Review of Available Water Temperature Data and Thermal Plume Characterizations related to the Merrimack Power Station in Bow, NH

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Prepared by:

Ken Hickey
Peter Shanahan, Ph.D., P.E.

HydroAnalysis

481 Great Road, Suite 3
Acton, Massachusetts 01720
(978) 263-1092

About the Authors

Ken Hickey

Ken Hickey is President of HydroAnalysis, Inc. and has twenty-five years of experience conducting surface water hydrologic and water quality investigations. He has successfully designed and conducted numerous river and estuarine hydrologic and water quality field investigations and modeling studies. Mr. Hickey has applied a wide range of hydrologic and water quality models, from simple to complex, to quantifying pollutant loads and potential impacts on ambient water quality and ecological receptors. He has conducted river studies for the U.S. Environmental Protection Agency, U. S. Army Corps of Engineers, state agencies, and commercial clients throughout New England and the United States. Mr. Hickey holds an M.S in Environmental Engineering from the University of Cincinnati.

Peter Shanahan

Dr. Peter Shanahan, P.E., is the founder and Vice President of HydroAnalysis, Inc. He has completed a wide variety of projects involving analysis and computer modeling of environmental water quality, hydrology, and hydraulics. Dr. Shanahan is retired from a position as Senior Lecturer at the Massachusetts Institute of Technology (MIT). He has over forty years of experience in environmental engineering and consulting, and is a registered professional engineer. Dr. Shanahan is a member of the International Water Association (IWA), Water Environment Federation, and American Society of Civil. Dr. Shanahan holds a PhD in Environmental Engineering from the Massachusetts Institute of Technology.

1.0 Introduction

This report summarizes a review of available Merrimack River water temperature data and thermal plume characterizations relative to Clean Water Act §316(a) demonstration guidelines and the ongoing NPDES permitting process for the Public Service of New Hampshire (PSNH) Merrimack Power Station in Bow, New Hampshire. EPA has recently elected to reopen the public comment period for the Merrimack Station draft NPDES permit for a limited set of topics including topics related to Merrimack River water temperatures and associated thermal impacts on aquatic species. An overview of EPA's limited Merrimack Station draft NPDES reopener, a description of the scope of this review, and a summary of findings are provided below.

In 2011, EPA proposed to reject the Merrimack Station's request for a CWA §316(a) thermal discharge variance (US EPA, 2011). Since 2011, PSNH has argued that EPA should not have rejected its draft NDPES permit and has submitted data, letters, and technical reports in support of this argument. EPA recently elected to reopen the public comment period for the Merrimack Station draft NPDES permit, stating "EPA is reopening the comment period because, since issuance of the Draft and Revised Draft Permits, new data, information, and arguments pertinent to certain aspects of the permit – including data, information, and arguments related to new EPA regulations applicable to the permit – have emerged and appear to raise substantial new questions concerning the permit." (US EPA, 2017). EPA states that "the comment period for the Draft Permit is not being reopened across the board'", but "is only being reopened with respect to certain questions, issues and information" (US EPA, 2017). The set of questions, issues, and information covered by the reopener include Merrimack River water temperature, effects and status of aquatic species in the Merrimack River, changes in regulations, and changes in treatment technologies.

This review is focused on the reopener topic; "New Information Raising Substantial New Questions Regarding the Application of CWA §316(a) and New Hampshire Water Quality Standards for Setting NPDES Permit Requirements for Merrimack Station's Thermal Discharges" (US EPA, 2017, p. 36-41, B). The issue of new Merrimack River water temperature information arose, in part, due to a misunderstanding between EPA and PSNH regarding interpretation of a statistical summary of Merrimack River water temperature data provided by PSNH in a probabilistic thermal modeling report (Normandeau, 2007). According to PSNH and their consultants, this misunderstanding is important because it contributed to EPA drawing inaccurate conclusions regarding Merrimack River water temperature data and, by extension, the nature and extent of the Merrimack River thermal plume (Normandeau, 2012).

Reopening the draft NPDES permit process to evaluate new river water temperature data and information necessitates a re-examination of Merrimack Station thermal plume characterization relative to CWA §316(a) requirements. As a result, the review provided herein includes an evaluation of available Merrimack Station thermal plume characterization information and comparison with 316(a) demonstration guidance.

2.0 Review Objectives and Summary of Findings

This review is focused on characterization of thermal plumes in the Merrimack River resulting from the Merrimack Station cooling-water discharge. The objectives of this review and our findings in brief are:

Objective 1: To determine whether PSNH had provided a sufficient thermal plume characterization to support a CWA §316(a) determination in accordance with EPA 316(a) guidance (US EPA, 1977).

Finding 1: A complete 316(a) demonstration does not appear to have ever been conducted for Merrimack Station. Further, we find that PSNH has failed to provide the key elements of a 316(a) thermal plume characterization. Specifically, PSNH does not appear to have provided the following CWA 316(a) guidance elements specified by US EPA (1977):

1. Delineating the full extent to the thermal plume (to beyond the 1°C isotherm);
2. Including additive or synergistic effects, such as dam operations;
3. Characterizing the thermal plume under a variety of conditions, including average and 7Q10 summertime low-flow (worst-case) conditions, and providing thermal plume maps with aerial and cross-sectional views of the full extent of the plume under a variety of conditions; and
4. Presenting river water temperature, thermal gradients, river flow, and related data in tables and illustrations under a variety of conditions.

PSNH has failed to have provided these key 316(a) thermal plume characterization elements. This finding is described in Section 3.

Objective 2: To determine whether PSNH had submitted sufficient new data and information to "lead to changes either to EPA's decision to deny PSNH's request for renewal of its existing thermal discharge variance under CWA § 316(a), 33 U.S.C. § 1326(a), or EPA's analysis of how to apply New Hampshire water quality standards to the regulation of Merrimack Station's thermal discharges" (US EPA, 2017, item 8, p. 4-5).

Finding 2: We found that recent PSNH submittals have not improved characterization of the Merrimack River thermal plume and are insufficient to support changes in previous EPA decisions. We reviewed several sources of data and information including:

- The water temperature statistical summary tables that were the subject of the misunderstanding between PSNH and EPA (Normandeau, 2007, Appendix A);
- The Probabilistic Thermal Plume Model report (Normandeau, 2007); and,
- CORMIX Thermal Plume Model report (Enercon Services, 2016, Appendix B).

These findings are described in Section 4.

Objective 3. To determine whether, based on available data and information, the Merrimack Station thermal plume appears to be sufficiently small that it would be expected to have a *de minimus* effect on aquatic species in Hooksett Pool.

Finding 3. We found that simple time-series plots of available temperature data reveal frequent and persistent exceedances of fish tolerance thresholds. Based on review of available data and reports (e.g., Gomez and Sullivan, 2003), it appears highly likely that the Merrimack Station thermal plume extends downstream well beyond the Hooksett Dam under typical summertime conditions. In brief, there is ample evidence that a comprehensive 316(a) demonstration study, including a detailed thermal plume characterization under a variety of conditions, should be conducted prior to approval of a water quality variance or a NPDES permit renewal. These findings are described in Section 5.

3.0 Clean Water Act §316(a) Demonstration Guidance

Thermal discharges to receiving waters are regulated under Section 316(a) of the federal Clean Water Act. In 1977, the United States Environmental Protection Agency (EPA) issued a technical guidance manual to guide development of 316(a) demonstration reports (US EPA, 1977). The EPA manual provides guidance for identifying the appropriate level of information in demonstrations and in scoping thermal, fisheries, and other surveys to support assessment of potential adverse impacts. The 1977 manual provides guidance, rather than requirements, and is intended to assist regulatory and industrial practitioners in designing and completing Section 316(a) demonstrations. Although forty years have elapsed since publication of the guidance document, it has never been updated by EPA. Nonetheless, in the 2011 Draft Merrimack Station NPDES Permit determination document (US EPA, 2011, p.33), EPA states that the 316(a) guidance document "is widely used by industry and regulators in the preparation and review of §316(a) variance request demonstration documents. For example, Merrimack Station refers to it in the Fisheries Analysis Report."

According to EPA guidance, "a 316(a) demonstration will be judged successful if the applicant can prove that fish communities will not suffer appreciable harm" from cold shock or excess heat, reduced reproduction success or growth, exclusion of unacceptably large areas, or blockage of migration (US EPA, 1977, pp. 28-29). In terms of thermal discharge analyses, EPA guidance specifies consideration of the near- and far-field areas that could potentially be affected by the discharge. EPA guidance also specifies consideration of additive or synergistic effects, such as other existing thermal discharges, dams, or other factors that could combine with the thermal discharge to increase the adverse effect on fisheries. The EPA guidance further specifies that the complete thermal plume be mapped under a variety of conditions and that the presentation of results should include relevant time-series data, such as facility discharge flow and temperature; ambient river flow, velocity, and temperature; and meteorological data.

A complete 316(a) demonstration does not appear to have ever been submitted for Merrimack Station. Further, there is no comprehensive document that pulls the thermal plume information together and presents it clearly. Over the years, PSNH has submitted reports and data summaries related to thermal plume characterization. These submittals include thermal monitoring reports from the 1970s (e.g., NH Fish and Game, 1971 and Normandeau, 1979), tables of average daily temperature measurements at three Merrimack River stations (e.g., AR-1301), and modeling studies (e.g., Normandeau, 2007 and Enercon, 2016). These PSNH thermal plume-related submittals provide fragments of information, but lack the comprehensive thermal plume characterization required in a CWA §316(a) demonstration.

The burden of proof for justifying alternative thermal discharge limitations under CWA §316(a) is on the permit applicant (US EPA, 2011, p. 24-26). By failing to provide thermal plume characterizations and presentations of data, as outlined below, PSNH has not met the burden-of-proof requirement. A full comprehensive 316(a) demonstration should be submitted by PSNH, in coordination with US EPA, and submitted for review prior to approval of a 316(a) water quality variance.

We identified several components of the EPA 316(a) demonstration guidance that are particularly relevant to the Merrimack Station. These are described in the following.

EPA guidance specifies that analysis and mapping be conducted to characterize the nature and extent of the thermal discharge and associated plume. The EPA guidance states that the applicant should include the four components outlined below. These four components are important in this context because it appears none have been provided for the Merrimack Station. Specifically, the EPA guidance includes the following instructions:

1. Include the discharge vicinity in the study domain (i.e., study area). The discharge vicinity is defined as "described by a radius that is 1.5 times the maximum distance from the point of discharge to within 1°C of ambient" temperature (US EPA 1977, p. 75).

We have not found any studies that include delineation of the thermal plume below the Hooksett Dam, located 2.9 miles downstream of the Merrimack Station discharge location. There is evidence that the thermal plume extends beyond the Hooksett Dam. For example, continuous water temperature measurements collected at Hooksett Dam during the summer of 2002 (Gomez and Sullivan, 2003, p.77-79) showed a typical increase in water temperature of 2 to 4°C (3.6 to 7.2°F) between Garvin's Dam, which is above the Merrimack Station thermal discharge, and Hooksett Dam, which is below. The 2003 report concluded: "The warmer water temperatures observed at Hooksett are likely due to the cooling water discharges into the river upstream of Hooksett at the Merrimack Station coal-fired power plant in Bow." (Gomez and Sullivan, 2003). The full extent of the Merrimack Station thermal plume, including below Hooksett Dam, should be delineated.

2. Include "the impact of additive or synergistic effects of heat combined with other existing thermal or other pollutants in the receiving waters" (US EPA, 1977, p. 38).

Hooksett Dam and Garvin's Dam operations represent additive or synergistic activities that could affect water temperatures in Hooksett Pool. According to the 2007 Probabilistic Thermal Model of the Merrimack River Downstream of Merrimack Station (Normandeau, 2007), "the extent and duration of the Station's thermal influence in Hooksett Pool have not been fully quantified to date, due to the complex relationship between the downstream thermal regime in Hooksett Pool and Station electrical output, river flow, and upstream ambient river temperature." The 2007 report appears to be describing a rationale for not characterizing the Hooksett Pool thermal plume. Instead, recognition that these factors affect the thermal plume should lead to the conclusion that these factors must be included in the 316(a) demonstration process. Unfortunately, we have not found studies that included the effects of dam operations on the Hooksett Pool thermal plume. The thermal plume should be characterized with inclusion of additive and synergistic effects.

3. Provide graphs of "the discharge plume out to the 1°C isotherm" under "worst case, anticipated average conditions, and ideal conditions" (US EPA, 1977, p. 46) and "Representative plumes of the maximum size and most frequently occurring plume shall be detailed showing instantaneous isotherms at the 2°C intervals to within 1°C of ambient for conditions …" (US EPA, 1977, p. 49).

US EPA (1977, p. 50) also states "Plumes for average and 7-day, 10-year low flows should be provided" and "vertical temperature profiles along the plume centerline extending to the bottom of the water body at 2°C intervals to within 1°C of ambient" temperature should be provided.

Some cross-sectional diagrams and areal-view thermal plume maps were provided in monitoring program reports from the 1970's (e.g., NH Fish and Game, 1971 and Normandeau, 1979). These maps do not characterize the full extent of the thermal plume nor do they represent a variety of conditions, such as average and worst-case low flow conditions. The 1970s maps characterize only parts of the thermal plume based on field measurements.

Full sets of thermal plume maps that delineate the entire plume in three dimensions and under different conditions, including average and worst-case, are not provided in the administrative record. The lack of thermal plume characterization maps makes it impossible to assess the spatial extent of the thermal plume or the associated zone of fish passage.

4. Provide tables or illustrations of ambient river flows and velocities over time and river temperatures and thermal gradients over time. Also, provide tables or illustrations of facility discharge flow and temperature over time and meteorological conditions over time (US EPA, 1977, pp. 47-50).

There is a paucity of river water temperature measurement data, tables, figures, or other illustrations available in the administrative record. The few time-series plots of water temperature in the administrative record provide insufficient characterization of the plume under varying river flow, dam operations, and power station operations. For example, time-series plots of river flow, dam operations, Merrimack Station power generation and water use, and river water temperatures are critically important and fundamental to describing and understanding thermal conditions in the Hooksett Pool. Similarly, three-dimensional thermal plume maps and dynamic model simulation videos are readily available technologies for presenting thermal plume measurements and predictions, but do not appear to have been used to present the Hooksett Pool thermal plume.

Instead, PSNH appears to have substituted complex statistical models, such as the 2007 probabilistic model (Normandeau, 2007), in place of the temperature data presentations and thermal plume characterizations that are recommended by US EPA (1977) for 316(a) demonstrations. Statistical models can be useful for supplementing our understanding, but should not be used as a replacement for presenting data. The lack of available water temperature measurement data in the administrative record is so severe that EPA was forced to rely on 21-year averaged statistical summaries in assessing thermal impacts (US EPA, 2011). Long-term statistical summaries are wholly insufficient to support characterization of thermal plumes as part of a 316(a) demonstration. All temperature, flow, power generation, dam operation, and other related data should be presented in a clear manner by the PSNH to support the 316(a) demonstration process.

4.0 Evaluation of New Data and Information

The following three data sets and reports were reviewed and are summarized below:

- The water temperature statistical summary tables that were the subject of the misunderstanding between PSNH and EPA (Normandeau, 2007, Appendix A);
- A Probabilistic Thermal Model of the Merrimack River Downstream of Merrimack Station (Normandeau, 2007); and,
- CORMIX Thermal Plume Model modeling (Enercon Services, 2016, Appendix B).

4.1 Overview of the misunderstanding regarding water temperature statistical summary tables

A misunderstanding between EPA and PSNH occurred regarding interpretation of a set of statistical summary tables provided in Appendix A of the 2007 Probabilistic Thermal Model report (Normandeau, 2007). The Appendix A tables are 21-year statistical summaries of daily statistical summaries, as described below.

The Merrimack Station 1992 NPDES permit requires submittal of "all" temperature measurements collected at three locations along the Merrimack River. Temperature measurements are collected every 15 minutes at Station N-10 upstream of the Merrimack Station discharge, at Station S-0 at the discharge, and at Station S-4, 0.38 miles downstream of the discharge. As discussed in Section 3.2, PSNH does not appear to submit continuous temperature measurement data in table, figure, or electronic form. Instead, PSNH has submitted daily statistical summaries (daily average, maximum, and minimum temperatures). Daily statistical summaries mask river temperature fluctuations over time making it impossible to see temperature fluctuations that would be apparent in the continuous temperature measurements. For example, large, short-term (e.g., over periods of minutes or hours) temperature variations that can harm aquatic organisms are not detectable in daily summary statistics. For each month, PSNH submits a temperature data statistical summary table to EPA in PDF format. Table 1 is an example of a monthly data summary table from August 2000.

For the probabilistic thermal modeling evaluation, PSNH's consultant, Normandeau, created statistical summary tables for the months of April through November using the monthly statistical summary tables from a 21-year period. The tables in Appendix A provide the average daily water temperature at three locations, N-10 (upstream), S-0 (at), and S-4 (0.38 miles downstream of the Merrimack Station thermal discharge) over a 21-year period from 1984 through 2004. Table 2 provides the August table from Appendix A of the Normandeau report. To create each average daily entry, the average daily temperatures for each of 21 years on the same date are averaged. For example, the entry of 85.2°F for August 5^{th} at Station S-4 represents the average of the 21 daily average water temperatures measured on August 5 at Station S-4 over a 21-year period.

The misunderstanding arose because EPA interpreted the tables as indicating that the minimum and maximum temperature columns were <u>average</u> minimum and <u>average</u> maximum temperatures for each day over the 21-year period. PSNH clarified that the maximum and minimum temperatures for each day were the maximum and minimum temperature for that day for the entire 21-year period of record. PSNH argued that EPA had misinterpreted the temperature measurement data and, based on that misinterpretation, had come to inaccurate conclusions.

4.2 Review of the Probabilistic Thermal Model and Discussion of the Statistical Data Summary Misunderstanding

We find the Normandeau 2007 probabilistic thermal modeling analysis report ill-suited for supporting a 316(a) demonstration and concur with EPA's rejection of the report (US EPA, 2011). Probabilistic modeling is not directly applicable to evaluating dynamic thermal plumes and potential effects on aquatic species. There was not a need for a probabilistic thermal model of the study area. Rather, there was a need for a clear presentation of available temperature data. The model is ill-suited to support a 316(a) demonstration because it uses long-term averaging and model predictions to replace presentation of temperature measurements. As a result, Normandeau has hidden peak water temperatures and temperature fluctuations experienced by aquatic species in Hooksett Pool from review.

Normandeau had access to a temperature data set consisting of temperature measurements collected every 15 minutes for 21 years at locations above, at, and below the Merrimack Station thermal discharge point. This comprehensive, long-term, and detailed characterization of temperature in the Merrimack River was essentially ignored and there are no descriptions, tables, figures, or other presentations of the actual measured temperatures anywhere in the report. Instead, only high-level summaries that hide peak temperatures and temperature variation over time are provided in Appendix A. Merrimack River temperature data should have been presented in a clear and comprehensive manner in the Normandeau report. Failure to present temperature data suggests an attempt to hide data and mislead readers.

The probabilistic thermal model was used to develop a family of curves of temperature versus time of year at the four stations, with each curve corresponding to a particular probability of occurrence. The curves identified as extreme conditions were those corresponding to "an infrequent (one in 100 year) probability of occurrence" (Normandeau, 2007, p. 12). The model predicted that "There would be no days of exceedance of 90°F at either Monitoring Station S-4 or A-0 for the extreme scenario" (Normandeau, 2007, p. 12). In summary, the report states that at these two stations, water temperatures are expected to exceed 90°F less often than one year in every 100 years.

We reviewed daily water temperature data summary tables for Station S-4 for the period of 1984 – 2004 (AR-1301 – 1304 and AR- 1307). We found that average daily water temperatures exceeded 90°F on at least one day in 14 of the 20 years (2001 data are missing). Thus, the 1984 – 2004 temperature data set reveals exceedances of the extreme scenario in 70% of years, strongly contradicting the probabilistic model predictions. It is important to note that the temperature data that we reviewed are the same data that were used to develop the probabilistic model that predicted a one-in-100-year recurrence interval for the extreme scenario.

The probabilistic model is ill-suited for use in 316(a) demonstrations and the resulting model predictions are demonstrably inaccurate and misleading. The practice of withholding temperature measurement data and substituting in probabilistic model predictions of water temperatures is wholly inappropriate and the form in which temperature data are presented in Appendix A is not useful for characterizing the thermal plume in Hooksett Pool. As a result, the misunderstanding relative to maximum and minimum temperatures in Appendix A tables is inconsequential. However defined, the 21-year statistical summaries of each year's statistical summaries do not represent useful or appropriate temperature data submittals in a 316(a) demonstration context.

4.3 CORMIX Thermal Plume Modeling Technical Report (2016)

EPA invited comments (US EPA, 2017, p. 40) on a CORMIX thermal plume modeling report (Enercon Services, 2016, Attachment B) submitted to EPA on December 22, 2016. We conducted a preliminary review of the CORMIX modeling report. The CORMIX modeling application described in the report featured use of the far-field component of the CORMIX model to predict the extent of the thermal plume in Hooksett Pool resulting from the Merrimack Station thermal discharge.

We find the 2016 CORMIX thermal plume modeling application to be inadequate for delineating the thermal discharge plume in Hooksett Pool for the following reasons:

1. The model used averaged data over a 10-year period (2006 – 2015). Averaging data over long time periods results in simulation of average conditions and masks dynamic and "worst-case" conditions.

2. CORMIX is a steady-state model and is therefore incapable of simulating dynamic conditions (e.g., changes in water temperature over time due to changes in waste heat load). Modeling of thermal plume dynamics is critically important to thermal plume characterization.

3. The far-field component of CORMIX requires a set of simplifying assumptions regarding the river including a uniform flow field (same water velocity throughout the river cross-section) and a straight channel of uniform depth and width. The reach of the Merrimack River downstream of the thermal discharge location is not straight, but rather enters a major bend just downstream of the discharge location. Water velocities in the Merrimack River are not uniform with depth or across the river. Water depths are also not uniform. Schreiner et al. (2002) tested the CORMIX model for complex river situations and found it wanting. They warn: "For complex discharges and complex ambient environments, the model often mixed plumes too rapidly, resulting in smaller modeled plumes that were cooler than the measured plumes."

   In addition, due to CORMIX model limitations, the Merrimack River was represented as uniformly 6-feet deep and 120-feet wide in the modeling application (Enercon Services, 2016, Appendix B, p. 15-16) whereas the river depth and width in fact vary. The width of the river ranges from approximately 400 to 580 feet downstream of the discharge location.

4. The modeling application was conducted without model calibration or validation. Model predictions do not appear to have been compared to river water temperature measurements or used to adjust the model and make it more accurate. Schreiner et al. (2002) address model validation as well: "CORMIX results should be used with caution in evaluating the effects of a discharge and only in conjunction with information from the field."

5. Heat-loss coefficients provided in Figure 1 of Enercon Services (2016) are high compared to those given by Edinger et al. (1974) in a well-recognized treatise on modeling temperature in the environment or by Adams et al. (1981), the ostensible source of the coefficients in CORMIX (Doneker and Jirka, 2007). There are numerous variations on the dependence of the heat-exchange coefficient on wind speed, of which some are more suited to natural conditions and others to highly heated conditions (Shanahan, 1985). The heat-loss coefficients used by

Enercon are representative of highly heated water bodies, like cooling ponds, rather than natural water bodies, which the Merrimack more closely approximates. The effect of the high heat-loss coefficients is to dissipate the plume more quickly in the model than actually occurs in the field.

For these reasons, the CORMIX far-field model does not appear to be an appropriate modeling tool for simulating a thermal plume resulting from a time-varying thermal discharge into a river with time-varying flows and non-uniform dimensions (i.e., with bends and large variations in width and depth). More broadly, a CORMIX thermal plume modeling analysis was not needed. A clear and compelling presentation of available Merrimack River temperature measurements was needed.

The report asserts that the CORMIX thermal model "results are valid to inform the biological evaluations presented in Dr. Barnthouse's evaluation of the influence of Merrimack Station's thermal plume on habitat utilization by fish species present in lower Hooksett Pool" (Enercon Services, 2016, App. B, p. 32). We strongly disagree that the results of this modeling analysis are appropriate or sufficient to support a biological impact analysis. Further, we find that the CORMIX modeling analysis did not contribute to thermal plume characterization.

5.0 Evaluation of the Thermal Plume based on Limited Available Data

The following two available temperature data sets were evaluated to partially characterize the Merrimack Station thermal plume:

- Continuous water temperature measurements collected at Garvin's Dam and Hooksett Dam during the summer of 2002 (Gomez and Sullivan, 2003, p. 77-79)
- Daily water temperature statistics from water temperature measurements collected upstream, at, and downstream of the Merrimack Station discharge location by PSNH from 2002 through 2014 (AR-1307, Excel files)

The temperature measurements made by Gomez and Sullivan (2003) help fill in the picture of temperature along the Merrimack River. The sequence of stations is as follows (see Figure 1):

- Garvin Dam at 2.9 miles upstream of Merrimack Station (by Gomez and Sullivan, 2003);
- Station N-10 at approximately 0.9 miles upstream of Merrimack Station discharge (by PSNH);
- Station S-0 adjacent to the discharge (by PSNH);
- Station S-4 at 0.38 miles downstream of the discharge (by PSNH); and,
- Hooksett Dam at 2.9 miles downstream of the discharge (by Gomez and Sullivan, 2003).

To be clear, burden of proof for characterizing the thermal plume and evaluating potential impacts lies entirely with the applicant and not with the authors of this review. The evaluation below provides examples of available temperature measurements and illustrates the need for a comprehensive 316(a) demonstration of Merrimack Station thermal impacts. Examples from each data set are presented and briefly discussed below.

5.1 Merrimack River Dam Water Temperature Measurements

Water temperature was measured below four dams along the Merrimack River during the summer of 2002 as part of the Federal Energy Regulatory Commission (FERC) relicensing-related project (Gomez and Sullivan, 2003). Time-series plots of continuously-recorded (every 15 minutes) water temperature measurements are presented in the report (Gomez and Sullivan, 2003, pages 77-79). Figure 2 shows water temperature measurements in July and August 2002 and Figure 3 shows water temperature measurements in September and October 2002. Garvin's Dam (water temperature measurements shown in dark blue) is located 2.9 miles upstream of the Merrimack Station thermal discharge and Hooksett Dam (lavender) is located 2.9 miles downstream of the thermal discharge. The time-series plots show a typical increase in water temperature of 2 to 4°C (3.6 to 7.2°F) between Garvin's Dam and Hooksett Dam. On September 5^{th} and 17^{th}, the increase in water temperature was approximately 5.6°C (10°F).

The Hooksett Dam water temperature measurement location is downstream of the dam where thorough mixing of Hooksett Pool waters is expected to have occurred. As a result, the ΔT values observed between the Garvin's and Hooksett Pool Dams are average ΔT values for the entire water volume of the lower Hooksett Pool area, from the Merrimack Station discharge location to the Hooksett Dam, a distance of 2.9 miles. In summary, the Merrimack River dam water temperature measurements led to the observation that the average water temperatures in the lower Hooksett Pool were typically increased by 3.6 to 7.2°F, with peak temperature increases of 10°F, during the summer of 2002. While elevated summertime air temperatures and solar heating could have contributed to these increases in river temperature, those contributions would have been minor and the majority of these temperature is likely due to the Merrimack Station discharge.

5.2 Merrimack River Water Temperature Measurements above, at, and below the Merrimack Station Discharge Location

Daily statistical summaries of Merrimack River water temperature measurements collected above (Station N-10), at (Station S-0) and 0.38 miles below (Station S-4) the Merrimack Station thermal discharge location for the non-winter months of 2002 – 2014 were provided by PSNH in the form of Excel files (AR-1304). We reviewed these data and created time-series plots of Merrimack River water temperatures during July and August of 2002, 2005, 2007, 2010, and 2012 (Figures 4 through 13).

In addition, we compared selected applicable fish temperature tolerance thresholds established by EPA for Hooksett Pool (US EPA, 2011, Table 8-5, p. 209) to July and August water temperature measurements during the selected years. The following applicable fish tolerance thresholds for July and August were compared to water temperature measurements:

July

American Shad (larva), acute: maximum hourly threshold of 85.1°F

American Shad (juvenile), weekly average threshold of 77.5°F

August

Yellow Perch (juvenile), acute: maximum hourly threshold of 87.6°F

American Shad (juvenile), acute: maximum hourly threshold of 85.3°F

American Shad (juvenile), weekly average threshold of 77.5°F

Figure 4 presents time-series plots of water temperature measurements collected in July 2002. Average daily upstream water temperatures (blue line) ranged from 72 to 79°F. Average daily Merrimack Station thermal discharge temperatures (red) ranged from 83 to 101°F and were typically between 91 and 98°F. The Merrimack Station ΔT between the upstream station, N-10, and Station S-0 was typically approximately 20°F. Average daily temperatures at downstream Station S-4 (orange solid line) ranged from 78 to 86°F. Daily maximum and minimum temperatures at Station S-4 are provided as dashed orange lines in Figure 4 and show that temperatures at Station S-4 vary throughout the day by 5 to over 10°F. PSNH's use of daily average statistics makes it impossible to determine the time period within each day that these variations occur (i.e., the rate of ΔT has been masked). The ΔT between the discharge location, S-0 and Station S-4, located 0.38 miles downstream, was typically 8 to 13°F. The ΔT between the downstream Station S-4 and the upstream station, N-10, was typically 5 to 10°F.

Lastly, Hooksett Dam water temperature measurements collected in July and August 2002 as part of the FERC project (Gomes and Sullivan, 2003) and presented above (Figure 2) were digitized and added (green) to Figures 4 and 5. The digitization process resulted in a ±1.5°F uncertainty in Hooksett Dam temperature data. The Hooksett Dam temperature measurements were collected below the dam.

Hooksett Dam temperature measurements ranged from 77 to 85°F. The ΔT between the Hooksett Dam station and the upstream station, N-10, was typically 5 to 8°F.

Comparison of selected July fish tolerance thresholds to water temperature measurements reveals that the acute threshold for American Shad larva of 85.1°F (line A in Figure 4), which should not be exceeded for more than one hour, was exceeded for all but the first day of July at Station S-0. Other than on July 1, exceedances at Station S-0 are always greater than 5ºF and often exceed 10ºF. The acute Shad tolerance was also exceeded by the maximum temperature observed at downstream Station S-4 on 17 of 31 days in July 2002, showing that exceedances extended at least 0.38 miles downstream.

The average weekly threshold of 77.5°F for juvenile American Shad (line B in Figure 4) was exceeded by the daily average temperature at Station S-0 and S-4 every day (and thus every week) of July 2002. The average weekly American Shad threshold was also exceeded nearly every day (and thus every week) at the Hooksett Dam, 2.9 miles downstream. Since there is complete mixing below the Hooksett Dam, the exceedance of the average weekly American Shad threshold below Hooksett Dam indicates that this threshold was exceeded throughout the entire lower Hooksett Pool area (a 2.9-mile reach).

Figure 5 presents August 2002 water temperature measurements and selected applicable fish tolerance thresholds. In August 2002, the acute criteria for Yellow Perch and American Shad (lines A and B in Figure 5) exceeded the daily average temperature at Station S-0 during the entire month. The acute criterion for American Shad at Station S-0 was exceeded by a maximum of 18.9°F on August 16th. Acute American Shad criterion also exceeded maximum daily temperature at Station S-4, 0.38 miles downstream, on 24 of 31 days in August 2002. Acute American Shad criterion also exceeded temperatures below the Hooksett Dam, 2.9 miles miles downstream, on August 13 through 16, indicating that all of lower Hooksett Pool exceeded the acute criteria thresholds during this period of time. The average weekly threshold for American Shad was exceeded at Stations S-0, S-4 and at Hooksett Dam for the entire month of August 2002.

Water temperature measurements and selected applicable fish tolerance thresholds are presented for July and August of 2005, 2007, 2010, and 2012 in Figures 6 through 13. These figures show exceedances of acute and average weekly fish tolerances for extended time periods at Merrimack River stations.

Based on review of available water temperature measurements, the Merrimack Station thermal plume appears to extend downstream well beyond the Hooksett Dam under typical summertime conditions. Within the thermal plume, large ΔTs and sustained temperatures exceeding fish tolerance thresholds were observed during the months of July and August. These observations provide ample evidence that a comprehensive 316(a) demonstration study, including a detailed thermal plume characterization under a variety of conditions, should be conducted prior to approval of a water quality variance or a NPDES permit renewal.

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Table 1. Example: Station S-0 Daily Temperature Statistical Summary for August 2000 (AR-1301 – 1304).

PUBLIC SERVICE OF NEW HAMPSHIRE
MERRIMACK GENERATING STATION
ENVIRONMENTAL MONITORING PROGRAM

MONTHLY SUMMARY REPORT FOR August 2000

STATION: Zero PARAMETER: Temperature (Deg. C)

DAY	MAXIMUM (PARAM)	MAXIMUM TIME	DAILY AVERAGE	MINIMUM (PARAM)	MINIMUM TIME	#of INT.
08/01/00	32.140	1530	31.918	31.740	2315	96
08/02/00	32.530	2115	31.982	31.500	0615	96
08/03/00	33.190	1400	32.689	32.230	0430	96
08/04/00	33.150	1830	32.712	32.290	0900	92
08/05/00	33.690	1615	32.893	31.980	0715	96
08/06/00	34.150	1830	33.144	31.940	0645	96
08/07/00	34.290	1900	33.573	33.020	0245	96
08/08/00	34.740	1900	33.946	33.140	0645	96
08/09/00	35.330	2000	34.383	33.380	0645	96
08/10/00	35.200	1630	34.555	32.250	2400	96
08/11/00	35.470	1530	33.676	30.690	0315	96
08/12/00	32.390	0230	29.830	25.240	2400	96
08/13/00	25.220	0015	24.010	23.450	1415	96
08/14/00	23.480	0015	22.831	22.430	2400	96
08/15/00	32.690	2400	25.465	22.200	0400	96
08/16/00	33.610	1615	32.989	32.440	0845	96
08/17/00	32.750	1945	32.292	31.770	0945	96
08/18/00	32.480	1800	31.831	30.950	0700	96
08/19/00	32.770	1730	32.124	31.520	0800	96
08/20/00	32.250	0015	31.546	30.920	1115	96
08/21/00	33.780	2345	31.552	30.660	0715	96
08/22/00	33.340	0015	31.448	30.500	0830	96
08/23/00	32.120	1445	31.796	31.340	2130	96
08/24/00	32.930	1700	32.028	31.260	0630	96
08/25/00	33.160	2015	32.241	31.200	0700	96
08/26/00	33.920	2000	33.033	31.940	0645	96
08/27/00	34.250	1700	33.504	32.650	0630	96
08/28/00	34.110	1700	33.552	32.960	0700	96
08/29/00	34.000	1730	32.776	31.090	0745	96
08/30/00	34.650	2000	33.567	32.400	0830	96
08/31/00	35.370	1515	34.556	33.630	0730	96
AVERAGE	33.005		31.885	30.797		
STD DEV.:	2.525		2.808	3.063		

Table 2. Example: 21-year Statistical Summary Table for August from Normandeau, 2007, Appendix A,

Average Daily Maximum, Minimum and Mean Water Temperature Measured at Monitoring Stations N-10, S-0 and S-4 and Predicted at A-0 for Merrimack Station for the 1 April to 1 November period of 1984 through 2004 (cont.)

		Station N-10			Station S-0			Station S-4			Station A-0		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Aug	1	69.4	76.1	84.7	77.9	91	99.9	69.3	81.8	89.2	70.8	80.9	91.1
	2	69.1	76.3	84.2	79.5	92.6	99.3	70	83	88.2	71.3	81	90.6
	3	69.6	76.3	81.3	80.1	93.9	99.5	72.7	84.3	91	71.2	79.6	88
	4	71.1	77.1	82.6	81	93.9	100.9	72.5	84.8	92.1	72	80.6	89.1
	5	71.8	77.1	83.3	84	94.5	103.8	74.7	85.2	93.7	73.9	81.8	89.7
	6	72.3	76.9	83.5	77.4	92.3	101.8	76.3	84.2	93.7	75.2	82.4	89.5
	7	72.1	76.6	83.5	76.1	91.3	101.7	75.7	82.7	93.4	75.4	82.5	89.6
	8	72.9	76.3	83.1	79.9	92.2	102.7	75.6	82.7	92.5	73.7	81.6	89.5
	9	71.4	75.9	83.8	79.2	92.5	102.2	74.7	82.3	91.9	71.4	80.7	90
	10	71.1	76.1	84	79.2	92.5	102.2	72.5	82.9	94.1	71.1	80.5	90
	11	71.1	75.9	83.5	85.5	92.9	102.6	73.6	83.2	93.6	71.1	80.3	89.5
	12	69.1	75.6	83.8	83.8	90.9	98.6	73	81.6	93.4	69.1	79.4	89.8
	13	68.7	75.5	84	75.2	91.7	100.8	72.3	81.1	92.5	68.7	79.5	90.2
	14	72	75.6	84	73	90.4	102.6	71.2	81.8	92.5	72	81.1	90.3
	15	64.8	75.1	83.3	77.9	89.9	103.3	71.4	82	95	64.8	77.1	89.5
	16	69.8	75.3	80.4	80.2	91.2	104.2	72.9	82.2	97.9	69.8	78.3	86.8
	17	68.9	75.4	80.6	80.8	92.4	103.1	73.8	82	93.2	68.9	78	87
	18	68.9	75.4	80.6	81.1	93.5	103.3	74.8	82.8	93	68.9	78	87
	19	70	75.2	81.7	80.8	92.4	103.1	75.2	83.2	93	71.2	79.6	88
	20	70.3	74.7	80.1	74.5	91	100.9	73.6	82.1	91.6	73	79.8	86.5
	21	70.2	74.2	78.4	76.3	90.5	99.9	71.1	81	89.8	70.9	77.9	85
	22	68.7	73.6	79.2	79.7	90	100	70.3	80.4	90.1	70.2	77.9	85.7
	23	69.8	73.6	79.5	80.8	89.5	99.5	69.4	79.9	89.2	71.8	78.9	86
	24	70.3	73.4	80.1	72.5	88.2	97.2	70.5	79.3	86.7	73.2	79.8	86.5
	25	68.4	73	80.8	73.9	87.3	96.4	69.8	79.1	87.1	72.2	79.7	87.1
	26	68.2	73.3	81.7	70	88.4	97	70	80.2	88	72.5	80.2	88
	27	67.5	73.8	80.8	77.5	89.8	98.2	71.6	80.9	88.5	71.5	79.3	87.2
	28	67.5	73.9	81.5	75.2	89.4	98.1	70.9	81.4	91.2	71.8	79.8	87.8
	29	65.1	73.6	81.1	73.8	88.8	95.5	68.2	80.6	86.5	70.1	78.7	87.4
	30	64.4	73.2	79.5	74.7	88.5	95.7	68	79.5	87.4	69.4	77.7	85.9
	31	64.9	72.5	77.2	75	88.9	97.5	69.3	79.6	88.3	68.3	76.1	83.8

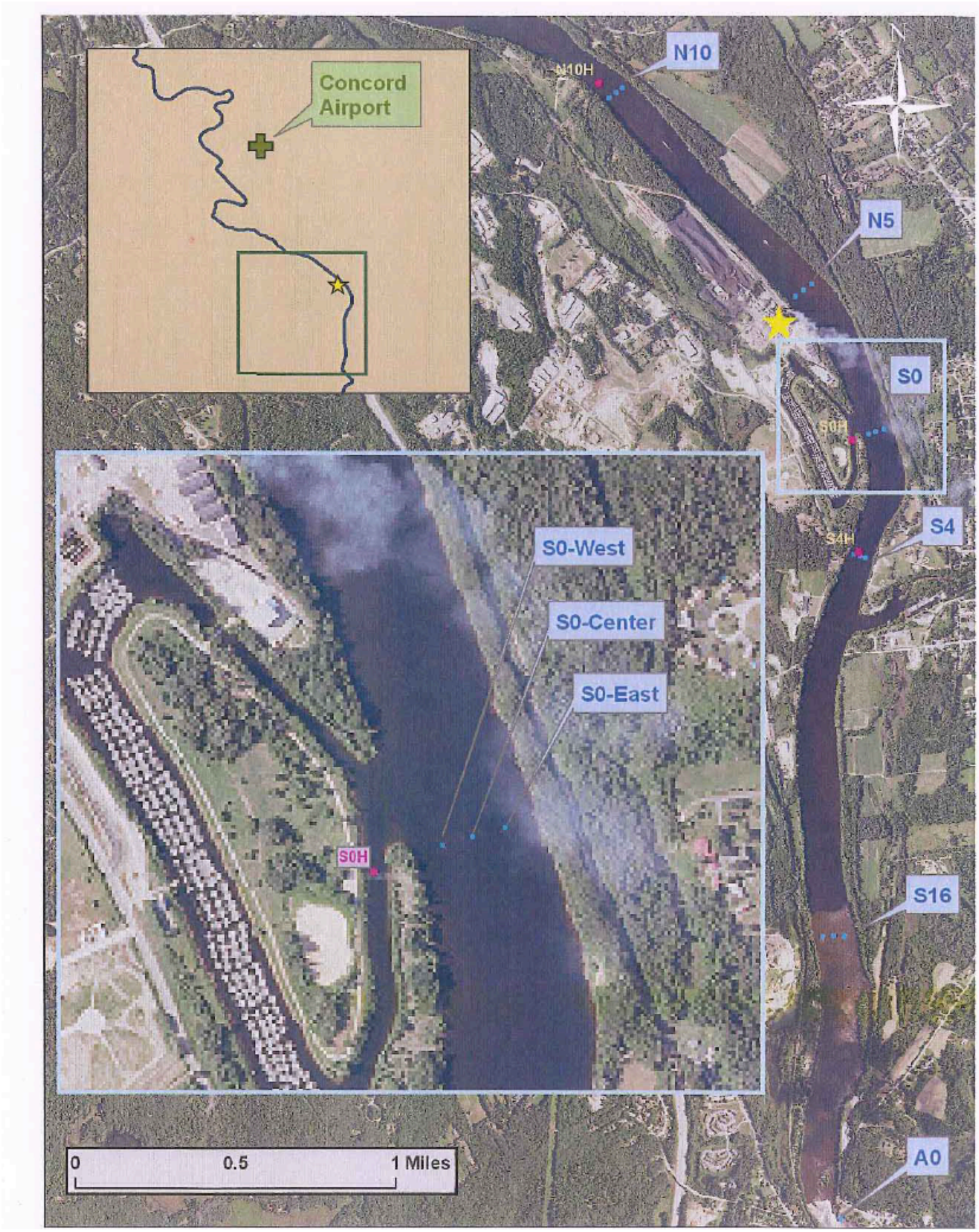

Figure 1. Map of the Merrimack River with Merrimack Station and Water Temperature Measurement Stations Locations Indicated (Source: ASA, 2012)

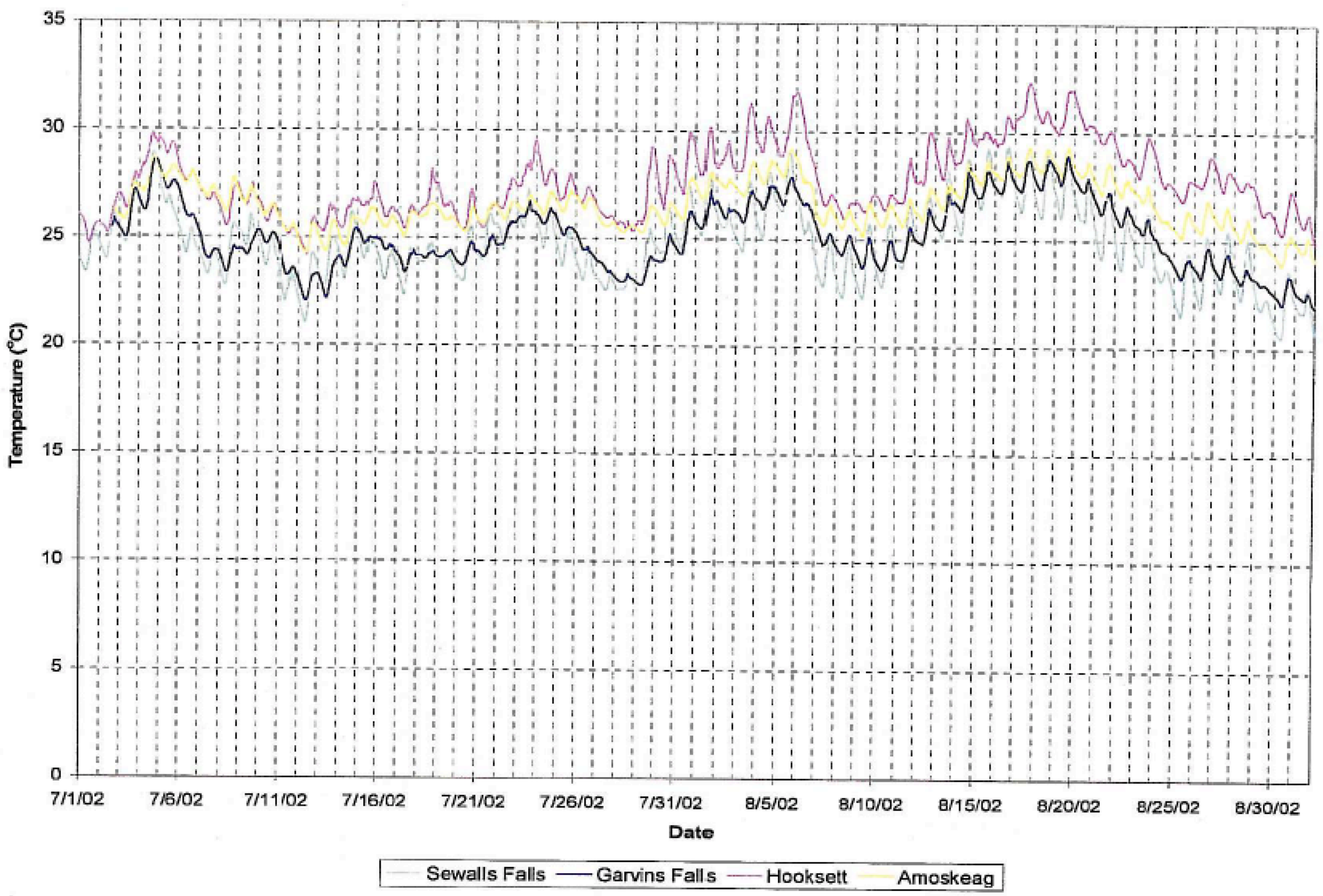

Figure 2. Water Temperature Measurements Collected Below Merrimack River Dams in July and August 2002 (Gomez and Sullivan, 2003, p. 78)

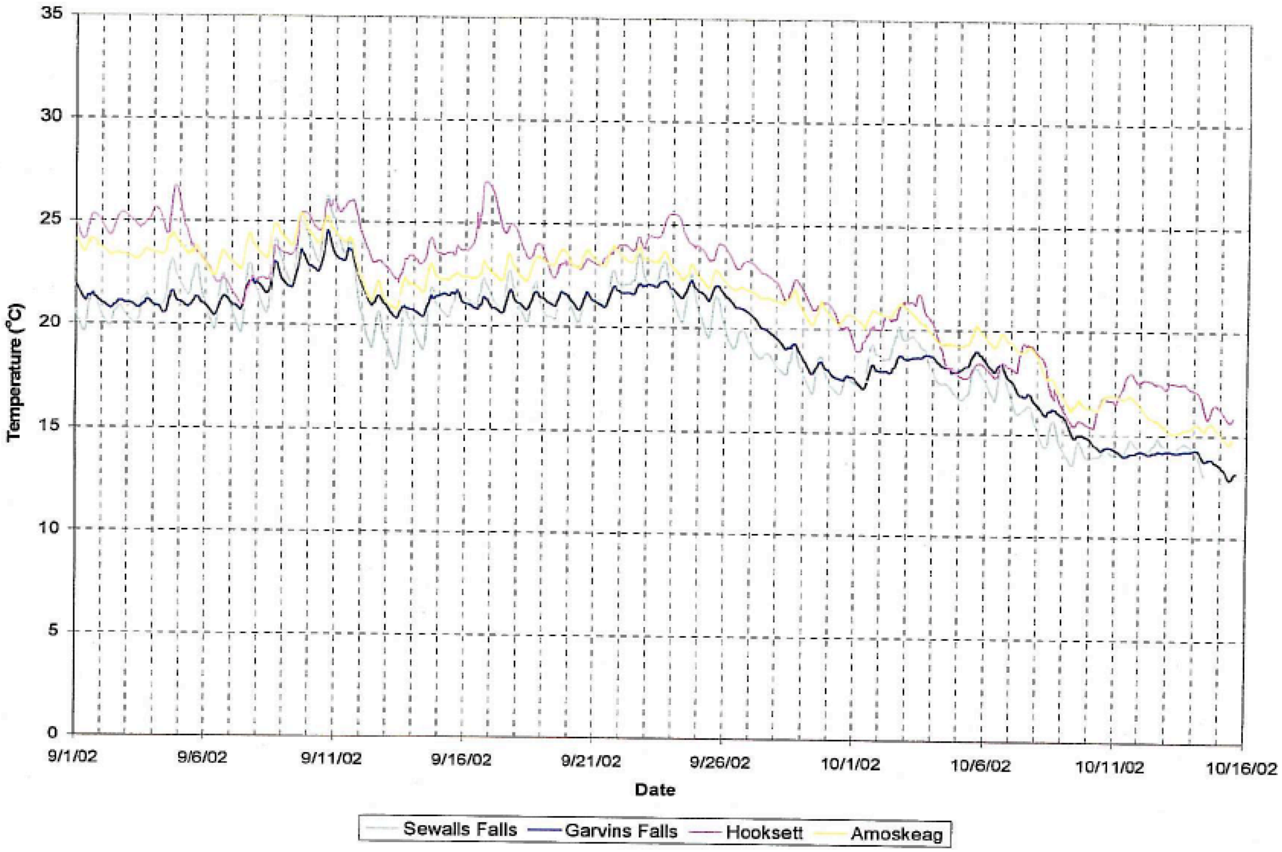

Figure 3. Water Temperature Measurements Collected Below Merrimack River Dams in September and October 2002 (Gomez and Sullivan, 2003, p. 79)

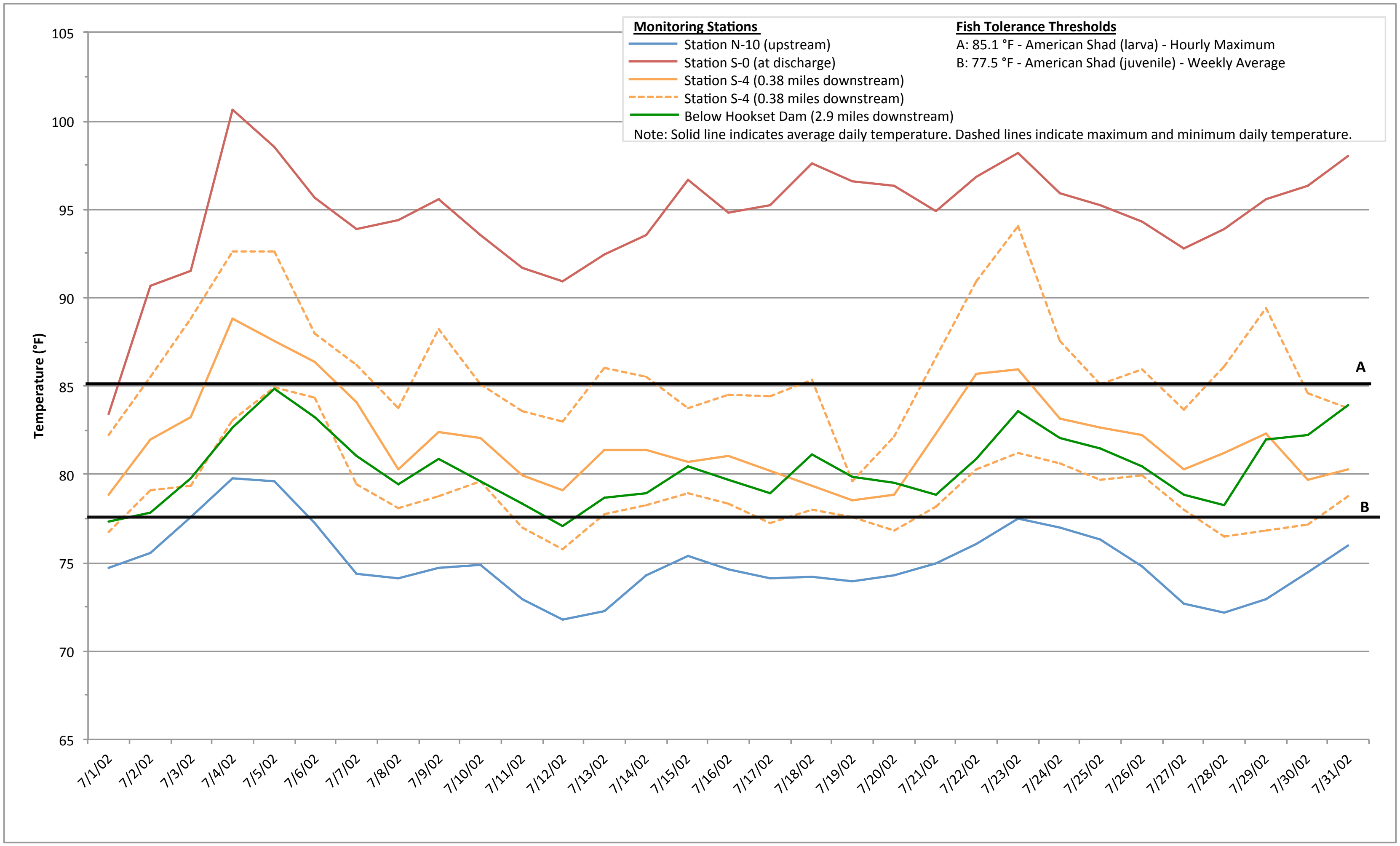

Figure 4. Daily Water Temperature Measurements at Four Monitoring Stations Compared to Selected Fish Tolerance Temperature Thresholds – July 2002

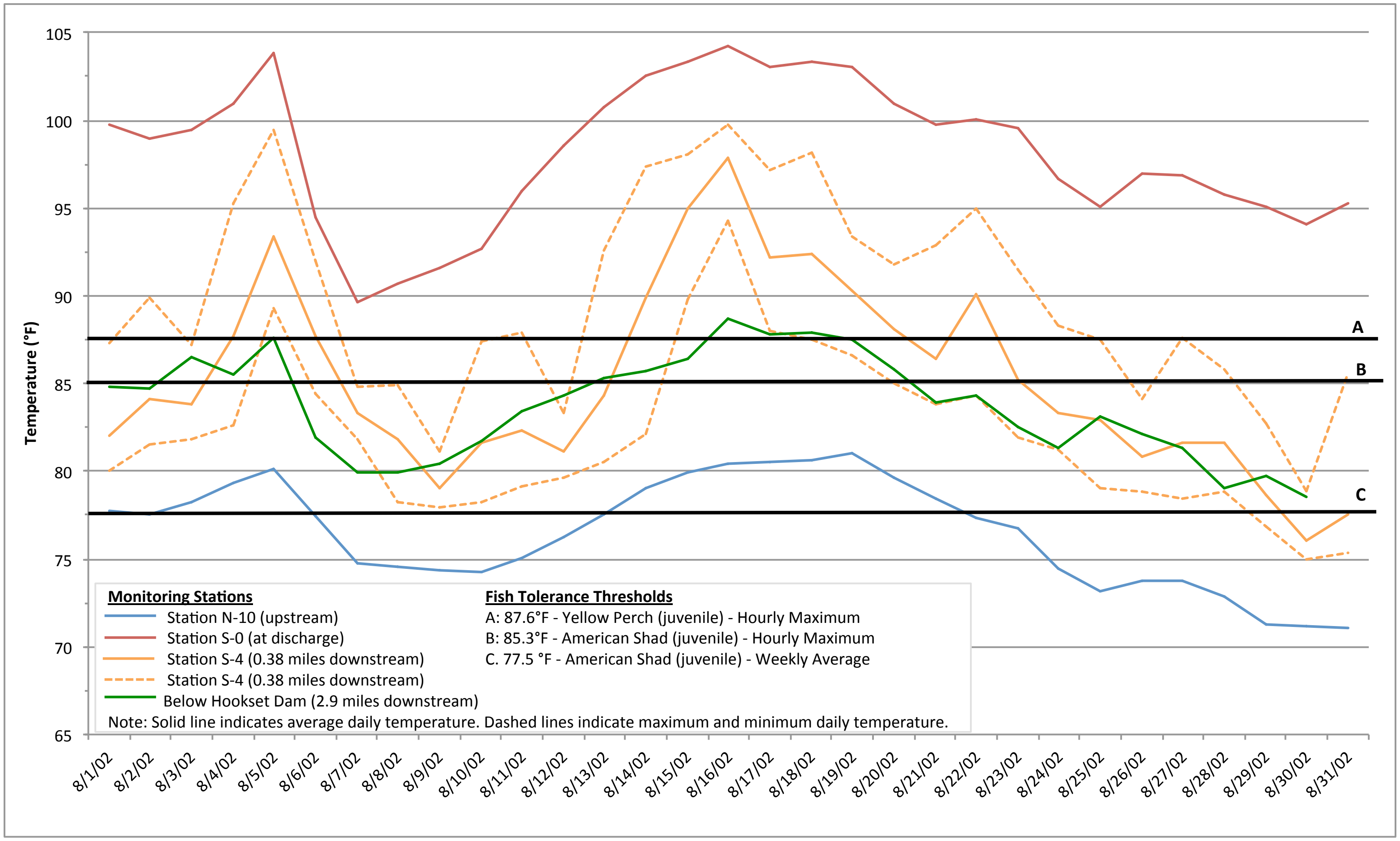

Figure 5. Daily Water Temperature Measurements at Four Monitoring Stations Compared to Selected Fish Tolerance Temperature Thresholds – August 2002

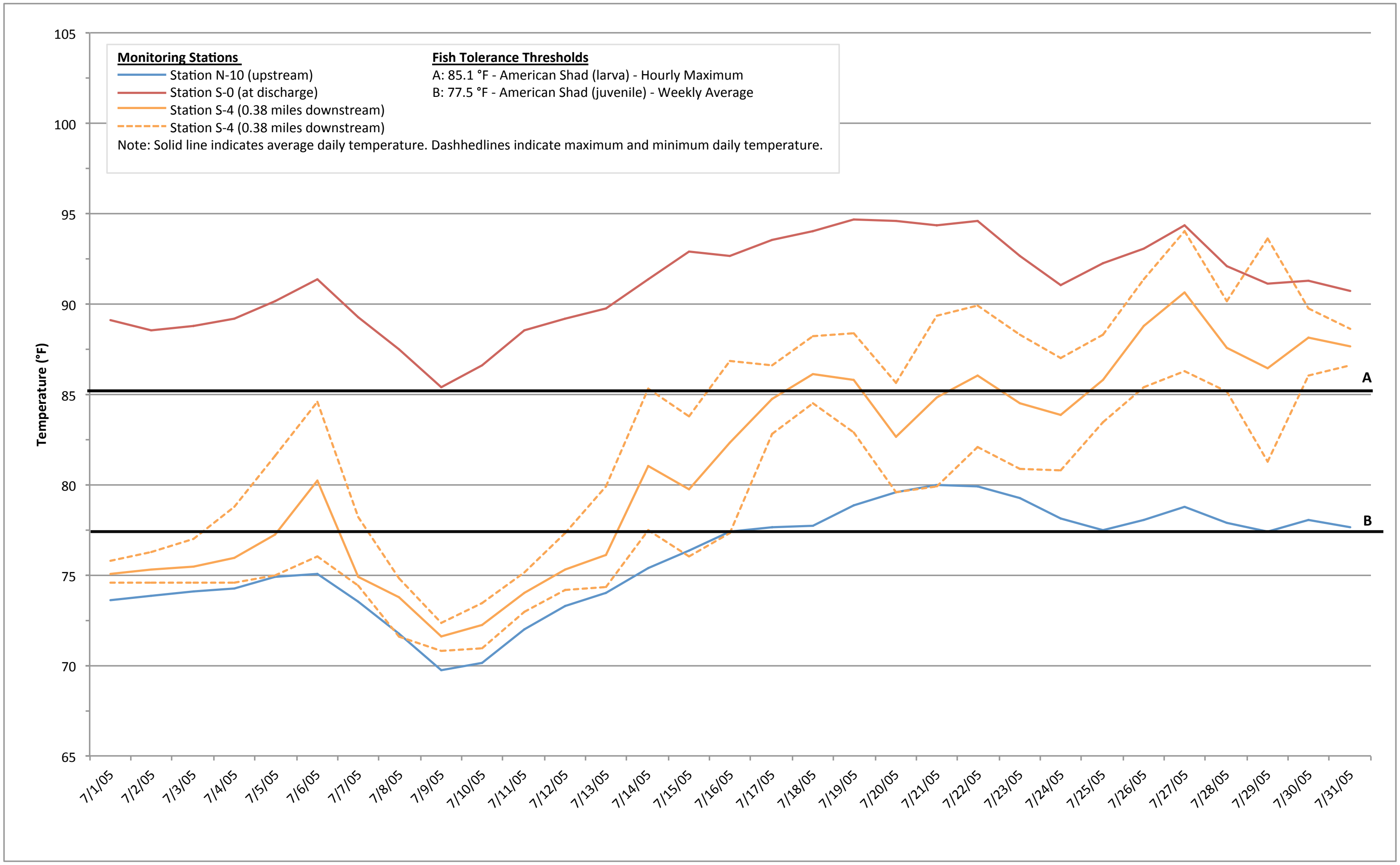

Figure 6. Daily Water Temperature Measurements at Three Monitoring Stations Compared to Selected Fish Tolerance Temperature Thresholds – July 2005

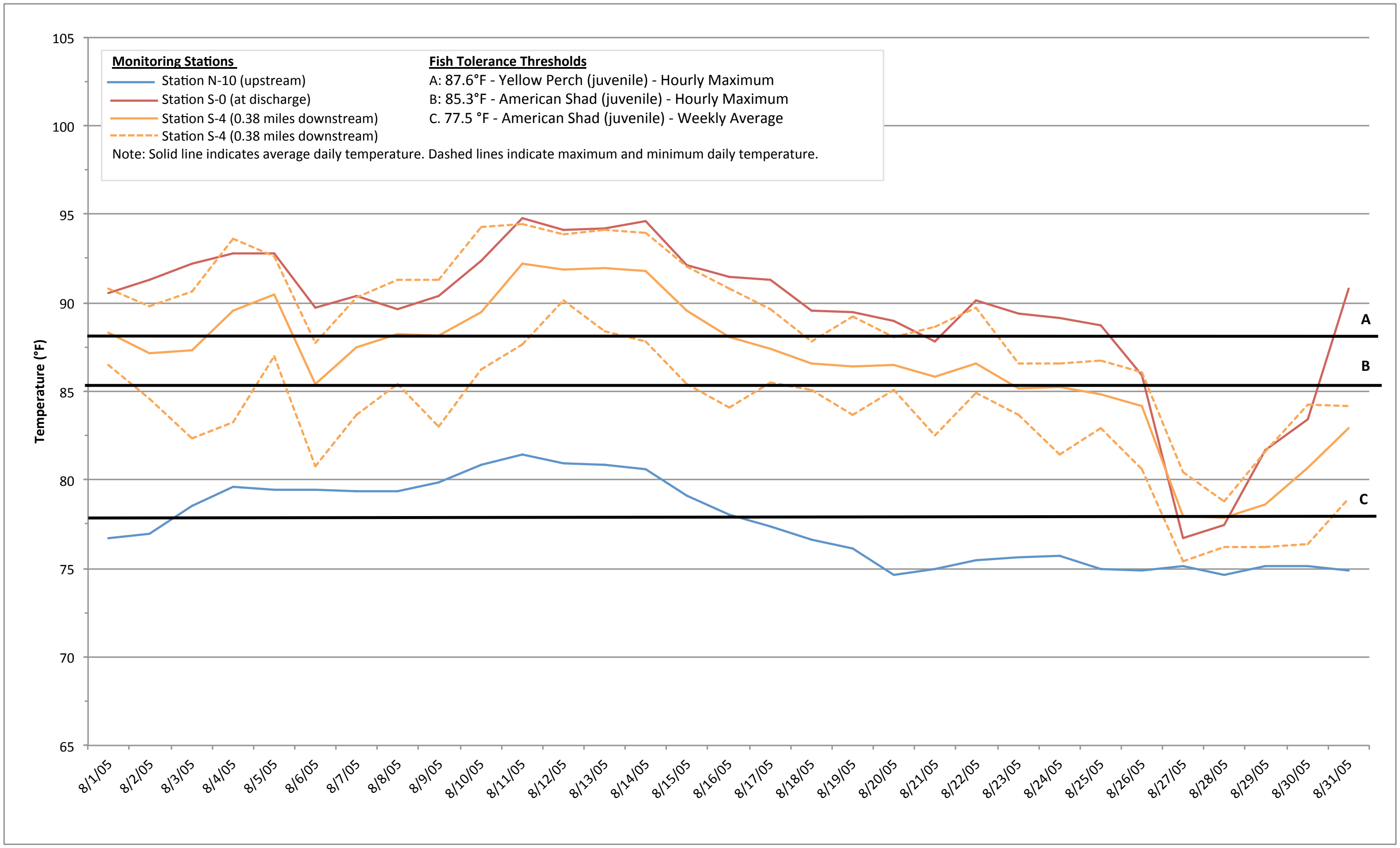

Figure 7. Daily Water Temperature Measurements at Three Monitoring Stations Compared to Selected Fish Tolerance Temperature Thresholds – August 2005

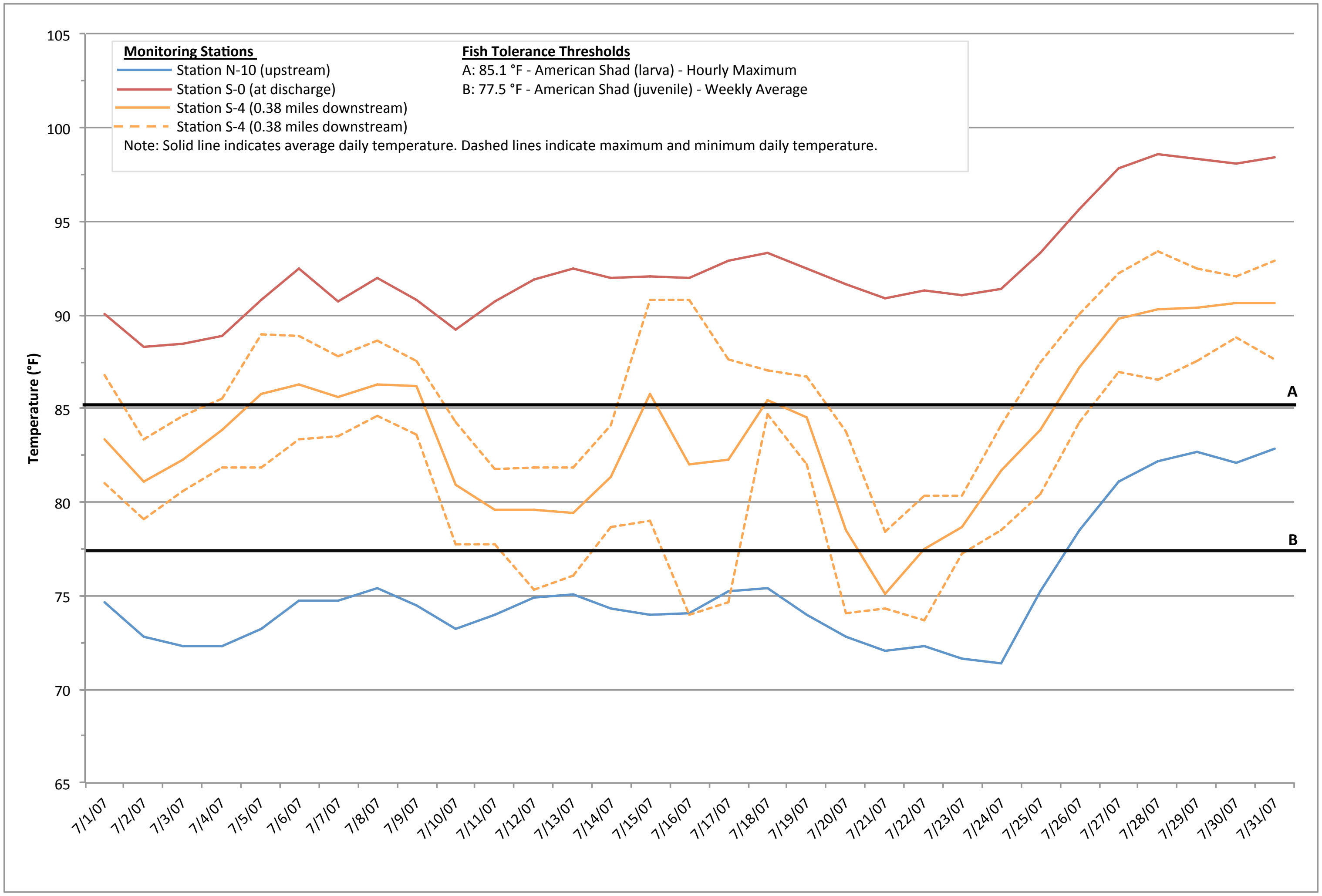

Figure 8. Daily Water Temperature Measurements at Three Monitoring Stations Compared to Selected Fish Tolerance Temperature Thresholds – July 2007

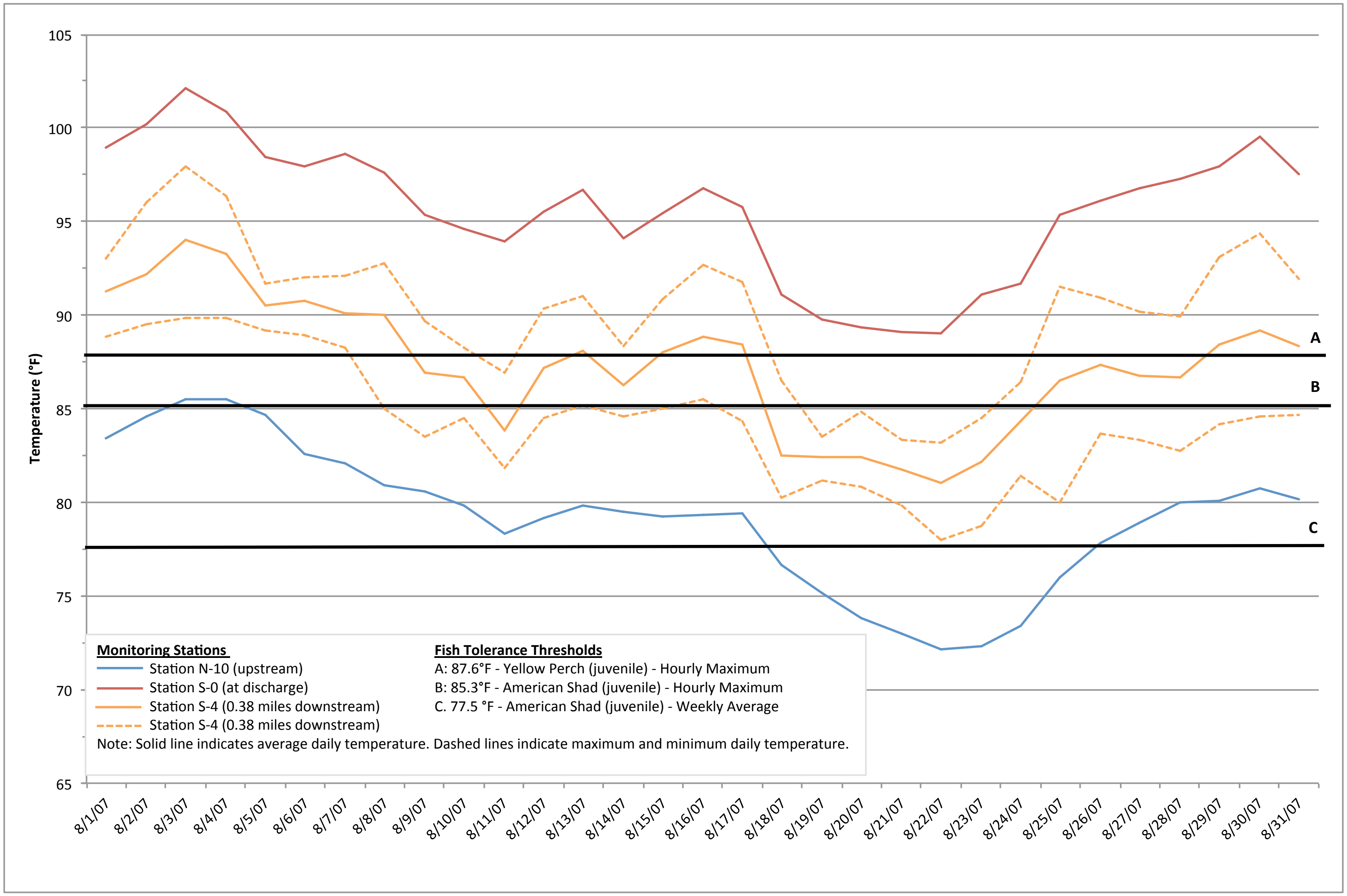

Figure 9. Daily Water Temperature Measurements at Three Monitoring Stations Compared to Selected Fish Tolerance Temperature Thresholds – August 2007

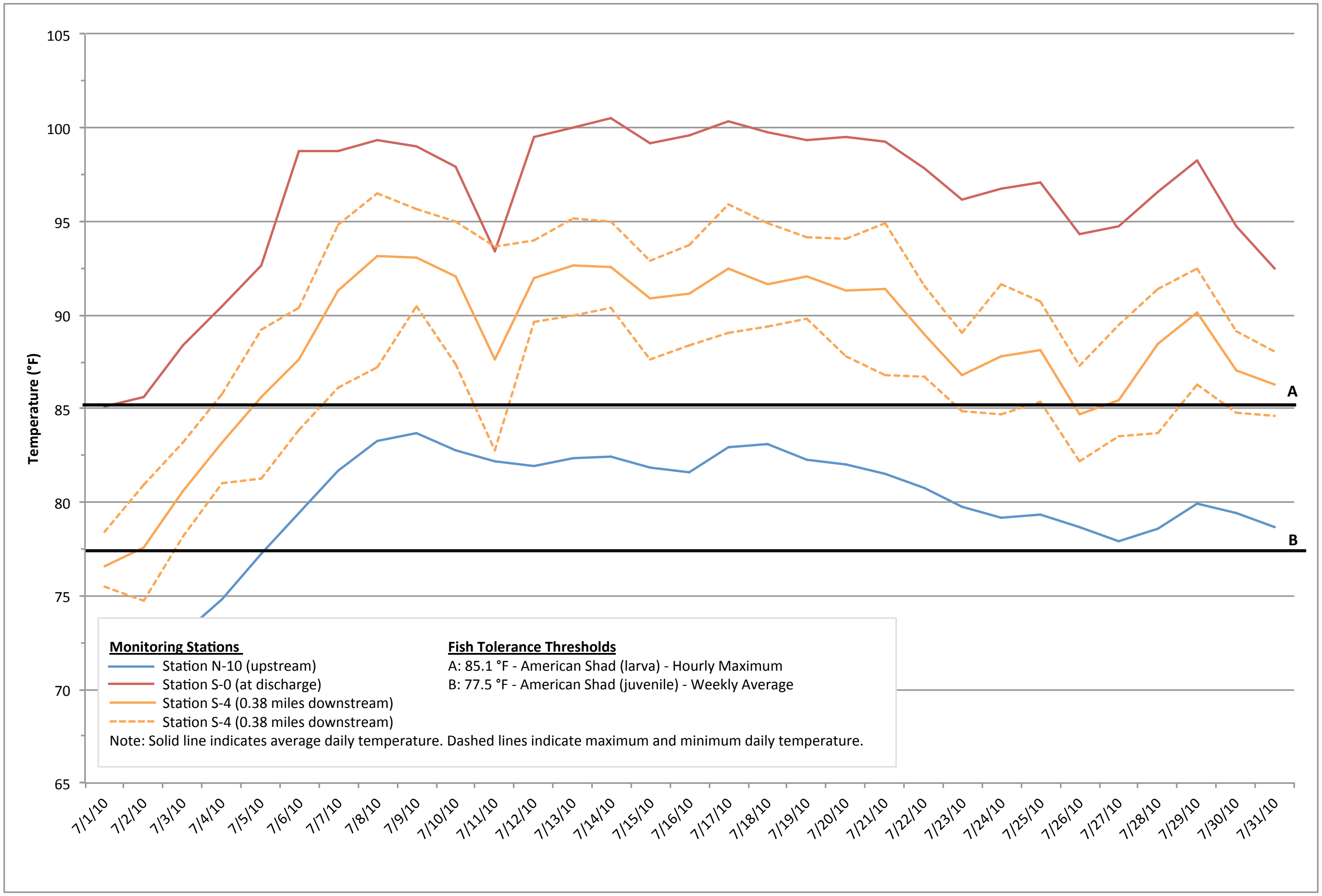

Figure 10. Daily Water Temperature Measurements at Three Monitoring Stations Compared to Selected Fish Tolerance Temperature Thresholds – July 2010

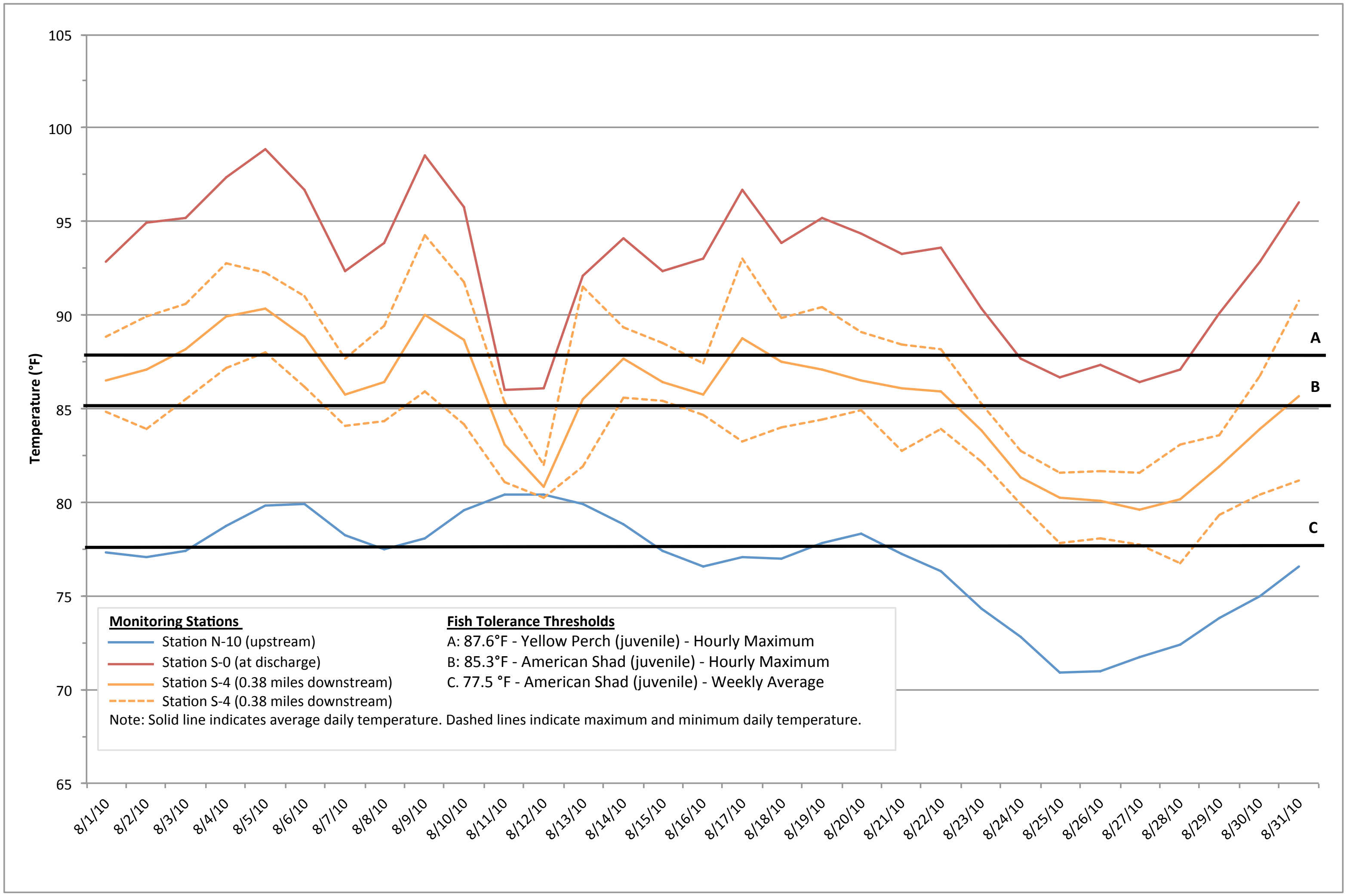

Figure 11. Daily Water Temperature Measurements at Three Monitoring Stations Compared to Selected Fish Tolerance Temperature Thresholds – August 2010

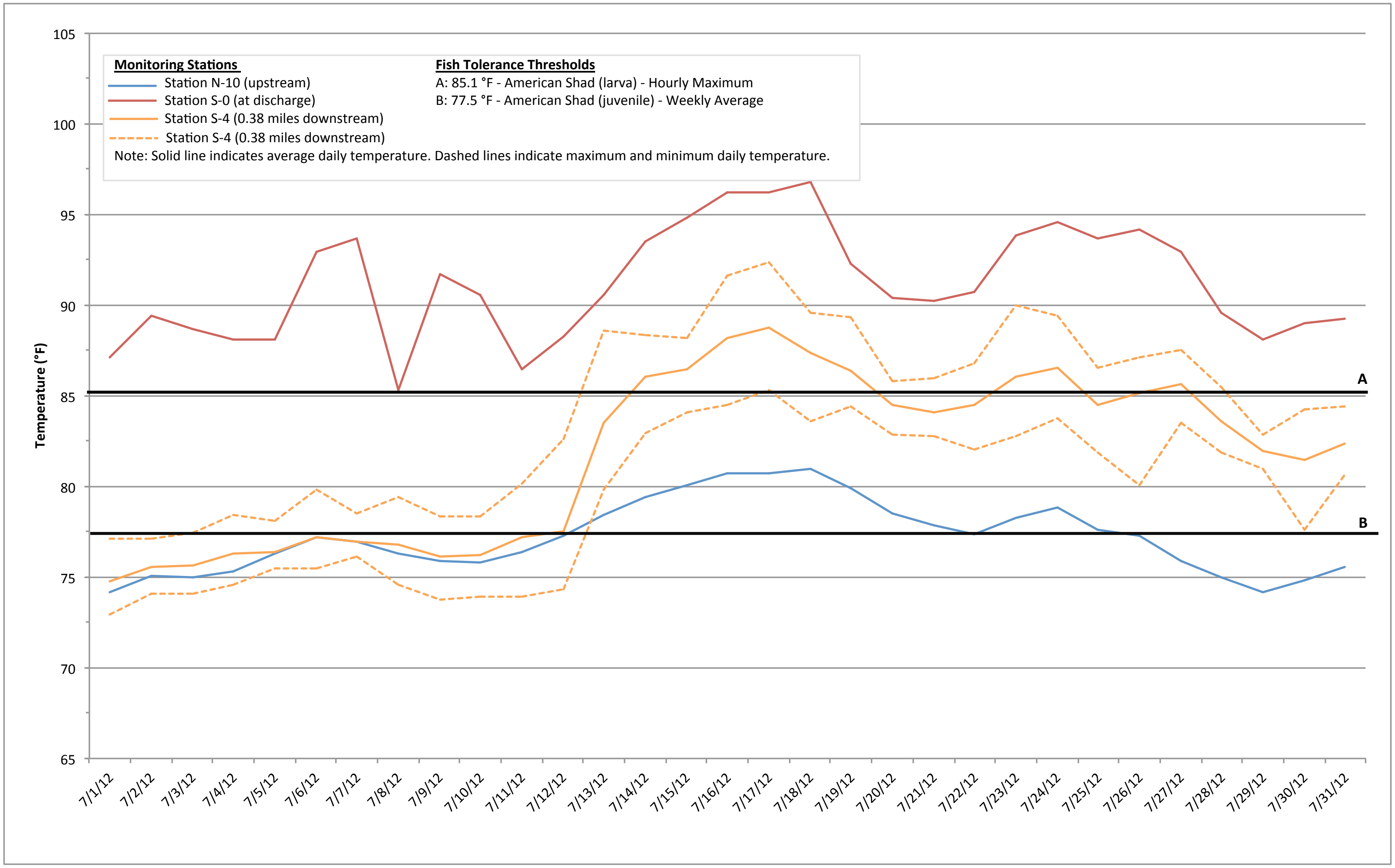

Figure 12. Daily Water Temperature Measurements at Three Monitoring Stations Compared to Selected Fish Tolerance Temperature Thresholds – July 2012

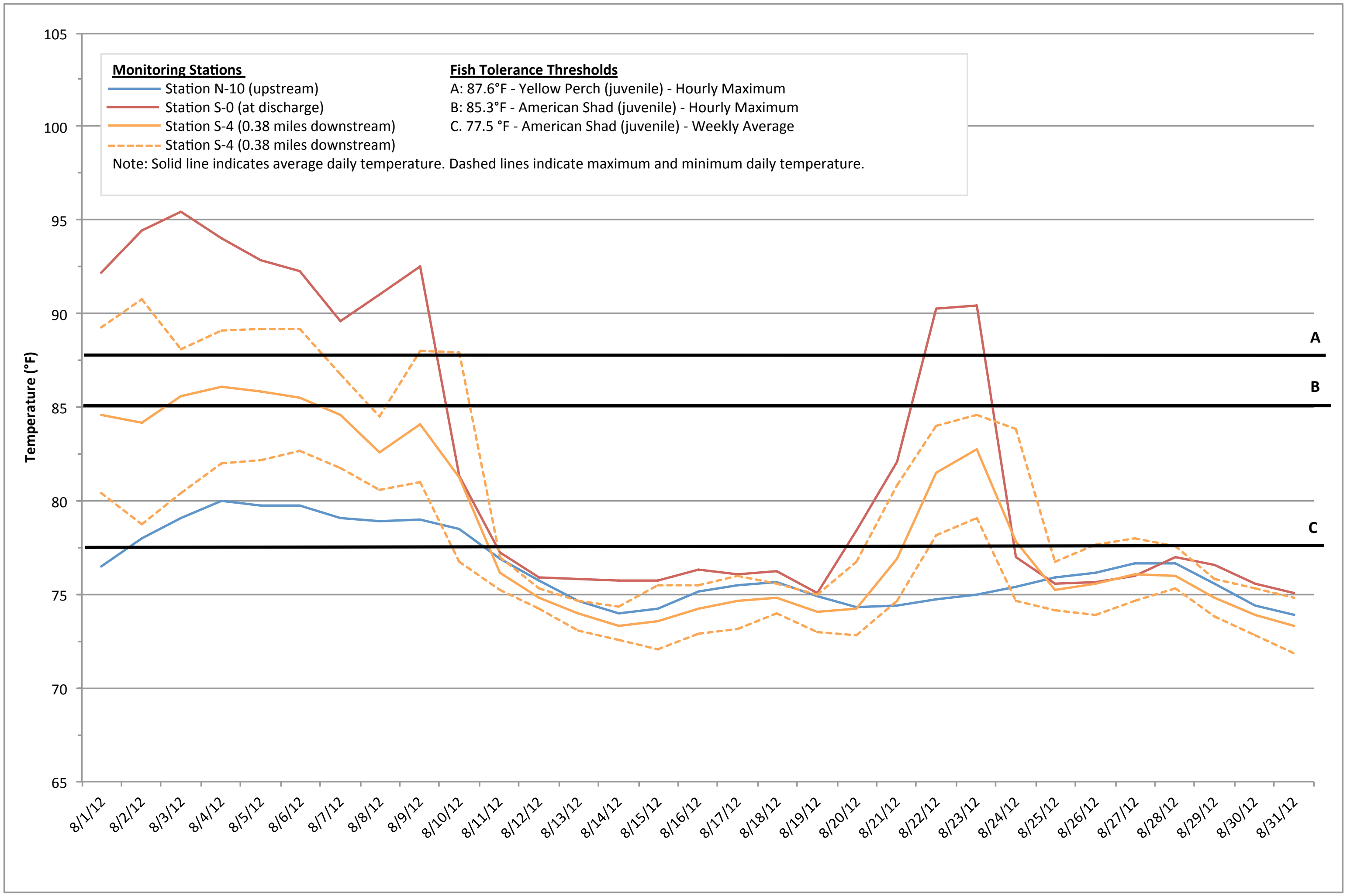

Figure 13. Daily Water Temperature Measurements at Three Monitoring Stations Compared to Selected Fish Tolerance Temperature Thresholds – August 2012