AR-1352 - PSNH advises that only page 19 of Attachment A of this document contains redacted text.

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December 22, 2016

VIA E-MAIL
VIA OVERNIGHT MAIL

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Mr. Mark A. Stein, Esq.
Senior Assistant Regional Counsel
U.S. Environmental Protection Agency - Region 1
Office of Regional Counsel, Region 1
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Boston, Massachusetts 02109-3912

Re: **Public Service Company of New Hampshire**
Merrimack Station, Bow, New Hampshire
Draft NPDES Permit No. NH0001465
Request for New Draft NPDES Permit for Public Notice and Comment

Dear Mr. Webster, Attorney Stein, and Ms. DeMeo:

Public Service Company of New Hampshire d/b/a Eversource Energy ("PSNH" or "the Company") by way of this letter formally requests that Region 1 of the Environmental Protection Agency ("EPA" or "the agency") issue for public notice and comment a revised draft of National Pollutant Discharge Elimination System ("NPDES") Permit No. NH 0001465 for Merrimack Station. Since the 2011 draft permit ("Draft Permit") was issued, extraordinary changes, with regulatory and technological implications, have taken place which directly and substantively impact Merrimack Station permitting considerations.

From its inception, the 2011 Draft Permit, as revised on April 18, 2014, was fatally flawed as shown in the comments of PSNH and the electric utility industry. In addition, the following developments since the issuance of the draft permits require a revised draft NPDES permit be issued that affords PSNH and other interested parties the opportunity for notice and comment:

1. EPA's new regulations setting technology requirements under Section 316(b) of the Clean Water Act ("CWA") for cooling water intake structures became final on August 15, 2014, and are directly applicable to the content of the NPDES permit for Merrimack Station and future compliance requirements.

2. The new Effluent Limitations Guidelines for the Steam-Electric Power Plant industrial category ("ELGs") were promulgated on September 30, 2015, and necessitate reconsideration of the proposed conditions and effluent limits contained in the 2011 Draft Permit and the revised portion of the draft permit issued in 2014 ("2014 Revised Draft Permit") for the Station. In fact, in May 2016 PSNH notified the agency of its decision to opt into the Voluntary Incentive Program under the ELGs, thus providing Merrimack Station until the end of 2023 to optimize its flue gas desulfurization wastewater treatment system and achieve the evaporative limits similar to those imposed by the 2014 Revised Draft Permit.

3. In February of this year, PSNH submitted extensive temperature data to EPA demonstrating a foundational error in the agency's Section 316(a) analysis—an error which contributed to EPA's denial of PSNH's 316(a) thermal variance. The enclosed CORMIX Thermal Plume Modeling Technical Report ("CORMIX Report") from Enercon Services, Inc. ("Enercon"), coupled with the enclosed report titled "Influence of Merrimack Station's Thermal Plume on Habitat Utilization by Fish Species Present in Lower Hooksett Pool" ("Habitat Report") authored by Dr. Lawrence W. Barnthouse ("Dr. Barnthouse"), confirm the conclusions in Dr. Barnthouse's February 29, 2016 report—namely, that thermal discharges from Merrimack Station have not caused, are not causing, and will not cause in the future appreciable harm to the balanced indigenous population ("BIP") of the Hooksett Pool portion of the Merrimack River. EPA's Section 316(a) analysis founded upon erroneous interpretations of key temperature data must be revised.

4. There have been remarkable engineering advances that provide environmentally beneficial, cost-effective options in reducing entrainment as required under 316(b). PSNH provided a report from Enercon in 2014 and has enclosed with this letter an updated version of that report titled "Wedgewire Half Screen Technical Memo" ("Technology Report") that describes a proposed engineering solution to reduce entrainment.

5. In the five years since the 2011 Draft Permit was issued, PSNH has received no response to the extensive comments filed by PSNH and its consultants related to Sections 316(a) and (b) or any indication about the agency's direction in dealing with the significant issues raised. As a result, PSNH has had no choice but to file a series of Freedom of Information Act requests, limited in scope but directly relevant to these issues. EPA has responded to the requests and provided significant information, and PSNH appreciates this effort. However, it is impossible from a review of hundreds of assorted documents on an array of subjects to glean the direction of the agency in handling permit matters. It is clear, however, that a number of subjects are being researched and considered that were not broached in the Draft Permit. As a result, PSNH respectfully requests, echoing earlier correspondence, the statutorily afforded opportunity to comment if, in fact, the agency intends to use new (*i.e.*, post-2011) information to support its conclusions related to Sections 316(a) and (b) in the Final Permit. Not only will this allow input from the various

stakeholders but it will also limit the number of issues that can be raised in any potential appeal of the Final Permit.

PSNH makes this request for a revised draft permit with full knowledge of Sierra Club's recent letter to EPA and the special interest group's Petition for Writ of Mandamus filed with the U.S. Court of Appeals for the First Circuit on November 23, 2016. Sierra Club's petition requests issuance of a court order compelling the agency to issue the final NPDES permits for Merrimack and Schiller Stations. Of greater concern than Sierra Club's sword-rattling is EPA's response to Sierra Club's letter providing that EPA wants "nothing more than to issue the Merrimack [permit]...as fast as possible." PSNH is likewise eager to conclude this permitting process as well, but needs a workable permit that not only benefits the environment but allows the Company to comply with the law while continuing to operate and provide safe, reliable, dependable power. PSNH is dedicated to achieving these goals.

In EPA's response to Sierra Club, the agency emphasized the impact of both the 2014 new 316(b) regulations and the 2015 ELGs and the need "to assess the ramifications of both." [page 4] In this letter, the permit writer for the Merrimack Station NPDES permit states the new 316(b) regulations have "necessitated careful consideration, and in some cases reconsideration, of proposed permit conditions to ensure consistency" with the new requirements. In addition, Mr. Houlihan wrote that the ELGs have similarly "necessitated careful consideration, and in some cases reconsideration, of certain proposed effluent limits to ensure consistency with the ELGs." [page 2]

Courts and the Environmental Appeals Board have held EPA may issue an NPDES permit as final without public notice and comment only if it is a "logical outgrowth" of the proposed permit. *See, e.g., NRDC v. EPA*, 279 F.3d 1180, 1186 (9th Cir.2002); *In re D.C. Water and Sewer Auth.*, NPDES Appeal Nos. 05-02, 07-10, 07-11, 07-12, 2008 EPA App. LEXIS 15, *112 (EAB March 19, 2008) ("a final permit that differs from a proposed permit and is not subject to public notice and comment must be a 'logical outgrowth' of the proposed permit"). In evaluating if a final permit is the logical outgrowth of a draft, "one of the salient questions is 'whether a new round of notice and comment would provide the first opportunity for interested parties to offer comments that could persuade the agency to modify its [permit].'" *NRDC*, 279 F.3d at 1186 (quoting *Am. Water Works Ass'n v. EPA*, 40 F.3d 1266, 1274 (D.C.Cir.1994)). As EPA itself has stated in response to Sierra Club, the substantial changes in the applicable regulations—the new 316(b) requirements and the ELGs—have required reconsideration of the contents of the 2011 Draft Permit. The revisions required to the permit to ensure consistency with the new regulations cannot be considered "a logical outgrowth" of either the 2011 Draft Permit or 2014 Revised Draft Permit. The 316(b) regulations, for example, now provide a number of compliance options from which a regulated entity may choose—many of which are dramatically more reasonable to implement than closed-cycle cooling from an engineering and cost perspective while still achieving environmental goals. Furthermore, a draft permit is compelled by EPA's misinterpretation of temperature data and the enclosed CORMIX and Habitat Reports that directly refute the agency's irrefutably flawed 316(a) analysis.

Regarding compliance with the new 316(b) regulations, which now provide steam electric generating utilities greater flexibility in terms of compliance options, the Station has continued to evaluate appropriate entrainment technologies. The enclosed Technology Report from Enercon provides additional analysis of wedgewire half screens, which are highly effective and able to achieve environmental goals while providing a much less expensive technology than closed-cycle cooling for reducing Merrimack Station's already low levels of entrainment.

In light of the reconsideration required by the new 316(b) regulations, the ELGs, and the corrections to the temperature data on which Region 1 based its 316(a) determination, PSNH requests Region 1 carefully consider this information and issue a revised draft permit for notice and comment. Given that the second-half of 2018 is the earliest timeframe by which industry is to comply with the new rulemakings, the agency should issue a revised NPDES permit for Merrimack Station that is consistent with these new legal requirements, rather than one that is rushed out the door in response to threats from Sierra Club.[1]

CWA § 316(b) – Best Technology Available ("BTA") for CWISs

In its 2011 Draft Permit, Region 1 utilized its best professional judgment ("BPJ") authority to determine BTA for the CWISs at Merrimack Station. Specifically, the Draft Permit requires PSNH to: (1) limit the intake flow volume of both CWISs at Merrimack Station to a level consistent with operating in a closed-cycle cooling mode from, at a minimum, April 1 through August 31 of each year; (2) install a low-pressure (<30 psi) spray wash system for each traveling screen to remove fish prior to exposure to the high-pressure, debris removal sprayers; and (3) install a new fish return sluice with a number of design specifications to ensure the proper return of any impinged organisms to the Merrimack River.

EPA issued its final 316(b) rule on August 15, 2014. Once uniform technology-based standards for a source category were promulgated, EPA's authority to set limitations utilizing its BPJ ceased. *See e.g.*, *NRDC v. EPA*, 822 F.2d 104, 111 (D.C. Cir. 1987) (noting that a state or permit writer may set limitations utilizing its BPJ authority only when there is no national standard that has been promulgated for a source category); *Riverkeeper, Inc. v. EPA*, 358 F.3d 174, 203 (2d Cir. 2004) ("It is, of course, true that once the EPA promulgates applicable standards, regulation of those facilities subject to those standards on a [BPJ] basis must cease . . . ."); *Citizens Coal Council v. EPA*, 447 F.3d 879, 891 n.11 (6th Cir. 2006) (noting that BPJ applies only when "EPA has not promulgated an applicable guideline"); *see also* H.R. Rep. No. 92-911, at 126 (1972), *reprinted in* A Legislative History of the Water Pollution Control Act Amendments of 1972 at 813 (1973) (providing that permits with BPJ limits may be issued only "prior to" the promulgation of nationally applicable effluent guidelines). Accordingly, EPA must issue a revised permit in accordance with the new 316(b) regulations. Of particular note, these regulations do not mandate the use of closed-cycle cooling—seasonally or otherwise—at a facility.

PSNH fully agrees with EPA's statements in its response to Sierra Club that the new 316(b) regulations necessitate reconsideration of the Draft Permit's 316(b) determinations. As demonstrated in PSNH's prior technical submissions, because the rate of impingement at Merrimack Station falls within the *de minimis* exception, additional impingement controls are not justified at the Station.

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[1] Region 1 should not allow Sierra Club and its meritless lawsuit to dictate Region 1's timeline. As Region 1 recognized more aptly in its letter, the timeline for finalizing the Merrimack NPDES permit should instead depend on an appropriate balancing of the agency's competing priorities and staffing limitations, and the agency's exercise of the "care that is needed to do the job well." *See* September 21, 2016 Letter at 1.

Further, PSNH has submitted entrainment technology evaluations by Enercon, including, most recently, Enercon's October 2014 Assessment of PSNH's 2007 Response to the EPA's CWA § 308 Letter ("Enercon 2014 Assessment") that demonstrate other viable technologies, such as wedgewire screens, are capable of substantially reducing entrainment at Merrimack Station at a reasonable cost.[2] Because there have been significant engineering advances made, with testing to confirm the efficacy of these advances, PSNH is submitting at this time the enclosed Technology Report prepared by Enercon. This Technology Report analyzes wedgewire half screens—a technology that is suitable to the site-specific conditions at Merrimack Station and consistent with regulatory goals. PSNH's engineers are confident that the wedgewire half screen technology solution will provide an effective reduction in entrainment that can be installed without delay once the proper wedgewire screen slot size is confirmed. Enercon and Normandeau Associates ("Normandeau") are in the process of finalizing a report that outlines the details of a proposed pilot program to identify the proper screen slot size. PSNH intends to submit this report to EPA for approval within the next few months and intends to carry out the pilot program at Merrimack Station in the Spring and Summer of 2017.[3] This wedgewire technology solution will provide an environmentally beneficial, cost effective solution to entrainment and resolve one of the more litigious issues associated with the Merrimack Station NPDES permit.

Should EPA determine any of the studies and compliance evaluations delineated in the new 316(b) regulations are necessary, PSNH will undertake these additional studies and evaluations—or supplement its previously submitted studies as may be necessary to address the specific requirements of the new 316(b) rule—to assist the agency in its permitting determinations. Given the impact of the new 316(b) regulations on BPJ and the recent advances in technology, a new draft permit is warranted so that PSNH and the public are afforded an opportunity to review and comment concerning how the rule is applied and Region 1's associated determinations in the revised draft permit.

Best Available Technology ("BAT") for the Treatment of FGD Wastewater

Region 1 invoked its BPJ authority in establishing the 2014 Revised Draft Permit's proposed effluent limitations for FGD wastewater. As recognized by Region 1 in its recent response to Sierra Club, these limitations also must be reconsidered. EPA issued its final ELGs on November 3, 2015,

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[2] As EPA recently recognized with respect to petitions challenging the new 316(b) regulations, "consideration of benefits (and their costs) is permissible under §316(b) and the amount of time the benefits will accrue from mandated controls is certainly relevant to that consideration." Brief of All Respondents, *Cooling Water Intake Structure Coalition v. USEPA*, Case No. 14-4645(L), at 83-84 (Oct. 12, 2015). As EPA further explained, "in making the determination of the best technology available at a given site, the Director should not ignore the costs associated with different technologies or the relative benefits of those technologies." *Id.* at 95.

[3] Because the average 3-year actual intake flow at Merrimack Station is below 125 million gallons per day, PSNH is not obligated to complete any entrainment-related studies delineated in the final 316(b) regulations (or any other entrainment studies) unless specifically requested by EPA. *See* 40 C.F.R. §§ 122.21(r)(1)(ii)(B); 125.98(g). No such requests have been issued by the agency. Nonetheless, the Company intends to complete the entrainment-related Enercon/Normandeau pilot program to demonstrate that a cost-effective technology suitable for Merrimack Station exists and, conversely, emphasize the unreasonableness in requiring the installation of closed-cycle cooling at the facility to comply with Section 316(b) of the CWA.

and the regulations became effective on January 4, 2016. Identical to the 316(b)-portion of the 2011 Draft Permit, effluent limitations in the final permit for Merrimack Station must be established in accordance with the limitations set out in the ELGs, as opposed to a determination of limits by BPJ. *See NRDC v. EPA*, 859 F.2d 156, 200 (D.C. Cir. 1988) (providing that CWA Section 402(a)(1) "preclude[s] the establishment of BPJ permit limits once applicable effluent guidelines are in place"); *see also In re: Certainteed Corporation*, NPDES Appeal No. 15-01, 2015 WL 10091224, at *1 (EAB May 7, 2015) ("If EPA has developed industrial category-wide (or subcategory-wide) effluent limitations—referred to as 'effluent limitation guidelines' . . .—such limits must be included in that facility's permit.") (citing 40 C.F.R. § 125.3(c)(1) and *E.I. du Pont de Nemours & Co. v. Train*, 430 U.S. 112 (1977)).

On March 23, 2016, PSNH notified Region 1 of the Company's decision to opt into the Voluntary Incentive Program created in the ELGs. The ELGs establish effluent limitations based on evaporative treatment technologies for facilities opting into the VIP that apply "as of December 31, 2023, to FGD wastewater generated on and after December 31, 2023." 80 Fed. Reg. 67,838, 67,858 (Nov. 3, 2015). Until such time, a facility in New Hampshire opting into the VIP is subject to the BAT total suspended solids ("TSS") effluent limitations, equal to Best Practicable Control Technology Currently Available for TSS, set forth at 40 C.F.R. § 423.12(b)(11), and any applicable water quality-based effluent limitations established by the New Hampshire Department of Environmental Services. Because the 2014 Revised Draft Permit must be revised accordingly, issuance of a new draft permit is appropriate.

CWA § 316(a) – Best Available Technology for Thermal Discharges

On February 29, 2016, PSNH responded to EPA's November 30, 2015 CWA Section 308 Information Request by providing additional temperature data calculations concerning its thermal discharges to the Merrimack River. Region 1 issued its 308 information request after PSNH informed it that the agency's conclusions in its 2011 Draft Permit were based on certain thermal data presented in Normandeau's April 2007 report titled "A Probabilistic Thermal Model of the Merrimack River Downstream of Merrimack Station" ("Normandeau Report"), that the agency incorrectly construed as providing calculated averages of the daily maximum water temperatures for each day at Station S-4 from June 15 to September 10. The effect of the discovery was substantial because Region 1 rejected PSNH's request to renew its existing 316(a) thermal discharge variance in the Draft Permit due to an erroneous interpretation of this temperature data.[4]

Upon discovery of the interpretive error in EPA's 2011 Draft Permit, PSNH promptly notified Region 1 on September 4, 2015, that the thermal results presented in the Normandeau Report are not the 21-year average of the daily maximum temperatures for each day of the calendar year. Instead, the data is the maximum daily average that occurred on a given calendar day typically *only one time during the 21 years* monitoring data was collected between 1984 and 2004.

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[4] To satisfy technology- and water quality-based CWA standards, Region 1 utilized its BPJ authority to determine that the best available technology economically achievable for the treatment of Merrimack Station's thermal discharges is the conversion of the facility's existing open-cycle cooling system to closed-cycle cooling using wet or wet-dry hybrid mechanical draft cooling towers that would operate year round.

In its February 29, 2016 308 response, PSNH provided the report of Dr. Barnthouse, a nationally-recognized ecologist, who confirmed the thermal discharges from Merrimack Station over the timeframe at issue are reasonable and have not caused appreciable harm to the BIP of the Hooksett Pool portion of the Merrimack River. The enclosed Enercon CORMIX Report and Habitat Report from Dr. Barnthouse supplement PSNH's February 29, 2016 response to EPA's November 30, 2015 CWA Section 308 Information Request and further support Dr. Barnthouse's previous conclusions that thermal discharges from Merrimack Station have not caused, are not causing, and will continue not to cause in the future, appreciable harm to the BIP of the Hooksett Pool portion of the Merrimack River.

EPA must review the Enercon CORMIX Report and Habitat Report from Dr. Barnthouse together because the reports are interdependent. Specifically, Enercon's CORMIX Report utilizes temperature criteria (i.e., thermal limits) provided in Tables 1 through 3 of Dr. Barnthouse's Habitat Report, as well as plant operational data and Merrimack River flow rate, temperature, and relevant wind speed data from the last ten years (2006-2015),[5] as inputs to the CORMIX model. The outputs from the CORMIX model characterize the thermal plume within the Merrimack River, including the area and volume the plume occupies within the waterbody. Dr. Barnthouse utilized the CORMIX outputs from Enercon's CORMIX Report to determine that "the thermal plume from the Merrimack Station [does not] affect more than a negligible fraction of the fish habitat present downriver from the cooling water discharge" and, thus, "that Merrimack Station's thermal discharge has had no measurable impacts on the fish community in the Hooksett Pool." Dr. Barnthouse concludes his Habitat Report by stating: "Given the small proportion of the available habitat within the pool that is influenced by the thermal plume, measurable impacts on the fish community would not be expected and none have, in fact, been found."

Based on all of this new information and its implications, Region 1 needs to revisit and substantially revise its analyses of the aquatic organisms in the Hooksett Pool and its evaluations of what impact, if any, thermal discharges from Merrimack Station have on the BIP. The revisions required for Region 1's thermal analyses and permit determinations to comply with law cannot reasonably be considered a "logical outgrowth" of the 316(a) conclusions set out in the 2011 Draft Permit.

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[5] The use of the last 10 years of plant and Merrimack River data is in accordance with EPA's standards for issuing NPDES permits. The new 316(b) regulations provide that studies, analyses, and/or data from the most recent 10-year period are most relevant for NPDES permit determinations and older data may only be considered if the permittee is able to demonstrate the data remains relevant and representative of current conditions at the facility. *See* 40 C.F.R. §§ 122.21(r)(6)(ii)(A) & (r)(7). With respect to the latter consideration, the opposite is true. Data from beyond this 10-year period is <u>no longer</u> representative of current conditions at Merrimack Station. Thus, only the last ten years of data was utilized by Enercon. Second, ten years of data constitutes two complete NPDES permit terms or renewal cycles, two times what EPA's own NPDES Permit Writers' Manual recommends using when establishing technology-based limitations for other pollutants of concern. *See, e.g.,* U.S. Environmental Protection Agency National Pollutant Discharge Elimination System (NPDES) Permit Writers' Manual, § 5.2.2.5, at 5-30 (Sept. 2010) (providing that permit writers can establish permit conditions using data from the past 3 to 5 years and that the goal in selecting the relevant data set is for it to be "representative of the actual [permit conditions] likely to prevail during the next term of the permit").

For all of these reasons, PSNH requests that Region 1 issue a new draft permit for Merrimack Station for public notice and comment. A new draft is compelled by the new 316(b) regulations, the recently promulgated ELGs, PSNH's March 2016 determination to opt into the VIP affecting the limits for the FGD discharge effluent, the corrected temperature data and analysis affecting Region 1's 316(a) determinations, the extensive new information considered by the agency specific to this permit, and engineering innovations that impact future compliance options for Merrimack Station. Allowing PSNH and the public the opportunity to comment on a revised draft permit that reflects and is fully responsive to these significant developments is not only legally required, it is especially appropriate here given the substantial public interest in the Merrimack Station NPDES permit and the likelihood of litigation.

PSNH includes the following documents directly relevant to the 2011 Draft Permit, as well as CORMIX modeling related to the corrected temperature data and EPA's November 30, 2015 CWA Section 308 Information Request, for EPA's consideration and inclusion in the administrative record:

1. Enercon's December 2016 Wedgewire Half Screen Technical Memo (with attachment from Normandeau);
2. Enercon's December 2016 CORMIX Thermal Plume Modeling Technical Report; and
3. Dr. Barnthouse's report titled "Influence of Merrimack Station's Thermal Plume on Habitat Utilization by Fish Species Present in Lower Hooksett Pool."

Please do not hesitate to call me if you have any questions or wish to discuss this matter further.

Very truly yours,

Linda T. Landis

Linda T. Landis
Senior Counsel

cc: William H. Smagula, P.E., Vice President-Generation, Eversource Energy
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Attachment 1

THIS DOCUMENT CONTAINS PROPRIETARY, COMPANY CONFIDENTIAL INFORMATION SUBJECT TO BUSINESS CONFIDENTIALITY CLAIM UNDER 40 C.F.R. PART 2 AND COMPARABLE STATE LAW

WEDGEWIRE HALF SCREEN TECHNICAL MEMO

PSNH MERRIMACK STATION UNITS 1 & 2
BOW, NEW HAMPSHIRE

Prepared for
Public Service Company of New Hampshire
D/B/A EVERSOURCE ENERGY

Prepared by:

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December 2016

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LIST OF ATTACHMENTS

1 Executive Summary

This memorandum provides a high-level design description for wedgewire half screen implementation at Merrimack Station, demonstrating that the technology is the most viable and compatible for use at Merrimack Station. ENERCON's 2014 Assessment of the 2007 Response to United States Environmental Protection Agency Clean Water Act (CWA) § 308 Letter (2014 Assessment, Ref. 6.1) listed several technologies that warranted further evaluation for entrainment reduction at Merrimack Station as part of the best technology available (BTA) determination. Recent industry experience and additional design effort, including design effort for Public Service Company of New Hampshire's (PSNH's) Schiller Station, have shown that wedgewire half screens would provide significant entrainment benefits at a greatly reduced cost. Further design efforts and testing are planned to occur at Merrimack Station through the summer of 2017, including confirmatory testing beginning in mid-May. This memo serves as notice of future design efforts and a confirmatory study that will be undertaken.

2 Introduction

This technical memo provides additional information regarding the evaluation of wedgewire half screens as the BTA at PSNH’s Merrimack Station. This memo describes future efforts that will be undertaken to complete the detailed design and confirmatory testing of this technology. As described in the 2014 Assessment (Ref. 6.1), and as reiterated in the subparts of Section 4 below, a detailed analysis of wedgewire half screens will provide information that should be considered in the BTA evaluation. These detailed analyses will include further site-specific design efforts associated with the technology, a cost estimate, and a site-specific confirmatory study to confirm the conclusions reached by Normandeau Associates, Inc. (Normandeau) in Attachment 1 regarding current velocity, direction, and the impact of hydraulic bypass on entrainment reduction. This memo provides preliminary information regarding wedgewire half screens that will be expanded upon in the more detailed submittal. A discussion of the application of wedgewire half screens at Merrimack Station is provided, in addition to a preliminary layout design of wedgewire half screens for both Unit 1 and Unit 2.

3 Background

PSNH's Merrimack Station electrical generating facility in Bow, New Hampshire is seeking a renewal of its existing NPDES permit. To this end, several engineering and biological assessments have been prepared by Enercon Services, Inc. (ENERCON) and Normandeau and submitted by PSNH to the United States Environmental Protection Agency (EPA) to respond to EPA's requests for certain technology and fisheries information to support development of a new permit for Merrimack Station.

Since the issuance of the draft NPDES permit for Merrimack Station in 2011, several regulatory and technological developments have occurred that warrant further investigation into the BTA evaluation for Merrimack Station. The most significant regulatory change with regard to cooling water intakes is the finalizing of the CWA Section 316(b) rule for existing facilities. Existing facilities that are designed to withdraw greater than 2 million gallons per day (MGD) of water from waters of the United States, and that use at least 25 percent of this water exclusively for cooling purposes, are subject to the BTA standard for impingement mortality unless a *de minimis* demonstration can be made, or unless an exemption is given for a low capacity utilization factor. According to the Normandeau evaluation contained in the 2014 Assessment, the impingement rate at Merrimack Station is *de minimis* and does not require further controls as stated in the rule (Ref. 6.1).

With the *de minimis* classification, the 2014 Assessment preemptively evaluated technologies with a specific focus on reducing entrainment abundance. This assessment included the Johnson Screens Half Intake Screen System, a relatively new technology that has been developed and installed in several applications starting in 2012. These screens are marketed as a solution for shallow water intakes, and can be installed in water that is half the depth of traditional intake screen systems of the same diameter. One benefit to using half-cylindrical screens is that larger diameter screens can be utilized since the screens are flush with the bottom. This would likely result in fewer screens being required. An additional benefit to the half screens is reduced in-river dredging; this is because the screens are not buried but are supported by a concrete pad, and above-ground piping can typically be used. Further research on wedgewire screens having slot widths of 2 mm and 3 mm has shown that entrainment can be reduced not only through physical exclusion due to the wedgewire screen mesh, but also through behavioral avoidance and hydraulic bypass. If the screen is installed with the river flow perpendicular to the slot width (i.e., parallel to the screen length), and the ratio of sweeping velocity to slot velocity is 1:1 or greater, avoidance and bypass become the primary mechanisms for wedgewire screen entrainment reduction (Attachment 1). Due to the relatively shallow river depth at Merrimack Station, and the benefit that the station would receive from reducing the number of screens used (such as lower costs and less environmental disruption during construction), it is expected that the wedgewire half screen technology provides significant advantages over the traditional cylindrical wedgewire screen technology as evaluated at Merrimack Station in the 2009 Supplemental Alternative Technology Evaluation (2009 Evaluation, Ref. 6.2). Because of this, half screens are more viable and compatible for Merrimack Station than cylindrical wedgewire screens.

Because wedgewire half screens are a viable technology that should be part of the BTA determination, preliminary information is provided in this memo, in addition to descriptions of future design and testing activities that will take place through summer 2017.

4 Wedgewire Half Screen Technology

Preliminary information regarding the design and implementation of this technology is provided in this section. A more detailed analysis will occur through summer 2017, and will consist of a detailed design, cost estimate, and confirmatory study for wedgewire half screens at Merrimack Station. This information should be considered by EPA in any BTA determination, since this technology is likely to provide significant entrainment benefits at reduced cost as compared to other entrainment reduction technologies.

4.1 Technology Overview

Wedgewire screens are designed to reduce entrainment by excluding organisms from passing through the screen and by achieving low velocities due to the large size of the screens. Hydraulic bypass also occurs as a result of the shape of the screen, particularly when the lengthwise dimension of the screen is oriented parallel to the direction of prevailing flow. Additionally, due to the round shape of the screens, the velocity pulling the organisms toward the screen is quickly dissipated, increasing the avoidance by organisms. As described in Attachment 1, applied research in both a laboratory flume and in the Hudson River estuary demonstrated that typically 80% or more of the larvae 12 mm in total length or larger were capable of actively swimming to avoid entrainment when the ratio of sweeping velocity to slot velocity was greater than 1:1 (See Figure 1 for ratio illustration). In the testing mentioned above, behavioral avoidance was observed to be higher for slot widths of 2 mm and 3 mm, and at a lower through-slot velocity (Attachment 1).

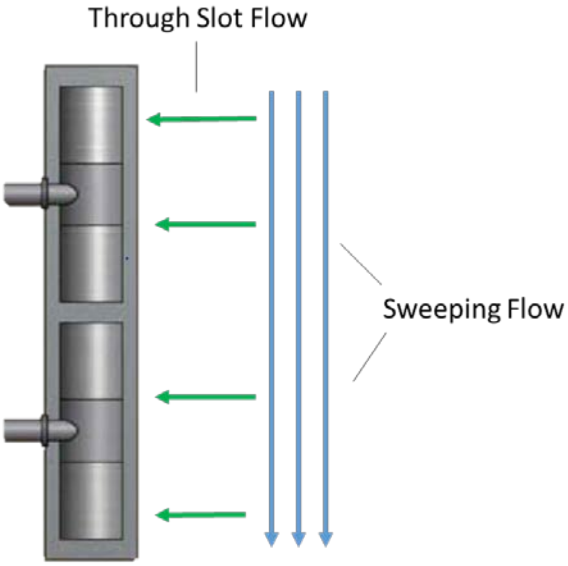

Figure 1: Sweeping Flow and Slot Flow Illustration

The 2014 Assessment introduced the Johnson Screens Half Intake Screen System as a new development in wedgewire screen technology that is well-suited for Merrimack Station (Ref. 6.1). This screen contains one curved, semi-circular surface and one downward-facing flat surface, as shown below in Figure 2.

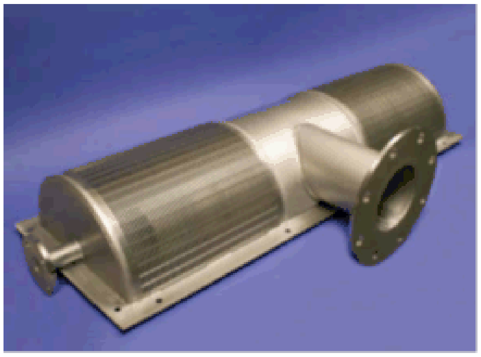

Figure 2: Johnson Screens Half Intake Screen System (Ref. 6.7)

These screens are marketed as a solution for shallow water intakes, and are able to provide a larger diameter screen for a given water depth than would be possible with traditional cylindrical wedgewire screens. The wedgewire half screen technology is of particular benefit at Merrimack Station, where the river depth is relatively shallow, averaging between 6 and 8 feet deep. A benefit of using larger diameter screens is that fewer screens are required, reducing the amount of construction and associated environmental disturbance. Use of the half screens would alleviate concerns regarding the large number of screens presented in the 2009 Alternative, which proposed a conceptual design using cylindrical wedgewire screens (Ref. 6.2).

As described in Attachment 1, from a biological perspective, the location of the Merrimack Station cooling water intake structure appears ideal for effective wedgewire screen entrainment reductions for three reasons. First, 88% of the entrained organisms collected during the 2005-2007 study were post yolk sac larvae. This life stage consistently experienced the greatest reduction in entrainment in the flume and field studies. Second, there is confidence that the observed entrainment reductions in the flume studies because White Sucker, Carp, and Minnows were the principal test organisms in the flume studies and were the predominant fish taxa in the Merrimack Station entrainment samples. Third, based on field observations from two surveys performed during the peak entrainment periods of 2009 and 2010, a relatively high and consistent sweeping velocity has been observed in the Merrimack River at Merrimack Station along the predominant north-south axis. These findings show that the hydraulic conditions are suitable for effective wedgewire screen performance, and that the studies described in Attachment 1, which demonstrated that bypass and avoidance contributes significantly to wedgewire screen effectiveness on these species (White Sucker, Carp, and Minnows), would be applicable to Merrimack Station. A confirmatory study is planned to occur through summer 2017 to validate the effectiveness of the wedgewire half screens in-situ at Merrimack Station.

4.2 Site Parameters and Screen Design

Since the development of the new wedgewire half screen technology, Johnson Screens has completed installations at approximately 20 different sites in multiple different intake water sources, including lakes, reservoirs, and rivers (Ref. 6.3). Several installations implemented multiple wedgewire half screens at a single site, with the largest diameter screen listed being a 5 foot diameter screen. All of these installations were completed in 2012 or later, after the draft NPDES permit for Merrimack Station had been issued.

In order to size the wedgewire half screens for application at Merrimack Station, several plant design parameters are required, including the intake structure layout and design intake flow rates. Due to the difference in intake flow between Unit 1 and Unit 2, and due to the physical distance between the intakes, the approach was taken to prepare two separate wedgewire half screen designs, one for each unit.

For Unit 1, an intake flow rate of 59,500 gpm was used. This flow rate includes 29,500 gpm for each of the two circulating water pumps (Ref. 6.2), as well as 500 gpm to supply the fire pump flow (Ref. 6.4). For Unit 2, an intake flow rate of 140,000 gpm was used, which consists of 70,000 gpm for each of the two circulating water pumps (Ref. 6.2). For both units, an inlet water depth of 8 feet was considered for the design. This water depth was selected based on the average depth of the river, as well as the assumption that minor dredging may be required during the installation of the wedgewire half screens.

The screens themselves were designed with a slot width of 3 mm. A slot width of 3 mm was selected because, as described in Attachment 1, slot sizes of 2 mm and 3 mm were shown to increase behavioral avoidance in the laboratory flume and Hudson River estuary testing. The 3 mm slot size is beneficial from a maintenance and operational standpoint because it can help reduce fouling and debris accumulation issues. The screens were designed to be constructed out of Z-Alloy (a proprietary copper-nickel alloy) metal. Although the original wedgewire screen design presented in the 2009 Evaluation specified that 304 stainless steel be used for construction (Ref. 6.2), Z-Alloy has been shown to substantially reduce bio-fouling compared with stainless steel, while providing excellent corrosion resistance in underwater environments (Ref. 6.5).

As described in the 2014 Assessment, based on the impingement rate at Merrimack Station being *de minimis*, the design through-screen velocity of 0.5 fps is no longer a design requirement. However, during the screen design process, it was identified that when the screens are sized for a higher through-screen velocity, an unacceptably high head loss (i.e., energy loss due to friction) through the screens would occur. The increased head loss would result in reduced water level within the intake bays, potentially causing cavitation and damage to the circulating water pumps. Therefore, although the 0.5 fps velocity is no longer a design requirement dictated by impingement concerns, due to the unacceptable head loss through the screens at higher velocities, a design through-screen velocity of approximately 0.4 fps was maintained.

With the above design parameters in consideration, two separate wedgewire half screen designs, one for each of the units at Merrimack Station, were created. For Unit 1, which has a design intake flow rate of 59,500 gpm, two Half T-96HCE Screens (30% extended) are utilized. These screens are 8 feet in diameter, 27’ – 7” in length, and have a slot size of 3 mm. A dimensioned drawing of these screens is provided by Johnson Screens in Attachment 3. Each of these screens is designed for a through-screen intake velocity of approximately 0.4 fps with a design flow rate of 29,750 gpm/screen, totaling 59,500 gpm of flow for the entire unit.

For Unit 2, which has a design intake flow rate of 140,000 gpm, five Half T-96HCE Screens (30% extended) are utilized. These screens have the same dimensions as described above for Unit 1. Each of these screens is designed for a through-screen intake velocity of approximately 0.4 fps with a design flow rate of 29,750 gpm/screen.

Wedgewire screens for both units are designed for a through-screen velocity of approximately 0.4 fps due to unacceptable head loss through the screens at higher velocities. As stated in Attachment 1, the frequency distribution of the Merrimack River velocities observed near the Merrimack Station intake during the entrainment season revealed that the average sweeping flow from north to south was 2.9 fps along the west bank near the Merrimack Station intake. A sweeping flow of this magnitude would result in a sweeping velocity to slot velocity ratio of approximately 7:1. This ratio is substantially above the 1:1 ratio shown to be effective at reducing entrainment (Attachment 1), indicating that entrainment reduction due to hydraulic bypass can be expected. As described in Attachment 1, this expected reduction in entrainment due to hydraulic bypass will be tested and confirmed through a site-specific confirmatory study beginning in mid-May.

4.3 Screen Layout and Operation

A conceptual layout of the wedgewire half screens for each unit is shown in Attachment 2. Both units are designed with a concrete plenum encompassing the front of the existing intake structure. To aid with construction, these plenums would likely be built with precast concrete and would not modify or interfere with the existing intake structure, but would instead be built adjacent to the existing structure. The purpose of these plenums is to collect the flow from all of a given unit's wedgewire screens, combining it and providing a suction source for the circulating water pumps. The combination of the flows from the various wedgewire half screens serves to both simplify the manner in which flow is provided from the screens to the suction of the circulating pumps, as well as to provide design redundancy. Because all of the wedgewire half screens feed flow into a common plenum for each unit, if one screen were to fail, flow can still be provided to both circulating water pumps through the remaining screen(s).

For Unit 1, the two wedgewire half screens are placed co-linearly from north to south, oriented in the direction of the prevailing river flow. The screens are oriented such that the slot width is perpendicular to the river flow (i.e., screen is parallel to river flow) in order to improve hydraulic bypass (Attachment 1). This layout allows for straightforward connections from the screens to the plenum without excessive piping friction losses, and also keeps the screens relatively close to the river shore, lowering construction costs. The north and south wedgewire screens connect to the north and south walls of the concrete plenum respectively. Attachment 2 provides a layout drawing which illustrates the wedgewire half screen installation at Unit 1.

For Unit 2, all five wedgewire half screens are placed co-linearly from north to south, oriented in the direction of the prevailing river flow. The screens are oriented such that the slot width is perpendicular to the river flow in order to improve hydraulic bypass (Attachment 1). Although the length of the wedgewire half screens will extend beyond the width of the intake structure, this layout is still expected to be the most efficient from an engineering standpoint, allowing for straightforward connections from the screens to the plenum without excessive piping friction losses, and keeping the screens relatively close to the river shore to limit construction costs. The two north screens and two south screens connect to the north and south plenum wall, respectively. Additionally, the middle screen, which sits directly in front of the plenum box, connects to the east wall of the plenum. Attachment 2 provides a layout drawing, which illustrates the wedgewire half screen installation at Unit 2.

For both units, the east wall of the concrete plenum includes two bypass gates that provide an alternate source of circulating water should the wedgewire screens become blocked. The water levels within the intake bay would be monitored continuously; and if necessary, the auxiliary intake system would be initiated to maintain plant operation. This would also prevent a large pressure differential from building up across the blocked screens, reducing the potential for screen damage due to blockage. The bypass gates could also be utilized without limiting operation during portions of the year where entrainment is not of concern. Additionally, these bypass gates may be required for operation in winter months, when frazil ice formation in the river can occur, as well as if a high level of debris loading on the wedgewire screens were to occur.

It is not expected that screen blockage will become an issue for screen operation during the entrainment season. Due to Merrimack Station's *de minimis* classification, the 0.5 fps design criteria to reduce impingement is not a requirement; therefore, a small amount of screen blockage that causes the through velocity to increase above 0.5 fps is not a concern as long as the ratio of sweeping flow to slot velocity is maintained at 1:1 or greater during the typical entrainment period. It is expected that, even during a minor blockage event, a ratio of 1:1 or greater would be maintained due to the high sweeping flow velocities in the Merrimack River. However, from a hydraulic loss standpoint, blockage could become a concern if it were to induce excessive head loss across the screen. Therefore, each screen would be equipped with an air burst system (ABS), which uses periodic bursts of compressed air to blow accumulated objects from the screens, preventing excessive blockage from accumulating over time. This system would also serve to reduce the amount of maintenance required for the screens due to blockage. It should be noted that a detailed design of the ABS has not yet been performed, and therefore the ABS is not represented on the drawings in Attachment 2. However, a sketch of a typical ABS design is provided below.

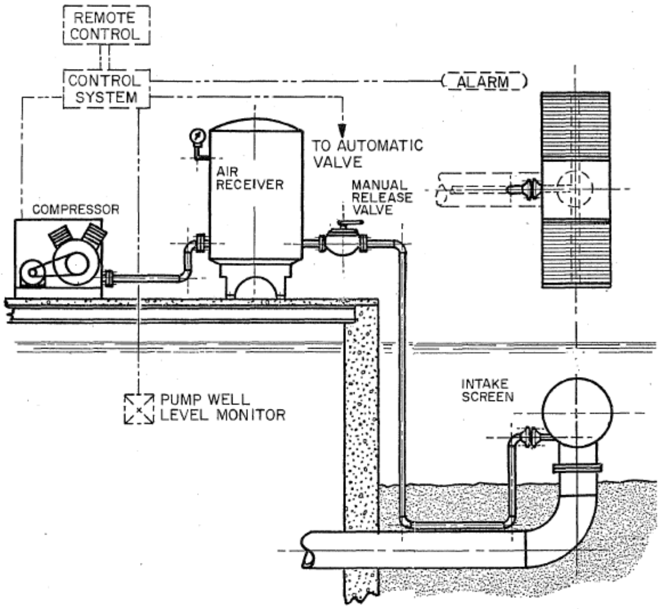

Figure 3: Sketch of a Typical ABS Design (Ref. 6.8)

The estimated head loss through a Half T-96HCE Screen (30% extended) operating at approximately 0.4 fps is provided by Johnson Screens as 0.698 psi (Ref. 6.6). While it is not expected that this head loss will challenge plant operability, it is possible that at low river levels, the submergence of the circulating water pumps may be challenged due to the increased head (i.e., friction) losses that will occur with the installation of the new screens. A detailed hydraulic analysis will be required to confirm that pump modifications are not required. As described in the 2014 assessment, this detailed hydraulic analysis would apply a realistic blockage factor to the screens (based on site-specific studies) to ensure that sufficient screening area exists to maintain sufficient submergence for the circulating water pumps. Vortex suppression features, such as grating or modified features beneath the suction of the pumps, may be required based on the expected intake water level and will be evaluated as part of this detailed hydraulic analysis.

5 Conclusion

The 2014 Assessment preemptively evaluated several entrainment reduction technologies for viability at Merrimack Station. Industry experience and design efforts conducted since 2012 have led to the conclusion that wedgewire half screens are the most viable and compatible technology for Merrimack Station.

The information above provides a high-level design description for wedgewire half screen implementation at Merrimack Station, demonstrating that the technology provides significant entrainment benefits at a greatly reduced cost. As described above, a detailed analysis is planned to occur through summer 2017, and will provide a final design and cost estimate for the implementation of wedgewire half screens at Merrimack Station. Layout drawings of the equipment and structures, vendor quotations, and a construction estimate will also be provided as part of this detailed analysis in order to further support the selection of wedgewire half screens as the BTA.

In addition to this detailed evaluation, a site-specific confirmatory study will be undertaken to validate the biological effectiveness of wedgewire half screens at Merrimack Station. As described in Attachment 1, this study will serve to confirm the entrainment reduction expected based on the high ratio of sweeping flow to slot flow ratio. A site-specific current velocity and direction study will occur coincident with the confirmatory entrainment reduction study to characterize the Merrimack River sweeping flows and the consistency of the current direction during the entrainment test period.

The detailed design and site-specific confirmatory study for wedgewire half screens will be undertaken to confirm that wedgewire half screens provide significant entrainment benefits at Merrimack Station with minimal operational impacts. These efforts will provide information that should be considered in the BTA determination for Merrimack Station.

6 References

6.1 Assessment of 2007 Response to United States Environmental Protection Agency CWA § 308 Letter, PSNH Merrimack Station Units 1 & 2. October 2014.

6.2 Supplemental Alternative Technology Evaluation, PSNH Merrimack Station Units 1 & 2. October 2009.

[redacted]

6.4 MK-M-1235, “Schematic of Water Flow Merrimack Station”, Revision 2.

6.5 Maxson, Richard C., “Evaluation of Zebra Mussel Resistant Materials of Construction for Intake Screens & Assemblies,” March 9, 1994.

6.6 Johnson Screens Flow/Screen vs. Headloss Chart, provided 10/19/2016.

6.7 Johnson Screens Half Intake Screen System: A Solution for Shallow Water Intakes, provided 10/7/2016.

6.8 Johnson Surface Water Intake Screens Product Application Guide.

NORMANDEAU
ASSOCIATES
Environmental Consultants

Memorandum

TO: Ms. Linda Landis, Eversource Energy
Mr. Richard Clubb, Enercon Services, Inc.
FROM: Mark T. Mattson, Ph.D., Vice President
DATE: 16 December 2016

RE: Wedgewire Screen Update: Attachment 1 to Enercon 316(b) Report for Merrimack Station

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Recent publically available information describing the entrainment reduction performance of cylindrical wedgewire (CWW) screens reveals that, when designed, installed, and operated to take advantage of certain ambient conditions, their biological efficacy is enhanced beyond their previously described performance as passive filters. As passive filters, CWW screens reduce entrainment primarily by excluding fish eggs and larvae due to narrow slot width openings being less than the physical limiting dimensions of the organisms in the intake flow (Mattson et al., 2011, 2014, and 2015). In addition to physical exclusion, this memorandum discusses how CWW screens also reduce entrainment by behavioral avoidance swimming ability of larvae, and by hydraulic bypass of eggs and larvae.

The appropriate ambient conditions to enhance entrainment reduction performance of CWW screens are present in Hooksett Pool near the cooling water intake structures at Merrimack Station Units 1 and 2 during the "typical" 13 week entrainment period from mid-May to early August when 97% of the annual entrainment has been observed (Normandeau 2007). Therefore, a confirmatory entrainment study is recommended to verify that the entrainment reduction performance of CWW screens expected based on the comprehensive flume and field studies performed for Indian Point Energy Center (Indian Point) demonstrate comparable effectiveness for the fish species and site-specific hydraulic conditions at Merrimack Station.

Applied research in both a laboratory flume and in the Hudson River estuary using test CWW screens demonstrated that the entrainment reduction performance of CWW screens is related to three factors: physical exclusion by the slot width of passive eggs and larvae, behavioral avoidance of the intake flow by the actively swimming larvae, and the hydraulic bypass of eggs and larvae due to sweeping flow of river currents along the surface of the wedgewire screen when they are installed so the river flow is in a direction perpendicular to the slot openings (i.e., parallel to the slot width). CWW screens (12 inch and 18 inch diameter) with slot widths of 2, 3, 6, and 9 mm were tested in a large hydraulic flume using approximately 450,000 fish larvae (including 207,000 White Sucker larvae) and an equal number of neutrally buoyant 1 mm diameter beads (representing fish eggs) at flume velocities of 0.25, 0.50, 1.0, 1.5, and 2.0 feet per second (fps), with through-slot velocities of 0.25 and 0.50 fps, for a total of 24 combinations of slot width, flume velocity, and through-slot velocity among 4,647 individual tests. Physical exclusion was observed to reduce entrainment in a direct relation to limiting dimensions of the test subjects, particularly passive test subjects like beads (eggs) and anesthetized larvae. Fish eggs, larvae, or juveniles with a greatest body depth larger than the slot width were physically excluded and not entrained. Behavioral avoidance was observed to be higher for the two smaller slot widths (2 mm and 3 mm) and for a lower through-slot velocity. Overall, avoidance and hydraulic bypass were higher at higher ratios of sweeping velocity to through-slot velocity, with typically 80% or more of the larvae 12 mm in total length or larger capable of actively swimming to avoid entrainment at a ratio of sweeping velocity to slot velocity greater than 1:1 (Mattson et al. 2011, 2014, and 2015). These mechanistic flume studies demonstrated that hydraulic bypass and avoidance were the prevailing modes of the entrainment reduction effectiveness for CWW screens if installed with the river flow perpendicular to the slot width and a sweeping velocity to slot velocity of 1:1 or greater (Mattson et al. 2011).

Field testing of a CWW screen conducted during the 2011 entrainment season in the Hudson River estuary at Indian Point confirmed the entrainment reduction performance observations from the laboratory flume tests. Entrainment sampling was performed at Indian Point *in situ* for 96 continuous hours each week for 24 consecutive weeks from mid-April through mid-September 2011 (Mattson et al. 2014 and 2015). A total of 1,104 pairs of two-hour pumped samples (100 m^3 each) were collected from a 2 mm slot width CWW test screen with a 0.25 fps through-slot velocity deployed 35 feet below the water surface and paired with control samples from coincident 1 m^2 Tucker trawl tows (300 m^3 each) deployed at 35 feet of depth and into the prevailing current immediately upstream from the test CWW screen. A total of 31 ichthyoplankton taxa and 275,245 individuals (83% post yolk-sac larvae) were collected and analyzed from these pairs of Hudson River samples filtered through a 300 micron mesh net. Larval avoidance of the test screen was observed to increase with increasing larval length for the most abundant species (striped bass, 35%; and Bay Anchovy, 28%) as predicted in the flume, and the overall entrainment reduction for 2 mm CWW screens at Indian Point was estimated to be 78% (Mattson et al. 2015).

The Merrimack River location of the Merrimack Station cooling water intake structure appears ideal for effective entrainment reductions of installed wedgewire screens for three reasons. First, 88% of the entrained organisms collected at Merrimack Station during the 2005-2007 study were post yolk-sac larvae and just 1% were eggs

(Normandeau 2007). Fish larvae in the post yolk-sac larval life stage are the largest fish larvae of each taxon, and this life stage consistently demonstrated the greatest reductions in entrainment in the flume and field studies (Mattson et al. 2011, 2014, and 2015). Second, White Sucker (24%) and Carp and Minnows (28%) were the predominant (52%) fish taxa in the Merrimack Station entrainment samples (Normandeau 2007), and both of these taxa were the principal test organisms in the Indian Point flume studies (Mattson et al. 2011), providing confidence that the observed Indian Point entrainment reductions are directly applicable to the expected performance of a wedgewire screen array if designed, installed and operated similarly to the test conditions at Merrimack Station. Third, we have observed relatively high and consistent sweeping velocity in the Merrimack River at Merrimack Station along a predominant north-south axis, based on field observations from two surveys performed there during the peak entrainment periods of 2009 and 2010. Geo-referenced depth and current data were collected across the river in the vicinity of the Merrimack Station intake in Hooksett Pool using a SonTek Mini ADP 1.0 MHz Acoustic Doppler Current Profiler (ADCP) and a Trimble DSM-232 GPS during the four-week periods from 17 May through 13 June 2009 and from 16 May through 12 June 2010. Data were collected twice weekly (Tuesday and Thursday) during each four-week period (eight sampling events per year) and consisted of one daytime set and one nighttime set. The order in which seven cross-sectional zones were sampled from west to east banks at the intake was randomized independently within each of the eight daytime and eight nighttime sampling events, to avoid the potential bias of always sampling a particular stratum at the same time of day or night. The frequency distribution of the Merrimack River velocities observed near the Merrimack Station intake revealed that the average sweeping flow from north to south was 2.9 fps along the west bank near the Merrimack Station intake.

Therefore, based on the Indian Point flume and Hudson River studies, wedgewire screens designed for Merrimack Station could have a design through-slot velocity as high as the observed average sweeping velocity of 2.9 fps to maintain a 1:1 sweeping velocity to slot velocity ratio that was proven effective at reducing entrainment (Mattson et al., 2011, 2014, and 2015). Further increases in the sweeping velocity to through-slot velocity ratio by reducing the through-slot velocity could be expected to improve the entrainment reduction performance of wedgewire screens if accommodated by the engineering design. A site-specific current velocity and direction study would be required coincident with the recommended confirmatory entrainment reduction performance study to characterize the Merrimack River sweeping flows and the consistency of the current direction during the entire entrainment test period. These data would assist the engineering design of a half-diameter wedgewire screen array for Merrimack Station to maximize entrainment reductions by determining the alignment of the long axis of each wedgewire screen so that the slots are perpendicular to the predominant flow direction and in a river bed location that maximizes the sweeping flow to slot flow ratio above 1:1 during the mid-May through July period of peak entrainment abundance.

LITERATURE CITED:

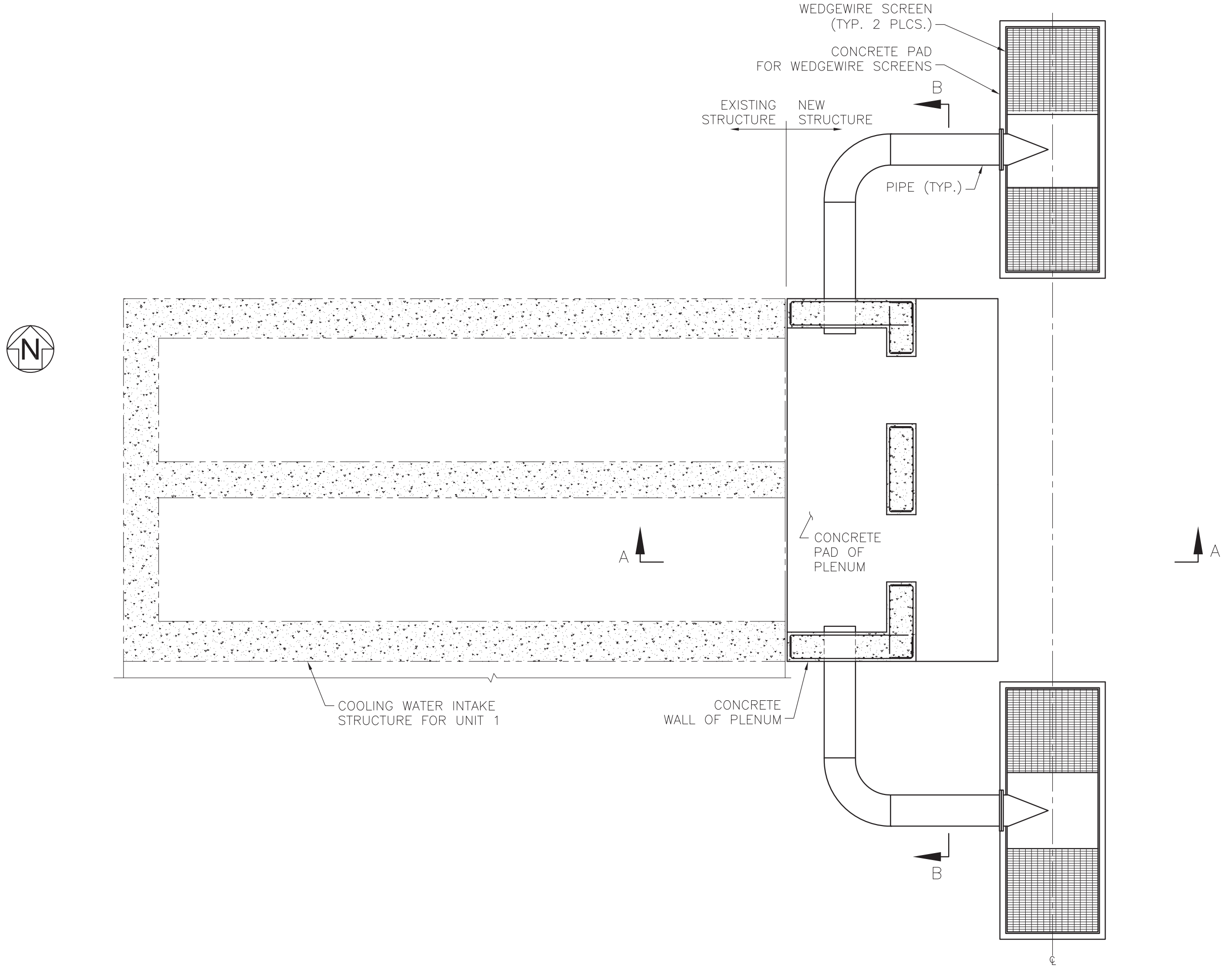
Mattson, M.T., P. Lindsay, J. Young, and J. Black. 2011. Larval avoidance enhances the entrainment reduction performance of cylindrical wedgewire screens. August 2011. Presentation to the American Fisheries Society annual meeting in Seattle, WA on behalf of Entergy's Indian Point Energy Center, Buchanan, NY.

Mattson, M.T., P. Lindsay, J. Young, D. Heimbuch, and L. Barnthouse. 2014. In-river Performance of a 2-mm slot wedgewire screen for reducing entrainment at Indian Point Station. August 2014. Presentation to the American Fisheries Society annual meeting in Quebec City, Quebec, Canada on behalf of Entergy's Indian Point Energy Center, Buchanan, NY.

Mattson, M.T., P. Lindsay, J. Young, D. Heimbuch, and L. Barnthouse. 2015. Performance of 2-mm slot width wedgewire screens for reducing entrainment at Indian Point Station. November 2015. Presentation to the Electric Power Research Institute National 316(b) Conference on behalf of Entergy's Indian Point Energy Center, Buchanan, NY.

Normandeau Associates, Inc. (Normandeau) 2007. Entrainment and impingement studies performed at Merrimack Generating Station from June 2005 through June 2007. Report prepared for Public Service of New Hampshire, October 2007.

Wedgewire Half Screen
Technical Memo
Attachment 2
Page 1 of 2



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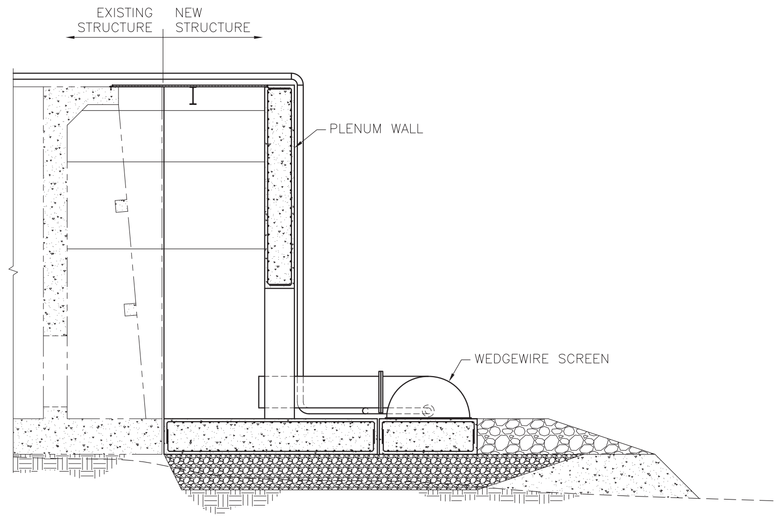

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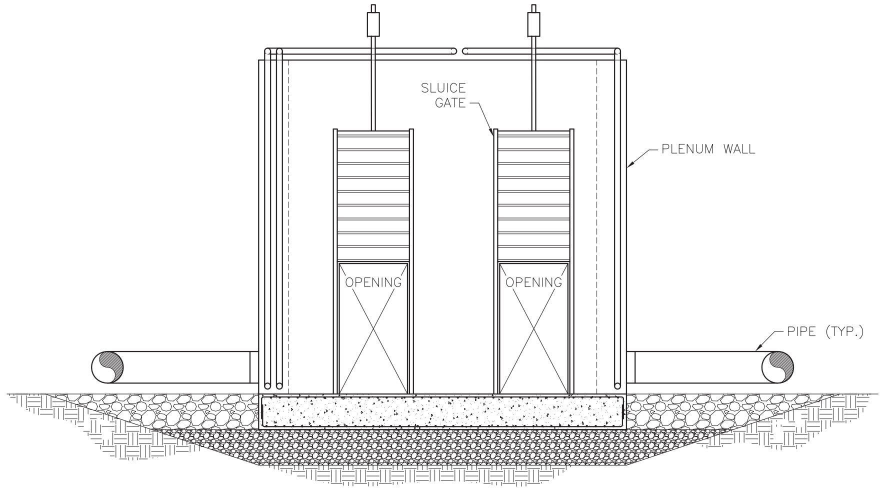

SECTION B–B

NOTES:

1. THIS DRAWING IS PRELIMINARY AND SUBJECT TO CHANGE, NOT FOR CONSTRUCTION.

REV	DESCRIPTION	DRN	CHK	REV	APP	DATE
0	INITIAL ISSUE					

ENERCON
Kennesaw, GA 30144

PUBLIC SERVICE CO. OF NEW HAMPSHIRE
MERRIMACK STATION-UNIT NO. 1

CONCEPTUAL DRAWING FOR PROPOSED WEDGEWIRE SCREENS AND PLENUM (SCREEN HOUSE #1)

SIZE D
DWG NO. PSNH014-SK-001
REV 0
SCALE NONE
SHEET 1 of 1

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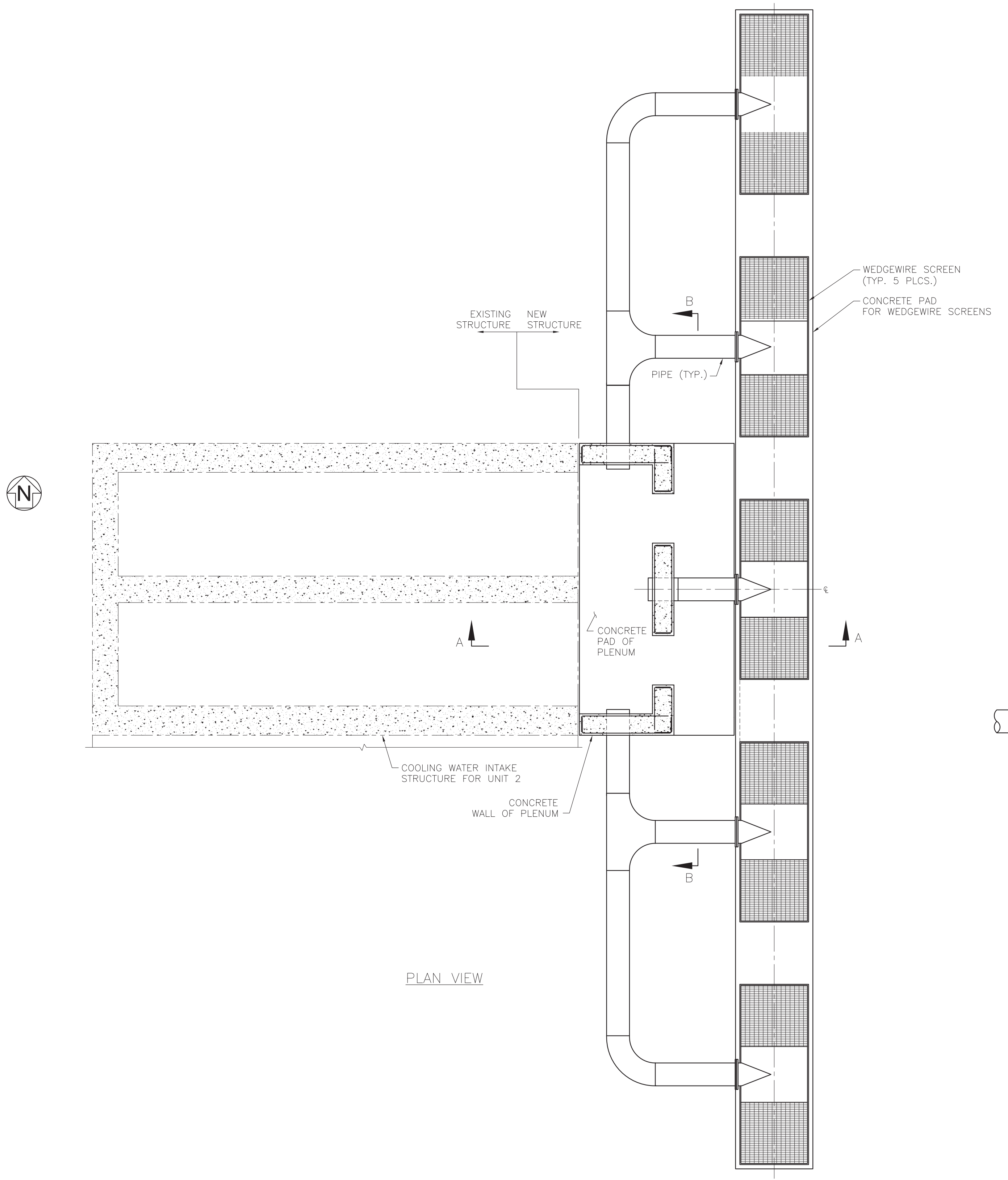
PRELIMINARY

Wedgewire Half Screen
Technical Memo
Attachment 2
Page 2 of 2



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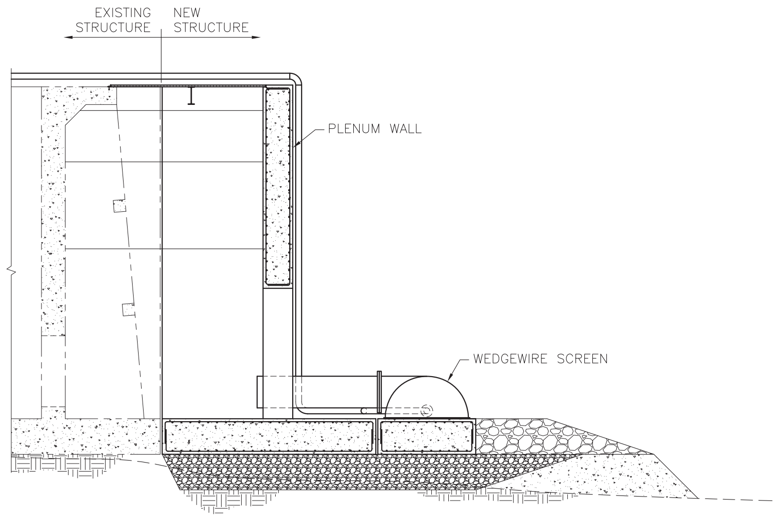

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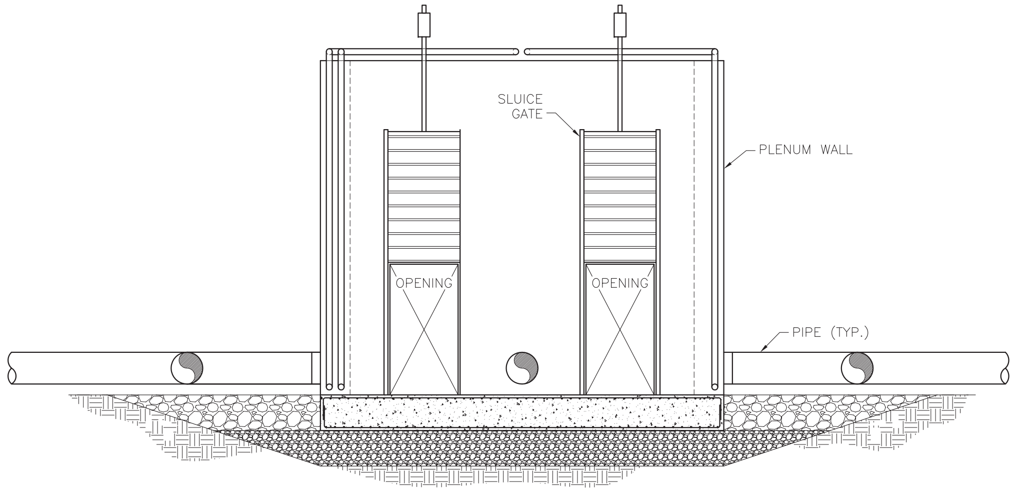

SECTION B–B

NOTES:

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REV	DESCRIPTION	DRN	CHK	REV	APP	DATE
0	INITIAL ISSUE					

ENERCON
Kennesaw, GA 30144

PUBLIC SERVICE CO. OF NEW HAMPSHIRE
MERRIMACK STATION-UNIT NO. 2

CONCEPTUAL DRAWING FOR PROPOSED WEDGEWIRE SCREENS AND PLENUM (SCREEN HOUSE #2)

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REV 0
SCALE NONE
SHEET 1 of 1

PRELIMINARY

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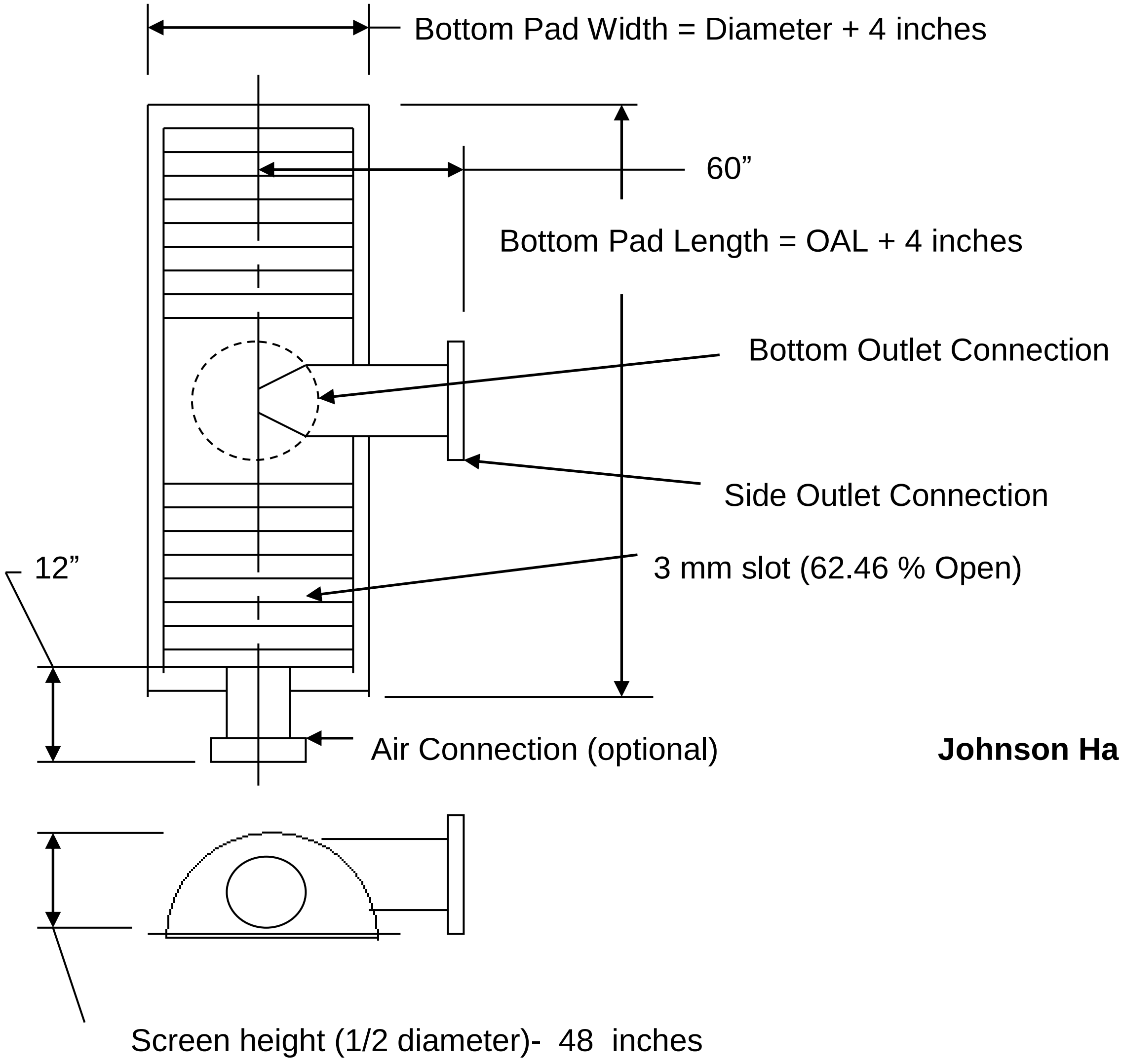


Notes:

1. Bottom pad to have 9/16 diameter holes all around the perimeter for Using several concrete anchor bolts.
2. OAL Screen Length = 331 inches
3. Screen Width/Diameter = 96 inches
4. Total Design Flow = **29,750 gpm/screen**
5. Outlet Flange = 42 inch diameter (side)
   Or 72 inch dia. (bottom)
6. Air Connection = 8 inch

Johnson Half Intake Model – T-96HCE (30% Extended)

PATENT # 8,297,448

Enercon Project

Low Profile Half Intake Screen

Johnson screens™

Attachment 2

CORMIX THERMAL PLUME MODELING TECHNICAL REPORT

PSNH MERRIMACK STATION UNITS 1 & 2
BOW, NEW HAMPSHIRE

Prepared for
Public Service Company of New Hampshire
D/B/A EVERSOURCE ENERGY

Prepared by:

Enercon Services, Inc.
500 TownPark Lane
Kennesaw, GA 30144
December 2016

TABLE OF CONTENTS

LIST OF ATTACHMENTS

1 Introduction and Purpose

Public Service Company of New Hampshire ("PSNH") operates Merrimack Station, located in Bow, New Hampshire. Merrimack Station is the largest of PSNH's fossil-fueled power plants, and has a total electrical output of approximately 480 MW. Merrimack Station operates two steam electric generating units (Unit 1 and Unit 2) and two combustion turbines. Unit 1 began operating in 1960 and has a rated production of 108 MW, while Unit 2 began operating in 1968 and has a rated production of 330 MW (Reference 6.13).

Several engineering and biological assessments have been prepared by Enercon Services, Inc. (ENERCON), Normandeau Associates, Inc. (Normandeau) and LWB Environmental Services (LWB) and submitted by PSNH to the United States Environmental Protection Agency (EPA) to respond to EPA's requests for certain technology and fisheries information to support development of a new permit for the Station.

The purpose of this technical report is to document the analysis that was performed to estimate the surface area and volume of the thermal plume in the Merrimack River during various weeks of interest, based on historical data. This thermal assessment is performed by using the CORMIX modeling software to quantify the size and location of thermal plumes that develop for various sets of flow and temperature parameters, based on Merrimack Station's historical data.

CORMIX is a modeling software for the analysis, prediction, and design of discharges into various types of water bodies. The focus of the software model is on the geometry and dilution characteristics of the initial mixing zone, including compliance with regulatory constraints, as well as predicting the behavior of the discharge plume at larger distances (Reference 6.1, Page 1).

CORMIX models the hydrodynamics of an effluent that is continuously discharging into a receiving water body by breaking the mixing process into two separate regions: the near-field and the far-field. The mixing in the near-field is heavily influenced by the initial discharge flow characteristics and outfall geometry, and the mixing in the far-field is more dependent on the ambient environment. (Reference 6.1, Page 8).

The EPA has historically provided institutional support for CORMIX, assisting with the development of all three CORMIX model types, including the CORMIX3 buoyant surface discharge model used in the present analysis, as well as other processing tools and the CORMIX User’s Manual (Reference 6.1, Page 1). In addition to supporting the development of CORMIX, the EPA has also traditionally used it as a tool for NPDES permit writing. The EPA NPDES Permit Writers’ Manual lists CORMIX as an example for a model that may be used in support of writing a permit (Reference 6.10, Page 6-24), and the 2013 Annual Report of Scientific Integrity describes CORMIX as “an EPA-supported mixing zone model and decision support system for environmental impact assessment of regulatory mixing zones that are a result of continuous point source discharges.” (Reference 6.11, Page 13). CORMIX is considered a proven software for use to assess the thermal plume formation at Merrimack Station.

Based on the recommendations of LWB, three sets of data, or cases, were used for this analysis. These three cases represent the early spring period when river flows are high and ambient river temperatures are relatively low, the late spring period when ambient river temperatures are rising and flows are falling, and the mid-summer period when ambient river temperatures are high and flows are low (Reference 6.2, Page 1). In order to assess these three cases, historical plant and ambient data from the last 10 years (2006-2015) was used and averaged over the 10-year time frame and over the time period of each case. The 10-year range was chosen because it provides a data set representative of two full 5-year NPDES permit renewal cycles. Additionally, this year range was used based on the Clean Water Act (CWA) §316(b) rule, which states that:

> *"The submission of studies more than 10 years old must include an explanation of why the data are still relevant and representative of conditions at the facility and explain how the data should be interpreted…"*

with regards to impingement performance studies (Reference 6.14, §122.21(r)(6)) and:

> *"In the case of studies more than 10 years old, the applicant must explain why the data are still relevant and representative of conditions at the facility and explain how the data should be interpreted…"*

with regards to entrainment performance studies (Reference 6.14, §122.21(r)(7)). Based on these two precedents, the most recent 10-year range was chosen for the cases analyzed with CORMIX.

The purpose of this analysis is to evaluate the thermal plume behavior in the Merrimack River for each of the three cases and various temperature criteria provided by LWB. In order to do this, plant and river operational parameters (flow rates, temperatures, and wind speed) from the last 10 years are considered to inform the input parameters to the CORMIX model, providing a historical assessment. The purpose of this historical assessment is to act as a screening tool that can be used in the biological evaluation provided by LWB's Dr. Barnthouse (Reference 6.2) to determine if further analysis for any of the cases is required.

2 Case-Dependent Model Parameters

Both the effluent and the ambient conditions can affect the mixing modeling in CORMIX and can impact the predicted thermal plume. Many of the conditions, such as geometry, remain constant for all cases considered. However, several of the effluent and ambient parameters required by CORMIX vary considerably at Merrimack Station based on the time of year. These parameters include effluent flow rate, effluent temperature, river flow rate, river temperature, ambient wind speed, and heat loss coefficient.

To account for the variation in these parameters, three cases were developed to model the thermal plume during critical timeframes. Case 1 assesses plume behavior during the week of May 2nd – May 8th, Case 2 assesses plume behavior during the week of June 9th – June 15th, and Case 3 assesses plume behavior during the week of July 29th – August 4th. These three weeks were recommended by Dr. Barnthouse for analysis in order to support the biological evaluation (Reference 6.2).

In order to analyze these three cases, daily values for the variable parameters listed above were averaged across a 10 year range, for the years 2006-2015. These daily values were then averaged together over the week of interest for each case, creating an overall average for each parameter, for each case. These averages are presented in the table below. The explanations and sources for each parameter are provided in detail in Sections 2.1 to 2.6. For the variable parameters, a complete set of daily values across the 10 year range was used, with no daily values missing during the weeks of interest.

Table 1: Case-Dependent Model Parameters

Case	Dates	Effluent Flow (MGD)	Effluent Temperature (°F)	River Flow (cfs)	River Temperature (°F)	Average Wind Speed (mph)	Heat Loss Coefficient (W/m^2*C)
1	5/2 – 5/8	63.07	63.11	7,441.50	54.00	5.65	23.14
2	6/9 – 6/15	152.02	77.78	5,665.64	66.72	4.79	22.89
3	7/29 – 8/4	175.11	87.92	3,881.82	76.52	4.18	23.62

The parameters presented in the table above were calculated over a 10 year span in order to capture their history and trend, providing a historical analysis. As described in Section 1, a span of 10 years was chosen because it includes two 5-year NPDES permit renewal cycles, and coincides with the timeframe provided in the CWA §316(b) rule for biological studies to be considered recent and relevant.

2.1 Effluent Flow Rate

The daily water usage for months April through October was provided by PSNH for years 2006-2015 in Reference 6.3. These flow rates include flow for the weir (slag settling pond discharge), as well as both circulating water pumps. As described above, the sums of these three flow rates were averaged across the 10 year range to create daily values, and then these daily values were averaged again over the weeks of interest for each case to create an overall average for that case.

2.2 Effluent Temperature

The effluent temperature is taken from temperature measurements at station S0, which is located at the mouth of the discharge channel, where the discharge canal interfaces with the Merrimack River. Daily average temperature readings for this station were provided by PSNH for years 2006-2015 in Reference 6.4. As described above, these values were averaged across the 10 year range to create daily values, and then these daily values were averaged again over the weeks of interest for each case to create an overall average for that case.

2.3 River Flow Rate

The daily average Merrimack River flow rate values at Merrimack Station were provided by PSNH for years 2006-2015 in Reference 6.5. These flow values were taken upstream from the Goffs Falls United States Geological Survey (USGS) gage. These flow values were corrected by Normandeau for Merrimack Station in order to accurately reflect the flow at the plant. As described above, these values were averaged across the 10 year range to create daily values, and then these daily values were averaged again over the weeks of interest for each case to create an overall average for that case.

2.4 River Temperature

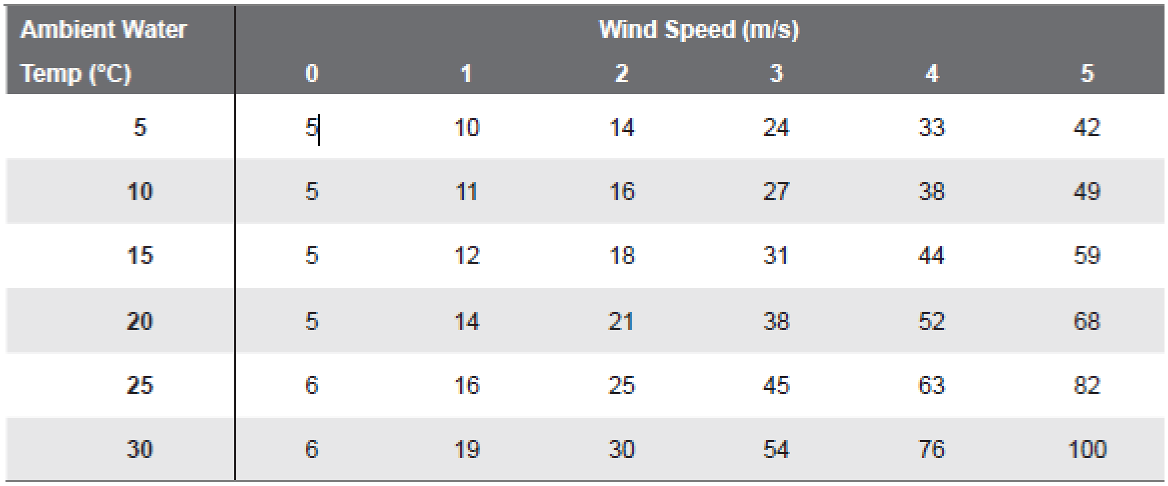
The river temperature was taken from temperature measurements at station N10, which is located upstream of the Merrimack Station intake structure and discharge canal. Daily average temperature readings for this station were provided by PSNH for years 2006-2015 in Reference 6.4. As described above, these values were averaged across the 10 year range to create daily values, and then these daily values were averaged again over the dates of interest for each case to create an overall average.

2.5 Wind Speed

Monthly averages of wind speed for years 2006-2015 were taken from Reference 6.6, which was ordered and downloaded from the National Oceanic and Atmospheric Administration (NOAA) database. These wind speed measurements were taken at Concord Municipal Airport, which is the closest location to Merrimack Station that reports quality controlled wind speeds. Compared to other variable parameters, such as effluent temperature or river flow rate, wind speed has a relatively minor impact on the CORMIX model results. Therefore, monthly averages (rather than daily averages) were utilized. These monthly averages were then averaged across the 10 year range, to create an overall average for each month. For Cases 1 and 2, the average wind speeds for May and June, respectively, were used. For Case 3 (July 29th – August 4th) the wind speeds for July and August were averaged together.

2.6 Heat Loss Coefficient

Although the heat loss coefficient is not a directly measured input parameter, it is dependent upon the river temperature and the wind speed, and is therefore considered a variable input parameter that must be calculated for each case. A table of heat loss coefficients is provided in Table 4.1 of Reference 6.1, and is reproduced below.



Ambient Water Temp (°C)	Wind Speed (m/s)					
	0	1	2	3	4	5
5	5	10	14	24	33	42
10	5	11	16	27	38	49
15	5	12	18	31	44	59
20	5	14	21	38	52	68
25	6	16	25	45	63	82
30	6	19	30	54	76	100

Figure 1: Heat Loss Coefficient (W/m^2-C) Look-up Table (Reference 6.1)

Using the river temperature and wind speed values described in Sections 2.4 and 2.5 above, the heat loss coefficient for each case is interpolated from this table.

3 Constant Model Parameters

Several model parameters required to run CORMIX remain constant for all three cases. These parameters and their values are described in this section.

In order to develop several of these constant model parameters, detailed bathymetry data of the discharge channel and the Merrimack River in the vicinity of the discharge channel was required. The raw bathymetry data in these areas of interest was provided by Normandeau in Reference 6.8. This raw data was then processed using a geographic information system (GIS) software to determine the river bed geometry of the transects of interest, such as the transect spanning across the river at the point of discharge (perpendicular to the river flow) and the transect spanning across the mouth of the discharge channel (parallel to the river flow). The geometry of these transects was then used to determine several of the model parameters as described below.

3.1 Effluent Parameters

3.1.1 Effluent Characterization

CORMIX contains the option to model several different effluent characterizations. The CORMIX effluent characterization utilized for this analysis is “Heated Discharge.” This effluent characterization was selected because the focus of this analysis is the behavior of the thermal plume. Therefore, since the primary concern is thermal, the effluent characterization of “Heated Discharge” was selected in order to model and analyze this type of plume.

3.2 Ambient Parameters

3.2.1 Average Depth

The CORMIX User's Manual states that the Average Depth parameter should be determined from the equivalent rectangular cross-sectional area at the discharge (Reference 6.1, Pages 44-45). The average depth is important for far-field transport only, with no effect on the near-field (Reference 6.7).

Bathymetry data for the Merrimack River is provided by Normandeau in Reference 6.8. The bathymetry of the transect that spans from the west river bank at the point of discharge to the east river bank was analyzed to determine the average depth (Transect #1 in Figure 2).

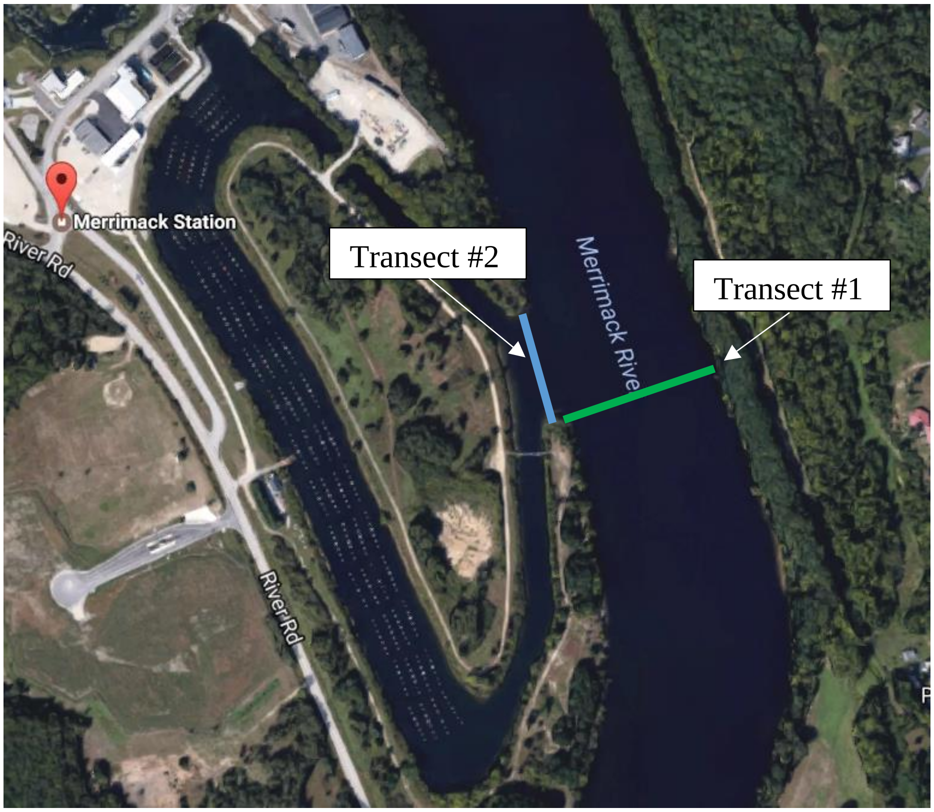


Figure 2: Bathymetry Transects[1]

This bathymetry data was used to estimate the cross-sectional area of this transect, which was then divided by the transect width to determine the average depth of 10.23 feet.

$$Average\ Depth = \frac{Transect\ Area}{Transect\ Width} = \frac{5036.00\ ft^2}{492.47\ ft} = 10.23\ ft$$

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[1] Image courtesy of Imagery ©2016 Google, Map data ©2016 Google

3.2.2 Depth at Discharge

The Depth at Discharge parameter is the local depth of the ambient water body near the effluent discharge location, and is important to the modeling of near-field mixing (Reference 6.1, Page 45). The CORMIX help menu notes that for surface discharges (which is the discharge type modeled for Merrimack Station), a depth further offshore should be specified, more or less equal to the average depth. Therefore, a prototypical depth of 11.47 feet was determined from the bathymetry of the transect spanning from the west river bank at the point of discharge to the east river bank (Transect #1 in Figure 2), and was used as the Depth at Discharge parameter.

3.2.3 River Width

The river width for a bounded ambient flow field is defined as the channel width in the vicinity of the discharge (Reference 6.7). From the bathymetry data provided in Reference 6.8, the river width at the discharge channel location is 492.47 ft.

3.2.4 River Appearance

There are three options in CORMIX to describe the river appearance. The first option, Type 1, is for fairly straight and uniform channels. Type 2 is for water bodies with a moderate downstream meander and a non-uniform channel. Type 3 is for strongly winding water bodies that have highly irregular downstream cross sections. The river appearance parameter can have an effect on the far-field mixing by increasing turbulent diffusivity, but will not significantly affect near-field mixing (Reference 6.1, Page 46).

Based on satellite images of the Merrimack River and the bathymetry data provided in Reference 6.8, Type 2 (moderate downstream meander) was chosen for the river appearance because the river does have moderate turns and relatively non-uniform cross-sections, but does not demonstrate a highly irregular geometry or depth profile.

3.2.5 Manning's Roughness Coefficient for the River

As a measure of the roughness characteristics in the channel, either the value of Manning's roughness coefficient (n) or the Darcy-Weisbach friction factor must be specified; and, for field cases it is preferable to specify Manning's roughness coefficient. The friction parameters influence the mixing process only in the final far-field diffusion stage and do not have a large impact on the predictions (Reference 6.1, Pages 45-46).

King and Brater's "Handbook of Hydraulics" provides a table of Manning's roughness coefficients for a range of different surfaces (Reference 6.9, Page 7-17). A Manning's roughness coefficient of 0.035 was selected from this table, which corresponds to the "Good" condition column for a natural stream channel that is winding with some pools and shoals and is relatively clean. The "Good" condition column was chosen for conservatism, because it has a lower Manning's roughness coefficient than the "Fair" or "Bad" columns. A lower Manning's roughness coefficient tends to decrease the speed of the diffusion process and generally tends to increase the size of the plume. This value is also within the range of Manning's roughness coefficients presented in Table 4.3 of the User's Manual (Reference 6.1).

3.3 Discharge Parameters

3.3.1 Discharge Geometry

CORMIX is capable of modeling three different types of discharge geometries: single port discharges, multiport diffuser discharges, and surface discharges. Because Merrimack Station mixes effluent into the Merrimack River via a discharge canal, rather than a discharge port flowing directly into the river, the surface discharge geometry was selected for the model.

3.3.2 Horizontal Angle of Discharge (Sigma)

The horizontal angle of discharge is the angle at which the discharge channel interacts with the ambient water body, measured counterclockwise from the ambient current direction (Reference 6.1, Page 60). Because the discharge channel flow direction is perpendicular to the Merrimack River flow, a horizontal angle of discharge of 90 degrees was chosen for the model.

3.3.3 Bottom Slope

As shown on Page 60 of the User’s Manual (Reference 6.1), the bottom slope is the slope of the receiving water body in the vicinity of the discharge channel. Based on the bathymetry data provided in Reference 6.8, the angle of the river bottom slope at the vicinity of the discharge canal was estimated to be 1.05 degrees.

3.3.4 Local Depth at Discharge Outlet

The local depth at the discharge outlet is the depth of the receiving water body in the vicinity of the discharge channel, as shown on Page 60 of the User's Manual (Reference 6.1). Based on the bathymetry data provided in Reference 6.8, the river depth at the mouth of the discharge canal is estimated to be 8.92 feet.

3.3.5 Channel Depth and Channel Width

The channel depth and channel width parameters are the depth and width of the discharge channel, which interfaces with the receiving water body. There is a limitation within the CORMIX model that the ratio of channel depth to channel width must be within the range of 0.05 to 5 (Reference 6.1, Page 61). The actual discharge channel depth and width for Merrimack Station are taken from the bathymetry data (see Transect #2 in Figure 2) provided in Reference 6.8, and are determined to be 4.92 feet and 340.30 feet, respectively. The 4.92 foot depth value is the average depth across the transect spanning the mouth of the discharge canal. However, these dimensions yield a depth-to-width ratio of 0.01, which falls outside of the range accepted by CORMIX.

In order to run the CORMIX model, the actual channel depth and width had to be adjusted to increase the ratio to above 0.05. After reviewing the bathymetry data of the transect spanning the mouth of the discharge channel, it was determined that the majority of the channel ranges between 5 feet and 6 feet deep. Therefore, the channel depth was selected to be 6 feet, with a corresponding channel width of 120 feet. This is the maximum channel width possible while still maintaining a depth to width ratio of at least 0.05. A review of the sensitivity of the results to changes in this ratio demonstrated that the plume size is insensitive to changes at the low end of the range allowed by CORMIX. Therefore, the use of these dimensions is acceptable.

3.4 Mixing Zone

3.4.1 Thermal Limits

When a heated discharge effluent characterization is modeled, the ambient "water quality standard" parameter is input into CORMIX as an allowable excess temperature over the ambient temperature. In order to calculate the allowable excess temperature over the ambient temperature, the ambient temperature is subtracted from the temperature criteria (i.e., thermal limits) for each case. The thermal limits are provided by LWB in Reference 6.2 and are shown in the table below.

Table 2: LWB-Provided Thermal Limits (Reference 6.2)

	Case 1 (May 2nd – May 8th)	Case 2 (June 9th – June 15th)	Case 3 (July 29th – August 4th)
Thermal Limit 1 (°F)	55	73	80
Thermal Limit 2 (°F)	59	77	83
Thermal Limit 3 (°F)	64	80	87
Thermal Limit 4 (°F)	N/A	N/A	89

3.4.2 Region of Interest

The region of interest is a user-defined region where mixing conditions are to be analyzed, and is specified in CORMIX as the maximum downstream distance to be analyzed (Reference 6.1, Page 62). The Hooksett Dam is approximately 3,932 meters downstream of the discharge channel. Therefore, the region of interest for the CORMIX models was set to 4,000 meters, in order to capture the mixing and plume formation in the region between the Merrimack Station discharge and the Hooksett Dam.

4 Methodology

As described in Section 2, three cases were created to model three different weeks during the 10 year period. For Case 1 and Case 2, three different temperature criteria were provided by LWB in Reference 6.2. For Case 3, four different temperature criteria were provided. Therefore, a total of 10 CORMIX models were run.

4.1 Temperature Criteria Isoline Methodology and Results

Once the CORMIX models for each of the 10 thermal limits were created, the output files were imported into CorVue, a post-processing tool built into the CORMIX software. The CorVue tool allows the plume to be visualized, enabling the user to view regulatory mixing zones and flow boundaries, as well as the near-field and far-field mixing zones. From within the CorVue post-processor, the CorPlot 2D Graphs tool was utilized. CorPlot 2D Graphs is a post-processing tool that graphs the plume formation within the region of interest, based on specified concentration criteria.

For this analysis, the CorPlot graphing tool was used to create isoline graphs of each temperature criteria for each case. An isoline graph shows the area of the river that has a concentration excess. For thermal discharge models, a concentration excess is a river temperature that is higher than the ambient temperature by a specified amount or greater. For example, a 5°F isoline would show all area of the river with a temperature that exceeds the ambient river temperature by 5°F or more. For each case that was run, CorPlot was used to generate a graph that contains isolines for each of the specified criteria based on the CORMIX model results of that case. These isoline plots are shown in Figure 3, Figure 4, and Figure 5 for Cases 1, 2, and 3, respectively.

The CORMIX software models the entire ambient river as a constant width and constant depth water body, with uniform flow throughout. Based on this, the isoline plots can be configured to show the region of the Merrimack River of interest, with the x-axis of the plot corresponding to the length of the river and the y-axis corresponding to the width of the river (which CORMIX models as constant). The x-axis and y-axis ranges for these graphs have been set to match the dimensions of the section of the Merrimack River that is of interest, from the Merrimack Station discharge down to the Hooksett Dam. For all three figures, the plot origin is the point of discharge and the maximum x-axis value (3,933 meters) represents the Hooksett Dam. Additionally, the minimum and maximum y-axis values represent the west and east banks of the river, respectively, as they are modeled in CORMIX.

For Cases 1 and 2, the effluent discharge temperature was below the third provided thermal limit, and so the modeled temperature of the plume did not exceed the third thermal limit at any point in the river. Likewise for Case 3, the effluent discharge temperature was below the fourth provided thermal limit, and so the modeled temperature of the plume did not exceed the fourth thermal limit at any point. Therefore, there are no isolines for these thermal limits.

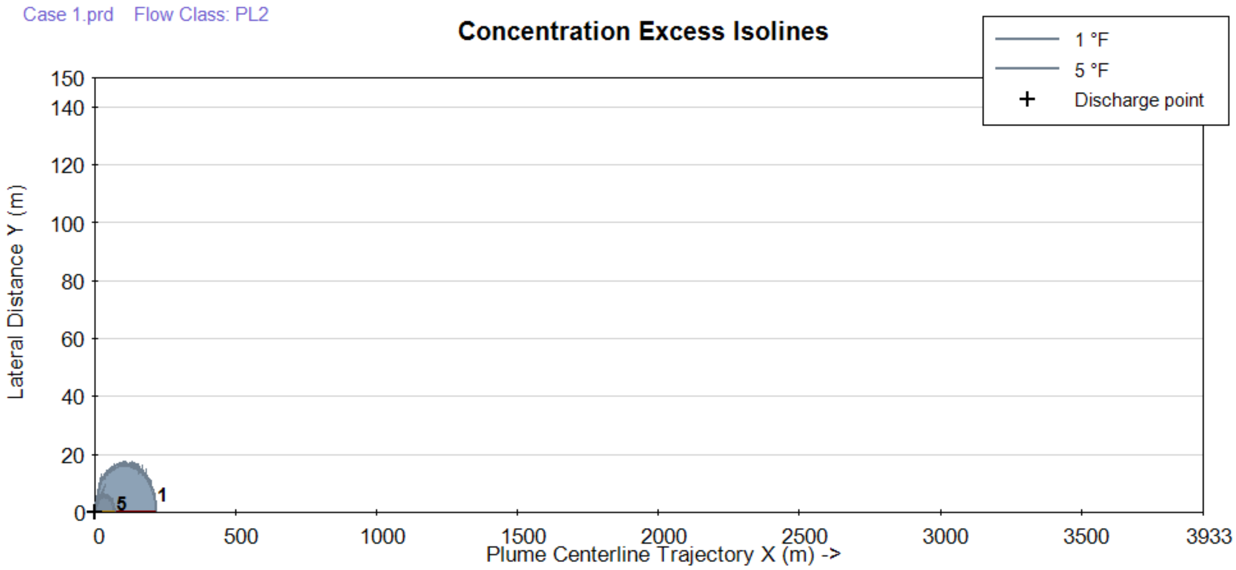

Figure 3: Temperature Isolines for Case 1 (1°F excess corresponds to 55°F, 5°F excess corresponds to 59°F)

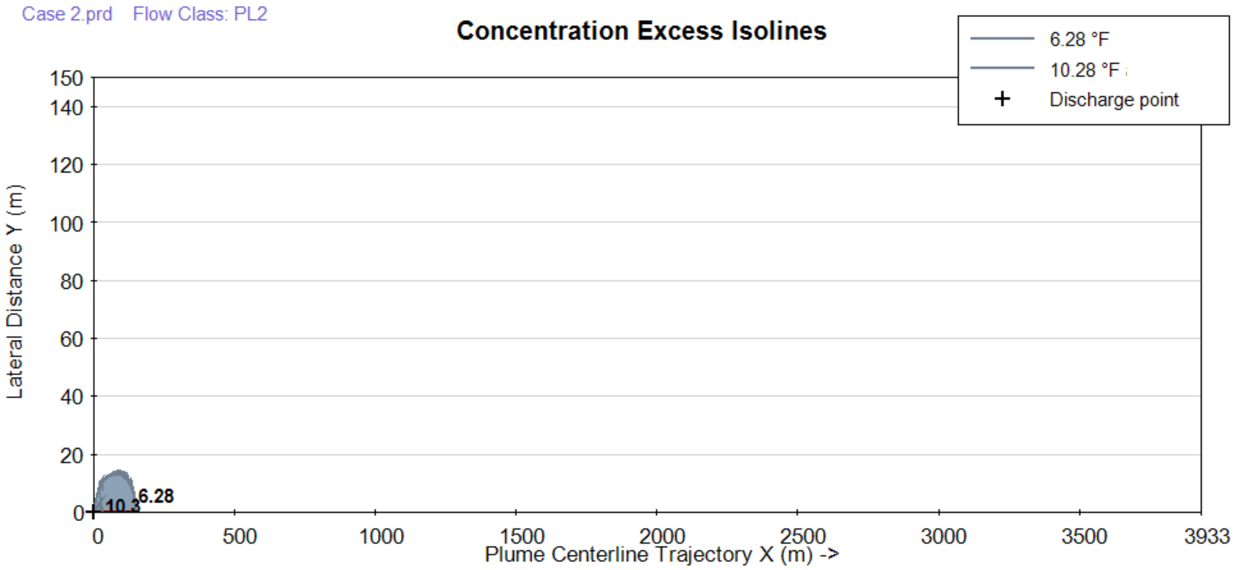

Figure 4: Temperature Isolines for Case 2 (6.28°F excess corresponds to 73°F, 10.28°F excess corresponds to 77°F)

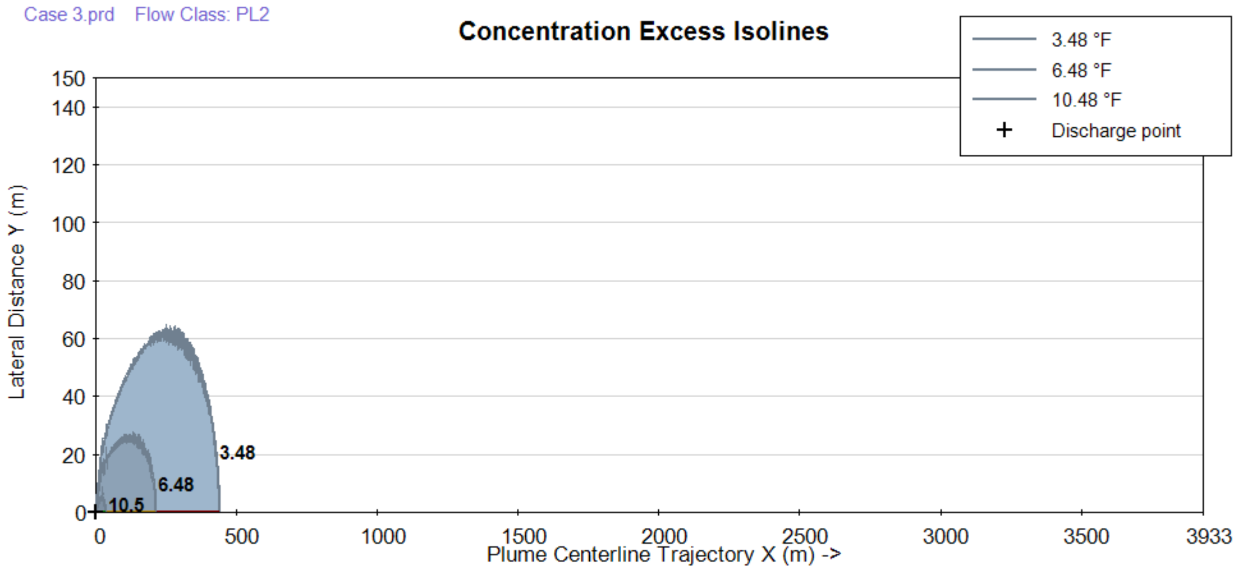

Figure 5: Temperature Isolines for Case 3 (3.48°F excess corresponds 80°F, 6.48°F excess corresponds to 83°F, 10.48°F corresponds to 87°F)

4.2 Plume Analysis Methodology

The isoline figures provide visual representation of the plume size and general shape at the surface of the river for each temperature criteria of all three cases. In order to analyze these plumes quantitatively, the x-y data used to generate each of the isoline plots was exported for each temperature criteria. This data provides the set of corresponding x and y coordinates showing the boundary of the plume for each case. For all models, the plume was attached to the right (when facing downstream) bank. Therefore, the y-coordinate of the plume edge also serves as the width of the plume. This x-y data was then combined with the raw data from the prediction file of each CORMIX run and was processed to analyze the total surface area of the plume, average plume thickness, and estimated volume of the plume. The methodologies for these calculations are described in the sections below.

4.2.1 Plume Surface Area

To analyze the surface area of the plume for each case and temperature criteria, the x-y data output from the isoline plot was numerically integrated. For each x-coordinate interval, the incremental area of the plume was estimated by applying the trapezoidal rule to the x and y coordinate values. To illustrate this process, the first two data points from the 55°F temperature criteria for Case 1 are shown below, and the area of the plume for the first interval is calculated.

Table 3: Plume X-Y Coordinate Data

Plume X-Coordinate (m)	Plume Y-Coordinate (m)
0.00	1.3675
18.29	10.4345

$$Plume\ Area = (X_2 - X_1) * \left(\frac{Y_2 + Y_1}{2}\right)$$

$$Plume\ Area = (18.29\ m - 0.00\ m) * \left(\frac{10.4345\ m + 1.3675\ m}{2}\right) = 107.93\ m^2$$

The above calculation was performed for every x-coordinate interval where a plume was present, and all of the incremental areas were summed to estimate a total surface area of the plume. In order to assess the relative size of the plume surface area, this area was then compared to the total river surface area to calculate the percentage of the total surface area covered by the plume.

This comparison was made for the portion of the plume and river surface areas between S0 and S24 (the Hooksett Dam). S24 is estimated to be located 3,932 meters downstream of the discharge. For this comparison, the river surface area between S0 and S24 was calculated assuming a constant river width of 492.5 feet. A constant width was assumed because CORMIX models the receiving water body with a constant width, using the River Width parameter (Section 3.2.3), and does not have the capability to provide the outputs required when considering a receiving water body of varying dimensions. Although the actual Merrimack River has varying widths between the discharge and the Hooksett Dam, assuming a constant width is required for comparing the plume and river surface areas because the predicted plume was generated by CORMIX assuming a constant river width.

4.2.2 Average Plume Thickness

The prediction file created for each CORMIX model run provides a plume thickness value for each x-coordinate that is analyzed within the region of interest. The reported plume thickness value (BV) can represent different dimensions based on the type of mixing that CORMIX is currently using. These models are selected automatically by the CORMIX software based on ambient and discharge flow conditions and geometry. For all 10 models, only two types of mixing models were used by CORMIX. The first portion of the plume is modeled via buoyant spreading along the water surface. Once the plume has mixed to an appropriate level using the buoyant spreading model, CORMIX switches and models the remainder of the plume using the ambient diffusion process. The exact location downstream where this model switch occurs varies for all 10 models. The dimensions that are reported for the plume thickness values during each of these mixing phases are shown in the figure below.

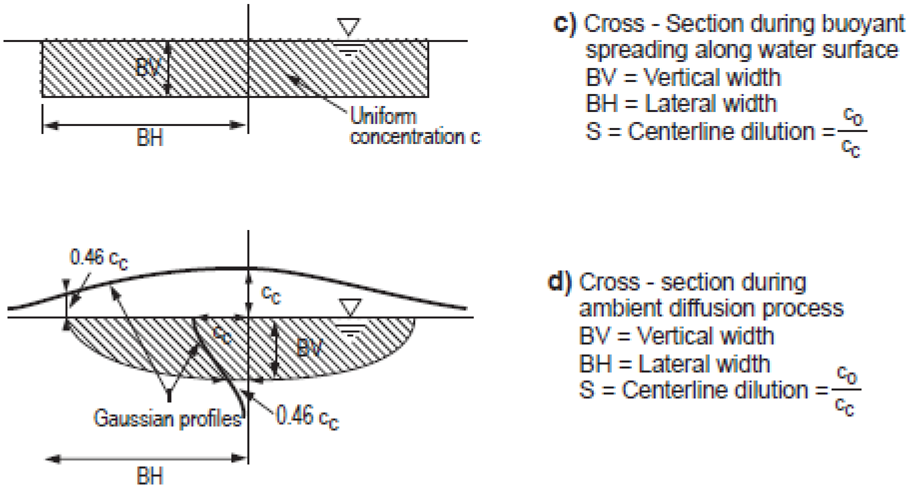

Figure 6: Cross-sections of CORMIX Predicted Plumes (Reference 6.1, Page 78)

Additionally, the thermal plume results presented by CORMIX have a constant temperature in the vertical direction throughout the entirety of the plume for any given x-coordinate. In other words, no temperature gradient is provided for the plume in the z-direction. This is an approximation and does not ideally model the expected vertical temperature profile. CORMIX presents the thickness results in this way because it is limited to two dimensional analyses. CORMIX extrapolates the two-dimensional temperature profile in the z-direction to produce the plume thickness results.

Plume thickness values are provided for every x-coordinate point without consideration of the temperature criteria defined by the user. As a result of this, a plume thickness value is reported even after the temperature criteria has been met and a thermal plume is no longer present. Therefore, in order to estimate the average thickness of the entire plume for each case and temperature criteria, the average plume thickness values in the prediction file are combined with the x-y coordinate data from the isoline plots in order to truncate the average thickness calculation when a thermal plume is no longer present.

All x-coordinates for which the temperature criteria is exceeded and a plume exists are shown in the isoline x-y coordinate data by the presence of a y-coordinate that is greater than zero. Therefore, for every x-coordinate interval where a plume is present (as determined by the y-coordinate value) the plume thickness value for the same x-coordinate interval is taken from the prediction file and weighted based on the size of the interval. This weighting is done by using the trapezoidal rule to calculate the area of the plume in the xz-plane, based on the x-interval length and plume thickness (or plume depth in the z-direction). This xz-plane area is the area of the plume as viewed in a cross-section taken through the center of the river along the downstream axis of the river. To illustrate this process, the first two data points from the 55°F temperature criteria for Case 1 are shown below, and the plume area in the xz-plane for the first interval is calculated.

Table 4: Plume X-Coordinate and Thickness Data

Plume X-Coordinate (m)	Plume Thickness (m)
0.00	0.92
18.29	0.87

$$Plume\ Area\ (XZ\ Plane) = (X_2 - X_1) * \left(\frac{T_2 + T_1}{2}\right)$$

$$Plume\ Area\ (XZ\ Plane) = (18.29\ m - 0.00\ m) * \left(\frac{0.92\ m + 0.87\ m}{2}\right) = 16.37\ m^2$$

The plume area in the xz-plane was calculated for each x-coordinate interval where a plume was present. These areas were then summed together and divided by the total x-coordinate distance where a plume was present to estimate the average plume thickness throughout the length of the plume.

4.2.3 Plume Volume

In order to assess the overall volume of the plume, the plume thickness for each x-coordinate interval (described in Section 4.2.2) was numerically integrated across the surface areas for each x-coordinate interval (described in Section 4.2.1) using the trapezoidal rule. To illustrate this process, the first two data points from the 55°F temperature criteria for Case 1 are shown below, and the volume of the plume for the first interval is calculated.

Table 5: Plume X-Coordinate, Interval Area, and Thickness Data

Plume X-Coordinate (m)	Interval Area (m^2)	Plume Thickness (m)
0.00	107.93	0.92
18.29	0.52	0.86

For the first x-coordinate interval, because there is no preceding interval, the trapezoidal rule cannot be used and the estimated plume volume is conservatively calculated using a constant plume thickness for the entire length of the interval as shown below. This method is conservative because assuming a constant plume thickness for the entire interval (rather than assuming the plume thickness starts at zero and increases) will result in a slight overestimation of the plume volume. However, because this methodology is only used for the first interval, the slight overestimation does not have a significant impact on the total results.

$$Estimated\ Plume\ Volume = Interval\ Surface\ Area * Plume\ Thickness$$

$$Estimated\ Plume\ Volume = (107.93\ m^2) * (0.92\ m) = 99.29\ m^3$$

For all following intervals, the trapezoidal rule is used to estimate the plume volume, as shown below.

$$Estimated\ Plume\ Volume = (Surface\ Area) * \left(\frac{T_2 + T_1}{2}\right)$$

$$Estimated\ Plume\ Volume = (0.52\ m^2) * \left(\frac{0.86\ m + 0.92\ m}{2}\right) = 0.46\ m^3$$

This calculation was performed for every x-coordinate interval evaluated in the model, and the calculated incremental volumes were summed up to estimate the total volume of the plume. In order to assess the relative size of the plume volume, it was then compared to the total river volume to calculate a percentage of the total river volume encompassed by the thermal plume.

For this comparison, the river surface area and volume between S0 and S24 were calculated assuming a constant river width and depth of 492.5 feet and 10.23 feet, respectively. This was done because CORMIX models the receiving water body with a constant width and constant depth, using the Average Depth and River Width parameters (Sections 3.2.1 and 3.2.3). Although the actual Merrimack River has varying width and depth values, assuming a constant width and depth is required for comparing the plume surface area and volume because the predicted plume was generated by CORMIX assuming a constant river width and depth.

The CORMIX prediction file provides one plume thickness value for each x-coordinate evaluated, even though it is expected that the plume thickness will vary in the y-direction (i.e., across the width of the river). When estimating the plume volume, the provided thickness value was conservatively assumed to be the plume thickness across the entire width. Although this assumption is conservative, it does introduce uncertainty into the estimated plume volume results. Additionally, as described in Section 4.2.2, CORMIX presents the plume thickness results with no temperature gradient provided in the z-direction. Because of this, the entire plume thickness must be assumed to be above the given thermal limit when estimating the plume volume. This is a limitation of the two-dimensional CORMIX model, but results in a conservative plume volume because it is not likely that the entirety of the actual plume thickness would exceed the given thermal limit. The temperature of the actual plume decreases in the z-direction (deeper into the river) as it comes into equilibrium with the ambient river temperature at lower depths. If a portion of the actual plume thickness is below the thermal limit, then volume of the actual plume that exceeds the thermal limit would be smaller than the results presented in this report indicate.

Although it is expected that using this methodology will conservatively overestimate the volume of the plume, it is still considered appropriate for use as a screening tool to determine if any cases require further evaluation.

5 Results

As described in Section 4, a total of 10 different case and temperature criteria combinations were modeled in CORMIX using the parameters described in Sections 2 and 3. The results of these 10 models were processed according to the methodology outlined in Section 4, and are presented below. The CORMIX session reports are provided in Attachment 1 for Case 1, Attachment 2 for Case 2, and Attachment 3 for Case 3.

It should be noted that all figures and numerical results (i.e. surface area percentages and volume percentages) presented in the sections below consider only the portion of the Hooksett Pool that extends from the Merrimack Station discharge downstream to the Hooksett Dam. As described by Normandeau, this portion of the river makes up approximately half of the total Hooksett Pool, with the other half extending from the Merrimack Station discharge upstream to the Garvins Falls Dam (Reference 6.12, Page 1). The half of the Hooksett Pool that is upstream of Merrimack Station is not considered when processing the thermal plume size results. If the upstream half of the Hooksett Pool was considered, it would be expected that the surface area and volume percentages would decrease by approximately half, because the thermal plume would not be present upstream of the Merrimack Station discharge.

Following the methodology described in the above sections, the plume surface area, average thickness, and estimated volume values are calculated for each case and temperature criteria. The results of this analysis are presented in the tables below. Note that for convenience, the plume surface area and volume results are presented as percentages of the total river surface area and volume values.

As described earlier, for Cases 1 and 2, the modeled temperature of the plume did not exceed the third thermal limit at any point in the river. Likewise for Case 3, the modeled temperature of the plume did not exceed the fourth thermal limit at any point in the river. Therefore, no surface area or volume results are presented for these thermal limits.

Table 6: Results for Case 1 (May 2nd – May 8th) (2006 – 2015)

Thermal Limit (°F)	% of River Area Covered by Plume between S0 and S24	Estimated Average Plume Thickness (ft)	% of River Volume Encompassed by Plume between S0 and S24
55	0.48%	4.24	0.19%
59	0.05%	2.80	0.01%
64	-	-	-

Table 7: Results for Case 2 (June 9th – June 15th) (2006 – 2015)

Thermal Limit (°F)	% of River Area Covered by Plume between S0 and S24	Estimated Average Plume Thickness (ft)	% of River Volume Encompassed by Plume between S0 and S24
73	0.27%	3.67	0.09%
77	0.01%	5.37	0.01%
80	-	-	-

Table 8: Results for Case 3 (July 29th – August 4th) (2006 – 2015)

Thermal Limit (°F)	% of River Area Covered by Plume between S0 and S24	Estimated Average Plume Thickness (ft)	% of River Volume Encompassed by Plume between S0 and S24
80	3.47%	2.80	0.88%
83	0.72%	3.21	0.21%
87	0.02%	5.36	0.01%
89	-	-	-

The results above are based on CORMIX models that use operational data that is averaged over the last 10 years, producing a historical assessment of plume formation rather than an assessment of a specific year or week. Several of the model inputs, such as determining the appropriate Manning's roughness coefficient, were selected using reasonable engineering judgement. Values were selected that were conservative (i.e., would have a tendency to overestimate the plume size), yet still accurately reflect the actual plant and river conditions.

This thermal plume analysis of the Merrimack River was performed utilizing the EPA-approved CORMIX software. This analysis is provided for use as a screening tool to determine if any of the evaluated scenarios require further evaluation. These 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 (Reference 6.2).

6 References

6.1 CORMIX User Manual, "A Hydrodynamic Mixing Zone Model and Decision Support System for Pollutant Discharges into Surface Waters."

6.2 "Influence of Merrimack Station's Thermal Plume on Habitat Utilization by Fish Species Present in Lower Hooksett Pool," LWB Environmental Services, Inc.

6.3 Merrimack Station Daily Water Usage Data spreadsheets, provided by PSNH on 10/3/16.

6.4 Merrimack Station Daily N10 and S0 Temperature Data spreadsheet, provided by PSNH on 11/17/16.

6.5 Daily Merrimack River Flow at Merrimack Station spreadsheet, provided by PSNH on 9/30/16.

6.6 "2006 through 2015 Monthly Average Wind Speed Data for Concord Municipal Airport, NH US", NOAA Database Order ID #860567.

6.7 CORMIX v10.0GT Help Menu.

6.8 Merrimack River Bathymetry Data, provided by Normandeau Associates, Inc. on 10/5/16.

6.9 "Handbook of Hydraulics for the Solution of Hydrostatic and Fluid-flow Problems," Horace Williams King and Ernest F. Brater, Fifth Edition.

6.10 "U.S. Environmental Protection Agency NPDES Permit Writers' Manual," Office of Wastewater Management, Water Permits Division, State and Regional Branch, September 2010.

6.11 "Annual Report on Scientific Integrity," United States Environmental Protection Agency, November 2013.

6.12 "Proposal for Information Collection to Address Compliance with the Clean Water Act § 316(b) Phase II Regulations at Merrimack Station, Bow, New Hampshire," Prepared by Normandeau Associates, Inc., April 2005.

6.13 Comments of Public Service Company of New Hampshire on EPA's Revised Draft National Pollutant Discharge Elimination System Permit No. NH 0001465. Submitted to the U.S. Environmental Protection Agency August 18, 2014.

6.14 Clean Water Act Section 316(b) Final Rule (79 FR 48300, August 15, 2014).

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXX
                      CORMIX MIXING ZONE EXPERT SYSTEM
                          CORMIX Version 10.0GT
                       HYDRO3:Version-10.0.0.0  July,2016
SITE NAME/LABEL:                Merrimack
  DESIGN CASE:                  Case 1 - Criteria 1
  FILE NAME:
\\nt2katl14\mdrive\Projects\PSNH\PSNH013 - Merrimack NPDES
Support\10.0 Working\Criteria 1\Case 1 - Criteria 1.prd
  Using subsystem CORMIX3:     Buoyant Surface Discharges
  Start of session:             12/21/2016--11:31:45
**********************************************************************
*******
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
-------
AMBIENT PARAMETERS:
  Cross-section                          = bounded
  Width                           BS     = 150.11 m
  Channel regularity              ICHREG = 2
  Ambient flowrate                QA     = 210.72 m^3/s
  Average depth                   HA     = 3.12 m
  Depth at discharge              HD     = 3.50 m
  Ambient velocity                UA     = 0.4502 m/s
  Darcy-Weisbach friction factor  F      = 0.0658
    Calculated from Manning's n          = 0.035
  Wind velocity                   UW     = 2.53 m/s
  Stratification Type             STRCND = U
  Surface temperature                    = 12.22 degC
  Bottom temperature                     = 12.22 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                 RHOAS  = 999.4737 kg/m^3
  Bottom density                  RHOAB  = 999.4737 kg/m^3
----------------------------------------------------------------------
-------
DISCHARGE PARAMETERS:             Surface Discharge
  Discharge located on                   = right bank/shoreline
  Discharge configuration                = flush discharge
  Distance from bank to outlet    DISTB  = 0 m
  Discharge angle                 SIGMA  = 90 deg
  Depth near discharge outlet     HD0    = 2.72 m
  Bottom slope at discharge       SLOPE  = 1.05 deg
  Rectangular discharge:
    Discharge cross-section area  A0     = 66.890189 m^2
    Discharge channel width       B0     = 36.576000 m
    Discharge channel depth       H0     = 1.8288 m
    Discharge aspect ratio        AR     = 0.05
  Reduced discharge channel due to intrusion:
```

```
    Cross-section area            A0     = 33.6454 m^2
    Channel width                 B0     = 36.5760 m
    Channel depth                 H0     = 0.92 m
    Aspect ratio                  AR     = 0.03
  Discharge flowrate              Q0     = 2.763263 m^3/s
  Discharge velocity              U0     = 0.08 m/s
  Discharge temperature (freshwater)     = 17.28 degC
  Corresponding density           RHO0   = 998.7264 kg/m^3
  Density difference              DRHO   = 0.7473 kg/m^3
  Buoyant acceleration            GP0    = 0.0073 m/s^2
  Discharge concentration         C0     = 9.110000 deg.F
  Surface heat exchange coeff.    KS     = 0.000006 m/s
  Coefficient of decay            KD     = 0 /s
----------------------------------------------------------------------
-------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  = 5.80 m         Lm  = 1.06 m         Lbb = 0.22 m
  LM  = 2.31 m
----------------------------------------------------------------------
-------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number       FR0    = 0.40 (based on LQ)
  Channel densimetric Froude no.  FRCH   = 1 (based on H0)
  Velocity ratio                  R      = 0.18
----------------------------------------------------------------------
-------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = no
  Water quality standard specified       = yes
  Water quality standard          CSTD   = 1 deg.F
  Regulatory mixing zone                 = no
  Region of interest                     = 4000 m downstream
**********************************************************************
*******
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   = PL2 |
  *------------------------*

  Limiting Dilution S = (QA/Q0)+ 1.0 = 77.3

**********************************************************************
*******
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

----------------------------------------------------------------------
-------
X-Y-Z Coordinate system:
Origin is located at WATER SURFACE and at centerline of discharge
channel:
```

```
    0 m from the right bank/shore.
  Number of display steps NSTEP = 5000 per module.
----------------------------------------------------------------------
-------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no
regulatory
  implication.  However, this information may be useful for the
discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at NFR edge  c = 9.110000 deg.F
  Dilution at edge of NFR              s = 1
  NFR Location:                        x = 18.29 m
    (centerline coordinates)           y = 0.99 m
                                       z = 0 m
  NFR plume dimensions:  half-width (bh) = 7.07 m
                          thickness (bv) = 0.87 m
Cumulative travel time:       40.6231 sec.
----------------------------------------------------------------------
-------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise
towards
  the surface.
----------------------------------------------------------------------
-------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at 272.31 m downstream.
----------------------------------------------------------------------
-------
PLUME BANK CONTACT SUMMARY:
  Plume in bounded section contacts one bank only at 0 m downstream.
************************ TOXIC DILUTION ZONE SUMMARY
************************
No TDZ was specified for this simulation.
*********************** REGULATORY MIXING ZONE SUMMARY
***********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered at the following
  plume position:
  Water quality standard                 = 1  deg.F
  Corresponding dilution               s = 9.1
  Plume location:                      x = 217.34 m
    (centerline coordinates)           y = 0 m
                                       z = 0 m
  Plume dimensions:      half-width (bh) = 23.74 m
```

```
                          thickness (bv) = 2.32 m
********************* FINAL DESIGN ADVICE AND COMMENTS
**********************

INTRUSION OF AMBIENT WATER into the discharge opening will occur!

For the present discharge/environment conditions the discharge
densimetric Froude number is well below unity. This is an UNDESIRABLE
operating condition.

To prevent intrusion, change the discharge parameters (e.g. decrease
the discharge opening area) in order to increase the discharge Froude
number.

In a future iteration, change the discharge parameters (e.g. decrease
port diameter) in order to increase the Froude number.
---------------------------------------------------------------------------
-------
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any
known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are
accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it
judges
  the design configuration as highly complex and uncertain for
prediction.
```

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXX
                      CORMIX MIXING ZONE EXPERT SYSTEM
                          CORMIX Version 10.0GT
                       HYDRO3:Version-10.0.0.0  July,2016
SITE NAME/LABEL:                Merrimack
  DESIGN CASE:                  Case 1 - Criteria 2
  FILE NAME:
\\nt2katl14\mdrive\Projects\PSNH\PSNH013 - Merrimack NPDES
Support\10.0 Working\Criteria 2\Case 1 - Criteria 2.prd
  Using subsystem CORMIX3:     Buoyant Surface Discharges
  Start of session:             12/21/2016--11:32:26
**********************************************************************
*******
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
-------
AMBIENT PARAMETERS:
  Cross-section                            = bounded
  Width                           BS       = 150.11 m
  Channel regularity              ICHREG = 2
  Ambient flowrate                QA       = 210.72 m^3/s
  Average depth                   HA       = 3.12 m
  Depth at discharge              HD       = 3.50 m
  Ambient velocity                UA       = 0.4502 m/s
  Darcy-Weisbach friction factor  F        = 0.0658
    Calculated from Manning's n            = 0.035
  Wind velocity                   UW       = 2.53 m/s
  Stratification Type             STRCND = U
  Surface temperature                      = 12.22 degC
  Bottom temperature                       = 12.22 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                 RHOAS  = 999.4737 kg/m^3
  Bottom density                  RHOAB  = 999.4737 kg/m^3
----------------------------------------------------------------------
-------
DISCHARGE PARAMETERS:             Surface Discharge
  Discharge located on                     = right bank/shoreline
  Discharge configuration                  = flush discharge
  Distance from bank to outlet    DISTB  = 0 m
  Discharge angle                 SIGMA  = 90 deg
  Depth near discharge outlet     HD0      = 2.72 m
  Bottom slope at discharge       SLOPE  = 1.05 deg
  Rectangular discharge:
    Discharge cross-section area  A0       = 66.890189 m^2
    Discharge channel width       B0       = 36.576000 m
    Discharge channel depth       H0       = 1.8288 m
    Discharge aspect ratio        AR       = 0.05
  Reduced discharge channel due to intrusion:
```

```
    Cross-section area            A0     = 33.6454 m^2
    Channel width                 B0     = 36.5760 m
    Channel depth                 H0     = 0.92 m
    Aspect ratio                  AR     = 0.03
  Discharge flowrate              Q0     = 2.763263 m^3/s
  Discharge velocity              U0     = 0.08 m/s
  Discharge temperature (freshwater)     = 17.28 degC
  Corresponding density           RHO0   = 998.7264 kg/m^3
  Density difference              DRHO   = 0.7473 kg/m^3
  Buoyant acceleration            GP0    = 0.0073 m/s^2
  Discharge concentration         C0     = 9.110000 deg.F
  Surface heat exchange coeff.    KS     = 0.000006 m/s
  Coefficient of decay            KD     = 0 /s
----------------------------------------------------------------------
-------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  = 5.80 m         Lm  = 1.06 m         Lbb = 0.22 m
  LM  = 2.31 m
----------------------------------------------------------------------
-------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number       FR0    = 0.40 (based on LQ)
  Channel densimetric Froude no.  FRCH   = 1 (based on H0)
  Velocity ratio                  R      = 0.18
----------------------------------------------------------------------
-------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = no
  Water quality standard specified       = yes
  Water quality standard          CSTD   = 5 deg.F
  Regulatory mixing zone                 = no
  Region of interest                     = 4000 m downstream
**********************************************************************
*******
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   = PL2 |
  *------------------------*

  Limiting Dilution S = (QA/Q0)+ 1.0 = 77.3

**********************************************************************
*******
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

----------------------------------------------------------------------
-------
X-Y-Z Coordinate system:
Origin is located at WATER SURFACE and at centerline of discharge
channel:
```

```
    0 m from the right bank/shore.
  Number of display steps NSTEP = 5000 per module.
----------------------------------------------------------------------
-------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no
regulatory
  implication.  However, this information may be useful for the
discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at NFR edge  c = 9.110000 deg.F
  Dilution at edge of NFR              s = 1
  NFR Location:                        x = 18.29 m
    (centerline coordinates)           y = 0.99 m
                                       z = 0 m
  NFR plume dimensions:  half-width (bh) = 7.07 m
                          thickness (bv) = 0.87 m
Cumulative travel time:       40.6231 sec.
----------------------------------------------------------------------
-------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise
towards
  the surface.
----------------------------------------------------------------------
-------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at 272.31 m downstream.
----------------------------------------------------------------------
-------
PLUME BANK CONTACT SUMMARY:
  Plume in bounded section contacts one bank only at 0 m downstream.
************************ TOXIC DILUTION ZONE SUMMARY
************************
No TDZ was specified for this simulation.
********************** REGULATORY MIXING ZONE SUMMARY
**********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered at the following
  plume position:
  Water quality standard                 = 5  deg.F
  Corresponding dilution               s = 1.8
  Plume location:                      x = 68.97 m
    (centerline coordinates)           y = 0 m
                                       z = 0 m
  Plume dimensions:      half-width (bh) = 12.34 m
```

```
                          thickness (bv) = 0.89 m
********************* FINAL DESIGN ADVICE AND COMMENTS
**********************

INTRUSION OF AMBIENT WATER into the discharge opening will occur!

For the present discharge/environment conditions the discharge
densimetric Froude number is well below unity. This is an UNDESIRABLE
operating condition.

To prevent intrusion, change the discharge parameters (e.g. decrease
the discharge opening area) in order to increase the discharge Froude
number.

In a future iteration, change the discharge parameters (e.g. decrease
port diameter) in order to increase the Froude number.
----------------------------------------------------------------------
-------
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any
known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are
accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it
judges
  the design configuration as highly complex and uncertain for
prediction.
```

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXX
                      CORMIX MIXING ZONE EXPERT SYSTEM
                          CORMIX Version 10.0GT
                       HYDRO3:Version-10.0.0.0  July,2016
SITE NAME/LABEL:                Merrimack
  DESIGN CASE:                  Case 1 - Criteria 3
  FILE NAME:
\\nt2katl14\mdrive\Projects\PSNH\PSNH013 - Merrimack NPDES
Support\10.0 Working\Criteria 3\Case 1 - Criteria 3.prd
  Using subsystem CORMIX3:     Buoyant Surface Discharges
  Start of session:             12/21/2016--11:33:08
**********************************************************************
*******
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
-------
AMBIENT PARAMETERS:
  Cross-section                           = bounded
  Width                           BS      = 150.11 m
  Channel regularity              ICHREG  = 2
  Ambient flowrate                QA      = 210.72 m^3/s
  Average depth                   HA      = 3.12 m
  Depth at discharge              HD      = 3.50 m
  Ambient velocity                UA      = 0.4502 m/s
  Darcy-Weisbach friction factor  F       = 0.0658
    Calculated from Manning's n           = 0.035
  Wind velocity                   UW      = 2.53 m/s
  Stratification Type             STRCND  = U
  Surface temperature                     = 12.22 degC
  Bottom temperature                      = 12.22 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                 RHOAS   = 999.4737 kg/m^3
  Bottom density                  RHOAB   = 999.4737 kg/m^3
----------------------------------------------------------------------
-------
DISCHARGE PARAMETERS:             Surface Discharge
  Discharge located on                    = right bank/shoreline
  Discharge configuration                 = flush discharge
  Distance from bank to outlet    DISTB   = 0 m
  Discharge angle                 SIGMA   = 90 deg
  Depth near discharge outlet     HD0     = 2.72 m
  Bottom slope at discharge       SLOPE   = 1.05 deg
  Rectangular discharge:
    Discharge cross-section area  A0      = 66.890189 m^2
    Discharge channel width       B0      = 36.576000 m
    Discharge channel depth       H0      = 1.8288 m
    Discharge aspect ratio        AR      = 0.05
  Reduced discharge channel due to intrusion:
```

```
    Cross-section area            A0     = 33.6454 m^2
    Channel width                 B0     = 36.5760 m
    Channel depth                 H0     = 0.92 m
    Aspect ratio                  AR     = 0.03
  Discharge flowrate              Q0     = 2.763263 m^3/s
  Discharge velocity              U0     = 0.08 m/s
  Discharge temperature (freshwater)     = 17.28 degC
  Corresponding density           RHO0   = 998.7264 kg/m^3
  Density difference              DRHO   = 0.7473 kg/m^3
  Buoyant acceleration            GP0    = 0.0073 m/s^2
  Discharge concentration         C0     = 9.110000 deg.F
  Surface heat exchange coeff.    KS     = 0.000006 m/s
  Coefficient of decay            KD     = 0 /s
----------------------------------------------------------------------
-------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  = 5.80 m         Lm  = 1.06 m         Lbb = 0.22 m
  LM  = 2.31 m
----------------------------------------------------------------------
-------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number       FR0    = 0.40 (based on LQ)
  Channel densimetric Froude no.  FRCH   = 1 (based on H0)
  Velocity ratio                  R      = 0.18
----------------------------------------------------------------------
-------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = no
  Water quality standard specified       = yes
  Water quality standard          CSTD   = 10 deg.F
  Regulatory mixing zone                 = no
  Region of interest                     = 4000 m downstream
**********************************************************************
*******
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   = PL2 |
  *------------------------*

  Limiting Dilution S = (QA/Q0)+ 1.0 = 77.3

**********************************************************************
*******
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

----------------------------------------------------------------------
-------
X-Y-Z Coordinate system:
Origin is located at WATER SURFACE and at centerline of discharge
channel:
```

```
    0 m from the right bank/shore.
  Number of display steps NSTEP = 5000 per module.
----------------------------------------------------------------------
-------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no
regulatory
  implication.  However, this information may be useful for the
discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at NFR edge  c = 9.110000 deg.F
  Dilution at edge of NFR              s = 1
  NFR Location:                        x = 18.29 m
    (centerline coordinates)           y = 0.99 m
                                       z = 0 m
  NFR plume dimensions:  half-width (bh) = 7.07 m
                          thickness (bv) = 0.87 m
Cumulative travel time:       40.6231 sec.
----------------------------------------------------------------------
-------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise
towards
  the surface.
----------------------------------------------------------------------
-------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at 272.31 m downstream.
----------------------------------------------------------------------
-------
PLUME BANK CONTACT SUMMARY:
  Plume in bounded section contacts one bank only at 0 m downstream.
************************ TOXIC DILUTION ZONE SUMMARY
************************
No TDZ was specified for this simulation.
********************** REGULATORY MIXING ZONE SUMMARY
**********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered within a control
  volume describing a portion of the discharge plume.
Therefore, the following plume conditions are a conservative estimate
(with
  lower concentrations or with larger dimensions) for the region at
whose
  boundary the standard is met:
  Local boundary concentration          = 9.110000  deg.F
```

```
Corresponding dilution                    = 1
  Water quality standard                  = 10  deg.F
  Corresponding dilution                s = 1
  Plume location:                       x = 18.29 m
    (centerline coordinates)            y = 0.99 m
                                        z = 0 m
  Plume dimensions:      half-width (bh) = 7.07 m
                          thickness (bv) = 0.87 m
********************* FINAL DESIGN ADVICE AND COMMENTS
**********************

INTRUSION OF AMBIENT WATER into the discharge opening will occur!

For the present discharge/environment conditions the discharge
densimetric Froude number is well below unity. This is an UNDESIRABLE
operating condition.

To prevent intrusion, change the discharge parameters (e.g. decrease
the discharge opening area) in order to increase the discharge Froude
number.

In a future iteration, change the discharge parameters (e.g. decrease
port diameter) in order to increase the Froude number.
----------------------------------------------------------------------
-------
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any
known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are
accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it
judges
  the design configuration as highly complex and uncertain for
prediction.
```

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXX
                      CORMIX MIXING ZONE EXPERT SYSTEM
                          CORMIX Version 10.0GT
                       HYDRO3:Version-10.0.0.0  July,2016
SITE NAME/LABEL:                Merrimack
  DESIGN CASE:                  Case 2 - Criteria 1
  FILE NAME:
\\nt2katl14\mdrive\Projects\PSNH\PSNH013 - Merrimack NPDES
Support\10.0 Working\Criteria 1\Case 2 - Criteria 1.prd
  Using subsystem CORMIX3:     Buoyant Surface Discharges
  Start of session:             12/21/2016--11:32:00
**********************************************************************
*******
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
-------
AMBIENT PARAMETERS:
  Cross-section                             = bounded
  Width                           BS        = 150.11 m
  Channel regularity              ICHREG = 2
  Ambient flowrate                QA        = 160.43 m^3/s
  Average depth                   HA        = 3.12 m
  Depth at discharge              HD        = 3.50 m
  Ambient velocity                UA        = 0.3428 m/s
  Darcy-Weisbach friction factor  F         = 0.0658
    Calculated from Manning's n             = 0.035
  Wind velocity                   UW        = 2.14 m/s
  Stratification Type             STRCND = U
  Surface temperature                       = 19.29 degC
  Bottom temperature                        = 19.29 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                 RHOAS  = 998.3493 kg/m^3
  Bottom density                  RHOAB  = 998.3493 kg/m^3
----------------------------------------------------------------------
-------
DISCHARGE PARAMETERS:             Surface Discharge
  Discharge located on                      = right bank/shoreline
  Discharge configuration                   = flush discharge
  Distance from bank to outlet    DISTB  = 0 m
  Discharge angle                 SIGMA  = 90 deg
  Depth near discharge outlet     HD0       = 2.72 m
  Bottom slope at discharge       SLOPE  = 1.05 deg
  Rectangular discharge:
    Discharge cross-section area  A0        = 66.890189 m^2
    Discharge channel width       B0        = 36.576000 m
    Discharge channel depth       H0        = 1.8288 m
    Discharge aspect ratio        AR        = 0.05
  Discharge flowrate              Q0        = 6.660397 m^3/s
```

```
  Discharge velocity              U0     = 0.10 m/s
  Discharge temperature (freshwater)     = 25.43 degC
  Corresponding density           RHO0   = 996.9335 kg/m^3
  Density difference              DRHO   = 1.4157 kg/m^3
  Buoyant acceleration            GP0    = 0.0139 m/s^2
  Discharge concentration         C0     = 11.07 deg.F
  Surface heat exchange coeff.    KS     = 0.000005 m/s
  Coefficient of decay            KD     = 0 /s
----------------------------------------------------------------------
-------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  = 8.18 m         Lm  = 2.38 m         Lbb = 2.30 m
  LM  = 2.41 m
----------------------------------------------------------------------
-------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number       FR0    = 0.30 (based on LQ)
  Channel densimetric Froude no.  FRCH   = 0.62 (based on H0)
  Velocity ratio                  R      = 0.29
----------------------------------------------------------------------
-------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = no
  Water quality standard specified       = yes
  Water quality standard          CSTD   = 6.28 deg.F
  Regulatory mixing zone                 = no
  Region of interest                     = 4000 m downstream
**********************************************************************
*******
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   = PL2 |
  *------------------------*

  Limiting Dilution S = (QA/Q0)+ 1.0 = 25.1

**********************************************************************
*******
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

----------------------------------------------------------------------
-------
X-Y-Z Coordinate system:
Origin is located at WATER SURFACE and at centerline of discharge
channel:
    0 m from the right bank/shore.
  Number of display steps NSTEP = 5000 per module.
----------------------------------------------------------------------
-------
NEAR-FIELD REGION (NFR) CONDITIONS :
```

```
Note: The NFR is the zone of strong initial mixing.  It has no
regulatory
  implication.  However, this information may be useful for the
discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at NFR edge  c = 11.07 deg.F
  Dilution at edge of NFR              s = 1
  NFR Location:                        x = 18.29 m
    (centerline coordinates)           y = 1.40 m
                                       z = 0 m
  NFR plume dimensions:  half-width (bh) = 11.63 m
                          thickness (bv) = 1.67 m
Cumulative travel time:       53.3561 sec.
----------------------------------------------------------------------
-------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise
towards
  the surface.
----------------------------------------------------------------------
-------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at 744.51 m downstream.
----------------------------------------------------------------------
-------
PLUME BANK CONTACT SUMMARY:
  Plume in bounded section contacts one bank only at 0 m downstream.
************************ TOXIC DILUTION ZONE SUMMARY
************************
No TDZ was specified for this simulation.
********************** REGULATORY MIXING ZONE SUMMARY
***********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered at the following
  plume position:
  Water quality standard                 = 6.28  deg.F
  Corresponding dilution               s = 1.8
  Plume location:                      x = 148.62 m
    (centerline coordinates)           y = 0 m
                                       z = 0 m
  Plume dimensions:     half-width (bh) = 37.96 m
                          thickness (bv) = 0.87 m
********************* FINAL DESIGN ADVICE AND COMMENTS
**********************
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any
known
```

```
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are
accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it
judges
  the design configuration as highly complex and uncertain for
prediction.
```

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXX
                      CORMIX MIXING ZONE EXPERT SYSTEM
                          CORMIX Version 10.0GT
                       HYDRO3:Version-10.0.0.0  July,2016
SITE NAME/LABEL:                Merrimack
  DESIGN CASE:                  Case 2 - Criteria 2
  FILE NAME:
\\nt2katl14\mdrive\Projects\PSNH\PSNH013 - Merrimack NPDES
Support\10.0 Working\Criteria 2\Case 2 - Criteria 2.prd
  Using subsystem CORMIX3:     Buoyant Surface Discharges
  Start of session:             12/21/2016--11:32:39
**********************************************************************
*******
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
-------
AMBIENT PARAMETERS:
  Cross-section                            = bounded
  Width                           BS       = 150.11 m
  Channel regularity              ICHREG = 2
  Ambient flowrate                QA       = 160.43 m^3/s
  Average depth                   HA       = 3.12 m
  Depth at discharge              HD       = 3.50 m
  Ambient velocity                UA       = 0.3428 m/s
  Darcy-Weisbach friction factor  F        = 0.0658
    Calculated from Manning's n            = 0.035
  Wind velocity                   UW       = 2.14 m/s
  Stratification Type             STRCND = U
  Surface temperature                      = 19.29 degC
  Bottom temperature                       = 19.29 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                 RHOAS  = 998.3493 kg/m^3
  Bottom density                  RHOAB  = 998.3493 kg/m^3
----------------------------------------------------------------------
-------
DISCHARGE PARAMETERS:             Surface Discharge
  Discharge located on                     = right bank/shoreline
  Discharge configuration                  = flush discharge
  Distance from bank to outlet    DISTB  = 0 m
  Discharge angle                 SIGMA  = 90 deg
  Depth near discharge outlet     HD0      = 2.72 m
  Bottom slope at discharge       SLOPE  = 1.05 deg
  Rectangular discharge:
    Discharge cross-section area  A0       = 66.890189 m^2
    Discharge channel width       B0       = 36.576000 m
    Discharge channel depth       H0       = 1.8288 m
    Discharge aspect ratio        AR       = 0.05
  Discharge flowrate              Q0       = 6.660397 m^3/s
```

```
  Discharge velocity               U0     = 0.10 m/s
  Discharge temperature (freshwater)      = 25.43 degC
  Corresponding density            RHO0   = 996.9335 kg/m^3
  Density difference               DRHO   = 1.4157 kg/m^3
  Buoyant acceleration             GP0    = 0.0139 m/s^2
  Discharge concentration          C0     = 11.07 deg.F
  Surface heat exchange coeff.     KS     = 0.000005 m/s
  Coefficient of decay             KD     = 0 /s
----------------------------------------------------------------------
-------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  = 8.18 m         Lm  = 2.38 m         Lbb = 2.30 m
  LM  = 2.41 m
----------------------------------------------------------------------
-------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number        FR0    = 0.30 (based on LQ)
  Channel densimetric Froude no.   FRCH   = 0.62 (based on H0)
  Velocity ratio                   R      = 0.29
----------------------------------------------------------------------
-------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                         = no
  Water quality standard specified        = yes
  Water quality standard           CSTD   = 10.280000 deg.F
  Regulatory mixing zone                  = no
  Region of interest                      = 4000 m downstream
**********************************************************************
*******
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   = PL2 |
  *------------------------*

  Limiting Dilution S = (QA/Q0)+ 1.0 = 25.1

**********************************************************************
*******
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

----------------------------------------------------------------------
-------
X-Y-Z Coordinate system:
Origin is located at WATER SURFACE and at centerline of discharge
channel:
    0 m from the right bank/shore.
  Number of display steps NSTEP = 5000 per module.
----------------------------------------------------------------------
-------
NEAR-FIELD REGION (NFR) CONDITIONS :
```

```
Note: The NFR is the zone of strong initial mixing.  It has no
regulatory
  implication.  However, this information may be useful for the
discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at NFR edge  c = 11.07 deg.F
  Dilution at edge of NFR              s = 1
  NFR Location:                        x = 18.29 m
    (centerline coordinates)           y = 1.40 m
                                       z = 0 m
  NFR plume dimensions:  half-width (bh) = 11.63 m
                          thickness (bv) = 1.67 m
Cumulative travel time:       53.3561 sec.
----------------------------------------------------------------------
-------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise
towards
  the surface.
----------------------------------------------------------------------
-------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at 744.51 m downstream.
----------------------------------------------------------------------
-------
PLUME BANK CONTACT SUMMARY:
  Plume in bounded section contacts one bank only at 0 m downstream.
************************ TOXIC DILUTION ZONE SUMMARY
************************
No TDZ was specified for this simulation.
********************** REGULATORY MIXING ZONE SUMMARY
**********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered at the following
  plume position:
  Water quality standard                 = 10.280000  deg.F
  Corresponding dilution               s = 1.1
  Plume location:                      x = 30.60 m
    (centerline coordinates)           y = 0 m
                                       z = 0 m
  Plume dimensions:      half-width (bh) = 14.82 m
                          thickness (bv) = 1.36 m
********************* FINAL DESIGN ADVICE AND COMMENTS
*********************
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any
known
```

```
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are
accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it
judges
  the design configuration as highly complex and uncertain for
prediction.
```

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXX
                      CORMIX MIXING ZONE EXPERT SYSTEM
                          CORMIX Version 10.0GT
                       HYDRO3:Version-10.0.0.0  July,2016
SITE NAME/LABEL:                Merrimack
  DESIGN CASE:                  Case 2 - Criteria 3
  FILE NAME:
\\nt2katl14\mdrive\Projects\PSNH\PSNH013 - Merrimack NPDES
Support\10.0 Working\Criteria 3\Case 2 - Criteria 3.prd
  Using subsystem CORMIX3:     Buoyant Surface Discharges
  Start of session:             12/21/2016--11:33:20
**********************************************************************
*******
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
-------
AMBIENT PARAMETERS:
  Cross-section                          = bounded
  Width                           BS     = 150.11 m
  Channel regularity              ICHREG = 2
  Ambient flowrate                QA     = 160.43 m^3/s
  Average depth                   HA     = 3.12 m
  Depth at discharge              HD     = 3.50 m
  Ambient velocity                UA     = 0.3428 m/s
  Darcy-Weisbach friction factor  F      = 0.0658
    Calculated from Manning's n          = 0.035
  Wind velocity                   UW     = 2.14 m/s
  Stratification Type             STRCND = U
  Surface temperature                    = 19.29 degC
  Bottom temperature                     = 19.29 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                 RHOAS  = 998.3493 kg/m^3
  Bottom density                  RHOAB  = 998.3493 kg/m^3
----------------------------------------------------------------------
-------
DISCHARGE PARAMETERS:             Surface Discharge
  Discharge located on                   = right bank/shoreline
  Discharge configuration                = flush discharge
  Distance from bank to outlet    DISTB  = 0 m
  Discharge angle                 SIGMA  = 90 deg
  Depth near discharge outlet     HD0    = 2.72 m
  Bottom slope at discharge       SLOPE  = 1.05 deg
  Rectangular discharge:
    Discharge cross-section area  A0     = 66.890189 m^2
    Discharge channel width       B0     = 36.576000 m
    Discharge channel depth       H0     = 1.8288 m
    Discharge aspect ratio        AR     = 0.05
  Discharge flowrate              Q0     = 6.660397 m^3/s
```

```
  Discharge velocity              U0     = 0.10 m/s
  Discharge temperature (freshwater)     = 25.43 degC
  Corresponding density           RHO0   = 996.9335 kg/m^3
  Density difference              DRHO   = 1.4157 kg/m^3
  Buoyant acceleration            GP0    = 0.0139 m/s^2
  Discharge concentration         C0     = 11.07 deg.F
  Surface heat exchange coeff.    KS     = 0.000005 m/s
  Coefficient of decay            KD     = 0 /s
----------------------------------------------------------------------
-------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  = 8.18 m         Lm  = 2.38 m         Lbb = 2.30 m
  LM  = 2.41 m
----------------------------------------------------------------------
-------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number       FR0    = 0.30 (based on LQ)
  Channel densimetric Froude no.  FRCH   = 0.62 (based on H0)
  Velocity ratio                  R      = 0.29
----------------------------------------------------------------------
-------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = no
  Water quality standard specified       = yes
  Water quality standard          CSTD   = 13.280000 deg.F
  Regulatory mixing zone                 = no
  Region of interest                     = 4000 m downstream
**********************************************************************
*******
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   = PL2 |
  *------------------------*

  Limiting Dilution S = (QA/Q0)+ 1.0 = 25.1

**********************************************************************
*******
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

----------------------------------------------------------------------
-------
X-Y-Z Coordinate system:
Origin is located at WATER SURFACE and at centerline of discharge
channel:
    0 m from the right bank/shore.
  Number of display steps NSTEP = 5000 per module.
----------------------------------------------------------------------
-------
NEAR-FIELD REGION (NFR) CONDITIONS :
```

```
Note: The NFR is the zone of strong initial mixing.  It has no
regulatory
  implication.  However, this information may be useful for the
discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at NFR edge  c = 11.07 deg.F
  Dilution at edge of NFR              s = 1
  NFR Location:                        x = 18.29 m
    (centerline coordinates)           y = 1.40 m
                                       z = 0 m
  NFR plume dimensions:  half-width (bh) = 11.63 m
                          thickness (bv) = 1.67 m
Cumulative travel time:       53.3561 sec.
----------------------------------------------------------------------
-------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise
towards
  the surface.
----------------------------------------------------------------------
-------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at 744.51 m downstream.
----------------------------------------------------------------------
-------
PLUME BANK CONTACT SUMMARY:
  Plume in bounded section contacts one bank only at 0 m downstream.
************************ TOXIC DILUTION ZONE SUMMARY
************************
No TDZ was specified for this simulation.
********************** REGULATORY MIXING ZONE SUMMARY
**********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered within a control
  volume describing a portion of the discharge plume.
Therefore, the following plume conditions are a conservative estimate
(with
  lower concentrations or with larger dimensions) for the region at
whose
  boundary the standard is met:
  Local boundary concentration           = 11.07  deg.F
Corresponding dilution                   = 1
  Water quality standard                 = 13.280000  deg.F
  Corresponding dilution               s = 1
  Plume location:                      x = 18.29 m
    (centerline coordinates)           y = 1.40 m
```

```
                               z = 0 m
  Plume dimensions:      half-width (bh) = 11.63 m
                          thickness (bv) = 1.67 m
******************** FINAL DESIGN ADVICE AND COMMENTS
**********************
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any
known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are
accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it
judges
  the design configuration as highly complex and uncertain for
prediction.
```

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXX
                      CORMIX MIXING ZONE EXPERT SYSTEM
                          CORMIX Version 10.0GT
                       HYDRO3:Version-10.0.0.0  July,2016
SITE NAME/LABEL:                Merrimack
  DESIGN CASE:                  Case 3 - Criteria 1
  FILE NAME:
\\nt2katl14\mdrive\Projects\PSNH\PSNH013 - Merrimack NPDES
Support\10.0 Working\Criteria 1\Case 3 - Criteria 1.prd
  Using subsystem CORMIX3:     Buoyant Surface Discharges
  Start of session:             12/21/2016--11:32:12
**********************************************************************
*******
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
-------
AMBIENT PARAMETERS:
  Cross-section                           = bounded
  Width                          BS       = 150.11 m
  Channel regularity             ICHREG = 2
  Ambient flowrate               QA       = 109.92 m^3/s
  Average depth                  HA       = 3.12 m
  Depth at discharge             HD       = 3.50 m
  Ambient velocity               UA       = 0.2348 m/s
  Darcy-Weisbach friction factor F        = 0.0658
    Calculated from Manning's n           = 0.035
  Wind velocity                  UW       = 1.87 m/s
  Stratification Type            STRCND = U
  Surface temperature                     = 24.73 degC
  Bottom temperature                      = 24.73 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                RHOAS  = 997.1137 kg/m^3
  Bottom density                 RHOAB  = 997.1137 kg/m^3
----------------------------------------------------------------------
-------
DISCHARGE PARAMETERS:            Surface Discharge
  Discharge located on                    = right bank/shoreline
  Discharge configuration                 = flush discharge
  Distance from bank to outlet   DISTB  = 0 m
  Discharge angle                SIGMA  = 90 deg
  Depth near discharge outlet    HD0      = 2.72 m
  Bottom slope at discharge      SLOPE  = 1.05 deg
  Rectangular discharge:
    Discharge cross-section area A0       = 66.890189 m^2
    Discharge channel width      B0       = 36.576000 m
    Discharge channel depth      H0       = 1.8288 m
    Discharge aspect ratio       AR       = 0.05
  Discharge flowrate             Q0       = 7.672031 m^3/s
```

```
  Discharge velocity              U0     = 0.11 m/s
  Discharge temperature (freshwater)     = 31.07 degC
  Corresponding density           RHO0   = 995.3197 kg/m^3
  Density difference              DRHO   = 1.7939 kg/m^3
  Buoyant acceleration            GP0    = 0.0176 m/s^2
  Discharge concentration         C0     = 11.4 deg.F
  Surface heat exchange coeff.    KS     = 0.000006 m/s
  Coefficient of decay            KD     = 0 /s
----------------------------------------------------------------------
-------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  = 8.18 m         Lm  = 3.99 m         Lbb = 10.45 m
  LM  = 2.47 m
----------------------------------------------------------------------
-------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number       FR0    = 0.30 (based on LQ)
  Channel densimetric Froude no.  FRCH   = 0.64 (based on H0)
  Velocity ratio                  R      = 0.49
----------------------------------------------------------------------
-------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = no
  Water quality standard specified       = yes
  Water quality standard          CSTD   = 3.48 deg.F
  Regulatory mixing zone                 = no
  Region of interest                     = 4000 m downstream
**********************************************************************
*******
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   = PL2 |
  *------------------------*

  Limiting Dilution S = (QA/Q0)+ 1.0 = 15.3

**********************************************************************
*******
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

----------------------------------------------------------------------
-------
X-Y-Z Coordinate system:
Origin is located at WATER SURFACE and at centerline of discharge
channel:
    0 m from the right bank/shore.
  Number of display steps NSTEP = 5000 per module.
----------------------------------------------------------------------
-------
NEAR-FIELD REGION (NFR) CONDITIONS :
```

```
Note: The NFR is the zone of strong initial mixing.  It has no
regulatory
  implication.  However, this information may be useful for the
discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at NFR edge  c = 11.4 deg.F
  Dilution at edge of NFR              s = 1
  NFR Location:                        x = 18.29 m
    (centerline coordinates)           y = 1.24 m
                                       z = 0 m
  NFR plume dimensions:  half-width (bh) = 18.90 m
                          thickness (bv) = 1.73 m
Cumulative travel time:       77.8749 sec.
----------------------------------------------------------------------
-------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise
towards
  the surface.
----------------------------------------------------------------------
-------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at 2701.62 m downstream
  and laterally fully mixed at 610.10 m downstream.
----------------------------------------------------------------------
-------
PLUME BANK CONTACT SUMMARY:
  Plume in bounded section contacts nearest bank at 0 m downstream.
  Plume contacts second bank at 610.10 m downstream.
************************ TOXIC DILUTION ZONE SUMMARY
************************
No TDZ was specified for this simulation.
********************** REGULATORY MIXING ZONE SUMMARY
**********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered at the following
  plume position:
  Water quality standard                 = 3.48  deg.F
  Corresponding dilution               s = 3.3
  Plume location:                      x = 437.61 m
    (centerline coordinates)           y = 0 m
                                       z = 0 m
  Plume dimensions:      half-width (bh) = 121.10 m
                          thickness (bv) = 0.82 m
******************** FINAL DESIGN ADVICE AND COMMENTS
*********************
```

```
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any
known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are
accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it
judges
  the design configuration as highly complex and uncertain for
prediction.
```

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXX
                      CORMIX MIXING ZONE EXPERT SYSTEM
                          CORMIX Version 10.0GT
                       HYDRO3:Version-10.0.0.0  July,2016
SITE NAME/LABEL:                Merrimack
  DESIGN CASE:                  Case 3 - Criteria 2
  FILE NAME:
\\nt2katl14\mdrive\Projects\PSNH\PSNH013 - Merrimack NPDES
Support\10.0 Working\Criteria 2\Case 3 - Criteria 2.prd
  Using subsystem CORMIX3:     Buoyant Surface Discharges
  Start of session:             12/21/2016--11:32:53
**********************************************************************
*******
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
-------
AMBIENT PARAMETERS:
  Cross-section                        = bounded
  Width                           BS     = 150.11 m
  Channel regularity              ICHREG = 2
  Ambient flowrate                QA     = 109.92 m^3/s
  Average depth                   HA     = 3.12 m
  Depth at discharge              HD     = 3.50 m
  Ambient velocity                UA     = 0.2348 m/s
  Darcy-Weisbach friction factor  F      = 0.0658
    Calculated from Manning's n          = 0.035
  Wind velocity                   UW     = 1.87 m/s
  Stratification Type             STRCND = U
  Surface temperature                    = 24.73 degC
  Bottom temperature                     = 24.73 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                 RHOAS  = 997.1137 kg/m^3
  Bottom density                  RHOAB  = 997.1137 kg/m^3
----------------------------------------------------------------------
-------
DISCHARGE PARAMETERS:             Surface Discharge
  Discharge located on                   = right bank/shoreline
  Discharge configuration                = flush discharge
  Distance from bank to outlet    DISTB  = 0 m
  Discharge angle                 SIGMA  = 90 deg
  Depth near discharge outlet     HD0    = 2.72 m
  Bottom slope at discharge       SLOPE  = 1.05 deg
  Rectangular discharge:
    Discharge cross-section area  A0     = 66.890189 m^2
    Discharge channel width       B0     = 36.576000 m
    Discharge channel depth       H0     = 1.8288 m
    Discharge aspect ratio        AR     = 0.05
  Discharge flowrate              Q0     = 7.672031 m^3/s
```

```
  Discharge velocity              U0     = 0.11 m/s
  Discharge temperature (freshwater)     = 31.07 degC
  Corresponding density           RHO0   = 995.3197 kg/m^3
  Density difference              DRHO   = 1.7939 kg/m^3
  Buoyant acceleration            GP0    = 0.0176 m/s^2
  Discharge concentration         C0     = 11.4 deg.F
  Surface heat exchange coeff.    KS     = 0.000006 m/s
  Coefficient of decay            KD     = 0 /s
----------------------------------------------------------------------
-------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  = 8.18 m         Lm  = 3.99 m         Lbb = 10.45 m
  LM  = 2.47 m
----------------------------------------------------------------------
-------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number       FR0    = 0.30 (based on LQ)
  Channel densimetric Froude no.  FRCH   = 0.64 (based on H0)
  Velocity ratio                  R      = 0.49
----------------------------------------------------------------------
-------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = no
  Water quality standard specified       = yes
  Water quality standard          CSTD   = 6.48 deg.F
  Regulatory mixing zone                 = no
  Region of interest                     = 4000 m downstream
**********************************************************************
*******
HYDRODYNAMIC CLASSIFICATION:
  *-------------------------*
  | FLOW CLASS   = PL2 |
  *-------------------------*

  Limiting Dilution S = (QA/Q0)+ 1.0 = 15.3

**********************************************************************
*******
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

----------------------------------------------------------------------
-------
X-Y-Z Coordinate system:
Origin is located at WATER SURFACE and at centerline of discharge
channel:
    0 m from the right bank/shore.
  Number of display steps NSTEP = 5000 per module.
----------------------------------------------------------------------
-------
NEAR-FIELD REGION (NFR) CONDITIONS :
```

```
Note: The NFR is the zone of strong initial mixing.  It has no
regulatory
  implication.  However, this information may be useful for the
discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at NFR edge  c = 11.4 deg.F
  Dilution at edge of NFR              s = 1
  NFR Location:                        x = 18.29 m
    (centerline coordinates)           y = 1.24 m
                                       z = 0 m
  NFR plume dimensions:  half-width (bh) = 18.90 m
                          thickness (bv) = 1.73 m
Cumulative travel time:       77.8749 sec.
----------------------------------------------------------------------
-------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise
towards
  the surface.
----------------------------------------------------------------------
-------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at 2701.62 m downstream
  and laterally fully mixed at 610.10 m downstream.
----------------------------------------------------------------------
-------
PLUME BANK CONTACT SUMMARY:
  Plume in bounded section contacts nearest bank at 0 m downstream.
  Plume contacts second bank at 610.10 m downstream.
************************ TOXIC DILUTION ZONE SUMMARY
************************
No TDZ was specified for this simulation.
********************** REGULATORY MIXING ZONE SUMMARY
***********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered at the following
  plume position:
  Water quality standard                 = 6.48  deg.F
  Corresponding dilution               s = 1.8
  Plume location:                      x = 213.14 m
    (centerline coordinates)           y = 0 m
                                       z = 0 m
  Plume dimensions:      half-width (bh) = 76.50 m
                          thickness (bv) = 0.70 m
********************* FINAL DESIGN ADVICE AND COMMENTS
**********************
```

```
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any
known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are
accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it
judges
  the design configuration as highly complex and uncertain for
prediction.
```

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXX
                      CORMIX MIXING ZONE EXPERT SYSTEM
                          CORMIX Version 10.0GT
                       HYDRO3:Version-10.0.0.0  July,2016
SITE NAME/LABEL:                Merrimack
  DESIGN CASE:                  Case 3 - Criteria 3
  FILE NAME:
\\nt2katl14\mdrive\Projects\PSNH\PSNH013 - Merrimack NPDES
Support\10.0 Working\Criteria 3\Case 3 - Criteria 3.prd
  Using subsystem CORMIX3:     Buoyant Surface Discharges
  Start of session:             12/21/2016--11:33:47
**********************************************************************
*******
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
-------
AMBIENT PARAMETERS:
  Cross-section                              = bounded
  Width                             BS       = 150.11 m
  Channel regularity                ICHREG = 2
  Ambient flowrate                  QA       = 109.92 m^3/s
  Average depth                     HA       = 3.12 m
  Depth at discharge                HD       = 3.50 m
  Ambient velocity                  UA       = 0.2348 m/s
  Darcy-Weisbach friction factor    F        = 0.0658
    Calculated from Manning's n              = 0.035
  Wind velocity                     UW       = 1.87 m/s
  Stratification Type               STRCND = U
  Surface temperature                        = 24.73 degC
  Bottom temperature                         = 24.73 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                   RHOAS  = 997.1137 kg/m^3
  Bottom density                    RHOAB  = 997.1137 kg/m^3
----------------------------------------------------------------------
-------
DISCHARGE PARAMETERS:               Surface Discharge
  Discharge located on                       = right bank/shoreline
  Discharge configuration                    = flush discharge
  Distance from bank to outlet      DISTB  = 0 m
  Discharge angle                   SIGMA  = 90 deg
  Depth near discharge outlet       HD0      = 2.72 m
  Bottom slope at discharge         SLOPE  = 1.05 deg
  Rectangular discharge:
    Discharge cross-section area    A0       = 66.890189 m^2
    Discharge channel width         B0       = 36.576000 m
    Discharge channel depth         H0       = 1.8288 m
    Discharge aspect ratio          AR       = 0.05
  Discharge flowrate                Q0       = 7.672031 m^3/s
```

```
  Discharge velocity               U0     = 0.11 m/s
  Discharge temperature (freshwater)      = 31.07 degC
  Corresponding density            RHO0   = 995.3197 kg/m^3
  Density difference               DRHO   = 1.7939 kg/m^3
  Buoyant acceleration             GP0    = 0.0176 m/s^2
  Discharge concentration          C0     = 11.4 deg.F
  Surface heat exchange coeff.     KS     = 0.000006 m/s
  Coefficient of decay             KD     = 0 /s
----------------------------------------------------------------------
-------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  = 8.18 m          Lm  = 3.99 m          Lbb = 10.45 m
  LM  = 2.47 m
----------------------------------------------------------------------
-------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number        FR0    = 0.30 (based on LQ)
  Channel densimetric Froude no.   FRCH   = 0.64 (based on H0)
  Velocity ratio                   R      = 0.49
----------------------------------------------------------------------
-------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                         = no
  Water quality standard specified        = yes
  Water quality standard           CSTD   = 10.48 deg.F
  Regulatory mixing zone                  = no
  Region of interest                      = 4000 m downstream
**********************************************************************
*******
HYDRODYNAMIC CLASSIFICATION:
  *-------------------------*
  | FLOW CLASS   = PL2 |
  *-------------------------*

  Limiting Dilution S = (QA/Q0)+ 1.0 = 15.3

**********************************************************************
*******
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

----------------------------------------------------------------------
-------
X-Y-Z Coordinate system:
Origin is located at WATER SURFACE and at centerline of discharge
channel:
    0 m from the right bank/shore.
  Number of display steps NSTEP = 5000 per module.
----------------------------------------------------------------------
-------
NEAR-FIELD REGION (NFR) CONDITIONS :
```

```
Note: The NFR is the zone of strong initial mixing.  It has no
regulatory
  implication.  However, this information may be useful for the
discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at NFR edge  c = 11.4 deg.F
  Dilution at edge of NFR              s = 1
  NFR Location:                        x = 18.29 m
    (centerline coordinates)           y = 1.24 m
                                       z = 0 m
  NFR plume dimensions:  half-width (bh) = 18.90 m
                          thickness (bv) = 1.73 m
Cumulative travel time:       77.8749 sec.
----------------------------------------------------------------------
-------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise
towards
  the surface.
----------------------------------------------------------------------
-------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at 2701.62 m downstream
  and laterally fully mixed at 610.10 m downstream.
----------------------------------------------------------------------
-------
PLUME BANK CONTACT SUMMARY:
  Plume in bounded section contacts nearest bank at 0 m downstream.
  Plume contacts second bank at 610.10 m downstream.
************************ TOXIC DILUTION ZONE SUMMARY
************************
No TDZ was specified for this simulation.
********************** REGULATORY MIXING ZONE SUMMARY
**********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered at the following
  plume position:
  Water quality standard                 = 10.48  deg.F
  Corresponding dilution               s = 1.1
  Plume location:                      x = 33.87 m
    (centerline coordinates)           y = 0 m
                                       z = 0 m
  Plume dimensions:      half-width (bh) = 25.16 m
                          thickness (bv) = 1.32 m
******************** FINAL DESIGN ADVICE AND COMMENTS
*********************
```

```
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any
known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are
accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it
judges
  the design configuration as highly complex and uncertain for
prediction.
```

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXX
                      CORMIX MIXING ZONE EXPERT SYSTEM
                          CORMIX Version 10.0GT
                       HYDRO3:Version-10.0.0.0  July,2016
SITE NAME/LABEL:                Merrimack
  DESIGN CASE:                  Case 3 - Criteria 4
  FILE NAME:
\\nt2katl14\mdrive\Projects\PSNH\PSNH013 - Merrimack NPDES
Support\10.0 Working\Critiera 4\Case 3 - Criteria 4.prd
  Using subsystem CORMIX3:     Buoyant Surface Discharges
  Start of session:             12/21/2016--11:34:02
**********************************************************************
*******
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
-------
AMBIENT PARAMETERS:
  Cross-section                             = bounded
  Width                           BS        = 150.11 m
  Channel regularity              ICHREG    = 2
  Ambient flowrate                QA        = 109.92 m^3/s
  Average depth                   HA        = 3.12 m
  Depth at discharge              HD        = 3.50 m
  Ambient velocity                UA        = 0.2348 m/s
  Darcy-Weisbach friction factor  F         = 0.0658
    Calculated from Manning's n             = 0.035
  Wind velocity                   UW        = 1.87 m/s
  Stratification Type             STRCND    = U
  Surface temperature                       = 24.73 degC
  Bottom temperature                        = 24.73 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density                 RHOAS     = 997.1137 kg/m^3
  Bottom density                  RHOAB     = 997.1137 kg/m^3
----------------------------------------------------------------------
-------
DISCHARGE PARAMETERS:             Surface Discharge
  Discharge located on                      = right bank/shoreline
  Discharge configuration                   = flush discharge
  Distance from bank to outlet    DISTB     = 0 m
  Discharge angle                 SIGMA     = 90 deg
  Depth near discharge outlet     HD0       = 2.72 m
  Bottom slope at discharge       SLOPE     = 1.05 deg
  Rectangular discharge:
    Discharge cross-section area  A0        = 66.890189 m^2
    Discharge channel width       B0        = 36.576000 m
    Discharge channel depth       H0        = 1.8288 m
    Discharge aspect ratio        AR        = 0.05
  Discharge flowrate              Q0        = 7.672031 m^3/s
```

```
  Discharge velocity              U0     = 0.11 m/s
  Discharge temperature (freshwater)     = 31.07 degC
  Corresponding density           RHO0   = 995.3197 kg/m^3
  Density difference              DRHO   = 1.7939 kg/m^3
  Buoyant acceleration            GP0    = 0.0176 m/s^2
  Discharge concentration         C0     = 11.4 deg.F
  Surface heat exchange coeff.    KS     = 0.000006 m/s
  Coefficient of decay            KD     = 0 /s
----------------------------------------------------------------------
-------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  = 8.18 m         Lm  = 3.99 m         Lbb = 10.45 m
  LM  = 2.47 m
----------------------------------------------------------------------
-------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number       FR0    = 0.30 (based on LQ)
  Channel densimetric Froude no.  FRCH   = 0.64 (based on H0)
  Velocity ratio                  R      = 0.49
----------------------------------------------------------------------
-------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                        = no
  Water quality standard specified       = yes
  Water quality standard          CSTD   = 12.48 deg.F
  Regulatory mixing zone                 = no
  Region of interest                     = 4000 m downstream
**********************************************************************
*******
HYDRODYNAMIC CLASSIFICATION:
  *-------------------------*
  | FLOW CLASS   = PL2 |
  *-------------------------*

  Limiting Dilution S = (QA/Q0)+ 1.0 = 15.3

**********************************************************************
*******
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):

----------------------------------------------------------------------
-------
X-Y-Z Coordinate system:
Origin is located at WATER SURFACE and at centerline of discharge
channel:
    0 m from the right bank/shore.
  Number of display steps NSTEP = 5000 per module.
----------------------------------------------------------------------
-------
NEAR-FIELD REGION (NFR) CONDITIONS :
```

```
Note: The NFR is the zone of strong initial mixing.  It has no
regulatory
  implication.  However, this information may be useful for the
discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at NFR edge  c = 11.4 deg.F
  Dilution at edge of NFR              s = 1
  NFR Location:                        x = 18.29 m
    (centerline coordinates)           y = 1.24 m
                                       z = 0 m
  NFR plume dimensions:  half-width (bh) = 18.90 m
                          thickness (bv) = 1.73 m
Cumulative travel time:       77.8749 sec.
----------------------------------------------------------------------
-------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise
towards
  the surface.
----------------------------------------------------------------------
-------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at 2701.62 m downstream
  and laterally fully mixed at 610.10 m downstream.
----------------------------------------------------------------------
-------
PLUME BANK CONTACT SUMMARY:
  Plume in bounded section contacts nearest bank at 0 m downstream.
  Plume contacts second bank at 610.10 m downstream.
************************* TOXIC DILUTION ZONE SUMMARY
*************************
No TDZ was specified for this simulation.
*********************** REGULATORY MIXING ZONE SUMMARY
***********************
No RMZ has been specified.
However:
The ambient water quality standard was encountered within a control
  volume describing a portion of the discharge plume.
Therefore, the following plume conditions are a conservative estimate
(with
  lower concentrations or with larger dimensions) for the region at
whose
  boundary the standard is met:
  Local boundary concentration           = 11.4  deg.F
Corresponding dilution                   = 1
  Water quality standard                 = 12.48  deg.F
  Corresponding dilution               s = 1
```

```
  Plume location:                      x = 18.29 m
    (centerline coordinates)           y = 1.24 m
                                       z = 0 m
  Plume dimensions:      half-width (bh) = 18.90 m
                          thickness (bv) = 1.73 m
********************* FINAL DESIGN ADVICE AND COMMENTS
**********************
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any
known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are
accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it
judges
  the design configuration as highly complex and uncertain for
prediction.
```

Attachment 3

Influence of Merrimack Station's Thermal Plume on Habitat Utilization by Fish Species Present in Lower Hooksett Pool

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Prepared for
Public Service Co. of New Hampshire
d/b/a Eversource Energy
Manchester, New Hampshire

Executive Summary

Documents submitted to EPA by Public Service Company of New Hampshire (PSNH) in support of the NPDES renewal application for Merrimack Station included information on the thermal sensitivities of 8 Representative Important Species (RIS). Although previous reports have compared the thermal tolerances of the RIS to available water temperature measurements in ambient and thermally-influenced zones of the Merrimack River, no specific analyses of the influence of the station's thermal plume on habitat utilization by the RIS have previously been performed. The analysis documented in this report uses a thermal plume analysis performed by Enercon Services, Inc. to identify regions within the river that would be excluded from use by one or more of the RIS due to the presence of the plume.

As discussed in Enercon (2016), the CORMIX thermal plume model was used to calculate average plume characteristics over the period 2006-2015 for three representative time periods: early spring (May 2 – May 8), late spring (June 9 – June 15), and mid-summer (July 29 – August 4). Exclusion of various RIS from different regions of the plume was evaluated by estimating the volume within which various "index temperatures" would be exceeded. The index temperatures were defined based on thermal tolerance data for the RIS. Species with thermal tolerances lower than a given index temperature would be excluded from the volume of habitat within which that index temperature was exceeded.

In none of the cases examined would the thermal plume from the Merrimack Station affect more than a negligible fraction of the fish habitat present downriver from the cooling water discharge. On average, 0.48% of the surface area and 0.19% of the habitat volume present between Station S0 and Hooksett Dam would be affected during the early spring period. For the late spring period, at most 0.27% of the surface area and 0.09% of the habitat volume present between Station S0 and Hooksett Dam would be affected. For the mid-summer period, at most 3.47% of the area and 0.88% of the volume present between Station S0 and Hoooksett Dam would be affected.

This thermal plume analysis supports conclusions from fish community surveys previously performed for PSNH. The survey data show that Merrimack Station's thermal discharge has had no measurable impacts on the fish community in the Hooksett Pool. Given the small proportion of the available habitat within the pool that is influenced by the thermal plume, measurable impacts on the fish community would not be expected and none have, in fact, been found.

Introduction

Documents submitted to EPA by PSNH in support of the NPDES renewal application for Merrimack Station included information on the thermal sensitivities of 9 Representative Important Species (RIS). As stated by Normandeau (2007), these species were selected in consultation with the Merrimack Station Advisory Committee. Previous reports submitted to EPA by PSNH (Normandeau 2007, 2011a) have documented long-term trends in the abundance of the RIS and other common fish species within Hooksett pool, and compared the thermal tolerances of the RIS to available water temperature measurements in ambient (i.e., upriver from Merrimack Station) and thermally-influenced (i.e., downriver from Merrimack Station) zones of Hooksett Pool. However, no specific analyses of the influence of the Merrimack Station thermal plume on habitat utilization by the RIS have previously been performed.

The purpose of this analysis is to identify regions within lower Hooksett Pool that would be excluded from use by one or more of the RIS due to the presence of the Merrimack Station thermal plume. It relies on (1) plume modeling results obtained from Enercon (2016) using the CORMIX model, and (2) thermal effects data compiled by Normandeau (2007). With one exception, the species chosen for the analysis are the RIS species discussed in Normandeau (2007) and in EPA's §316 Determination:

Anadromous species
Alewife
American shad

Resident species
Smallmouth bass
Largemouth bass
Pumpkinseed
Yellow perch
Fallfish
White sucker

Atlantic salmon was not included in this analysis because the Merrimack River Atlantic salmon restoration program has been terminated. Three representative time periods were selected for analysis: May 2 to May 8, June 9 to June 15, and July 29 to August 4. These three weeks represent, respectively, the early spring period when river flows are high and ambient temperatures are relatively low; the late spring period when ambient temperatures are rising rapidly; and the mid-summer period when river temperatures are high and flows are low.

In some years, alewives have been stocked in the Hooksett Pool; when stocking does occur early life stages of alewife would be present during early spring. Yellow perch, fallfish, white sucker, smallmouth bass, and largemouth bass would be spawning within the Hooksett Pool, and adults of all resident species would be present.

During the late spring period, smallmouth bass, largemouth bass, and pumpkinseed would be spawning. Juvenile alewives could be present, larvae of early-spawning species would be present, and juveniles and adults of all resident species would be present. Juvenile American shad spawned by fish stocked upstream could also be present.

During the mid-summer period spawning activity would have ceased, but juvenile alewives and American shad could be present, and juveniles and adults of all resident species would be present.

Thermal benchmarks for species and life stages expected to be present in lower Hooksett Pool during the above three time periods are listed in Tables 1 through 3. Except as noted, all values were taken from Appendix C of Normandeau (2007), which is attached for reference. Criteria used to specify benchmarks for this analysis included growth optima (where available), avoidance temperatures, preferred temperatures, spawning temperatures, and early life stage development and survival. Except in the case of larvae, lethal temperatures were not used because juvenile and adult fish would be expected to detect and avoid these temperatures. Where Appendix C provided a range of preferred temperatures or spawning temperatures for a species, the upper end of the range was selected because any value within the range would indicate that the habitat was suitable for use by that species. Where Appendix C provided a range of avoidance temperatures, the lower end of the range was selected to be conservative.

This approach to thermal effects analysis is substantially different from, and more ecologically realistic than the approach taken by EPA in its §316 Determination for Merrimack Station (Attachment D to the 2011 Draft Permit). EPA's approach (Sections 5.6.3 and 8.3 of Attachment D) relied on comparisons between thermal effect criteria for the most sensitive life stage of each species expected to be present in the river on a given date and the measured or predicted temperatures at Stations S0 (the end of the Merrimack Station discharge canal) and S4 (downriver from the discharge point)[1]. EPA did not estimate the area or volume of habitat within which these temperatures would be exceeded, or whether the habitat present at these stations would still be suitable for use by other life stages or species. EPA's approach considers only whether the most thermally sensitive organisms expected to be exposed to the discharge at stations S0 and S4 might be affected. It does not address whether the amount of habitat exposed to elevated temperatures is large enough to adversely affect the populations to which these organisms belong. In contrast, the approach utilized in this report explicitly addresses the quantity of habitat that would be denied to each RIS population by exposure to the thermal plume. This focus on populations rather than on individual organisms is consistent with the "balanced indigenous population" concept embodied in §316a of the Clean Water Act.

The thermal plume from Merrimack Station during the three above weeks was characterized by Enercon (2016) using the CORMIX model. Input parameters for the model runs represent average conditions, within each week of interest, over the 10-year period 2006-2015 and were derived from environmental and plant operational data for these years. Figures 3-5 included in Enercon's (2016) report depict the average surface area occupied by the plume for each week, from the end of the discharge canal (Station S0) to Hooksett Dam (Station S24). To illustrate the influence of the plume on species and life stages with differing thermal sensitivities, three "index temperatures" were selected for the first two weeks and four index temperatures were selected for the third week:

May 2-May 8: 55°F, 59°F, and 64°F

June 9 – June 15: 73°F, 77°F, and 80°F

---

[1] Barnthouse (2016) identified numerous errors in EPA's thermal effects analysis; even if all those errors were corrected EPA's general approach would still be inadequate for addressing the impact of the thermal discharge on RIS populations.

July 29 – August 4: 80°F, 83°F, 87°F, and 89°F

The temperature of the water within the plume is highest at the point of discharge to the river (Station S0), and declines as the plume dissipates and diffuses outward as it moves downriver. The plume temperature is lowest near the edge of the plume and highest along the centerline. This means that different regions within the plume have different effects on habitat usage by the RIS species. Isolines on each of Enercon's figures define the surface area of each plume within which one or more of the index temperatures would be exceeded. Although not depicted on the figures, the CORMIX output can be used to estimate the average volume of the plume as a function of plume area and thickness. The volume enclosed within each isoline is a conservative estimate of the volume within which the corresponding index temperature is exceeded as described within the Enercon (2016) report. This volume is, for the purpose of this analysis, considered to be thermally unsuitable habitat for the species and life stages with thermal benchmarks lower than the index temperature. For example, the benchmark temperature for yellow perch spawning is 55°F. Locations with temperatures higher than 55°F are considered to be unsuitable for spawning by yellow perch. The 55°F isoline on Figure 3 of Enercon (2016) bounds the habitat within which the plume temperature equals or exceeds 55°F; this habitat is assumed to be unsuitable for spawning by yellow perch. It would, however, be suitable for use by species and life stages with thermal benchmarks higher than 55°F.

This interpretation of the CORMIX output is inherently conservative because it does not consider the location of the plume relative to the actual shoreline and bottom contours of the Merrimack River. Yellow perch, for example, spawn over vegetation and woody debris near the shoreline; if the plume does not come into contact with these habitats spawning by perch will not be affected regardless of the plume temperature. Moreover, the CORMIX modeling considers only the reach of the river between the end of the Merrimack Station discharge canal (station S0) and Hooksett Dam. Approximately 50% of the Hooksett Pool is upriver from the station.

Results

Tables 4 through 6 of the Enercon report show, for each week, the volume of the habitat within each isoline that exceeds the corresponding index temperature, and the number of thermal benchmarks enclosed within each isoline.

<u>May 2-May8</u>

The 55°F isoline includes 0.48% of the surface area and 0.19% of the volume between the Station S0 and Hookset dam. These areas and volumes would be unsuitable for yellow perch spawning. The remainder of the Merrimack River would still be suitable for spawning.

The 59°F isoline includes 0.05% of the surface area and 0.01% of the volume between Station S0 and Hooksett Dam. In addition to being unsuitable for yellow perch spawning, this habitat would be slightly warmer than optimal for white sucker hatching success, and for maximum larval alewife survival. The remainder of the Merrimack River would be within the optimal temperature ranges for both species.

Temperatures of 64°F or higher would, in addition, exceed the temperature range for fallfish spawning and embryo incubation. However, for the 10-year period 2006-2015, the average discharge temperature measured at station S0 was lower than 64°F, therefore, the average plume temperature did not exceed this index value at any point. Fallfish spawning would, therefore, not be affected at any location within the plume.

<u>June 9 – June 15</u>

Temperature values of 70°F and lower were not analyzed because of their proximity to the ambient temperature measured at Station N10. Plume temperatures 73°F and higher would exceed thermal benchmarks for pumpkinseed spawning, fallfish adult and juvenile growth, smallmouth and largemouth bass spawning, and yellow perch larval survival. The 73°F isoline encloses only 0.27% of the surface area and 0.09% of the volume between the Station S0 and Hookset dam. Within the remaining areas and volumes, no life stages of any species would be adversely affected by the thermal plume.

Temperatures between 73°F and 77°F would, in addition, exceed thermal benchmarks for white sucker optimal growth, yellow perch optimal growth, and pumpkinseed hatching success. The 77°F isoline includes 0.01% of the surface area and 0.01% of the volume between Station S0 and Hooksett Dam. None of these species would be adversely affected in habitats outside the 77°F isoline.

Temperatures between 77°F and 80°F would exceed thermal benchmarks for smallmouth bass hatching success, largemouth bass larval survival, yellow perch juvenile/adult avoidance, alewife juvenile biomass gain, and American shad larval growth; and would be outside the optimal temperature range for yellow perch adults and white sucker larvae. However, the average discharge temperature for the week of June 9-June 15 is 77.78°F. This value does not exceed thermal benchmarks for any of these species, therefore, none would be affected by the thermal plume.

July 29 – August 4

Temperature values less than 80°F and lower were not analyzed because of their proximity to the ambient temperature measured at Station N10. A plume temperature of 80°F exceeds thermal benchmarks for several of the species expected to be present in the river during the week of July 29-August 4. However, the ambient temperature of the river, as measured at station N10, also exceeds some of these benchmarks. The average ambient temperature during this week for the years included in the analysis is approximately 76°F, which equals or exceeds thermal benchmarks for optimal growth of yellow perch, fallfish, and white sucker. Since the entire Hooksett Pool is apparently suboptimal for these species during late July and early August even when Merrimack Station is not operating, thermal benchmarks lower than 77°F were not included in this thermal plume analysis.

Plume temperature between 77°F and 80°F would exceed thermal benchmarks for yellow perch adults, white sucker larvae, and alewife juveniles. The 80°F isoline includes 3.47% of the surface area and 0.88% of the volume between Station S0 and Hooksett Dam. No other species or life stages would be affected by exposure to temperatures of 80°F or lower.

Plume temperatures between 80°F and 83°F would exceed the preferred temperatures of smallmouth bass juveniles and adults, yellow perch juveniles, white sucker juveniles and adults, fallfish juveniles and adults, and pumpkinseed adults. The 83°F isoline includes 0.72% of the surface area and 0.21% of the volume between Station S0 and Hooksett Dam. No other species or life stages would be affected by exposure to temperatures of 83°F or lower.

Plume temperatures between 83°F and 87°F would exceed the avoidance temperatures of yellow perch juveniles and adults, American shad juveniles, and largemouth bass adults, and would exceed optimal growth temperatures for white sucker, largemouth bass, and pumpkinseed. The 87°F isoline includes 0.02% of the surface area and 0.01% of the volume between Station S0 and Hooksett Dam. No other species or life stages would be affected by exposure to temperatures of 87°F or lower.

A plume temperature of 89°F would exceed the avoidance temperature of pumpkinseed adults, and would exceed preferred or optimal growth temperatures of smallmouth bass, American shad juveniles, alewife juveniles, largemouth bass juveniles, and pumpkinseed juveniles. However, the average discharge temperature for the week of July 29-August 4 is 87.92°F. This value does not exceed thermal benchmarks for any of these species, therefore, none would be affected by the thermal plume.

Discussion

In none of the cases examined using the CORMIX model would the thermal plume from the Merrimack Station affect more than a negligible fraction of the fish habitat present downriver from the cooling water discharge. On average, 0.48% of the surface area and 0.19% of the habitat volume present between Station S0 and Hooksett Dam would be affected during the early spring period. For the late spring period, at most 0.27% of the surface area and 0.09% of the habitat volume present between Station S0 and Hooksett Dam would be affected. For the mid-summer period, at most 3.47% of the area and 0.88% of the volume present between Station S0 and Hoooksett Dam would be affected. These values do not account for the fact that approximately half of the available fish habitat present in the Hooksett Pool is upriver from Merrimack Station and is unaffected by the station’s thermal discharge. They also do not account for the fact that a substantial fraction of the habitat influenced by the plume is of low quality and not extensively utilized by many fish species. Habitat mapping performed by

Normandeau (2011a) showed that most of the river bottom between Station S0 and Hooksett Dam consists of sand, silt, and clay. This type of substrate is not suitable spawning habitat for vegetation-oriented species like yellow perch or for nest-building species like bass and pumpkinseed.

This thermal plume analysis supports conclusions from fish community surveys previously published by Normandeau, (2007, 2011b) and summarized by Barnthouse (2016). The survey data show that Merrimack Station's thermal discharge has had no measurable impacts on the fish community in the Hooksett Pool. Given the small proportion of the available habitat within the pool that is influenced by the thermal plume, measurable impacts on the fish community would not be expected and none have, in fact, been found.

References

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Normandeau Associates. 2007. Merrimack Station fisheries survey and analysis of 1967 through 2005 catch and habitat data. Prepared for Public Service Company of New Hampshire.

Normandeau Associates. 2011a. Quantification of the physical habitat within Garvins, Hooksett, and Amoskeag pools within the Merrimack River. Prepared for Public Service Company of New Hampshire.

Normandeau Associates. 2011b. Merrimack Station fisheries survey analysis of 1972-2011 catch data. Prepared for Public Service Company of New Hampshire.

Table 1. Relevant thermal benchmarks for the period May 2-May 8.

Species	**Life stage**	**Benchmark Temperature (°F)**	**Parameter**	**Season**
Yellow perch	adults	55[a]	spawning	April - May
White sucker	eggs	59	hatching success	April -May
Alewife	larvae	59	peak survival	May - June
Fallfish	adults	64	spawning	May
Fallfish	eggs	64	embryo incubation	May
White sucker	adults	68	spawning	May
Yellow perch	eggs	69	hatching	May
Smallmouth bass	adults	70	spawning	Late April - early June
Largemouth bass	adults	70	spawning	Late April - early June
White sucker	larvae	71	upper end of range where found	May
Yellow perch	larvae	73	survival	May-June
Smallmouth bass	larvae	77	hatching success	Late April - early June
Largemouth bass	larvae	79	survival	Late April - early June
American shad	larvae	80	optimal for growth	May - June
Alewife	juvenile	80	Maximum net biomass gain	all year
White sucker	larvae	81	avoidance	May
Yellow perch	larvae	85	UILT	April-early May

[a] Krieger et al. 1983, Habitat suitability information: yellow perch. FWS/OBS 82/10.55. U.S. Fish & Wildlife Service, Washington D.C.

Table 2. Relevant thermal benchmarks for the period June 9-June 15

Species	Life stage	Benchmark Temperature (°F)	Parameter	Season
Pumpkinseed	adults	67	spawning	June-August
Fallfish	juv/adult	68	optimum for growth	all year
Smallmouth bass	adults	70	spawning	Late April - early June
Largemouth bass	adults	70	spawning	Late April - early June
Yellow perch	larvae	73	survival	May-June
White sucker	juv/adult	75	optimum for growth	all year
Yellow perch	juv/adult	76	optimal for growth	all year
Pumpkinseed	larvae	76.5	hatching	June - August
Smallmouth bass	larvae	77	hatching success	Late April - early June
Yellow perch	adults	77	preferred	all year
White sucker	larvae	77	preferred	all year
Largemouth bass	larvae	79	survival	Late April - early June
Yellow perch	juv/adult	79	avoidance	all year
Alewife	juvenile	80	Maximum net biomass gain	all year
American shad	larvae	80	optimal for growth	May - June
Smallmouth bass	adults	80.6	preferred	all year
Yellow perch	juvenile	81	preferred	all year
White sucker	uv/adult	81	preferred	all year
Atlantic salmon	juvenile	82	max for summer survival	Late April - early June
Smallmouth bass	juvenile	82	preferred	all year
Fallfish	juv/adult	82	avoidance	all year
Pumkinseed	adults	83	preferred	all year
Yellow perch	juv/adult	84	avoidance	all year
White sucker	juv/adult	84	optimum for growth	all year
American shad	juvenile	86	avoidance	May - October
Largemouth bass	adults	86	optimal for growth	all year
Pumpkinseed	adults	86	optimal for growth	all year
Largemouth bass	adults	87	avoidance	all year
Smallmouth bass	juvenile	87.8	preferred	all year
Alewife	juvenile	88	summer preferred	May - October

American shad	juvenile	88	optimal for growth	May - October
Pumpkinseed	adults	88	avoidance	all year
Largemouth bass	juvenile	89	preferred	all year
Pumpkinseed	juvenile	89	preferred	all year
Smallmouth bass	juv/adult	89.6	optimal for growth	all year
Largemouth bass	juvenile	90	avoidance	all year
Pumpkinseed	adults	90	preferred	all year
White sucker	juvenile	90	avoidance	all year
smallmouth bass	juv/adult	91.4	optimal for growth	all year
Smallmouth bass	juv/adult	95	avoidance	all year

Table 3. Relevant thermal benchmarks for the period July 29 – August 4.

Species	**Life stage**	**Benchmark Temperature (°F)**	**Parameter**	**Season**
Fallfish	juv/adult	68	optimum for growth	all year
White sucker	juv/adult	75	optimum for growth	all year
Yellow perch	juv/adult	76	optimal for growth	all year
Pumpkinseed	larvae	76.5	hatching	June - August
Yellow perch	adults	77	preferred	all year
White sucker	larvae	77	preferred	all year
Yellow perch	juv/adult	79	avoidance	all year
Alewife	juvenile	80	Maximum net biomass gain	all year
Smallmouth bass	adults	80.6	preferred	all year
Yellow perch	juvenile	81	preferred	all year
White sucker	juv/adult	81	preferred	all year
Smallmouth bass	juvenile	82	preferred	all year
Fallfish	juv/adult	82	avoidance	all year
Pumkinseed	adults	83	preferred	all year
Yellow perch	juv/adult	84	avoidance	all year
White sucker	juv/adult	84	optimum for growth	all year
American shad	juvenile	86	avoidance	May - October
Largemouth bass	adults	86	optimal for growth	all year
Pumpkinseed	adults	86	optimal for growth	all year
Largemouth bass	adults	87	avoidance	all year
Smallmouth bass	juvenile	87.8	preferred	all year
Alewife	juvenile	88	summer preferred	May - October
American shad	juvenile	88	optimal for growth	May - October
Pumpkinseed	adults	88	avoidance	all year
Largemouth bass	juvenile	89	preferred	all year
Pumpkinseed	juvenile	89	preferred	all year
Smallmouth bass	juv/adult	89.6	optimal for growth	all year
Largemouth bass	juvenile	90	avoidance	all year
Pumpkinseed	adults	90	preferred	all year
White sucker	juvenile	90	avoidance	all year
smallmouth bass	juv/adult	91.4	optimal for growth	all year
Smallmouth bass	juv/adult	95	avoidance	all year

Table 4. Results for the period May 2-May 8; 2006-2015 data set (source: Enercon 2016).

Index temperature	% Area covered between S0 and Hooksett Dam	Estimated Average Plume Thickness (ft.)	% Volume Encompassed by Plume between S0 and Hooksett Dam	Thermal Benchmarks Exceeded
55°F	0.48%	4.24	0.19%	1
59°F	0.05%	2.80	0.012%	3
64°F	0%	0	0%	N/A

Table 5. Results for the period June 9-June 15; 2006-2015 data set (source: Enercon 2016)

Index temperature	% Area covered between S0 and Hooksett Dam	Estimated Average Plume Thickness (ft.)	% Volume Encompassed by Plume between S0 and Hooksett Dam	Thermal Benchmarks Exceeded
73°F	0.27%	3.67	0.09%	5
77°F	0.01%	5.37	0.01%	8
80°F	0%	0	0%	N/A

Table 6. Results for the period July 29-August 4; 2006-2015 data set (source: Enercon 2016)

Index temperature	**% Area covered between S0 and Hooksett Dam**	**Estimated Average Plume Thickness (ft.)**	**% Volume Encompassed by Plume between S0 and Hooksett Dam**	**Thermal Benchmarks Exceeded**
80°F	3.47%	2.80	0.88%	4
83°F	0.72%	3.21	0.21%	10
87°F	0.02%	5.36	0.01%	16
89°F	0%	0%	0%	N/A

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APPENDIX C

Temperature Response Data for Merrimack Station RIS

Appendix Table C. Temperature Response Data for Merrimack Station RIS.

Temperatures at which thermal effects have been reported for Alewife.

Species: Alewife

	Temperature (F)				
Parameter	**Critical**	**Acclimation**	**Comments**	**References**	**Temperature Selection Rationale**
Max. for summer survival. or UILT	88-93	81	Adult	McCauley and Binkowski (1982)	90: Acceptable value based on reported ranges
	80-90		Young of year	Otto et al. (1976)	
	88	57-59	Yolk sac larvae	Kellog (1982)	
Optimum for growth	80		Maximum net biomass gain for YOY	Kellog (1982)	80: Single value available
Avoidance	72		Adult spring avoidance for spawning streams	Becker (1983)	84: Based on preferred summer Temps of adult and YOY fish -provides conservative estimate
	46		Adult spring avoidance for spawning streams	Becker (1983)	
Preferred	80		Adult- summer	Spotila et al. (1979)	84: Midpoint of adult and YOY ranges
	88		Young of year – summer	Spotila et al. (1979)	
	79		Preferred larval temperature	Kellog (1982)	
Spawning	48-54		Spawning migration – coastal NH	Scarola (1987)	60: Approx. midpoint of range
	59-68		Ripe adults present – Neuse River. NC	Bozeman and VanDenAvyle (1989)	
	51-71		Reported spawning range	Smith (1985)	
	80.6		Cease spawning	Bozeman and VanDenAvyle (1989)	
Early Life History	45-84		Range –egg incubation and development	Pardue (1983)	60: Conservative midpoint of Peak hatch and larval survival range
	64		Peak hatching temperature	Edsall (1970)	
	58-59		Peak survival of unfed larvae	Edsall (1970)	

Temperatures at which thermal effects have been reported for American Shad.

American shad

Parameter	Temperature (F) Critical	Temperature (F) Acclimation	Comments	References	Temperature Selection Rationale
Max. for summer survival, or UILT	90.5	75.2-82.4	Young experience rapid mortality.	Moss (1970)	90: single value available
Optimum for growth	50-88		Juv's found over this range in Conn. R. Apparent wide temp tolerance in rivers	Marcy et al. (1972) Stier and Crance (1985)	70: approximate mid-point of range
Avoidance	86		Avoided thermal plume, Conn. R.	Marcy (1976b)	86: single value available is reasonable considering max. for summer survival and temperatures at which juveniles were found by Marcy et al. (1972)
	46		Juveniles generally avoid temps. less than this. Juveniles begin emigrating from river when temps. drop below 60°F.	Marcy (1976b) Crance (1985)	
	50		Juveniles absent below this temp., had outmigrated from Conn. R.	Marcy (1976b)	
Preferred	60-70		Spend majority of time at these temps.	Leggett and Whitney (1972)	65: mid-point of range
Spawning	near 65		Peak movement of spawning run into rivers.	Leggett and Whitney (1972)	65: spawning, lower mid-range
	60-75		Approx. range- during passage by Vermont Yankee, fishway daily mean temps., 1998-2002.	Vernon Dam fishway data	
	46-79		Range- during spawning	Scott and Crossman (1973)	
	57-70		Peak spawning activity	Stier and Crance (1985)	
Early life history	50-86		Range- egg incubation, development	Scott and Crossman (1973)	70: egg, larval development
	60-80		Optimum for egg, larval development; Conn. R.	Marcy (1976b)	

Temperatures at which thermal effects have been reported for Atlantic Salmon.

Species: Atlantic salmon

	Temperature (F)				
Parameter	**Critical**	**Acclimation**	**Comments**	**References**	**Temperature Selection Rationale**
Max. for summer survival, or UILT	82	81.5	Juveniles (parr) No mortality below this temp.	Stanley and Trial (1995)	82: single value. Note that optimum parr habitat is not found in lower Hooksett Pool
Optimum for growth	59-66 72.5		Juveniles (parr) Maximum limit for feeding, parr	Stanley and Trial (1995)	Not Applicable: Preferred parr habitat not present.
Avoidance	N/A		No appropriate data found		78: It is assumed that the fish will avoid near-lethal temperatures.
Preferred	58		Juveniles (parr)	Stanley and Trial (1995)	Not Applicable: Preferred habitat not present.
Spawning	60-74		Approx. range- upriver passage at Vernon. fishway daily mean temps.. 1998-2002.	Vernon Dam fishway data	Not Applicable: Do not spawn in Merrimack. R. near Merrimack Station
	<73		Adults generally found to migrate to spawning grounds at or below temp.	Stanley and Trial (1995)	

Temperatures at which thermal effects have been reported for Smallmouth Bass.

Species: Smallmouth bass

Parameter	Temperature (F) Critical	Temperature (F) Acclimation	Comments	References	Temperature Selection Rationale
Max. for summer survival, or UILT	98.6	95	UILT, young and adults	Armour (1993a)	98: suggested UILT
Optimum for growth	89.6-91.4		MWAT for adequate juvenile and adult growth.	Armour (1993a)	90: mid-range
Avoidance	95-100	70-90	Juveniles	Peterson and Schutsky (1977)	95: Minimum of range
Preferred	73-82	80-82	Juveniles	Peterson and Schutsky (1977)	81: conservative temperature
	80.6		Adults	Armour (1993a)	
	86-87.8	75.2-86	Juveniles	Cherry et al. (1975)	
Spawning	59-70		Spawning, daily mean	Armour (1993a)	63: spawning.lower mid-range; incubation
	61-65		Most egg deposition	Scott and Crossman (1973)	
Early life history	59-77		Favorable hatching success	Armour (1993a)	70: hatching, early development

Temperatures at which thermal effects have been reported for Largemouth Bass.

Species: Largemouth Bass

	Temperature (F)				
Parameter	**Critical**	**Acclimation**	**Comments**	**References**	**Temperature Selection Rationale**
Max. for summer survival, or UILT	95-98	85	95F sublethal 98F lethal to 50% in <3 hours	Peterson and Schutsky (1977)	95: minimum of range
Optimum for growth	75-86		Adults, very little growth, <59 >97	Stuber et al. (1982)	83: slightly below maximum, lower than preferred
	81-86		Optimal for fry		
Avoidance	87-91	77		Meldrim and Gift (1971)	90: conservatively low
	90-99	80-84	Juveniles	Peterson and Schutsky (1977)	
	96		MWAT tolerance	Eaton and Scheller (1996)	
Preferred	86-89	79-82	Juveniles	Peterson and Schutsky (1977)	86: minimum of range in lab tests
	81		Final preferred temp. determined by sonic tagging	Coutant (1974)	
Spawning	68-70		Optimal	Stuber et al. (1982)	70: spawning
Early life history	55-79		Acceptable range Survival very low, <50 >86		75: incubation, early development

Temperatures at which thermal effects have been reported for Pumpkinseed.

Species: Pumpkinseed

Parameter	Temperature (F) Critical	Acclimation	Comments	References	Temperature Selection Rationale
Max. for summer survival, or UILT	94	77		Spotilat et al. (1979)	94: Single value
Optimum for growth	86		Fall captured, wild fish	Jobling (1981)	86: Single value
Avoidance	88		Adult fish, lab setting	Coutant (1977)	88: Single value
Preferred	83-90		Adult fish	Coutant (1977)	86: Approx. midpoint of adult and juvenile temps.
	89		Juvenile fish	Coutnat (1977)	
Spawning	55-63		Adult nest building	Becker (1983)	67: Single value for spawning activity
	67		Spawning activity	Becker (1983)	
Early life history	66-76.5		Hatching in 47 hours	Becker (1983)	71: Approx. midpoint of peak hatching temps.

Temperatures at which thermal effects have been reported for Yellow Perch.

Species: Yellow perch

Parameter	Temperature (F) Critical	Temperature (F) Acclimation	Comments	References	Temperature Selection Rationale
Max. for summer survival, or UILT	84-95		UILT- juveniles	Krieger et al. (1983)	90: UILT typically higher than upper avoidance and MWAT tolerance reported by Eaton and Scheller (1996)
	90		UILT- adults	Krieger et al. (1983)	
	84	77	UILT- adults, juveniles.	Wismer and Christie (1987)	
	85	72-75	UILT- larvae	Wismer and Christie (1987)	
Optimum for growth	72		MWAT	Wismer and Christie (1987)	74: within optimum range
	73-76		Optimum	Krieger et al. (1983)	
	50		Near the upper limit of low temp. period needed for maturation of eggs.	Krieger et al. (1983)	
Avoidance	79-84			Krieger et al. (1983)	83: upper mid-range
	84		MWAT tolerance	Eaton and Scheller (1996)	
	84-88	75-77	Upper avoidance	Wismer and Christie (1987)	
Preferred	64-77		Range- young, adults	Krieger et al. (1983)	77: approximate mid-range
	77-81		Range- young of year	Wismer and Christie (1987)	
Spawning	45-59		Range- spawning	Wismer and Christie (1987)	50: lower mid-range spawning
Early life history	45-68		Range- good incubation, hatching	Krieger et al. (1983)	65: incubation, hatching
	46-70		Ichthyoplankton collected over this range		

Temperatures at which thermal effects have been reported for Fallfish.

Species: Fallfish

Parameter	Temperature (F) Critical	Temperature (F) Acclimation	Comments	References	Temperature Selection Rationale
Max. for summer survival, or UILT	90		UILT	Trial et al. (1983)	90: single value
Optimum for growth	50-68		Apparent highest suitability; avg. temp. during warmest time of year	Trial et al. (1983)	68: reasonable to select maximum to evaluate warmest period of year
Avoidance	82		Seldom occur in waters with average above this temp.	Trial et al. (1983)	82: consensus temperature
	82		Upper avoidance	Scott and Crossman (1973)	
Preferred	Not Available				
Spawning	54		Nest building	Wismer and Christie (1987)	
	59-64		Spawning, usual range	Trial et al. (1983)	60: spawning
Early life history	61-64		Embryo incubation usually occurs		65: hatching, early development

Temperatures at which thermal effects have been reported for White Sucker.

Species: White sucker

Parameter	Temperature (F) Critical	Temperature (F) Acclimation	Comments	References	Temperature Selection Rationale
Max. for summer survival, or UILT	88	79	Adults, juveniles	Twomey et al. (1984)	88: at high acclimation temperature
Optimum for growth	75		Summer. Optimum temps may vary geographically; broad temp. tolerances.	Twomey et al. (1984)	81: within range, approximates preferred temperature
	54-84		Range	Wismer and Christie (1987)	
Avoidance	81		Larvae	Twomey et al. (1984)	86: approximate mid-range
	81		MWAT tolerance	Eaton and Scheller (1996)	
	90	75	Juveniles, lab tests	Peterson and Schutsky (1977)	
Preferred	73-77		Larvae	Twomey et al. (1984)	81: reasonable based on acclimation temperature
	81	77	Juveniles, lab tests	Peterson and Schutsky (1977)	
Spawning & early life history	50-68		Usual spawning range	Trautman (1957)	60: approximate mid-range, spawning, hatching 65: early development
	59		Max. hatching success; diminished <48 >63	Twomey et al. (1984)	
	57-71		Ichthyoplankton collected over this range		