Attachment A

Review of technical documents related to NPDES Permitting Determinations for the Thermal Discharge and Cooling Water Intake Structures at Merrimack Station

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Introduction

In 2007, to support its request for a §316(a) variance as part of the current permit determination, Public Service of New Hampshire (PSNH) submitted a set of technical documents which, together with other documents previously submitted to EPA, constituted a §316(a) Demonstration. EPA performed an independent analysis of the data submitted by PSNH and concluded that PSNH's submission did not support the issuance of a §316(a) variance.

At issue in the current permit proceeding are (1) whether operation of Merrimack Station using the existing once-through cooling system has caused appreciable harm to the balanced, indigenous population of shellfish, fish, and wildlife ("BIP") in the Merrimack River, (2) whether continued operation of Merrimack Station will assure the protection and propagation of the BIP, (3) whether alternative cooling water technologies must be installed to satisfy the technology-based requirements of §316(a), (4) whether more stringent thermal discharge limits are required to satisfy New Hampshire's thermal water quality standards, and (5) whether an alternative cooling water withdrawal technology must be installed to minimize adverse impacts of entrainment and impingement (E&I) as required by §316(b).

At the request of PSNH, I reviewed EPA's §316 determination and also documents prepared by PSNH's consultants Normandeau and Enercon to determine whether the available data and analyses support EPA's conclusions.

Evaluation of EPA's §316(a) Determination

EPA's "Clean Water Act NPDES Permitting Determinations for the Thermal Discharge and Cooling Water Intake Structures at Merrimack Station in Bow, New Hampshire" contains a critique of materials submitted by PSNH in support of a variance request under §316(a) of the Act. In addition, the Determination contains EPA's own independent analysis of the data submitted by PSNH, from which EPA concludes that the operation of

Merrimack Station has caused appreciable harm to the fish community present in the Hooksett Pool. This analysis provides the technical justification for EPA's denial of PSNH's variance request.

EPA's argument that operation of Merrimack Station has caused appreciable harm to the fish community present in the Hooksett Pool is based on four major premises:

1. The fish species present and dominant in the 1960s, prior to the startup of unit 2, constitute the appropriate Balanced Indigenous Population (BIP) for evaluating appreciable harm caused by the station's thermal discharge.

2. The fish species that were dominant in the 1960s, declined greatly beginning in the early 1970s. These species were "coolwater" species that were replaced by "warmwater" species, especially bluegill.

3. Comparisons of published thermal tolerance data to measured and predicted temperatures in the Merrimack Station discharge canal and in the river downstream from the discharge support a conclusion that elevated temperatures caused by the thermal plume have harmed yellow perch and other members of the BIP.

4. Comparisons between fish populations in the Hooksett Pool and fish populations in other similar waterbodies support a conclusion that Merrimack Station has caused appreciable harm to members of the BIP

Each of these premises is discussed in turn below:

The fish species present and dominant in the 1960s, prior to the startup of Unit 2, constitute the appropriate BIP for 316(a) determination

It might seem reasonable to base a 316(a) determination on a "before" vs. "after" comparison of the kind relied on by EPA. However, in this case there is a significant complicating factor, namely the transition of the Merrimack River from the highly polluted conditions prevalent prior to 1970 to the greatly improved conditions present in more recent years.

The following quotation is from EPA's draft §316(a) Guidance (USEPA 1977):

> "For purpose of a 316(a) demonstration, distribution and composition of the indigenous population should be defined in terms of the population which would be impacted by the thermal discharge caused by the alternative effluent limitation proposed under 316(a). *A determination of the indigenous population should take into account all impacts on the population except the thermal discharge*[1]. Then, the discrete impact of the thermal discharge on the indigenous population may be estimated in the course of a 316(a) demonstration. In order to determine the indigenous population which will be subject to a thermal discharge under an alternative 316(a) effluent limitation, it is necessary to account for all non-thermal impacts on the population such as industrial pollution, commercial fishing, and the entrapment and entrainment effects of any withdrawal of cooling water through intake structures under the alternative 316(a) effluent limitation. The above considerations will then make it possible to estimate the true impact of the thermal discharge on the population.

The above paragraph makes it clear that in evaluating the effects of Merrimack Station's thermal discharge it is necessary to account for the potential effects of other stressors, in particular water pollution. As noted by EPA in its NPDES permitting determination for Merrimack Station (p. 22), EPA regulations *require* applicants seeking alternative effluent limitations to evaluate the cumulative impact of the proposed thermal discharge together with other stressors affecting the Balanced Indigenous Population (BIP). Logically the same requirement should be placed on EPA when performing an independent evaluation of applicants' data.

Available historical data show that during the 1960s the section of the Merrimack River that includes Hooksett Pool was adversely affected by water pollution. USDI's (1966) report on pollution of the Merrimack River identified 11 untreated waste discharges to the Merrimack River and tributaries upriver from Manchester, NH. These included

[1] Emphasis added

municipal sewage discharges from Concord, Pembroke, Allentown, and Hooksett (USDI 1966, Table 3). Minimum dissolved oxygen levels measured at all stations between Concord and Manchester were below 5 PPM, the limit established by EPA for protection of aquatic life (USDI 1966, Figure 19).

Nitrate and phosphate, although not directly toxic to aquatic life, are plant nutrients that stimulate plant growth and sometimes cause blooms of harmful algae. Data on nitrogen and phosphorus concentrations in the Merrimack River during the 1960s are scanty. Yet, data summarized in Normandeau's report on "Historic water quality and selected biological conditions of the upper Merrimack River, New Hampshire" (Normandeau 2011a) indicate that nitrate and phosphate concentrations in the vicinity of Merrimack Station declined by approximately 90% between 1967 and 1972 (Normandeau 2011a, Figure 5-1).

As required by the Clean Water Act, all of the untreated discharges identified in the USDI (1966) report ceased by 1972. The resulting improvements in water quality, which are documented in Normandeau's (2011a) report, would have been expected to lead to biological changes in the Merrimack River, including replacement of highly pollution-tolerant species by species with lower pollution tolerance. An increase in the number of species present in the community would be expected (Rapport et al. 1985). Rather than being limited to those species present at the time Merrimack Unit 2 was constructed in 1968, the BIP should include species whose presence in the river may have been facilitated by implementation of the pollution control requirements of the Clean Water Act.

Evaluation of historical data on benthic invertebrate communities in the Merrimack River

To provide additional insights into the potential influence of improved water quality on biological communities present in the Hooksett Pool, Normandeau (2012) compared benthic invertebrate data collected in the early 1970s (1972 and 1973) to data collected in 2011. Information on the composition of benthic invertebrate communities is now routinely used to assess the extent of impairment of aquatic communities due to stressors such as habitat degradation and pollutant discharges (Barbour et al. 1999, Karr and Chu

1999). The objective of the Normandeau (2012) study was to determine whether changes in Merrimack River benthic invertebrate communities between these two time periods were consistent with improvements in water quality that have occurred since the 1960s.

Benthic invertebrates were collected from wadeable shoreline areas using a dip net, and from deep, non-wadeable sediments using a Ponar dredge. The same locations were sampled during the same month in all three years. The dip net method is considered to be "qualitative," because it does not sample a defined area of benthic habitat and therefore cannot provide a measure of invertebrate population size or density. However, this method can effectively sample a relatively large area and collect large numbers of organisms, if they are present. The Ponar dredge is considered to be "quantitative" because it samples a defined area of habitat and therefore can provide estimates of invertebrate density in organisms per square foot or meter. However, the dredge samples a relatively small area (typically 6" x 6" or 9" by 9") and may collected few organisms if densities are low.

Data collected using both sampling methods were used to calculate five benthic community indices:

- Taxa richness – the number of different types of benthic macroinvertebrates present in a sample
- Hilsenhoff Biotic Index – a ranking based on literature-reported sensitivities of different taxa to organic pollution stress
- Ratio of Ephemeroptera, Plecoptera, and Trichoptera (EPT) abundance to Chrinomidae abundance
- Percent contribution of the dominant taxon to the total number of organisms in each sample
- EPT richness – the number of EPT taxa present in each sample

All of these metrics can be used to assess whether benthic invertebrate communities have been impaired due to environmental stress (Barbour et al. 1999).

Results of the sampling discussed above are provided in Table 3 of Normandeau (2012). The Ponar dredge data for 2011 was similar to the data for 1972 and 1973. Relatively few taxa were collected, and in particular relatively few members of the pollution-sensitive EPT taxa were collected. The relatively low numbers of these organisms could reflect either small sample sizes collected by the dredge or poor habitat quality, since the river bottom at the sampled stations consists primarily of medium-grained sand (Normandeau et al. 2012, Table 2). The kick sampling produced more organisms and provides some evidence that the near-shore benthic environment improved between the early 1970s and 2011. The total abundance or organisms per sample was much higher in 2011 on both the east and west sides of the river, and total taxa richness, EPT richness, and the EPT/Chironimidae ratio were all higher in 2011.

Overall, this study provides some evidence that biological conditions in the Hooksett Pool have improved since the 1970s.

Coolwater fish species that were dominant in the 1960s were replaced by warmwater species beginning in the 1970s.

Although EPA identified the fish community present in the 1960s as the BIP for Merrimack Station, the agency's quantitative trends analysis focused on the years 1972 through 2005. This was done because PSNH had argued that the fish sampling performed during the 1960s used a different sampling protocol and was insufficiently documented to support quantitative analysis. Data collected using two different gears, electrofishing and trap nets, are available for analysis. Table 5-5 of the Determination summarizes the electrofishing data used by EPA. According to this table, most of the species that dominated the fish community in 1972 had greatly declined in abundance by 2005. These species included pumpkinseed, yellow perch, brown bullhead, and white sucker. These declining species were replaced by two new species, bluegill and spottail shiner, that were not collected in 1972. EPA found that the total catch-per-unit-effort (CPUE) of the fish species present in 1972 declined from 63.2 in 1972 to 15.6 in 2005, with similar declines occurring in both the ambient zone and the thermally influenced zone of the Hooksett Pool. It should be noted that most of this decline can be attributed to a single species, pumpkinseed, which accounted for approximately 50% of all fish caught by electrofishing gear during each year between 1972 and 1976.

According to EPA, results of the trapnet sampling program support conclusions derived from the electrofishing program. Use of the trapnet data is complicated by the fact that different sampling designs and deployment methods were used in different years. Moreover, nets with different mesh sizes may have been used during different years of sampling. According to PSNH, during the 1994-1995 sampling, nets with a 2-inch mesh size were used, whereas nets with a 0.75-inch mesh size were used in other years. Many fish that would be retained by the 0.75-inch mesh would pass through a net with 2-inch mesh, therefore, data collected using these different mesh sizes would not be comparable. EPA disputed the contention by PSNH that different nets were used in 1975, claiming that there was no evidence of a gear change other than recollections of PSNH biologists. Nonetheless, EPA's analysis, as presented in the Determination, compared data collected in the 1970s to data collected in 2004 and 2005.

Like the electrofishing data, the trapnet show substantial declines in the abundance of those species that were included by EPA in the BIP.   Also like the electrofishing data, most of the decline can be attributed to a decline in the abundance of pumpkinseed.

In addition to analyzing total fish abundance, EPA performed species-specific analyses for yellow perch, pumpkinseed, white sucker, smallmouth bass, largemouth bass, fallfish, and alewife. The alewife analysis is relatively uninformative, because the presence of this species in the Hooksett Pool is maintained by upstream stocking rather than natural reproduction. Of the other species analyzed, EPA found statistically-significant declines in the abundance of yellow perch, pumpkinseed, and white sucker. EPA found no declines in the abundance of the remaining species, but noted that most of the fallfish captured were collected from the ambient zone of Hooksett Pool.

It seems clear that there have been changes in the Hooksett Pool fish community since the 1960s, but EPA's conclusion that the changes were caused by Merrimack Station's thermal discharge are highly questionable. EPA's argument rests heavily on an assertion that "coolwater" species were replaced by more thermally tolerant "warmwater" species. However, as noted in Kendall (1978) the classification of species as "coolwater" or "warmwater" is based primarily on geographic ranges, not on thermal tolerance data. Some species, e.g. brown bullhead and smallmouth bass, are classified differently by different authorities.

In Table 1 of this review I have tabulated the geographic ranges, pollution tolerances, thermal tolerances, and feeding guilds of the species discussed in EPA's Determination. Regardless of temperature preference classification, all of these species are widely distributed throughout eastern North America, from Canada to the U.S. mid-Atlantic or even Gulf Coast states. Each species inhabits a wide variety of thermal regimes and possesses a wide range of thermal tolerances. Small changes in temperature would be most likely to affect these species near the limit of their ranges, however, the Merrimack River is well within the geographic range of every species listed in Table 1.

As noted above, the changes in total fish abundance documented by EPA in Table 5-5 of the Determination is driven primarily by a decline in abundance of pumpkinseed. EPA itself classified this species as a warmwater species (Determination, Table 5-1), although it is identified elsewhere as a coolwater species (Carlander 1977; Eaton and Scheller 1996). The other species showing substantial declines between 1972 and 2005 according to the electrofishing data were yellow perch, white sucker, brown bullhead, chain pickerel, and yellow bullhead. Of these, only chain pickerel, yellow perch, and white sucker are generally recognized as coolwater species. Brown bullhead has been classified variously as either a coolwater or a warmwater species, and yellow bullhead is generally recognized as a warmwater species. The other species identified by EPA as part of the BIP are a mix of coolwater and warmwater species, all of which fluctuated in abundance during the time period examined without apparent trend.

Table 1. Geographic ranges, temperature tolerance classifications, pollution tolerance classifications, and feeding guilds of fish species discussed in EPA's §316 Determination

Species	**Geographic range**	**Temperature classification**	**Pollutant tolerance classification**	**Feeding Guild**
Yellow perch	Arctic, Great Lakes, Mississippi River basins; Atlantic drainage of northeastern and central Atlantic states[a]	CW	M	piscivore
Black Crappie	Southern Manitoba to Quebec south to Florida and Texas[b]	CW	M	piscivore
Pumpkinseed	Southern Canada, Upper Mississippi drainage, Great Lakes, Atlantic coast south to Georgia[b]	CW/WW	M	generalist
bluegill	Southern Ontario, Great Lakes and Mississippi River basins to Gulf of Mexico, Northeast Mexico and Florida, Atlantic coastal drainage up to North Carolina. Introduced widely throughout North America[b]	WW	M/T	generalist
Largemouth bass	Original range – East of Rocky Mountains from southern Quebec and Ontario through the Great Lakes and Mississippi valley to the Gulf of Mexico and from Mexico to Florida and the Carolinas. Introduced in the eastern states to New England.[b]	WW	M	piscivore
Smallmouth bass	Original range – Northern Minnesota and southern Quebec to the Tennessee River in Alabama and west to eastern Oklahoma. Invaded Hudson Valley about 1825, introduced in Atlantic coastal states in 1850s.[b]	CW/WW	M	piscivore
White sucker	East of the Rockies from northern Alberta to southern Labrador and south to northern Georgia, Oklahoma and Colorado[c]	CW	T	generalist

Fallfish	Eastern Canada to James Bay drainage and south on the east side of the Appalachians to Virginia[c]	CW	M	generalist
Brown bullhead	Southern Manitoba, Great Lakes to Maine south to Florida and northern Mississippi, Widely introduced elsewhere[c]	CW/WW	T	generalist
Yellow Bullhead	North Dakota to Hudson River south to Florida and Mexico[c]	WW	T	generalist
Redbreast sunfish	Maine to Florida in Atlantic drainages; westward along Gulf Coast to Texas[b]	WW	M	generalist
Rock bass	Manitoba to Quebec south to Gulf of Mexico[b]	CW	M/I	piscivore
Golden shiner	Manitoba to Quebec and south to Florida and Mexico[c]	WW	T	generalist
Spottail shiner	Alberta, Hudson Bay, Quebec south along coast to northern Georgia and in the Mississippi Valley to Missouri and Kansas[c]	WW	M	insectivore
Common shiner	Southern Alberta to Nova Scotia south to Virginia, Mississippi, Louisiana, Oklahoma, and Colorado[c]	CW	M	generalist
Chain Pickerel	Eastern seaboard from St. Lawrence River through Florida and in Gulf of Mexico drainage north to southern Missouri[c]	CW	M	piscivore

[a]Carlander (1997)
[b]Carlander (1977)
[c]Carlander (1969)

Table 1 of this report lists the pollution tolerance classification of each species, according to EPA's Rapid Bioassessment Protocol (USEPA 1999). Three of the declining species, white sucker, brown bullhead, and yellow bullhead, are classified as pollution-tolerant, i.e., the types of species that would be expected to decline in abundance as a result of improved water quality. Although pumpkinseed is classified as moderate with respect to pollution tolerance, the scientific literature documents a relatively high tolerance to low dissolved oxygen levels, as compared to bluegill (Osenberg et al. 1992, Fox 1994).

Comparisons of published thermal tolerance data to measured and predicted temperatures in the Merrimack Station discharge canal and in the river

The data used by EPA in its thermal tolerance analysis were taken from Appendix A of Normandeau's probabilistic thermal modeling report (Normandeau 2007a). EPA's general approach to evaluating thermal effects on fish relied on comparisons between critical temperature values for various life stages of fish to temperatures from Appendix A for two stations: Stations S-0, at the end of the Merrimack Station discharge canal, and Station S-4, a thermally influenced station downstream from the canal. For each calendar date between June 1 and September 30, Appendix A provides the mean, minimum, and maximum temperature observed on that date over the 21-year period of 1984 through 2004. Each value is based on average temperatures over a 24-hour period. The mean temperature for a given date is the mean of 24-hour average temperatures on that date over the entire 21-year time series. The minimum and maximum average temperatures for that date are, respectively, the lowest and highest 24-hour averages for that date within the 21-year time series. EPA appears to have misinterpreted Appendix A by assuming that the maximum temperatures provided in the table are averages of the maximum temperature observed on each date. Under this assumption, the maximum temperature in Appendix A for a given date would represent the average maximum temperature reached on that date during every year in the 21-year time series. This assumption substantially overstates the actual temperatures to which fish would have been exposed during those years.

Species addressed by EPA include alewife, American shad, Atlantic salmon, Smallmouth and largemouth bass, pumpkinseed, yellow perch, fallfish, and white sucker. Three of the species evaluated by EPA, alewife, American shad, and Atlantic salmon, do not reproduce naturally in the Merrimack River. To the extent that any of these three species are present, their presence is due to stocking upstream from Hooksett Pool. Juveniles of all three species would pass through Hooksett Pool during outmigration, and in addition small numbers of eggs, larvae, and juveniles could drift downstream to Hooksett Pool after spawning. It is unknown whether significant numbers of early life stages of any of these species are present in Hooksett Pool (they would not be vulnerable to capture by either electrofishing or trapnet), where they could be exposed to the thermal discharge from Merrimack Station. Nonetheless, EPA concluded that Merrimack Station's discharge creates "unsuitable habitat" for alewife larvae, based on a comparison between a temperature observed to be lethal to alewife larvae (94.1°F) and the maximum temperature recorded at Station S-0 on a date on which herring larvae were collected in entrainment samples at the station (also 94.1°F). As noted above, this was the highest average temperature observed at Station S-0 on that date over a 21-year period, not the average maximum temperature for that date over all years. This is an unrealistically conservative analysis that does not support a conclusion of appreciable harm. Similarly, EPA cites temperatures higher than the published preferred temperatures of alewife juveniles at Station S-4 downstream from the discharge as evidence that Merrimack's thermal discharge creates an unsuitable habitat for juvenile alewives. However, these temperatures occur between June 25 and September 4, whereas impingement data indicate that outmigrating juvenile alewives pass by the station primarily from early September through October. Again, EPA's analysis does not support a conclusion of appreciable harm.

EPA's analyses of the effects of Merrimack's thermal discharge on American shad are similarly based on comparisons between laboratory-derived thermal tolerance limits and mean or maximum temperatures observed at Stations S-0 or S-4. As noted above, the comparisons to maximum temperatures are unreasonably conservative because they misinterpret the maximum 24-hour average temperatures listed in Appendix A of

Normandeau (2007a) as average maximum daily temperatures. On p. 93, EPA states that the habitat at Station S-4 is unsuitable habitat for juvenile American shad because the average maximum temperature at that station from Appendix A exceeds the maximum tolerance limit from published literature on “every date from June 25 through September 3.” This conclusion is invalid because each of those temperatures cited by EPA occurred in only one of the 21 years included in Appendix A. In fact, the average daily temperatures over the 21 year period were well below the tolerance limit (85°F) for all dates between June 25 and September 3. This means that on average the habitat at Station S-4 was suitable for American shad on all days throughout this period, although during exceptionally warm years temperatures outside the preferred range occurred on some days. EPA’s analysis of acute mortality due to thermal plume exposure is also invalid, because it assumes that juvenile shad are acclimated to cool temperatures found upstream of the discharge (Station N-10), swim or drift downstream to Station S-0, and remain within the plume long enough to die. In reality, any juvenile shad approaching the plume would simply avoid the elevated temperatures.

EPA’s discussion of yellow perch focuses on reproduction, and in particular reproduction within the Merrimack Station discharge canal. Citing literature on the requirement of a “chill period” for complete development of yellow perch gonads, EPA states that yellow perch attracted to the discharge canal during winter may have impaired reproductive ability. EPA also expressed concern that yellow perch could spawn prematurely in the discharge canal, therefore suffering reduced egg viability or exposing the larvae to lethal cold shock when they are flushed out of the discharge canal and into the river. The “chill period” hypothesis is purely speculative, and the premature spawning hypothesis is highly unlikely. According to Carlander (1997), yellow perch prefer to spawn over vegetation or submerged branches, which would not be present in the discharge canal.

EPA’s analysis of effects of the thermal discharge on larval survival are erroneously based on comparisons between maximum daily average temperatures (misinterpreted as average daily maximum temperatures) at the end of the discharge canal (Station S-0) to thermal tolerance data from the published literature. Mean daily temperatures at Stations

S-0 did not exceed any of the thermal limits discussed by EPA during the period (May1-June 14) when yellow perch larvae were collected in Normandeau's ichthyoplankton survey, and neither the mean nor the maximum average daily temperature exceeded these limits at Station S-4. EPA's analysis of effects of thermal exposure on juvenile and adult yellow perch similarly are based on misinterpretation of temperature maxima provided in Appendix A. EPA states (p. 106) that the average daily maximum water temperature at Station S-4 exceeded the avoidance temperature of white perch on every day from June 15 to September 10, every year, when in reality the maximum temperature listed in Appendix A for each date was reached during only one year out of 21. Average daily temperatures at Station S-4 reached or exceeded this value on 9 dates during this period, indicating that there are at least some conditions during some years when the habitat at this station is unsuitable for yellow perch.

The thermal analyses for white sucker larvae and juveniles are similarly based on inappropriate comparisons between maximum average daily temperatures at Stations S-0 and S-4 and laboratory-derived thermal tolerance limits. Looking only at the mean average daily temperatures, it appears that temperatures at Station S-0 would have begun to exceed the lethal temperature for white sucker larvae on or about June 22, near the end of the period during which white sucker larvae are present in the vicinity of Merrimack Station. At Station S-4 downstream from the discharge, the average temperature would never exceed the thermal tolerance limit. Similarly, the average daily temperatures at Station S-4 never exceeded the thermal tolerance limit identified by EPA for juvenile and adult white perch, although the maximum average daily temperature values in Appendix A show that during exceptionally warm periods average temperatures at this station do exceed the tolerance limit for white sucker. Data on the distribution of white suckers in electrofishing samples discussed by EPA on p. 114 appear to show that during summer white suckers are found primarily upstream from the thermal discharge, indicating that these fish may prefer cooler water upstream from the discharge than warmer water below the discharge, although other habitat characteristics besides temperature could explain this distribution.

Comparisons between fish populations in the Hooksett Pool and fish populations in other similar waterbodies

EPA did not conduct a thermal effects analysis for pumpkinseed. Instead, EPA compared trends in pumpkinseed and bluegill abundance within the Hooksett Pool to trends observed in the Vernon Pool of the Connecticut River upstream from the Vermont Yankee Nuclear Power Station. EPA noted that the relative abundance of pumpkinseed as compared to bluegill did not decline over the period 1991-2002 in Vernon Pool, and concluded from this that competition between bluegill and pumpkinseed did not cause the decline in pumpkinseed abundance in Hooksett Pool. Further, EPA concluded that the increased thermal discharges related to operation of Merrimack Station Unit 2 "…contributed to the decline of pumpkinseed by altering the thermal environment in much of the Hooksett Pool, in combination with the introduction of heat-tolerant, non-native species such as bluegill."

EPA's chain of inferences is invalid for several reasons. First, there is no evidence of any change in water quality within the Vernon Pool of the Connecticut River comparable to those that occurred within the Hooksett Pool of the Merrimack River during the period in which Unit 2 has been operating. Second, bluegill and pumpkinseed coexist throughout their respective ranges (which closely overlap), in a great variety of temperature regimes. Third, the published literature, as summarized in Appendix C of Normandeau (2007b) shows that the temperature tolerances of these two species are similar.

Similarly, EPA compared yellow perch abundance estimates for Hooksett Pool to abundance estimates in the Garvins Pool of the Merrimack River and the Vernon Pool of the Connecticut River. EPA argued that since yellow perch are abundant in these systems in spite of the presence of centrarchids such as bluegill and rock bass that might compete with them, the much lower abundance in Hooksett Pool could be due to reductions in available habitat caused by the thermal discharge from Merrimack Station. However, as shown in Table 5-21 of EPA's §316(a) Determination, yellow perch appear to also be even less abundant in Amoskeag Pool downstream from Hooksett Pool, at least in 2008. No information is presented anywhere in EPA's Demonstration concerning other aspects of habitat suitability for yellow perch, so it is not possible to draw any inferences simply from comparisons of abundance estimates. A more detailed comparison of the fish communities present in Garvins Pool, Hookset Pool and Amoskeag Pool is provided below, using a more extensive data set collected by Normandeau in 2010 and 2011.

Evaluation of Normandeau's 2012 population and community analyses

Subsequent to PSNH's 2007 filing, Normandeau (2012) performed a new set of analyses that included data collected in 2011 and 2012 and concluded that Merrimack Station has caused no appreciable harm to the Merrimack River BIP. This argument, as documented in section 2.2 of Normandeau (2012), is based primarily on (1) trends in abundance of various fish species in Hooksett Pool, and (2) comparisons between the fish communities in Hooksett Pool and Garvins Pool, which is upstream from Hooksett Pool and unaffected by the thermal discharge from Merrimack Station. The data are documented in Normandeau's report on "Merrimack Station Fisheries Survey Analysis of 1972-2011 Catch Data" (Normandeau 2011b).

The trends analysis component of this report extends the analyses submitted to EPA in 2007, which included data only from 1972 through 2005, to include data from 2010 and 2011. Only electrofishing data are discussed[2]. Trends in fish community composition are discussed in section 3.3 of the report. Taxa richness, meaning the number of different fish species collected, has increased from 12 species collected in 1972 to 19 species collected in 2011. Except for the anomalous year 1995 when bluegill dominated the electrofishing catch, species diversity as measured by the Shannon Diversity Index has increased since the 1970s. Since environmental stress has been frequently found to decrease taxonomic richness and diversity (Rapport et al. 1985), these increases could be responses to improved water quality in the Merrimack River. They are definitely

[2] In its §316 determination, EPA asserted that Normandeau's electrofishing data are unreliable for trends analysis. This assertion is incorrect. Electrofishing is a widely used, relatively non-selective sampling method that is recommended by EPA (1999) for sampling both small streams and large rivers.

inconsistent with the expected effects of thermal stress, which would be to decrease richness and diversity. Normandeau (2011b) also found that the percent of species classified as "generalist feeders," another indicator of environmental degradation, has decreased. The percent of species classified as pollution-tolerant has varied but not noticeably changed. Taken together, these community-level results support a conclusion that there has been no appreciable harm to the BIP due to the operation of Merrimack Station.

Statistical analyses of trends data for 15 resident fish species are summarized in Table 3-4 of Normandeau et al. (2011b). The results are somewhat surprising in that no statistically significant increase in abundance was found for either bluegill or spottail shiner, the two species that EPA asserted now dominate the Hooksett River fish community. Significant decreases in abundance were found only for brown bullhead, chain pickerel, pumpkinseed, redbreast sunfish, and yellow perch. A statistically significant increase in abundance was found for only one species, black crappie, which was relatively recently introduced into the Merrimack River.

These results can be readily explained by examining the trends plots for the 15 species (Figures 3-1 through 3-15). Although the time interval covered by the data spans 40 years, data were collected in only 9 years. Inter-annual variability within these 9 years of data is high for many species, meaning that the ability of the statistical test used by Normandeau to detect changes in abundance is low. This is especially true if, as in the case of bluegill and spottail shiner, a year of anomalously high abundance occurred during the middle of the time series. Trends in abundance could only be detected for species that were much more abundant in the early 1970s than in any later years (brown bullhead, chain pickerel, pumpkinseed, and redbreast sunfish) or nearly absent in the early 1970s and abundant in later years (black crappie).

The most revealing results presented in Normandeau's (2011b) report are the comparisons between the fish communities present in Garvins, Hooksett, and Amoskeag pools. The community similarity analysis showed that the fish communities in Garvins

Pool is more similar to the community in Hooksett Pool than in Amoskeag Pool, i.e., there is an upstream-to-downstream gradient in community composition. Upstream-to-downstream gradients are common in river fish communities, due to natural upstream to downstream gradients in habitat conditions. It could be argued that Amoskeag Pool is influenced by the thermal discharge from Merrimack Station, however, because of mixing at Hooksett Dam, there would be no thermal plume exposure. Any station-related temperature increase in Amoskeag Pool would be small in comparison to the increase occurring in lower Hooksett Pool.

Detailed information on fish community composition in the three pools is provided in Tables 2-7 through 2-13 of Normandeau (2011b). These data show that the most abundant species in Garvins pool in 2010 and 2011 was spottail shiner, a warmwater species that EPA asserted was favored by elevated temperatures in Hooksett Pool. In 2010, largemouth bass was the second most abundant species in Garvins Pool. Yellow perch and pumpkinseed were more abundant in Garvins Pool than in Hooksett Pool, but they were not the dominant species. Fish community composition in Amoskeag Pool was very different. In this pool, smallmouth bass was dominant in both 2010 and 2011, and spottail shiner was virtually absent. Brown bullhead, which had been abundant in Hooksett Pool in 1972, was nearly absent from all three pools in 2010 and 2011. The fish communities present in all three pools consist of a mix of coolwater and warmwater species, with no clear pattern of dominance with respect to temperature classification, pollution tolerance, or feeding guild. These data clearly provide no evidence that the thermal discharge from Merrimack Station has harmed the fish community in Hooksett Pool.

Evaluation of EPA's alternative thermal limits

In section 8.3 of its Determination, EPA derived a set of exposure temperature limits that, according to the agency, would satisfy the requirements of New Hampshire's water quality standards. These standards would be met if the discharge of heat by Merrimack Station were limited to levels that would protect all life stages of the most temperature-sensitive species present in the river. The standards include both weekly average standards to be applied at Station S-4 downstream from the discharge canal and hourly standards to be applied to Station S-0 at the end of the discharge canal.

Prior to evaluating the specific temperature limits proposed by EPA, it is important to recognize some general limitations on the utility of thermal tolerance limits derived from published literature.

General limitations of thermal tolerance data

Appendix C of Normandeau (2007a) summarizes thermal effects data for most of the fish species discussed in EPA's §316 determination. Of particular interest are the data for alewife, American shad, yellow perch, and white sucker. These are the species that are emphasized in EPA's development of alternative thermal limits, which is discussed here. For most of these species, relatively broad temperature ranges are identified in Appendix C as 'preferred' or 'optimal' for growth, spawning, and early life stage survival. Temperatures identified as 'avoidance' temperatures are also relatively broad for many species. For example, reported avoidance temperatures for yellow perch range from 79˚F to 84˚F. For white sucker, ranges of 'optimal' temperatures for growth range from 75˚F to 84˚F, and reported critical temperatures for spawning range from 50˚F to 68˚F. Temperatures between 57˚F and 71˚F were reported to be suitable for white sucker larvae.

Two inferences can be drawn from these reported temperature ranges:

(1) determining thermal preferences and optima for fish species, especially in the field, is a very inexact science, and

(2) the wide ranges of reported critical temperatures reported for these species reflects the obvious fact that all of them are adapted for survival in environments with highly variable temperatures.

EPRI (2011a) conducted a critical review of the thermal effects literature, focusing on experimental data used to establish thermal tolerance criteria for freshwater fish species. EPRI's rationale for performing the review was that, unlike the methods and data used to determine chemical toxicity for establishing water quality criteria, methods and data for determining thermal toxicity have never been critically reviewed or standardized. The focus of EPRI's report was on three commonly-used experimental methods for determining lethal thermal toxicity: the incipient lethal temperature (ILT) method, the critical thermal maximum (CTM) method, and the chronic lethal maximum (CLM) method. Data for 11 coldwater species (all salmonids), 5 coolwater species, and 20 warmwater species were evaluated.

With respect to experimental methods, EPRI (2011a) found that test conditions, especially acclimation temperatures, strongly affect estimates of thermal mortality thresholds, especially for the ILT and CTM methods. Tolerance estimates for the same species, measured using different methods or acclimation temperatures, can produce results that differ by as much as 10°C.

With respect to species sensitivities, EPRI (2011a) found that salmonids are consistently more thermally sensitive than coolwater or warmwater species, regardless of test method, but that the overlap between the tolerances of coolwater and warmwater species is broad. EPRI concluded that identifying any particular group of species as a "coolwater guild" is "largely artificial and certainly not rigorously defined by temperature tolerance."

Finally, EPRI (2011a) noted that "none of the laboratory methods accurately reproduces what happens in the field when fish are exposed to spatially and temporally varying thermal fields and have the ability to select specific locations."

EPRI's (2011a) literature review appears to support two conclusions with respect to thermal analyses for Merrimack River fish populations:

(1) attempting to identify effects of Merrimack’s thermal discharge based on changes in the relative abundance of “coolwater” and “warmwater” species is futile because there is no clear distinction between these two guilds, and

(2) the available science does not support the use of thermal effects data to establish temperature criteria analogous to the water-quality criteria established for toxic chemicals.

EPA’s Alternative Thermal Tolerance Limits

Among resident species, EPA identified yellow perch as the most sensitive and established limits for each of the following life stages: (1) adult reproductive condition, (2) spawning stage, (3) egg stage, (4) larval stage, (5) juvenile stage, and (6) adult stage (non-reproductive). Temperature limits were defined for each of these stages, to be applied during the period in which that life stage was present in the river.

Among anadromous species, EPA identified certain life stages of American shad and river herring as being potentially more sensitive than yellow perch, and established temperature limits for these species and life stages as well.

As discussed below, these limits are more restrictive than is necessary to protect the relevant populations present in the Hooksett Pool, given the wide range of thermal environments inhabited by all of these species, and especially given the limitations on test methodologies discussed by EPRI (2011a).

Yellow perch

Maturation

Section 8.3.3.1 discusses maturation of yellow perch gonads during the fall, winter, and early spring, relying heavily on a paper by Hokanson (1977). According to Hokanson (1977), yellow perch must be exposed to temperatures of 10°C or lower for an extended period in order for proper gonadal development to occur. In laboratory studies, investigators in Minnesota found that the spawning success of yellow perch held over the winter at a constant temperature of 10°C for 185 had a spawning success rate of approximately 30% (Hokanson 1977, Figure 1). Yellow perch held at a constant temperature of 8°C for 170 days had a spawning success rate of approximately 58%. EPA asserted that the ambient temperature in Hooksett Pool is at or below 8°C from early November until April 20, and on this basis established a maximum temperature limit at Station S-4 of 8.0°C for the period from November 5 through April 20.

The problem with EPA's analysis is that the data on which the 8.0°C limit was based were laboratory data collected under constant exposures temperatures. In the Merrimack River and other systems inhabited by yellow perch, temperatures are lower than 8.0°C for a large part of the winter. This fact is important because Hokanson (1977) found that spawning success was maximized at temperatures of 4°C-6°C. Yellow perch exposed to these temperatures reached 95% (6°C) to 100% (4°C) spawning success with an exposure duration of 160 days, and reached the 58% spawning success (considered acceptable by EPA) within 140 days (Hokanson 1977, Figure 1).

The temperature time series summarized in Appendix A of Normandeau (2007b) extends only from April 1 through October 31, so that no winter temperature data are available for the reach of Hooksett Pool exposed to Merrimack Station's thermal discharge. However, Normandeau (2009) measured temperatures at Station A-0 in the tailwaters of Hooksett Dam from December 18, 2007 through February 12, 2009. These data can be used to approximate the temperatures that occurred upriver at Station S-4.

When measurement began on December 18, the temperature at Station A-0 was approximately 2°C. The temperature then fell to near 0°C for the remainder of the winter and did not rise above 5°C until April 18, 2008. The temperature at Station A-0 the following fall dropped below 5°C on November 25, 2008, and was below 2°C from December 1 through the end of the monitoring period.

According to Appendix A of Normandeau (2007b), temperatures measured at Station S-4 are very similar to those measured at Station A-0. For the last week of October, the mean temperature measured at S-4 during 1984-2004 was 1.5°C higher than the temperature measured at A-0. For the period April 1-April 18, the average temperature measured at S-4 was actually 0.7°C lower than the temperature at A-0. Assuming that on average the temperature at station S-4 is about 1°C higher than the temperature at A-0, the winter temperature at Station S-4 would still have been within the optimal temperature range for yellow perch maturation sufficiently long (~150 days) to ensure a degree of maturation higher than the 58% considered acceptable by EPA.

Figure 9 of Hokanson (1977) provides additional support for a conclusion that EPA's proposed alternative thermal limit is more stringent than necessary to protect yellow perch maturation. This figure provides an "envelope" of temperature regimes in water bodies inhabited by this species. This figure shows that the median date in such habitats at which the water temperature falls below 10°C is approximately November 1. However, in 5% of yellow perch habitats the temperature is still 15° or higher on that date, and does not fall to 10°C until mid-November. Similarly, the median temperature in the spring rises to about 10°C approximately on May 1, but in 5% of habitats the temperature reaches that level by April 1. Hokanson (1977) identified 10°C as the maximum winter temperature for maturation, and EPA has not provided a valid justification for establishing a temperature limit lower than this value. Applying that limit to the period November 15-April 1 would ensure that the winter temperature regime downstream from the discharge is within the envelope of winter temperatures in water bodies in which yellow perch are known to successfully reproduce.

Spawning

In section 8.3.1.2, EPA discusses spawning temperature requirements for white perch. This section cites Hartel et al. (2002) and Scott and Crossman (1973) as reporting that yellow perch spawn at water temperatures between 6.7°C and 12.2°C. EPA also cites Krieger et al. (1983) as concluding that the optimum temperatures for yellow perch spawning are between 8.5°C and 12°C. Based on this literature EPA selected a maximum temperature limit at Station S-4 of 12°C, to be applied over a spawning season from April 10 to May 8.

There are two problems with EPA's approach: First, the ranges cited by EPA are not the only published ranges of spawning temperature for yellow perch. Wismer and Christie (1987) reported that yellow perch spawn over a temperature range of 45°F-59°F (7.2°C-15°C), and Hokanson reported that spawning is possible between 4.0°C and 18.5°C. Hence, selection of 12°C as an upper temperature limit that cannot be exceeded is not supported by the scientific literature. Second, Station S-4 may not provide suitable spawning habitat for yellow perch. The available scientific literature indicates that yellow perch spawn predominantly in at least moderately vegetated littoral (near-shore) areas, often over vegetation or submerged branches (Krieger et al. 1983, Carlander 1997). Station S-4 is located in an unvegetated area of the Merrimack River channel, and may not be utilized as spawning habitat by yellow perch. If there is no spawning at Station S-4, then no spawning-related temperature maximum is necessary.

Egg development

In section 8.3.1.3, EPA discussed thermal tolerances of yellow perch eggs. Based on a laboratory study by Koonce et al. (1977), EPA selected a maximum temperature limit for yellow perch eggs of 18°C. The basis for this limit was that in the Koonce et al. (1977) study, egg mortality increased from 16% at a temperature of 18°C to 70% at 21°C. Based on (1) the preferred spawning temperature range provided by Hartel et al. (2002),

(2) the 21-year average daily mean temperatures from Appendix A of Normandeau (2007b), and (3) a time vs. temperature hatch rate from Hokanson (1977), EPA applied the 18°C thermal limit for egg development to the period April 10, through May 27.

Other investigators have reported broader ranges of temperature tolerance for yellow perch eggs. Hokanson (1977) reported a temperature tolerance range of 3.7°C to 21°C for early embryonic stages and 7.0°C to 22.9°C for late embryonic stages. These results, like those of Koonce et al. (1977) reflect eggs incubated at constant temperatures in a laboratory. In reality, wild yellow perch eggs are spawned during a season of rapidly increasing water temperatures, so that their exposure temperatures are much lower at spawning than at hatching. Krieger et al. (1983) stated that the optimum conditions for embryo development involve an initial temperature of 10°C, increasing at 1°C per day to 20°C. The upper end of this range is just below the temperature at which Koonce et al. (1977) observed elevated mortality under a constant temperature exposure.

As shown in Appendix A of Normandeau (2007b), average daily temperatures at Station S-4 from 1984 through 2004 were below 18°C (64.4°F) until May 30, and did not exceed 21°C (69.8°F) until June 11, well after the end of the egg development period assumed by EPA. In 2007, the temperature at Station A-0 rose from 10°C to 20°C between approximately May 1 and June 1 (Normandeau 2009). These data indicate that a yellow perch egg spawned at the end of the spawning period (assumed by EPA to be May 8) would most likely be exposed to temperatures within the optimal range for its entire developmental period and would not likely be exposed to temperatures as high as 20°C until the end of this period. According to Appendix A of Normandeau (2007b), maximum average daily temperatures have exceeded 20°C in mid-May during some years, however, these likely reflect warm springs in which spawning and egg development would have occurred earlier than assumed by EPA.

Given that the Koonce et al. (1977) experiments were performed at constant exposure temperatures, and that actual exposure conditions in the field would involve much lower temperatures for most of the egg development period, a thermal limit of 21°C appears to be much more supportable than the limit of 18°C proposed by EPA. Even this value may be unnecessarily conservative, given that Station S-4 is probably not located in habitat that would be utilized for spawning by yellow perch.

Larval stage

Based on the period of occurrence of yellow perch larvae in entrainment samples, EPA concluded that yellow perch larvae are present in the vicinity of Merrimack Station from early May through mid-June. EPA developed two types of temperature limits to protect yellow perch larvae during this period: a chronic limit to account for exposure throughout the larval period, and an acute limit to account for exposure of drifting larvae to the thermal plume.

Based on thermal mortality data from Koonce et al. (1977), EPA concluded that thermal mortality of yellow perch larvae would be low throughout most of the larval period. However, EPA used a formula obtained from the guidance manual “Water Quality Criteria for 1986” (USEPA 1987) to calculate an upper limiting temperature applicable to the warmer temperatures that occur near the end of the larval period (assumed to be June 15). The formula extracted from the guidance document calculates a limit on weekly average temperatures based on (1) a physiologically optimal temperature (preferably based on growth) and an upper incipient lethal temperature. This limit is equal to 1/3 the distance between the optimal temperature and the lethal temperature. EPA used 18°C, the temperature at which no larval mortality was found by Koonce et al. (1977), and 28°C, the upper end of the tolerance range cited by Hokanson (1977) for newly-hatched larvae, to calculate an upper temperature limit of 21.3°C (70.3°F) for the protection of yellow perch larvae in Hooksett Pool.

This value is unrealistically low, for several reasons. First, the temperature data summarized in Appendix A of Normandeau (2007b) show that ambient temperatures at Station N-10 upstream from Merrimack Station sometimes have exceeded 70.3°F. In fact, the maximum observed daily average temperature at Station N-10 met or exceeded

70.3°F for every date from May 25 through June 15 during the 21 years included in the data set. This means that for every date during this period the average temperature at Station N-10 met or exceeded EPA's proposed criterion at least once in 21 years. Second, EPA's choice of an optimal temperature is questionable. The temperature selected by EPA is not a "physiological optimum," as specified in the guidance, but a level at which no mortality was observed in a laboratory experiment. Hokanson (1977) concluded that the physiological optimum temperature for well-fed yellow perch larvae is higher than 20°C, although somewhat lower for larvae with restricted rations. Assuming an approximate physiological optimum temperature of 20°C, EPA's formula would yield a thermal criterion of 22.7°C (72.8°F). Third, EPA identified its proposed criterion as a value not to be exceeded, without specifying an averaging period. The guidance document clearly states that the value calculated using the above formula is a limit on the *weekly average* temperature.

Hence, if a thermal criterion were necessary to protect yellow perch larvae in Hooksett Pool, a value of 22.7°C, applied to the weekly average temperature at Station S-4, would be more defensible than the value selected by EPA. However, even this value is low compared to temperatures at which yellow perch can thrive. Figure 9 of Hokanson (1977) shows that water bodies in which the average temperature in mid-June exceeds both EPA's proposed limit and the alternative limit calculated here are still within the temperature envelope that supports healthy yellow perch populations.

EPA examined several different methods for calculating a short-term exposure limit for yellow perch larvae, assuming that 61 minutes are required for drifting larvae to travel from Station S0 at the mouth of the discharge to Station S4. . EPA used a formula from the 1987 guidance document to calculate an exposure limit for this trip, but rejected the result in favor of a lower value derived from a study by Wismer and Christie (1987). This limit, 29.3°C (84.7°F), would be applied to the hourly temperature measured at Station S-0, for the period May 1 through June 15.

EPA's proposed limit is based on very little data, although it is consistent with Hokanson's (1977) 28°C upper thermal tolerance limit for yellow perch larvae. However, EPA assumed a constant exposure over the estimated one-hour transit time from Station S-0 to Station S-4. In reality, a substantial dilution of the plume, and a consequent decrease in exposure temperature, occurs during this transit. From Appendix A of Normandeau (2007b), the temperature measured at Station S-4 during June is approximately 20°F (11.1°C) lower than the temperature at Station S-0. This means that the exposure temperature for larvae drifting downstream in the plume would decline rapidly below the maximum measured at the end of the discharge canal. Moreover, the only larvae actually exposed at Station S-0 would be entrained larvae, for which EPA already assumes 100% mortality. Larvae drifting past the plant and entering the plume downstream from the discharge point (i.e., the larvae this criterion is intended to protect) would be exposed only to lower, rapidly declining temperatures. Thermal plume modeling would be required to estimate a realistic profile of exposure temperatures and to establish a reasonable temperature limit for ambient larvae drifting downstream and entering the plume.

Juvenile and adult stages

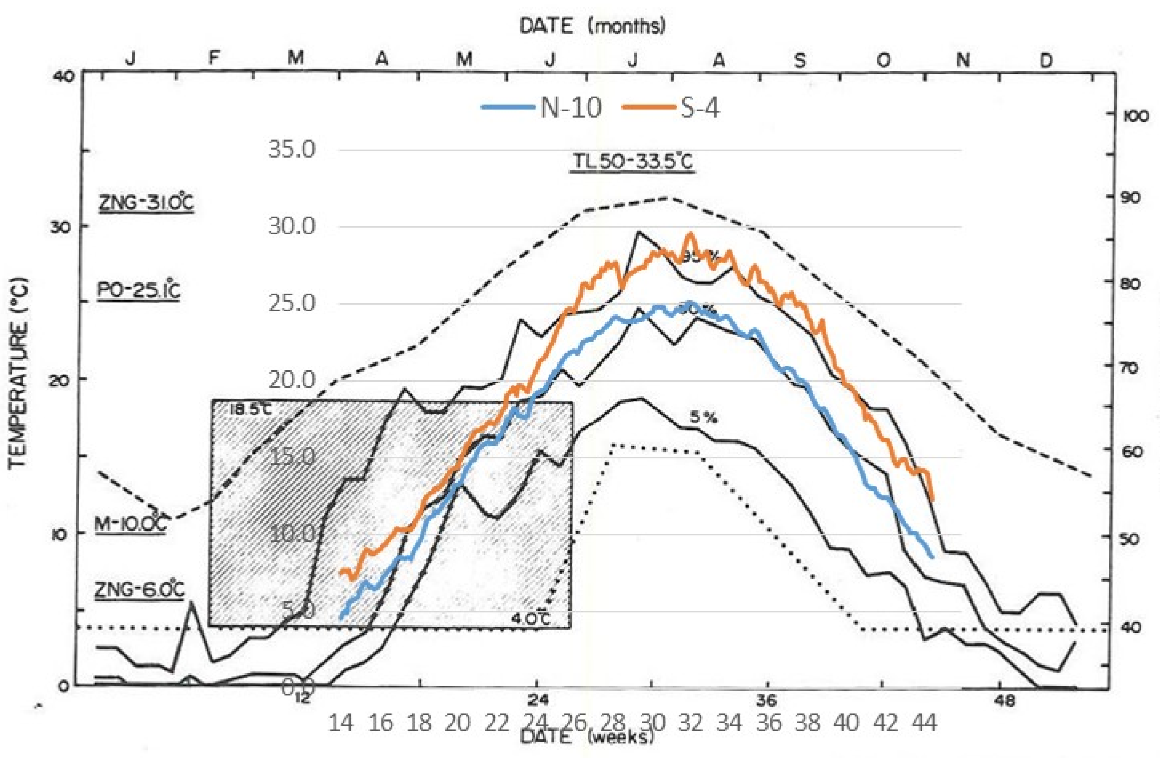
EPA calculated weekly average temperature limits for juvenile and adult yellow perch using the same equation from the EPA (1987) guidance document that was used to calculate a long-term temperature limit for larvae. Because adult yellow perch are more thermally sensitive than juveniles, and because both life stages are present in the Merrimack River throughout the year, the thermal limit for adults is always lower than the limit for juveniles and is the limit that would drive water-quality-based thermal discharge regulations. EPA chose the midpoint of the range of optimum temperatures provided by Krieger et al. (1983), together with an incipient lethal temperature from Hokanson (1977), for use in calculating a weekly average temperature limit for adult yellow perch. The value calculated by EPA, 25.1°C (77.2°F) would be applied to the weekly average temperature at Station S-4, unless superseded by a lower limit needed to protect a more sensitive life stage.

As in the case of larvae, the temperature limit proposed for adult yellow perch has often been exceeded at Station N-0 upstream from the Merrimack Station discharge. The maximum daily average temperature at this station over the period from 1984 through 2004 equaled or exceeded 77.2°F on 10 dates in June and on *every* date in July and August (Normandeau 2007b, Appendix A). Of greater relevance, Hokanson (1977) identified 77.2°F (25.1°C), as the physiological optimum temperature for yellow perch, not an upper thermal tolerance limit. Figure 9 of Hokanson (1977) shows that a summer temperature of 25.1°F is well within the envelope of summer temperatures within which healthy yellow perch populations are found. Hence, it does not appear that a thermal limit as low as 25.1°C during the summer months should be necessary to protect yellow perch.

EPA also calculated a short-term (hourly) exposure limit using equations from its guidance documents. This value, 30.9°C (87.6°F) would be applied to hourly temperature measurements at Station S-0. EPA's justification for establishing this limit is that "Studies referenced by Hokanson (1977) observed yellow perch invade water temperatures in excess of their upper incipient lethal temperature and die." However, Hokanson (1977) also stated (p. 1544) that "Fish kills from heat are rare in nature and generally occur only when escapement is blocked or when the coolest water available to fish exceeds the lethal temperature or is deficient in oxygen." Clearly, these are not the conditions present met in the vicinity of the Merrimack Station discharge. Juvenile and adult yellow perch approaching the discharge would be able to detect and avoid the plume.

Discussion of Yellow Perch temperature limits

Figure 9 of Hokanson (1977) depicts the envelope of seasonal thermal environments inhabited by yellow perch. At the extremes, yellow perch appear to be excluded from habitats in which the maximum summer temperature is 15°C or less or higher than 30°C. Between these extremes, yellow perch inhabit a wide range of temperature regimes. Hokanson (1977) plotted seasonal temperature curves for the 5th, 50th, and 95th percentiles of temperature environments in which yellow perch are found. The Figure below reproduces Hokanson's (1977) figure, overlaid with the daily average temperatures measured at Stations N-0 and S-4 (from Appendix A of Normandeau 2007b) from April 1 through October 31. The line for Station N-0 falls approximately on the 50th percentile line of Hokanson's (1977) figure, meaning that 50% of yellow perch populations inhabit environments warmer than that station. The line for Station S-4 falls approximately on the 95th percentile line, meaning that 5% of yellow perch populations inhabit environments warmer than Station S-4. Even assuming that a yellow perch could reside for its entire lifetime at Station S-4, this fish would experience a thermal environment similar to environments successfully occupied by many yellow perch populations.



American shad

Although EPA selected yellow perch as the most thermally sensitive resident species, the agency also evaluated the thermal tolerances of anadromous species that could potentially utilize the Hooksett Pool. Because of the absence of fish passage facilities at downstream dams, viable populations of species such as American shad, Atlantic salmon, and river herring do not occur in the Merrimack River. However, in anticipation that such facilities might be constructed in the future, limited stocking of all three of these taxa has been performed upstream from Hooksett Pool. American shad have been stocked within Hooksett Pool itself. EPA examined thermal tolerance data for these species and determined that, for American shad larvae and juveniles, thermal limits more stringent than those calculated for yellow perch would be appropriate.

The methods and data EPA used to calculate thermal limits for American shad were similar to those used to calculate limits for yellow perch, and suffer from the same weaknesses. Like yellow perch, American shad occupy a broad geographic range, with widely varying temperature regimes. Spawning runs of American shad occur from the St. Lawrence River, Canada to the St. Johns River, Florida (Limburg et al. 2003). The Merrimack River is well within this range.

Not surprisingly, the range of temperatures reported as being “optimal” for various American shad life stages is quite broad: 14°C-24.5°C for spawning, 15.5°C-26.5°C for larvae, and 10°C-25°C for juveniles (Greene et al. 2009). As in the case of yellow perch, EPA calculated limiting temperatures for long-term exposures using the midpoints of the optimal temperature ranges and the incipient lethal temperatures for each life stage. The resulting 26°C value for larvae is within the “optimal” or “suitable” ranges found in three of the studies reviewed by Greene et al. (2009, Table 2-5). The 25.3°C value EPA calculated for juveniles is within the range of optimal temperatures (15.6°C – 28.5°C) used by EPA to perform its calculations. Hence, the temperature limits proposed by EPA could be violated by thermal discharges that are actually within the optimal temperature range for American shad.

The acute exposure temperatures derived for American shad, intended for application to Station S-0 at the end of the discharge canal, are also flawed. As in the case of yellow perch, the only American shad larvae that would be exposed at station S-0 would be entrained larvae. These larvae, according to assumptions made by EPA in its §316(b) determination, would already be dead. The acute exposure temperature derived for juvenile American was based on a study by Marcy et al. (1972) in which caged juvenile American shad were exposed to the thermal discharge from the Connecticut Yankee nuclear power plant. Young shad were observed to attempt to escape lethal exposures, but were unable to do so because of their confinement. In discussing this study, Marcy (2004) noted that juvenile American shad can avoid potentially lethal temperatures and are capable of traversing or avoiding the heated effluent from Connecticut Yankee plant during their downstream migration. Similarly, juvenile American shad would be able to detect and avoid lethal temperatures within the thermal plume from Merrimack Station. No short-term temperature limit is needed to protect them.

The published literature provides additional support for a conclusion that the thermal limits proposed by EPA are not necessary to protect American shad. Impacts of cooling water withdrawals and thermal discharges from the Connecticut Yankee plant were studied in depth between 1965 and 1973, with special attention being paid to American shad (Jacobson et al. 2004a). Although many changes have occurred in the lower Connecticut River since the study was initiated, no evidence of any impacts of the plant on American shad or any other fish species have been found (Jacobson et al. 2004b). The failure of the Connecticut River study to find any evidence of thermal impacts on American shad (or other species) provides additional evidence that the thermal discharge from the Merrimack Station should not affect this species, if it is ever reestablished in the Merrimack River.

Implications of new thermal data requested by EPA

As noted above, the data used by EPA in its thermal tolerance analysis were taken from Appendix A of Normandeau's probabilistic thermal modeling report (Normandeau 2007a). EPA's general approach to evaluating thermal effects on fish relied on comparisons between critical temperature values for various life stages of fish to temperatures from Appendix A for two stations: Stations S-0, at the end of the

Merrimack Station discharge canal, and Station S-4, a thermally influenced station downstream from the canal. For each calendar date between June 1 and September 30, Appendix A provides the mean, minimum, and maximum temperature observed on that date over the 21-year period of 1984 through 2004. Each value is based on average temperatures over a 24-hour period. The mean temperature for a given date is the mean of 24-hour average temperatures on that date over the entire 21-year time series. The minimum and maximum average temperatures for that date are, respectively, the lowest and highest 24-hour averages for that date within the 21-year time series.

EPA appears to have misinterpreted Appendix A by assuming that the maximum temperatures provided in the table are averages of the maximum temperature observed on each date. Under this assumption, the maximum temperature in Appendix A for a given date would represent the average maximum temperature reached on that date during every year in the 21-year time series. This assumption substantially overstates the actual temperatures to which fish would have been exposed during those years.

The table heading for Appendix A referred to these temperatures as "average daily maximum, minimum, and mean" water temperatures. I was able to confirm through discussions with Normandeau staff that the values in the table were computed from 24-hour average temperature values on each date between May 1 and October 31 of each year. The maximum values for each date in Appendix A are the *highest 24-hour average temperatures* observed on that date during the 21 years. However, the table heading could be interpreted as stating that the table provides the *average of maximum temperatures* observed on each date over the 21 years. EPA's error, I believe, resulted from a misunderstanding of the table heading.

In a §308 request dated November 30, 2016, EPA requested that PSNH provide the 21-year averages of the minimum, mean, and maximum temperature on each date. In response to this request, Enercon and Normandeau (2016) compiled data on the average minimum, mean, and maximum temperatures for the years 2002-2015. These years were selected because digitized temperature data were unavailable for the years 1984-2001. In addition, the data from more recent years reflect current operational conditions at Merrimack Station. Average daily minimum, average, and maximum temperatures for every data from April 1 through October 31 for the period 2002-2015 are provided in Appendix 1 of Enercon and Normandeau (2016).

Compared to the values provided in Appendix A of the thermal modeling report, the maximum temperatures on each date in the revised data set are lower Even the average temperatures for Stations S0 and S4 are lower in the revised data set, reflecting altered station operations (Enercon and Normandeau 2016, Table 3).

Here, I repeat the analyses performed by EPA in its §316 Determination, but using the thermal estimates developed in response to the §308 request rather than the data provided in Appendix A of the thermal modeling report.

EPA's thermal tolerance analysis focused on four species: alewife, American shad, yellow perch, and white sucker.

Alewife

EPA compared maximum temperatures at station S0 to a lethal temperature value for alewife larvae, and the mean and maximum temperatures at station S4 to a thermal avoidance temperature for juvenile alewives. EPA identified 94.1°F as a lethal temperature for alewife larvae, and stated (erroneously) that the average maximum temperature at station S0 reached 94.1°F on June 11, a date "on or about" which alewife larvae were entrained at Merrimack. The data provided in the §308 response, however, show that the average maximum temperature at station S0 on that date was only 82°F, 12 degrees below the lethal temperature identified by EPA. The average maximum temperature at station S0 did not reach or exceed 94.1°F until July 16, long after any alewife larvae present in Hooksett Pool would have transformed to the juvenile life stage.

EPA also stated that the average maximum temperature at station S4 exceeded the avoidance temperature for juveniles (84°F) on every date from June 25 to September 8. However, the data provided in the §308 response show that the average maximum temperature at this station exceeded 84°F on 14 days between July 16 and August 10, and on no dates before or after that range. As noted by EPA on page 89 of the Determination, "young-of-year and adult alewives generally are not common in Hooksett Pool except during periods of out-migration, which typically occur in September or October." Impingement of alewives at Merrimack station has been documented no earlier than September 3. Hence, during the period in which alewives would be migrating past Merrimack Station, maximum temperatures at station S0 would have been lower than the 84°F avoidance temperature. The average maximum temperature on September 3 is 80°F, and lower than 80°F on all subsequent dates during the outmigration period.

American shad

EPA compared maximum temperatures at station S0 to two lethal temperature values for American shad larvae: 92.3°F and 91.9°F. EPA stated that maximum temperatures exceeding 92.3°F could occur as early as May 26, and that maximum temperatures exceeding that value had been reported on all but 9 dates in June and July. Maximum temperatures at Station S0, according to EPA, reached or exceeded 91.9°F on all but 6 dates in June, and every date in July. However, the revised thermal data show that the earliest date on which the average maximum temperature at Station S0 exceeded either of the lethal temperature limits cited by EPA was July 6, and those values were exceeded on only 15 dates in July.

EPA identified 85°F as a temperature at which habitat quality is "completely unsuitable" for American shad juveniles, and 88.9°F as a lethal thermal limit. EPA then asserted that the average maximum temperature at station S4 exceeded the 85°F limit on every date from June 25 to September 3, implying that the habitat at station S4 was unsuitable for American shad during this entire time period. However, the revised thermal data show that the average maximum temperature at station S4 reached 85°F on only 6 dates between July 18 and August 5, and on no dates outside this window.

Yellow perch

EPA compared maximum temperatures at station S0 to two lethal temperature values for yellow perch larvae (88.3°F and 89.6°F). EPA asserted that the average daily maximum water temperatures at station S0 during the period (May 1-June 15) when yellow perch larvae have been collect at the Merrimack Station intake structures can exceed 88.3°F as early as May 20 and can exceed 89.6°F as early as May 22. Temperatures exceeding these values, according to EPA, continue for the duration of the yellow perch larval period, which EPA estimates to end on June 15. However, the revised thermal data show that the average maximum temperature at station S0 did not exceed 88.3°F until June 28, after the end of the larval period.

EPA compared maximum daily average temperatures at station S4 to an avoidance temperature of 83.0°F. EPA asserted that these temperatures exceeded 83.0°F on every day from June 15 to September 10. However, the revised thermal data show that the average maximum temperature at this station only on 22 dates between July 16 and August 10. The average daily temperature did not exceed 83.0° on any date, so that even on days when the temperature at station S4 rose above 83°F, the habitat at that location would have been avoided by perch only during the hottest part of the day.

White sucker

EPA compared maximum daily average temperatures at stations S0 and S4 to upper incipient lethal temperatures (UILTs) for white sucker larvae of 85.0-89.1°F. EPA asserted that these temperatures were exceeded at station S0 from June 4, when the peak concentration of white sucker larvae was observed, through July 2, the last date on which larval white sucker were collected. In addition, EPA asserted that the average daily maximum temperature at station S4 also exceeded the white sucker UILT. However, the revised thermal data show that the average maximum temperature during all dates between June 4 and July 2 never exceeded the white sucker UILT at either station S0 or station S4.

EPA estimated a thermal avoidance temperature of 85.8°F for white perch, and compared this value to maximum daily average temperatures at station S4. EPA asserted that the maximum daily average temperature at this station exceeded this value on every date from June 25 to Sepember 1. However, the revised thermal data show that the average maximum temperature at this station reached 85° on only 3 dates during July, and never exceeded EPA's avoidance temperature.

Implications of the new thermal data for EPA's §316(a) Determination

The revised thermal data, providing the actual average maximum daily temperatures for each date from April through October, do not support the conclusions reached by EPA in the §316 Determination. In most cases, actual exposure temperatures in recent years have been lower than the thermal limits developed by EPA. In those few cases where these limits were still occasionally exceeded, the number of dates on which they were exceeded, and the durations of the periods when any exceedances occurred, were much smaller than was asserted by EPA and do not support a finding of appreciable harm.

EPA's §316b Determination

Section 10 of EPA's §316b Determination provides the Agency's statutory rationale for applying the Best Technology Available (BTA) standard to the cooling water intake structures at Merrimack Station. Section 11 of the document provides discussions of the adverse impacts of entrainment and impingement on Merrimack River fish populations, and also evaluates alternative technologies for reducing those impacts. Section 12 documents the technology selected as BTA by the Agency. This review focuses primarily on Section 11. I did not review EPA's analysis of impingement survival studies (or the sections of Normandeau's entrainment and impingement study report dealing with survival) because the current intake structure does not include a fish return system. Should PSNH modify the intake structure to include such a system, a new survival study would need to be performed, and would supersede the study discussed in Normandeau (2007c).

In Sections 11.1, 11.2, and 11.3 of the Fact Sheet EPA argues that entrainment and impingement at Merrimack Station impose significant adverse impacts on fish populations that must be reduced to promote recovery of those populations. EPA's arguments are based in part on the agency's interpretation of an entrainment/impingement study performed by Normandeau (2007c) in 2006 and 2007. However, EPA also used comparisons between monthly cooling withdrawals and river flow rates as an approximate measure of the fraction of the ichthyoplankton present in the river that could be entrained, and raised general arguments about potential impacts of entrainment and impingement that are derived from other Agency documents.

Adverse impacts of entrainment and impingement

<u>EPA's flow comparisons</u>

According to EPA, Merrimack Station often withdraws a very high fraction of the available flow in the Merrimack River. According to Figure 11-1 of the §316b Determination, the highest withdrawals, up to 60% of the total available flow, have occurred in August and September. Under low-flow conditions up to 24% of the available flow has been withdrawn in June, the month of highest entrainment.

To use the percentage of available flow withdrawn as measure of the potential percentage of susceptible populations entrained requires an assumption that ichthyoplankton are distributed uniformly within the water column and are passively transported with the currents. However, this assumption is invalid. Even EPA acknowledges that most of the resident fish species in the river spawn on the river bottom and have non-buoyant or even adhesive eggs. For example, yellow perch spawn on rocks, branches or other physical structures in shoreline areas, and deposit their eggs as adhesive ribbons (Carlander 1997). Centrarchid species such as largemouth bass, smallmouth bass, and bluegill build nests (Carlander 1977). Eggs of these species have very low exposure to currents, which probably explains why very few fish eggs are ever entrained at Merrimack Station.

Even mobile larvae that rise into the water column and can potentially drift with the current are far from passive. In studies of ichthyoplankton transport in the Hudson River, it was found that the movements of striped bass larvae could not be predicted based on hydrodynamic transport processes alone (Barnthouse et al. 1984). Larvae were found to be able to exploit tidal flows, eddies, and boundary layers to maintain themselves in optimal habitats rather than being swept downstream and out of the river. Fish larvae in the Merrimack River likely have a similar capability to maintain themselves in preferred habitats rather than being swept downstream and out of the Hooksett Pool. Hence, it is likely that the percentage of flow withdrawn is an overestimate of the percentage of larvae entrained.

EPA's arguments concerning indirect effects

On page 251, EPA discussed the role of eggs and larvae as food sources for other species and stated that "losses within these life stages represent losses to the area's overall energy budget and food web at multiple trophic levels, both now and in the future." On p. 254, EPA restated this argument, stating that "The environmental impact of this loss of forage opportunity cannot be quantified at present, but it clearly creates added stress on the Hooksett Pool ecosystem because, in the absence of the organisms lost, foraging must be directed towards other available sources." Similar arguments were made by EPA in case study reports (e.g.,USEPA 2006), economic benefits analyses (e.g., USEPA 20014) and in Section III D of the §316(b) Final Rule (USEPA 2014b).

These arguments are purely speculative. None of the above documents include any analyses of data, and none include citations to documented cases in which these kinds of indirect effects have been observed to be caused by entrainment or impingement. EPRI

(2011b) reviewed the scientific literature on potential impacts of entrainment and impingement on food webs and found that (1) no such effects have ever been documented, and (2) on theoretical grounds such effects are very unlikely. Entrained organisms, and at many facilities impinged organisms as well, are returned to the source water body and are still available as forage for other species, so that there is no loss of biomass to the ecosystem.

<u>EPA's analysis of Normandeau's entrainment and impingement study</u>

In evaluating Normandeau's (2007c) 2-year entrainment and impingement study, EPA chose to discount the sampling at Unit 1 in May, 2006, on the grounds that no organisms were collected during the single sampling date in May, 2006 at that unit. Instead, EPA used the sampling data at Unit 2 to represent Unit 1 sampling, substantially inflating Normandeau's estimate of average annual entrainment at Merrimack Station. The fact that no larvae were collected on that date does not in and of itself invalidate the data point. Ichthyoplankton distributions are highly patchy, and sampling effort was relatively low: only 2 100 m^3 samples were collected at each station on each sampling date. Although Normandeau estimated a monthly entrainment rate of 742,481 larvae for Unit 2 in May, 2006, this estimate appears to have been based on a total of 30 larvae (28 of them white suckers) collected on a single sampling date, extrapolated to a monthly total using total cooling water withdrawals for the month. It's highly likely that organisms actually were entrained at Unit 1 during May, 2006, but it's also possible that the single value for Unit 2 substantially inflates the number of organisms entrained during May, 2006. Absent an objective reason for discounting the Unit 1 data (e.g., data quality issues identified through Normandeau's QA/QC procedures), the Unit 1 value should be included in the average. However, discussion of the results should emphasize the high uncertainty concerning actual entrainment totals for May, 2006.

Normandeau (2007c) expressed the numbers of fish entrained and impinged during 2006-2007 as equivalent adults, a common metric for assessing impacts of power plants on fish populations (EPRI 2004). To be useful for this purpose, an estimate of the size of the source population providing the entrained or impinged fish is needed. In the absence of such estimates, EPA attempted to provide an interpretive context for Normandeau's (2007c) equivalent adult losses by comparing these losses to numbers of fish collected in electrofishing and trapnet samples. EPA noted that only 76 yellow perch were collected over the two years 2004 and 2005, and additional 76 were collected in 2008. According to the EPA, the 195 adult equivalent yellow perch calculated by Normandeau for 2007 entrainment "takes on greater significance" in light of the low numbers of yellow perch present in the river. This comparison is not legitimate, because neither electrofishing nor trapnetting is designed to provide a complete population census. Only a very small fraction of the river is sampled by either gear. Obtaining an estimate of the total size of the yellow perch population in the Hooksett Pool would require a mark-recapture study, and no such study has ever been performed.

With respect to impingement, EPA concluded that (1) the routine impingement monitoring required in the existing NPDES permit is inadequate because it is limited to the period July 1-October 15, (2) the special impingement study conducted from 2005-2007 shows that impingement at Merrimack Station is much higher than previously believed and constitutes a significant additional stress on the ecosystem, and (3) impingement of American shad and river herring is likely to impede or undermine efforts to restore runs of these fish in the Merrimack River.

The results of the 2-year impingement study show that most impingement does, in fact, occur outside the July 1-October 15 window specified in the existing permit. However, the numbers of fish impinged during the 2-year study were quite low compared to numbers impinged at most power plants. According to Normandeau (2007c), an estimated 8,007 fish were impinged from July 2005 through June 2007. Of this total, more than half (4,300) occurred during a single month, June 2006. Of this anomalous monthly total, 95% (4,089) were juvenile bluegills. For all other months included in the study, total impingement ranged from 11 to 581 fish per month. By way of comparison, annual impingement at 9 Ohio River power plants included in EPA's 2002 §316b Case Study (USEPA 2002, Appendix C) ranged from 47 thousand to 1.7 million fish per year.

Impingement totals from Normandeau's (2007c) study are comparable to numbers of fish collected during the Hooksett Pool fish surveys. For example, according to Table 2-5 of Normandeau (2007a) 3367 fish were collected by electrofishing in 2004 and 1032 were collected in 2005 (Table 2-9). This comparison implies that the impact of impinging 4,000 fish per year at Merrimack Station is similar to the impact of Normandeau's pool-wide fish surveys, and should be considered *de minimis*.

Discussion of adverse impact assessment

EPA concluded that both entrainment and impingement at Merrimack Station have had direct adverse impacts on fish populations and indirect adverse impacts on the Merrimack River food web. None of these conclusions are supported by available data. EPA's conclusions regarding indirect impacts are purely speculative and supported neither by site-specific data nor by other published studies. EPA's conclusions regarding impacts on specific fish populations are similarly unsupported. Since both the numbers impinged and the numbers entrained (when expressed as equivalent adults) are similar to numbers collected during annual pool-wide surveys, it is reasonable to conclude that (1) impacts of entrainment and impingement are similar to impacts of fish surveys, and (2) biological benefits of reducing entrainment and impingement are likely to be similar to benefits of ceasing to perform the surveys.

EPA's evaluation of alternative intake technologies

I have no comments concerning EPA's analysis of alternative intake technologies in Section 11.3. I have read the evaluation of alternative intake technologies prepared by Enercon (2014). Enercon's conclusions are consistent with results of other intake technology assessments with which I am familiar. In particular, Attachment 1 to Enercon's report, which was prepared by Normandeau, accurately summarizes the recent laboratory, field, and modeling studies of cylindrical wedgewire (CWW) screens performed at the Alden Research Laboratory and at the Indian Point Energy Center. It should be noted, however, that white sucker was one of the test species used in the laboratory studies. EPA cannot validly raise an objection that the organisms tested were not representative of fish species susceptible to entrainment at Merrimack Station.

Overall Conclusions

EPA's biological analysis of Merrimack Station's §316(a) Demonstration contains three significant flaws that invalidate its conclusion that the operation of Merrimack Station with once-through cooling has caused appreciable harm to the BIP present in the Hooksett Pool of the Merrimack River. These flaws are:

1. Failure to account for the effects of historic water quality improvements when interpreting changes in the Merrimack River fish community;
2. Over-reliance on classification of fishes as "coolwater" or "warmwater" when interpreting population trends, and
3. Erroneous interpretation of Merrimack River temperature data when evaluating effects of thermal exposures on representative fish species.

Over time, all biological communities can be expected to change, and given the pollution history of the Merrimack River substantial changes in the fish communities present throughout the river from the 1970s to the present should be expected. The available benthic invertebrate community data support a conclusion that biological conditions in the Hooksett Pool have improved since the early 1970s, most likely as a result of improved sewage treatment. This improvement must be considered when interpreting data on changes in fish community composition over the past 40 years.

The currently existing fish communities in Garvins Pool and Amoskeag Pool appear to me to be the most appropriate context for evaluating appreciable harm due to operation of Merrimack Station. All three pools have been influenced by the same historic water quality impacts, and subjected to the same influences of introduced (or naturally invading) species such as black crappie and bluegill. All three support roughly the same species, although the relative abundances vary. I see no indication that the temperature tolerances of these species vary among pools.

It would be possible to perform additional analyses comparing temperature tolerances from published literature to (properly interpreted) measured river temperatures, but I do not believe that such analyses would provide useful insights. The literature-derived tolerance values themselves are highly uncertain and often of limited value. Given the 40-year operational history of the Station, I believe that analysis of field data on the composition of the Merrimack River fish community is the most appropriate approach to evaluating the effects of Merrimack's thermal discharge. From this perspective, the data provided in the Normandeau (2011b) report appear to support a conclusion that operation of Merrimack Station has caused no appreciable harm to the BIP present in the Hooksett Pool.

A more in-depth review of thermal tolerance data for fish species discussed by EPA confirms that, consistent with their broad geographic distributions, these species have very broad temperature tolerances. EPRI's (2011a) review of published literature on thermal toxicity called into question the value of grouping fish species into "coolwater" and "warmwater" guilds. If EPRI (2011a) is correct, then EPA's premise that Merrimack's thermal discharge has caused coolwater species to be replaced by warmwater species is nonsensical because no such groupings exist.

EPA's attempt to define thermal tolerance criteria analogous to the toxicity-based water-quality criteria for chemicals is similarly unsupported by available information concerning the thermal tolerances of yellow perch and American shad. Both of these species inhabit wide ranges of thermal environments, both warmer and cooler than the Merrimack River. Hokanson's (1977) comprehensive review of yellow perch life history and temperature requirements shows that temperatures that typically occur in the Merrimack River downstream from the thermal discharge are well within the range of thermal regimes inhabited by this species.

Finally, EPA's conclusion that entrainment and impingement are having adverse impacts on Merrimack River fish populations is purely speculative and is unsupported by any credible scientific analyses.

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