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A PROBABILISTIC THERMAL MODEL OF THE MERRIMACK RIVER DOWNSTREAM OF MERRIMACK STATION

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1.0 INTRODUCTION

Public Service Company of New Hampshire's (PSNH's) Merrimack Station in Bow, New Hampshire ("the Station") is seeking a renewal of its existing variance under Section 316(a) of the Clean Water Act (CWA), 33 U.S.C. §1326(a), as part of its renewal of its existing National Pollutant Discharge Elimination System (NPDES) permit (NPDES Permit NH0001465; i.e., "the Permit"). The United States Environmental Protection Agency (EPA), in collaboration with the New Hampshire Fish and Game Department (NHFG) and the United States Fish and Wildlife Service (USFW) has indicated its intent to propose new thermal criteria that are more stringent than the §316(a) variance-based alternative thermal criteria presently contained in the Station's existing NPDES permit.

The Station's existing §316(a) variance, as evidenced by its NPDES permit, requires water temperature monitoring and reporting of the Station's thermal discharge and at selected upstream and downstream locations. Figure 1-1 shows the locations of these surface water temperature monitoring stations. Monitoring Stations N-5 (at the cooling water intake) and S-0 (at the cooling canal discharge) are operated year-round because the water remains ice-free there, while Monitoring Stations N-10 (upstream ambient) and S-4 (downstream from the cooling canal discharge) are removed in the fall when ambient temperature at N-10 falls below 40°F and re-installed in the spring when ambient temperature at Monitoring Station N-5 rises above 50°F, because winter and spring ice conditions in the Merrimack River make it technically infeasible to maintain monitoring equipment at these two in-river monitoring stations. The permit further requires the Station to operate its power spray module (PSM) system to "maintain either a mixing zone (Station S-4) river temperature not in excess of 69°F, or a Station N-10 (upstream ambient) to S-4 change in temperature (Delta T) of no more 1°F when ambient (N-10) river temperature exceeds 68°F" (EPA 1992). The PSM system is a series of spray nozzles located in the upper portion of the 0.74 mile long cooling canal that spray the cooling water from the canal into the air, providing approximately 2-4°F of cooling, prior to discharge into the Merrimack River. The permit requires all PSMs to be operated when the Monitoring Station S-4 river temperature measured at the surface exceeds both of the above criteria.

PSNH believes that implementation of more restrictive thermal criteria could severely impact the Station's ability to generate electricity, especially during critical, peak-demand, summer periods when the power in most needed, and is not warranted because the present limits are protective of the balanced indigenous population[s] ("the BIP") that reside within, or are migratory through, the receiving water body. The BIP have been the subject of monitoring studies since the 1960's (Normandeau 2007). However, the extent and duration of the Station's thermal influence in Hooksett Pool have not been fully quantified to date, due to the complex relationship between the downstream thermal regime in Hooksett Pool and Station electricity output, river flow, and upstream ambient river temperature. Accordingly, this report quantifies the thermal regime in lower Hooksett and upper Amoskeag Pools that is potentially influenced by the Station's cooling water discharge by 1) developing predictive methods for estimating downstream temperatures at Monitoring Stations S-0 (at the cooling canal discharge), S-4 (downstream from the cooling canal discharge) and A-0 (Hooksett Dam tailwaters) during the open water season; and 2) presenting these predicted data in time-correlated "probability of occurrence" tables and graphs for comparison of the thermal environment among the downriver water temperature monitoring stations.

The Merrimack River thermal regime is then evaluated for significance relative to three selected temperature thresholds: 86°F, 90°F and 95°F. These temperatures represent the mid-point of literature-reported values for limiting or exclusionary river water temperatures designated as the upper incipient lethal temperature (UILT) and the avoidance temperature values for several of the Representative Important Species (RIS) of fish found in Hooksett Pool (Normandeau 2007). The RIS are used as indicators of the BIP that reside within, or are migratory through, the receiving water body. These three water temperature values were selected to illustrate and interpret the complex interaction among Merrimack River flow, ambient water temperature, and Station generation revealed by the following hydrothermal analysis. Their selection was not intended to represent critical temperatures for all of the Station's RIS. A river water temperature of 86°F is reported as the mid-point of the range of avoidance temperatures for American shad and white sucker, two of the Station's RIS found in Hooksett Pool (Normandeau 2007). A river water temperature of 90°F is reported as the mid-point of the range of UILT temperature values for alewife, American shad, yellow perch and fallfish, and is the mid-point of the range of avoidance temperature for largemouth bass, additional Station RIS found in Hooksett Pool (Normandeau 2007). A river water temperature of 95°F is reported as the mid-point of the range of UILT temperature values for largemouth bass, and is the mid-point of the range of avoidance temperature for smallmouth bass, two of the Station's RIS found in Hooksett Pool (Normandeau 2007). Development and interpretation of thermal criteria for all of the Station's RIS and a habitat analysis of thermal effects for Hooksett Pool and upper Amoskeag Pool are presented in Normandeau (2007).

Finally, this report provides objective criteria for selecting 1) a compliance monitoring location and 2) the corresponding thermal limits based on the report's analysis of the thermal discharge in the receiving water body experienced by the BIP.

2.0 MERRIMACK STATION

Merrimack Station is located on the west bank of the Merrimack River in the Town of Bow, New Hampshire. It withdraws non-contact cooling water from, and discharges it back into, a reach of the river called Hooksett Pool (Figure 1-1). Hooksett Pool is formed by Hooksett Dam and Hydroelectric Station, which is one of three hydroelectric facilities in the immediate vicinity of the Station that are collectively known as the Merrimack River Hydroelectric Project (FERC No. 1893-NH). Garvins Falls Dam forms the upstream boundary of Hooksett Pool while Hooksett Dam forms the lower boundary. The Hooksett Dam tailwater is in the upper headpond of the Amoskeag Dam pool, which is the third component of the Merrimack River Hydroelectric Project. The Station is 2.9 miles downstream from Garvin Falls Dam, 2.9 miles upstream from Hooksett Dam and 10.7 miles upstream from Amoskeag Dam. All four power stations are owned and operated by PSNH.

The Station has two separate generating units, Unit 1 and Unit 2. Unit 1, which became operational in 1960, produces electricity at a rated capacity of 120 MWe. Unit 2, which became operational in 1968, was originally rated at 350 MWe, but now generates at 320 MWe. Both units withdraw once-through cooling water from separate cooling water intake structures (intake temperature represented by Monitoring Station N-5, Figure 1-1) in the Merrimack River adjacent to the Station. The intake structure for Unit 1 is located approximately 120 feet upstream from the intake structure for Unit 2. PSNH's normal operating mode, except for occasional maintenance shutdowns, is to operate both units at or near full power. Maintenance generally occurs during the early spring or late fall so that both units are available to meet peak demand during summer and winter months (Table 1-1). When both units are operating, total cooling water intake volume is approximately 397 cubic feet per second (cfs), which achieves a design Station maximum delta T of 25°F. After passing through the Station, cooling water from each unit is discharged from a common bulkhead into the upstream end of a 3,900 ft cooling canal. The cooling water becomes thoroughly mixed between the two units in the upstream portion of the cooling canal, and then flows downstream past 54 banks of four PSMs (216 total), which provide approximately 2-4°F of cooling prior to discharge into the Merrimack River. The downstream end of the cooling canal where the cooling water discharges into the Merrimack River is located on the west bank of Hooksett Pool about 0.5 miles downstream from the Station (represented by Monitoring Station S-0, Figure 1-1).

3.0 PREVIOUS ASSESSMENTS

The Station has monitored upstream ambient (Monitoring Station N-10), cooling water intake (Monitoring Station N-5), cooling canal discharge (Monitoring Station S-0) and downstream (Monitoring Station S-4) water temperatures in Hooksett Pool of the Merrimack River since the Station became fully operational in 1968. As described above, Monitoring Stations N-10 and S-4 are operated when ambient river temperature is greater than 40-50°F, while Monitoring Stations N-5 and S-0 are operated year-round. The maximum, minimum and mean average daily water temperatures measured at Monitoring Stations N-10, S-0 and S-4 for each day from 1 April to 1 November of each year from 1984 through 2004 are presented in Appendix A. Monitoring Station N-5 (cooling water intake) was not used in this analysis and is therefore not included in Appendix A. In addition, numerous thermal and biological studies have been conducted upstream and downstream of the Station since 1968 to establish baseline conditions and assess potential impacts from the Station's thermal discharges on Merrimack River biota (e.g., St. Anselm's College 1969; Saunders 1992; Normandeau 1979, 2006, 2007). Although certain of these studies have documented elevated temperatures in the lower Hooksett Pool and upper Amoskeag Pool, none has documented any appreciable harm to the BIP in the Merrimack River segment receiving the Station discharge.

4.0 MODELING APPROACH

This study used a probabilistic modeling approach to describe the relationship between ambient Merrimack River temperature, river flow, and Station electrical generation and predict average daily water temperatures at the Station's three downstream monitoring stations under different ambient water temperature and river flow conditions. First, multiple linear regression was used to develop equations capable of predicting water temperatures at Monitoring Stations S-0 (at the cooling canal discharge), S-4 (downstream from the cooling canal discharge) and A-0 (Hooksett Dam tailwaters) with a relatively high degree of confidence, using monitoring and plant generation data compiled by the Station and river flow and supplemental temperature data calculated from available U.S. Geological Survey data. Second, using long-term river flow and temperature data, the daily probability of occurrence for both river flow and ambient river temperature was determined for each day of the "open water" (i.e., 1 April to 1 November) time period.

The relationship between the Station's thermal discharge and the downstream water temperature in Hooksett Pool and tailwater is a complex function of ambient water temperature, river flow, Station generation (i.e., heat load to the river), cooling water intake and discharge volume, PSM operation and ambient meteorological conditions. Although water quality analysts often use a "worst case" mass balance approach to estimate the potential impact of a thermal discharge on a single or "limiting" set of conditions in the receiving waterbody, this approach is inappropriate for estimating the potential impact of the Station's thermal discharge on Hooksett Pool for three reasons. First, there are thermally-stratified conditions in the vicinity of Monitoring Station S-4 (downstream from the cooling canal discharge, and often designated as representative of the "mixing zone") that typically occur during key migratory and limiting mid-summer periods (Normandeau 1996, 2006a, 2006b). Second, significant cooling occurs in the discharge canal, before discharge to the river, because of the PSMs and radiation throughout the 0.74 mile length of the discharge canal. Third, fish are mobile and will avoid intolerable conditions delimited by the single "worst case," and the use of a single "limiting" set of conditions does not determine the duration of avoidance and loss of access to the habitat cumulatively throughout the year. The first two factors cause the thermal influence of the Station's discharge on the lower portion of Hooksett Pool and Hooksett Dam tailwaters to be complex and continually changing, requiring an empirical analysis as presented in this report to characterize the likelihood of occurrence of these conditions to address the third.

Normandeau originally used a similar empirical approach for predicting downstream temperature in the Merrimack River by developing a regression equation that correlated river temperature at Monitoring Station A-0 (Hooksett Dam tailwaters) to ambient river temperature, river flow and Station electrical output (Normandeau 1996). This predictive equation was developed using ten years (1985-1994) of spring (May and June) and fall (September and October) average daily data. The factors considered to be independent variables in the predictive equation (ambient river water temperature, river flow and electricity output) explained more than 99% of the variation in predicted downstream river water temperature at Monitoring Station A-0 (the dependent variable), with a coefficient of determination (r^2) of 0.9961 (r^2 is a statistical term that indicates how well the independent data is predicted by the dependent data, with a r^2 of 1.0 indicating a perfect fit and a r^2 of 0.0 indicating no predictive relationship). The Normandeau (1996) study provided several important conclusions relative to anadromous fish considerations during the spring (1 May to 30 June) and fall (1 September through 31 October) migratory periods, which were the focus of the analysis. First, it determined that based on actual flow and predicted temperature duration curves and literature-derived thermal tolerance data, the Station has a <1% probability of causing exceedences of upper optimal temperature criteria for upstream migrating Atlantic salmon, American shad and alewives from 1 May to 15 May and a <10% probability of causing exceedences from 15 May to approximately 10 June, at Station full power operations. Second, it determined that the probability of the Station causing an exceedence of upper optimal temperature criteria for downstream fall migration of juvenile shad and alewives is <10% from 1 September to 8 September, <3% for 9 September to 22 September and <1% after 22 September.

This present study expands upon Normandeau's 1996 study in several ways: 1) by increasing the modeling period to nearly the entire open water season (i.e., 1 April to 1 November); 2) by developing predictive equations for Monitoring Stations S-0 and S-4 as well as A-0; 3) by developing long-term, site-specific average daily river flow estimates; and 4) by expanding the ambient river temperature database to approximately 25 years of average daily temperature. These last two improvements in particular have improved the statistical reliability of this modeling analysis even further.

4.1 Calculated Site-Specific River Flow

The watershed area for the Merrimack River at the Station is approximately 2,535 sq. mi. River flow is not gaged at the Station, but flow is gaged about 15 miles downstream at Goffs Falls in Manchester (drainage area = 3,083 sq. mi., USGS Gage #01092000) and about 33 miles upstream at Franklin

Junction in Franklin (drainage area = 1,510 sq. mi., USGS Gage #01081500). In addition, there are several major tributaries flowing into the River between the Goffs Falls and the Franklin Junction gages (or in adjacent watersheds, as in the case of the Souhegan) where discharge is or has been gaged (the Contoocook River, USGS Gage #01088000, the mouth of which is about 18 miles upstream of the Station; the Soucook River, USGS Gages #01089000 and #01089100, about 3 miles upstream of the Station; the Suncook River, USGS Gage #01089500, about 0.5 mile downstream of the Station, the Piscataquog River, USGS Gage #01091500, about 12 miles downstream of the Station and the Souhegan River, USGS Gage #01094000, used to simulate the adjacent Piscataquog River). All gaging locations are shown in Figure 4-1.

Not all of these gages are currently operational. Furthermore, the period of record for each gage was generally concurrent for only a portion of the data set from one or more of the other gages. Table 4-1 shows the gaging period of record for each of the gages. Since statistical reliability and representativeness are often related to the temporal extent of the data set and the variability therein, it was desirable to use a database encompassing as many years as possible. The Franklin Junction gage spans slightly more than 100 years, but is missing more than 20 years of data from the late 70s, 80s and 90s. The Goffs Falls gage covers nearly 70 years (late 1936-present) and includes data for the 20+ years that are missing for the Franklin Junction gage. By comparing measured flow between the two gages during those times when both were collecting simultaneous data (1937-1977, and 2001-2004), it was possible to develop yield ratios (in this case, Goffs Falls flow = 1.88 x Franklin Junction flow) which then allowed a determination of estimated flow at each of gages where data were missing. For example, actual Goffs Falls flows were divided by 1.88 to estimate the probable flow at Franklin Junction for the missing data years of the late 70s, 80s and 90s. Similarly, Franklin Junction data for the 1903-1936 period was multiplied by 1.88 to estimate flow at Goffs Falls, since this gage was not operational until late 1936. In this way, a nearly complete 100+ year flow record (1903-2004) was generated for Franklin Junction and Goffs Falls.

Similar techniques were used to generate approximately 100 years of data for the Contoocook, Soucook, Suncook and Piscataquog Rivers. When available, comparably-sized, oriented and adjacent watersheds were used preferentially to generate yield ratios. For example, the Soucook River served as the surrogate for the Suncook River and vice versa, since their watersheds are adjacent to each other and are both west facing. The Souhegan River was used as a surrogate for the Piscataquog River because their watersheds are adjacent and east facing, even though the mouth of the Souhegan River is downstream of Goffs Falls. When data were lacking for the preferred surrogate, either Goffs Falls or Franklin Junction was used as the surrogate. Because of its more northerly location and higher watershed yield, Franklin Junction was only used to generate flow estimates when data were missing for all other surrogates.

Not all of the watershed between Goffs Falls and Franklin Junction is/was gaged. Of the 1,585 sq. mi. of watershed between the two gages, about 1,200 sq. mi. are accounted for with an actual or simulated gaging record, as shown in Appendix A. The remaining 385 sq. mi. of the watershed are ungaged. Of this amount, 128 sq. mi. are associated with existing gaged rivers (eg., the watershed of the Suncook River is 256 sq. mi. at the mouth, but only 157 sq. mi. is/was gaged). The flow contributions from these portions of the watershed were accounted for by multiplying the flow at the gage by the ratio of the watershed at the mouth to the watershed at the gage.

The remaining 257 sq. mi. of watershed are comprised of ungaged, small stream or non-stream, directly-contributing drainage areas. Contribution from these small point and non-point source areas was assumed to equal the watershed yield, on a yield per sq. mi. basis, of an adjacent gaged watershed or a combination of adjacent watersheds.

Using methods described above, a nearly 100-year database of either actual or estimated daily average streamflow data for each gaged and ungaged portion of the watershed between Goffs Falls and Franklin Junction, inclusively, was compiled. Three methods of determining Merrimack River flow at the point in Hooksett Pool where the Station intakes are located were then evaluated using these data:

- Goffs Falls gaging data, prorated or apportioned based on differences in watershed area by multiplying the Goffs Falls flow data by the ratio of the Station watershed to the Goffs Falls watershed (Method #1);
- Goffs Falls gaging data, adjusted by subtracting the gaged and estimated ungaged flows contributed by the watershed between the Station and Goffs Falls from the Goffs Falls flow data (Method #2); and
- Franklin Junction gaging data, adjusted by adding the gaged and estimated ungaged flows contributed by the watershed between Franklin Junction and the Station to the Franklin Junction flow data (Method #3).

Although these three methods produced results that were generally within 10% of each other, Method #2 is considered to be the best estimate of Merrimack River flow at the Station's intake structures. This is because the Method #2 estimate is influenced by a much smaller amount of non-gaged watershed (74.9 sq. mi.), compared to Method #3 (169.8 sq. mi.), and, unlike Method #1, it accurately accounts for lower watershed yields in the Suncook River and Piscataquog River watersheds (annually yield is 1.39 and 1.41 cfsm, respectively) as compared to the watershed yield at Goffs Falls (1.71 cfsm). Method #2 provides a watershed yield at the Station of 1.78 cfsm, which is consistent with expectations when combining the yields of the upriver gaging stations (Franklin Junction at 1.85 cfsm, Contoocook River at 1.46 cfsm and the Soucook River at 1.38 cfsm) with that of Goffs Falls (1.71 cfsm). Methods # 1 and 3 derived yields of 1.71 and 1.69 cfsm, both of which are considerable lower than expected yields. Consequently, all river flow evaluations at the Station were based on flow determinations using Method #2.

Merrimack River flows at the specific location of the Station were used for two purposes. First, the daily flow record that was commensurate with the available in-river temperature monitoring and Station electric output data (1984-2004) was compiled for use in the predictive modeling. Second, the entire 100 year flow record was used to generate daily probability of occurrence flow statistics for each day in the 1 April to 1 November evaluation period. To assure that the entire 100-year flow record was representative of likely future flow conditions at the Station, a trend analysis of the average annual flow values for each complete year of the record was performed. Figure 4-2 presents the average annual data and an associated trend line, determined by linear regression. Statistical analysis ("t test") of the regression equation indicated that the slope of the line was not significantly different from zero, at a 95% confidence level. Thus, it was concluded that the entire 100-year flow record was representative of probable future conditions.

4.2 Measured and Calculated Site-Specific Ambient River Temperature

Ambient average daily water temperatures for the Merrimack River were determined by two methods. First, all readily available upstream ambient Monitoring Station N-10 data were obtained from PSNH.

While this provided a fairly complete open water data base of 21 years (1984 – 2004), significant data gaps nonetheless existed for the 1984-1994 summer periods (early historic data are not computerized and therefore not readily available). To fill these data gaps and to provide as robust a database as possible, these data were supplemented with temperature data from another source. Data were obtained from USGS for two sites in Maine on the Androscoggin River and a regression equation was generated that allowed prediction of Monitoring Station N-10 temperatures from the Androscoggin River data. As expected, temperature data for the two rivers were highly correlated ($r^2 = 0.99$,) and the combination of the two allowed creation of a nearly complete 24-year database of Monitoring Station N-10 open-water ambient Merrimack River temperatures.

As with Merrimack River flows (Section 4.1 above), the Monitoring Station N-10 (upstream ambient) average daily Merrimack River water temperatures obtained from this 24-year database were used for two purposes. First, the daily water temperature record that was commensurate with the available Station river flow and electric output data (1984-2004) was compiled for use in the predictive modeling. Second, the entire 24-year temperature database was used to generate daily probability of occurrence temperature statistics for each day in the 1 April to 1 November evaluation period. As with river flow, a trend analysis was performed on the annual average (1 April to 1 November) Monitoring Station N-10 temperature to evaluate the "representativeness" of the dataset to predict future conditions (Figure 4-3). Although there is an apparent increasing trend in Monitoring Station N-10 water temperature, statistical analysis ("t test") of the regression equation found that the slope of the line is not significantly different from zero, at the 95% confidence level. Furthermore, this "trend" appears to be largely created by relative cool temperatures during the 1980s. If one evaluated just the 1990-2004 data, a slightly decreasing (and equally insignificant) trend would likely be determined. Thus it was concluded that the entire 24-year temperature database was representative of expected future conditions.

4.3 Modeling Results

Multiple linear regression was used to develop predictive equations for Monitoring Stations S-0, S-4 and A-0 from three independent variables – average daily river flow (cfs), average daily upstream (Monitoring Station N-10) river water temperature (°C), and Station net electrical output (MWe) – for which commensurate data from the 1984-2004 period were available for each independent and dependent variable. Monitoring Station S-0 and S-4 data were compiled from the Station's NPDES permit-required monitoring data, while Monitoring Station A-0 data were compiled both from biweekly sampling data collected during 1 May through 30 June and 1 September through 31 October 1995 (Normandeau 1996), and from continuously recorded temperature data collected during 24 May through 15 October 2002 as part of the FERC relicensing of the Merrimack River Hydroelectric Project. The equations developed for each Monitoring Station located at or downstream from the cooling canal discharge point (Monitoring Stations S-0, S-4, and A-0) are as follows:

$$\text{S-0} = (0.8282 * \text{N-10 TEMP}) + (0.01607 * \text{MW}) + (0.000051 * \text{FLOW}) + 7.64778 \qquad r^2 = 0.8926$$

$$\text{S-4} = (0.9864 * \text{N-10 TEMP}) + (0.0070 * \text{MW}) - (0.00012 * \text{FLOW}) + 1.7876 \qquad r^2 = 0.9359$$

$$\text{A-0} = (0.9864 * \text{N-10 TEMP}) + (0.004349 * \text{MW}) - (0.0005395 * \text{FLOW}) + 4.23944 \qquad r^2 = 0.9765$$

Where: N-10 TEMP = average daily temperature at upstream ambient Monitoring Station N-10 (°C)
MW = Merrimack Station average daily electrical output (MWe)
FLOW = average daily river flow at Merrimack Station (cfs)

It can be seen that the coefficient of determination (r^2) value for the Monitoring Station A-0 (Hooksett Dam tailwaters) equation is higher (i.e., better) than the r^2's for either of the predictive equations developed for Monitoring Stations S-0 (at the cooling canal discharge) or S-4 (downstream from the cooling canal). This means that the most reliable predictions of downstream Merrimack River water temperature, as a function of upstream river water temperature, thermal discharge from the Station, and river flow, can be made for the monitoring location (i.e., Monitoring Station A-0) in the thoroughly mixed water at the foot of Hooksett Dam (Figure 1-1). Figure 4-4 presents a graphical comparison of the predictability of water temperature at each of the downstream monitoring stations, represented by the amount of "scatter" or spread of predicted values about the predictive equations. The reason for the observed differences in r^2's among downstream monitoring stations is apparent in Figure 4-4, which shows that the scatter of data points associated with Monitoring Station S-0 is clearly greater than the data scatter associated with Monitoring Station S-4, which in turn is greater than the data scatter associated with Monitoring Station A-0. This analysis confirms that the thermally influenced Merrimack River water temperature is most reliably predicted at Monitoring Station A-0, as compared to the predictions from Monitoring Stations S-0 and S-4, when using Monitoring Station N-10 river water temperature (upstream ambient), plant output and river flow as the independent variables.

The differences among the downstream monitoring stations in the amount of variation attributable to the factors in the regression equations can be explained as follows. Monitoring Station S-0 (at the cooling canal discharge) is independent of river flow during normal river flows and more directly affected by the operation of the PSMs, which, depending on ambient atmospheric conditions (most notably wet bulb temperature, which is a measure of humidity), may be variably effective. At higher river flows, Monitoring Station S-0 also becomes inundated by river water which introduces additional uncertainty about the reliability of Monitoring Station S-0 to predict either effluent or river temperature.

Monitoring Station S-4 (downstream from the cooling canal discharge) is not as strongly correlated to the independent variables as Monitoring Station A-0 (Hooksett Dam tailwaters) because lower Hooksett Pool is often and variably thermally stratified due to river flow, atmospheric heating and cooling of the surface water and the Station's thermal discharge. Water temperature monitoring during May-June and September-October of 1995 (Normandeau 1996) consistently found strong horizontal and vertical stratification at Monitoring Station S-4.

Monitoring Station A-0 is located immediately downstream of the Hooksett Dam. Due to water flow through the turbines under low to moderate flows and turbulent flow over the dam under higher flows, conditions at Monitoring Station A-0 are well-mixed and therefore are most reliably predictive of the contribution of the Station's thermal discharge to the thermal regime of the river as compared to Monitoring Stations S-0 or S-4. Well-mixed conditions at Monitoring Station A-0 were consistently observed during 1995 temperature monitoring study (Normandeau 1996).

4.3.1 Probabilistic Modeling of Ambient Conditions

The regression equations presented in the preceding section predict the expected downstream thermal impact of the Station with a reasonably high degree of accuracy, depending on the monitoring station, where ambient river temperature and river flow conditions are known and specified. Prospectively, there are essentially an infinite number of combinations of river flow and temperature during any annual 1 April to 1 November period. A probabilistic modeling approach provides the best method of determining the likelihood of occurrence of a particular combination of river flow and temperature during this time period (assuming Station electrical output at full power) without having to physically model each possible combination. Such an approach is more robust and broadly applicable than a traditional modeling approach such as CORMIX which typically describes expected near-field downstream thermal impact under a single set of "limiting" input conditions. In fact, there may be many sets of limiting conditions whose defining parameters may vary with time (season), river flow and temperature. A probabilistic model allows one to easily explore the significance of many combinations of input parameters whereas a traditional model does not.

More particularly, the probabilistic modeling approach used in this study was designed to address two basic questions: (1) what is the probability of occurrence of Merrimack River water temperature and flow that, when combined with the Station thermal discharge, would cause the temperature measured at some location downstream of Merrimack Station to equal or exceed a particular temperature on a particular day during the 1 April to 1 November evaluation period, and (2) what is the probability of occurrence of ambient and Station discharge conditions that would cause an exceedence of biologically significant temperatures (upper incipient lethal temperature (UILT) and the avoidance temperature values for the Station's RIS designated for Hooksett Pool) on any given day during the evaluation period.

To answer these two questions, Normandeau used the long-term river flow and upstream ambient temperature data generated as described above, and determined the joint probability distribution of both flow and temperature for each day of the evaluation period (in this case, 1 April to 1 November). By "joint probability," this study means that the likelihood of occurrence of a given daily river water temperature is conditioned on the likelihood of occurrence of a given daily river flow. These distributions allowed the selection and interpretation of relevant combinations of flow and temperature (for example, the 1 June river flow and ambient temperature that would each be equaled or exceeded 50% of the time) to determine the likelihood that a particular downstream river temperature would be exceeded at each monitoring station on a particular day.

Figure 4-5 presents the probability distribution for Merrimack River flow at the Station for the 1 April to 1 November evaluation period. Three curves are presented for illustrative purposes: 90%, 50% and 10% probabilities of exceedance, which respectively provide the flows that would have a 90%, 50% or 10% chance of being exceeded on a particular day. For example, Figure 4-5 shows that on 1 May, there is a 90% probability that river flow will exceed about 5,000 cfs, a 50% chance that it will exceed 9,000 cfs, and only a 10% probability that flow would exceed 20,000 cfs. By 1 June, expected river flows drop to about 2,500 cfs, 5,000 cfs, and 10,000 cfs respectively for 90, 50 and 10% probabilities of exceedance. By 1 September, there is a 90, 50 and 10% probability, respectively, that river flow will exceed 1,000 cfs, 2000 cfs and 3,500 cfs.

Figure 4-6 presents a similar analysis for upstream ambient river temperature as measured at Monitoring Station N-10. On 1 May, there is a 90% chance that temperature will exceed 47°F, a 50% chance of exceeding 50°F and only a 10 % probability of exceeding 55°F. By 1 June, these exceedance temperatures rise to 57°F, 63°F and 69°F, respectively, for the 90, 50 and 10% probabilities of exceedance, and by 1 September, there is a 90, 50 and 10% probability, respectively, that upstream ambient temperature will exceed 67°F, 72°F and 76°F.

Since Merrimack River water temperature at and downstream from the Station's discharge canal is primarily dependent on three factors - river flow, upstream ambient temperature and the thermal contribution of the Station's discharge evaluation of the probability of occurrence of a particular downstream temperature (at a particular monitoring station and on a particular day) must consider the joint probability of occurrence of both river flow and ambient temperature (also in a particular location and on a particular day) for each condition of Station discharge (i.e., Unit 1, Unit 2, or both operating at full power). However, there are an infinite number of such combinations of flow and temperature and a resulting significant variability in downstream temperature response that can be expected for various combinations of probabilities of exceedance of ambient temperature and river flow. For illustrative purposes, we arbitrarily selected two different days, 1 June and 1 August, and Monitoring Station A-0, to provide an example of how to evaluate the joint probabilities when both of the Station's units are operating. The results are displayed in Table 4-2. On 1 June, expected downstream water temperatures at Monitoring Station A-0 (Hooksett Dam tailwaters) range from 55.7°F to 75.0°F, depending on which combination of ambient temperature and river flow is selected. Thus, it can be expected that the 1 June temperature at Monitoring Station A-0 could vary by as much as 20°F, depending on the year. For 1 August, the range is considerably less, but expected Monitoring Station A-0 temperatures still vary between 74.8°F and 85.9°F, a difference of more than 11°F. Historically then, these data show that downstream river temperature on any particular day has varied considerably from year to year and may be expected to continue to do so in the future.

Thus, the particular combination of upstream ambient water temperature and river flow probabilities of occurrence plays a critical role in determining the observed downstream river water temperature influence from the Station thermal discharge among the different monitoring stations. To focus this study's analysis, two "biologically significant" events were selected as the basis for the evaluation. First, the simultaneous median occurrence of flow and temperature (i.e., the event in which a particular temperature and river flow each would be equaled or exceeded 50% of the time) was selected as the "typical" case (i.e., the "median scenario"). Then, a more extreme case (i.e., the event in which there is a 10% probability of exceeding a particular high ambient temperature and a 10% probability of river flow being less than a particular low flow) was selected as the "extreme, seldom exceeded" case (i.e., the "extreme scenario"). Because the joint probabilities of exceedance for independent events are multiplicative, the median scenario actually has a joint probability of occurrence nominally representing an event happening one year out of every four. Similarly, the extreme scenario has a joint probability of occurrence nominally representing an event happening one year out of every 100 years. Each case is considered to have biological significance for the following reasons. The median scenario represents the typical flow and ambient temperature conditions within which aquatic ecosystems have evolved. In fact, USFW's New England Flow Policy uses median low-flow conditions during the summer, fall/winter and spring to define in-stream minimum flow requirements on the grounds that "[o]ver the long term, stream flora and fauna have evolved to survive these adversities without major population changes" (Lang 1999). The extreme scenario is considered to be biologically significant because it describes an adverse or limiting combination of river flow and ambient temperature that would be seldom expected, but within which the aquatic ecosystem must still survive to remain viable. The present study provides an analysis of the median and extreme scenarios below in Sections 4.3.2 and 4.3.3, respectively, but it should be recognized that many other combinations of river flow and upstream ambient temperature, both with reasonably frequent probabilities of occurrence, could have been selected.

4.3.2 Probabilistic Modeling of Median Conditions (50% Probability of Occurrence of both River Flow and Ambient Temperature)

Figure 4-7 presents the predicted daily downstream temperatures that would occur under the median scenario, i.e., if both Merrimack River flow and upstream ambient temperature were at median probabilities of occurrence and both units of the Station were operating under normal full load conditions. Having both units operating at full generation adds a degree of conservatism to the probabilistic modeling approach because the predicted daily temperatures derived are from the maximum thermal load from the Station for each day in the 1 April to 1 November period, even though one or the other generating unit is occasionally off-line for maintenance during portions of the evaluation period. Four data curves are presented, one representing upstream ambient water temperature or "control" conditions that were predicted without the influence of the Station's thermal discharge (i.e., Monitoring Station N-10), and the remaining three representing the downstream water temperature predicted at each of the monitoring stations influenced by the thermal discharge (i.e., Monitoring Stations S-0, S-4 and A-0). Each curve in Figure 4-7 provides the expected temperatures for each day of the evaluation period (1 April to 1 November). The curves in Figure 4-7 show that under median conditions of ambient temperature and river flow and normal full load operation of the Station, the 1 May temperature at Monitoring Stations N-10, S-0, S-4 and A-0 would respectively be about 50°F, 75°F, 57°F and 50°F. By 1 June, the expected Monitoring Stations N-10, S-0, S-4 and A-0 temperatures have respectively risen to 62°F, 85°F, 70°F and 67°F. Temperatures at the monitoring stations respectively reach maximums of about 77°F, 97°F, 84°F and 83°F by about 22 July and decline thereafter. By 1 September, expected temperatures at Monitoring Stations N-10, S-0, S-4 and A-0 are respectively 72°F, 92°F, 80°F and 78°F.

Figure 4-7 can also be examined to see how expected temperatures at the various downstream monitoring stations compare under this median scenario to the three critical threshold temperatures for the Station's RIS that are presented and interpreted in Normandeau (2007). These temperatures represent the mid-point of literature-reported values for limiting or exclusionary river water temperatures designated as the upper incipient lethal temperature (UILT) and the avoidance temperature values for several of the Station's RIS of fish found in Hooksett Pool, variously determined to be 86°F, 90°F and 95°F. In particular, the period of times when predicted water temperature exceeds the threshold values can be determined. From Figure 4-7, it can be seen that only Monitoring Station S-0 (discharge end of the cooling canal and representative of the cooling water effluent at the point of discharge) is expected to exceed 86°F during the evaluation period, under median scenario conditions. Monitoring Stations N-10, S-4 and A-0 (each representative of in-river conditions) are not predicted to exceed 86°, even during the late July – early August time period. Monitoring Station S-0 is also expected to exceed both 90°F and 95°F under the median scenario, but the durations of exceedence are respectively reduced with increasing temperature.

The predicted number of days and percent of total number of days of exceedence at each monitoring station and for median and extreme conditions of ambient river flow and water temperature is presented in Appendix B. Under the median scenario, it can be seen that Monitoring Station S-0 water temperatures are expected to exceed 86°F for 105 days, 90°F for 81 days and 95°F for 14 days, out of a total of 214 days during the 1 April to 1 November evaluation period. There are no days of exceedence of these three limiting water temperatures for Monitoring Stations N-10, S-4 or A-0.

4.3.3 Probabilistic Modeling of Extreme Conditions (10% Probability of Occurrence of Both High Ambient Temperature and Low River Flow)

The results presented in the preceding section (Section 4.3.2) were for the median scenario representing the 50% likelihood of occurrence of river flow and ambient water temperature. Other combinations of river flow and ambient water temperature would have different probabilities of occurrence. In an attempt to provide a reasonable bound to the continuum of expected downstream thermal impact of the Station's discharge, as noted above, this study also evaluated an extreme scenario representing the joint 1% likelihood of exceeding both low river flow and high ambient water temperature (i.e., a "10%-10%" occurrence event). Although this is an extreme scenario with an infrequent (one in 100 year) probability of occurrence, it provides a reasonable estimate of limiting or upper threshold river water temperatures during the 1 April to 1 November period in lower Hooksett and upper Amoskeag Pools.

Figure 4-8 presents the daily Merrimack River water temperatures predicted for each of the three downstream thermal discharge-influenced monitoring stations (i.e., Monitoring Stations S-0, S-4 and A-0) for the extreme scenario. As with the median scenario (Section 4.3.2 above), the Station is conservatively assumed to be operating under normal full load conditions. A fourth curve representing the upstream ambient water temperature or "control" conditions that was predicted without the influence of the Station's thermal discharge (i.e., Monitoring Station N-10) is also presented for the extreme scenario for comparison with the three thermally influenced stations. Each of the four curves in Figure 4-8 provides the expected temperatures for each day of the evaluation period (April 1 to November 1). On 1 May, temperatures at Monitoring Stations N-10, S-0, S-4 and A-0 are predicted to be about 54°, 78°, 62° and 59°F, respectively, for the extreme scenario. By 1 June, the expected Monitoring Stations N-10, S-0, S-4 and A-0 temperatures have risen, respectively, to 69°F, 90°F, 77°F and 75°F for the extreme scenario. Predicted river water temperatures reach maximums of approximately 81°F, 99°F, 89°F and 87°F for Monitoring Stations N-10, S-0, S-4 and A-0, respectively, for the extreme scenario during the early July to early August period and decline thereafter. By 1 September, expected temperatures at Monitoring Stations N-10, S-0, S-4 and A-0, respectively, are 75°F, 94°F, 82°F and 81°F for the extreme scenario.

Figure 4-8 can also be examined to determine the period of time when predicted water temperature exceeds the threshold values presented above. From Figure 4-8, it can be seen that all Monitoring Stations except N-10 are expected to exceed 86°F during the evaluation period, for extreme scenario conditions. However, only Monitoring Station S-0 is expected to exceed either 90°F or 95°F for the extreme scenario, which means the in-river Monitoring Stations S-4 and A-0 are expected to remain under 90°F, even under extreme conditions of high ambient river water temperature and low river flow.

From Appendix B, it can be seen that Monitoring Station S-0 water temperatures are expected to exceed 86°F for 134 days, 90°F for 102 days and 95°F for 67 days, out of a total of 214 days during the 1 April to 1 November evaluation period for the extreme scenario. Monitoring Stations S-4 and A-0 are expected to exceed 86°F for 53 and 20 days, respectively, but these exceedences would only occur during the months of July and August. There would be no days of exceedence of 90°F at either Monitoring Station S-4 or A-0 for the extreme scenario.

5.0 OBJECTIVE CRITERIA FOR SELECTION OF A COMPLIANCE MONITORING LOCATION AND THERMAL CRITERIA

Merrimack Station's current NPDES permit contains water temperature monitoring requirements for two in-river (Monitoring Stations N-10 and S-4) locations and an "end of pipe" effluent location (Monitoring Station S-0). It not known what monitoring requirements may be imposed by EPA in the new permit. This report provides objective criteria for selecting both a location and the corresponding thermal limits for compliance monitoring that are representative of the thermal discharge in the receiving water body experienced by the BIP. In this Section we examine the appropriateness of using each of the three "downstream" Monitoring Stations (S-0, S-4, or A-0) for compliance monitoring and describe how these results can be used as guidance for selection of appropriate thermal criteria.

Monitoring Station S-0 (at the end of the cooling canal) is largely representative of the effluent, but it is not representative of in-river thermal conditions. Furthermore, at high river flow, this monitoring station becomes inundated, and therefore is differentially influenced by river water and is not directly representative of the effluent. This high-flow inundation, when combined with variable effectiveness of the PMSs noted above, is the primary reason why the regression equation developed for Monitoring Station S-0 in Section 4.3 has the lowest coefficient of variation of the three predictive equations developed for this report. A low coefficient of variation indicates that Monitoring Station S-0 is not reliably representative of the Station effluent at all times during the 1 April to 1 November period of each year. As an "end of pipe" location, water temperatures measured at Monitoring Station S-0 also do not reliably represent the conditions experienced by the BIP in Hooksett Pool or in upper Amoskeag Pool. Therefore, river water temperatures observed at Monitoring Station S-0 are not representative of the potential impacts of the Station's thermal discharge.

Monitoring Station S-4 (downstream from the cooling canal discharge) is frequently and variably stratified during the open water period and therefore is not consistently representative of in-river water temperatures experienced by the BIP in lower Hooksett Pool. Thermal stratification at Monitoring Station S-4 varies daily, and even within the day, as river flow changes due to upstream hydroelectric generation, atmospheric heating and cooling of the surface water, and the Station's thermal discharge. Daytime stratification places the warmest portion of the Station's thermal discharge near the river surface where it receives additional heating from solar input (Normandeau 1996). Temperature monitoring during May-June and September-October of 1995 (Normandeau 1996) confirms the observed strong horizontal and vertical thermal stratification at Monitoring Station S-4. However, since most of the fish in Hooksett Pool orient towards the river bottom habitat, the surface water temperatures observed at Monitoring Station S-4 do not measure the thermal conditions experienced by the Station's RIS (Normandeau 2007).

Monitoring Station A-0 is located in the tailwaters immediately downstream of the Hooksett Dam. Due to water flow through the turbines under low to moderate flows and turbulent flow over the dam under high flows, conditions at Monitoring Station A-0 are well-mixed and therefore are most reliably predictive of the contribution of the Station's thermal discharge to the thermal regime of the river as compared to Monitoring Stations S-0 or S-4. Well-mixed conditions at Monitoring Station A-0 were consistently observed during 1995 temperature monitoring (Normandeau 1996). Consequently in-stream temperature monitoring at Monitoring Station A-0 would most accurately reflect whole-river temperatures downstream of the Station and therefore the potential impacts of the Station's thermal discharge on the BIP. Furthermore, it can be seen in both Figures 4-7 and 4-8 that Monitoring Station

A-0 closely tracks temperatures at Monitoring Station S-4, although at about 2°F less. This indicates that monitoring at Monitoring Station A-0 would serve as an excellent surrogate for Monitoring Station S-4, but with somewhat greater accuracy (as indicated by the r-square values of the regression equations) and better representation of whole river, completely mixed conditions. Monitoring Station A-0 could also record temperature year-round, due to its location in the ice-free Hooksett Dam tailrace, whereas Monitoring Station S-4 can only be operated in the ice free seasons. It is therefore concluded that thermal compliance monitoring at Monitoring Station A-0 best ensures that the Station's §316(a) variance-based thermal criteria will assure the protection and propagation of a balanced, indigenous population of the BIP in the Merrimack River.

With respect to thermal criteria, this report describes the existing thermal conditions in Hooksett Pool and upper Amoskeag Pool both upstream and downstream of the Station and graphically presents probability of exceedence of water temperature at various locations for each day during the entire 1 April to 1 November period. Certain water temperatures (86°F, 90°F and 95°F) were selected from among the range of exclusionary thermal effects parameters for the Station's RIS of fish (Normandeau 2007) to illustrate and interpret the complex interaction among Merrimack River flow, ambient water temperature, and Station generation revealed by the hydrothermal analysis. These three selected temperatures are not intended to represent limiting water temperatures for all of the RIS. Instead, they represent the mid-point of literature-reported values for limiting or exclusionary river water temperatures designated as UILT and avoidance temperature values for several of the RIS found in Hooksett Pool (Normandeau 2007). The thermal effects parameters described for each of the Station's RIS can be evaluated by plotting a horizontal reference line for the appropriate water temperature and time period on Figures 4-7 and 4-8 and examining the proximity of this reference line to the probability of exceedence curves for the upstream ambient (Monitoring Station N-10) or thermally influenced (Monitoring Stations S-0, S-4 and A-0) compliance locations.

This hydrothermal analysis reveals that Merrimack River in-stream water temperatures in the vicinity of the Station have not exceeded and are not predicted to exceed the selected in-river, RIS-specific threshold temperatures represented by median conditions during the biologically relevant timeframes. Since Merrimack Station has proposed no change in its thermal discharge, it is concluded that the existing thermal environment has assured, and in the future will continue to assure, the protection and propagation of the BIP in the Merrimack River segment receiving the Station's thermal discharge. The analysis presented in this report provides a conservative and technically sound basis for establishing as compliance criteria in-stream water temperature limits that appropriately track the seasonal pattern of change in water temperature in the thermally influenced portion of Hooksett Pool and upper Amoskeag Pool, and allow Merrimack Station to continue its present mode of operation while assuring the protection and propagation of the BIP.

6.0 SUMMARY AND CONCLUSIONS

A probabilistic modeling approach was undertaken to describe the relationship between ambient Merrimack River temperature, river flow, and Merrimack Station electrical generation to predict average daily water temperature at three different downstream monitoring stations. Multiple regression equations were derived that explained between 89% and 98% of the variation among the dependent variables (depending on the downstream monitoring station examined) and were capable of predicting water temperature at Monitoring Stations S-0 (cooling canal discharge), S-4 (downstream from the cooling canal discharge) and A-0 (fully mixed waters in the Hooksett Dam tailwaters) with an increasing high degree of confidence and reliability. The regression equations used river water temperature monitoring and plant generation data compiled by Merrimack Station and river flow and selected temperature data derived from U.S. Geological Survey monitoring data. Using long-term river flow and temperature data, the daily probability of occurrence for both river flow and temperature was determined for each day of the open water (1 April to 1 November) time period. By combining the predictive regression equations and the probabilistic river flow and temperature models, potential exceedences of the river water temperatures were evaluated for three downstream locations under median (50%-50%) and extreme (10%-10%) scenarios selected among an infinite continuum of possible conditions to represent biologically relevant "typical" or "average" conditions and "rare" or "limiting" conditions, respectively.

Based on the results of this evaluation, the following conclusions can be made:

- Thermal conditions downstream of Merrimack Station are largely determined by upstream ambient conditions, as evidenced by the derived regression equations.
- Merrimack River water temperature was most reliably predicted at Monitoring Station A-0 (Hooksett Dam tailwaters), less so at Monitoring Station S-4 (downstream from the cooling canal discharge), and least so at Monitoring Station S-0 (at the cooling canal discharge). Variable diel and seasonal thermal stratification at Monitoring Station S-4 reduced predictive ability of the regression equation for this monitoring location. Variable cooling efficiency of the PSMs (occurring before the discharge water temperature is measured at Monitoring Station S-0), and river flow inundation of Monitoring Station S-0 during high flows, both contribute to the reduced predictive ability of the regression equation for Monitoring Station S-0.
- Monitoring Station S-0 water temperature is representative of an "end of pipe" effluent temperature of the Station's discharge at the cooling canal discharge point (except at higher river flow), but it is not representative of downstream, in-river thermal conditions that influence the BIP. River water temperature at Monitoring Stations S-4 and A-0 are both substantially modified by river flow, while temperature at Monitoring Station S-0 is largely independent of river flow except in high river flow conditions when Monitoring Station S-0 becomes inundated and no longer representative of "end-of-pipe" conditions.
- Under "typical" or "average" river temperature and flow conditions (the median scenario), with a joint probability of occurrence of one year out of every four years, the probabilistic regression model predicts that maximum water temperatures at Monitoring Stations N-10, S-0, S-4 and A-0 will not exceed 77°F, 97°F, 85°F or 84°F, respectively, for the 1 April to 1 November evaluation period. Under "rare" or "limiting" river temperature and flow conditions (the extreme scenario), with a joint probability of occurrence of one year out of every 100 years, the maximum water temperatures are predicted to be 81°F, 99°F, 89°F and 87°F, respectively, at Monitoring Stations N-10, S-0, S-4 and A-0.
- Water temperature monitoring to ensure that the Station's §316(a) variance-based alternative thermal criteria will assure the protection and propagation of the BIP in the section of the Merrimack River that is influenced by the Station's thermal discharge is best achieved by in-river monitoring at Monitoring Station A-0 (Hooksett Dam tailwaters) rather than effluent monitoring at Monitoring Station S-0 (at the cooling canal discharge) or in-river monitoring at Monitoring Station S-4. It is recommended that Monitoring Station A-0 be used as the compliance monitoring location for the Station because river water temperatures at Monitoring Station A-0 are most representative of completely mixed in-river conditions. It should be noted that temperatures measured at

Monitoring Station A-0 closely "track" temperatures at Monitoring Station S-4, but with less variability and at a reduced temperature of about 2ºF. Consequently, compliance monitoring at Monitoring Station A-0 achieves a more reliable compliance record while still maintaining the value of the historic monitoring record at Monitoring Station S-4.

- Previous studies have documented that current operations of the Station have not caused any appreciable harm to the balanced indigenous population of resident and migratory fish and other aquatic organisms in the River segment receiving the Station discharge (Normandeau 2006 and 2007). Since historic thermal conditions have been protective of the BIP, it is recommended that historic, in-river temperatures form the basis of the NPDES permit compliance criteria.

7.0 REFERENCES

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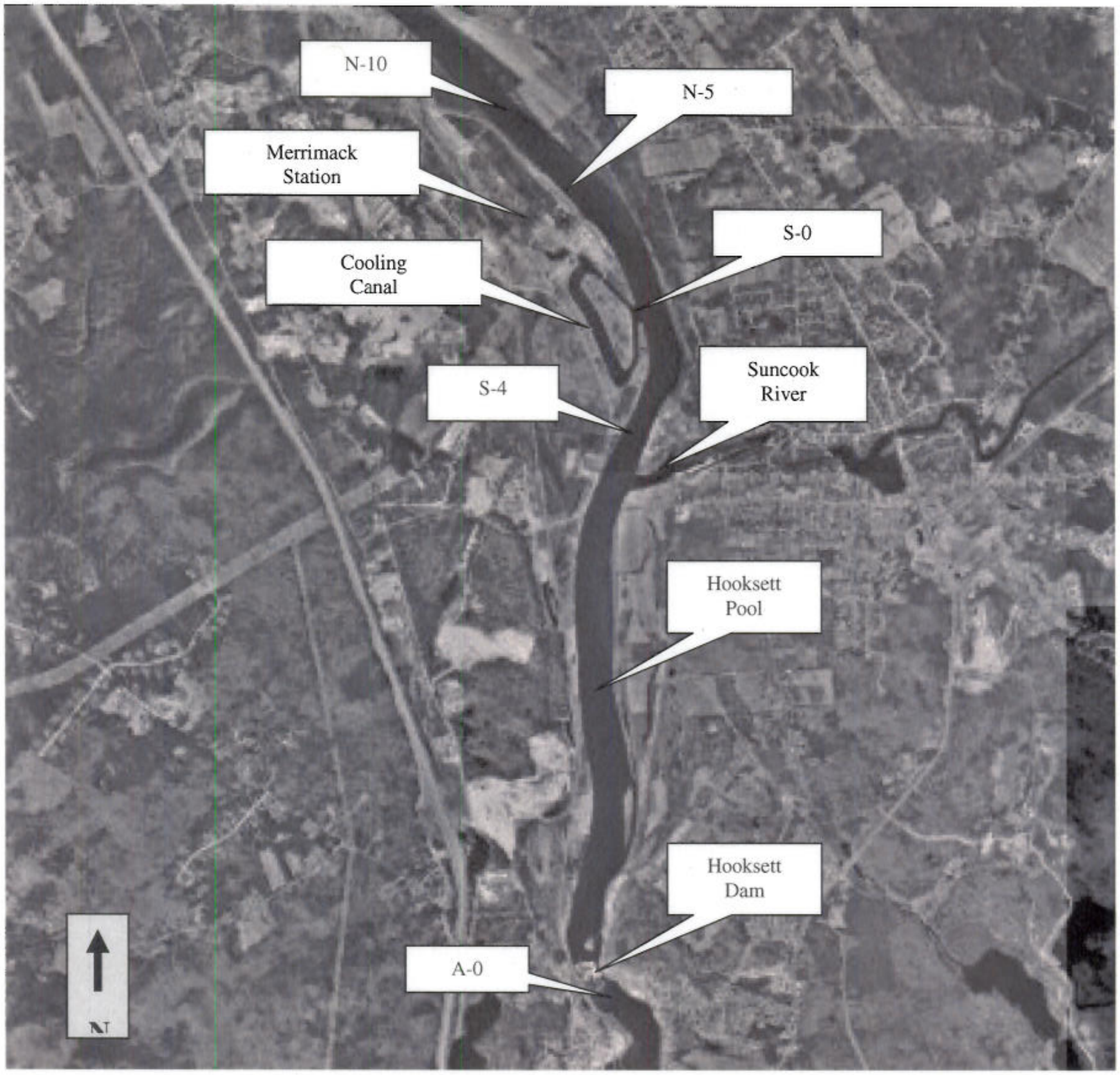
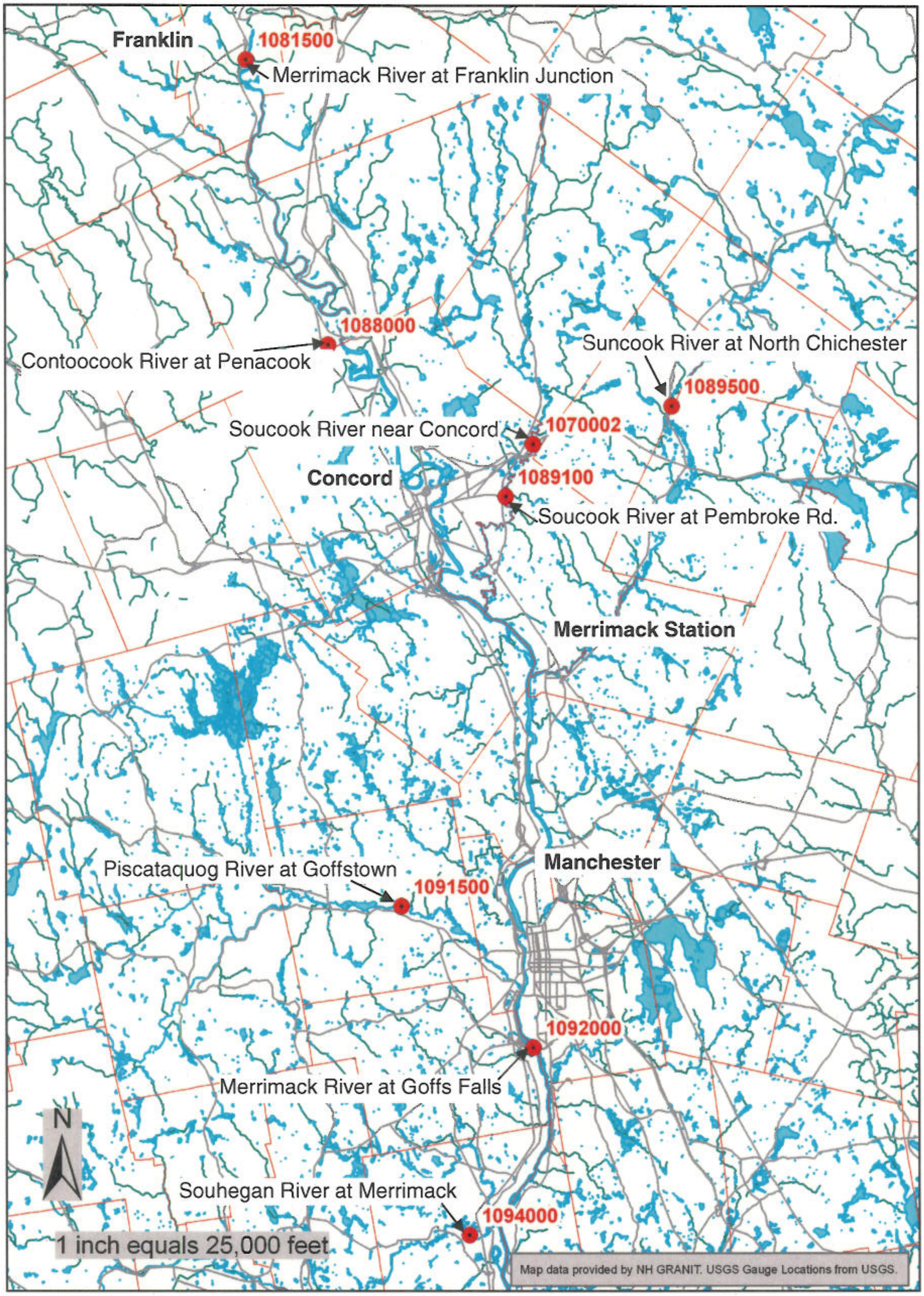


Figure 1-1. Merrimack River Temperature Monitoring Station Locations in the Vicinity of Merrimack Station in Bow, New Hampshire.



Map data provided by NH GRANIT. USGS Gauge Locations from USGS.

Figure 4-1. USGS Gaging Station Locations in the Upper Merrimack River Watershed.

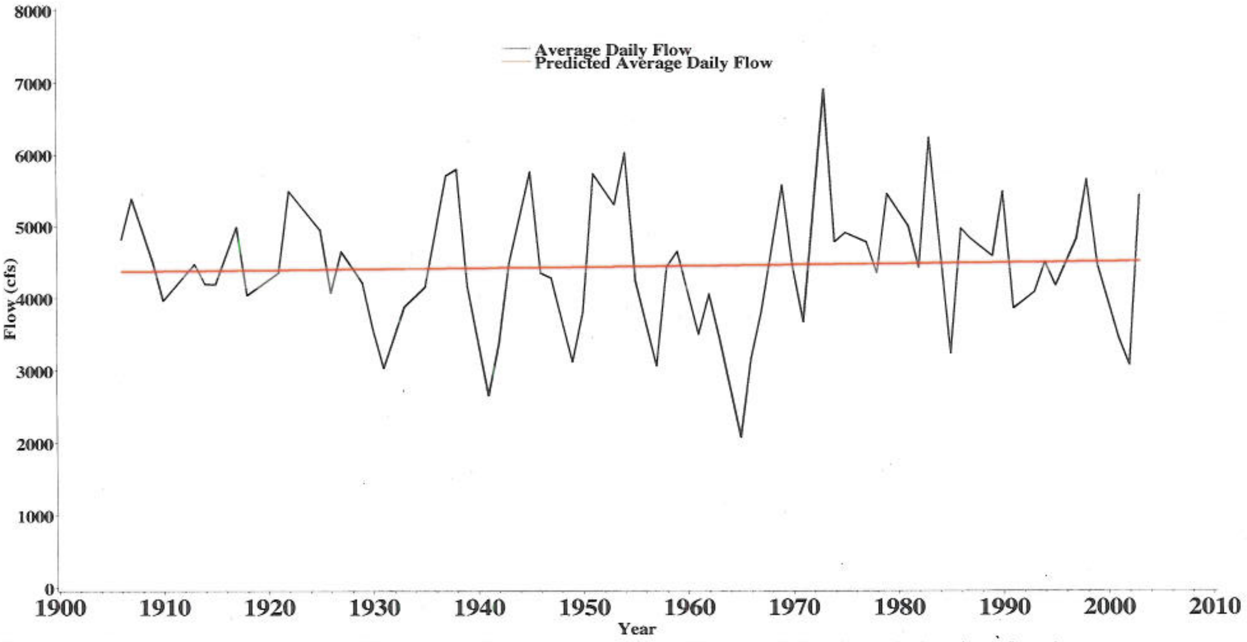


Figure 4-2. Average Annual Estimated Merrimack River Flow at Merrimack Station for the period 1903 through 2004.

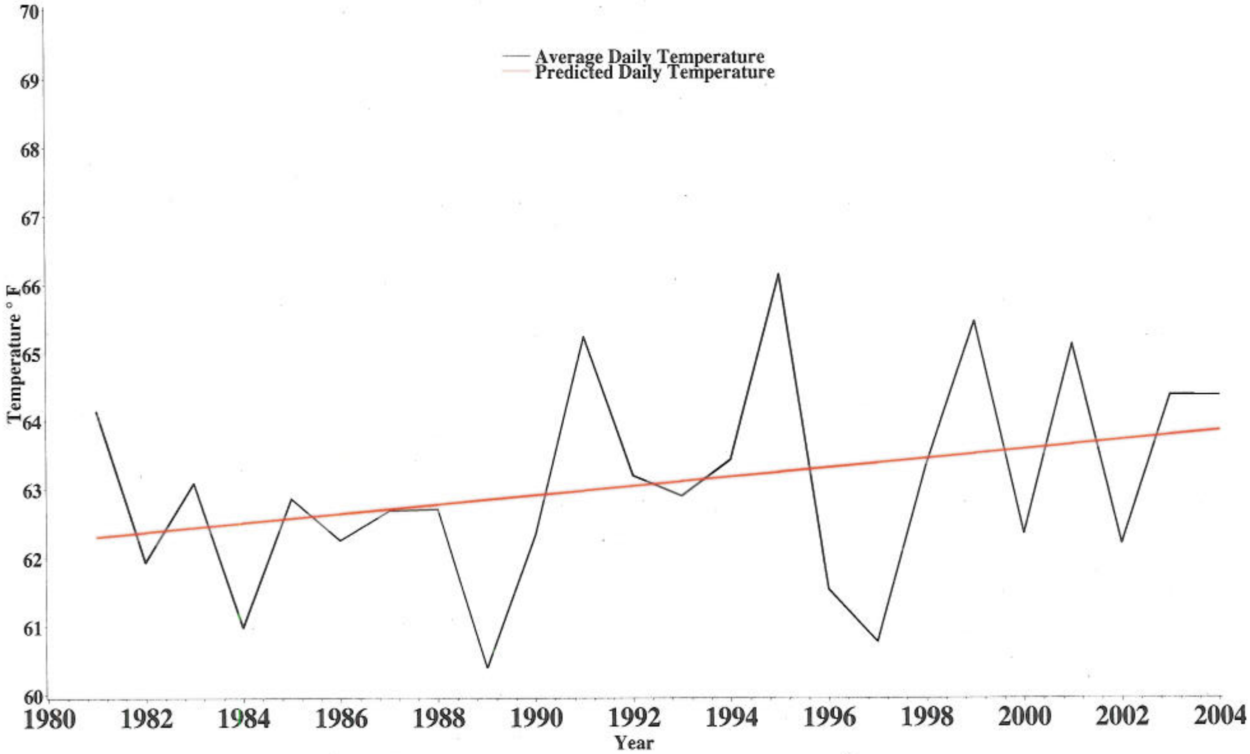
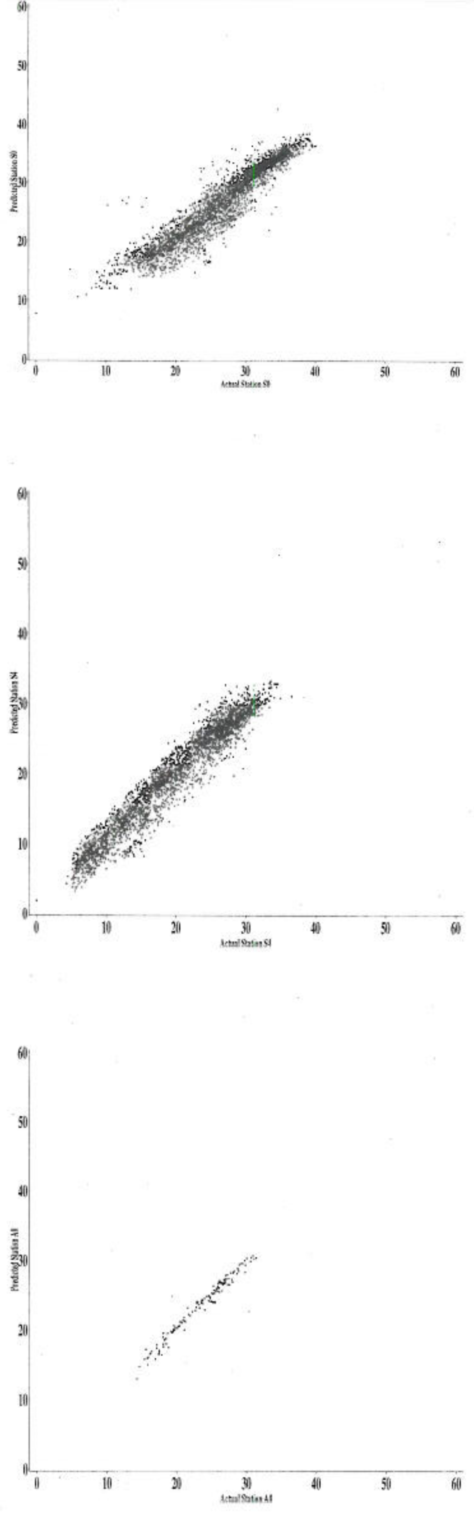


Figure 4-3. Average 1 April to 1 November Measured and Projected Upstream Ambient (Monitoring Station N-10) Merrimack River Water Temperature for the period 1981 through 2004.



Station S-0
r^2 =0.8927

Station S-4
r^2 =0.9359

Station A-0
r^2 =0.9765

Figure 4-4. Comparison of the Scatter of Observed Daily Water Temperature Data About Multiple Regression Equations Developed to Predict Merrimack River Water Temperature at Downstream Monitoring Stations S-0, S-4, and A-0 Using Ambient Temperature, Merrimack River Flow and Merrimack Station Generation.

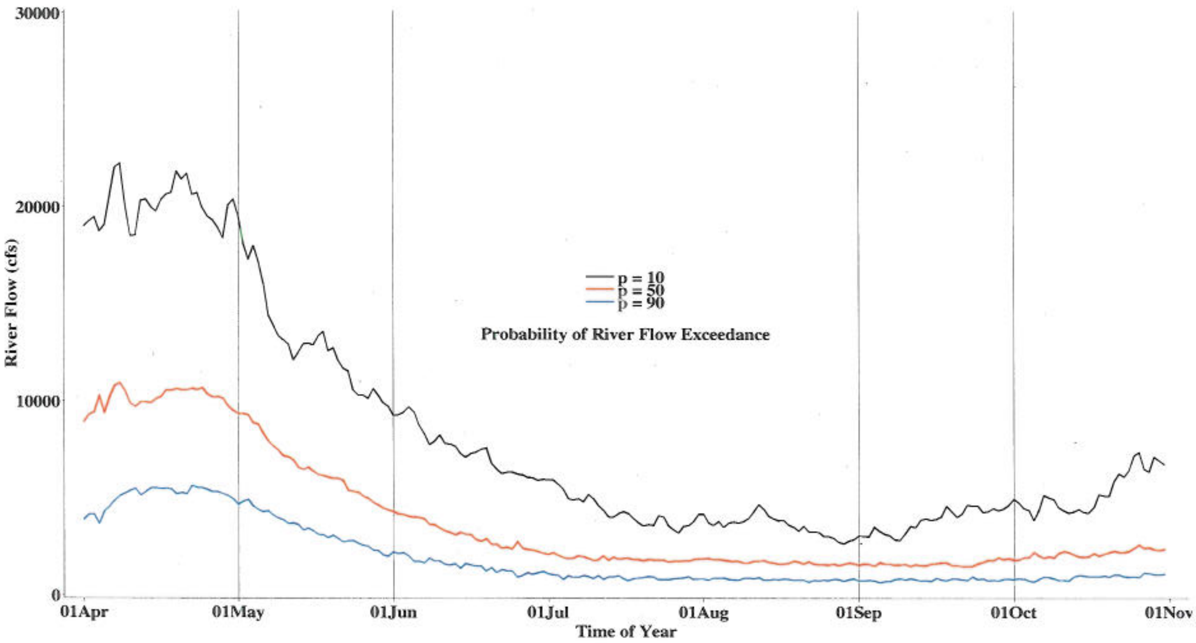


Figure 4-5. Expected Daily Merrimack River Flow at Merrimack Station.

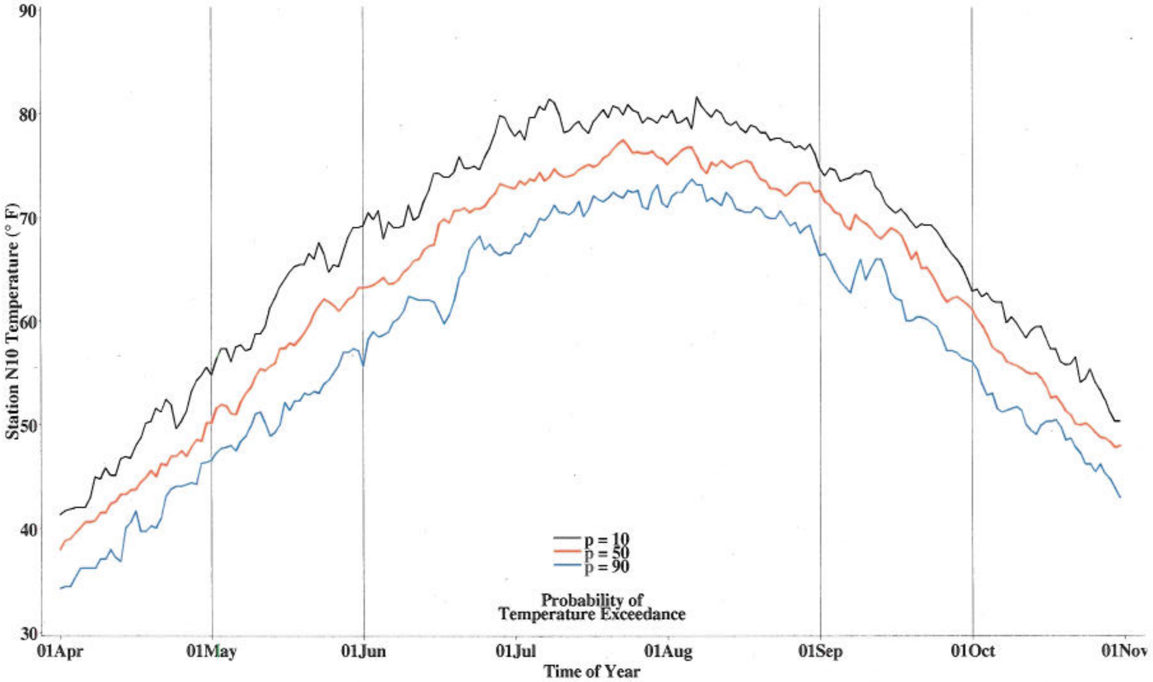


Figure 4-6. Expected Daily Merrimack River Water Temperature at Upstream Ambient Monitoring Station N-10.

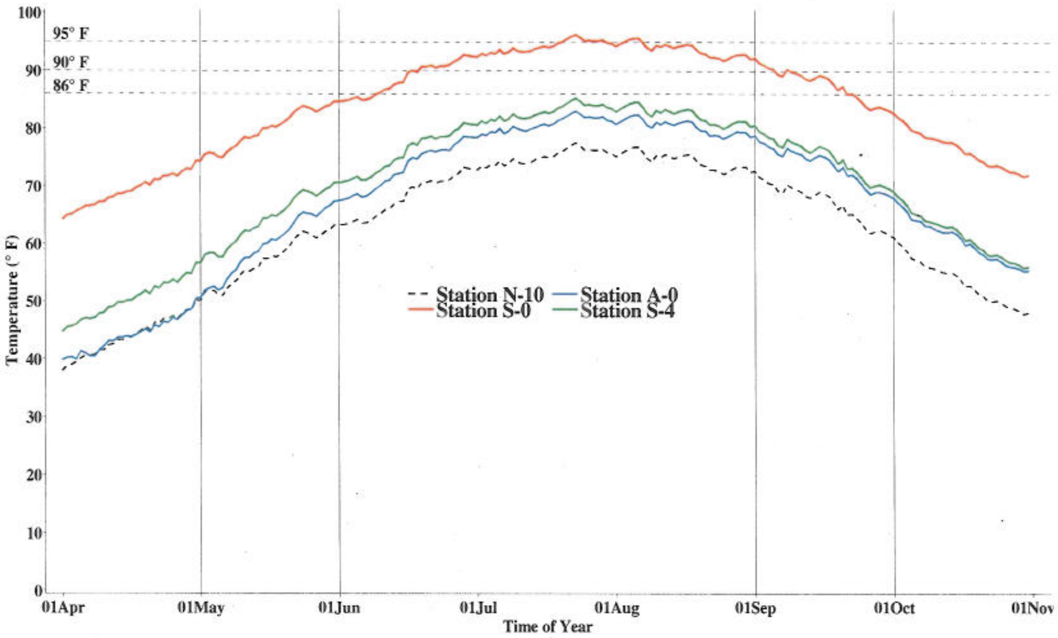


Figure 4-7. Expected Merrimack River Temperature at Upstream Ambient Monitoring Station N-10, and Predicted Temperature at Downstream Monitoring Stations S-0, S-4 and A-0 for the Median (50%-50%) Scenario.

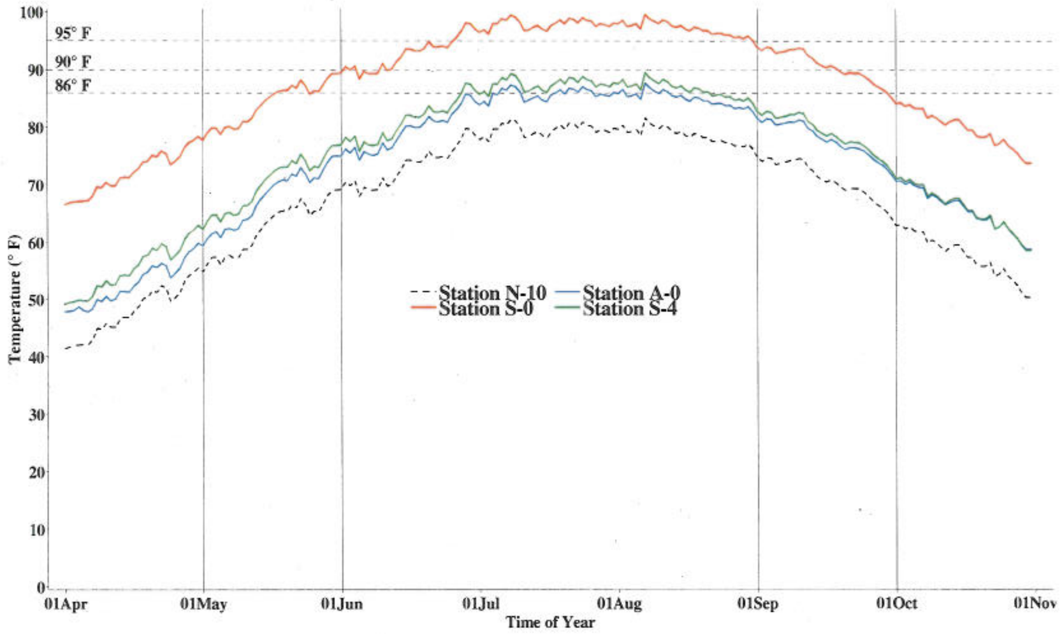


Figure 4-8. Expected Merrimack River Temperature at Upstream Ambient Monitoring Station N-10 and Predicted Temperature at Downstream Monitoring Stations S-0, S-4, and A-0 for the Extreme (10%-10%) Scenario.

Table 1-1 Recent (1996-2004) Historic Monthly Total Electric Power Production at Merrimack Station (MWe).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	386.1	377.5	320.9	182.6	237.6	410.7	379.2	408.1	398.0	300.1	414.4	361.0
2003	367.2	419.1	340.3	106.1	173.5	381.0	280.1	389.3	360.4	411.6	378.1	412.5
2002	405.5	325.4	385.3	242.0	172.5	361.4	357.0	378.5	274.3	244.8	329.5	364.2
2001	406.0	378.4	352.1	296.5	108.6	284.0	307.2	327.2	388.6	374.9	373.7	313.7
2000	332.2	362.1	361.6	205.8	254.6	389.9	374.4	370.3	361.2	417.8	370.8	337.4
1999	395.8	274.3	259.3	328.2	260.7	171.1	331.4	303.1	108.0	384.6	387.4	407.7
1998	408.7	372.2	105.3	184.7	343.1	341.4	361.0	370.6	347.7	285.2	295.5	390.5
1997	286.7	366.3	412.4	372.1	428.0	411.8	420.3	431.0	391.7	412.4	412.6	429.8
1996	378.0	324.3	335.8	431.6	389.6	428.0	404.7	400.8	316.1	260.5	178.4	357.9
Ave.	385.9	358.5	303.5	220.8	221.5	334.2	341.5	363.9	319.8	345.5	364.2	369.6

Table 4-1. Stream Gaging Record for Selected Merrimack River Watershed Gages.

Station	1903-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2004
Souhegan River-Merrimack	minimal	complete	complete	complete	complete	complete	complete	partial	none	none	nearly complete
Merrimack River-Goffs Falls	none	none	none	partial	complete	complete	complete	complete	complete	complete	complete
Piscataquog River-Goffstown	none	none	none	minimal	complete	complete	complete	partial	none	none	none
Suncook River-North Chichester	none	partial	nearly complete	complete	complete	complete	complete	none	none	none	none
Soucook River-Concord	none	none	none	none	none	partial	complete	complete	nearly complete	complete	complete
Contoocook River-Penacook	none	none	partial	complete	complete	complete	complete	partial	none	none	none
Merrimack River-Franklin Junction	nearly complete	nearly complete	complete	complete	complete	complete	partial	none	none	partial	complete

Table 4-2. Predicted Temperature Response at Monitoring Station A-0 (Hooksett Dam tailwaters) to Varying Conditions of Time, Ambient River Temperature and River Flow when Merrimack Station is Generating at Normal Full Power Operation.

Day	Ambient River Temperature – °F (Probability of Exceedance p = %)	River Flow – cfs (Probability of Exceedance p = %)	Downstream Station A-0 – °F
1 June	55.7 (ρ=90)	9,268 (ρ=10)	55.7
		4,311 (ρ=50)	60.6
		2,234 (ρ=90)	62.6
	63.2 (ρ=50)	9,268 (ρ=10)	62.7
		4,311 (ρ=50)	67.5
		2,234 (ρ=90)	69.5
	69.3 (ρ=10)	9,268 (ρ=10)	68.2
		4,311 (ρ=50)	73.0
		2,234 (ρ=90)	75.0
1 August	71.1 (ρ=90)	9,268 (ρ=10)	74.8
		4,311 (ρ=50)	77.0
		2,234 (ρ=90)	78.0
	75.2 (ρ=50)	9,268 (ρ=10)	78.5
		4,311 (ρ=50)	80.8
		2,234 (ρ=90)	81.8
	79.7 (ρ=10)	9,268 (ρ=10)	82.7
		4,311 (ρ=50)	84.9
		2,234 (ρ=90)	85.9

APPENDIX A

Historical Maximum, Minimum and Mean Average Daily Temperature as Measured at Merrimack Station Monitoring Stations N-10, S-0 and S-4 and Predicted at Monitoring Station A-0 during the 1 April to 1 November period of 1984-2004

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

		Station N-10			Station S-0			Station S-4			Station A-0		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Apr	**1**	37.2	40.2	41.4	36.5	60.5	73	41.4	45.5	49.1	37.2	42	46.7
	2	38.8	40.9	42.4	40.5	59.9	67.6	43	45.8	49.3	38.8	43.2	47.6
	3	39	40.7	41.9	48.6	59.6	68.4	42.4	45.7	49.6	39	43.3	47.5
	4	38.5	42	54.7	54.3	60.9	66.6	42.1	45.9	49.8	38.5	49.4	60.4
	5	38.7	42.3	52.3	54.3	61	73.8	38.7	44.7	50.7	38.7	48.1	57.6
	6	38.3	42.4	51.6	55.6	61	73.9	39.6	45	52	38.3	47.7	57.2
	7	37.9	42.6	54.7	51.1	61.2	71.2	41.5	45.8	54	37.9	49.2	60.4
	8	37.6	43.4	55.2	52.9	61.6	70.3	42.8	46.6	55.6	37.6	49.1	60.6
	9	37.4	44.2	55.9	57.2	62.4	70.9	43.7	47.6	56.8	37.4	49.6	61.8
	10	38.8	44.6	54.1	54.9	62.2	68.7	42.8	48.2	56.7	38.8	49.3	59.8
	11	38.1	43.8	54.5	42.4	61.9	80.4	42.8	48	55.6	38.1	49.3	60.5
	12	37.2	43.9	56.8	52.2	62.2	80.4	42.4	47.7	54	37.2	49.7	62.3
	13	36.9	43.5	54.3	50.7	63.2	81	41.7	47.7	53.2	36.9	49	61.1
	14	37	43.7	54	51.3	62.9	74.1	41.2	48	52.7	37	48.2	59.5
	15	37.6	44.4	55.8	53.1	62	72.9	41.4	48.3	52.5	37.6	49.3	61.1
	16	38.7	44.9	57	53.4	62.7	71.2	42.8	48.7	53.4	38.7	50.5	62.3
	17	39.6	45.2	57	53.4	63.1	70.7	41	48.9	54.3	39.6	51.1	62.6
	18	39.2	45.9	59.9	51.1	63.4	72.5	40.8	49.4	54.3	39.2	52.4	65.6
	19	40.3	46.1	54.7	47.8	64.2	73.6	41.7	49.6	55	40.3	50.5	60.7
	20	40.1	46.4	52	50.5	64.2	72.1	43.7	50	55.4	40.1	49.2	58.2
	21	41	47.1	53.1	52.5	64.3	72.3	44.4	50.7	55.9	41	50.1	59.3
	22	42.6	47.3	52.5	53.2	64.6	73.4	44.8	50.5	54.9	42.6	50.4	58.3
	23	41.9	47.3	52.7	51.6	65.2	73.2	45	50.6	54.9	41.9	50.4	58.8
	24	42.3	47.2	51.8	53.8	66.1	72.3	45.7	50.5	55	42.3	50.1	58
	25	43	47.3	51.1	54.7	66.7	75.6	46.6	50.7	55.8	43	50	57
	26	43.5	47.1	51.3	52.2	66.4	75.7	47.1	50.6	55.6	43.5	50.4	57.3
	27	43.5	47.8	54.1	52.2	66.1	75	47.5	50.9	56.7	43.5	51.8	60.1
	28	44.2	48.4	55.2	49.1	67.3	77.2	47.7	51.7	59.2	44.2	52.8	61.3
	29	44.2	49	56.1	55.8	68.1	80.6	47.3	52.3	60.1	44.2	53.1	62
	30	44.6	49.7	55.6	57.6	69	83.1	47.8	53.1	60.8	44.6	53	61.4

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

		Station N-10			Station S-0			Station S-4			Station A-0		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
May	1	44.8	50.6	57	63.5	70.7	83.3	47.3	53.9	60.4	44.8	54.1	63.3
	2	44.2	51.7	59.2	59	69.8	81.5	46	54.4	59.7	44.2	54.5	64.8
	3	44.2	52.1	59.7	61.7	69.2	79.2	45.9	54.8	60.6	44.2	54.7	65.1
	4	45.5	52.3	58.3	58.6	69.5	80.4	47.1	55.1	61.3	45.5	55.1	64.7
	5	45.1	52.7	60.4	58.1	70.4	80.8	47.8	55.3	62.8	45.1	55.8	66.5
	6	45.5	52.6	61.7	52.9	69.3	81.1	47.7	55.4	63.9	45.5	56.6	67.8
	7	47.1	53.2	61.7	52.9	70.5	81.1	50.4	55.8	64	47.1	57.2	67.3
	8	46	53.5	61.9	55.6	71.4	81.1	50.9	56	64.2	46	56.9	67.8
	9	45.9	53.9	63.7	59.2	72.9	82	51.8	56.7	66	45.9	58	70.1
	10	45.3	54.5	63.5	60.1	72.4	83.3	51.6	57.2	65.7	45.3	57.6	69.9
	11	45.9	55.1	62.4	61.7	73	83.1	50.9	57.6	64.9	45.9	57.5	69.2
	12	46	55.8	64.4	61.2	73.5	83.3	48.4	57.7	66	46	58	70
	13	46.2	55.8	64.4	57.6	73.9	82.6	46.4	57.9	66	46.2	58	69.8
	14	46.9	56	64.2	61.9	75.2	83.7	46.8	58.8	70.7	46.9	58.9	70.9
	15	48.4	56.9	64.6	66.6	75.6	84.6	48.6	59.5	69.4	48.4	59.4	70.5
	16	48	57.5	65.7	67.5	75.9	84.4	50	60.1	67.6	48	60	71.9
	17	49.8	58	65.8	62.8	75.8	84.4	50.5	60.7	69.3	49.8	61	72.3
	18	50.4	58.6	66	61.9	75.6	84.2	51.6	61.3	70.7	50.4	61.4	72.4
	19	49.5	58.8	68.5	68	76.4	87.8	51.8	61.9	71.8	49.5	62	74.5
	20	49.8	59.5	70.7	70.3	77.2	89.2	52.3	62.1	73.2	49.8	63.1	76.5
	21	49.6	60.1	69.8	68.5	77.3	90.7	51.8	62.2	73.4	49.6	62.7	75.8
	22	50.4	60.4	68.9	69.8	77.5	87.6	52.2	62.5	71.1	50.4	62.7	74.9
	23	51.4	60.6	69.3	65.3	77.2	87.3	54.5	62.7	72	51.4	63.5	75.5
	24	52	60.8	70	67.6	77.8	90.3	55	63.1	74.8	52.7	64.5	76.2
	25	52.5	60.6	71.8	66.2	79.4	93.9	53.4	63.1	78.8	52.5	65.1	77.6
	26	50.9	60.7	72.1	61.9	79.5	92.8	51.8	62.9	81.7	50.9	64.5	78
	27	51.3	60.7	71.1	64.9	78.1	90.7	52.3	63.1	84.2	51.3	64.2	77.1
	28	52.9	61.3	71.2	63.9	77.9	91.4	54.3	63.6	81.1	52.9	65	77.2
	29	54.7	62	72.3	64	78.5	93	56.3	64.3	81.5	54.7	66.5	78.3
	30	56.3	62.9	72.9	68.4	79.3	93.2	56.8	65	84	56.3	67.5	78.7
	31	57.2	63.4	71.4	69.8	80.7	91.4	57.6	66.2	84.6	57.2	67.4	77.6

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

		Station N-10			Station S-0			Station S-4			Station A-0		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Jun	1	51.1	63.7	74.5	68.5	82.3	93.7	52.9	66.6	82	51.1	65.5	79.9
	2	58.3	64.7	73	68.5	82.7	93.2	53.1	67.2	77.9	58.3	68.7	79.1
	3	59	64.5	72.5	71.1	82.6	91.9	53.8	66.2	76.8	59	68.8	78.7
	4	52	63.9	71.2	73	82.7	90.3	55.4	67.3	81.7	52	64.6	77.2
	5	54	63.9	70.3	71.8	81.6	88.5	56.1	67.3	80.1	54	65.2	76.4
	6	55	63.7	70.9	70	80.6	89.4	59.9	67.1	79.9	55	66.1	77.2
	7	54	63.9	72.9	65.5	79.7	90.3	61.9	66.6	77.9	54	66.6	79.2
	8	55.9	64.8	75	68	80.4	91.8	59	67.4	79.5	55.9	68.4	80.9
	9	61	65.9	74.5	66.2	82.1	90.9	60.4	68.4	80.8	61	70.8	80.6
	10	62.4	66.5	73.8	65.5	82.7	92.1	61.7	69.1	82.6	62.4	71.3	80.2
	11	61	66.7	74.5	64.4	83.7	94.1	61.5	70.1	86.9	61	71	81
	12	62.1	66.8	75.2	64.4	84	94.3	61.2	70.4	88.3	62.1	71.7	81.4
	13	61.7	66.9	74.3	64.8	83.1	93.9	62.6	70.5	87.8	61.7	71.2	80.7
	14	60.8	67.3	75.6	66.6	82.8	92.1	63.3	71.1	81.5	60.8	71.4	82
	15	59.2	67.8	75.4	67.5	84.3	92.8	62.6	71.6	83.8	59.2	70.4	81.7
	16	56.7	68.5	75.7	69.1	84.9	94.1	61.3	72.2	83.5	56.7	69.4	82.1
	17	58.3	69	75.2	70.7	85	94.5	62.1	73.2	83.7	58.3	69.8	81.4
	18	59.9	69.2	76.5	71.8	85	96.3	63.5	74.4	85.6	59.9	71.4	82.8
	19	61.9	69.8	77.9	72.3	84.9	96.6	65.8	74.3	83.8	61.9	72.9	83.9
	20	62.6	70.4	77.5	74.7	84.8	94.1	66.6	75.5	86.9	62.6	73.1	83.7
	21	64.6	71	77.7	76.1	85.9	94.8	68.4	76.2	85.5	64.6	74.3	83.9
	22	66	71.2	77.5	77.7	86.5	95	70.5	76.4	83.3	66	74.9	83.7
	23	65.8	71.4	76.8	77.2	86.9	93.2	70.3	76.4	84.9	65.8	74.4	83
	24	66.4	71.5	79	75.2	86.3	92.5	69.3	76	83.5	66.4	75.9	85.4
	25	64	71.1	79.2	77.5	87.6	96.1	68.9	77.1	87.8	64	74.8	85.5
	26	64	71.9	79.7	79.2	89.7	97.3	68.9	77.8	89.2	64	75	86
	27	66.2	72.5	80.8	78.3	90.3	98.8	69.1	79.1	91	66.2	76.8	87.4
	28	64.4	72.7	80.4	78.3	89.3	99.1	69.6	79.3	91.6	64.4	75.5	86.7
	29	64.6	72.8	80.2	72	88.1	95.5	68.7	78.9	90.3	64.6	75.6	86.6
	30	65.5	72.9	79.9	71.6	86.9	97.3	68	78.9	89.4	65.5	75.9	86.2

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

		Station N-10			Station S-0			Station S-4			Station A-0		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Jul	**1**	67.1	73	79.3	73	87.1	97	69.8	79.9	90.1	67.1	76.4	85.7
	2	67.5	73.6	79.3	70.2	88.3	95.4	70.7	80.2	89.2	67.5	76.5	85.6
	3	66.7	73.5	79.9	68.9	88.3	96.1	69.3	80.1	88.9	66.7	76.5	86.2
	4	66.7	73.7	80.6	68.4	89.4	100.8	68.5	81	90	66.7	76.9	87
	5	68.5	74.1	81.5	70	89.8	98.6	69.3	80.9	89.6	68.5	78.1	87.7
	6	68.7	74.5	82.2	69.1	89.9	100.8	69.3	81.8	90.9	68.7	78.6	88.4
	7	69.3	74.8	82.6	77.9	90.9	101.5	71.8	81.2	92.7	69.3	79	88.8
	8	70.2	75.2	82.8	79.3	91.6	101.8	73	81.4	93.9	70.2	79.6	89
	9	70.7	75.5	82.4	78.3	90.5	102.6	73.6	81.9	91.9	70.7	79.6	88.6
	10	68.5	75.2	82.8	80.4	91.5	102.4	71.8	80.1	92.3	68.5	78.7	88.9
	11	68.4	75	81.7	78.8	89.2	100	71.8	78.8	90.3	69.7	78.8	87.9
	12	69.3	74.8	81.7	76.3	89.6	101.8	71.8	79.3	91.4	71.3	79.6	87.9
	13	67.8	74.8	81.9	70	90.7	100	69.3	80.2	93.2	69.4	78.7	88.1
	14	66.4	74.8	81.9	76.5	90.9	100.2	68.5	80.5	90	67.1	77.5	88
	15	67.6	75	82.2	80.1	91.7	99	68.5	80.7	90.3	67.6	78	88.5
	16	68.2	74.9	82.6	80.4	91.6	98.4	69.1	80.8	90.9	68.2	78.5	88.8
	17	69.4	75	80.4	83.3	92.4	99.1	70	81.1	90.3	69.4	78	86.7
	18	69.6	75.1	81.1	84.7	93.2	99.9	69.3	81.3	92.5	69.6	78.5	87.3
	19	70.5	75.5	81.7	85.1	93.6	101.1	70.3	81.3	93	70.5	79.2	87.9
	20	68.5	75.5	83.3	82.2	92.6	98.6	68.4	82	94.1	68.5	79	89.5
	21	67.3	75.8	84	82.8	92	98.6	67.3	82	94.1	67.3	78.7	90.1
	22	67.6	76	83.8	77.7	91	99.1	67.8	82.9	93.9	67.8	78.9	90
	23	66.9	76.6	84.2	82.6	91.6	100.4	67.1	82.9	89.6	68.5	79.4	90.4
	24	66.7	76.6	83.8	78.8	90.9	99.9	66.6	82.6	92.3	69.2	79.6	90
	25	67.8	76.5	82	82	91.9	99.9	69.3	82.9	91	71.1	79.7	88.4
	26	67.8	76.5	81.3	85.6	92.2	100.6	68.7	83.3	91.9	71.8	79.7	87.7
	27	68.7	76	81.7	86	92.7	99.9	68.5	82.9	90	72	79.9	87.9
	28	68.9	75.8	82.4	84.6	93.1	99.7	69.3	82.5	91	70.8	79.8	88.7
	29	68.5	75.7	79.9	82.6	92.8	96.8	69.3	83	92.8	70.9	78.6	86.4
	30	70.2	76	80.8	81.1	92	96.3	71.1	82.4	91.9	73.7	80.4	87.2
	31	70.7	76.3	85.1	77.9	91.6	98.1	70.7	82	90.5	72.6	81.9	91.2

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

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

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

		Station N-10			Station S-0			Station S-4			Station A-0		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Sep	**1**	65.8	71.6	75.9	75	87	97	71.2	79.3	87.1	69	75.8	82.7
	2	65.3	71	78.6	75.6	86.4	95.4	72	78.4	85.6	70.3	77.8	85.3
	3	65.1	70.6	79.3	72	85.8	95.5	73.4	78.9	86	70.9	78.6	86.2
	4	64	70	81	69.3	85.2	95.4	66.7	78	84.2	69.9	78.7	87.5
	5	62.6	69.5	76.6	68.2	83.4	93.6	68	76.9	84.2	68	75.7	83.4
	6	62.6	69.2	76.3	73	85	95	68.2	76.8	85.3	68	75.5	83.1
	7	61.5	69.1	77.2	73.6	86.3	93.6	68	77.6	84.2	66.2	75	83.9
	8	60.6	69.5	77.5	72	86.8	94.5	67.8	78	85.8	65.6	74.9	84.2
	9	60.6	69.5	77.4	64.2	86	95.7	65.3	77.6	83.7	66.4	75.2	84
	10	61.3	69.2	76.3	66.9	85.8	96.4	66.4	78.2	86.2	66.5	74.8	83
	11	61.7	69.1	76.3	74.3	85.6	94.1	69.6	77.6	82.4	64.8	73.9	83.1
	12	60.6	68.4	75.6	75.4	85.6	93.9	71.2	76.8	81.5	63.9	73.2	82.5
	13	59.9	68	73.9	74.1	85.4	94.1	70.9	77.1	81.9	65.1	73	81
	14	59.4	67.9	72.5	67.5	85	91.8	69.3	76.5	84.4	65.2	72.5	79.7
	15	58.8	67.7	71.4	68.9	84.5	91	66.9	76.7	84	61.8	70.2	78.7
	16	58.1	67.3	70.5	70.9	84.7	91	66.9	75.5	81.3	61.3	69.5	77.8
	17	57.4	66.4	72.3	67.1	84.1	91.8	64.4	74.9	83.7	57.4	68.5	79.6
	18	57.6	65.8	73.9	71.4	84.2	90.7	62.6	73.9	85.5	57.6	69.2	80.9
	19	58.3	65.1	73.9	68.7	82.9	90.7	61	73.6	82	58.3	69.6	80.8
	20	59.2	64.8	71.6	73.6	83.4	90.5	61.2	74	82.2	59.2	69	78.8
	21	60.1	64.6	69.8	77.5	84	91.2	62.8	75.1	85.3	60.1	68.6	77.1
	22	59	64.7	70.2	77.4	84.1	92.5	63.1	73.7	82.4	59	68.2	77.3
	23	59	64.2	70.3	70.7	82.3	90.7	62.4	72.3	80.6	59	68.2	77.4
	24	59	63.5	69.6	66.4	80.5	92.7	63	71.5	82.9	60.2	68.6	77
	25	57.4	62.7	69.8	71.4	80.7	91.9	63.5	70.7	81.9	59.8	68.4	77.1
	26	56.8	62.1	69.3	72.1	79.8	90	62.4	69.6	81.1	59.7	68.2	76.6
	27	54.9	61.6	67.6	68	79.6	87.8	61.3	69.2	80.8	58.5	66.8	75.1
	28	56.1	61.6	66	66.6	77.9	86.7	61	69.1	76.6	58.4	66	73.6
	29	55.8	61.2	65.7	57.6	76.5	85.3	59.9	67.6	75.4	58.4	65.9	73.3
	30	54.5	60.7	64.9	60.8	76.5	83.5	58.1	67.3	75.7	58.4	65.5	72.6

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

		Station N-10			Station S-0			Station S-4			Station A-0		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Oct	**1**	56.1	60.2	63.9	58.5	77	83.5	56.7	67.4	74.5	60.3	65.9	71.5
	2	54.5	59.5	63.5	61.7	78	85.8	56.8	67.1	76.5	57.6	64.4	71.2
	3	53.1	59.1	63.7	67.1	78	86	57.9	66.5	74.1	56.6	64.1	71.6
	4	52.7	58.4	63.9	60.4	76.3	84.9	58.1	65.7	74.3	57.4	64.6	71.7
	5	52.5	57.6	64.8	55.9	74.4	86.7	58.3	65.4	72.3	57.5	65	72.6
	6	48.9	56.7	64.6	54.3	75	84.6	57.2	65	73.9	51.2	61.8	72.3
	7	48.9	56	62.6	55.4	74	81.7	56.3	63.4	67.8	51.5	61	70.5
	8	48.6	55.6	59.9	56.3	73.4	82.4	55	64	69.6	48.8	58.4	67.9
	9	47.7	55.4	61	60.3	74.3	82.8	55.2	63.3	70.3	47.8	58.4	68.9
	10	46	55.3	61.5	64.4	75.7	82.2	55.9	63.1	69.6	49.2	59.3	69.3
	11	45.5	54.8	59.7	62.1	75.9	81.9	55.8	62.5	70.9	50	58.9	67.8
	12	45.1	54.4	58.6	55.8	75.1	82.2	53.4	61.6	68.4	50.2	58.5	66.8
	13	47.7	54.3	59.4	52.3	74.1	83.7	53.1	61.1	70.3	52.4	59.9	67.4
	14	47.7	54.3	59.9	55	74.1	87.4	53.8	61	68.2	51.7	59.8	68
	15	48.9	54.3	60.3	52	73.6	88.5	51.8	61.1	70.2	49.9	59.1	68.3
	16	48.9	53.8	59.9	51.8	73.3	87.8	52	60.1	68.9	50.9	59.4	67.9
	17	49.5	53.2	60.3	60.3	72.6	84.2	51.6	58.5	66.7	49.8	58.9	67.9
	18	48.7	52.7	57.7	60.6	72.3	81	50.9	58	68.5	51.8	58.7	65.6
	19	48	52.4	56.5	60.6	72.1	82.2	51.3	58.4	70.3	51.5	58.1	64.7
	20	47.5	51.6	57.4	60.3	71.9	84	50.7	58.7	72.3	52.2	58.9	65.6
	21	48.2	51.1	58.5	59	71.5	79.9	52.2	58.8	72.5	48.2	57.3	66.4
	22	47.1	50.7	58.8	57.6	70.4	78.1	50	57.7	68.9	47.1	56.8	66.6
	23	46.8	50.1	59.2	57	70.1	79.3	49.5	57.7	71.4	46.8	56.9	67
	24	45.5	50.1	59.5	57.7	69.7	84.2	47.5	57	70.5	45.5	56.6	67.6
	25	44.6	50.1	59	61.2	70	82.2	47.8	57.3	69.3	44.6	55.7	66.7
	26	44.1	49.5	57.6	61.7	69.4	78.8	49.3	57.7	69.1	44.1	54.7	65.3
	27	44.2	49.3	56.7	58.1	69.9	77	49.1	57.5	68.4	44.2	54.4	64.5
	28	43.9	48.9	55.6	61.7	69.8	75.4	48.4	57.5	69.3	43.9	53.7	63.5
	29	43.3	48.3	55.4	64.9	69.5	77	47.3	57	69.8	43.3	53.4	63.5
	30	43	47.8	55.2	53.1	68	77	46.8	55.9	70	43	53.1	63.3
	31	42.3	47.3	55.4	40.8	66.5	73.8	46	54.1	64.2	42.3	52.9	63.5

APPENDIX B

Number of Days during the 1 April to 1 November Evaluation Period when Water Temperature at Selected Monitoring Stations is Predicted to Exceed Selected Values under Median and Extreme Scenarios of Ambient River Flow and Water Temperature

APPENDIX B	**Median Scenario - 50% - 50% Temperature and Flow Probability of Exceedence at Monitoring Station**				**Extreme Scenario - 10% - 10% Temperature (high) and Flow (low) Probability of Exceedence at Monitoring Station**			
TEMPERATURE (°F)	**N-10**	**S-0**	**S-4**	**A-0**	**N-10**	**S-0**	**S-4**	**A-0**
38	213	214	214	214	214	214	214	214
39	212	214	214	214	214	214	214	214
40	210	214	214	212	214	214	214	214
41	206	214	214	208	214	214	214	214
42	204	214	214	205	211	214	214	214
43	202	214	214	204	207	214	214	214
44	198	214	214	198	207	214	214	214
45	195	214	213	195	205	214	214	214
46	194	214	210	192	202	214	214	214
47	189	214	208	189	199	214	214	214
48	186	214	205	187	199	214	214	211
49	180	214	203	185	197	214	214	207
50	177	214	200	185	196	214	208	204
51	171	214	197	183	191	214	207	202
52	166	214	194	181	186	214	207	199
53	162	214	192	178	184	214	203	198
54	159	214	188	177	182	214	202	196
55	156	214	185	176	176	214	199	193
56	147	214	184	171	172	214	198	189
57	145	214	178	167	168	214	196	188
58	139	214	174	162	160	214	193	187
59	136	214	167	158	156	214	188	183
60	134	214	164	155	149	214	185	180
61	131	214	160	151	148	214	183	177
62	124	214	158	147	145	214	181	174
63	117	214	152	141	140	214	175	167
64	109	214	147	138	138	214	172	163
65	105	212	141	133	134	214	164	159
66	101	209	137	128	128	214	160	157
67	97	206	135	125	122	212	156	154
68	93	203	133	120	119	207	151	147
69	88	200	128	111	116	207	147	145
70	80	197	121	107	102	203	146	141
71	71	194	113	104	95	202	140	132
72	67	187	107	101	92	199	137	126
73	57	180	104	96	90	197	133	123
74	42	175	99	94	84	193	127	120
75	30	170	96	88	70	188	122	118
76	14	162	93	78	67	184	118	108
77	2	159	87	70	62	180	112	99
78	0	154	80	66	54	175	102	93
79	0	146	70	54	38	168	95	91

APPENDIX B (cont.)	**Median Scenario - 50% - 50% Temperature and Flow Probability of Exceedence at Monitoring Station**				**Extreme Scenario - 10% - 10% Temperature (high) and Flow (low) Probability of Exceedence at Monitoring Station**			
TEMPERATURE (°F)	**N-10**	**S-0**	**S-4**	**A-0**	**N-10**	**S-0**	**S-4**	**A-0**
80	0	143	67	39	17	161	92	89
81	0	137	54	25	3	156	90	76
82	0	134	40	9	0	149	84	68
83	0	130	25	1	0	148	69	66
84	0	118	12	0	0	141	67	58
85	0	111	1	0	0	138	62	42
86	0	105	0	0	0	134	53	20
87	0	99	0	0	0	126	38	4
88	0	95	0	0	0	121	16	0
89	0	90	0	0	0	116	3	0
90	0	81	0	0	0	102	0	0
91	0	71	0	0	0	95	0	0
92	0	66	0	0	0	92	0	0
93	0	50	0	0	0	88	0	0
94	0	35	0	0	0	72	0	0
95	0	14	0	0	0	67	0	0
96	0	2	0	0	0	61	0	0
97	0	0	0	0	0	46	0	0
98	0	0	0	0	0	29	0	0
99	0	0	0	0	0	4	0	0
100	0	0	0	0	0	0	0	0
101	0	0	0	0	0	0	0	0
102	0	0	0	0	0	0	0	0