MODELING THE THERMAL STRUCTURE IN THE HOOKSETT POOL OF THE MERRIMACK RIVER DURING PERIODS OF BIOLOGICAL SIGNIFICANCE

ASA Project 2010-011

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EXECUTIVE SUMMARY

Merrimack Station (the Station) is a coal fired power plant owned and operated by Public Service New Hampshire (PSNH), a subsidiary of Northeast Utilities, which is the largest electric utility provider in the state of New Hampshire. The plant is located along the western side of the Merrimack River (the River) in Bow, New Hampshire. The Station is located along the Hooksett Pool (the Pool) which is approximately 8 km (5 mi) long and runs from Garvins Falls Dam to the Hooksett Dam, receiving tributary inputs from the Soucook and Suncook Rivers located on the east side of the Pool. The River extends 45 km (28 mi) upstream of Garvins Falls where it is ultimately fed by regulated Lake Winnipesaukee discharges and groundwater discharge. All of the hydropower plants along the river are run-of-the-river that do not allow significant pooling of water. Units of measurement used in this report are a mixture of English and metric (or both) to facilitate comparison to customary units used in regulatory permits.

The Station has two generators which in combination have a capacity of 433 MWe (electrical); Unit 1 (MK1) is rated at 113 MWe and Unit 2 (MK2) is rated at 320 MWe. The plant takes in ambient River water which is used to condense steam in the power generation process. This heated water is subsequently discharged into a manmade canal which discharges to the River at a location downstream of the Station and intake structure. The maximum process flow, temperature rise and rejected heat are 364 cfs, 34°F (~19°C) and 800 MWt (thermal), respectively. Furthermore the cooling canal has 56 sets of four power spray modules (PSMs) which provide enhanced cooling by pumping and spraying the water into the atmosphere above the canal; while the sprayed water falls back in to the canal, this operation provides increased heat exchange with the environment, meaning increased evaporative cooling.

PSNH had previously contracted with Applied Science Associates, Inc. (ASA) to prepare a calibrated and verified hydrothermal model of the Pool that incorporated environmental and Station characteristics. Subsequent to that study (Crowley et al., 2010) PSNH requested ASA to review historical data to identify years of average and extreme environmental conditions during periods of biological interest and use the calibrated hydrothermal model to simulate these time periods. The different time periods included late spring, fall, summer and early spring. These time periods were defined by Normandeau Associates, Inc. (NAI), as periods when biological activity may be most affected by the thermal discharge from the Station. Each time period was defined as a specific calendar week within the year. The objective of the biological impacts analysis was to evaluate the average and extreme conditions. In order to identify the years when the average and extreme conditions occurred, a joint probability analysis using River flow and River temperature as the parameters characterizing the environmental conditions was performed on the 21-year historical record. This analysis determined the percentile rank of each year for the different periods of biological interest. An evaluation was performed where average years were defined as years close to a 50th percentile combination of low flow and high temperature and extreme years were identified by years with approximately a 90th percentile

combination of low flow and high water temperature. The average and extreme years along with their calculated percentile rank are shown in Table ES-1 below.

Table ES-1. Summary of extreme and average years for each biological period of interest along with the associated percentile rank.

	Late Spring	Fall	Summer	Early Spring
Dates	1-7 June	24-30 September	7-13 August	7-13 May
Extreme Year (Percentile)	1999 (91)	2002 (95)	2001 (91)	1995 (53)
Average Year (Percentile)	1995 (57)	2001 (43)	2002 (57)	2004 (46)

The previously calibrated and validated hydrothermal model was run for each of these biologically significant time periods for maximum Station loadings and no Station loadings and the results were post processed to evaluate the temperature rise due to the maximum Station load. The magnitude and extent of the thermal plume mixing and dilution was found heavily dependent on River flow, where low flow resulted in a larger plume extent with a higher temperature rise. In all cases the thermal plume was most evident at the surface on the western side of the River, closest to the confluence of the discharge canal with the River. The model predicted results, in terms of temperature rise at the water surface and vertical cross sections at S0 and S4, were provided to NAI at a time representing the median environmental condition for all biological periods (both average and extreme years) for use in the biological impacts analysis.

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1 INTRODUCTION

Merrimack Station (the Station) is a coal fired power plant owned and operated by Public Service New Hampshire (PSNH), a subsidiary of Northeast Utilities, which is the largest electric utility provider in the state of New Hampshire. The plant is located along the western side of the Merrimack River (the River) in Bow, New Hampshire as shown in Figure 1-1.

Merrimack Station has two generators which in combination have a capacity of 433 MWe (electrical); Unit 1 (MK1) is rated at 113 MWe and Unit 2 (MK2) is rated at 320 MWe. The plant takes in ambient River water which is used to condense steam in the power generation process. This heated water is subsequently discharged into a manmade canal which discharges to the River at a location downstream of the plant and intake structure. Furthermore the cooling canal has 56 sets of four power spray modules (PSMs) which provide enhanced cooling by pumping and spraying the water into the atmosphere above the canal; while the sprayed water falls back in to the canal, this operation provides increased heat exchange with the environment, meaning increased evaporative cooling.

PSNH had previously contracted with Applied Science Associates, Inc. (ASA) to develop a calibrated and validated hydrothermal model of River that incorporated environmental and plant characteristics. This previous effort provided an analysis of plant discharge and the resulting downstream temperature profiles for a model calibration period, a validation period and one additional scenario identified as having elevated upstream river temperatures and low river flow. An extensive data set from 2009 was used for calibration and validation. The background, assumptions and findings which included field data analysis as well as model calibration and validation was documented in an ASA report (Crowley, et al., 2010).

Subsequent to that study PSNH contracted with ASA to review historical data to characterize the environmental conditions during different time periods of biological significance (late spring, fall, summer, and early spring) and identify the average and extreme years for each of these time periods, run the hydrothermal model for these scenarios and post process the model results to be provided to Normandeau Associates, Inc. (NAI) for use in their biological impacts analysis.

Units of measurement used in this report are a mixture of English and metric to facilitate comparison to typical regulatory permits.

The scenario timeframe development is described in Section 2, the scenario modeling is presented in Section 3, and the study summary and conclusions are provided in Section 4.

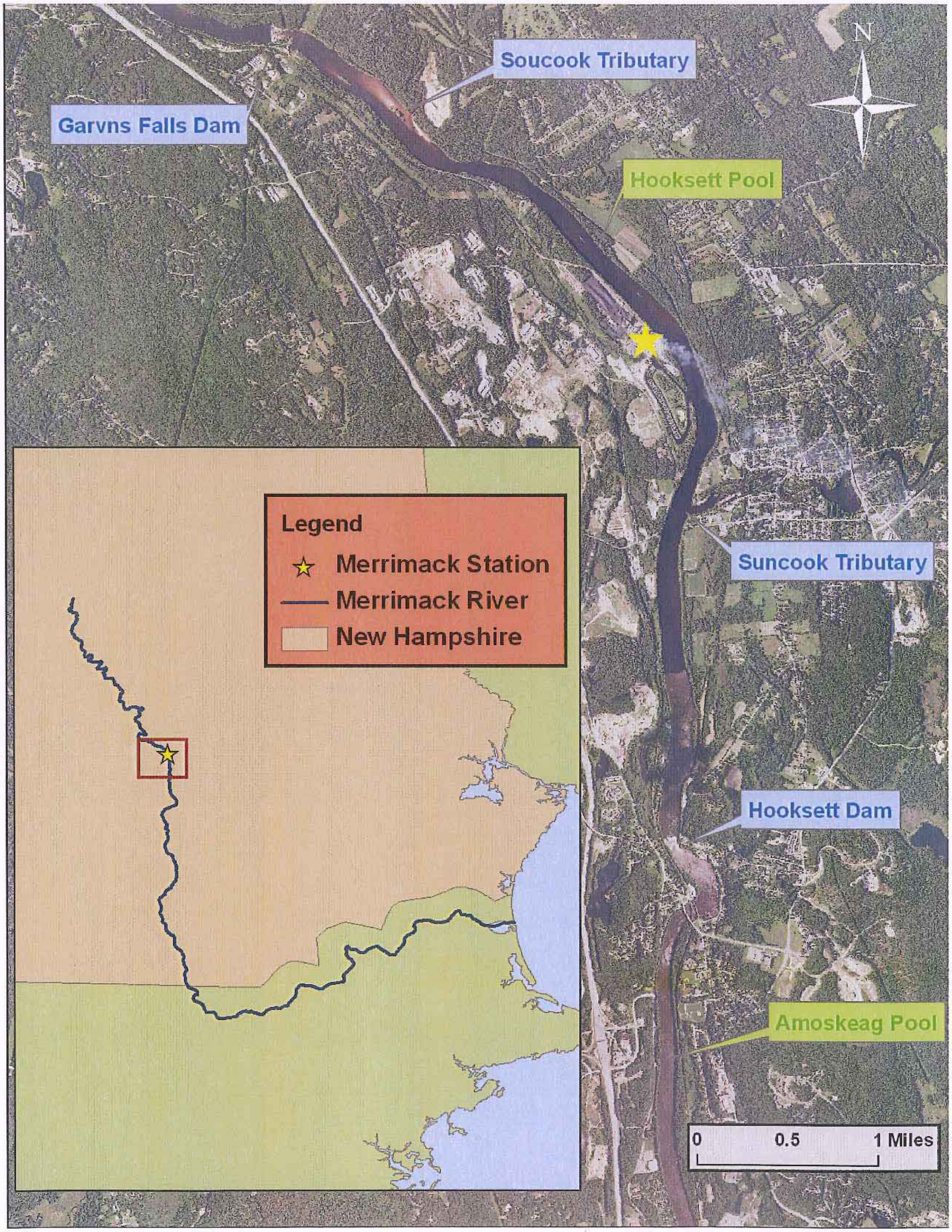

Figure 1-1. Merrimack River study area.

2 SCENARIO TIMEFRAME DEVELOPMENT

2.1 BIOLOGICAL PERIODS OF INTEREST

The impact of the thermal discharge relative to the environment is most often evaluated in terms of the impact to the biological community. Different species have different thresholds of absolute temperature as well as temperature differentials that they avoid or that may be detrimental to their health. Therefore, in order for NAI to estimate biological impacts of the thermal plume, additional hydrothermal modeling was needed to evaluate the thermal regime during different periods of biological significance. Four critical periods of interest were defined by NAI:

- Late Spring: First week in June (1-7 June)
- Fall: Fourth week of September (24-30 September)
- Summer: Identified from historical data (described in Section 2.2.1) to be second week in August (7-13 August)
- Early Spring: Second week in May (7-13 May)

For each period of interest the biological assessment was performed for average and extreme conditions which were identified through a joint probability analysis described below.

2.2 JOINT PROBABILITY ANALYSIS

A review of historical river data was first used to identify the historical warmest week and subsequently to identify average and extreme periods for each of the biological periods of interest. Both analyses were carried out with a joint probability analysis using river flow and river temperature as the parameters characterizing the environmental conditions.

A 21-year (1984 -2005) record of daily average river flow and river temperature data was provided by NAI for use in this analysis. The daily averaged river flow was provided for the flows at Merrimack Station within the Hooksett Pool based on correlations of river flow and watershed yield throughout the Merrimack River basin (NAI, 2007) and the daily averaged temperatures were based on temperatures observed at station N10H located upstream of the plant, as shown in Figure 2-1.

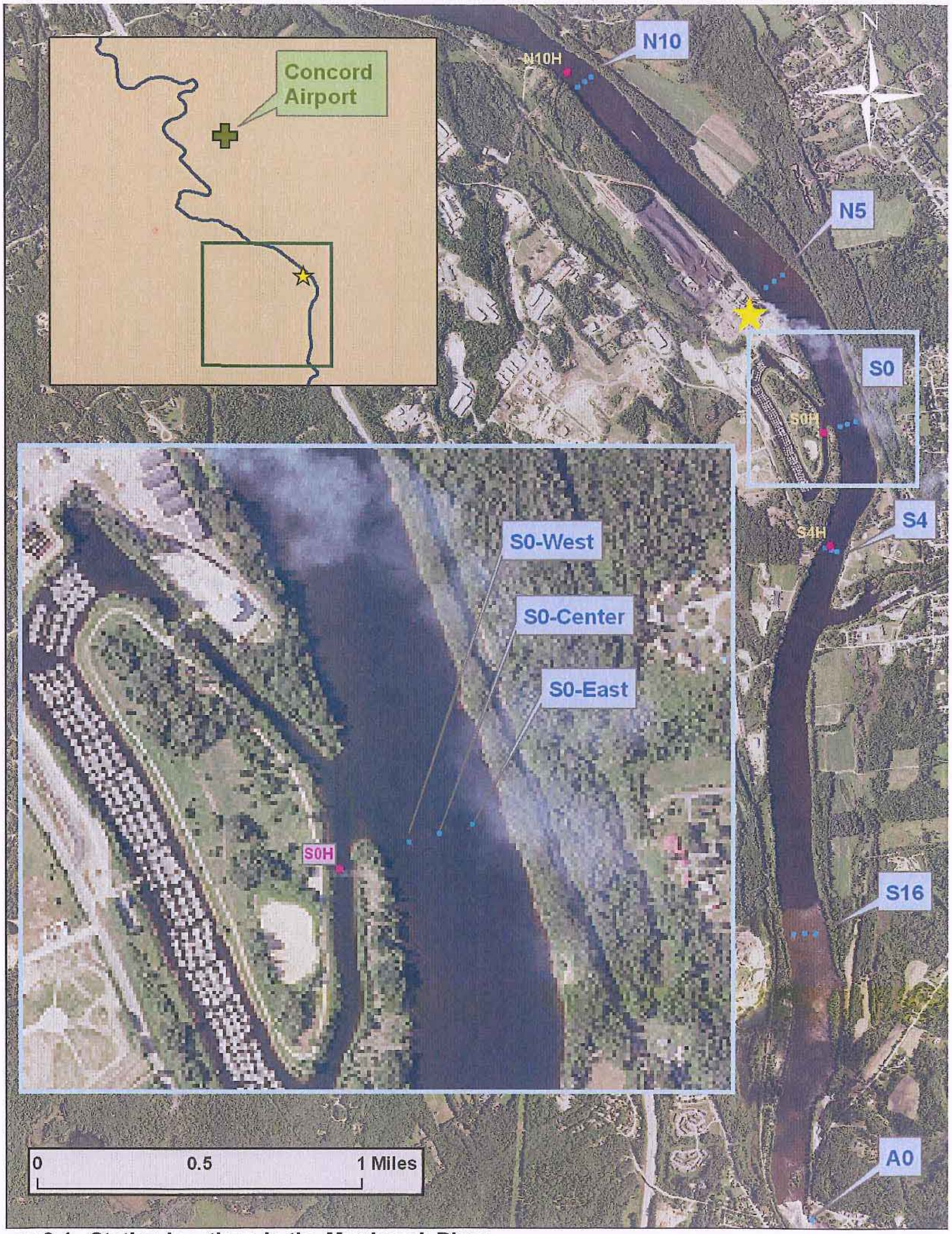

Figure 2-1. Station locations in the Merrimack River.

2.2.1 SUMMER TIMEFRAME

A review of historical river data was used to identify the summer period reflecting the week that is characterized by the warmest temperatures. This was identified by evaluating the running seven day average temperature for the entire 21-yr record and selecting the seven day period with the highest average. The summer period was identified as 7-13 August 1988 occurring at the peak of the summer season where persistent high temperatures and low rainfall resulted in low river flow and elevated water temperature. This identified period (7-13 August) was used as the summer period for all years in the joint probability analysis.

2.2.2 IDENTIFICATION OF AVERAGE AND EXTREME TIMEFRAME

A joint probability analysis was used to determine average and extreme years for the four different biological periods of interest. Joint probability is the process of taking two or more independent variables and characterizing a system based on simultaneous values for each variable. In this case river flow and in-river temperature were used to find observed average and extreme combinations out of the 21-yr data set. The data set of daily averaged flow estimates and associated daily average temperatures at N10 were provided by NAI. Daily average flow estimates were generated based on the relationships developed between gaged sites and watershed characteristics in the Hooksett Pool (NAI, 2007). Daily averaged temperatures were generated based on the observations at N10, which were originally recorded at a 15-minute interval.

For each week-long period of interest the individual daily average flows and temperatures were averaged so that the individual years could be compared. The joint probability of low flow and high water temperature, *P(x,y)*, was determined using the formula:

$$P(x, y) = Prob[x(k) \geq x \text{ and } y(k) \leq y]$$

where *x* is river flow and *y* is river temperature with both assumed to be independent time series, and the data are taken in pairs (indexed by k). The joint probability density function of x(k) is greater than some set river flow at the same time as y(k) is less than some set temperature, is equal to

$$P(x, y) = P(x)P(y)$$

where *P(x)* and *P(y)* are individual probabilities (Bendat and Piersol, 2000). The individual probability rank of river flow and temperature were calculated, and then combined as summarized in Table 2-1 for the four periods of biological significance. These values indicate which years are average (joint probability at 50th percentile) and which are extreme (joint probability > 90th percentile) and are shown with bolded, blue font. Figure 2-2 through Figure 2-4 display this information graphically for the four periods, respectively, with the individual values of river flow and temperature shown along with the corresponding joint probability percentiles. In these figures the top panel shows a time series of river flow and temperature with weekly averages represented by a circle and the seven day individual measurements represented by smaller points in a lighter color. The middle panel shows the joint distribution rank for each year, and the bottom panel shows temperature and river flow plotted against each other. The events with higher temperatures and lower river flows are shown in darker red and move through yellow, green and light blue towards dark blue for the higher river flows and lower temperatures based on their joint distribution rank.

Table 2-1. Summary of actual joint probabilities for each biological period of interest.

Year	Late Spring (1-7 June) Joint Probability Percentile	Fall (24-30 September) Joint Probability Percentile	Summer (7-13 August) Joint Probability Percentile	Early Spring (7 -13 May) Joint Probability Percentile
1984	1	68	47	N/A
1985	71	23	66	26
1986	58	10	1	N/A
1987	81	11	23	N/A
1988	10	6	67	N/A
1989	36	2	4	1
1990	25	24	1	25
1991	82	3	35	45
1992	13	35	8	30
1993	20	18	16	82
1994	38	17	29	8
1995	**57**	47	17	**53**
1996	16	36	30	2
1997	6	12	44	4
1998	29	65	37	10
1999	**91**	3	30	78
2000	38	31	5	31
2001	1	**43**	**91**	66
2002	25	**95**	**57**	32
2003	5	6	5	10
2004	2	20	25	**46**

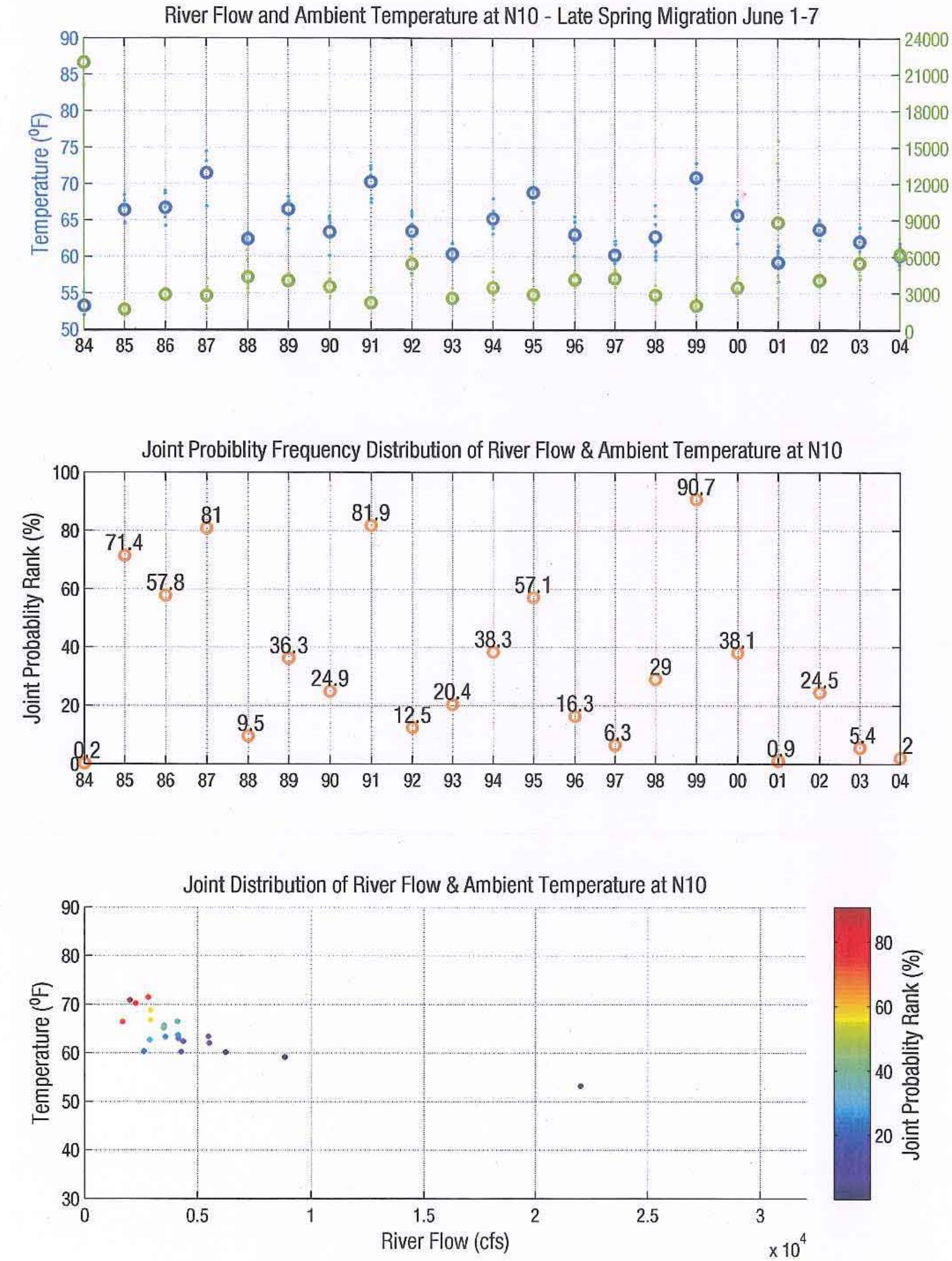

Figure 2-2. Joint probability analysis data for late spring period: 1-7 June.

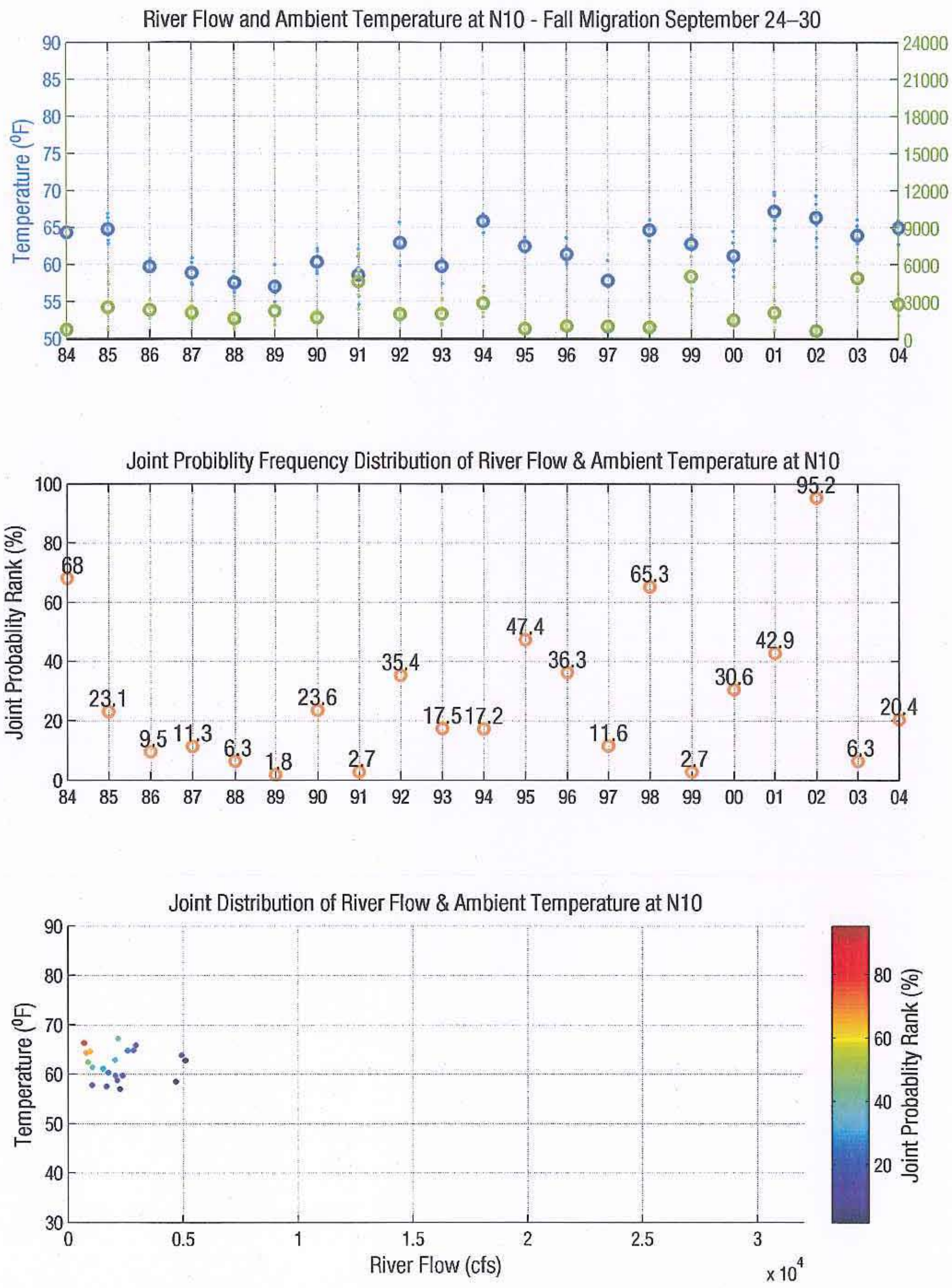

Figure 2-3. Joint probability analysis data for fall period: 24-30 September.

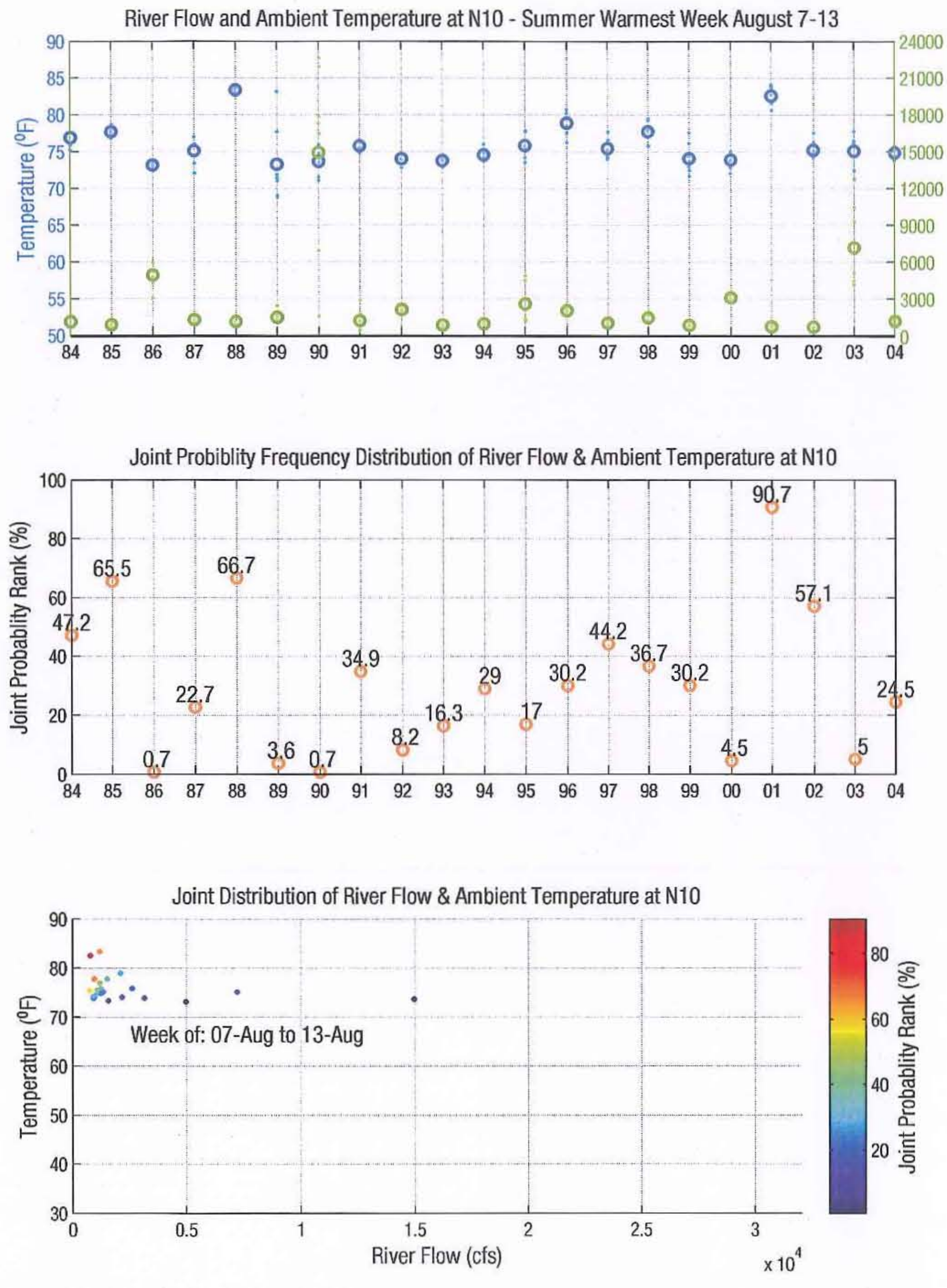

Figure 2-4. Joint probability analysis data for summer period: 7-13 August.

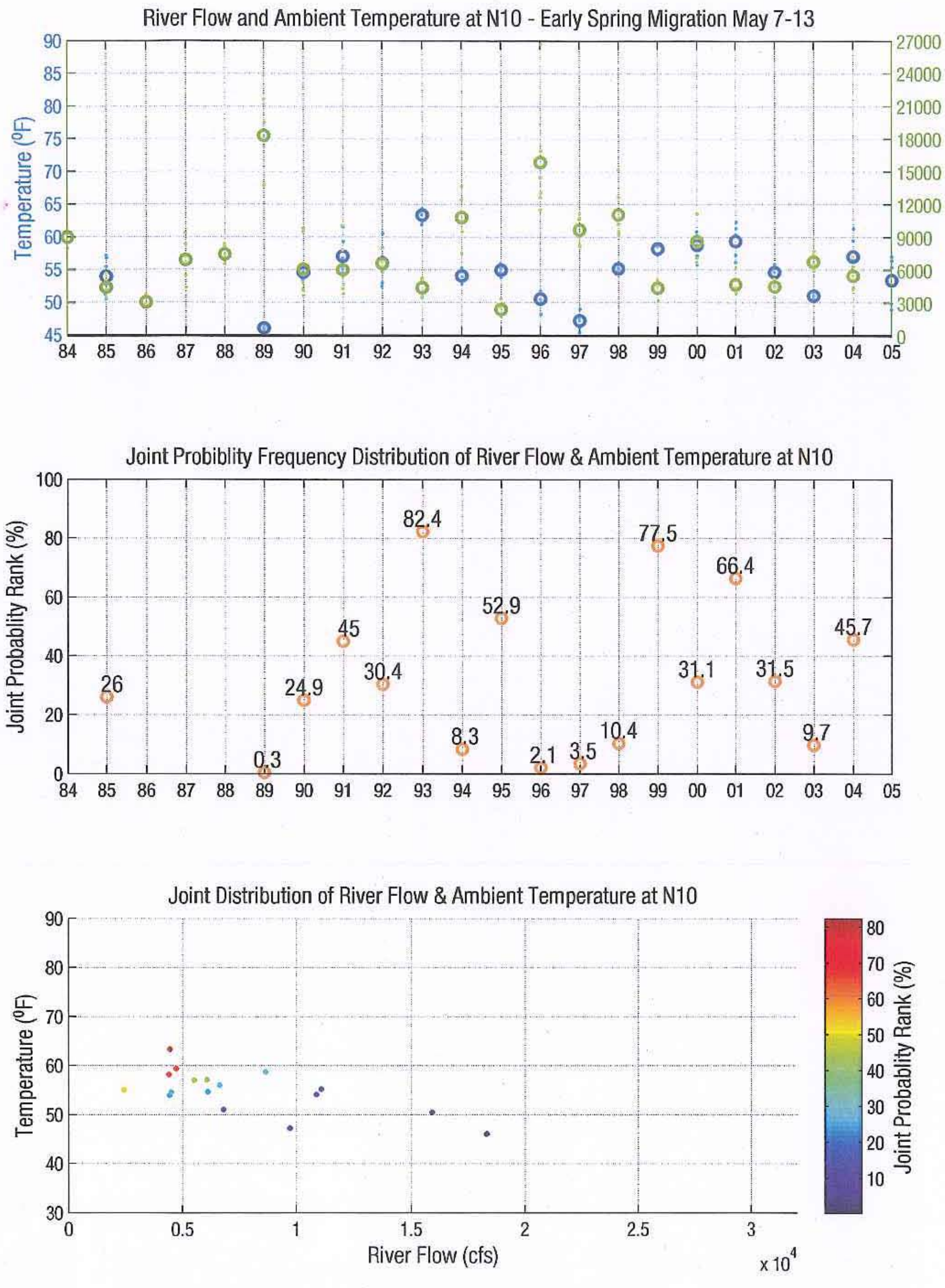

Figure 2-5. Joint probability analysis data for early spring period: 7-13 May.

With the exception of the early spring (7-13 May) timeframe, the observations from each week-long period of interest fell within a relatively small range. For the late spring period (1-7 June) the river flow typically ranged between 1,000 and 5,000 cfs with a maximum of 22,000 cfs while river temperatures typically ranged from 60 to 72°F with one outlier year with a minimum of 53°F. For the fall period (24-30 September) river flow typically ranged between 1,000 and 3,000 cfs with a maximum of 5,000 cfs and river temperatures typically varied between 57 and 66°F, while for the summer period (7-13 August) river flow typically ranged between 500 and 3,000 cfs with a maximum of 15,000 cfs and river temperatures ranged between 73 to 84°F. The early spring period (7-13 May) exhibited more variability, river flow typically ranged between 2,500 and 11,000 cfs with a maximum of 18,000 cfs and river temperatures typically varied between 50 and 60°F though do extend as low as 46°F and as high as 64°F.

The extreme and average years for each period are given in Table 2-2 with their respective percentiles, where for the late spring, fall and summer time periods the extreme year was identified as a year joint temperature and river flow combination at a 90th percentile or above and the average year identified as one close to a 50th percentile. The early spring time period had a smaller sample size and larger range of values of both river flow and river temperature. Based on these factors, the identification of average and extreme year was given further consideration because the results of the joint probability analysis did not always reflect the expected trend. For example, the joint probability analysis had found that 1995 was close to a 50th percentile year at 52.9, however this year had the lowest overall river flow and therefore qualitatively would be described as a year with typical river temperature and extreme low river flow. The analysis also found that 1993, 2001 and 2003 did have higher joint probability values (which would infer that they were more extreme) than 1995 which were due to the relatively higher river temperatures while these years were characterized by more typical river flow values. Since the larger impacts in terms of change in temperature are associated with less river flow, 1995 was chosen as the extreme year since more impacts are expected. The average year was identified as 2004 as this year was close to a 50th percentile (46) and did have temperature and river flow values that fell close to the middle of the range for both parameters.

Table 2-2. Summary of extreme and average years for each biological period of interest along with the associated percentile rank.

	Late Spring	Fall	Summer	Early Spring
Dates	June 1-7	24-30 September	7-13 August	7-13 May
Extreme Year (Percentile)	1999 (91)	2002 (95)	2001 (91)	1995 (53)
Average Year (Percentile)	1995 (57)	2001 (43)	2002 (57)	2004 (46)

3 Scenario Model Simulations

Model simulations were performed for each of the periods of biological significance using the calibrated and validated model documented in Crowley et al. (2010). The model application for each specific timeframe was modified to include the observed river flow and temperature as well as meteorological forcing. Each period was run for two different conditions:

- Maximum plant loads
- No plant loads

The maximum plant loads and no plant loads cases were run to evaluate the maximum thermal impacts from the plant for both average and extreme conditions. The results were post processed to determine the difference in water temperatures between the two cases in order to provide input to the subsequent biological impacts analysis.

3.1 Model Forcing

For each of the periods of biological significance, the observed environmental conditions, including pool elevation, river flow, river temperature, and meteorological conditions, were used to force the model. Environmental forcing was applied using the same methodology documented in the previous model calibration and validation study (Crowley et al., 2010). Plant data in the form of plant flow and associated temperature rise were also used in model forcing, using assumptions associated with maximum plant output for the simulations Model simulations were run for a total of eleven days, with the last seven days being the specific dates corresponding to the period of interest, and the first four days used for ramping in the environmental conditions and allowing enough time for the system to come to dynamic equilibrium.

The rejected heat (MWt [thermal]) is the scaled product of the flow and temperature rise. For each of the four biological periods of interest the simulations with maximum plant loads and no plant loads. The maximum plant load was assumed to reflect a plant flow of 364 cfs with a 34°F (~19 °C) temperature rise for a rejected heat of 800 MWt. Note that this was the peak combination of temperature rise and plant flow observed in any of the biological periods of interest examined with available data.

3.2 Model Results

Each of the biological periods of interest was simulated using (1) maximum plant loads, and (2) no plant loads, to determine the relative temperature rise due to the plant thermal plume for maximum conditions by subtraction of (2) from (1).

The relative temperature rise due to the plant loading is variable, changing with changes in environmental conditions. Illustrations of the temperature rise for times characterized as the median environmental condition for the average and extreme period for each biological period of interest are shown in Figure 3-1 through Figure 3-16. These figures show the temperature rise at the surface along with section views at S0 and S4 to illustrate the vertical variability of temperature rise at these locations. Note that these figures show temperature rise in degrees Celsius, and conversion of temperature rise to degrees Fahrenheit is °F = °C*1.8. Temperature rise in degrees Celsius was requested for the biological impacts analysis. The median environmental condition was characterized as the time at which the upstream temperatures were at the 50th percentile for that period.

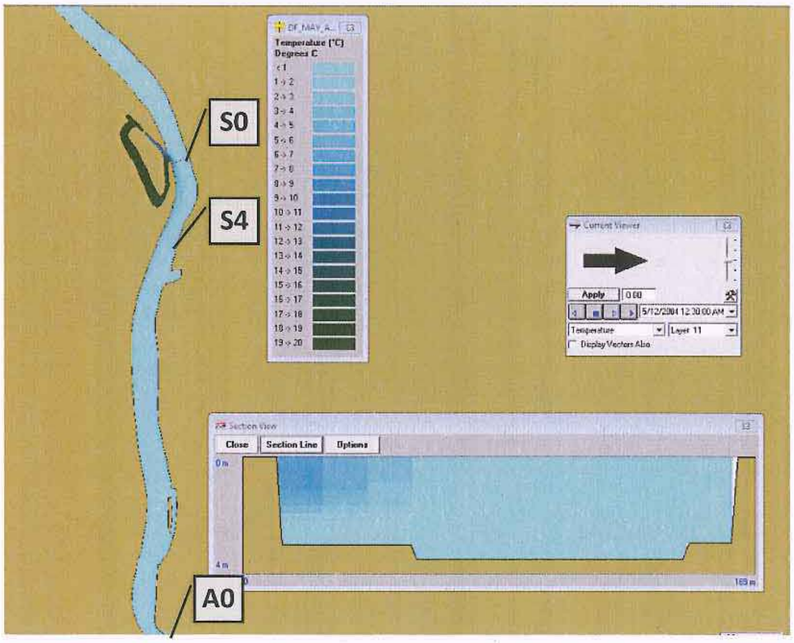

Figure 3-1. Model predicted delta temperature contours at 50th percentile upstream ambient condition during the early spring biological period for an average year: 7-14 May 2004. Surface temperatures and cross section at S0 shown.

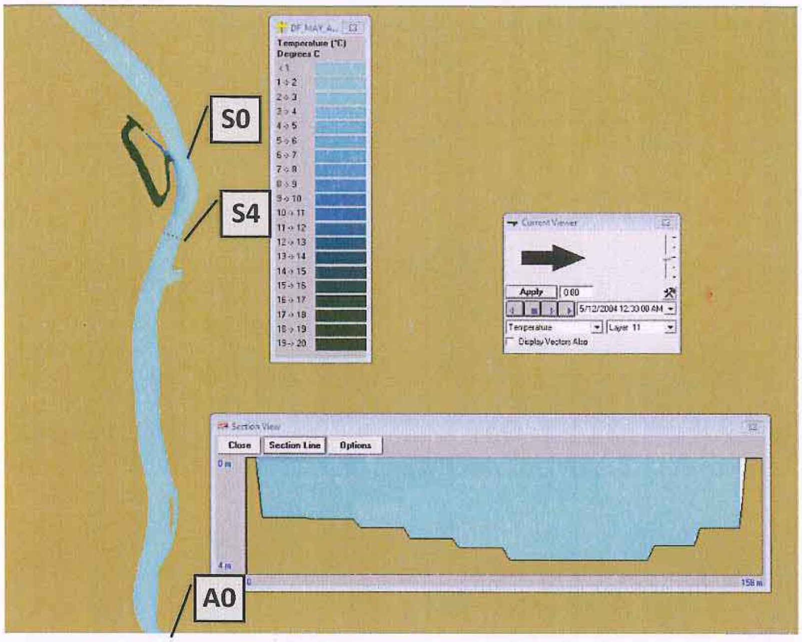

Figure 3-2. Model predicted delta temperature contours at 50th percentile upstream ambient condition during the early spring biological period for an average year: 7-14 May 2004. Surface temperatures and cross section at S4 shown.

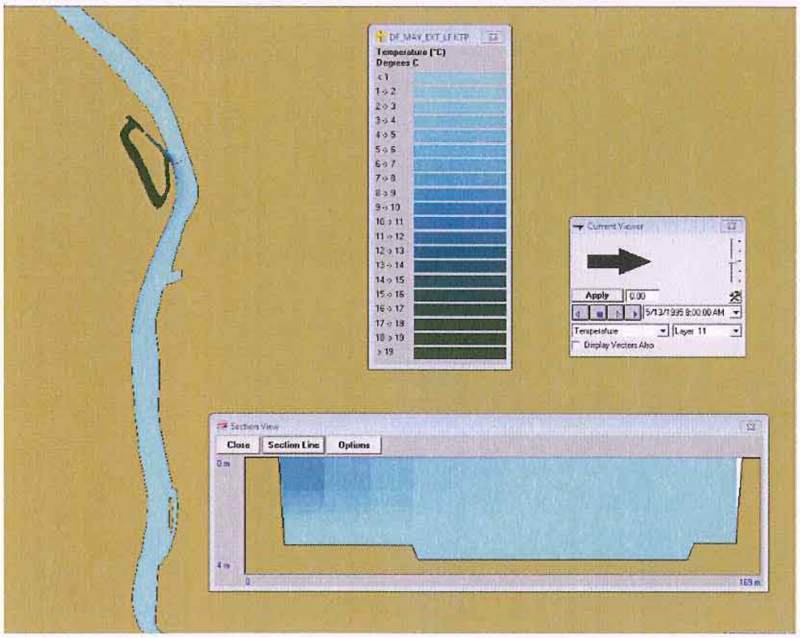

Figure 3-3. Model predicted delta temperature contours at 50th percentile upstream ambient condition during the early spring biological period for an extreme year: 7-14 May 1995. Surface temperatures and cross section at S0 shown.

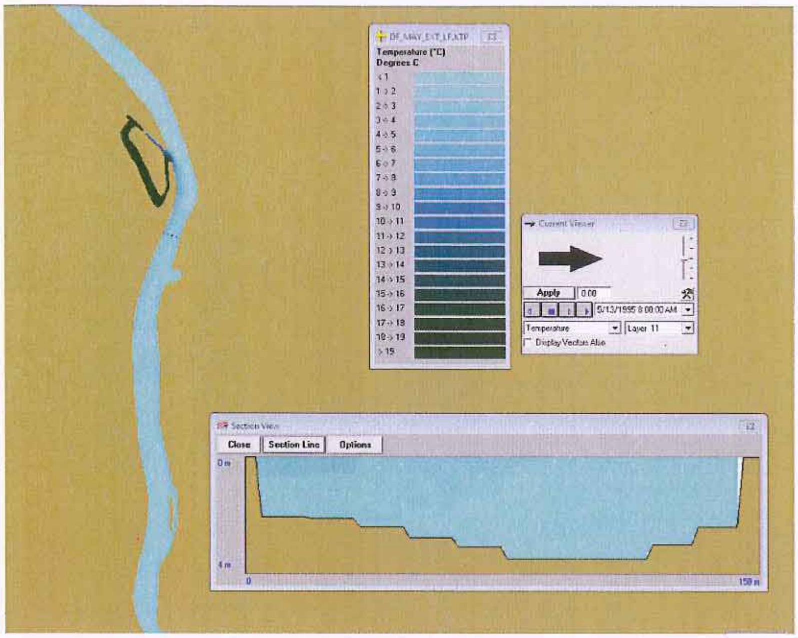

Figure 3-4. Model predicted delta temperature contours at 50th percentile upstream ambient condition during the early spring biological period for an extreme year: 7-14 May 1995. Surface temperatures and cross section at S4 shown.

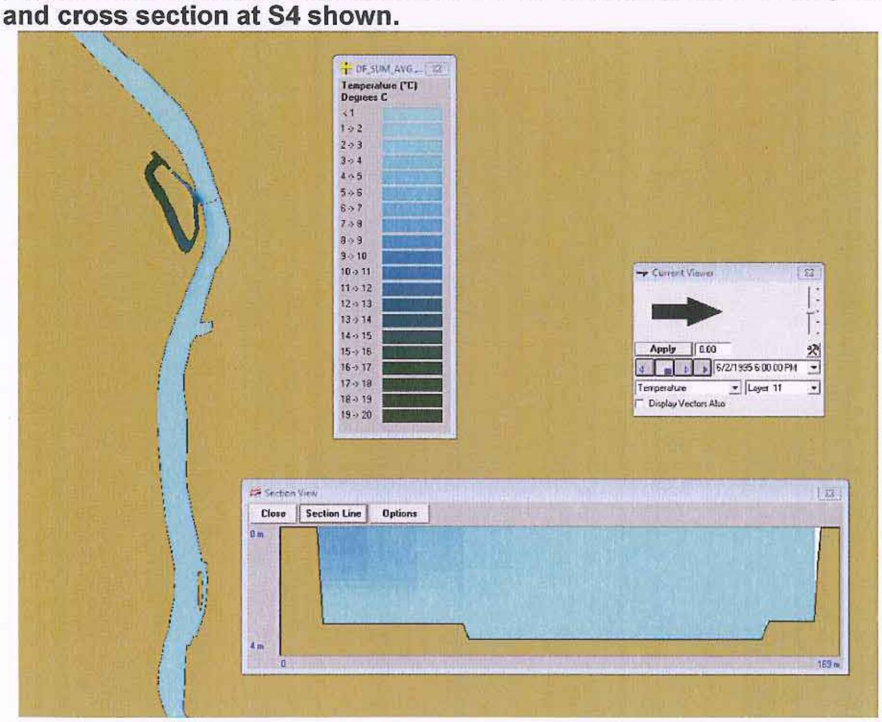

Figure 3-5. Model predicted delta temperature contours at 50th percentile upstream ambient condition during the late spring biological period for an average year: 7-14 June 1995. Surface temperatures and cross section at S0 shown.

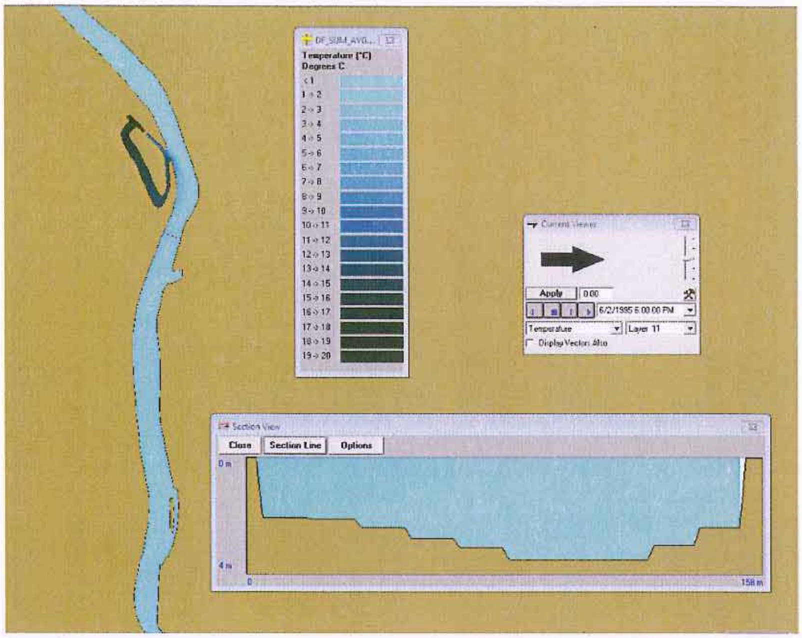

Figure 3-6. Model predicted delta temperature contours at 50th percentile upstream ambient condition during the late spring biological period for an average year: 7-14 June 1995. Surface temperatures and cross section at S4 shown.

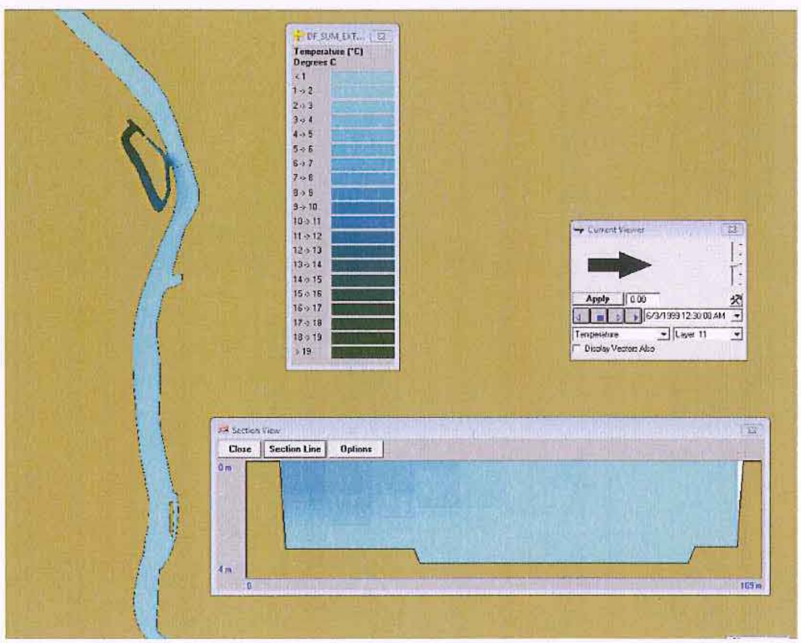

Figure 3-7. Model predicted delta temperature contours at 50th percentile upstream ambient condition during the late spring biological period for an extreme year: 7-14 June 1999. Surface temperatures and cross section at S0 shown.

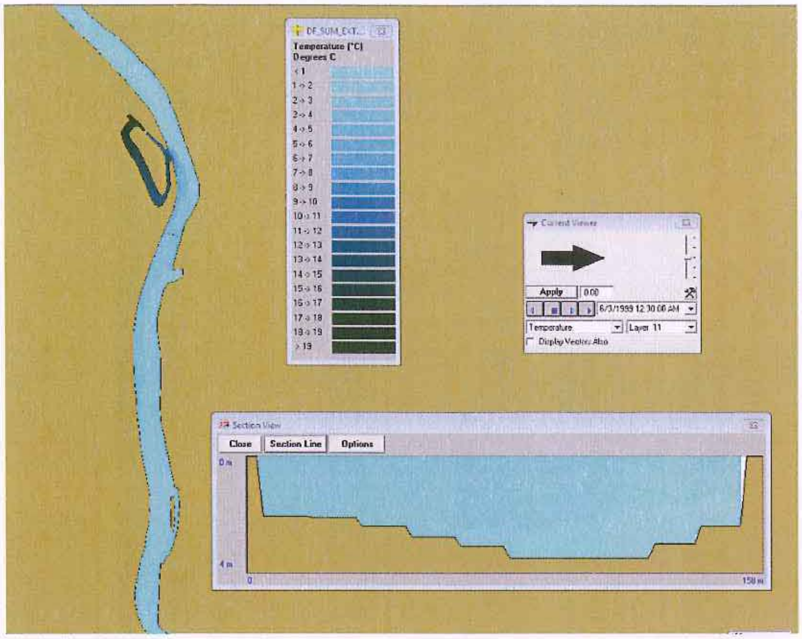

Figure 3-8. Model predicted delta temperature contours at 50th percentile upstream ambient condition during the late spring biological period for an extreme year: 7-14 June 1999. Surface temperatures and cross section at S4 shown.

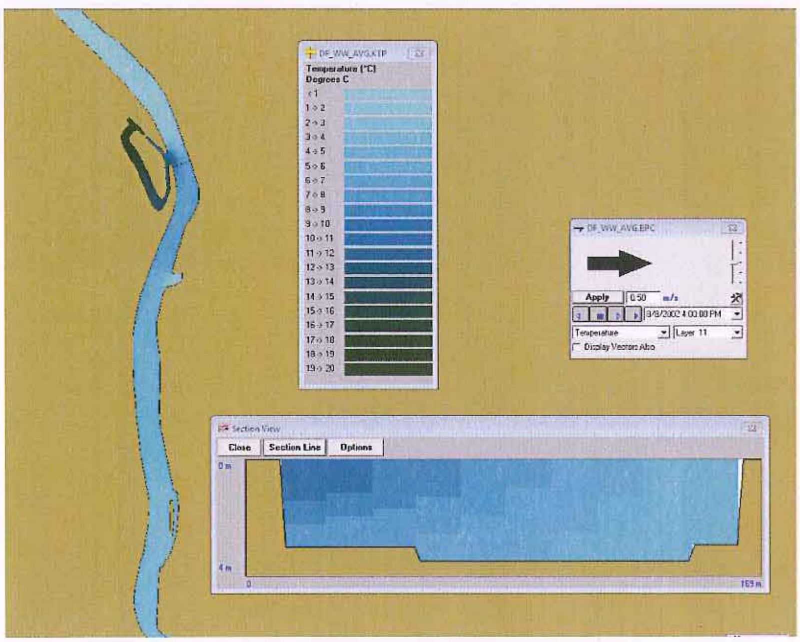

Figure 3-9. Model predicted delta temperature contours at 50th percentile upstream ambient condition during summer biological period for an average year: 13-20 August 2002. Surface temperatures and cross section at S0 shown.

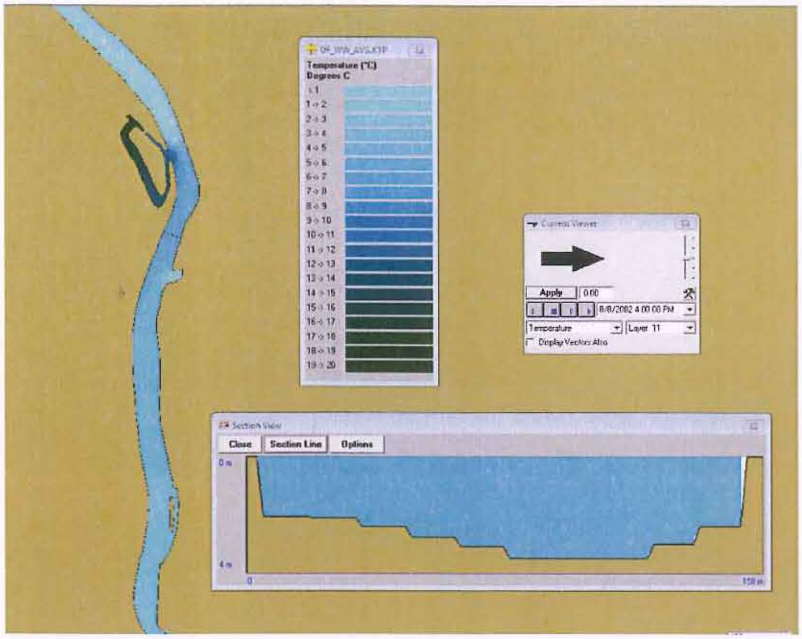

Figure 3-10. Model predicted delta temperature contours at 50^th percentile upstream ambient condition during summer biological period for an average year: 13-20 August 2002. Surface temperatures and cross section at S4 shown.

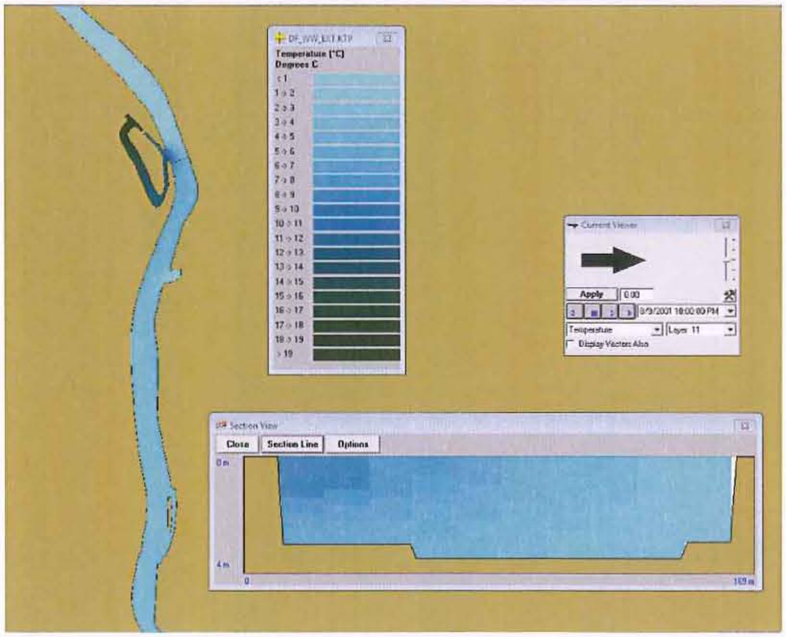

Figure 3-11. Model predicted delta temperature contours at 50^th percentile upstream ambient condition during summer period for an extreme year: 13-20 August 2001. Surface temperatures and cross section at S0 shown.

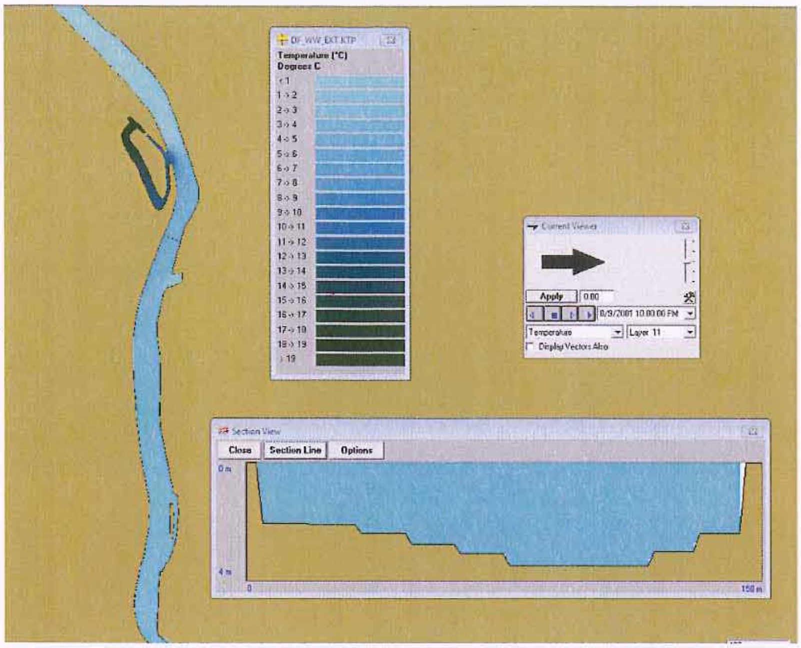

Figure 3-12. Model predicted delta temperature contours at 50th percentile upstream ambient condition during summer biological period for an extreme year: 13-20 August 2001. Surface temperatures and cross section at S4 shown.

Figure 3-13. Model predicted delta temperature contours at 50th percentile upstream ambient condition during fall biological period for an average year: 24-30 September 2001. Surface temperatures and cross section at S0 shown.

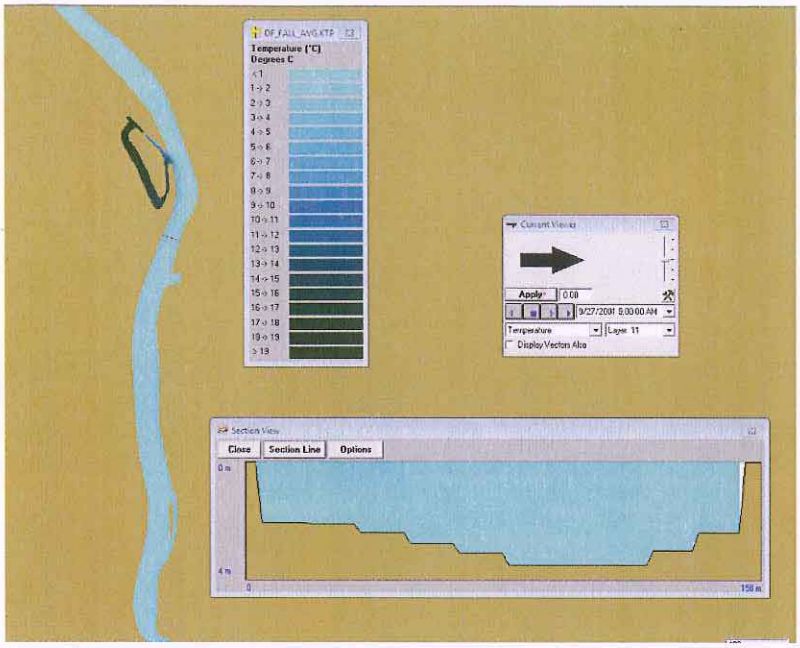

Figure 3-14. Model predicted delta temperature contours at 50th percentile upstream ambient condition during fall biological period for an average year: 24-30 September 2001. Surface temperatures and cross section at S4 shown.

Figure 3-15. Model predicted delta temperature contours at 50th percentile upstream ambient condition during fall biological period for an extreme year: 24-30 September 2002. Surface temperatures and cross section at S0 shown.

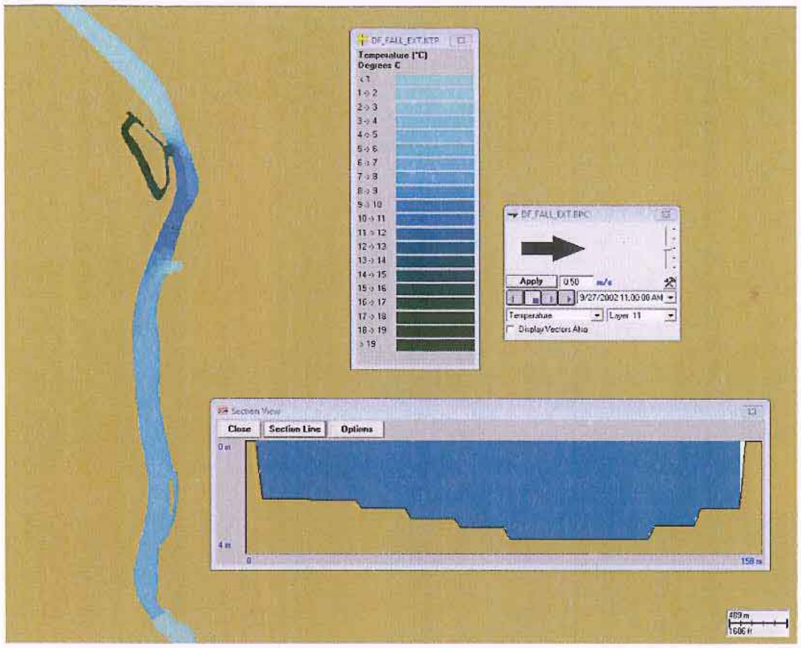

Figure 3-16. Model predicted delta temperature contours at 50th percentile upstream ambient condition during fall biological period for an extreme year: 24-30 September 2002. Surface temperatures and cross section at S4 shown.

4 SUMMARY AND CONCLUSIONS

The objective of this study was to identify average and extreme periods for four different biological periods of significance (late spring, fall, summer, and early spring) and to use the previously calibrated and validated hydrothermal model of the Hooksett Pool (Crowley et al., 2010) to simulate the Merrimack Station thermal plume and associated Hooksett Pool temperature profiles during these periods. Furthermore, the results, in terms of temperature rise at the water surface and vertical cross sections at S0 and S4, were provided to NAI at a time representing the median environmental condition for all biological periods (both average and extreme years) for use in the biological impacts analysis.

A joint probability analysis and qualitative review of the data was used to identify years of average and extreme environmental conditions for each biological period of interest. Table 4-1 summarizes the identified year for each condition.

Table 4-1. Summary of extreme and average years for each biological period of interest along with the associated percentile rank.

	Late Spring	Fall	Summer	Early Spring
Dates	1-7 June	24-30 September	7-13 August	7-13 May
Extreme Year (Percentile)	1999 (91)	2002 (95)	2001 (91)	1995 (53)
Average Year (Percentile)	1995 (57)	2001 (43)	2002 (57)	2004 (46)

The previously calibrated and validated model was run for each of these biologically significant time periods for two plant conditions, constant maximum plant loadings and no plant loadings. The results were post processed to determine the temperature rise relative to the plant loading. The relative temperature rise due to the plant loading is variable, changing with changes in environmental conditions. The magnitude and extent of the thermal plume mixing and dilution was found heavily dependent on river flow, where low river flow resulted in a larger plume extent with a higher temperature rise. In all cases however the thermal plume was most evident at the surface on the western side of the river, closest to the confluence of the discharge canal with the river. For periods of lower river flow (less than 800 cfs seven day average) the thermal plume spread further across the river at S0 and resulted in a larger extent of elevated temperature at S4.

5 References

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