smelt
- Spottail shiner
- White sucker
- Yellow bullhead
- Brown bullhead
- Bluegill
- Pumpkinseed
- Smallmouth bass
- Largemouth bass
- Black crappie
- Yellow perch

These 11 species were selected as they are both representative of species typically entrained or impinged at Merrimack and of each of the economic benefits categories. In addition, sufficient information exists on each of these species for a technically-sound estimate of economic valuation.

For entrainment, fish larvae are difficult to identify to species, rather they were identified to groups of similar species that corresponded with the species that were impinged. Cyprinid species were assigned to spottail shiner and sunfish species were assigned to bluegill. Other species groups were presumed to correspond to the listed species listed but they likely contained other closely related species. Together, these 11 species and species groups accounted for approximately 91.9 percent of total annual entrainment and 89.4 percent of total annual impingement at Merrimack.

No federally listed threatened or endangered species and no state listed rare species or species of special concern were identified in entrainment or impingement sampling.

Table 2-1. Estimated Annual Entrainment and Species and Life-stage Assignments at Merrimack based on Samples Collected in 2006 and 2007

	Life Stage						
Taxon	Egg	Yolk-sac larvae	Post Yolk-Sac Larvae	Entrainable Juveniles	Larva/Juv. Stage Undet.	Total	Percent
Herring family	0	0	8,536	0	0	8,536	0.28%
Spottail shiner spp. [a]	7,366	119,500	725,535	12,866	0	865,266	28.66%
White sucker	0	0	1,246,213	12,866	0	1,259,079	41.71%
Brown bullhead	0	0	34,143	0	0	34,143	1.13%
Margined madtom	0	0	17,071	6,433	0	23,504	0.78%
Bluegill spp. [b]	0	31,508	315,082	0	0	346,591	11.48%
Rock bass	0	0	42,679	0	0	42,679	1.41%
Black crappie	0	2,635	26,346	0	0	28,980	0.96%
Yellow perch	0	0	239,000	0	0	239,000	7.92%
Tessellated darter	0	34,143	34,143	0	0	68,286	2.26%
Unidentified	22,098	0	0	0	80,779	102,876	3.41%
Total	29,464	187,785	2,688,747	32,165	80,779	3,018,939	100.00%

[a] Spottail shiner spp. indicates spottail shiner and related minnow species.
[b] Bluegill spp. indicates bluegill and related sunfish species.

Table 2-2. Mean Monthly Estimates of Total Impingement Numbers at Merrimack based on Samples Collected from June 2005 to June 2007

	Total Impingement Numbers													
Species	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Total**	**Percent**
American eel	0	0	0	0	0	0	0	0	8	1	0	0	9	0.26%
Golden shiner	8	9	0	0	0	4	0	11	0	17	21	4	73	2.25%
Spottail shiner	0	14	0	0	5	21	143	35	36	14	0	0	267	8.21%
Fallfish	0	0	0	0	0	0	3	27	0	0	0	0	29	0.89%
White sucker	3	6	0	0	0	0	0	0	0	0	0	0	9	0.27%
Yellow bullhead	0	6	0	0	0	0	0	0	0	7	0	0	13	0.38%
Brown bullhead	8	6	0	0	0	0	0	0	0	0	0	0	14	0.43%
Margined madtom	22	6	0	0	6	0	0	8	0	22	23	12	97	2.99%
Chain pickerel	0	0	0	0	0	0	0	8	0	0	0	0	8	0.25%
Rainbow smelt	0	0	0	0	0	2	38	19	35	0	0	0	93	2.86%
White perch	0	0	0	0	0	3	2	5	1	0	0	0	11	0.32%
Rock bass	5	2	0	0	0	1	5	0	0	0	0	0	12	0.38%
Banded sunfish	0	0	0	0	0	0	0	0	0	0	12	6	18	0.55%
Redbreast sunfish	1	0	0	7	0	0	0	0	0	4	1	4	15	0.47%
Pumpkinseed	21	0	0	0	42	12	9	0	0	4	0	35	122	3.77%
Bluegill	1,384	99	14	16	37	43	47	8	0	23	5	130	1,804	55.56%
Sunfish family	20	10	0	7	0	0	0	0	0	0	1	6	43	1.31%
Smallmouth bass	1	6	10	0	0	4	4	0	4	5	0	0	33	1.00%
Largemouth bass	10	13	0	0	62	55	14	2	15	2	0	0	172	5.29%
Black crappie	9	0	0	21	59	50	19	4	0	0	21	37	218	6.72%
Tessellated darter	0	5	0	0	0	0	0	0	0	24	2	0	30	0.92%
Yellow perch	17	0	0	0	0	9	60	16	8	41	2	9	159	4.91%
Total	1,511	179	24	50	210	202	341	141	106	161	86	241	3,247	100.00%

3

ESTIMATES OF TARGET SPECIES EQUIVALENT LOSSES

In order to calculate economic value of entrainment and impingement at Merrimack, estimates of the number of individuals entrained and impinged for the Target Species must be converted to equivalent measures that can be assigned economic value for these species. For species of commercial and/or recreational importance, the equivalent measure selected was the yield to the fishery that would have been expected had the individuals not been entrained or impinged. For species that serve as forage for other, generally larger, aquatic organisms, the measure selected was the production of biomass available as food for higher trophic levels that would have been expected had the individuals not been entrained or impinged. Methods used in this report to calculate these two measures are consistent with those used by USEPA in the Phase II (USEPA 2004b) and Phase III (USEPA 2006) rulemaking efforts and are described below.

The measure "yield to the fishery" is defined as the total yield (in weight) that could have occurred in the commercial or recreational fishery from those individuals lost to entrainment or impingement in the absence of compensatory changes in total mortality. This yield is calculated using the Equivalent Yield Model (EYM), which integrates Baranov's catch equation (Ricker 1975) with estimates of the mean weight by age (Dey 2002, EPRI 2004a). This method is conservative in that potential density-dependent changes in mortality or growth rates that often occur in natural populations were not included. Using the EYM, equivalent yield for each Target Species from entrainment and impingement was estimated as follows:

$$EY = \sum_{i=1}^{n_f} \left[\sum_{j=1}^{n_l} \left(NL_j S_{j \to i} \right) A_i W_i \frac{V_i F_i}{Z_i} \right]$$

where:

EY	=	Equivalent yield to fishery
NL_j	=	Number of each Stage or Age Category (j) lost to entrainment and impingement at the facility
$S_{j\rightarrow i}$	=	Total survival from Stage or Age Category (j) to Age (i)
n_j	=	Number of Stage or Age Category (j) entrained or impinged at the facility
V_i	=	Fraction of Stage or Age Category (i) vulnerable to fishing
F_i	=	Instantaneous fishing mortality rate for Stage or Age Category (i)
Z_i	=	Instantaneous total mortality rate for Stage or Age Category (i)
A_i	=	Total mortality rate for Stage or Age Category (i) = $1\text{-}e^{-Z_i}$

W_i	=	Average weight for individual of Stage or Age Category (i) captured in the fishery
n_f	=	Maximum number of Stage or Age categories vulnerable to fishery.

The EYM results in an estimate of yield defined in the same units used to describe the average weight of the individuals and integrates yield across all ages. In this assessment, the EYM was applied to each of the Target Species that support either commercial or recreational fishing.

The measure of biomass production that could have resulted from species impinged or entrained at each facility was calculated using the Production Foregone Model (PFM) (Dey 2002, EPRI 2004a). As with the EYM, this method is also conservative in that potential density-dependent changes in mortality or growth rates that often occur in natural populations were not included. Using the PFM, potential biomass production from entrainment and impingement was estimated for each of the Target Species as follows:

$$P_i = \sum_{i=1}^{L} \frac{\sum_{j=1}^{n_l} \left(NL_j S_{j\rightarrow i}\right) G_i W_i \left(e^{(G_i - Z_i)} - 1\right)}{G_i - Z_i}$$

and the total production foregone (P) can be found by summing over all the age categories that are entrained or impinged:

$$P = \sum_{i=1}^{m} P_i$$

where:

P	=	Total production foregone
P_i	=	Production foregone for individuals entrained or impinged at each facility in Stage or Age Category (i)
G_i	=	Instantaneous growth rate in weight for Stage or Age Category (i)
NL_j	=	Number of each Stage or Age Category (j) lost to entrainment or impingement at the facility
$S_{j\rightarrow i}$	=	Total survival from Stage or Age Category (j) to Age (i)
n_j	=	Number of Stage or Age categories entrained or impinged at the facility
W_i	=	Average weight of individuals in Stage or Age Category (i)
Z_i	=	Instantaneous mortality rate for Life Stage or Age Category (i)
m	=	Total number of age categories entrained or impinged at the facility
L	=	Final age category.

The PFM was applied to all Target Species that as individuals serve as food for other aquatic organisms during at least part of their life cycle.

Additionally, relationships among the key inputs to the EYM and PFM are as follows:

$$Z_i = M_i + F_i$$

$$A_i = 1 - e^{-Z_i}$$

$$S_{j \to i} = 1 - \prod_{i=j}^{r} (1 - A_i)$$

$$G_i = \ln\left(\frac{BW_{i+1}}{BW_i}\right)$$

$$W_i = BW_i e^{G_i \overline{T_i}}$$

where:

M_i	=	Instantaneous natural mortality rate for Stage or Age Category (i)
BW_i	=	Average weight of individuals at the beginning of Stage or Age Category (i)
BW_i	=	Average weight of individuals at the beginning of Stage or Age Category (i+1)
$S_{j \to i}$	=	Total survival from Stage or Age Category (j) to Age (i)
r	=	Total number of age categories between Age Category (j) and Age Category (i)
$\overline{T_i}$	=	Median fraction of Stage or Age Category (i) completed $= \frac{\log(2) - \log(1 + e^{-Z_i t_i})}{Z_i}$
t_i	=	Duration of Stage or Age Category (i).

More information on these inputs and relationships can be found in Ricker (1975).Estimation of the biological input parameters for each of the Target Species is described below.

ASSIGNMENT OF AGE CATEGORIES FOR IMPINGED AND ENTRAINED INDIVIDUALS

One of the necessities of equivalent loss calculation is that the direct measures of impingement mortality must be assigned to individual age categories as defined in the production foregone and equivalent yield models. For this assessment, age was assigned using length information for each Target Species obtained from impingement monitoring conducted at the facility, together with estimates of length at age for these same species obtained from the scientific literature and from an analysis of the length frequency patterns for each species. Details are provided in Appendix A.

Life Table Information

Biological input parameters for the Production Foregone and Equivalent Yield models include life stage durations, instantaneous natural and fishing mortality rates, and the fraction vulnerable to the fishery for each life stage and age, as well as mean weights at the beginning of each life stage and age for each Target Species. Each of these model inputs were determined as described below.

Life Stage Durations

Estimates of life stage durations for entrainable life stages of each target species were based on information provided in EPRI (2005a) and EPRI (In Preparation). For some species, duration information was only available for the total larval period, hence, best professional judgment was used to develop estimated durations for the two larval stages. Median life-stage durations for each target species used in this assessment are:

Entrained Taxon	Life Stage Duration (Days) Egg	Yolk-sac larvae	Post Yolk-Sac Larvae	Entrainable Juveniles
Black crappie	2	4	36	40
Bluegill type	6	4	20	31
Brown bullhead	8	9	14	29
Largemouth bass	6	10	7	40
Pumpkinseed	6	4	20	31
Rainbow smelt	20	4	86	10
Smallmouth bass	6	10	7	40
Spottail shiner	6	4	36	10
White sucker	4	8	38	7
Yellow bullhead	8	9	14	29
Yellow perch	6	8	17	10

Estimates of impingement on a monthly basis were developed for this assessment. Consequently, the duration of each month was set as 30.4 days, the average monthly duration across the entire year. However, it is important to recognize that fish do not become vulnerable to impingement until they are approximately 1 inch long and typically 1 to 2 months of age on a traditional 3/8-inch mesh traveling screen. Hence, the number of months remaining in the first year of life is normally less than 12. The number of whole months of impingement vulnerability during Age 0 was determined by dividing the total time between the median date of initial impingement vulnerability and the end of the first year of life by the average month duration (30.4 days). Any remainder was assigned as the duration of the first month of impingement vulnerability. Median date of initial impingement vulnerability for each target species, shown below, was determined using best professional judgment:

Taxon	Median Month of Initial Impingement Vulnerability
Black crappie	Sep
Bluegill type	Sep
Brown bullhead	Jul
Largemouth bass	Aug
Pumpkinseed	Sep
Rainbow smelt	Aug
Smallmouth bass	Aug
Spottail shiner	Sep
White sucker	Jun

Yellow bullhead	Jul
Yellow perch	May

In this assessment, we assumed that all individuals entrained or impinged in each age category were at the median age for that category. The median age is the age at which half of the individuals in that age category were older than the median age while the remaining half were younger. Median age for each age category was calculated as:

$$d_i = \frac{\ln 2 - \ln(1+e^{-Z_i t_i})}{Z_i}$$

where:

d_i = median age of Stage or Age Category (i)

t_i = duration (days) for Stage or Age Category (i).

Natural Mortality Rates

In this assessment natural mortality refers to any source of death other than through fishing or entrainment and impingement. In aquatic ecosystems, the ultimate cause of death, especially in the early stages of fish, is principally through predation. For calculation of production foregone, it was assumed that all natural mortality is a result of being consumed by predators.

A range (maximum, most probable, and minimum) of instantaneous natural mortality rates for each target species was obtained from the following sources:

Black crappie – Most probable daily instantaneous natural mortality rates for eggs, yolk-sac larvae, and post yolk-sac larvae were obtained from EPRI (2005a) Table 4-41. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively. Maximum and minimum daily instantaneous natural mortality rates for juvenile and older fish were obtained from EPRI (2005a) Table 4-41, and the most probable rate was assumed to be the midpoint between the maximum and minimum values.

Bluegill – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation a). Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Brown bullhead – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation a). Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Largemouth bass – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation a) for smallmouth bass. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Pumpkinseed – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation a) for bluegill as a surrogate. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Rainbow smelt – Most probable daily instantaneous natural mortality rates for eggs, yolk-sac larvae, and post yolk-sac larvae were obtained from EPRI (2005a) Table 4-37. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively. Most probable, maximum, and minimum daily instantaneous natural mortality rates for entrainable juveniles were obtained from EPRI (2005a) Table 4-37. Maximum and minimum daily instantaneous natural mortality rates for impingeable juveniles and for older fish were obtained from EPRI (2005a) Table 4-37, and the most probable value was assumed to be the midpoint between the maximum and minimum values.

Smallmouth bass – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation a). Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Spottail shiner – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation a) for a "generic" minnow or shiner species. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

White sucker — Most probable daily natural morality rates were obtained from EPRI (In preparation a) for shorthead redhorse as a surrogate. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Yellow bullhead – Most probable daily instantaneous natural morality rates were obtained from EPRI (In preparation a) for brown bullhead. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Yellow perch – Most probable, maximum, and minimum daily instantaneous natural mortality rates for eggs, yolk-sac larvae, and post yolk-sac larvae were obtained from EPRI (2005a) Table 4-39. Maximum and minimum daily instantaneous natural mortality rates for impingeable juveniles and for older fish were obtained from EPRI (2005a) Table 4-39, and the most probable value was assumed to be the midpoint between the maximum and minimum values.

The most probable values were used to provide the best estimates of equivalent loss, while the maximum and minimum values were considered in the uncertainty analysis.

Fishing Mortality Rates

Fishing mortality refers to the death of individuals as a result of commercial, recreational and/or subsistence fishing. In this assessment, fishing mortality was assumed to apply only to those 10 target taxa subject to fishing (black crappie, bluegill, brown bullhead, largemouth bass, pumpkinseed, rainbow smelt, smallmouth bass, white sucker, yellow bullhead, and yellow perch). One taxon, spottail shiner, was assumed not to be harvested by fishermen.

A range (maximum, most probable, and minimum) of instantaneous fishing mortality rates for all 10 target taxa subject to fishing were selected as follows:

Black crappie – Most probable daily instantaneous fishing morality rates were assumed to be one-half of the total annual mortality rate, which was obtained from EPRI (In preparation a), and equal to the natural mortality rate.

Bluegill – Most probable daily instantaneous fishing morality rates were obtained from EPRI (In preparation a). Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Brown bullhead – – Most probable daily instantaneous fishing morality rates were obtained from EPRI (In preparation). Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Largemouth bass – Most probable daily instantaneous fishing morality rates were assumed to be one-half of the total annual mortality rate, which was obtained from EPRI (In preparation a) for smallmouth bass, and equal to the natural mortality rate.

Pumpkinseed – Most probable daily instantaneous fishing morality rates were obtained from EPRI (In preparation a) for bluegill as a surrogate. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Rainbow smelt – Most probable daily instantaneous fishing morality rates were assumed to be one-half of the total annual mortality rate, which was obtained from EPRI (In preparation a), and equal to the natural mortality rate.

Smallmouth bass – Most probable daily instantaneous fishing morality rates were assumed to be one-half of the total annual mortality rate, which was obtained from EPRI (In preparation a), and equal to the natural mortality rate.

White sucker – Most probable daily fishing morality rates were obtained from EPRI (In preparation a) for shorthead redhorse as a surrogate. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Yellow bullhead – – Most probable daily instantaneous fishing morality rates were obtained from EPRI (In preparation a) for brown bullhead. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

Yellow perch – Most probable daily instantaneous fishing mortality rates were assumed to be one-half of the total annual mortality rate obtained from EPRI (2005a) Table 4-39, and equal to the natural mortality rate. Maximum and minimum values were assumed to be 25 percent higher and 25 percent lower than the most probable value, respectively.

As with natural mortality, the most probable values were used to provide the best estimates of equivalent loss, while the maximum and minimum values were considered in the uncertainty analysis.

Fishing Vulnerability Rates

Fishing vulnerability rates refer to the fraction of each age at a size vulnerable to be harvested by anglers. For the maximum and minimum fishing vulnerability rates used in this assessment, individuals were assumed to be not vulnerable (rate = 0) up to a set age and completely vulnerable (rate = 1) above that age. The ages of complete vulnerability were estimated using best professional judgment based on length at age information from the scientific literature and current fishing regulations. Resulting estimates are as follows:

Species	Age at Initial Fishing Vulnerability (Years)	
	Earliest	Latest
Black crappie		
Bluegill type	3	7
Brown bullhead	2	3
Largemouth bass	4	7
Pumpkinseed	3	7
Rainbow smelt	2	3
Smallmouth bass	4	7
White sucker	1	2
Yellow bullhead	2	3
Yellow perch	2	4

The maximum vulnerability was assigned using the earliest age whereas the minimum vulnerability was assigned using the latest age. The most probable values were assigned assuming that half of the population became vulnerable at the age of maximum initial vulnerability while the remaining half became vulnerable at the age of minimum initial vulnerability. These most probable values were used to provide the best estimates of equivalent loss, while the maximum and minimum values were considered in the uncertainty analysis.

Weight at Beginning of Age

This input parameter refers to the average weight of individuals as they enter each age category. These weights are then used to determine the average weight of harvested individuals for calculation of equivalent fishery yield and to determine the daily instantaneous growth rate used for calculation of production foregone.

A range (maximum, most probable, and minimum) of estimated weights at the beginning of each age were obtained for each target species from the following sources:

Black crappie –Most probable mean weights (g) for each life stage for eggs, yolk-sac larvae, and post yolk-sac larvae were obtained from EPRI (2005a) Table 4-41. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively. Maximum and minimum mean weights (g) at the beginning of each age for juvenile and older fish were obtained from EPRI (2005a) Table 4-41, and the most probable rate was assumed to be the midpoint between the maximum and minimum values.

Bluegill – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation a).   Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Brown bullhead – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation a). Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Largemouth bass – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation a) for smallmouth bass. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Pumpkinseed – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation) for bluegill. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Rainbow smelt – Most probable mean weights (g) of eggs, larvae, entrainable juveniles were obtained from EPRI (2005a) Table 4-37. Maximum and minimum values for the egg through age-0 juvenile life stages were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively. For age-1 and older fish, the maximum and minimum mean weights at the beginning of each age were obtained from EPRI (2005a) Table 4-37, and the most probable value was assumed to be the average of the maximum and minimum weights.

Spottail shiner – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation a) for a "generic" shiner or minnow. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Smallmouth bass – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation a). Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

White sucker – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation a) for shorthead redhorse. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Yellow bullhead – Most probable mean weights (g) at the beginning of each age were obtained from EPRI (In preparation a) for brown bullhead. Maximum and minimum values were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively.

Yellow perch – Most probable mean weights (g) of eggs, larvae, and entrainable juveniles were obtained from EPRI (2005a) Table 4-39. Maximum and minimum values for the egg through age-0 juvenile life stages were assumed to be 20 percent higher and 20 percent lower than the most probable value, respectively. For age-1 and older fish, the maximum and minimum mean weights at the beginning of each age were obtained from

EPRI (2005a) Table 4-39, and the most probable value was assumed to be the average of the maximum and minimum weights.

For all species, weights at the beginning of each month within an age were interpolated using an instantaneous growth rate based on the weights at the beginning and end of that age. The most probable values were used to provide the best estimates of equivalent loss, while the maximum and minimum values were considered in the uncertainty analysis.

Equivalent Loss Estimates

Equivalent loss estimates, defined in terms of equivalent fishery yield and production foregone, are the primary biological input to the economic valuation described in Chapter 4.

Annual fishery yield equivalent to the current entrainment and impingement losses at Merrimack totaled 313 lb for entrainment and 97 lb for impingement under actual cooling water flows (Table 3-1). Elimination of both entrainment and impingement at Merrimack could result in an additional annual fishery yield of 410 lb. Most (>73 percent) of this equivalent yield was attributed to just two species, white sucker and yellow perch.

Annual production foregone equivalent to the current entrainment and impingement losses at Merrimack totaled 2,160 lb for entrainment and 222 lb for impingement under actual cooling water flows (Table 3-2). Elimination of both entrainment and impingement at Merrimack could result in an additional annual biomass production of 2,382 lb. Most (> 83 percent) of this production foregone was attributed to three species, white sucker, yellow perch and brown bullhead.

Table 3-1 Estimates of Total Annual Equivalent Fishery Yield (lb) for each Target Species Equivalent to Entrainment and Impingement Losses at Merrimack

Taxa	Total Annual Equivalent Fishery Yield (lb)		
	Entrainment	Impingement	Combined
Black crappie	1	14	16
Bluegill type	0	39	39
Brown bullhead	29	2	30
Largemouth bass	0	8	8
Pumpkinseed	0	3	3
Rainbow smelt	0	1	1
Smallmouth bass	0	9	9
Spottail shiner[a]	0	0	0
White sucker	163	3	165
Yellow bullhead	0	2	2
Yellow perch	119	17	136
Total	313	97	410

[a] This species directly supports no commercial or recreational fisheries. Its value is indirect as forage to support other predator species.

Table 3-2 Estimates of Total Annual Production Foregone (lb) for each Target Species Equivalent to Entrainment and Impingement at Merrimack

Taxa	Total Annual Production Foregone (lb)		
	Entrainment	Impingement	Combined
Black crappie	6	36	41
Bluegill type	8	96	104
Brown bullhead	251	4	254
Largemouth bass	0	25	25
Pumpkinseed	0	6	6
Rainbow smelt	0	2	2
Smallmouth bass	0	16	16
Spottail shiner	187	0	187
White sucker	1,253	4	1,257
Yellow bullhead	0	3	3
Yellow perch	455	30	485
Total	2,160	222	2,382

4

ECONOMIC VALUATION

ECONOMIC VALUATION OF EQUIVALENT LOSSES

In the original Phase II rulemaking, USEPA defines “economic benefits” under §316(b) as the dollar value associated with environmental changes that enhance the welfare of individual humans resulting from the implementation of an alternative intake structure fish protection technology (USEPA 2004b). In this assessment, we calculated economic value by assuming that the economic value of fish entrained or impinged is equivalent to the total economic benefit that could accrue to the public had they not been entrained or impinged. In addition, we provide an estimate of the potential economic benefit that could accrue from the installation of closed-cycle cooling (i.e., cooling towers). USEPA defines methods for measuring four categories of benefit values relevant to §316(b) regulations for existing facilities: market direct use benefits, nonmarket direct use benefits, indirect use benefits, and nonuse benefits. The value of marketed goods is equivalent to the sum of predicted changes in “consumer and producer surplus”. Producer surplus is the difference between the price obtained for a good (e.g., fish) and the cost of producing that commodity. Consumer surplus is the difference between the perceived value of a good or service to the consumer and the cost of acquiring that good or service. Non-marketed goods, such as recreational fishing, normally require using indirect markets, such as travel and the cost of fishing gear, to infer their value. Indirect use benefits refer to increases in direct use benefits that might result indirectly such as through increases in forage fish abundance even though the resources themselves are not directly used. Finally, in addition to these direct and indirect use-related values, there is a potential for environmental changes to increase the welfare of individuals who do not use the resource at all. These latter benefits are considered nonuse benefits. More details on the economic value categories and the estimation process used are provided in EPRI (2005b).

METHODS TO ESTIMATE ANNUAL ECONOMIC VALUES

The potential economic values of entrainment and impingement for the facility were calculated for each of the benefit categories described using standard economic concepts outlined in USEPA (2004b, Part A: Evaluation Methods, Chapter A9: Benefit Categories and Valuation). Each of these benefit categories are discussed in detail below.

Direct Use Values

Direct use values accrue to those individuals that directly use the aquatic resources affected; in other words, commercial and recreational fishermen. The economic value of this benefit category is then equivalent to the economic value of the increased harvest by fishermen that would result had the fish not been impinged. Estimates of this increased harvest are equivalent to the biological benefit defined as equivalent fishery yield as described in the previous chapter and listed in Table 3-1. These biological benefit values were defined in terms of pounds to be consistent with reported fishery economic statistics. Using these estimates of increased fishery harvest, the economic value of the direct use benefit category was estimated for each sub-component (market and nonmarket) as follows.

Market Values (Commercial Fishing)

Market benefits refer to economic benefits that can be directly measured from data obtained in the marketplace. Changes in the magnitude of commercial fish and shellfish harvests are the principal market benefits relevant to §316(b) regulations. Since reductions in entrainment and impingement losses at cooling water intake structures have the potential to increase stock size, and hence commercial harvests, positive market benefits could potentially accrue from compliance with §316(b) regulations. These market benefits represent the increase in profits to commercial fishermen that could result from any increase in harvest. Market benefits were calculated as follows:

$$CFB_S = BBR_S \times CP_S \times FC_s \times PS$$

where:

CFB_S = Economic benefits ($) to commercial fishing for each Target Species (S)
BBR_S = Equivalent fishery yield (lbs) for each Target Species (S)
CP_S = Dockside price per pound paid to commercial fishermen for Target Species (S)
FC_S = Fraction of the total fishery yield harvested by commercial fishermen for Target Species (S)
PS = Producer surplus.

Estimates of the annual dockside landings and value for the only Target Species that might be commercially fished in the facility's watershed, the rainbow smelt, were obtained from the National Marine Fisheries Service (NMFS) commercial fish statistics website for 2008 in Great Lakes states). The total value was then divided by the total landings to determine the average dockside price per pound. Therepor values were inflated to 2010 values using the CPI and were used as the most probable value. Maximum and minimum values used in the uncertainty analysis were assumed to be 25 percent higher and lower than the most probable value, respectively. The resulting commercial values used in this assessment are as follows:

Target Species Subject to Commercial Harvest	Commercial Value (2010 $/lb)		
	Minimum	Most Probable	Maximum
Rainbow smelt	1.44	1.92	2.40

These dockside values, however, represent only the revenue returned to commercial fishermen and not the economic benefit (i.e., profits) of these fish. To estimate commercial fishing profits, the estimates of revenue need to be adjusted by both the consumer and the producer surplus rates. As assumed by USEPA (2004b) and USEPA (2006), we assumed that the levels of entrainment and impingement, if eliminated, would yield no consumer surplus. While there are many methods that can be used to estimate producer surplus, USEPA (2006) provided a range of estimates defined as a fraction of revenue based on a review of relevant studies for the Great Lakes region. Using these values, a most probable value of 29 percent (median of all USEPA values) and the minimum and maximum of 22 and 36 percent, respectively, were used for all commercially-harvested species in this assessment.

Finally the maximum, minimum, and most probable estimates for the fraction of the total fishery harvest attributable to commercial fishing was based on best professional judgment, guided by available information regarding the relative importance of commercial fisheries in the area compared to recreational fisheries. The resulting estimated fraction of the total harvest attributed to the commercial fishery for each species are as follows:

Target Species Subject to Commercial Harvest	Fraction of Total Fishery Yield Harvested by Commercial Fishermen		
	Minimum	**Most Probable**	**Maximum**
Rainbow smelt	0.05	0.10	0.15

Non-Market Direct Use Values (Recreational Fishing)

As the title suggests, this category includes values derived through use of the resource that are not reflected in the market for the resource. Relative to §316(b) regulations, the most common benefit that would accrue from reductions in entrainment and impingement would be through increases in recreational fishing opportunities. Increased abundance of adult fish that could result from decreasing entrainment and impingement losses can lead to increased catch rates for individual fisherman as well as an increase in the number of fishing trips by fishermen.

Unfortunately, economic value of increased recreational use of the resource are not directly reflected in the primary market – i.e., the market for recreational fishing. However, USEPA concluded that there is considerable literature to support valuing this benefit through estimation of a fisherman's "willingness to pay" for recreational opportunities. Thus, the non-market direct use value for additional recreational catch can be defined as the increase in the total "willingness to pay" across all fishermen resulting from any greater recreational opportunities due to reduction in entrainment and impingement losses. The recreational values used represent the marginal benefit per unit change in recreational catch.

For this assessment, total "willingness to pay" for each Target Species harvested by recreational fishermen was calculated by multiplying the estimated equivalent fishery yield to the recreational fishermen by the expected value per pound recreational fishermen were willing to pay for that increased harvest:

$$RFB_S = BBR_S \times RP_S \times (1 - FC_s)$$

where:

- RFB_S = Economic benefits ($) to recreational fishing for each Target Species (S)
- BBR_S = Biological benefits (lbs) to recreational fishing for each Target Species (S)
- RP_S = Value per pound recreational fishermen are willing to pay for the increase in harvest of the Target Species (S)
- FC_S = Fraction of the total fishery yield harvested by commercial fishermen for Target Species (S).

The equivalent yield to the recreational fishery at Merrimack (Table 3-1) appears to be only a very small fraction of the expected recreational catch of comparable species in the source river system. Hence, there is no reason to expect that changes in recreational fishing harvest that might result from reductions in entrainment and impingement at the facility will be sufficiently large so as to affect the price the fishermen are willing to pay. Therefore, it is assumed that the values the recreational fishermen are currently willing to pay for each species should be a reasonable measure of the value they would be willing to pay had entrainment and impingement not occured. This is the same assumption used by USEPA in calculating the national benefits of the Phase II rule (USEPA 2004b).

For this assessment, the values provided in USEPA (2006) Table A5-7 for the Inland region were used to assign the recreational value per fish for each of the Target Species. The maximum and minimum values were assumed to be represented by the upper and lower 95th percent confidence bounds (Table A5-8 of USEPA 2006). Bluegill, brown bullhead, yellow bullhead, pumpkinseed, black crappie and yellow perch were assigned values from the USEPA's "panfish" category. Smallmouth bass and largemouth bass were assigned values from the USEPA's "bass" category. White sucker was assigned one-half the value of panfish since, although occasionally caught, it is not actively sought by recreational fishermen. Values presented in USEPA (2006) were adjusted upward by the CPI to reflect values in 2010:

Species Group	Recreational Value (2010 $/fish)		
	Minimum	**Most Probable**	**Maximum**
Panfish	0.55	1.02	1.87
Bass	5.62	8.27	12.21
White sucker	0.28	0.51	0.93

To convert these values to a weight basis to be consistent with the biological benefits calculation, each of these recreational values were divided by range of estimated average weight per harvested fish expected based on available information and best professional judgement. The resulting average weights per fish used are as follows:

Recreationally-Harvested Species	Average Weight per Fish Harvested (lb/fish)		
	Minimum	Most Probable	Maximum
Black crappie	0.2	0.3	0.4
Bluegill type	0.1	0.2	0.3
Brown bullhead	0.5	0.8	1.0
Largemouth bass	1.0	1.5	2.0
Pumpkinseed	0.1	0.15	0.2
Smallmouth bass	1.0	1.5	2.0
White sucker	0.3	0.5	0.8
Yellow bullhead	0.5	0.8	1.0
Yellow perch	0.3	0.4	0.5

The resulting minimum and maximum values per pound of fish were the lowest and highest values calculated whereas the most probable was assigned as the median value for all combinations of value per fish and average weight. The resulting recreational values for each Target Species are as follows:

Recreationally-Harvested Species	Recreational Value (2010 $/lb)		
	Minimum	Most Probable	Maximum
Black crappie	1.38	3.40	9.35
Bluegill type	1.38	3.40	9.35
Brown bullhead	0.55	1.28	3.74
Largemouth bass	2.55	5.80	14.87
Pumpkinseed	2.75	6.81	18.70
Smallmouth bass	2.55	5.80	14.87
White sucker	0.34	1.02	3.12
Yellow bullhead	0.55	1.28	3.74
Yellow perch	1.10	2.55	6.23

These most probable values were used to provide the best estimates of equivalent loss while the maximum and minimum values were considered in the uncertainty analysis.

Indirect Use Benefits

This category includes benefits that accrue to humans from the use of the resource indirectly. Relative to §316(b) regulations, the indirect benefit that could result from reductions in entrainment and impingement would be through an increased consumption by higher trophic levels of production that results from these organisms. This increased consumption could result in greater growth and survival rates among fish in these higher trophic levels, and hence, increase fishing opportunities. Production consumed by higher trophic levels results from both forage species, such as spottail shiner, as well as individuals of harvested species that die of natural causes.

Unfortunately, there are no generally accepted methods to directly assign a value to this benefit. Instead, the value of this benefit is assigned indirectly by quantifying the amount of commercially and/or recreationally important species that could be supported by the production potentially generated by these entrained and impinged organisms, which were subsequently harvested by man. Hence, the value of the production increase resulting from implementation of any entrainment or impingement reduction efforts is equal to the value of the increase in commercial and/or recreational harvest that could be supported by that production.

The value of the indirect benefits was estimated for the Target Species impinged at Merrimack using the following three-step process.

<u>Step 1 – Estimation of Total Biomass of Higher Trophic Levels Supportable by the Annual Productivity Equivalent to the Reduction in Entrainment or Impingement.</u> The total biomass of higher trophic levels supportable is calculated by using a trophic transfer method as follows:

$$HTB = \sum_{S=1}^{11} \left(PFB_S \right) \times TTC$$

where:

HTB = Total annual higher trophic level biomass (lb) supported by production foregone attributable to entrainment and impingement

PFB_S = Biomass production foregone for Target Species (S) attributable to entrainment and impingement

TTC = Trophic transfer coefficient.

This approach is identical to that used by USEPA in the original Section 316(b) Final Phase II (USEPA 2004b) and Phase III (USEPA 2006) rules.

For this assessment, production foregone estimates from entrainment and impingement for each of the Target Species were calculated using the Production Foregone Model as described in Section 3 and listed in Table 3-2. These estimates of production foregone were based on estimates of annual entrainment and impingement at the facility. A trophic transfer coefficient of 10 percent, consistent with USEPA (2004b), was then used to convert the total biomass forgone to an amount of higher trophic level biomass supportable by that production foregone. The coefficient means that an average of 10 percent of the production foregone would have ended up as predator biomass. For the uncertainty analysis, a range for the trophic transfer coefficient of 5 to 15 percent was assumed.

Step 2 – Estimation of Fishery Harvest Supported by Annual Productivity Equivalent to the Annual Entrainment and Impingement. As previously noted, the value of indirect benefits is determined by the value of the commercial and/or recreational harvest supported by the increased productivity. Hence, the total higher trophic level biomass estimated under Step 1 needs to be converted to an estimate of actual yield to the fishery expressed as equivalent predator harvest. This is accomplished by assuming that the total higher level biomass is converted to biomass of a popular commercial or recreational species and then multiplying the value by the annual fishery exploitation rate for that species as follows:

$$EPY = HTB \times ER_{EP}$$

where:

EPY = Equivalent predatory yield (lbs) attributable to entrainment and impingement

HTB = Higher trophic level biomass (lbs) attributable to entrainment and impingement

ER_{EP} = Fishery exploitation rate for the selected equivalent predator.

For this assessment, the equivalent predator was assumed to be largemouth bass, a popular target of recreational fishermen in the region. In reality, any potential production increase would of course be transferred among many species, including some with little or no recreational or commercial importance. Hence, this species should be a reasonably representative species for assigning economic value for this assessment. The annual exploitation rate for the equivalent predator was estimated to be 25 percent. For the uncertainty analysis, a range of 15 to 35 percent was assumed.

Step 3 – Estimation of Indirect Use Economic Benefits of Entrainment and Impingement. The equivalent predator species selected for this study (largemouth bass) is a popular target of and recreational fishermen but is not subject to a commercial fishery.

For this assessment, the recreational value of largemouth bass per pound was determined as described above for other recreational species. Largemouth bass were assigned values per fish from the USEPA's "bass" category. Average harvested weights per fish and resulting recreational values as a follows:

Average Weight per Fish Harvested (lb/fish)		
Minimum	**Most Probable**	**Maximum**
1.0	1.5	2.0
Recreational Value (2010 $/lb)		
2.55	5.80	14.87

Non-Use Benefits

As previously discussed, this category, also known as passive use values, includes all benefits above and beyond any accrued through use of the resource. Most commonly cited non-use benefits include bequest and existence values (EPRI 2005b). USEPA (2004a) acknowledges that these benefits can best be estimated using contingent valuation methods on a site-specific basis. However, they concluded that such studies are unlikely to be conducted for specific facilities and were clearly beyond the scope and budget of USEPA for development of the §316(b) regulations.

In the original Phase II rule, USEPA provided that, "In cases where an impingement mortality and entrainment characterization study does not identify substantial harm to a threatened or endangered species, to the sustainability of populations of important species of fish, shellfish, or wildlife, or to the maintenance of community structure and function in a facility's waterbody or watershed, monetization [of non-use benefits] is not necessary" [p.41648]. However, they do require a qualitative discussion of these benefits if they are believed to exist.

A detailed examination of current levels of entrainment and impingement at the facility does not provide any evidence that its cooling water intake structure is causing “substantial harm” to threatened and endangered species or to aquatic populations and communities of the river from which cooling water is withdrawn. Therefore, consistent with the USEPA approach for the Section 316(b) Phase II Rule, non-use values were not included in this economic valuation.

Estimated Total Annual Economic Value

The total annual economic value of the Target Species entrained or impinged is the sum of the annual economic values for all benefit categories described above. These Target Species, however, do not account for all fish entrained or impinged at the facilities included in this assessment. The following equation was used to account for the value of non-Target Species impinged at each facility:

$$Ben_{non-TS} = \left(\frac{1}{IF_{TS}} - 1 \right) \times \sum_{TS=1}^{12} Ben_{TS}$$

where:

$Ben_{non\text{-}TS}$	=	Economic value of non-Target Species
Ben_{TS}	=	Economic value of the 11 Target Species and the Equivalent Predator
IF_{TS}	=	The fraction of total annual loss accounted for by the 11 Target Species (0.919 for entrainment and 0.894 for impingement.

The total annual economic value of <u>all</u> fish species impinged and entrained at the facility is then the sum of the benefits to the Target Species, the benefit to the Equivalent Predator, and the benefit to non-Target Species.

ESTIMATES OF TOTAL ANNUAL ECONOMIC VALUE

Annual economic value of all fish lost to the cooling water intake system at the Merrimack totaled $901 for entrainment and $520 for impingement under actual cooling water flows (Table 4-1). Elimination of both entrainment and impingement at the facility could result in an additional annual economic value of $1,420. Most (> 64 percent) of this economic value can be attributed to the increased production foregone through the equivalent predator and two representative species, yellow perch and bluegill. Entrainment accounted for approximately 63 percent of the total economic value of entrainment and impingement at this facility.

If closed cycle cooling was implemented at both units at Merrimack, it is reasonable to expect that reductions of approximately 93 percent in water withdrawals would occur. Assuming that entrainment and impingement levels at this facility are proportional to water withdrawals, one would expect a similar reduction in entrainment and impingement losses yielding an annual economic benefit of $1,321 ($838 from entrainment and $484 from impingement) from the installation of cooling towers at this facility.

Table 4-1 Estimates of Total Annual Economic Value (2010$) for each Target Species Equivalent to Entrainment and Impingement at Merrimack

Taxa	Total Annual Economic Value (2010$)		
	Entrainment	Impingement	Combined
Black crappie	4.70	48.17	52.88
Bluegill type	2.26	214.13	216.39
Brown bullhead	36.74	2.22	38.96
Largemouth bass	0.00	45.34	45.34
Pumpkinseed	0.00	21.27	21.27
Rainbow smelt	0.00	0.05	0.05
Smallmouth bass	0.00	53.44	53.44
Spottail shiner[a]	0.00	0.00	0.00
White sucker	166.09	2.56	168.65
Yellow bullhead	0.00	2.87	2.87
Yellow perch	304.39	42.85	347.24
Equivalent predator	313.18	32.21	345.24
Non-target species	73.32	55.15	128.46
Total	900.68	520.26	1,420.94

[a] This species directly supports no commercial or recreational fisheries. Its value is indirect as forage to support other predator species.

5

UNCERTAINTY ANALYSIS

USEPA's Phase II §316(b) Rule requires that a facility seeking a site-specific determination based on benefits valuation also submit "an analysis of the effects of significant sources of uncertainty on the results of the study" [§125.95(b) (6) (iii) (C)]. Uncertainty refers to the lack of knowledge about measures and components that go into each element of the Benefits Valuation Study. The purpose of the Uncertainty Analysis is to make transparent all the underlying sources of uncertainty in the calculation of economic value such that the appropriate regulatory authority can independently determine whether the results have sufficient precision and accuracy to meet regulatory needs (USEPA 2004b) and form sufficient basis for sound regulatory decisions. The purpose of this chapter is to evaluate the effects of uncertainty in key input parameters on the estimates of economic value in this assessment.

Uncertainty is not unique to an Economic Valuation Study under §316(b). Some uncertainty exists in almost all predictions of future conditions based on past or existing information and this is especially true when dealing with environmental science and economic issues. In both environmental science and economics, inherent variability and limited understanding of underlying processes coupled with difficulty in making accurate measurements of underlying parameters makes consideration of uncertainty in these cases especially important. Uncertainty analysis is becoming an increasingly important part of cost-benefit assessments as they play a greater role in the environmental regulatory process.

USEPA (2000) identified the following minimum requirements applicable to most uncertainty analyses related to environmental regulations:

- To present the outcomes or conclusions based on expected or most plausible values;
- To provide descriptions of all known key assumptions, biases, and omissions;
- To perform sensitivity analysis on key assumptions; and
- To justify the assumptions used in the sensitivity analysis.

Uncertainty arises in assessments such as an Economic Valuation Study from three general sources: natural variation, uncertainty in model structure, and uncertainty in model parameters. Natural variation results from natural differences across elements within a population or in a population across time. For example, not all members of the United States population are expected to value increased recreational fishing opportunities to the same degree. Alternatively, wide year-to-year differences in entrainment and impingement densities at the same station are common. These differences in abundance can result in large differences in the annual economic value.

Both of these examples can yield uncertainty in the total economic value estimated under §316(b).

Uncertainty related to model structure arises from the lack of knowledge as to what is the most appropriate form of the model to accurately describe the process being modeled. For example, the form of the relationship between the number of trips and travel cost in a simple travel cost model has been assumed to be linear, semi-log, or log by various analysts (Rosenberger and Loomis 2001). However, the most appropriate form is still a matter of debate. Likewise, alternatives that reduce total cooling water flow, such as cooling towers, can result in reduced entrainment and impingement. Most commonly, an assumption of a linear relationship with cooling water volume is made. However, this assumption also remains an area of debate (reference result of E&I database analysis when available.

Finally, uncertainty in model parameters can result from difficulty in measurement or in inherent variability in the model parameter. This is likely to be the most frequently encountered source of uncertainty in economic valuation under §316(b). Examples of this source of uncertainty include estimates of life stage-specific life table parameters for equivalent loss estimation and measurements of fishermen's "willingness to pay" obtained from surveys.

In this chapter we address three broad areas of uncertainty: parameters used to estimate direct and indirect use values, questions regarding the use and magnitude of nonuse benefits, and the economic factors used to estimate the lifetime benefits, focusing primarily on uncertainty in model parameters. More general information on these sources of uncertainty relative to §316(b) is provided in EPRI (In preparation b).

As indicated by USEPA (2000), uncertainty can be addressed either quantitatively (e.g., sensitivity or Monte Carlo analysis) or qualitatively. The results of uncertainty analysis using each of these approaches for Merrimack are discussed below.

QUANTITATIVE ANALYSIS OF UNCERTAINTY

Sufficient information exists to conduct a technically sound quantitative uncertainty analysis for many of the inputs used to estimate equivalent loss and resulting economic value. Key input parameters addressed quantitatively include:

- Natural mortality rate,
- Fishing mortality rate,
- Fraction commercial,
- Vulnerability to fishery,
- Mean weight at beginning of each stage,
- Trophic conversion factor,
- Exploitation rate for equivalent predator,
- Commercial price per pound,

- Producer surplus, and
- Recreational value per pound.

Three other key input parameters, entrainment and impingement rates and age composition, were not explicitly addressed in this uncertainty analysis as reliable information on the uncertainty was unavailable from the existing studies. Uncertainty for this assessment was addressed by two means. First, a sensitivity analysis was conducted on individual input parameters. Second, a Monte Carlo analysis was conducted to determine the likely overall uncertainty in the estimates of annual economic value resulting from the current levels of uncertainty. The results of each of these analyses are provided below.

Sensitivity Analysis

A sensitivity analysis was conducted individually on each of the ten input parameters listed above. Multiple calculations of annual benefits were made using the extreme values (i.e., maximum and minimum) for each parameter while holding all other parameters constant at their most probable values. The purpose of this sensitivity analysis is to determine the parameters for which the current levels of uncertainty have the greatest effect on the estimates of annual economic benefit.

Uncertainty in the natural mortality rate yielded the greatest range in estimates of annual economic value (-50 to +218 percent) while uncertainty in the recreational price per pound yielded the second greatest range (-60 to +176 percent) (Figure 5-1). Uncertainty in these two parameters was clearly the most important factor in determining the total uncertainty in the estimate of annual economic value. Uncertainty in the remaining eight input parameters individually had relatively minor effects on estimates of annual economic value (< ± 25 percent).

Monte Carlo Analysis

Monte Carlo analysis was used to assess the overall uncertainty in the estimates of total annual economic value based on the current levels of uncertainty in each of the ten input parameters. For each of these parameters, random values were selected from a triangular distribution[3] wherein the maximum and minimum values for the distribution were set to the maximum and minimum values for each parameter described earlier and the mode of the distribution was set to the mid-point used as the best estimate for each parameter. Values for each parameter were randomly selected separately for each species and life stage and the Monte Carlo analysis was run using 1,000 iterations to define the resulting frequency distribution in annual estimates of economic benefit.

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[3] *THE TRIANGULAR DISTRIBUTION IS ONE OF A LARGE NUMBER OF POSSIBLE DISTRIBUTIONS THAT COULD BE USED FOR EACH OF THE INPUT PARAMETERS. UNFORTUNATELY, SUFFICIENT INFORMATION TO ACCURATELY DESCRIBE THE UNDERLYING FREQUENCY DISTRIBUTIONS FOR EACH INPUT PARAMETER DOES NOT EXIST. THIS COMMONLY-USED DISTRIBUTION IS FLEXIBLE TO MEET A WIDE VARIETY OF SITUATIONS AND IS DEFINED BY SET MAXIMUM, MINIMUM AND MOST PROBABLE VALUES. AS USED IN THIS ANALYSIS, THE TRIANGULAR DISTRIBUTION IS SYMMETRICAL LIKE THE NORMAL DISTRIBUTION BUT CONSTRAINED WITHIN SET MAXIMUM AND MINIMUM VALUES.*

The frequency distribution of the resulting annual estimates from the Monte Carlo analysis appeared generally symmetrical, although most of the estimates of economic value resulting from this uncertainty analysis were higher than the most probable estimate (Figure 5-2). The median value from the Monte Carlo analysis was 41 percent higher than the most probable estimate while the 25th and 75th percentiles were 23 percent and 60 percent higher, respectively. There was less than a 3 percent chance that the true annual economic benefit was more than twice the most probable estimate reported in Table 4-1. The fact that most of the estimates of economic value were higher than the most probable estimate is likely related to the non-symmetrical effects of the two key parameters, the natural mortality rate and the recreational price per pound, described above.

QUALITATIVE DISCUSSION OF UNCERTAINTY

Uncertainty in a variety of other assessment inputs and assumptions could not be assessed quantitatively with any degree of certainty. These factors were addressed qualitatively. In this qualitative assessment, the nature of the uncertainty is discussed along with an assessment of the likely magnitude, and, if possible, direction of the effect that uncertainty might have in estimates of economic value. Each of these factors are grouped into one of three categories and discussed below.

Factors that lead to overestimates of economic value

Uncertainty in these factors tends to result in estimates of economic value that are higher than the true value:

Entrainment and impingement survival

Estimates of loss in this assessment assumed that all individuals entrained or impinged at Merrimack die as a result of exposure to the facility's cooling water system. However, numerous studies at facilities located throughout the country that are summarized in EPRI (2000, 2003, 2010) demonstrate that individuals of some species are returned to the source waterbody alive following entrainment and impingement. These studies revealed that the rate of survival is very site-specific and depends on both species composition and the nature of the stressors encountered. For example, both entrainment and impingement survival at Merrimack can be expected to be very low for delicate species such as rainbow smelt and spottail shiner. On the other hand, both entrainment and impingement survival could be moderate to high for many of the other Target Species, such as the bullheads and bass. It is not unreasonable to expect that 50 percent or more of these other Target Species can and do survive being entrained or impinged.

While no attempt was made to quantify the effects of either entrainment or impingement survival at Merrimack, it is reasonable to expect that had such site-specific data been available, then estimates of economic value of entrainment and impingement and the potential economic benefits of cooling tower installation would have been much lower than that provided in this report.

Density dependence

While there is general agreement as to the importance of density to population processes, the magnitude of effects of organism density on growth, reproductive and mortality rates, especially when it comes to assessment of entrainment and impingement effects, has been an area of controversy for many years. In valuation, we have assumed that the life table inputs (i.e., mortality and growth rates) remain constant and equal to those developed using available scientific information together with best professional judgment. Since entrainment and impingement result in the loss of organisms, it is possible that such processes could lead to in reductions in densities sufficient to yield increases in population survival and growth rates. To the extent that such processes occur, estimates of economic value and the benefits of cooling tower installation will be over estimated. The magnitude of such overestimation will depend on a variety of factors including the magnitude of other sources of mortality as well as the life history strategies of those species involved.

Selection of equivalent predator

In this assessment, a single equivalent predator, largemouth bass, was used. The means that we assumed that all biomass production that the organisms entrained or impinged would have produced had they not been entrained or impinged would have been consumed only by largemouth bass. However, in reality, biomass produced by organisms not entrained or impinged could have been consumed by a wide variety of predators including fish, larger invertebrates, and birds as well as by lower trophic levels through decay.

Largemouth bass is a popular target of recreational fishermen in the area and, as a result, is highly valued as measured in willingness-to-pay measures. Hence, it is likely that in reality at least a portion of the production foregone estimated in this report would be consumed by predators less value by fishermen. To the extent that this occurs, the economic value and benefits of cooling tower retrofits as estimated in this report will be higher than actually exists.

Factors that lead to underestimates of economic value

Uncertainty in these factors tends to result in estimates of economic value that are lower than the true value:

Entrainment and impingement collection efficiency

In this assessment, we assume that the estimates of entrainment and impingement for the target species are accurate. However, there are a variety of factors that can lead to underestimates of actual entrainment and impingement. These factors are typically site-specific and can vary with species and characteristics of the entrainment and impingement sampling design. Collectively the degree to which measures of entrainment and impingement accurately reflect true entrainment and impingement is known as collection efficiency. Collection efficiency in entrainment and impingement studies are discussed in detail in EPRI (2004b and 2005b). To the extent that reduced collection efficiency lead to estimates of entrainment and impingement that are biased low, an underestimate of true economic value and benefit of cooling tower installation will result.

Factors that could yield either overestimates or underestimates of economic value

Uncertainty in these factors tends to result in estimates of economic value that are lower than the true value:

Inter-annual variability

Total entrainment and impingement at any single cooling water intake structure is rarely consistent from one year to the next. In fact, wide swings in entrainment and impingement at any single facility are the norm rather than the exception (EPRI 2004b, 2005b). Recent monitoring of impingement at 15 cooling water intake structures on the Ohio River found differences impingement levels from one year to the next to be as much as 10-fold (EPRI 2009). Such wide swings in abundance are most common where species with especially high reproductive potential dominate entrainment and impingement collections. These species tend to naturally exhibit large differences in early life stage abundance from one year to the next as a result of highly variable environmental conditions.

Given the potential magnitude of variability in annual entrainment and impingement from one year to the next, it is likely that this single factor will dominate uncertainty in estimates of economic value and the benefits of cooling tower installation at many, if not most, facilities. Unfortunately, without long-term entrainment and impingement monitoring over potentially decades, it will be difficult to assessment the uncertainty in both economic value as well as benefits of cooling tower installation attributable to this factor at any single facility.

Reduction in thermal effects

Installation of cooling towers at a facility will virtually eliminate the discharge of waste heat into the receiving waterbody normally associated with once-through cooling. Such installation will virtually eliminate the discharge of waste heat into the receiving waterbody normally associated with once-through cooling. This waste heat can have detrimental effects on aquatic communities in the receiving waterbody. These discharges of waste heat are regulated under §316(a) of the Clean Water Act which requires that discharge permits ensure the protection and propagation of a balance, indigenous aquatic community in the receiving waterbody. Hence, assuming that an individual facility is in compliance with §316(a) requirements, then removal of the waste heat discharges should have only a minor benefit to the aquatic ecosystem.

On the other hand, these thermal discharges can have some positive benefits for the aquatic ecosystem and to man's utilization of this resource. For example, heated discharge can actually increase aquatic productivity during times of the year when temperatures are less than optimal. In addition, heated discharges serve as important refuges for less cold-tolerant species in some areas of the country. Finally, thermal discharges can attract fish during colder months of the year and yield popular destination for recreational fishermen from late fall through early spring.

Hence, the removal of thermal discharges through the installation of cooling towers could have both positive and negative effects. The overall net benefit will be highly site-specific and will depend on the relative importance assigned to each effect.

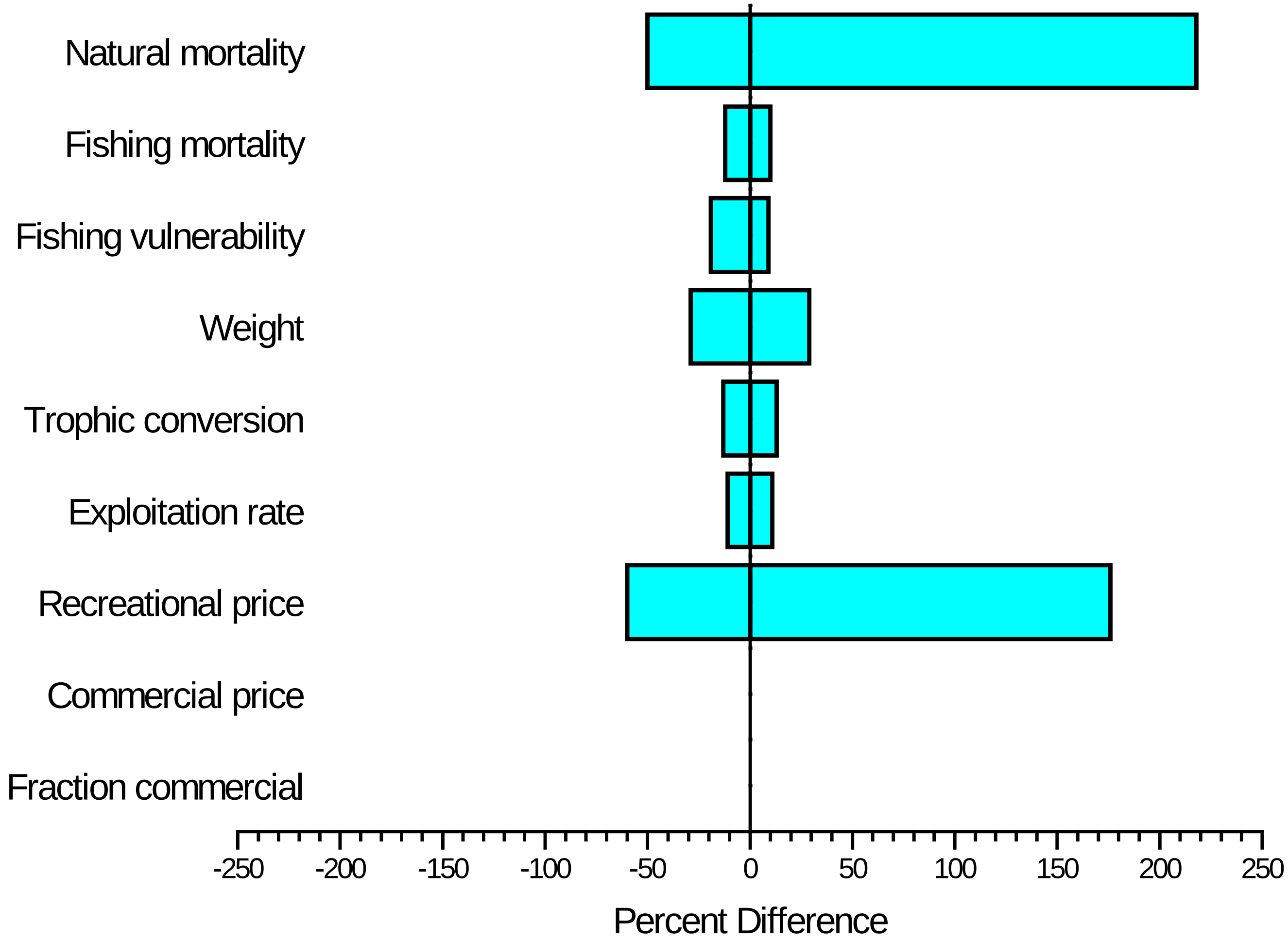

Figure 5-1 Estimates of the Range of Effects of Uncertainty in each Input Parameter on Estimates of Annual Economic Benefit for Merrimack

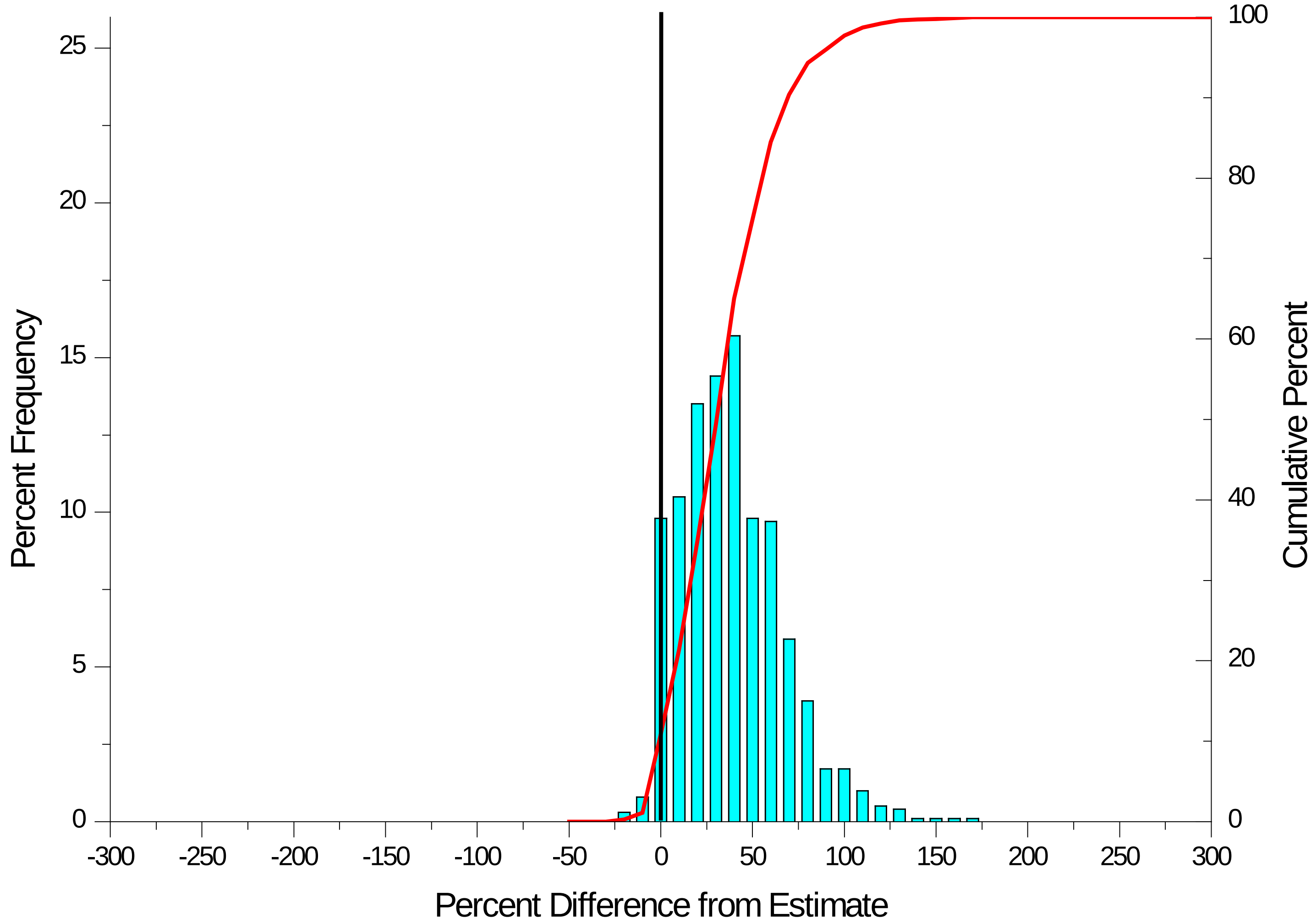

Figure 5-2 Results of Monte Carlo Analysis of Uncertainty in all Input Parameters on Estimates of Annual Economic Benefits at the Merrimack

6
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A

APPENDIX A: ESTIMATION OF AGE COMPOSITION FOR IMPINGED FISH

Age composition of impinged fish was estimated from length data. Cut-point lengths between ages were set mid-way between the mean lengths of successive age classes. The process is illustrated for a hypothetical example in Figure A-1. Note that even though length distributions are highly overlapping this approach yields reasonable estimates. These cut-points were first estimated for the month of annulus formation. Cut-points for other months were interpolated by eye. The upper cut-points used to designate each age group are provided in Table A-1; the assigned ages are in Table A-2.

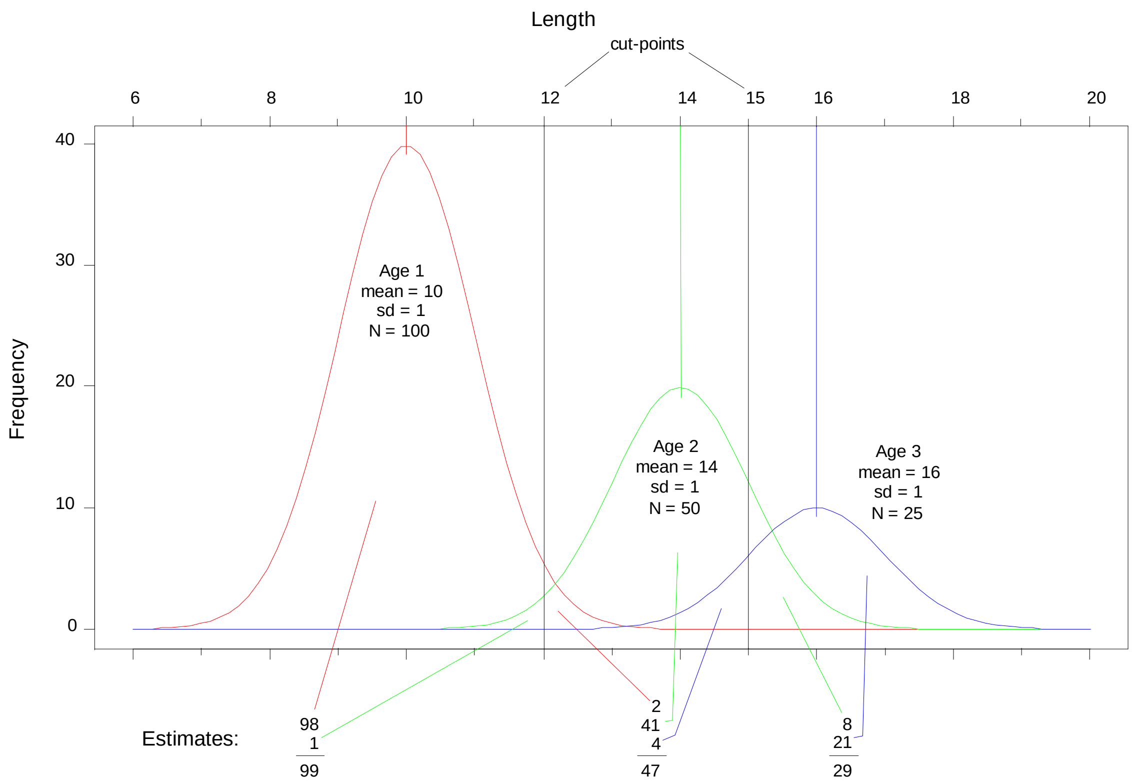

Figure A-1. Method of Setting Cut-point Halfway Between Mean Lengths for a Plausible Hypothetical Example

Table A-1. Spawning Month for Target Species and Associated Cut-points for Age Classes

Age	Spottail shiner	White sucker	Yellow bullhead	Brown bullhead	Rainbow smelt	Bluegill
	May	May	June	June	May	June
1	70	81	90	90	124	78
2	98	153	140	165	165	116
3	112	219	190	212	>165	146
4	121	268	229	249		170
5	>121	322	>229	>249		194
6		351				>194
7		369				
8		>369				

Age	Pumpkinseed	Smallmouth bass	Largemouth bass	Black crappie	Yellow perch
	June	June	June	June	May
1	78	125	125	78	100
2	89	257	197	146	149
3	122	355	267	200	180
4	148	>355	334	243	196
5	144		391	263	211
6	>144		408	>263	264
7			432		275
8			449		>275
9			>449		

Table A-2. Assigned Age-frequency Distributions Based on Length Frequencies for Target Species at Merrimack from June 2005 to June 2007

Age	Age Frequency					
	Spottail shiner	White sucker	Yellow bullhead	Brown bullhead	Rainbow smelt	Bluegill
0	15.58%	0.00%	0.00%	0.00%	100.00%	12.10%
1	18.50%	0.00%	0.00%	79.92%	0.00%	82.14%
2	23.96%	0.00%	48.00%	0.00%	0.00%	3.35%
3	28.67%	0.00%	52.00%	20.08%	0.00%	1.07%
4	6.74%	0.00%	0.00%	0.00%	0.00%	0.82%
5	6.55%	0.00%	0.00%	0.00%	0.00%	0.00%
6	0.00%	0.00%	0.00%	0.00%	0.00%	0.52%
7	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
8	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%
Sum	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Age	Pumpkinseed	Smallmouth bass	Largemouth bass	Black crappie	Yellow perch
0	19.13%	26.32%	91.39%	63.29%	5.99%
1	31.05%	40.35%	8.61%	36.71%	55.03%
2	36.68%	0.00%	0.00%	0.00%	22.84%
3	13.14%	16.67%	0.00%	0.00%	11.54%
4	0.00%	0.00%	0.00%	0.00%	1.55%
5	0.00%	16.67%	0.00%	0.00%	0.00%
6	0.00%	0.00%	0.00%	0.00%	3.06%
7	0.00%	0.00%	0.00%	0.00%	0.00%
8	0.00%	0.00%	0.00%	0.00%	0.00%
Sum	100.00%	100.00%	100.00%	100.00%	100.00%