4. *ASSESSMENT OF COOLING TOWER BLOWDOWN IMPACTS*

This section describes the analyses that were performed to assess potential increases in river water temperature (the "thermal plume") due to the BBNPP cooling tower blowdown discharge and related, potential reductions in dissolved oxygen (DO) concentrations. The analyses include two elements: (1) an assessment of surveyed thermal plume sizes and configurations for the nearly-identical SSES blowdown release system and (2) modeling for two periods when the largest thermal plumes are likely to occur. These periods are (1) a winter period when the maximum difference between the BBNPP blowdown temperature and Susquehanna River temperature occurs and (2) a late summer period when river flows are lowest. The SSES thermal plume surveys presented here correspond to these winter and late summer periods. For each of these two periods, average and worst-case conditions were modeled using EPA's Cornell Mixing Zone Model (CORMIX), a total of four scenarios. Potential changes in DO due to temperature increases in the thermal plume were computed by calculating changes in DO saturation concentrations for each of the four scenarios.

An examination of the observed SSES thermal plumes and an assessment of the model results show that the BBNPP thermal plume is small and that temperature increases are limited to the immediate vicinity of the diffusers. Temperature increases from the combined SSES and BBNPP cooling blowdown releases will be virtually undetectable at the end of the pool in which the SSES and BBNPP discharge structures are located. Reductions in DO concentrations due to the small temperature rises that occur adjacent to the BBNPP diffuser would be minimal.

4.1. COOLING TOWER OPERATION AND DIFFUSER SYSTEMS

Cooling towers are designated Best Technology Available (BTA) for condenser cooling. The BBNPP and SSES diffusers are virtually identical engineered structures designed to rapidly mix cooling tower blowdown with the waters of the Susquehanna River. The diffusers are located on the bottom of the Susquehanna River approximately 80 ft from the shoreline, and separated by 350 ft (Figure 4-1). Each diffuser consists of a 120-ft long, 42-in. diameter manifold with 72 ports. Each port is four inches in diameter, spaced 18 inches apart, and angled upward at 45° to the horizontal oriented downstream.

A significant difference between the SSES and BBNPP cooling towers is that the BBNPP towers are designed to limit discharge blowdown temperatures to less than 90°F, whereas the SSES blowdown temperatures can exceed 90°F under certain conditions.

An important feature of cooling tower blowdown temperatures is that they are functions of wet bulb temperature and the cooling tower approach temperature. The approach temperature indicates how closely the blowdown temperatures (referred to as the "cold side" temperature by cooling tower design engineers) will approach the wet bulb temperature. The wet bulb temperature is the limiting temperature for evaporative cooling. Winter wet bulb temperatures can be high relative to river water temperatures because the latter respond slowly to meteorological changes and can be near freezing for long periods whereas winter air and wet bulb temperatures can be relatively high when warm air masses are present. This phenomenon means that the largest differences between blowdown temperatures and river water temperatures (the "ΔT") occur during the winter.

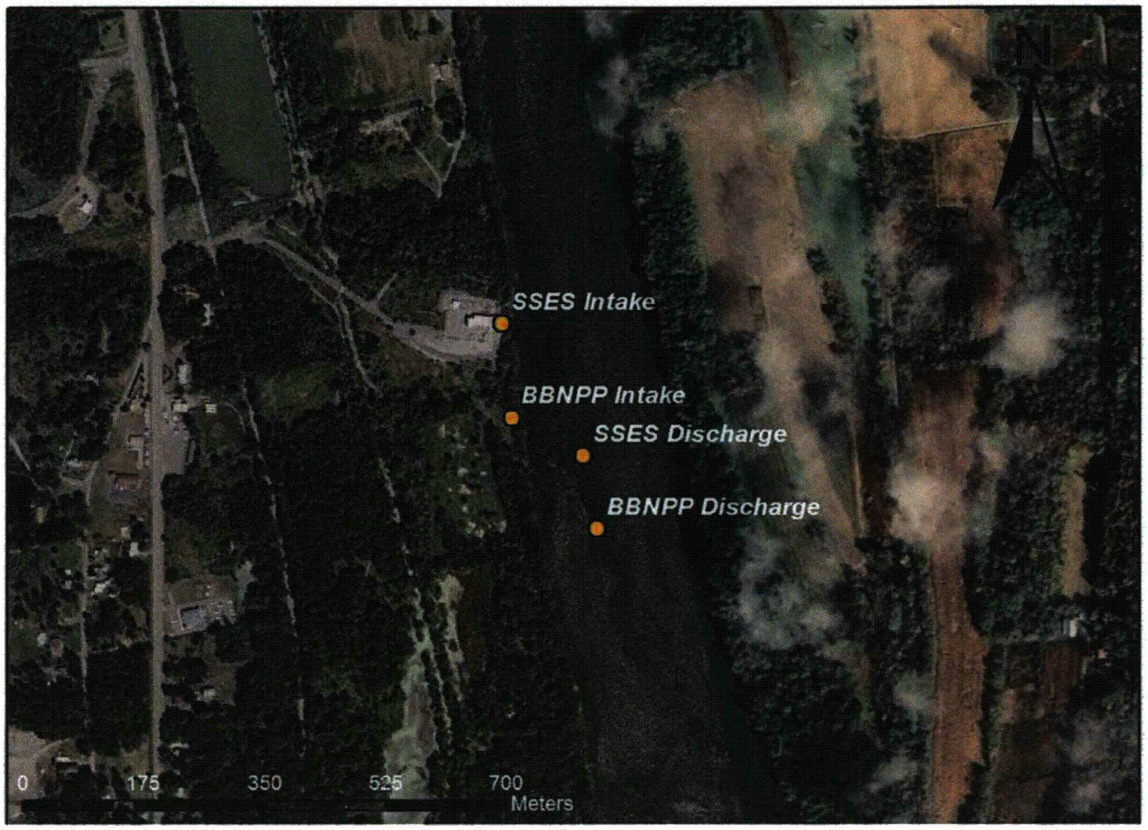

Figure 4-1 Arrangement of the SSES and BBNPP intake and discharge structures

4.2. THE SSES THERMAL PLUME SURVEYS

Ecology III measured the SSES cooling tower blowdown discharge plume on five occasions covering the winter, spring, summer, and fall seasons. The surveys were performed for a range of Susquehanna River flows from 2,140 to 9,250 cfs. All surveys were made when SSES was fully operational. Each survey measured temperatures at a minimum of 20 stations. At each station, temperatures were measured at 1-ft intervals in the vertical (a total of 10 to 15 measurements at each station). Overall, about 300 temperatures were obtained for each survey. The surveys are documented in two Ecology III reports (1987 and 2009).

Susquehanna River and SSES conditions for each of the surveys are summarized in Table 4-1. The ΔT is the difference between the discharge temperature as measured in the cooling tower basins (the cold side temperature) and the upstream Susquehanna River temperature as measured during the survey. Because the surveys took one to two hours to complete and were generally done later in the morning (a period of rapidly rising natural temperatures), the upstream temperature increased from the start to the end of the survey. For the analysis, the upstream temperature at the start of the survey was used as the ambient temperature. Choosing the lower temperature as the ambient value tends to overestimate the size of the thermal plume.

The five surveys show that the largest ΔT occurred in the winter and the smallest ΔT in the summer. The maximum observed surface temperature rise was 1°F, which occurred during the low flow survey of 3 September 2008. The length of the 1°F temperature rise isotherm at the surface for this survey was 16 ft. For the other surveys, no 1°F temperature rise isotherm was detectable at the surface, and the maximum temperature rise isotherm rise for these surveys was 0.5°F. The average length of the 0.5°F isotherm (maximum distance from the diffuser to the isotherm in the downstream direction) over all surveys was 130 ft.

Table 4-1 Susquehanna River and SSES parameters for the five thermal plume surveys

	11/5/1986	1/9/1987	5/14/1987	8/21/2008	9/3/2008
Susquehanna River flow (reported), cfs	4,840	9,250	5,120	3,230	2,140
Water surface elevation, ft	487.8	489.0	487.9	487.0	486.5
Susquehanna River water temperature, °F	47.0	33.5	65.5	74.5	74.3
SSES blowdown flow rate, gpm	8,000	8,000	8,000	12,000	12,000
SSES blowdown temperature, °F	62.0	61.0	75.0	81.1	84.3
ΔT, °F	15.0	27.5	9.5	6.6	10.0

4.2.1. SSES Thermal Plume for Winter and Late Summer Conditions

Of interest in the context of low summer flow and high winter conditions are the January and September surveys. Results of these surveys are summarized in the plots shown in Figure 4-2 and Figure 4-3. These plots show the small surface temperature rises and the limited length of the thermal plumes. Also plotted in Figure 4-3 is the shape of the plume at depth.

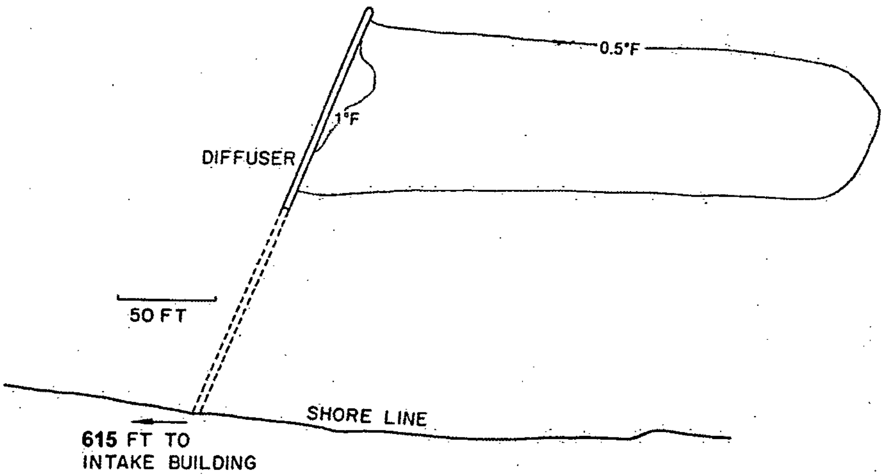

Figure 4-2 Observed surface temperature rises for the low-flow survey (3 September 2008)

The measured upstream temperature at the beginning of the survey was 74.3°F

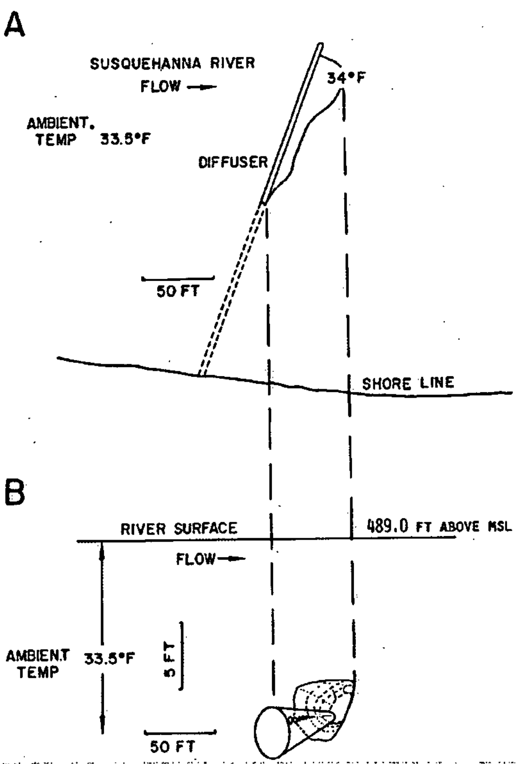

Figure 4-3 Plume configuration for the high-ΔT survey (9 January 1987)

A temperature of 34°F corresponds to a rise above ambient of 0.5°F; the isotherms indicated at the bottom adjacent to the diffuser ("B") are projected onto the water surface in "A".

4.2.2. *Sources of Uncertainty in the Surveys*

The fall, winter and spring surveys were conducted in 1986 and 1987 and used instrumentation accurate to 0.5°F (p. 3, Ecology III, 1987). This level of measurement accuracy essentially forecloses a precise measure of the length of the 0.5°F isotherm for these three surveys. The two summer surveys, conducted in August and September 2008, used instrumentation accurate to 0.1°F (p. 2, Ecology III, 2009).

Each of the five surveys lasted on average 1.5 hours and all surveys except the January survey were performed during periods of rising ambient temperature. The thermal plume diagrams drawn by Ecology III rely on subtracting an upstream ambient temperature from the temperature observed downstream of the diffuser to calculate the temperature rise. Ecology III noted the difficulty of assessing temperature rises given the changing ambient temperature (p. 6, Ecology III, 1987 and pp. 3 and 4, Ecology III, 2009).

The distances to the 0.5°F isotherm were based on a visual interpolation of observed values at discrete stations. An examination of the Ecology III data showed that for the August 2008 survey the length of the 0.5°F isotherm is dependent on a single data point (Station 23; see p. 10, Ecology III, 2009). An underestimate of 0.1°F in the observation or an overestimate of 0.1°F in the ambient temperature would shorten the isotherm length to 40 ft from 120 ft. Similarly for the September survey, an overestimate of 0.1°F in the observation or an underestimate of 0.1°F in the ambient temperature at Station 14 (see p. 11, Ecology III, 2009) would lengthen the observed isotherm to 420.

The small extent of the SSES plume can be confirmed by overlaying the largest observed plume (September 2003) onto the full width of the Susquehanna River – see Figure 4-4 below.

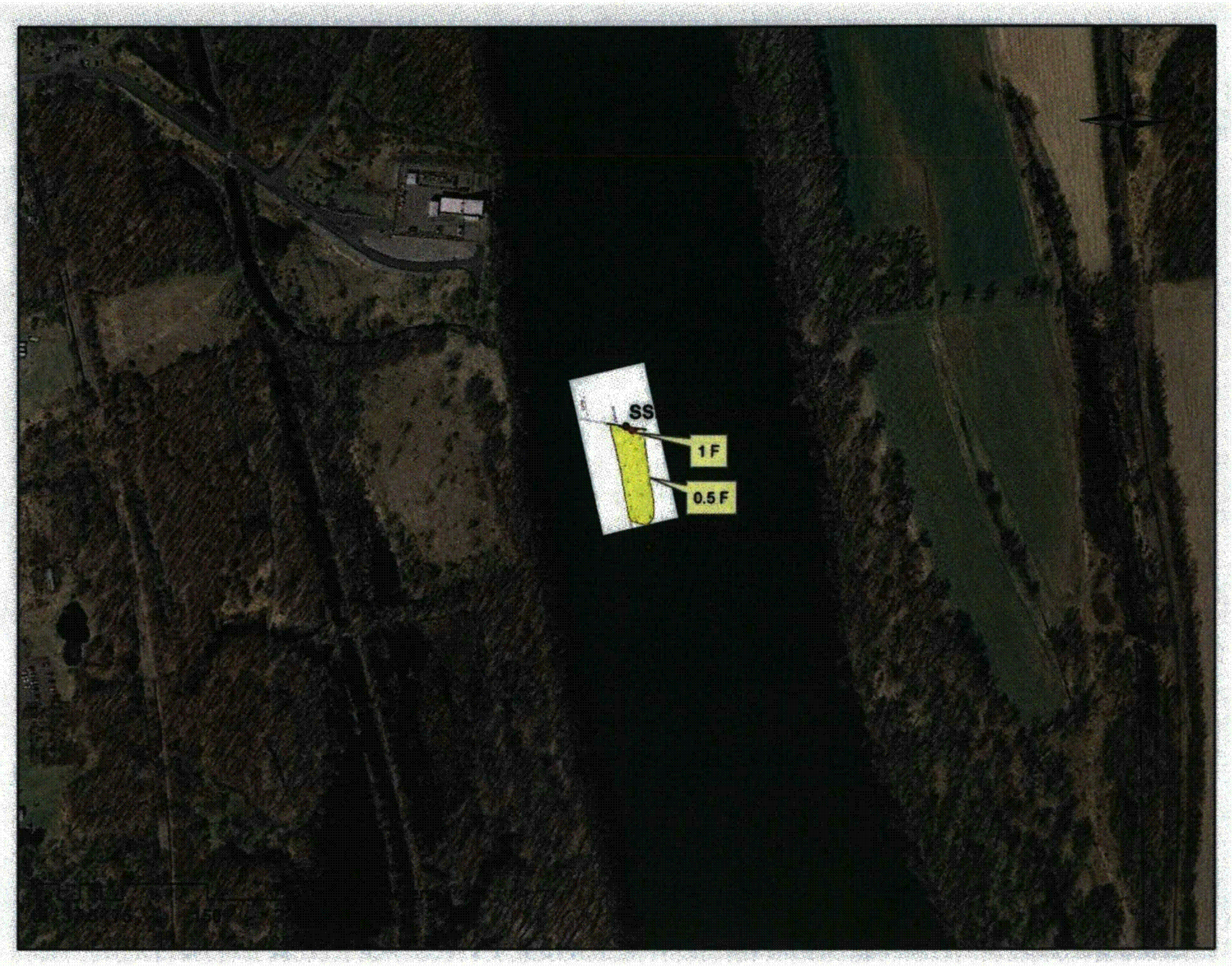

Figure 4-4 Observed thermal plume for the low-flow survey (3 September 2008) mapped onto the Susquehanna River

4.3. MODELING THE BBNPP THERMAL PLUME

Because the SSES blowdown system is similar to the system to be built for BBNPP, the SSES thermal plume observations constitute a useful "model" of the BBNPP thermal plume: SSES and BBNP have similar blowdown rates and temperatures and have nearly-identical diffusers located in the same reach of the Susquehanna River. However, because the scenarios evaluated are combinations of infrequent events, the conditions under which the observations were obtained do not match the scenario conditions. Modeling was therefore used to estimate thermal plume sizes for these scenarios.

4.3.1. Model Selection

EPA developed the CORMIX model specifically for the analysis of the wastewater plumes from surface discharges, submerged multi-port diffusers, and submerged single-port discharges. CORMIX is a rule-based expert system and is used both for design studies and analysis of existing discharges. Because the model is based on analytical solutions to the dynamic plume equations and on extensive experimental and field data, there are no calibration parameters.

Example CORMIX applications can be found on the MixZon Inc. website (http://www.cormix.info/index.php), which also lists references, validations, and benchmarks. Regionally, CORMIX has been adopted by the Delaware River Basin Commission as its standard mixing zone model.

To quote the CORMIX User Manual (p. 17, Jirka, et al. 1996):

> The CORMIX system represents a robust and versatile computerized methodology for predicting both the qualitative features (e.g. flow classification) and the quantitative aspects (e.g. dilution ratio, plume trajectory) of the hydrodynamic mixing processes resulting from different discharge configurations and in all types of ambient water bodies, including small streams, large rivers, lakes, reservoirs, estuaries, and coastal waters. The methodology: (a) has been extensively verified by the developers through comparison of simulation results to available field and laboratory data on mixing processes (Doneker and Jirka 1990; Akar and Jirka 1991; Jones et al.1996a; Jirka et al. 1996), (b) has undergone independent peer review in journal proceedings (Doneker, and Jirka 1991; Jirka and Doneker 1991; Jirka and Akar 1991; Akar and Jirka 1994; Akar and Jirka 1995; Mendéz Díaz and Jirka, 1996; Jones et al. 1996b; Jones and Jirka, 1996; Nash and Jirka 1996) and (c) is equally applicable to a wide range of problems from a simple single submerged pipe discharge into a small stream with rapid cross-sectional mixing to a complicated multiport diffuser installation in a deeply stratified coastal water.

CORMIX divides the plume calculations into near- and far-field regions. In the near-field, the size, configuration, and mixing characteristics of the plume are dominated by the diffuser exit velocity and buoyancy of the discharge. Beyond the near-field is the far-field, in which the plume is passive and its trajectory and mixing are dominated by the ambient velocity and temperature fields. The near-field algorithms for CORMIX are very detailed; the far-field algorithms less so.

CORMIX calculates the location of the plume centerline in three dimensions and, at each location, the temperature rise, the thickness and width of the plume, and the time of travel to that location. Temperature rises along the centerline are often presented as a way of summarizing results, but it should be noted that the temperature rises decrease rapidly with distance from the centerline as a Gaussian distribution. The plume edges are defined by CORMIX as occurring one standard deviation on each side of the centerline.

CORMIX also identifies the flow class for each location along the centerline. As an example, the initial flow class for the BBNPP diffuser is "acceleration zone of unidirectional co-flowing diffuser," which applies immediately adjacent to the diffuser. The flow classification system also indicates at what point the near-field ends and the far-field begins.

CORMIX has a number of limitations. It is a steady-state model[7] and assumes unidirectional ambient flow and a prismatic channel for the receiving waterbody. Neither of these limitations disqualifies its use for computing the size and configuration of the BBNPP blowdown plume. Its suitability can be demonstrated by comparing the computed CORMIX plume sizes with the observed plume sizes for each of the five surveys of the SSES thermal plume.

4.3.2. Comparison to SSES Thermal Plume Dimensions

Table 4-2 shows computed and observed distances from the SSES diffuser to the 1°F and 0.5°F temperature rise isotherms. Computed distances to the 1°F isotherm show good agreement with those observed. CORMIX both over- and under predicts distances relative to the 0.5°F isotherm, notably over predicting the distance for the low-flow case. An important discussion of uncertainty in the observation is presented in Section 4.2.2.

Table 4-2 Observed and computed isotherm distances (SSES)

	11/5/1986	1/9/1987	5/14/1987	8/21/2008	9/3/2008
Observed distance to the 0.5°F isotherm, ft	125	25	80	120	300
Computed distance to the 0.5°F isotherm, ft	27	26	9	21	498
Observed distance to the 1.0°F isotherm, ft	0	0	0	0	16
Computed distance to the 1.0°F isotherm, ft	6	6	2	4	21

CORMIX (Version 7) input and output files for these five surveys are provided on DVD (Appendix 4-CTB).

4.4. Scenarios

Susquehanna River, BBNPP and SSES parameters were derived from daily data for the three-year period August 2004 to July 2007. These data consisted of available observations, including monitored flows and temperatures at SSES and simulated BBNP flows and temperatures. A three-year period was judged to be of sufficient length to represent the range of parameter values. The data used to develop Susquehanna River temperatures used in the scenarios were measured by Ecology III upstream of the SSES intake.

To obtain the parameters for the summer low flow scenario (shown in Table 4-3), the daily differences (ΔTs) between calculated BBNPP discharge temperatures and observed Susquehanna River temperatures were examined for the period when the 7Q10 is most likely to occur (September). The maximum ΔT in the three-year record (16.9°F) occurred on 9/23/2004 when the observed Susquehanna River temperature was 62.3 F. All other parameters were selected

[7] An implication of the steady-state nature of CORMIX is that the results are not indicative of changes in temperature over any particular period, instead they show temperature rises over background. Because SSES operates at a steady rate and BBNPP is expected to operate similarly, temperature changes are expected to be small.

from September values to be consistent with the seasonal behavior of the cooling tower performance, e.g., blowdown rates corresponding to the date of maximum ΔT were selected for this analysis instead of the overall maximum temperature values. Also selected were the minimum Susquehanna River temperature, the average SSES withdrawal rate, blowdown rate, and blowdown temperature for all Septembers in the three-year analysis period. At the Commission's request, the Susquehanna River annual 7Q10 for the period of record adjusted to the BBNPP site was used. The worst case scenarios therefore represent infrequent events of short duration.

For the winter scenario ("high ΔT"), parameters were selected by choosing the day of the maximum BBNPP ΔT from the three-year analysis period (12/23/2004) and the withdrawal rate, blowdown rate, and blowdown temperature for that day. For Susquehanna River parameters, the period-of-record 7Q10 flow for December and the minimum observed temperature for the three-year analysis period were selected. For SSES the average withdrawal rate, blowdown rate, and blowdown temperature over all Decembers in the three-year analysis period were used.

Two similar scenarios were developed using average values of the Susquehanna River, BBNPP and SSES parameters. Parameters for these and the worst case scenarios are summarized in Table 4-3. The four scenarios are similar to those selected for analysis for the 1972 SSES Environmental Report and to conditions observed for the five plume surveys.

Table 4-3 Scenario parameters

Parameter	Winter low flow	Winter average	Summer low flow	Summer average
Nominal Susquehanna River flow, cfs	December 7Q10	December mean	Annual 7Q10	September mean
	2,220	14,906	843	4,729
Net Susquehanna River flow[8], cfs	2,146	14,836	755	4,641
Water surface elevation, ft	486.5	490.4	485.7	487.6
Susquehanna River water temperature, °F	12/23/2004	December mean	9/23/2004	September mean
	33.2	37.8	62.3	69.1
BBNPP blowdown flow rate, gpm	12/23/2004	December mean	9/23/2004	September mean
	6,867	5,967	7,664	7,620
BBNPP blowdown temperature, °F	12/23/2004	December mean	9/23/2004	September mean
	68.4	58.2	79.2	77.6
BBNPP ΔT, °F	35.2	20.4	16.9	8.5
SSES blowdown flow rate, gpm	December mean	September mean	December mean	September mean
	8,119	8,119	8,119	8,119
SSES blowdown temperature, °F	December mean	December mean	September mean	September mean
	62.4	62.4	79.5	79.5
SSES ΔT, °F	29.2	24.6	17.2	10.4

The selected parameters can be used to estimate fully-mixed temperature rises using a mass-balance approach. The fully-mixed temperatures for each of the scenarios are shown in Table 4-4. The fully-mixed calculation uses the net Susquehanna River flow shown in Table 4-3 as follows:

$$\Delta T_{FM} = \frac{\Delta T_{SSES} B_{SSES} + \Delta T_{BBNPP} B_{BBNPP}}{Q_{SRnet}}$$

[8] The net Susquehanna River flow is the nominal flow show minus the consumptive use at SSES and BBNPP.

where

ΔT_{FM}	Fully-mixed temperature rise, °F
$\Delta T_{SSES}, B_{SSES}$	SSES blowdown ΔT and flow rate, °F and cfs, respectively
$\Delta T_{BBNPP}, B_{BBNPP}$	BBNPP blowdown ΔT and flow rate, °F and cfs, respectively
Q_{SRnet}	Net Susquehanna River flow, cfs

These temperatures represent the temperature increases downstream after the blowdown discharges are mixed entirely with the Susquehanna River but do not account for surface heat loss, an important heat transfer process in the far-field. The temperatures in Table 4-4 are therefore overestimates of actual temperature increases.

Table 4-4 Fully-mixed temperature rises for BBNPP and SSES for the four scenarios

	Winter low flow	Winter average	Summer low flow	Summer average
BBNPP fully-mixed rise, °F	0.24	0.02	0.34	0.03
SSES fully-mixed rise, °F	0.24	0.03	0.49	0.05
Combined fully-mixed rise, °F	0.48	0.05	0.83	0.08

4.5. Thermal Plume Size and Configuration Estimates

For each of the four scenarios, CORMIX shows a short near-field region for the BBNPP plume consistent with the behavior observed in the surveys of the SSES plume. For the two worst-case scenarios (winter high ΔT and summer low flow) and the summer average scenario, the plume beyond the near-field becomes stratified, reflecting the buoyancy of the discharge. For the winter average scenario (higher Susquehanna River flow and somewhat lower ΔT), the plume is mixed vertically in the far-field.

The near-field and stratified behaviors can be understood by studying side views of the plumes (Figure 4-5, Figure 4-6, Figure 4-7, and Figure 4-8). For all scenarios, the overall behavior is intense mixing at the diffuser (the near-field) followed by stratification in the far-field for the two low-flow and summer average scenarios or by vertical mixing for the winter average scenario. Although not shown, the CORMIX results indicate that the SSES plumes behave in a manner similar to that shown by the BBNPP plumes for each of the four scenarios.

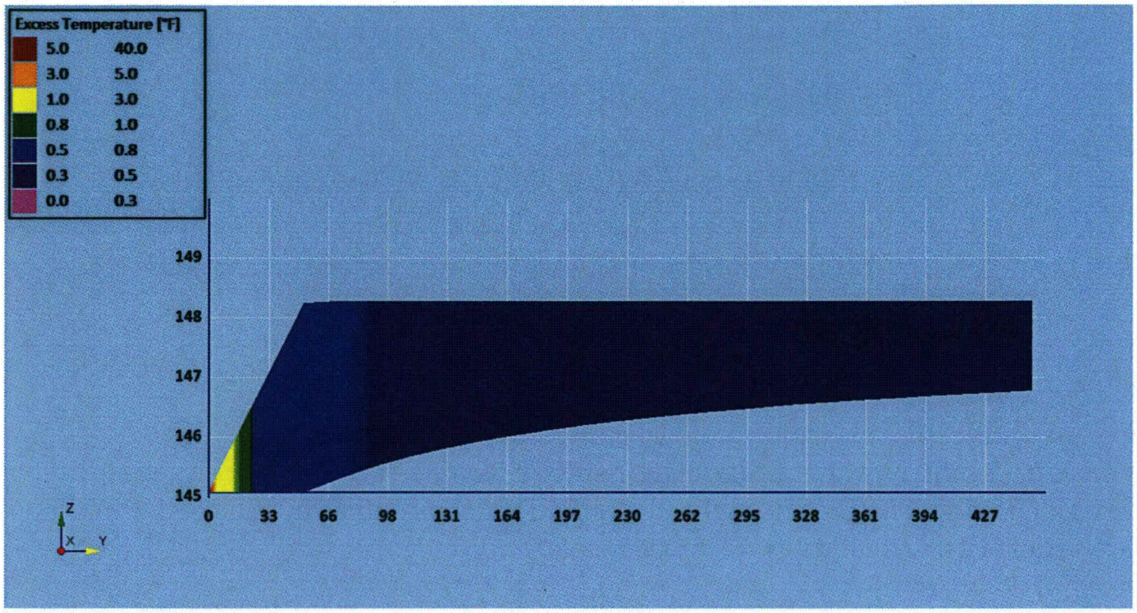

Figure 4-5 BBNPP winter low-flow scenario - plume side view

Vertical axis is mMSL; horizontal axis is ft downstream of the BBNPP diffuser.

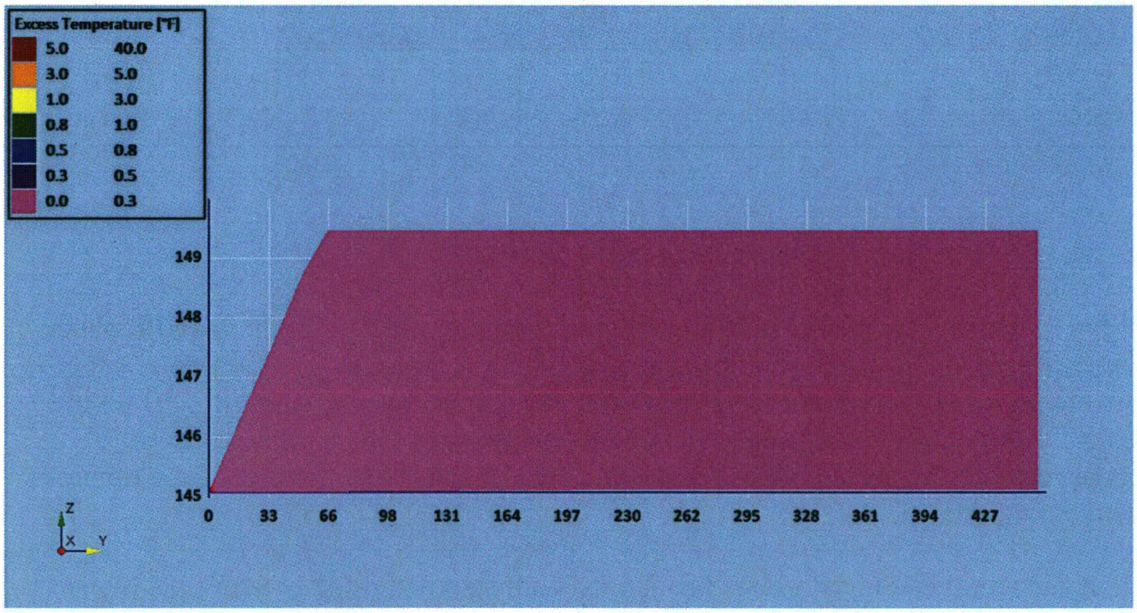

Figure 4-6 BBNPP winter average-flow scenario - plume side view

Vertical axis is mMSL; horizontal axis is ft downstream of the BBNPP diffuser.

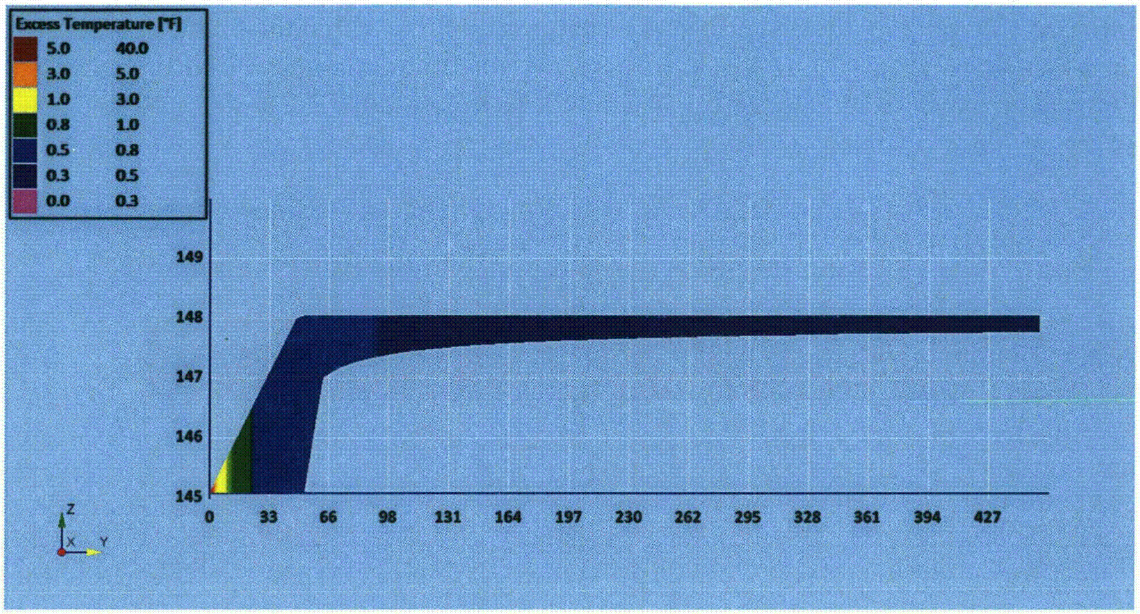

Figure 4-7 BBNPP summer low-flow scenario - plume side view

Vertical axis is mMSL; horizontal axis is ft downstream of the BBNPP diffuser.

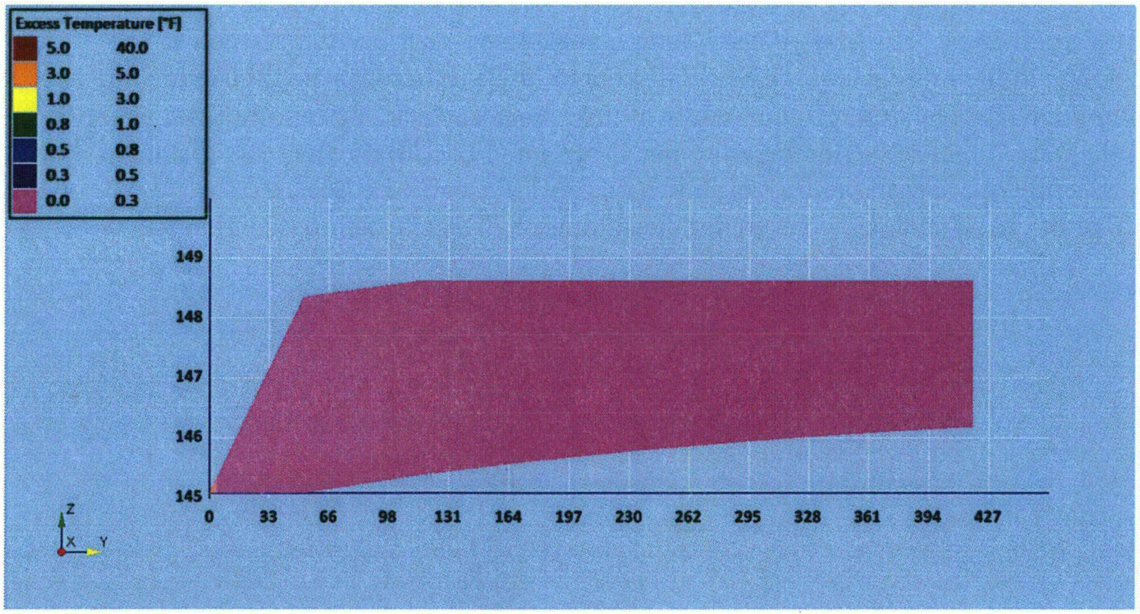

Figure 4-8 BBNPP summer average-flow scenario - plume side view

Vertical axis is mMSL; horizontal axis is ft downstream of the BBNPP diffuser.

Although separated by 350 ft, the SSES discharge plume can overlap the BBNPP plume at low temperature rise values. An estimate of the extent of overlapping can be made by studying the temperature rise from SSES at the BBNPP discharge. Table 4-5 shows the temperature rise within the SSES thermal plume at a downstream distance of 350 ft. Only the low-flow scenarios (winter low flow and summer low flow) show an SSES plume that overlaps the BBNPP plume at a temperature rise above 1°F at the centerline. The temperature rise within the plume drops rapidly to less than 0.5°F at the plume edges. The temperature rise within the BBNPP plumes shown earlier can be expected to increase by the amount shown in Table 4-5 at the centerline and plume edges.

Table 4-5 Temperature rise from the SSES thermal plume at the BBNPP discharge

Scenario	Temperature rise at centerline, °F	Temperature rise at plume edge, °F
Winter low flow	1.09	0.40
Winter average	0.18	0.07
Summer low flow	1.29	0.48
Summer average	0.28	0.10

The overlapping of the plumes will result in an increase in the size of the combined plume. The worst-case scenario of summer low flow was used to study the implications of overlapped plumes. To illustrate the spatial relationship of the SSES and BBNPP thermal plumes, the plume can be shown as an isosurface (i.e., a three-dimensional surface defined by a constant temperature rise). Figure 4-9 shows the 1°F temperature rise isosurface due to the BBNPP discharge alone. In the presence of the SSES discharge, the 1°F isosurface will expand and is shown in Figure 4-10. The downstream extent of the 1°F isosurface does not increase as much as the lateral extent, because the temperature rise drops quickly with downstream distance. The lateral extent of the overlapping plume as shown by the 1°F isosurface does not extend over the entire width of the Susquehanna River under the summer extreme low flow scenario.

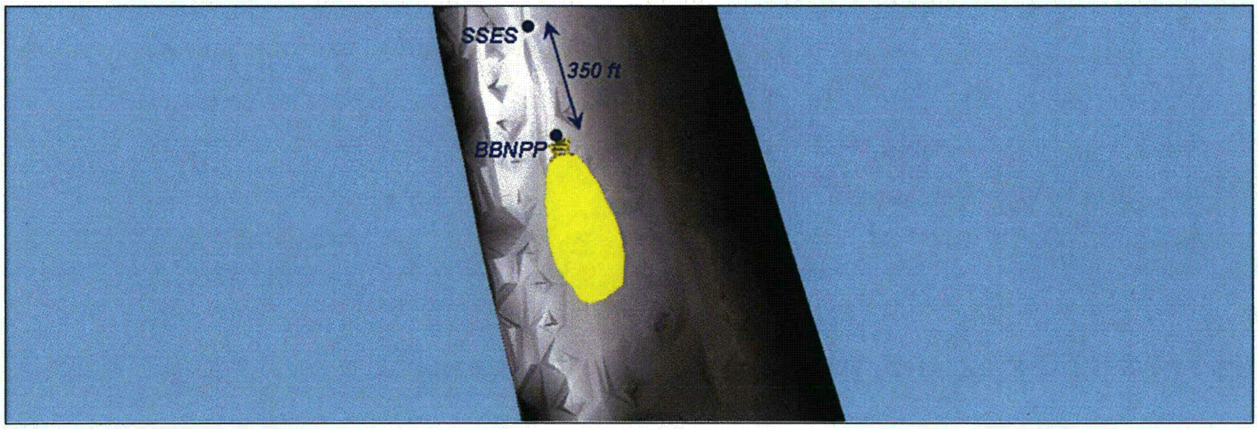

Figure 4-9 The 1°F temperature rise isosurface emerging from BBNPP discharge alone for the summer low-flow scenario

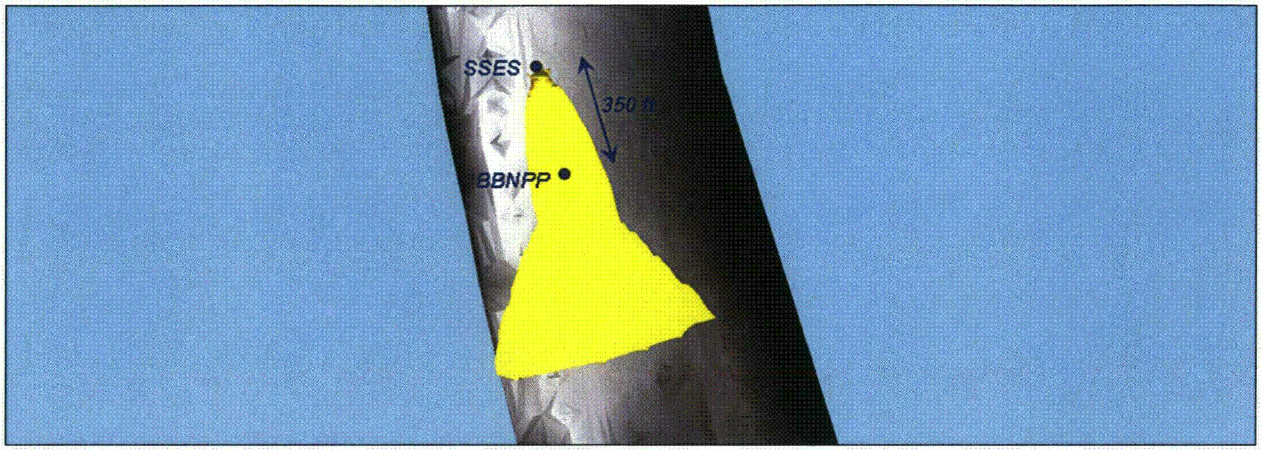

Figure 4-10 The 1°F temperature rise isosurface emerging from combined BBNPP and SSES discharge for the summer low-flow scenario

Besides the lateral extent of the plumes, the vertical extent is of interest in evaluating the potential for thermal blockage. As noted, all plumes calculated for the scenarios are stratified except for the winter average scenario. For this scenario, the temperature rise is so small (less than 0.25°F) as to make the plume nearly indistinguishable from ambient water. For the other three scenarios, the average temperature rise in the stratified layers of the BBNPP can be calculated from the CORMIX results. These values are shown in Table 4-6 at a representative distance of 100 ft from the BBNPP discharge and indicate that the plume does not extend over the entire water column. There is a thin bottom layer unaffected by the plume that occurs with the summer average flow scenario, but the temperature rise in the surface layer is only 0.19°F. The summer low-flow scenario that shows the highest temperature rise (1.35°F) has the thickest bottom layer at 7.6 ft.

Table 4-6 Surface and bottom layer temperature rises for the four scenarios

Location: 100 ft downstream of BBNPP discharge	Winter low flow	Winter average	Summer low flow	Summer average
Surface layer rise at the centerline, °F	1.32	0.12	1.35	0.19
Surface layer rise at plume edge, °F	0.49	0.04	0.50	0.07
Surface layer thickness, ft	7.9	14.4	2.1	10.6
Surface layer width, ft	150.9	110.3	193.6	124.7
Bottom layer rise, °F	0.00	(not stratified)	0.00	0.00
Bottom layer thickness, ft	2.0	(not stratified)	7.6	1.0

Plume overlapping and its implications in the vertical direction can be studied in a similar fashion to that in the horizontal plane. The summer low-flow scenario was used for this analysis. Figure 4-11 shows the 1°F temperature rise isosurface from the BBNPP discharge alone. Figure 4-12 shows the 1°F temperature rise isosurface from the combined SSES and BBNPP discharges. Due to the overlapping of the plumes, the BBNPP plume has increased in the vertical direction and in its downstream extent. However, the increase in size is small relative to the river water column depth. The side view of the plume shows that the bottom ambient temperature layer occupies most of the water column and provides a large zone for fish passage.

Similar diagrams are included for the 0.5°F temperature rise isotherm in Figure 4-13 and Figure 4-14

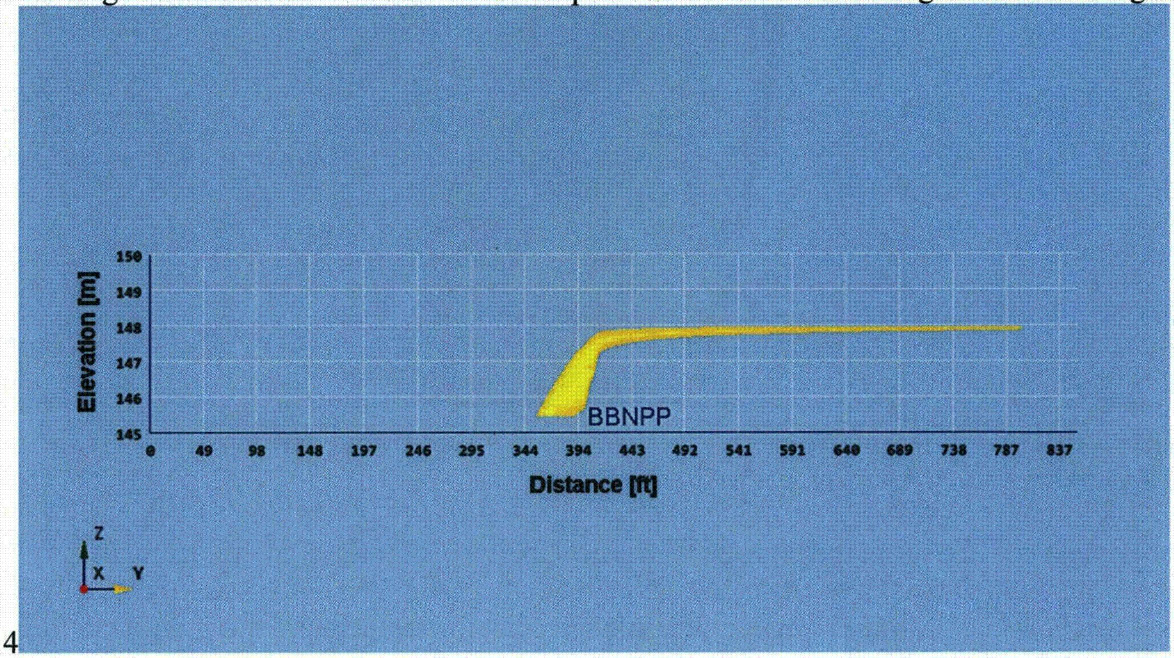

Figure 4-11 The 1°F temperature rise isosurface emerging from BBNPP discharge alone for the summer low-flow scenario

Distances are from the SSES discharge.

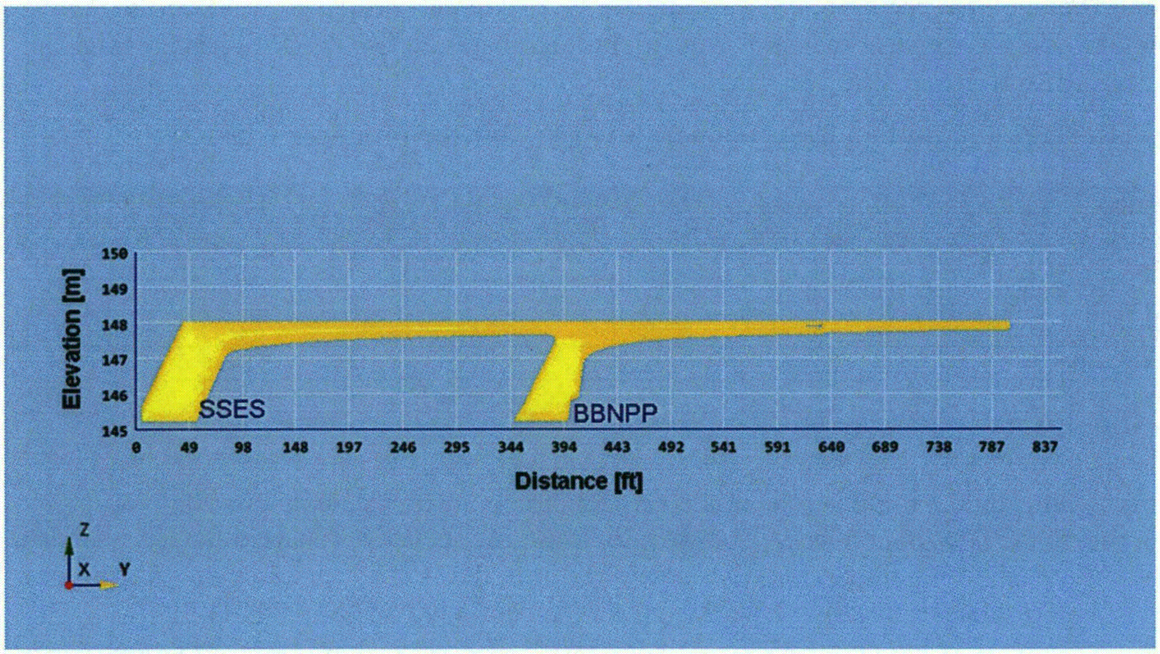

Figure 4-12 The 1°F temperature rise isosurface emerging from combined BBNPP and SSES discharge for the summer low-flow scenario

Distances are from the SSES discharge.

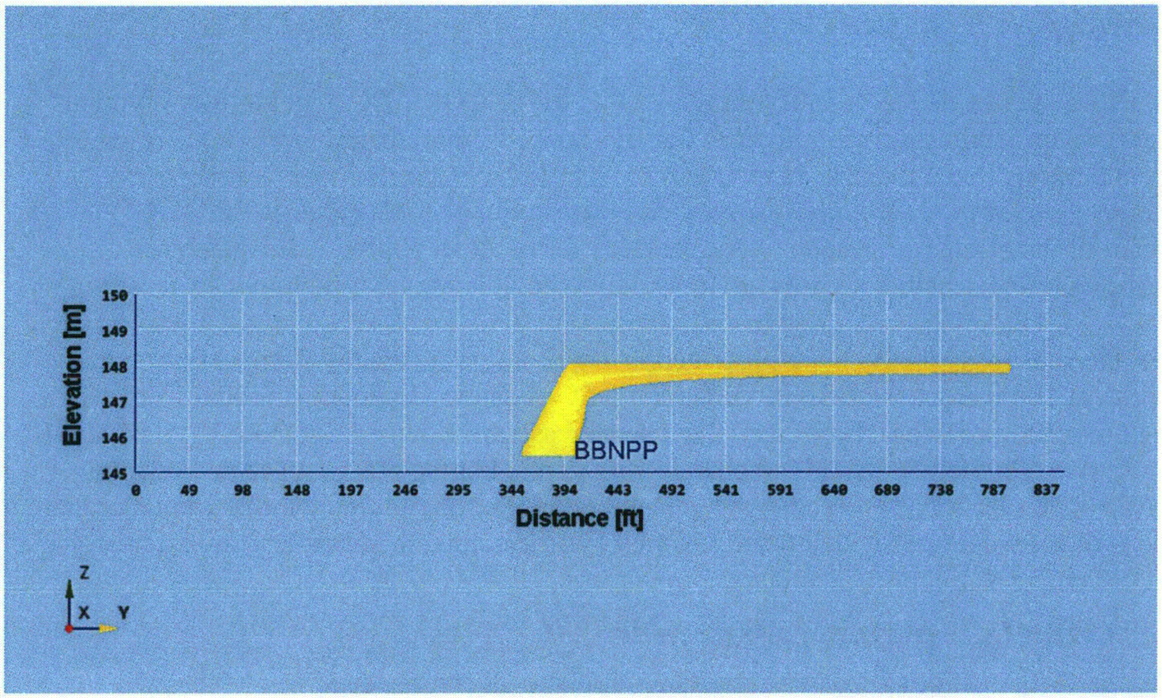

Figure 4-13 The 0.5°F temperature rise isosurface emerging from BBNPP discharge alone for the summer low-flow scenario

Distances are from the SSES discharge.

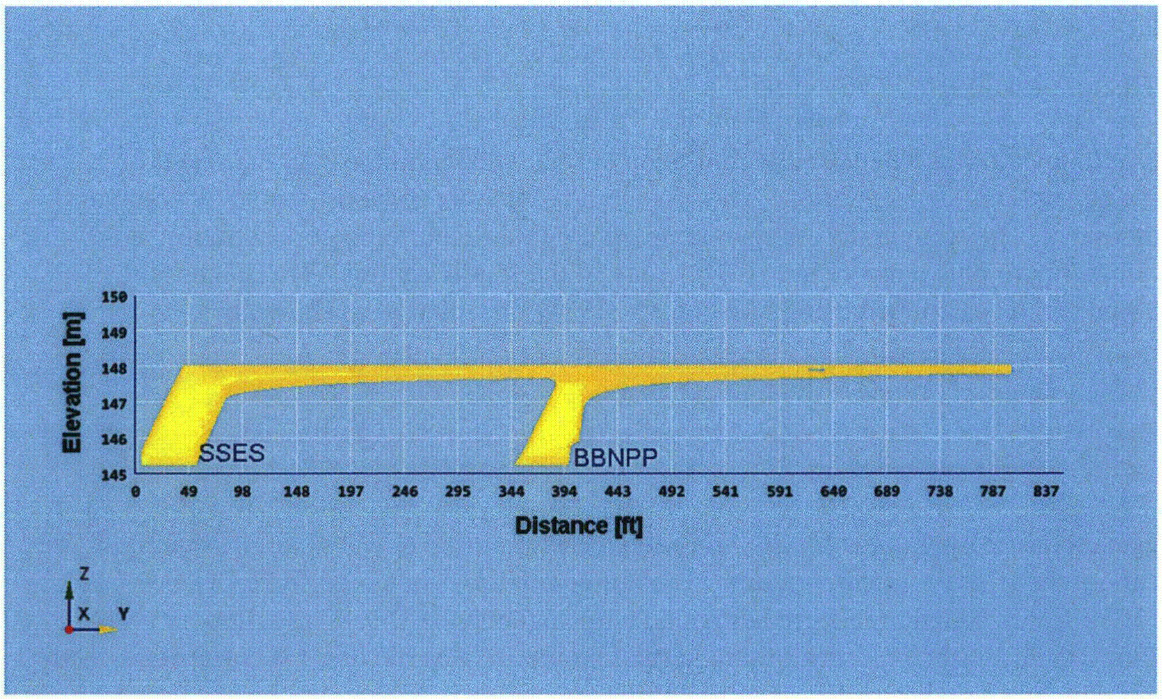

Figure 4-14 The 0.5°F temperature rise isosurface emerging from combined BBNPP and SSES discharge for the summer low-flow scenario

Distances are from the SSES discharge.

4.6. Sensitivity Analysis

An analysis was performed to quantify the sensitivity of the CORMIX model to two key input parameters, water depth and river velocity. For this analysis, these parameters were varied by 5% (plus and minus) from the base case values for the BBNPP summer low flow scenario. Temperature rises for the base and sensitivity cases are compared at a distance 100 feet downstream of the discharge structure. At distances further than 100 feet, the differences between the base and sensitivity cases are too small to be illustrative of the model's sensitivity.

Results of the sensitivity analysis are presented in Table 4-7, which shows temperature rise and plume width at 100 ft from the BBNPP diffuser. A 5% reduction in depth caused a 1.6% increase in temperature rise at 100 ft, and the 5% decrease in velocity caused a 2.1% increase in temperature rise. Plume widths did not change with depth, but the 5% increase in velocity widened the plume by 3.3%. The changes in temperature rise and plume width are smaller than the changes in the values of the depth and velocity input parameters indicating limited model sensitivity to changes in input parameters.

Table 4-7 CORMIX sensitivity analysis results

Case	Temperature rise (°F) at 100 ft	Plume width (feet) at 100 feet distance
Base, i.e., summer low flow	2.43	196.8
+ 5% depth	2.39	196.8
- 5% depth	2.47	196.8
+ 5% velocity	2.38	203.4
- 5% velocity	2.48	196.8

4.7. Dissolved Oxygen Effects

Increases in temperature in the BBNPP cooling tower blowdown plume may cause a decrease in dissolved oxygen (DO) concentration. This potential reduction can be estimated by comparing the saturation concentration at the ambient temperature to the saturation concentration at the ambient temperature plus temperature rise for each of the four scenarios. The saturation concentration can be calculated using Mortimer's (1981) formulation as shown below:

$$DO_{sat} = \exp(7.7117 - 1.31403 \ln[T + 45.93])$$

where T is the water temperature in °C.

Susquehanna River temperatures for the four scenarios were used to calculate the saturation DO values without the BBNPP thermal plume. The temperature rise obtained from CORMIX at a distance of 54 ft was added to the ambient value to recalculate the DO. The difference is the reduction in DO due to the presence of the thermal plume. The value of 54 ft corresponds to the end of the near-field for all scenarios except for the summer low-flow scenario. As noted earlier, CORMIX does not report a near-field termination distance for the summer low-flow scenario; for consistency the DO calculation for this scenario is also reported for the 54 ft distance. Use of the 54 ft distance for the DO calculation is conservative, because centerline temperature rises are used.

The calculated values of DO saturation concentration at the end of the near-field (54 ft) are shown in Table 4-8. The temperature rise is largest for the two low-flow scenarios; these scenarios show the largest reduction in saturation DO. However, the relative temperature rise is largest for the winter low-flow scenario; consequently, the largest DO saturation reduction (0.31 mg/L) is obtained for this scenario. For the summer low flow case the reduction (0.16 mg/L) is much smaller and likely to fall below detection by standard field instrumentation. None of the reductions in saturation DO would cause DO to fall below water quality standards. In addition, as noted in the thermal plume discussions, the plumes themselves are limited in extent so the volume of water in which saturation DO is reduced is similarly limited in extent.

Table 4-8 DO values at the plume centerline at the end of the near-field with and without the influence of the BBNPP thermal plume

Scenario	Winter low flow	Winter average flow	Summer low flow	Summer average flow
Susquehanna River temperature (°F)	33.2	37.8	62.3	69.1
Susquehanna River saturation DO (mg/L)	14.35	13.38	9.70	8.99
Temperature rise (°F)	1.41	0.12	1.40	0.19
Temperature (°F)	34.61	37.92	63.70	69.29
Saturation DO (mg/L)	14.04	13.35	9.55	8.97
Reduction in DO saturation (mg/L)	0.31	0.02	0.16	0.02

4.8. Conclusions

Because the BBNPP diffuser is nearly identical to the existing SSES diffuser, the latter's performance provides the best estimate of the anticipated performance of the BBNPP diffuser. The SSES blowdown discharge plume has been measured on five occasions covering a range of flows, including a September survey when the Susquehanna River flow rate was 2,140 cfs. All five surveys showed small thermal plumes.

To provide estimates of the BBNPP thermal plume at lower flows, EPA's standard thermal plume model, CORMIX, was used. To confirm its applicability, the model was first used to reproduce the observed dimensions of the SSES thermal plume. EPA's model similarly calculates small sizes for the BBNPP thermal plume for average and worst case conditions.

Potential reductions in dissolved oxygen concentrations were estimated by comparing the saturation DO concentration at ambient temperature to the saturation DO at the plume temperatures. Potential reductions in dissolved oxygen concentrations due to the small rises in temperature adjacent to the BBNPP diffuser would be minimal and of limited extent.

5. WATER QUALITY ASSESSMENT OF SHALLOW AREAS USED BY FRY AND YOUNG-OF-THE-YEAR (YOY) SMALLMOUTH BASS (SMB)

5.1. OBJECTIVE

The Bell Bend water quality study was designed to identify whether stressful water-quality conditions occurred in 2010 in microhabitats and main-channel habitats during the critical period for fry ($\leq$25 mm) and young-of-the-year (YOY) smallmouth bass (*Micropterus dolomieui*) (SMB). A report by Chaplin *et al.* (2009) postulated that sub-optimal dissolved oxygen (DO), particularly during the nighttime and in combination with relatively warm temperatures in habitats of YOY SMB, may play a role in predisposing the fish to bacterial infections. The bacterium (*Flavobacterium columnare*) is common in soil and water and causes secondary infections in stressed fish (PFBC 2005, cited in Chaplin *et al.* 2010).

Microhabitats in which such sub-optimal DO and warm temperatures occur are typically in side channels or shallow areas that are characterized by relatively low velocities (<0.1 ft/sec) and shallow depths (<2 ft) compared to the main river channel. These microhabitats, occupied by YOY SMB for the first 2-3 months of their lives, can be subject to wide fluctuations in DO and are susceptible to heating by solar radiation (Chaplin *et al.* 2009). YOY SMB utilizing these habitats during a sustained, extreme low river flow may be subject to potentially stressful, low DO concentrations (<5.0 mg/L) at night and elevated water temperatures exceeding both the PA WQ Standard and/or other biological threshold during the day. It is important to note that state water quality standards for Warm Water Fisheries (WWF) streams do not always coincide with the 84°F described as a possible biological threshold temperature for YOY SMB. For example, the WWF regulatory standard upper limit for temperature is 87°F from 1 July through 31 August. In addition, a 5.0 mg/L biological measure needs to be considered in light of the state regulatory standard for dissolved oxygen in a WWF which is an instantaneous lower limit of 4.0 mg/L or greater and a daily average equal to 5.0 mg/L or greater. As a result both temperature thresholds and both DO levels are evaluated in this report.

Relative to the proposed Bell Bend Project, an agency concern arose that its consumptive water use of the Susquehanna River water may exacerbate the summer water quality conditions in the SMB microhabitats concomitant with depth changes. Figure 5-1 shows SMB fry usage of shallow, low velocity areas in the study reach for the proposed Bell Bend Project.

Figure 5-1 Smallmouth usage of shallow with negligible velocity microhabitat

There was no attempt as a part of this study effort to quantitatively identify "backwater areas" in absolute terms based on the stated characteristics described above for such microhabitats. It may generally be assumed that these areas are typically floodplain aquatic habitats that are seasonally or periodically connected to the main channel and for the purpose of this study, support early life stage maturation habitat for fry and YOY SMB. In the project area, these microhabitats are typically found during the summer months on the shallow side of island outcrops and/or naturally formed shallow coves sheltered from higher river velocities. It is important to note that there are few if any proper or persistent backwater areas in this stretch of river and that these intermittent backwater characteristics are subject to seasonal variation. This assessment instead uses the three shallow areas where data sondes were deployed to assess shallow water conditions, which may or may not be "backwaters" in the strict meaning of the term.

According to Chaplin, *et al.* (2009), SMB typically spawn from late April to early June when temperatures reach 15°C (59°F). Eggs hatch in 2 to 9 days and they are ready to leave the nest and disperse in 5 to 6 days. Since fry are susceptible to predation and cannot withstand higher mid-channel velocities, they typically spend the first 2 to 3 months after swim up (roughly May through July) in the same microhabitat where they were born.

5.2. *PENNSYLVANIA WATER QUALITY CRITERIA*

The Susquehanna River adjacent to the proposed Bell Bend Project is designated as a WWF. The Pennsylvania Water Quality Standards, (PA Code, Chapter 93, §93.7) applicable to a WWF are as follows: For DO a minimum daily average of 5.0 mg/L and a minimum instantaneous 4.0 mg/L. The pH range is between 6.0 and 9.0 inclusive. Pennsylvania provides the following criteria (Table 5-1) for temperature. Maximum temperatures in the receiving water body resulting from heated waste sources are regulated under Chapters 92, 96 and other sources where temperature limits are necessary to protect designated and existing uses. The temperature values shown are considered to be instantaneous limits based on cross-sectional average temperatures.

Table 5-1 Temperature limits applicable to Warm Water Fishery streams. Highlighted areas denote sampling period of the 2010 water quality study

Critical Use Period:	Temperature (°F)
January1-31	40
February1-29	40
March1-31	46
April1-15	52
April16-30	58
May1-15	64*
May16-31	72*
June1-15	80*
June16-30	84*
July1-31	87*
August1-15	87**
August16-30	87**
September1-15	84
September16-30	78
October1-15	72
October16-31	66
November1-15	58
November16-30	50
December1-31	42

* Critical Period for Fry per Chaplin *et al.* (2009)
**Additional Period Evaluated by this Study

5.3. *FIELD MEASUREMENTS AND OBSERVATIONS*

The assessment of shallow areas in the vicinity of the Bell Bend Project was conducted during the summer of 2010 to identify water quality-related conditions that may be stressful to YOY (fry and juvenile) SMB. The assessment was also to determine if the proposed consumptive water use associated with the Bell Bend Project could potentially intensify those conditions.

Water temperature, DO, pH, and conductivity[9] were continuously monitored using Hydro Lab data sonde recorders at three paired locations (inshore (shallow) and main channel habitats). The three monitored locations were the Susquehanna SES Environmental Laboratory (Environmental

[9] Conductivity data is available but not reported herein.

Lab) boat ramp, Goose Island, and Berwick Test Track ramp. The former location is upstream of the proposed Bell Bend Project and the latter two are downstream of the project with the Goose Island location 2.8 mi and the Berwick Test Track Ramp 8.4 mi downstream of the proposed discharge structure, respectively.

Continuous monitoring of DO and water temperature in representative shallow areas (upstream and downstream of the proposed Bell Bend Project intake) was conducted from 22 June to 3 September 2010, a potential period of high water temperature and low nighttime DO values in shallow areas. This monitoring program was implemented to identify whether stressful water quality conditions occur during the critical nursery and rearing times of fry and YOY SMB and to define the magnitude and frequency of occurrence of these conditions. The "critical period" according to Chaplin *et al.* (2009) for survival and development of SMB is 1 May through 31 July.[10] This study extended that evaluation through the end of August.

As in the Chaplin *et al.* (2009) study, paired sondes were deployed (one each in a shallow microhabitat and a corresponding main channel location to monitor DO) water temperature, and pH (Figure 5-2). This pairing was intended to document the extent of differences in water quality between main channel and shallow microhabitats. Table 5-2 provides descriptions of sampled locations.

[10] Jeffery J. Chaplin, et al., Water Quality Monitoring in 2008 in Response to Young-of-the-Year Smallmouth Bass Mortality in the Susquehanna River and Major Tributaries, Pennsylvania, 2009, p. 11.

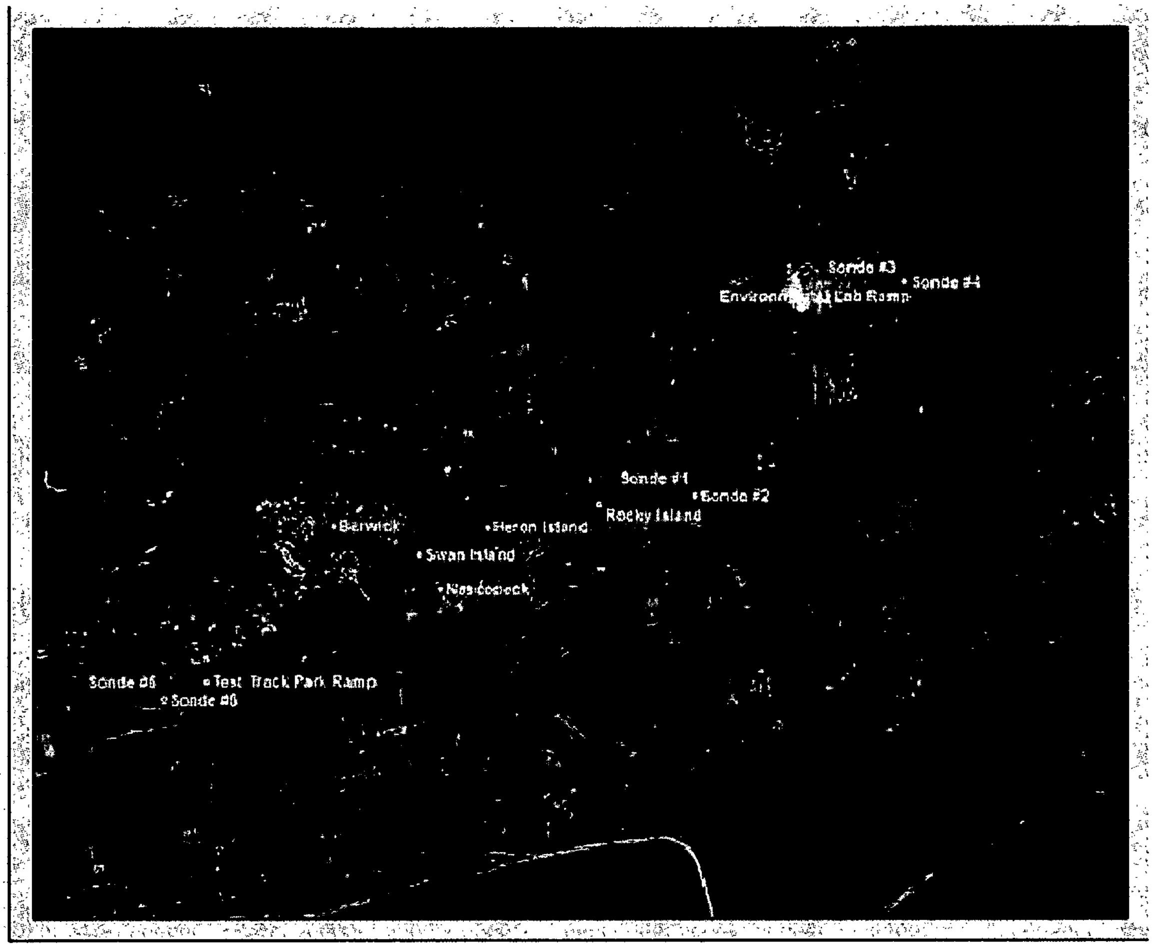

Figure 5-2 Water quality data sonde locations with habitat characteristics

Table 5-2 Sonde locations

Location	Sonde Number	Latitude/Longitude
Near southern tip of Goose Island - near east bank shoreline. Water depth <1.5 feet with very little current. Area contained abundant submerged aquatic vegetation. River width 1430 feet.	1	41°03.901N/076°10.151W
Near southern tip of Goose Island - approximately 100 feet from east bank. Water depth 3 feet with notably more current than Sonde 1 location. River width 1430 feet.	2	41°03.884N/076°10.160W
Near Environmental Lab boat ramp - near west bank. Water depth <1.5 feet located in an eddy situation. River width 870 feet.	3	41°05.580N/076°07.827W
Near Environmental Lab boat ramp - approximately 100 feet from west bank in main river channel. Water depth 3 feet. River width 870 feet.	4	41°05.588N/076°07.803W
Approximately ½-mile downriver from Berwick Test Track boat ramp - 100 feet from east bank in main river channel. Water depth 4 feet with a cobble substrate. River width 660 feet.	5	41°02.271N/076°16.126W
Approximately ½-mile downriver from Berwick Test Track boat ramp - near east bank. Water depth 2.5 feet near shoreline. Similar flow conditions as Sonde 5 location. River width 660 feet.	6	41°02.260N/076°16.126W

Figure 5-3, Figure 5-4, and Figure 5-5 show the sampling locations and their habitats for this monitoring study. These locations were selected for accessibility, ease of servicing, and representativeness of potential shallow habitat for assessing SMB spawning, fry emergence, juvenile nursery, and rearing. An upstream location (Data Sondes 3 and 4 at the Environmental Lab boat ramp) was selected to determine whether a relationship exists in water temperature and DO between upstream and downstream locations within the aquatic habitat study reach.[11]

[11] No meaningful correlation between upstream and downstream 2010 water quality data was found. Therefore this is not discussed further in this report.

Figure 5-3 Southeast shore of Goose Island on the Susquehanna River with abundant aquatic vegetation, July 2010 (data sonde locations 1, inshore, and 2, main channel)

Figure 5-4 Environmental Lab boat ramp on west bank of Susquehanna River, July 2010 (data sonde locations 3, inshore, and 4, main channel)

Figure 5-5 Southeast shore of Susquehanna River across from Berwick Test Track boat ramp, July 2010 (data sonde locations 5, main channel, and 6, inshore)

As specified in the study plan, the continuous monitoring data were analyzed for detection of deviations from the Pennsylvania State Water Quality Criteria. Temperature data was also evaluated with respect to the possible threshold level of 84°F regardless of whether this temperature was within state water quality standards.

Mean daily temperature data by month for 2010 as recorded at the Environmental Lab shown in Figure 5-6 indicates that 2010 water temperatures in the Susquehanna River for the area of interest were higher than the average monthly historical temperature data (1974-2009). Figure 5-6 also shows the +1 and +2 standard deviation for the 1974 – 2009 period of record to further demonstrate that the 2010 water temperatures were not only higher than average, but exceeded +1 standard deviation for the May 1 through August 31 period of interest and were nearly 2 standard deviations higher in July which is the most stressed month. Figure 5-7 shows the 2010 flows relative to a historical flow period (1974 – 2011) demonstrating that 2010 was not only a high temperature year, but also a low flow year for the period of interest.

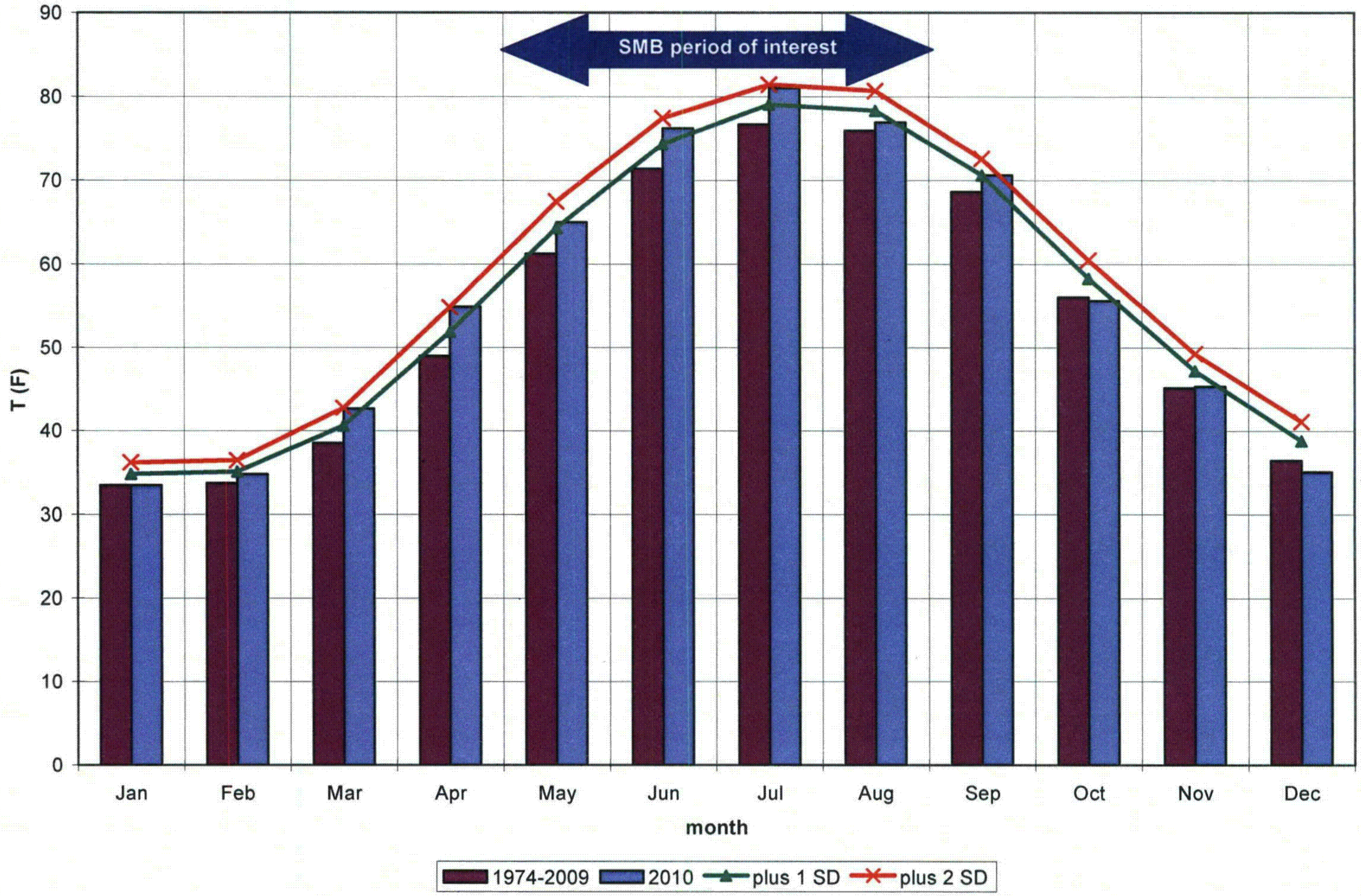

Figure 5-6 Average monthly temperatures compared with 2010 temperatures and showing 1 and 2 standard deviations above mean long term (1974 – 2009) averages

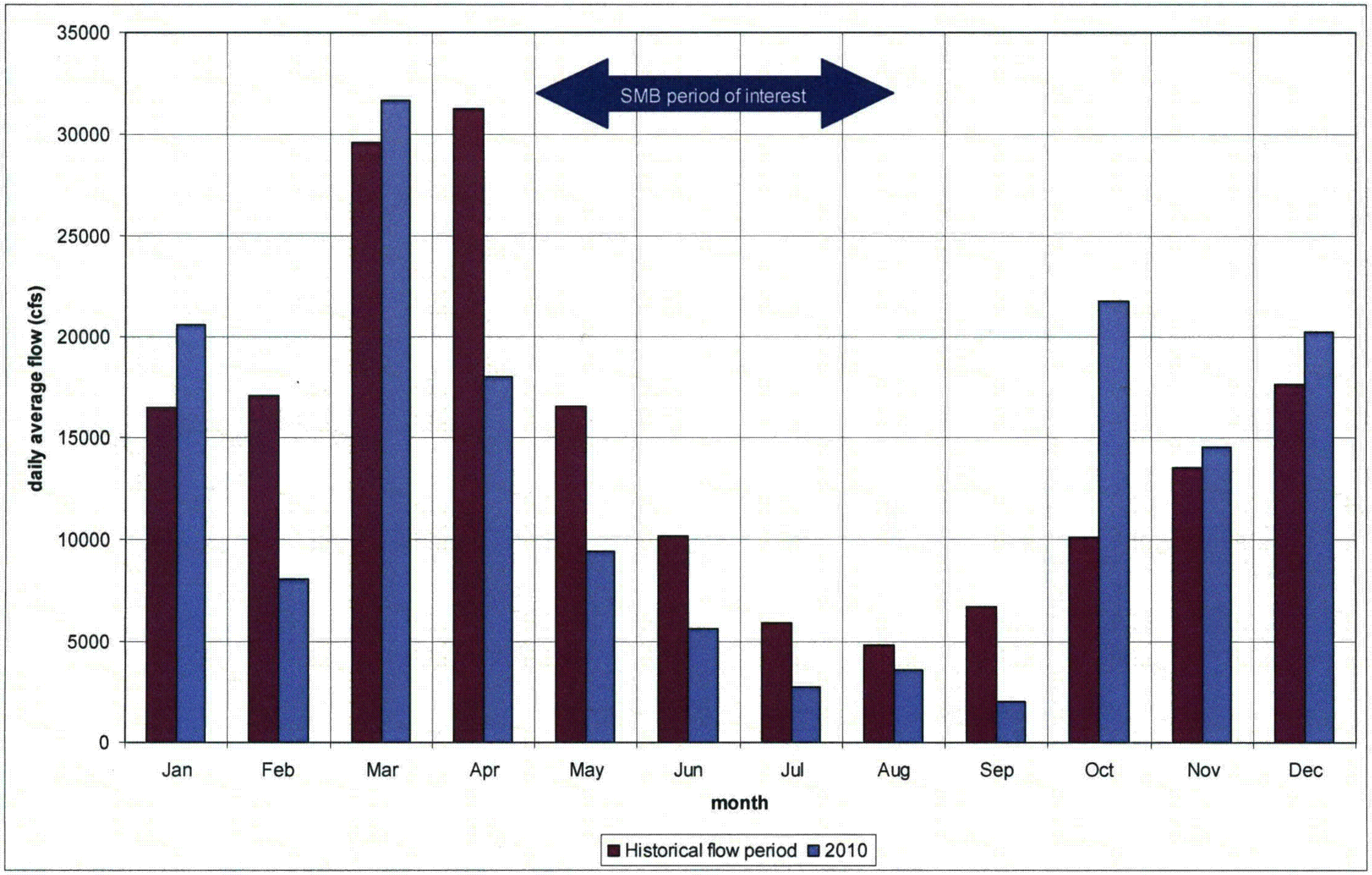

Figure 5-7 Average daily flow by month (1974 – 2011) compared with 2010 Average daily flows by month

5.4. Results of Continuous Monitoring of Water Quality Parameters

Table 5-3 presents overall summary statistics for water temperature, dissolved oxygen, and pH hourly measurements recorded at the three paired continuous monitors within the study reach between 22 June and 3 September 2010.

The average water temperature for the monitoring period was highest (80.0°F) in the main channel location near the Goose Island site (Sonde 2) with similarity in average temperatures (77.9 °F to 78.8 °F) at other locations (Table 5-3). The widest range (21.8°F) in water temperature was measured at the inshore location near the Goose Island site (Sonde 1).

The average DO values were lowest at inshore locations near the Goose Island (Sonde 1) and Environmental Lab boat ramp (Sonde 3). The widest range in DO values (≥11.0 mg/L) also occurred at these locations.

Average pH values were lower at Goose Island and the Environmental Lab boat ramp locations (Table 5-3).

Table 5-3 Summary statistics of hourly measurements of water temperature (°F), dissolved oxygen (DO), and pH recorded on Data Sondes 1-6, June 23 – September 3, 2010

	Data Sondes					
	1	2	3	4	5	6
Temp (°F)						
Range	70.0-91.8	70.3-85.8	69.7-89.0	70.5-87.1	69.4-87.1	68.7-89.6
Mean	78.8	80.0	78.3	78.6	77.9	78.3
Number of observations	1,595	1,718	1,733	1,336	1,339	1,518
DO (mg/L)						
Range	2.5-14.7	5.9-13.2	3.3-17.8	5.5-13.2	5.5-12.2	5.5-15.9
Mean	7.8	8.5	7.8	8.4	8.4	8.9
Number of observations	1,534	1,720	1,264	1,334	1,339	1,507
pH						
Range	6.7-9.0	7.1-9.0	6.9-8.9	7.2-9.1	7.3-9.2	7.2-9.0
Median	7.7	7.8	7.5	7.9	8.0	7.8
Number of observations	1,683	1,717	1,734	1,336	1,339	1,518

5.5. Water Temperature

Hourly temperature data from all sonde locations is shown in Figure 5-8 through Figure 5-13. As noted above, that state water quality standards for WWF streams do not always coincide with the 84°F described as a possible biological threshold temperature for YOY SMB. For example, the

WWF standard upper limit for temperature is 87°F from 1 July through 31 August. As a result, both temperatures are evaluated in this report.

Although daily fluctuations in temperature occurred at all locations, the amplitude of these fluctuations was higher at the inshore Goose Island site, particularly in July and August. See Figure 5-8. The frequency of temperatures exceeding either 84°F or 87°F was highest at the Goose Island inshore location; with most exceedances occurring in July. This location is characterized by shallow depth and negligible current and subject to elevated temperature during the daytime. Some values exceeded either 84°F or 87°F at other inshore locations though at much lower frequencies. See Figure 5-9. Analyses provided in Section 4.7 illustrate that small thermal and DO changes will occur due to reduced depth. The approximate impact on depth based on the BBNPP consumptive use of 43 cfs throughout the study area for flows <1,000 cfs is 0.5 inches (Figure 5-35). According to the analysis, depths characteristic of spawning areas (<2 feet) produce a thermal change of approximately < 0.5°F based on a reduction in water depth of 0.5 inches under worst case summer conditions. These potential changes are small in comparison to natural diurnal T and DO changes.

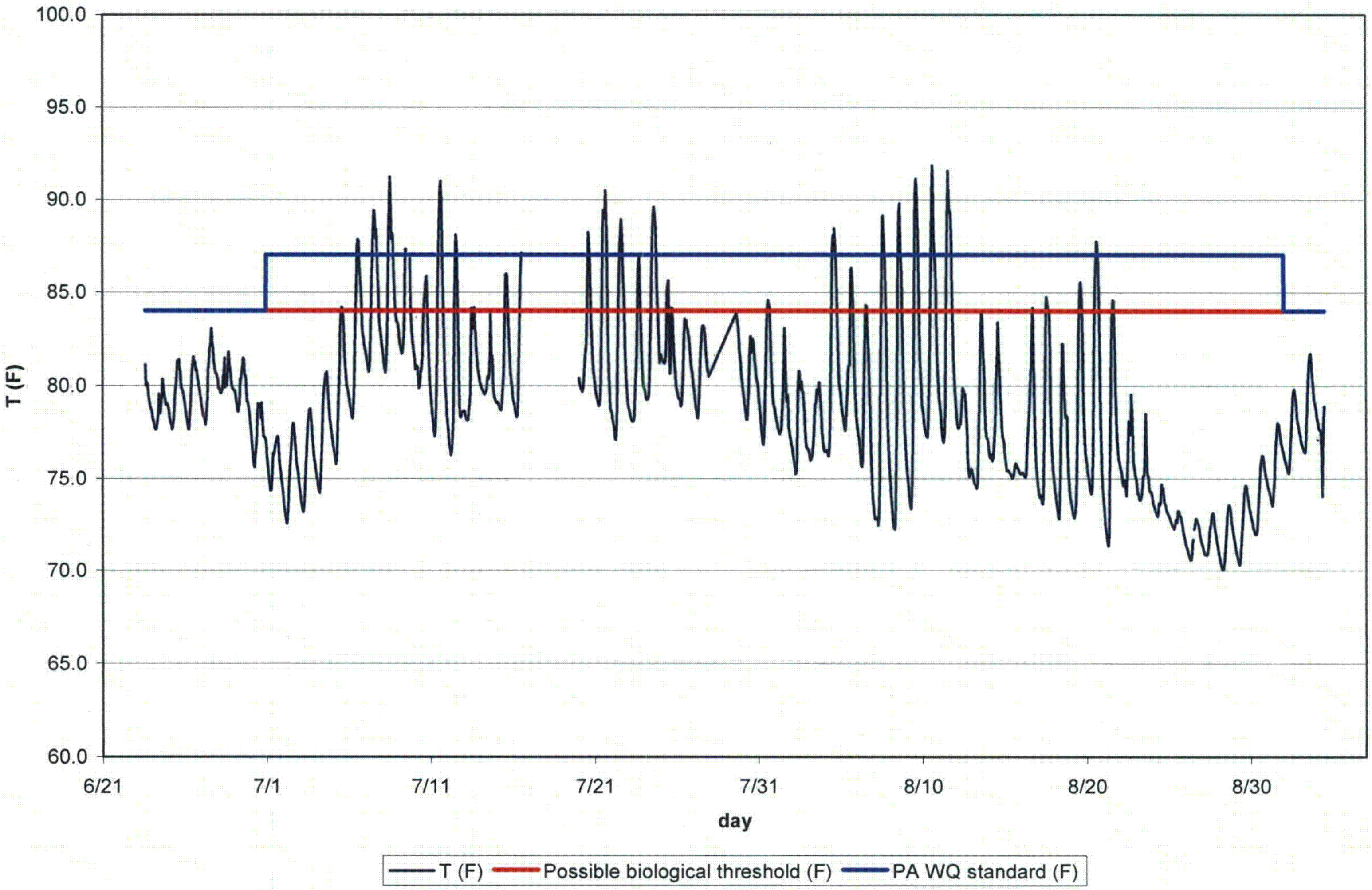

Figure 5-8 Sonde 1 (Goose Island shallow) hourly temperature data (F)

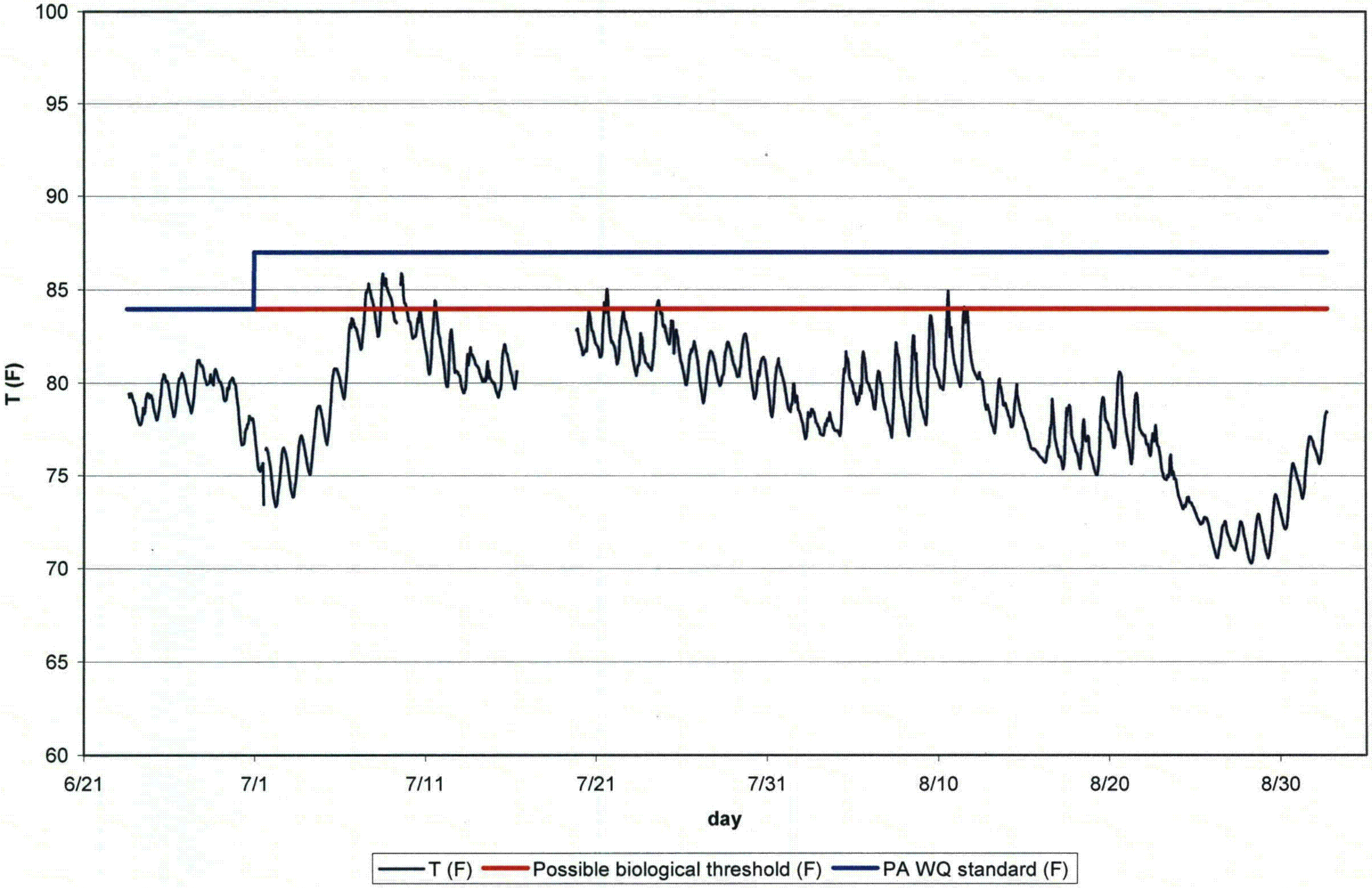

Figure 5-9 Sonde 2 (Goose Island main channel) hourly temperature data (F)

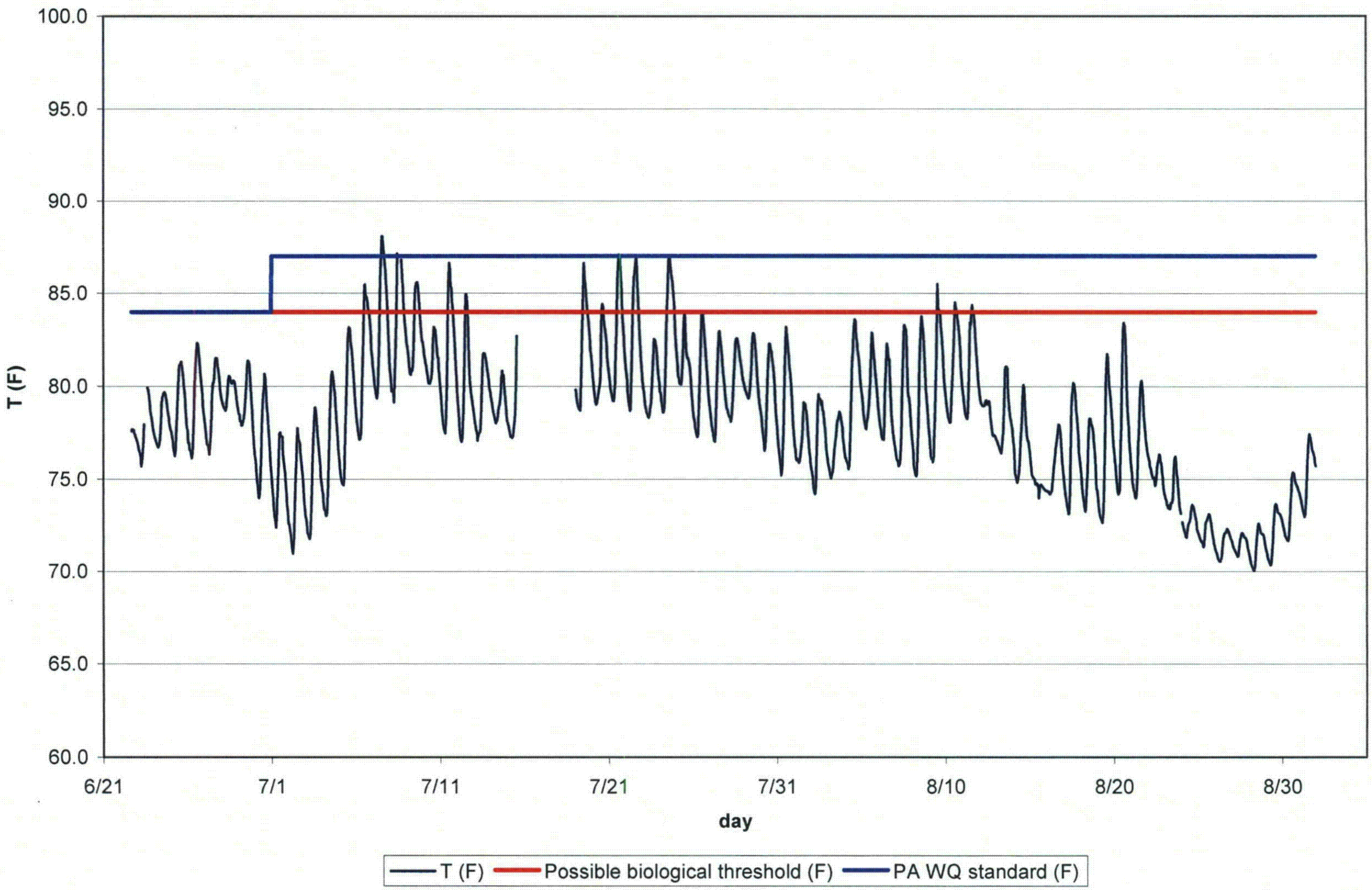

Figure 5-10 Sonde 3 (Environmental lab shallow) hourly temperature data (F)

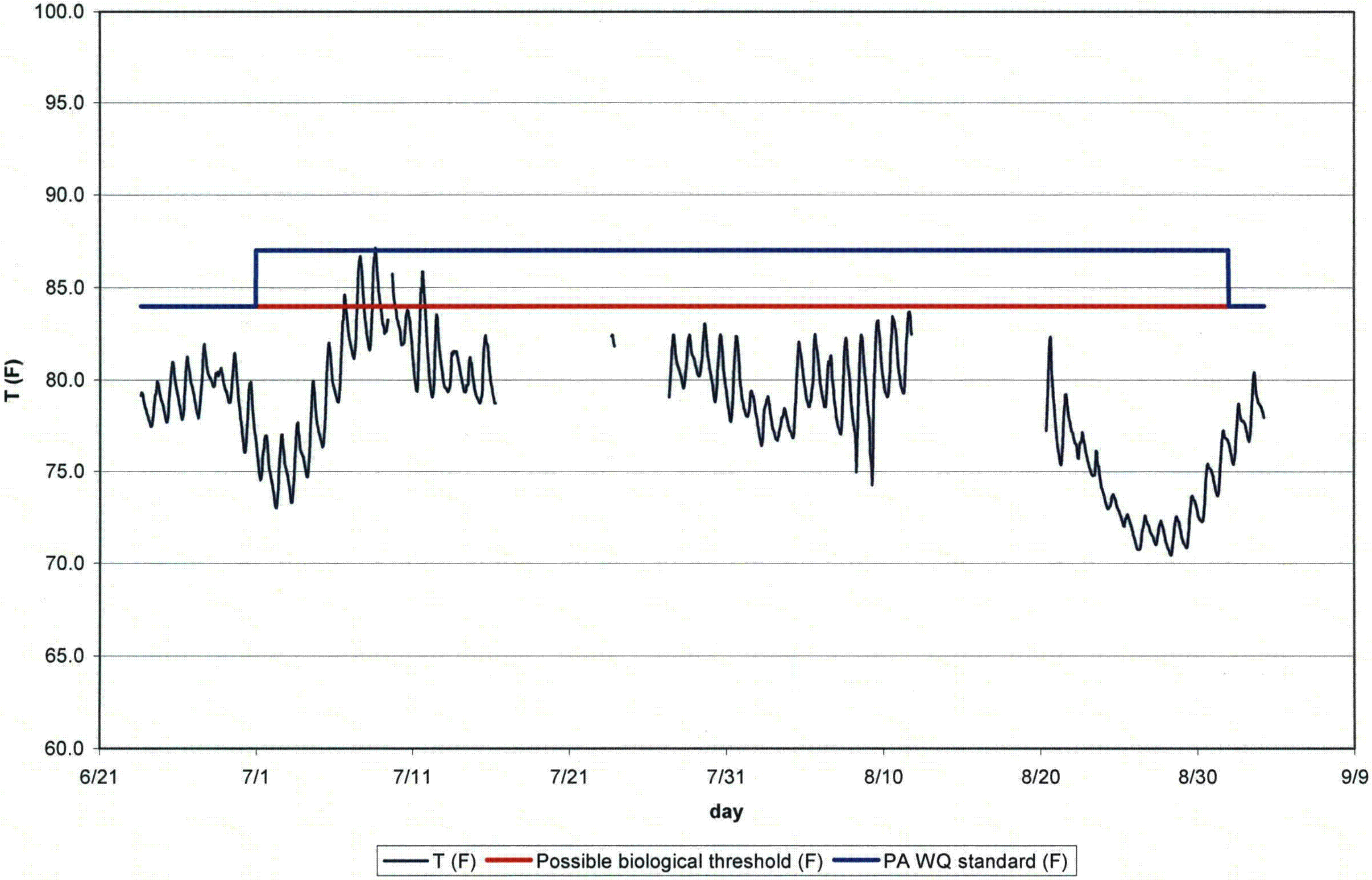

Figure 5-11 Sonde 4 (Environmental lab main channel) hourly temperature data (F)

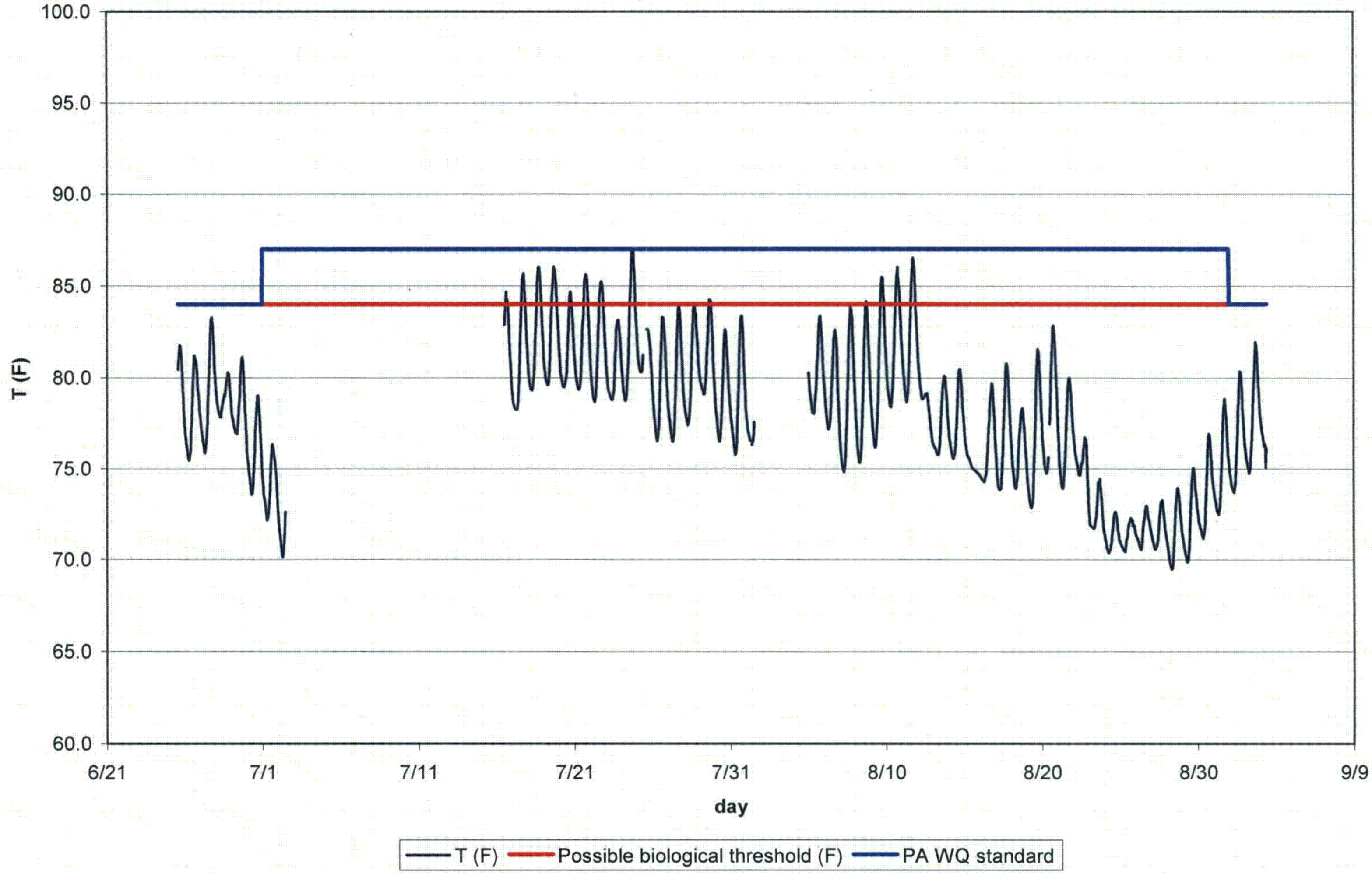

Figure 5-12 Sonde 5 (Downstream from Test Track, main channel) hourly temperature data (F)

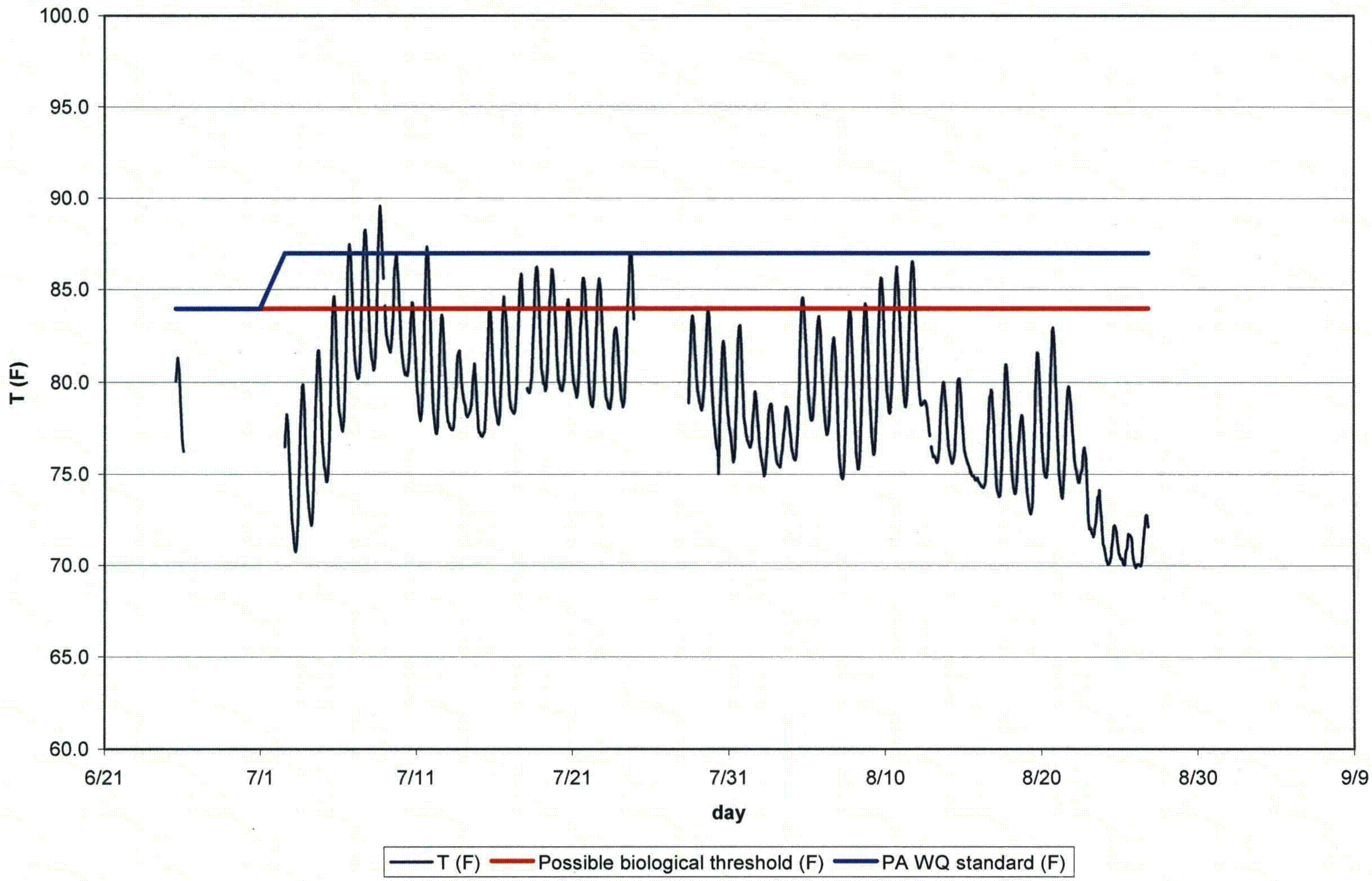

Figure 5-13 Sonde 6 (Downstream from Test Track, shallow) hourly temperature data (F)

Figure 5-14 shows a summary of the hours at each sonde above the 84°F SMB possible biological threshold for July and August data as well as the PA 87 °F water quality standard for July and August.

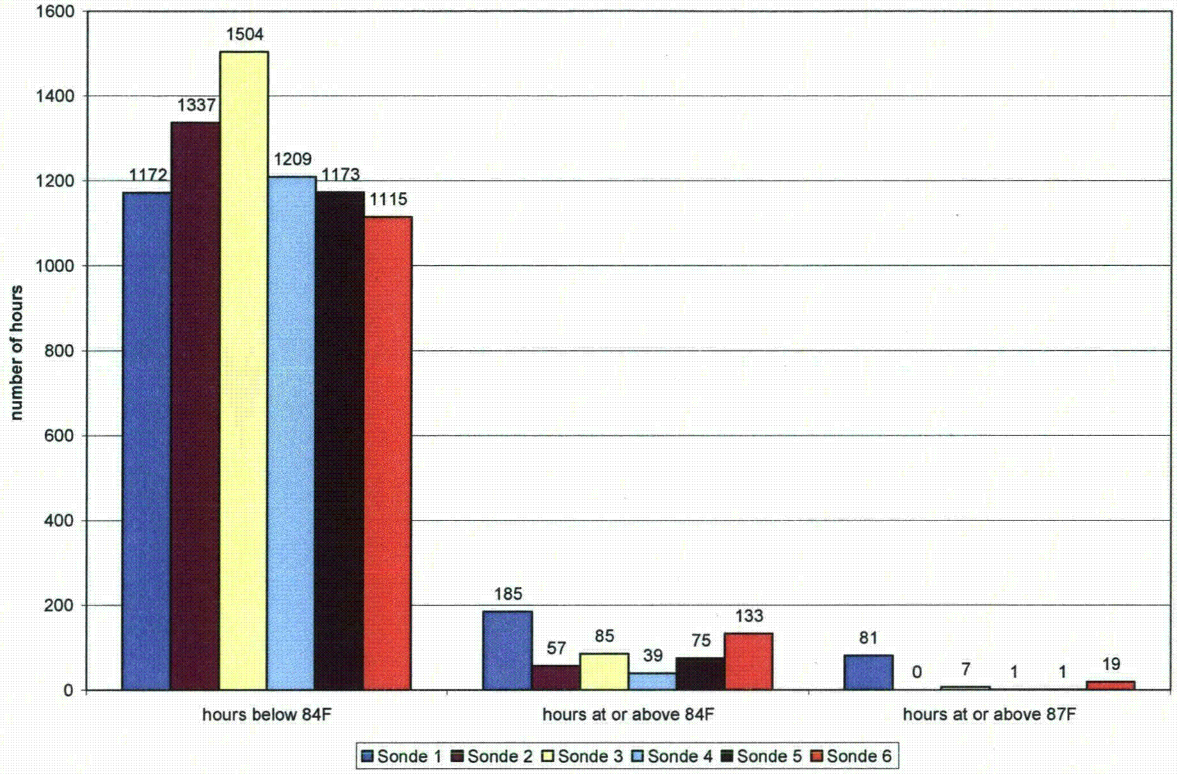

Figure 5-14 Hours below 84F, above or at 84F and above or at 87F for all sondes

5.6. Dissolved Oxygen

Hourly dissolved oxygen data from all sonde locations is shown in Figure 5-15 through Figure 5-20. Daily average dissolved oxygen levels are illustrated in Figure 5-21 through Figure 5-26. Daily diurnal fluctuations of ≥11 mg/L were observed between the three monitored locations (Environmental Lab boat ramp, Goose Island, and Berwick Test Track ramp). The largest fluctuations were at the inshore (Sonde 1) Goose Island site (Figure 5-15).

Most hourly DO values <4.0 mg/L (instantaneous standard) occurred at the inshore Goose Island location and in July (Figure 5-15). The Environmental Lab boat ramp inshore location (Sonde 3) ranked second in exhibiting < 4.0 mg/L DO. Other locations did not show DO < 4.0 mg/L. Although more hourly low DO values were observed at the Goose Island location (Sonde 1), the average daily DO was ≥ 5.0 mg/L (daily average standard, see Figure 5-21).

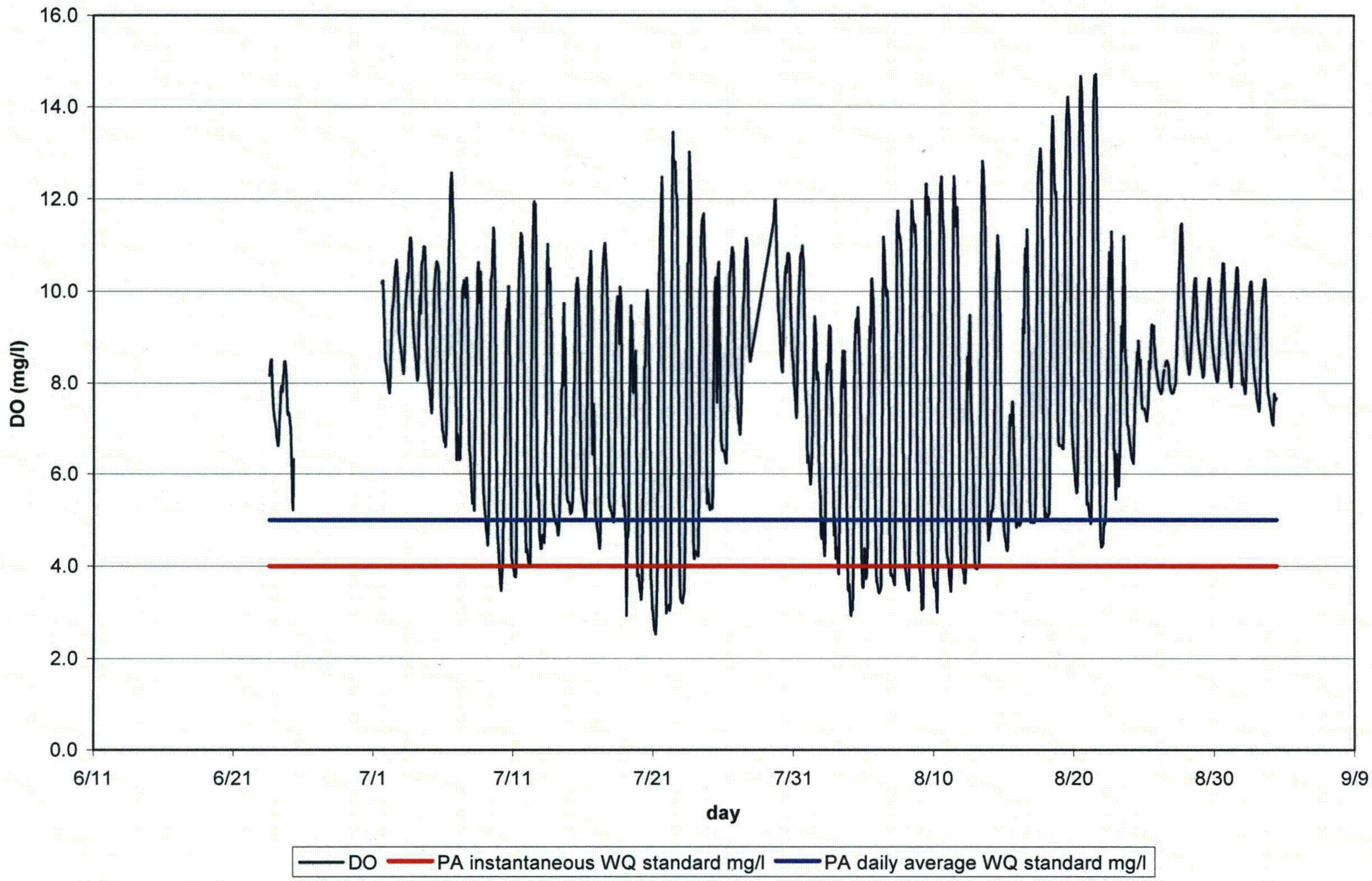

Figure 5-15 Sonde 1 (Goose Island, shallow) dissolved oxygen

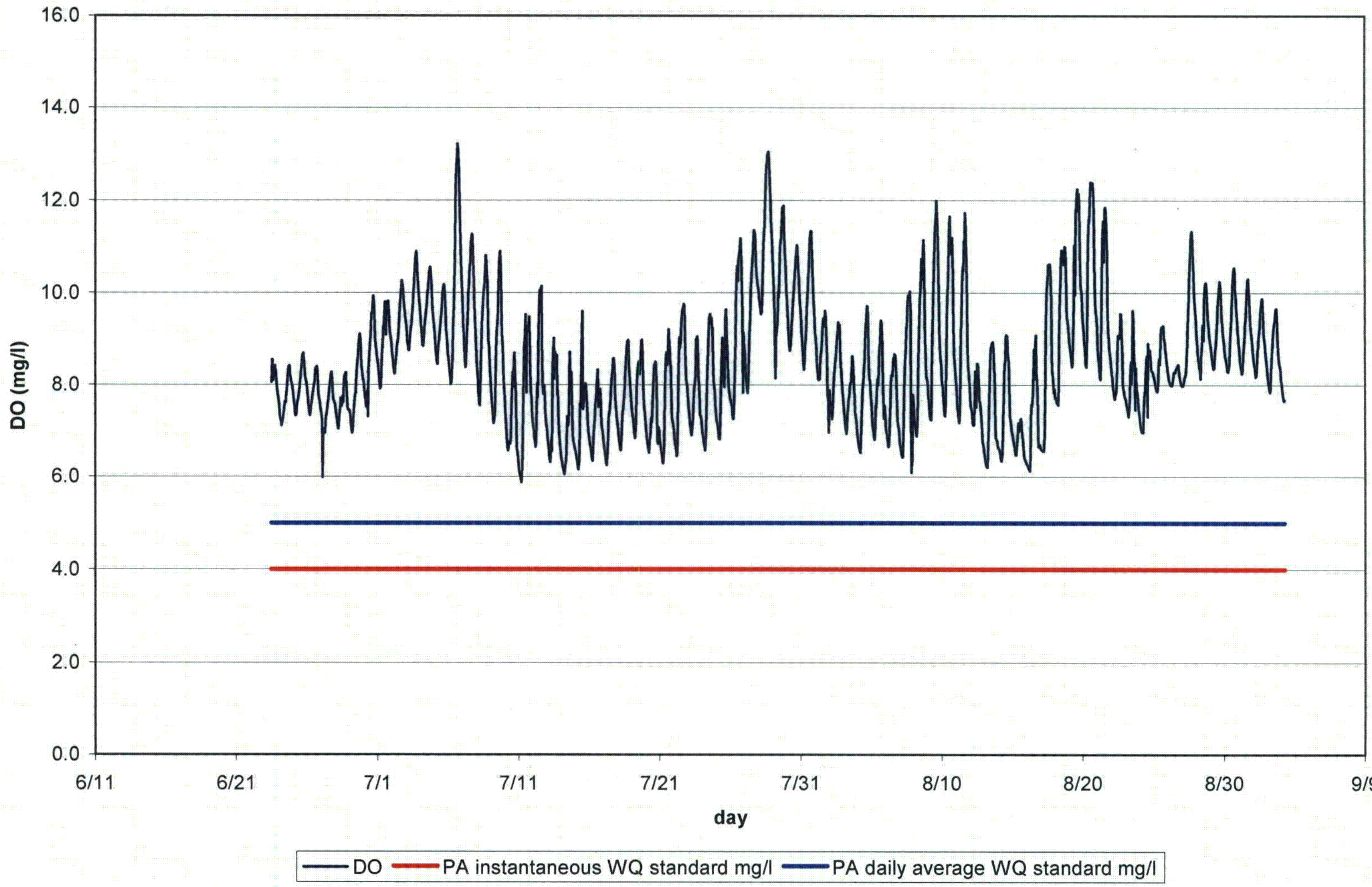

Figure 5-16 Sonde 2 (Goose Island, main channel) dissolved oxygen

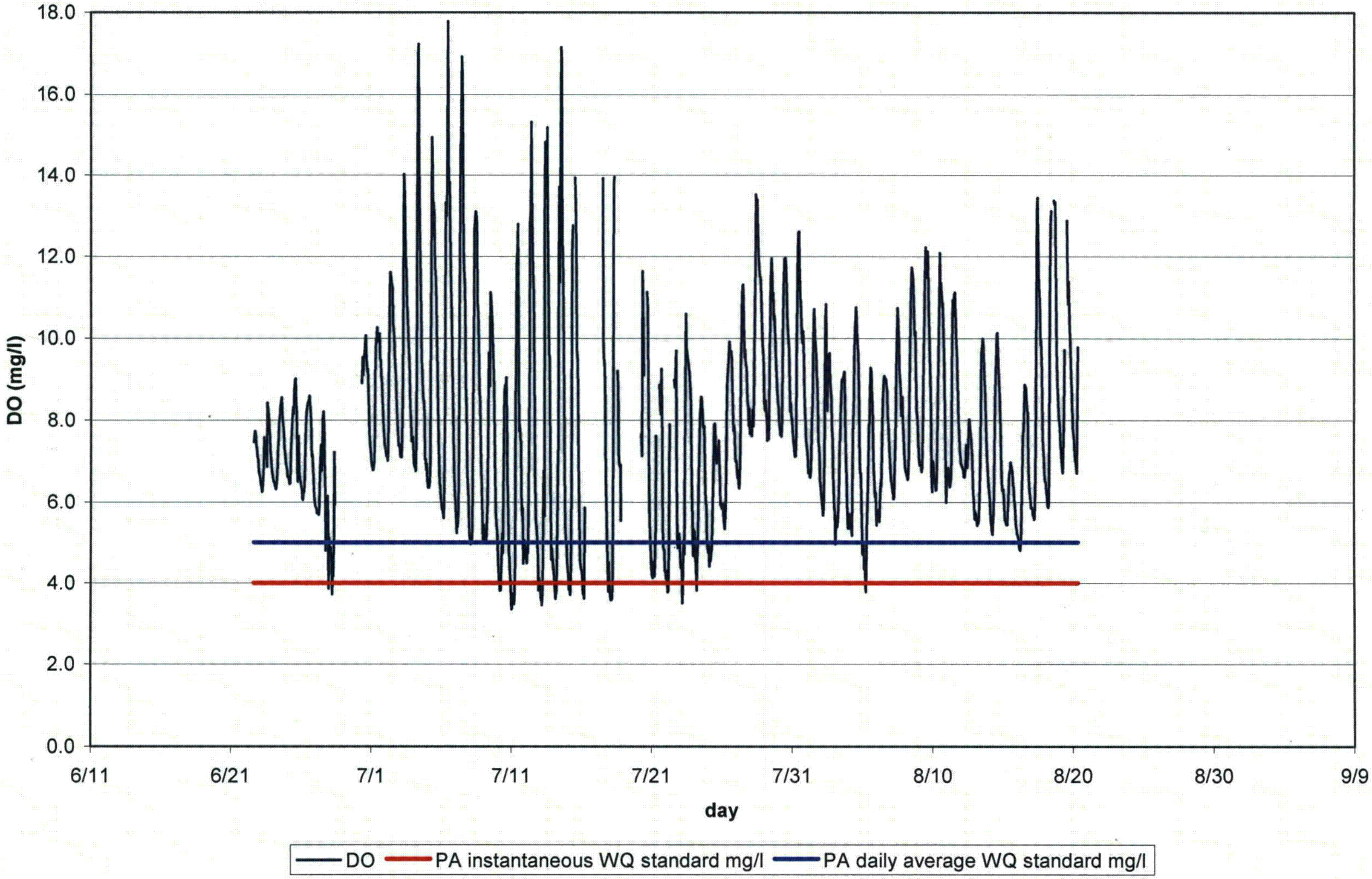

Figure 5-17 Sonde 3 (Environmental lab, shallow) dissolved oxygen

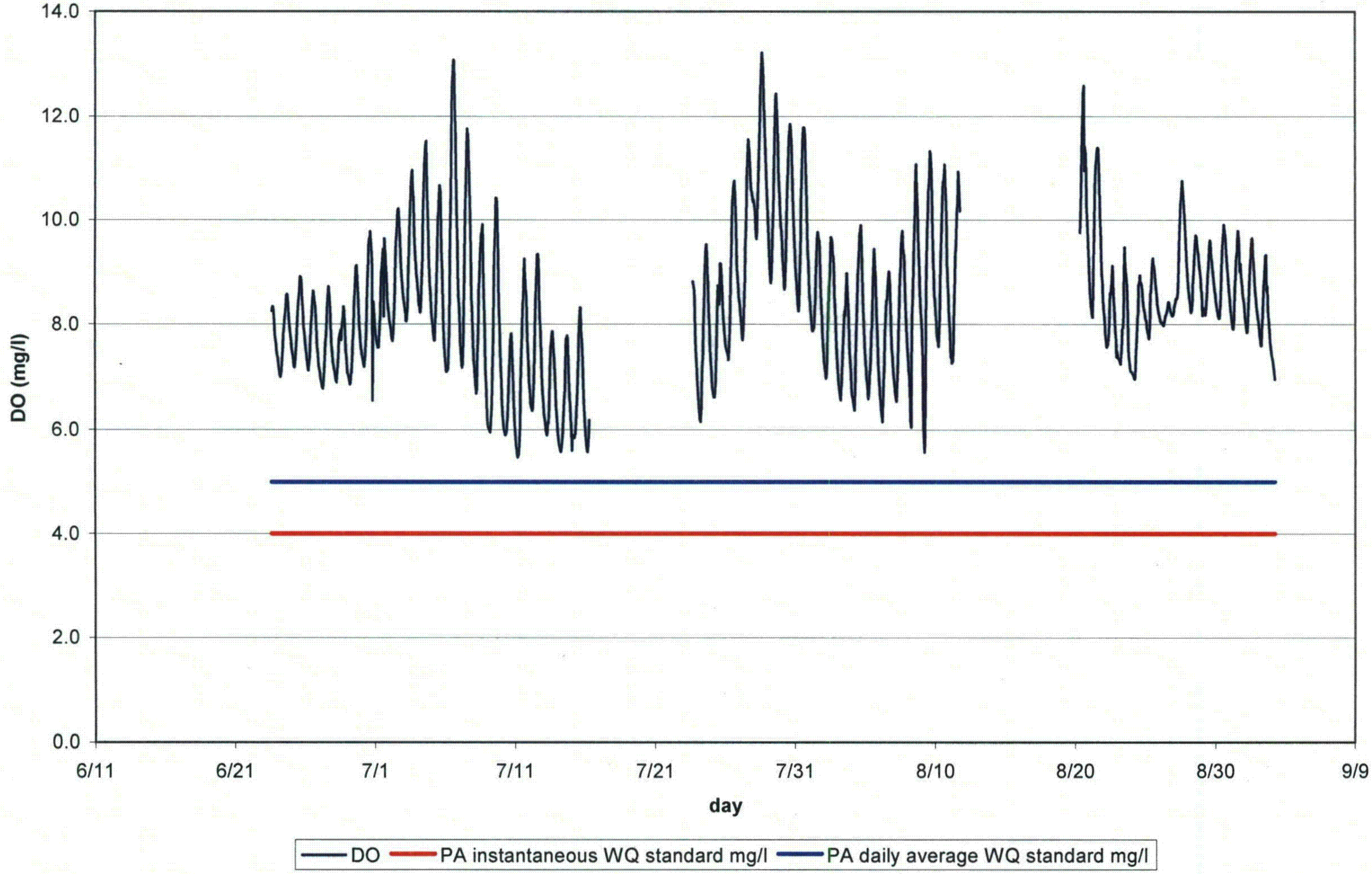

Figure 5-18 Sonde 4 (Environmental lab, main channel) dissolved oxygen

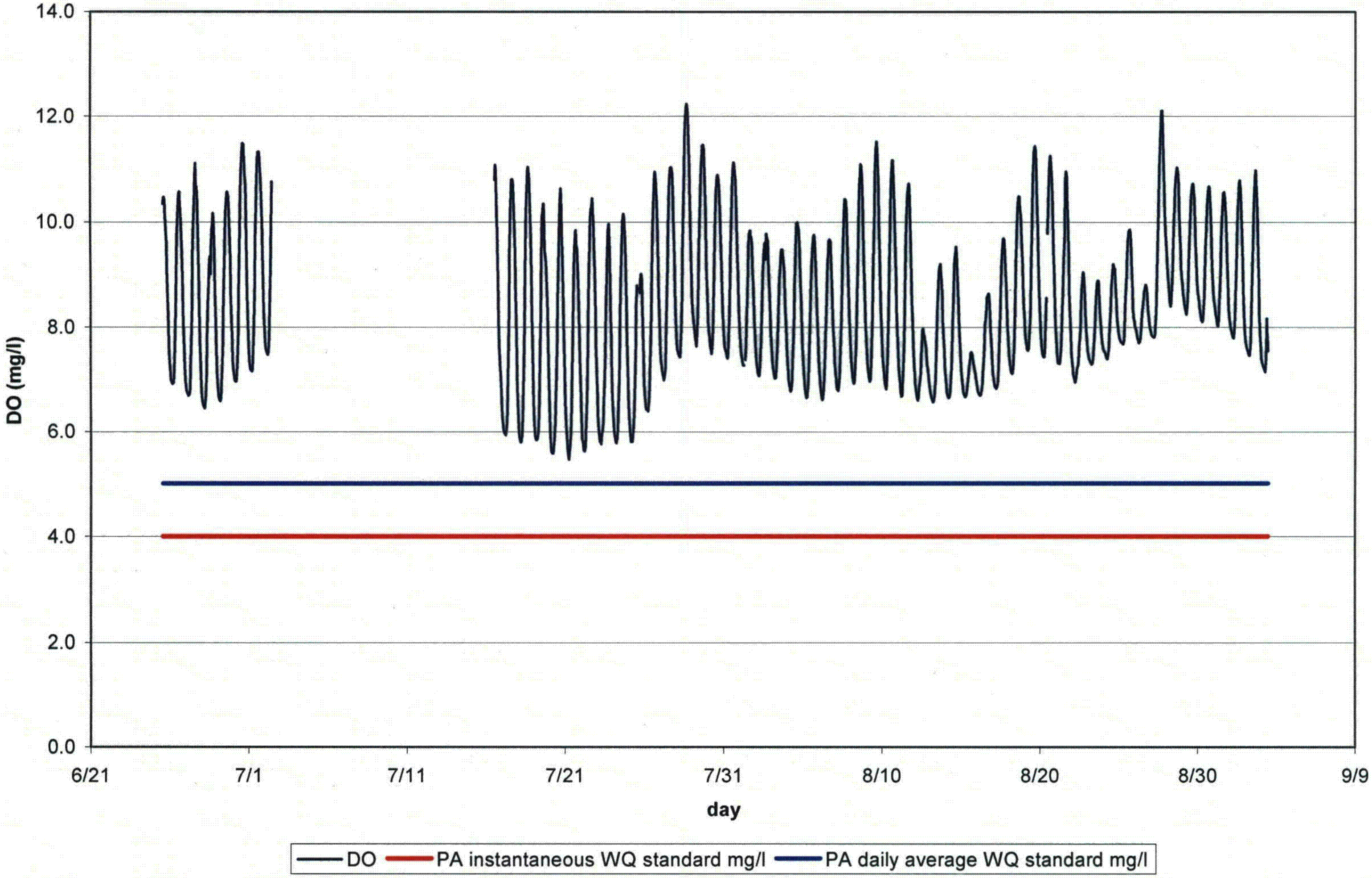

Figure 5-19 Sonde 5 (Downstream from Test Track, main channel) dissolved oxygen

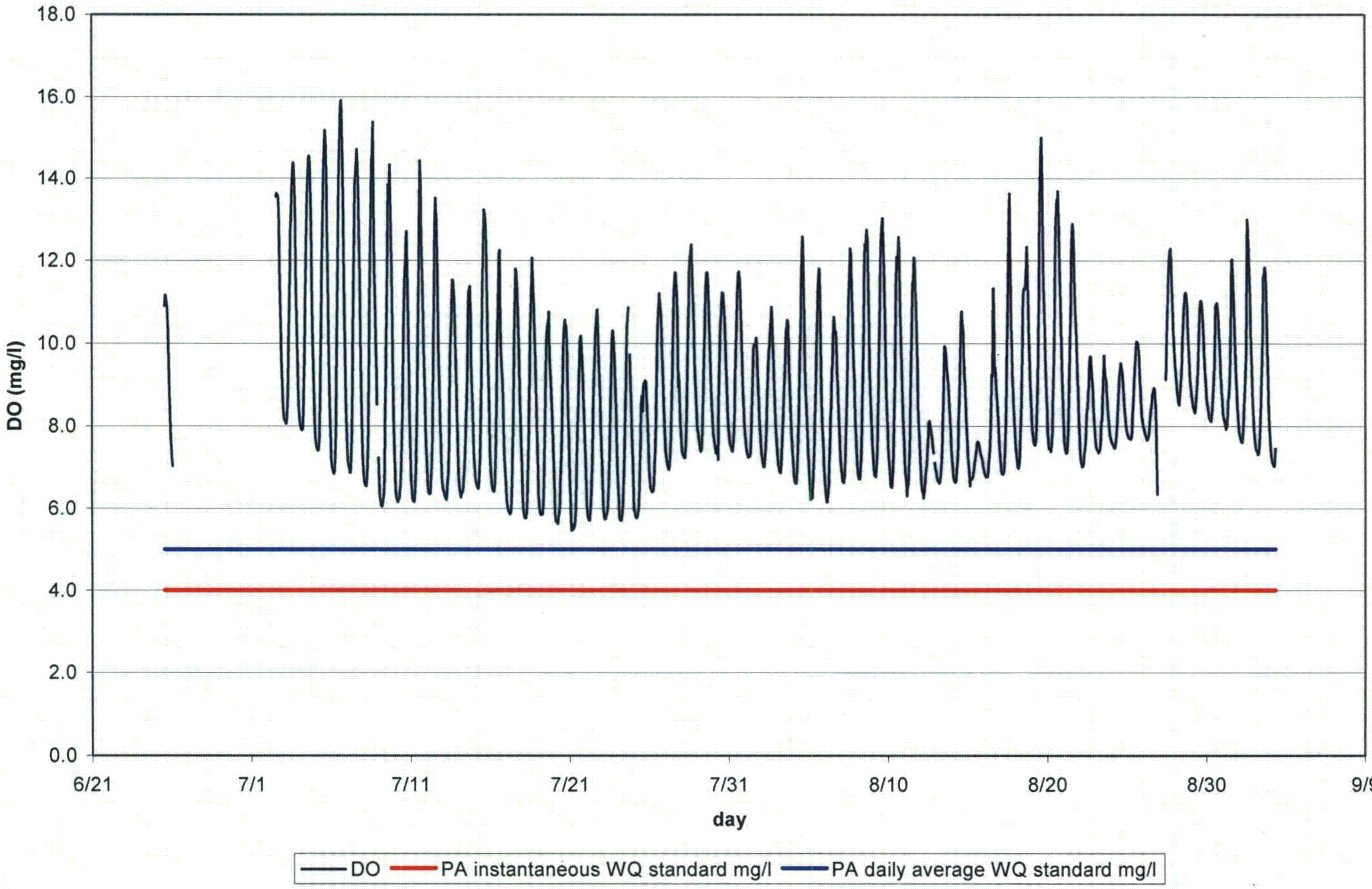

Figure 5-20 Sonde 6 (Downstream from Test Track, shallow) dissolved oxygen

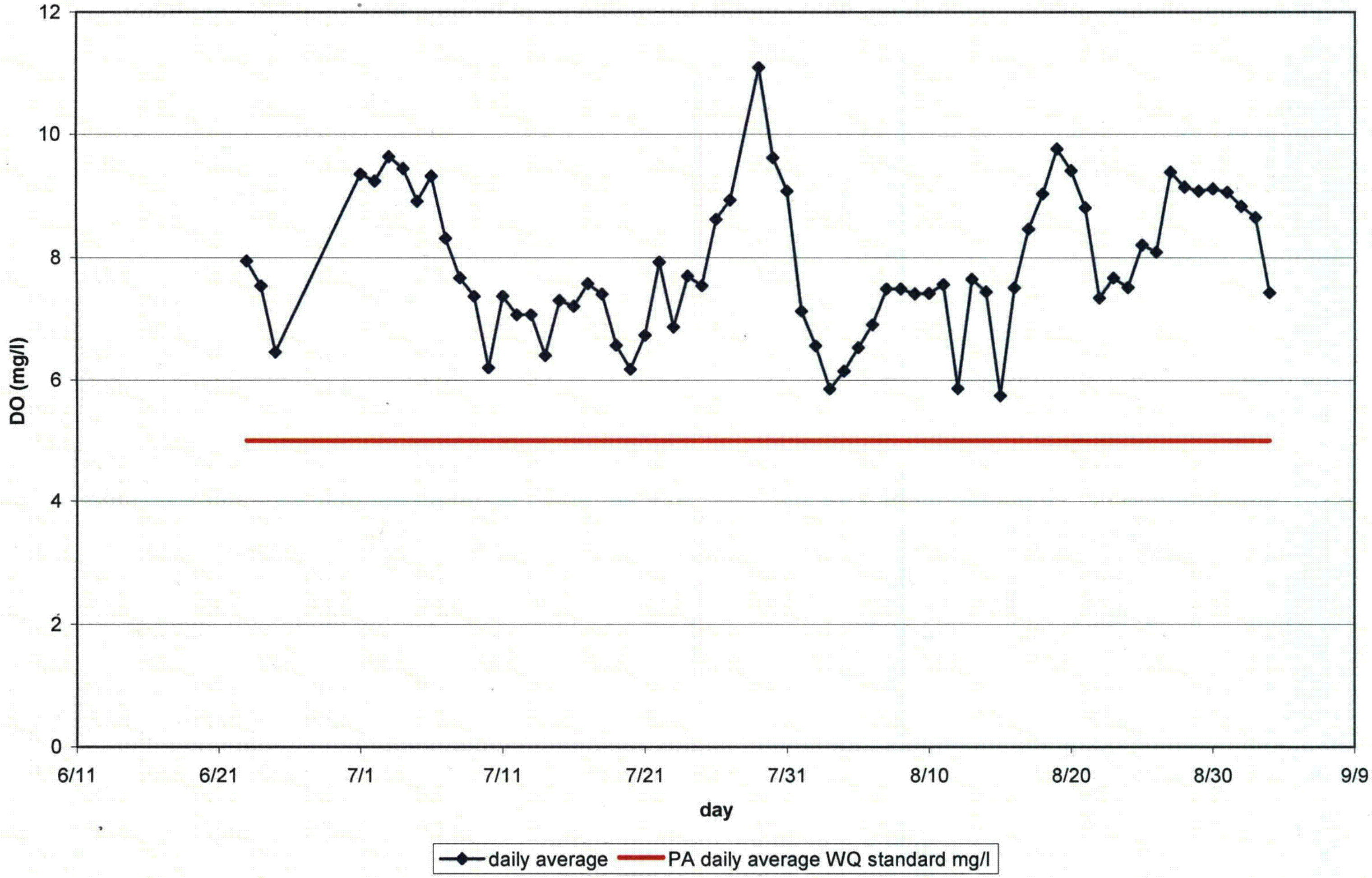

Figure 5-21 Sonde 1 (Goose Island, shallow) DO daily average

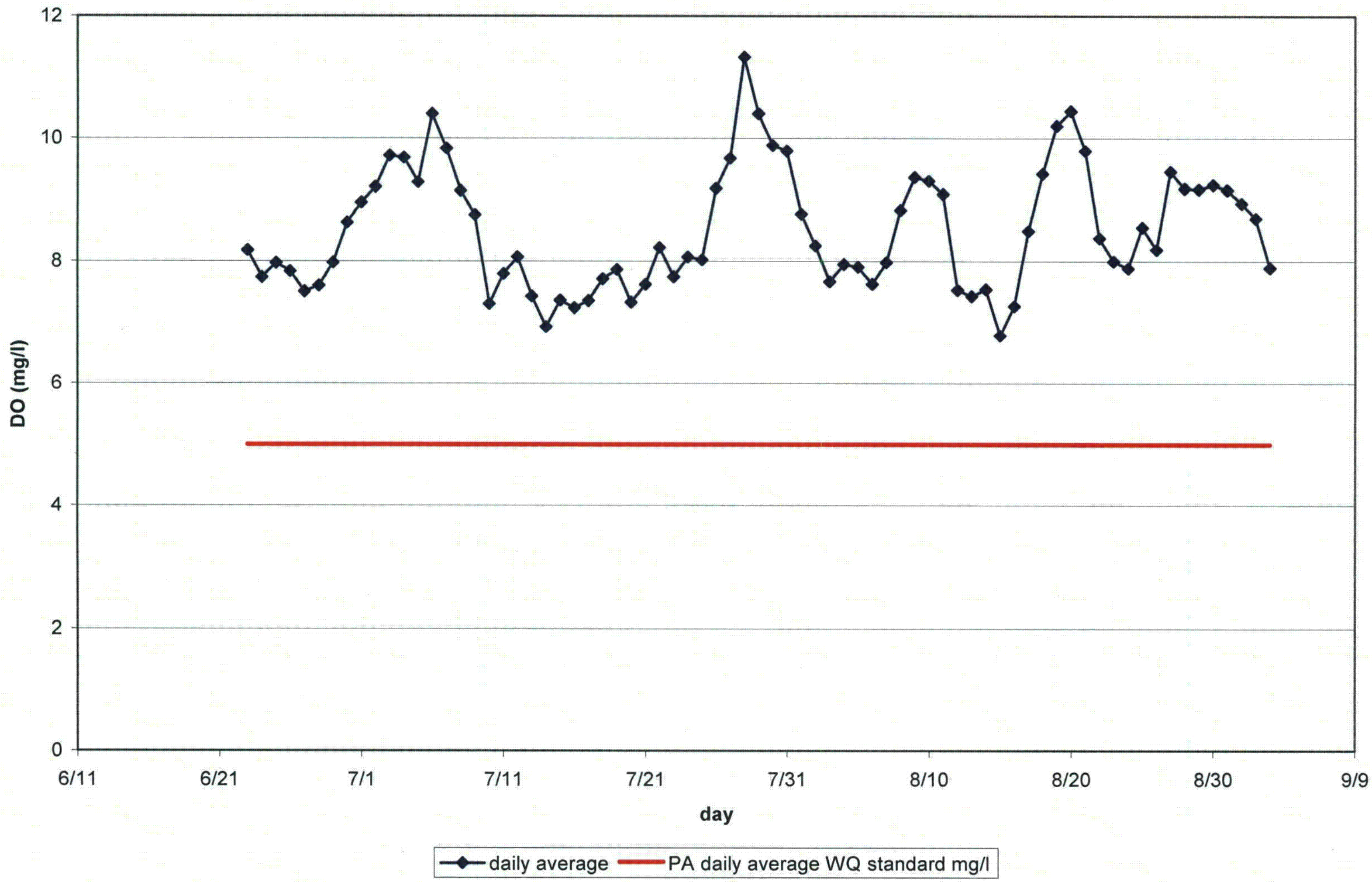

Figure 5-22 Sonde 2 (Goose Island, main channel) DO daily average

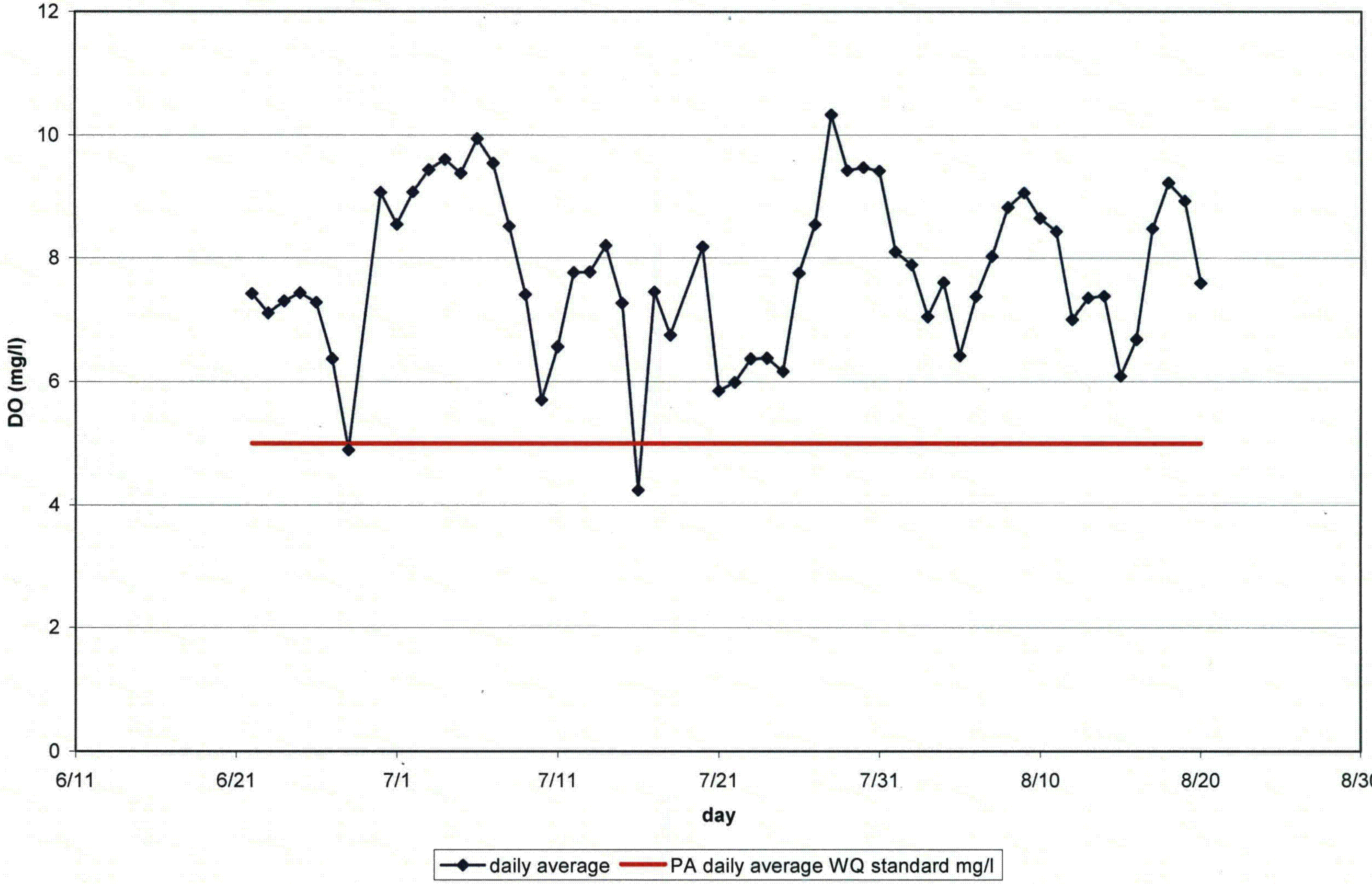

Figure 5-23 Sonde 3 (Environmental lab, shallow) DO daily average

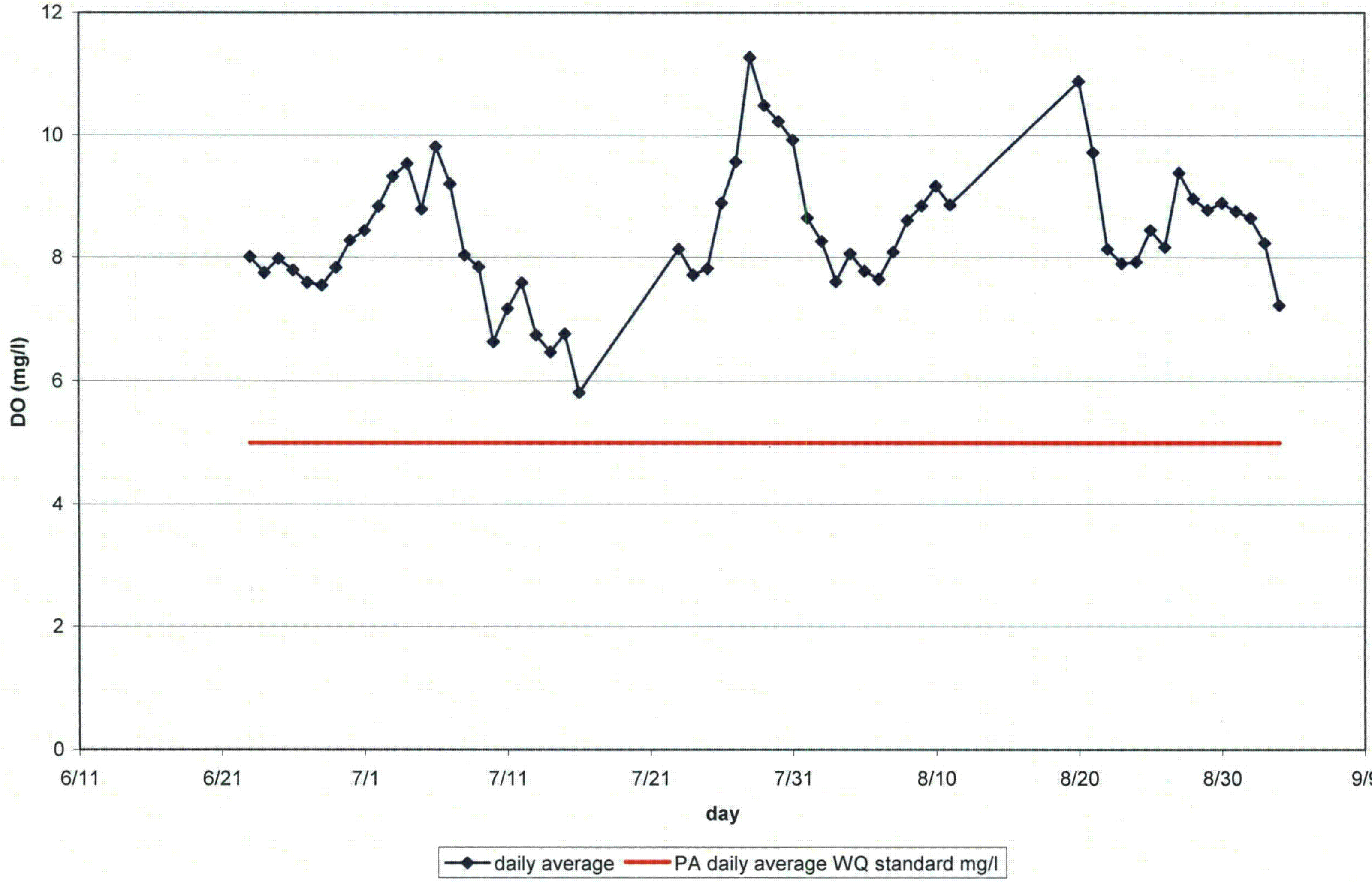

Figure 5-24 Sonde 4 (Environmental lab, main channel) DO daily average

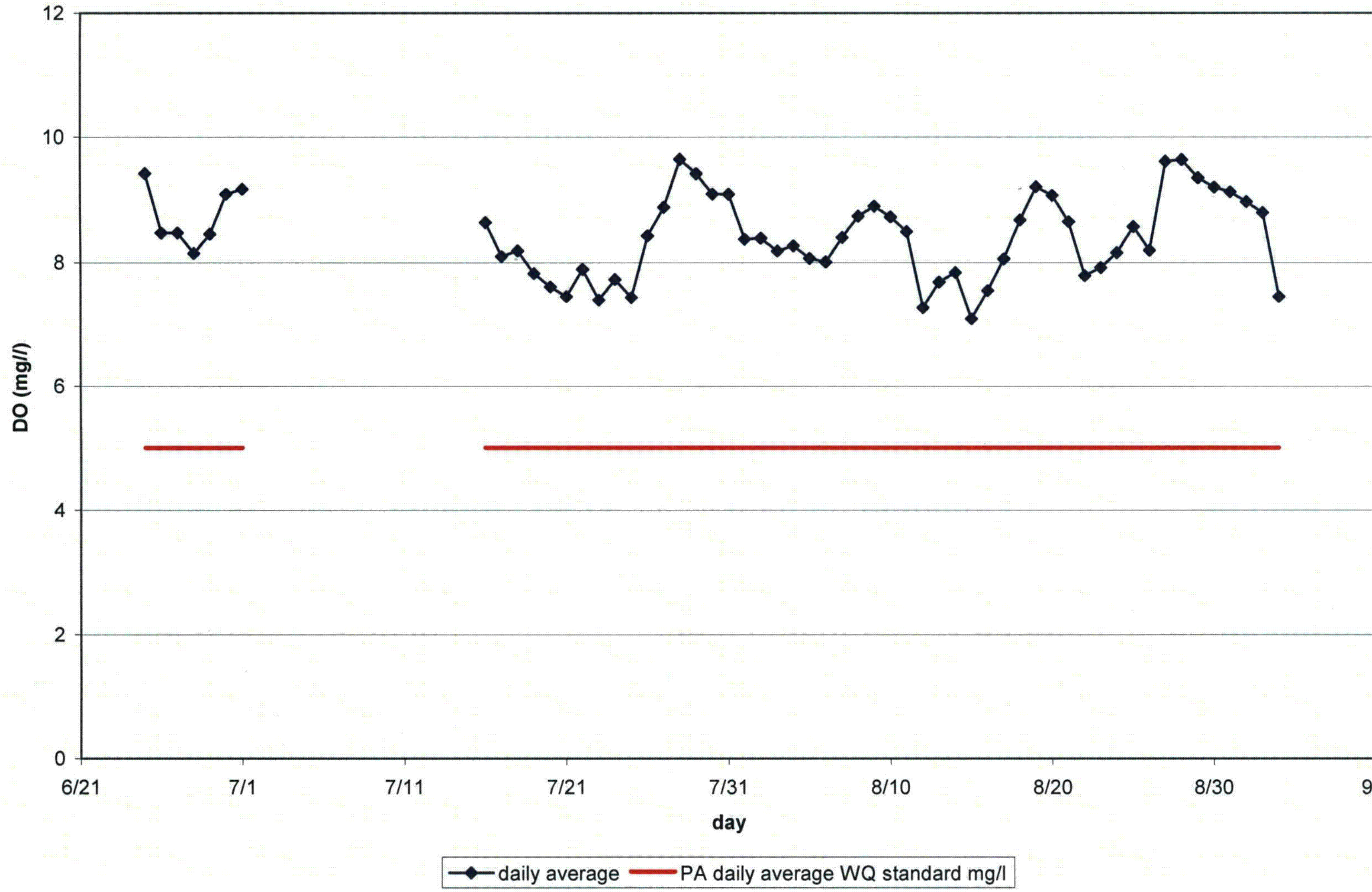

Figure 5-25 Sonde 5 (Downstream from Test Track, main channel) DO daily average

Figure 5-27 shows a summary of the hours at each sonde below 4 and 5 mg/l DO and hours above 4 mg/l.

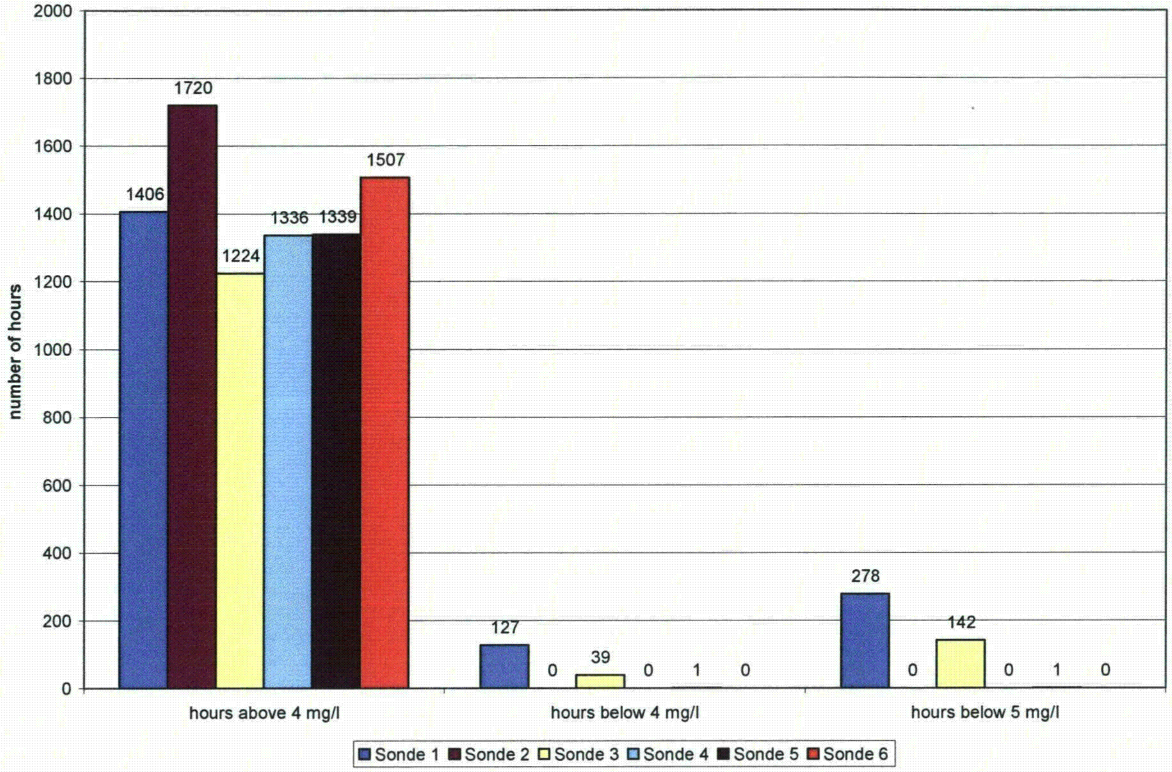

Figure 5-27 Hours below 4 and 5 mg/l DO and above 4 mg/l for all sondes

5.7. pH

Figure 5-28 through Figure 5-33 present the temporal pattern of pH recorded at the six data sondes. Although pH varied between dates, the fluctuations were generally within 1.0 pH unit and followed a similar pattern at all sites.

Approximately 30 (2.2%) pH values out of 1,339 slightly exceeded the upper range of PA State criteria of 9.0 at the main channel habitat of Berwick Test Track; five (0.3%) out of 1,336 at main channel habitat at the Environmental Lab boat ramp. All were naturally occurring events in July, and the longest consecutive period was 9 hours.

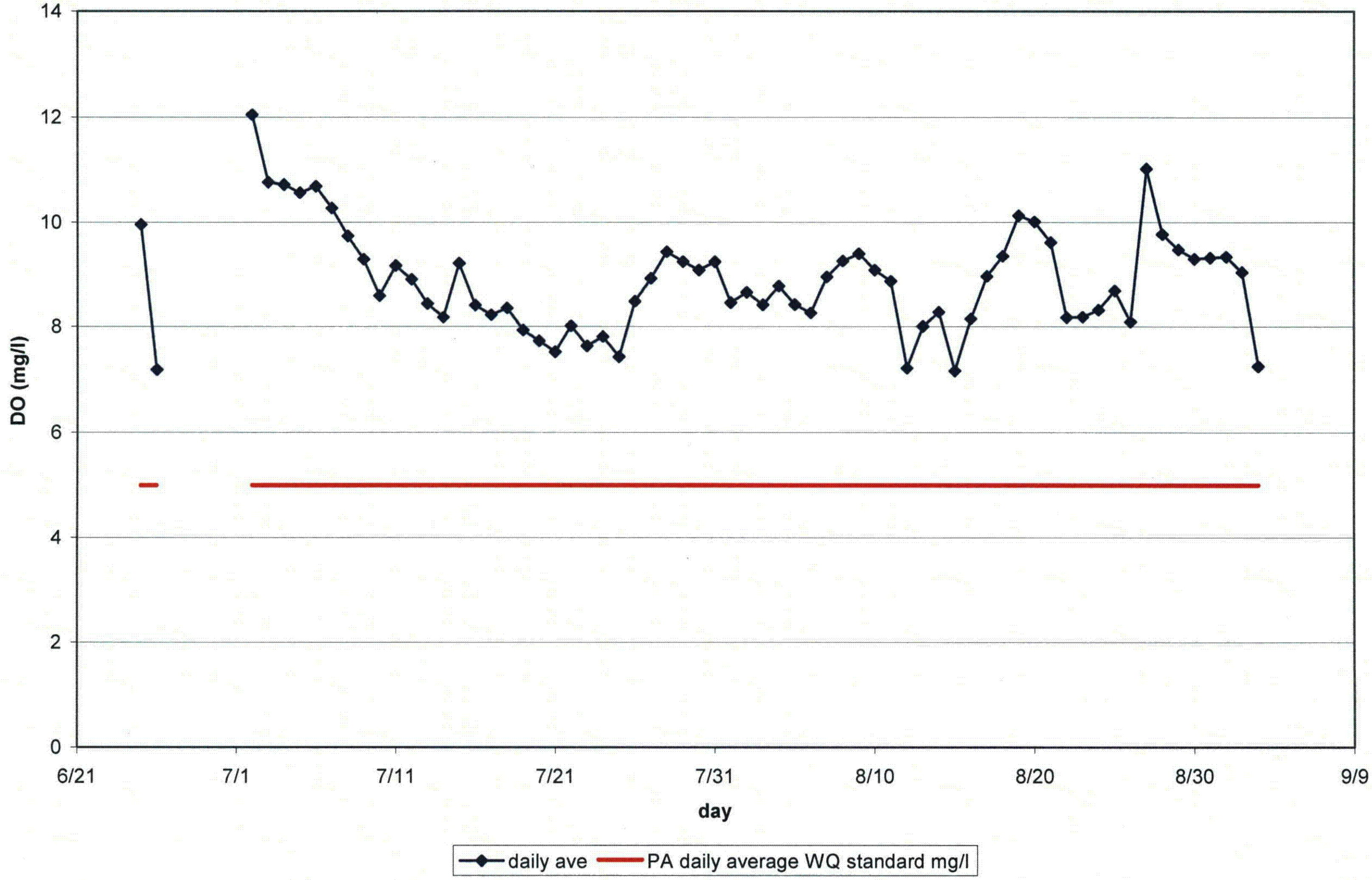

Figure 5-26 Sonde 5 (Downstream from Test Track, main channel) DO daily average

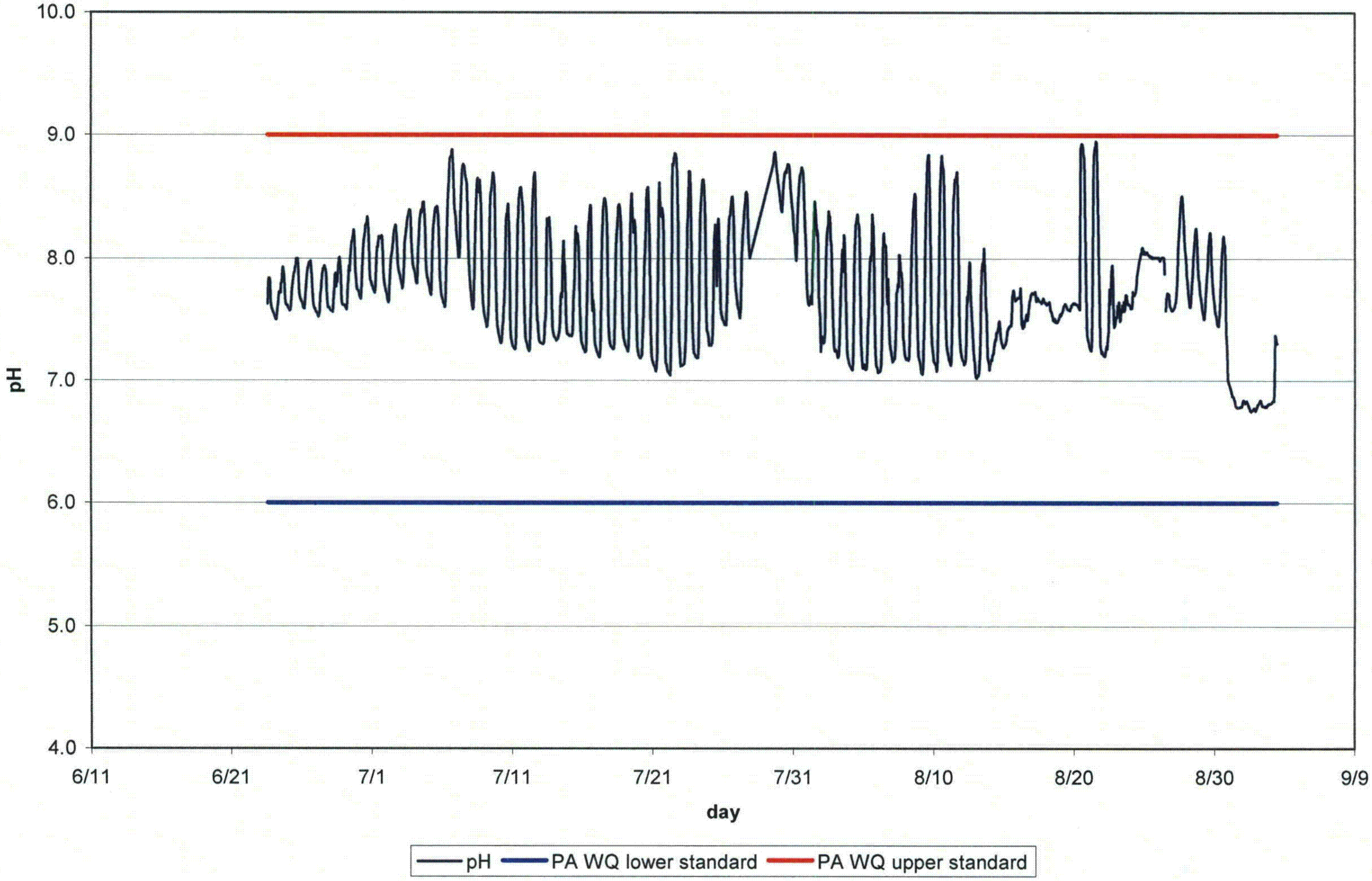

Figure 5-28 Sonde 1 (Goose Island, shallow) pH

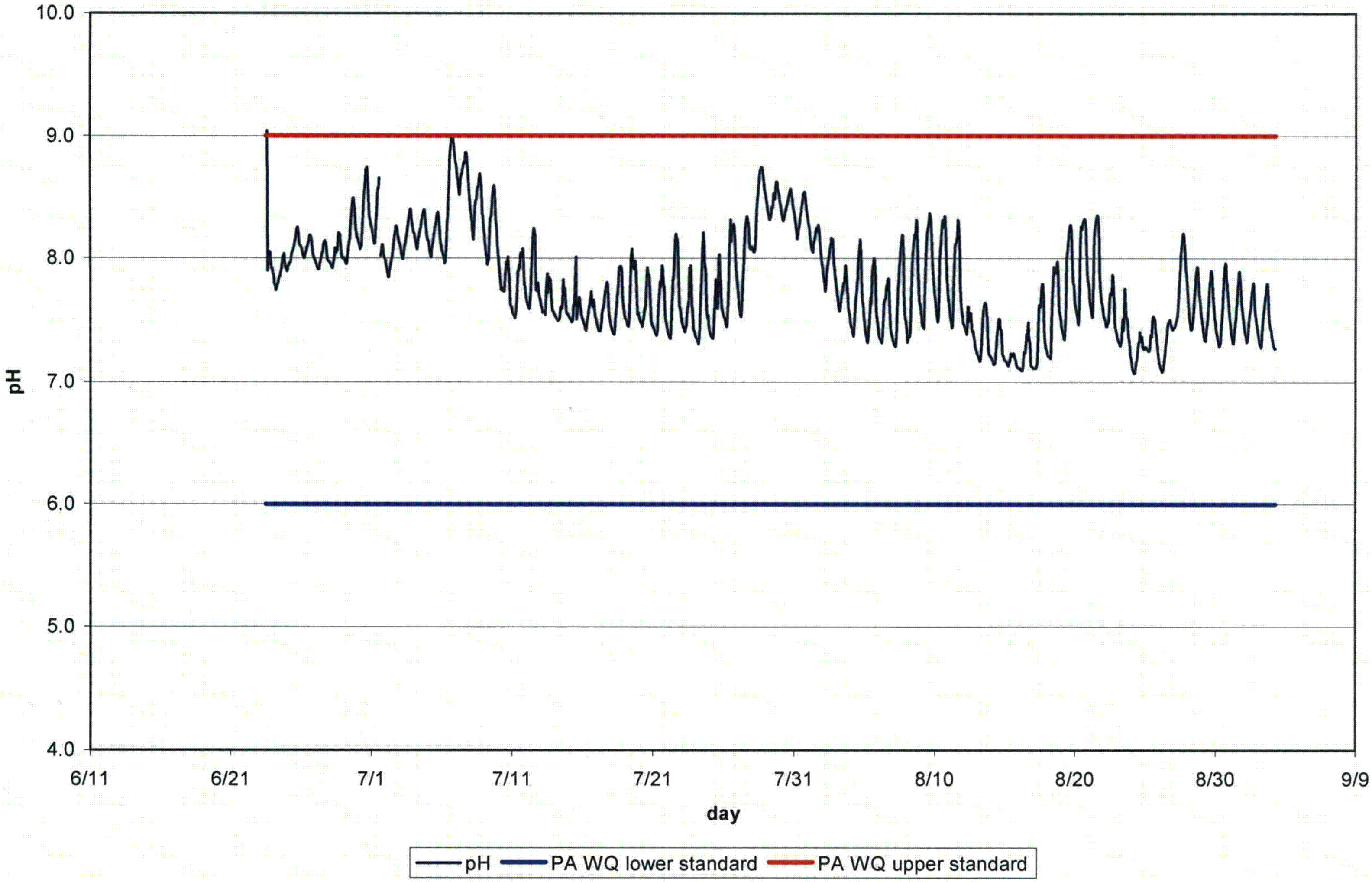

Figure 5-29 Sonde 2 (Goose Island, main channel) pH

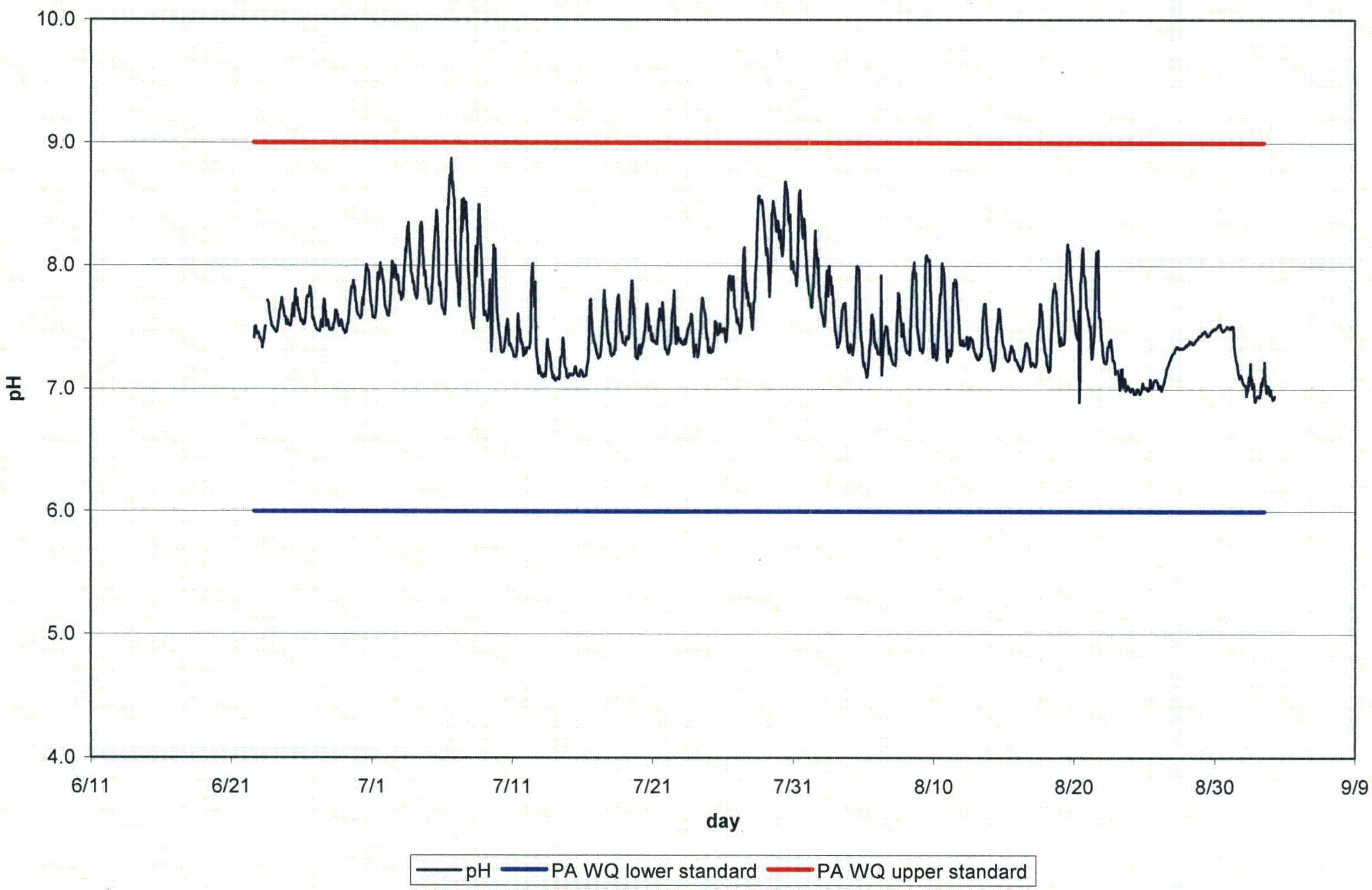

Figure 5-30 Sonde 3 (Environmental lab, shallow) pH

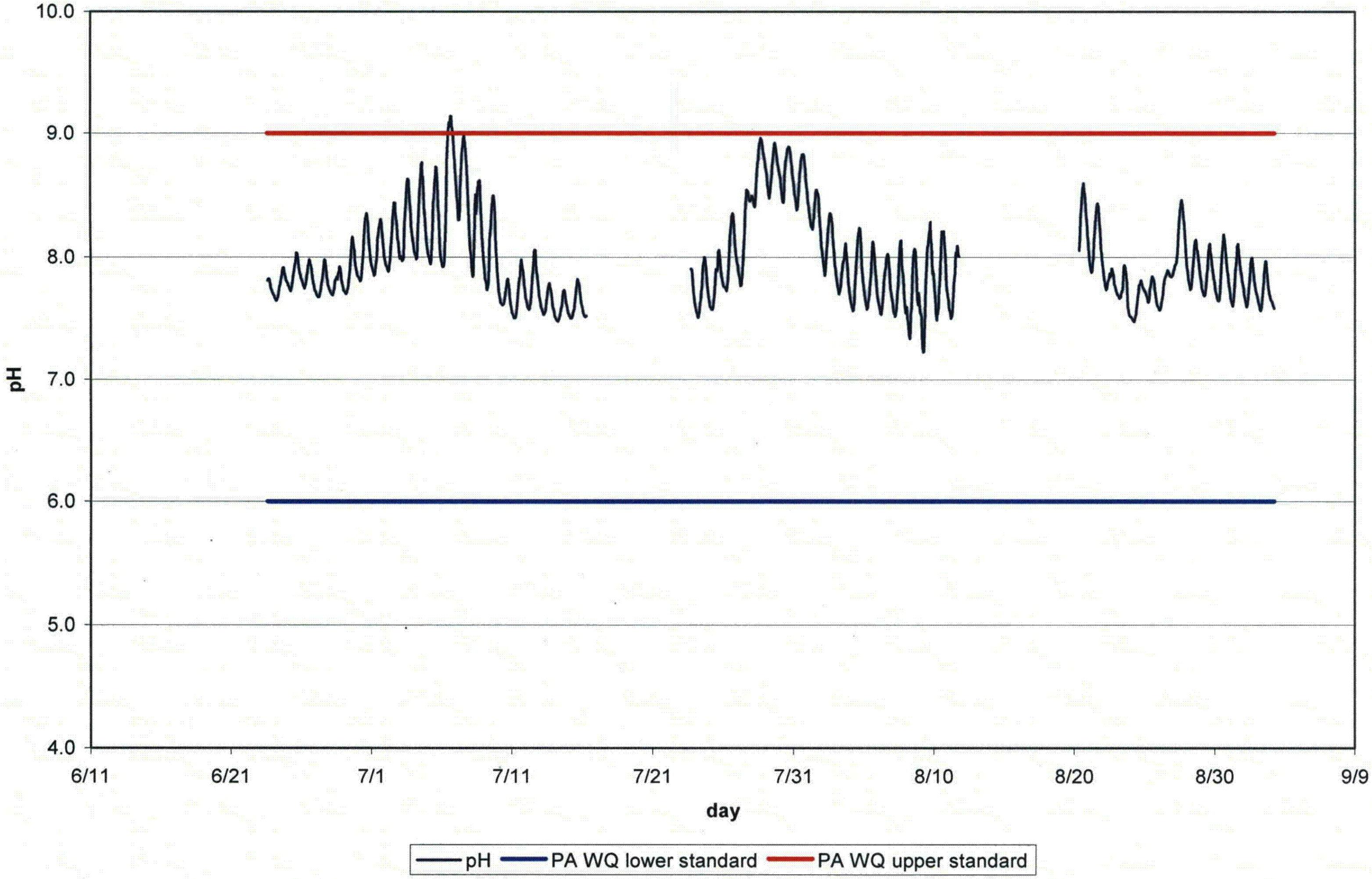

Figure 5-31 Sonde 4 (Environmental lab, main channel) pH

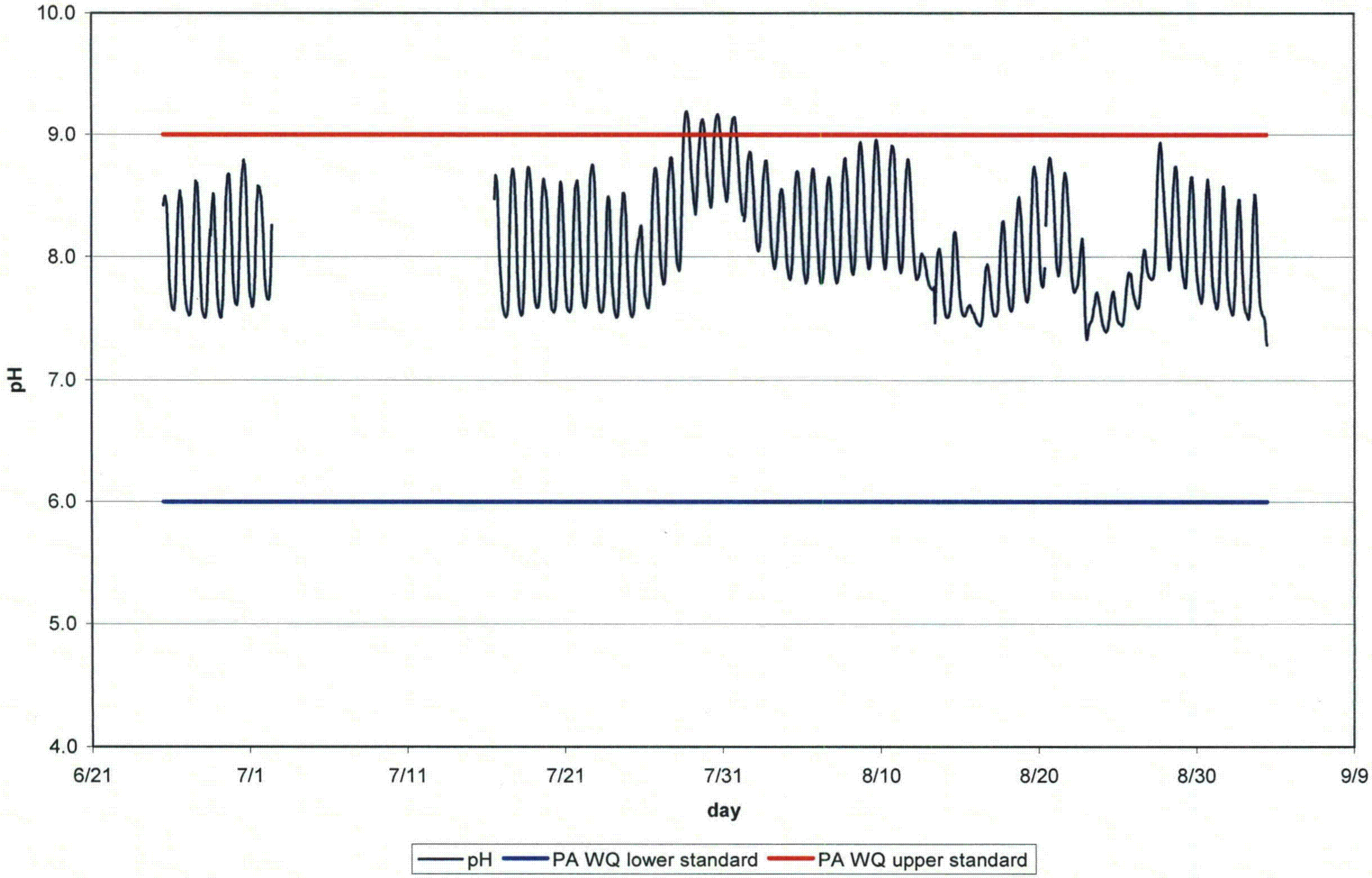

Figure 5-32 Sonde 5 (Downstream from Test Track, main channel) pH

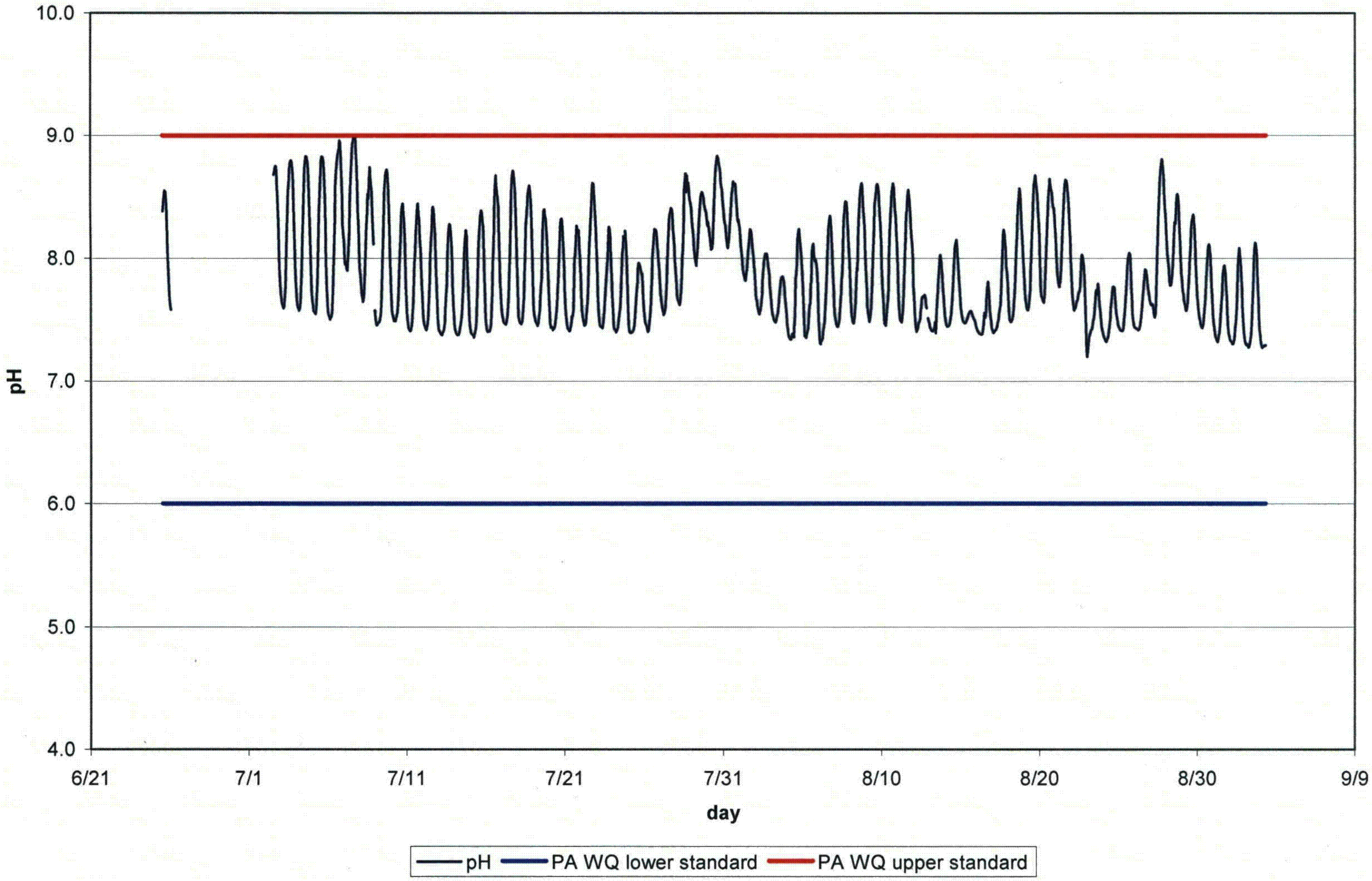

Figure 5-33 Sonde 6 (Downstream from Test Track, shallow) pH

5.8. OBSERVATIONS ON SMB SPAWNING, REARING, AND NURSERY AREAS

Ten surveys of SMB spawning activity, fry behavior, and subsequent survival were conducted from May through July 2010. A narrative of survey activities is provided in Appendix 5-A. Most observations were made in the upriver section of the study area which afforded the most spawning sites. A motorized kayak was used to gain easy access to the shoreline in shallow water.

Most spawning, fry emergence, and YOY SMB were observed at Rocky Island, Goose Island, Environmental Lab boat ramp, and upriver of the mouth of Little Wapwallopen Creek. Spawning occurred in shallow areas (<2 ft deep) with little or no current, mostly on gravel substrate. Fry and juveniles utilized near-shore shallow (<1 ft deep) and low velocity areas. Occasionally in July and more often in August, naturally occurring water temperature exceeded 87°F (PA state standard for temperature in WWF stream from 1 July to 30 August) in SMB nursery areas but field observations noted that juveniles vacated those locales prior to the occurrence of temperatures.

YOY SMB, apparently infected by the bacterium *Flavobacterium columnare*, were observed in July; these infected juvenile bass appeared vulnerable to Blue Heron predation. These fish appeared stressed to the extent that they could be hand-dipped. A detailed description of observations is included in Appendix 5-A.

5.9. IMPACT ANALYSIS

The 2010 sonde data cover a period from late June through 3 September. These data partially overlap the 1 May through 31 July SMB fry period of interest, as well as the potential juvenile SMB activity period through August. Three of the sondes were set in shallow areas that provide habitat to fry and juvenile SMB. To assess the potential effects of the 43 cfs withdrawal on the quality of these representative backwater habitats, the number of hours was calculated that the water temperature was equal to or greater than 1) the possible biological threshold of 84°F and 2) was equal to or greater than the PA WQ Standard of 87°F in July and August and 84°F in June. As discussed in Section 5.1, 84°F is considered a "possible biological threshold" temperature condition that prior studies suggest may be associated with increased *Flavobacterium columnare* virulence in fish fry.

For the impact assessment, the change in temperature due to the maximum expected reduction in depth of 0.5 inch was estimated with a thermal response calculation that uses meteorological data to assess heat transfer rates and the overall heat balance. The estimated changes in temperature were then applied to the observed sonde temperatures to obtain a modified sonde record. The observed sonde temperatures and the modified sonde temperatures were compared to both the PA WQ standard and the "possible biological threshold" to determine how often the number of exceedances increased for the reduced depth case.

5.10. THERMAL RESPONSE ANALYSIS

Changes in water temperature due to changes in water depth can be estimated by calculating the response temperature[12,13,14,15]. Response temperature is defined as the temperature a column of fully-mixed water would have if surface heat exchange were the only active heat transfer process (i.e., the water temperature "responds" only to surface heat exchange). This calculation is useful because it isolates temperature changes due to depth variations, which is the intent of the impact assessment. The calculation does not consider temperature changes in shallow areas due to overtopping during high flows or replenishment due to inflow and outflows through sands and gravels. These two processes would mitigate increases in temperature due to depth reduction.

The rate of change of response temperature can be written in terms of the net rate of surface heat exchange as

$$D\frac{dT}{dt} = \frac{R_n}{\rho c_p}$$

where

D	=	mean depth of the water column, m
dT	=	change water column temperature, °C
dt	=	change in time, s
R_n	=	net rate of surface heat exchange, W/m^2
ρ	=	density of water, 1000 kg/m^3
c_p	=	specific heat of water, 4186 J /kg/°C

[12] Joy, J., R. Noll and E. Snouwaert. 2009. Hangman (Latah) Creek Watershed Fecal Coliform, Temperature, and Turbidity Total Maximum Daily Load, Water Quality Improvement Report. Publication No. 09-10-030. Washington State Department of Ecology, Olympia, Washington 98504-7710. June.

[13] Edinger, J. E., D. K. Brady and J. C. Geyer. 1974. Heat Exchange and Transport in the Environment. Cooling Water Studies for the Electric Power Research Institute, Research Project RP-49, Report 14. Palo Alto, California. EPRI Publication Number 74-049-00-3. November.

[14] Baldwin, K. and A. J. Whiley. 2011. Pend Oreille River, Temperature Total Maximum Daily Load, Water Quality Improvement Report, Revised. Publication No. 10-10-065. Washington State Department of Ecology, Olympia, Washington 98504-7710. November

[15] Chapra, S.C. and G.J. Pelletier 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

The rate of surface heat exchange can be computed from air and dew point temperature, windspeed, cloud cover, solar radiation, and atmospheric pressure. These meteorological variables are used to compute the seven individual terms that make up the net rate of surface heat exchange. These terms include shortwave solar radiation; reflected shortwave solar radiation; longwave atmospheric radiation; reflected longwave atmospheric radiation; back radiation; evaporative heat loss; and conduction.

For the present calculation, hourly meteorological data from the NOAA station at Avoca, PA (WBAN 14777), six miles southwest of Scranton and 27 miles northeast of the site, were used to calculate the hourly response temperature for the sonde data period. Solar radiation is not observed at Avoca and was instead calculated using cloud cover observations. However, to emphasize maximum water temperature changes for this assessment and to show more warming than actually would have occurred, clear sky solar radiation rates were used instead of the reduced values due to cloud cover.

When hourly or more frequent meteorological data are used to compute the response temperature, the characteristic diurnal pattern of warm afternoon temperatures and cool overnight temperatures emerges. Daytime heating is due primarily to incident solar radiation; nighttime cooling is due primarily to nighttime longwave back radiation. Furthermore, the diurnal pattern is more pronounced for waterbodies with shallow depths than for very deep waterbodies. Damping of the diurnal amplitude as depths increase is due to the increased mass of water on which the heating and cooling processes operate.

As noted, observed meteorological data were used for this impact assessment, except that clear sky solar radiation was used instead of a reduced value due to cloud cover. Use of observed meteorological data resulted in a variable pattern of heating and cooling from day to day as various processes become more or less important to the heat balance. For example, evaporation is an important heat loss process which increases with wind speed which varies during the day and from day-to-day. Inclusion of observed meteorological data results in an irregular diurnal temperature pattern, as shown in Figure 5-34.

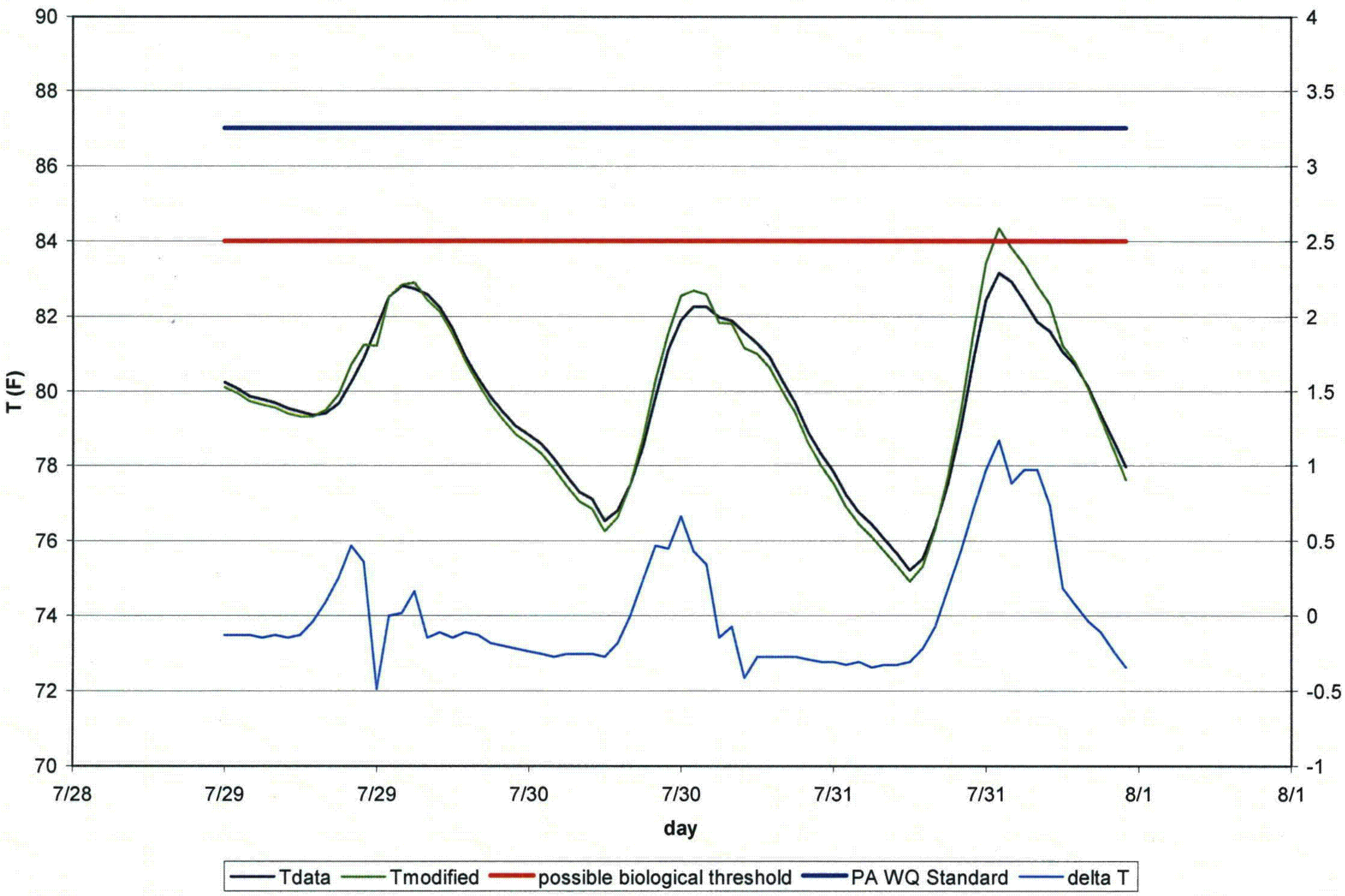

Figure 5-34 Sample sonde observed and modified temperature series and computed change in temperature from depth effect (ΔT) shown in light blue below on right hand y-axis (Sonde 3 Environmental Lab July 29 – 31 2010)

The calculation was run for six cases: once for each of the three shallow sondes (1, 3 and 6) at their nominal depths and once for these sondes at their nominal depth minus 0.5 inches. The hourly change in temperature (ΔT) was then applied to the hourly sonde observations to create a reduced-depth temperature record, referred to as the "modified record."

Drawdown values as a function of river flow from the stage-discharge curves developed for each PHABSIM transect are shown in Figure 5-35 for representative transects within the study reach. The 0.5 inch reduction in depth that was used in the thermal response analysis is the maximum drawdown value which occurs at 7Q10 at Transect Rl1-RC regardless of location, time of year, or river flow.

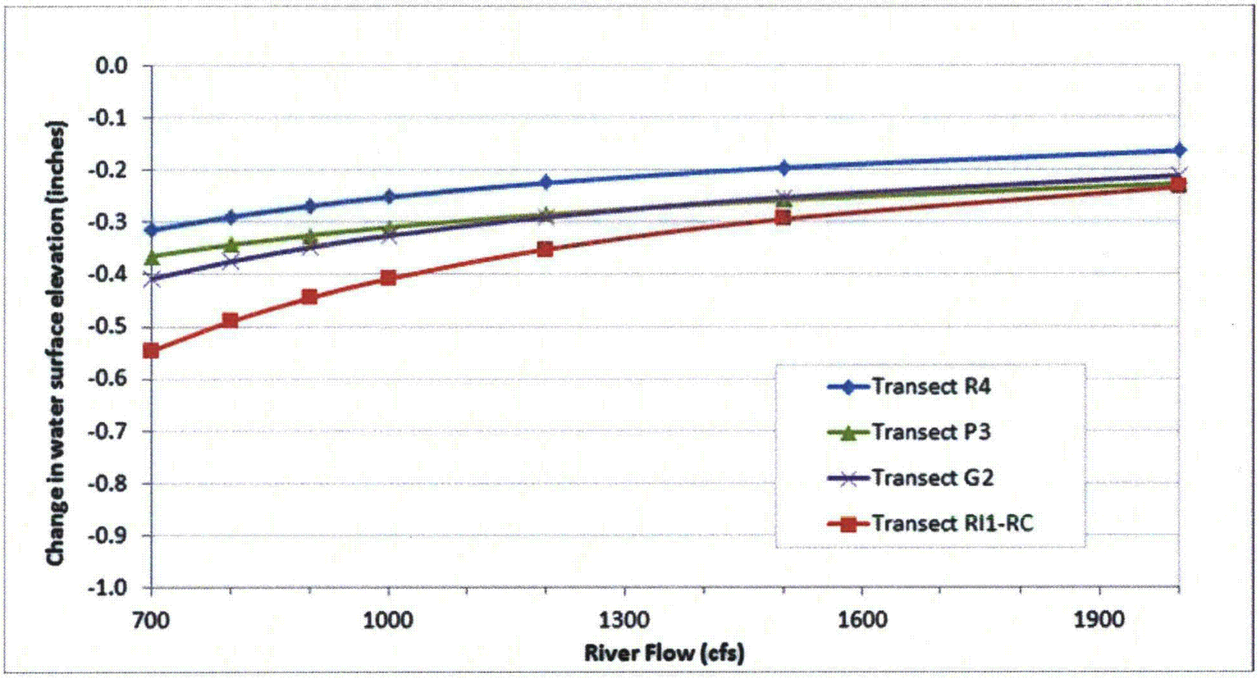

Figure 5-35 Depth reduction at four transects as a function of river flow

For illustration purposes, Figure 5-36 shows the observed Sonde 3 temperature, the calculated ΔT, and the modified Sonde 3 record obtained by adding the observed temperature and the ΔT. The period selected for this example includes the highest calculated ΔT (1.12°F) which results in the modified record exceeding one of the threshold values, in this case 84°F.

Both the observed temperatures and the calculated ΔT show daytime heating and nighttime cooling characteristic of heat balances controlled by surface heat exchange. The same positive, net heat flux that causes high temperatures in the early afternoon results in high ΔT values because the net heat flux is acting on a smaller mass.

The distribution of positive ΔT's for Sonde 3 for those occasions when the 0.5 inch depth reduction increases temperature is shown in Figure 5-36. This figure shows that the majority of increases are less than 0.5°F and that the example shown earlier is in fact the maximum change.

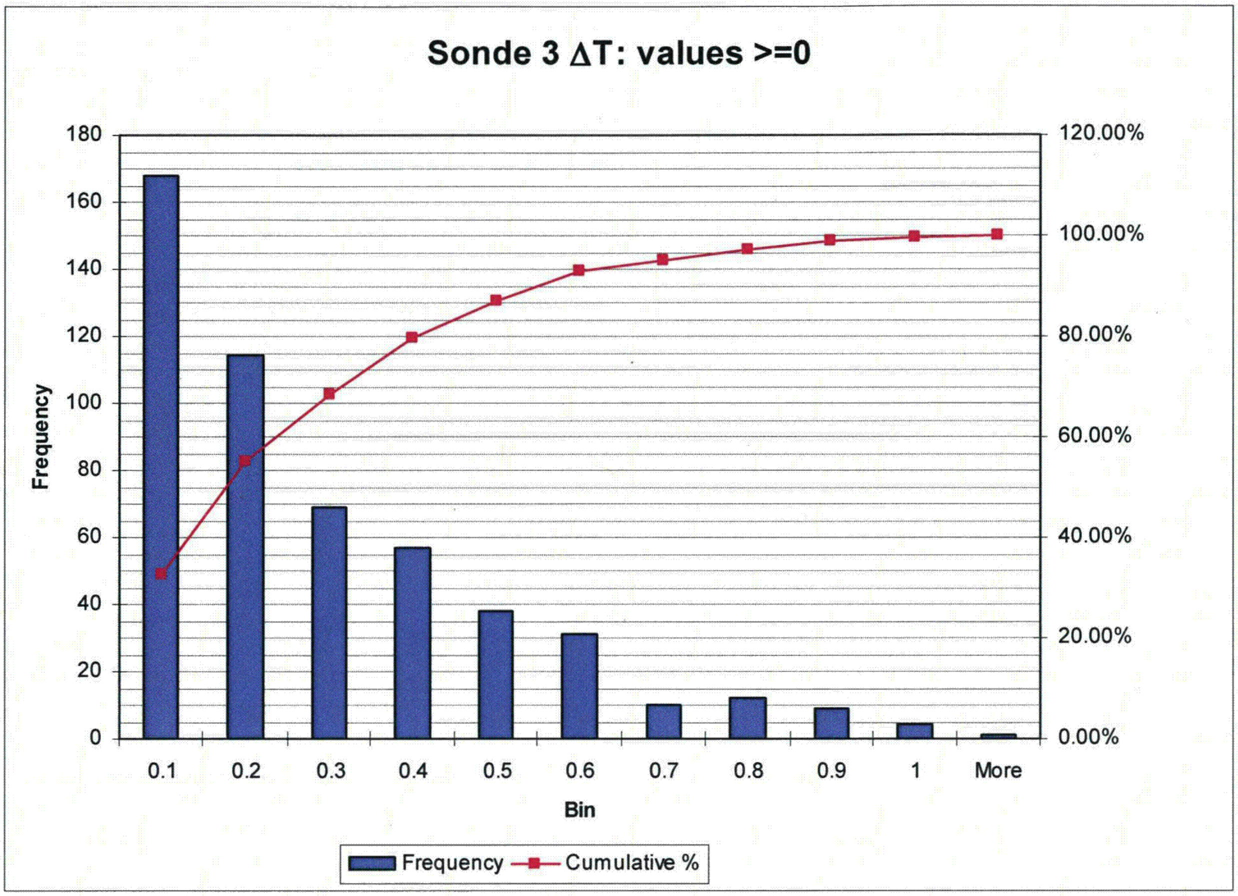

Figure 5-36 Frequency of occurrence of positive ΔTs for Sonde 3

The foregoing approach to calculating maximum temperatures is conservative, i.e., the calculation is an overestimate of the temperature increases that are likely to occur, for the following reasons:

- The calculation assumes a fully-insulated cylinder open only to heat gain or loss at the surface and assumes no replenishment due to mixing with groundwater in the hyporheic zone or due to flows that overtop the microhabitat boundary.
- The drawdown is a constant 0.5 inch for all Susquehanna River flows for all locations and times.
- The calculation assumes no cloud cover and therefore maximizes solar radiation and temperature change.

5.11. RESULTS

The computed response temperatures show the expected daytime heating and nighttime cooling cycle. When the predicted 0.5 inch maximum depth reduction associated with the 43 cfs is applied, the daytime maximum temperature is increased and the nighttime minimum temperature is decreased.

Figure 5-37, Figure 5-38, and Figure 5-39 show the diurnal hourly change in temperature (ΔT), averaged over the sonde data period for Sondes 1, 3, and 6, respectively. The average shown in these figures summarizes the overall effects of the 0.5 inch depth reduction: small increases in afternoon temperature and small decreases in nighttime temperature. This result is expected given the decreased water mass undergoing the same amount of daytime heating and nighttime cooling. The maximum and minimums in the figures illustrate the largest and smallest changes for each hour of the day over the period of analysis.

The calculated hourly changes in temperature were applied to the sonde data hour-by-hour. Figure 5-40, Figure 5-41, and Figure 5-42 show the sonde temperature record as observed and as modified for Sondes 1, 3 and 6, respectively. Also shown is the hourly change in temperature (ΔT). The changes in temperature due to the anticipated reduction in depth of 0.5 inch are so slight as to make the observed and modified temperature curves overlay closely and show no appreciable difference. However an analysis of the observed and modified record presented in both tabular and graphic format (Appendix 5-B and 5-C) shows that there are occasions when the daytime temperature increases cause the temperature to exceed the 84°F possible biological threshold and to exceed the PA WQ standard.

Table 5-4 provides a summary of the threshold analysis that shows the frequency and duration of exceedance of the PA WQ standard and the 84°F for the observed and modified sonde record.

Quantifying frequency and duration consists of counting the number of hours exceeding these values for the observed and the modified sonde temperature records. Two metrics can be derived from this procedure: the number of additional hours exceeded and the number of additional events. An event is a set of consecutive exceedances, that is, the duration of the exceedance. An event therefore is representative of potential recurring stress. It is important to note with regard to recurring (or cyclic) stress that Chaplin *et al.* (2009) indicated that the effect is poorly understood and that little is known about it over a period of days or weeks in YOY SMB microhabitats. Since additional recurring stress events associated with consumptive use as identified by the analysis in this report are extremely infrequent and are certainly not on the order of either days or weeks, no adverse effect is considered for this particular effect.

Because the temperature changes are small with increases confined to the afternoon, Table 5-4 shows that the 0.5 inch reduction in depth has no appreciable effect on the magnitude, the duration or the frequency of events greater than the possible biological threshold of 84°F. Similarly, the table shows that the reduction in depth due to consumptive use has no appreciable effect on the magnitude, the duration or the frequency of events greater than the PA WQ Standard.

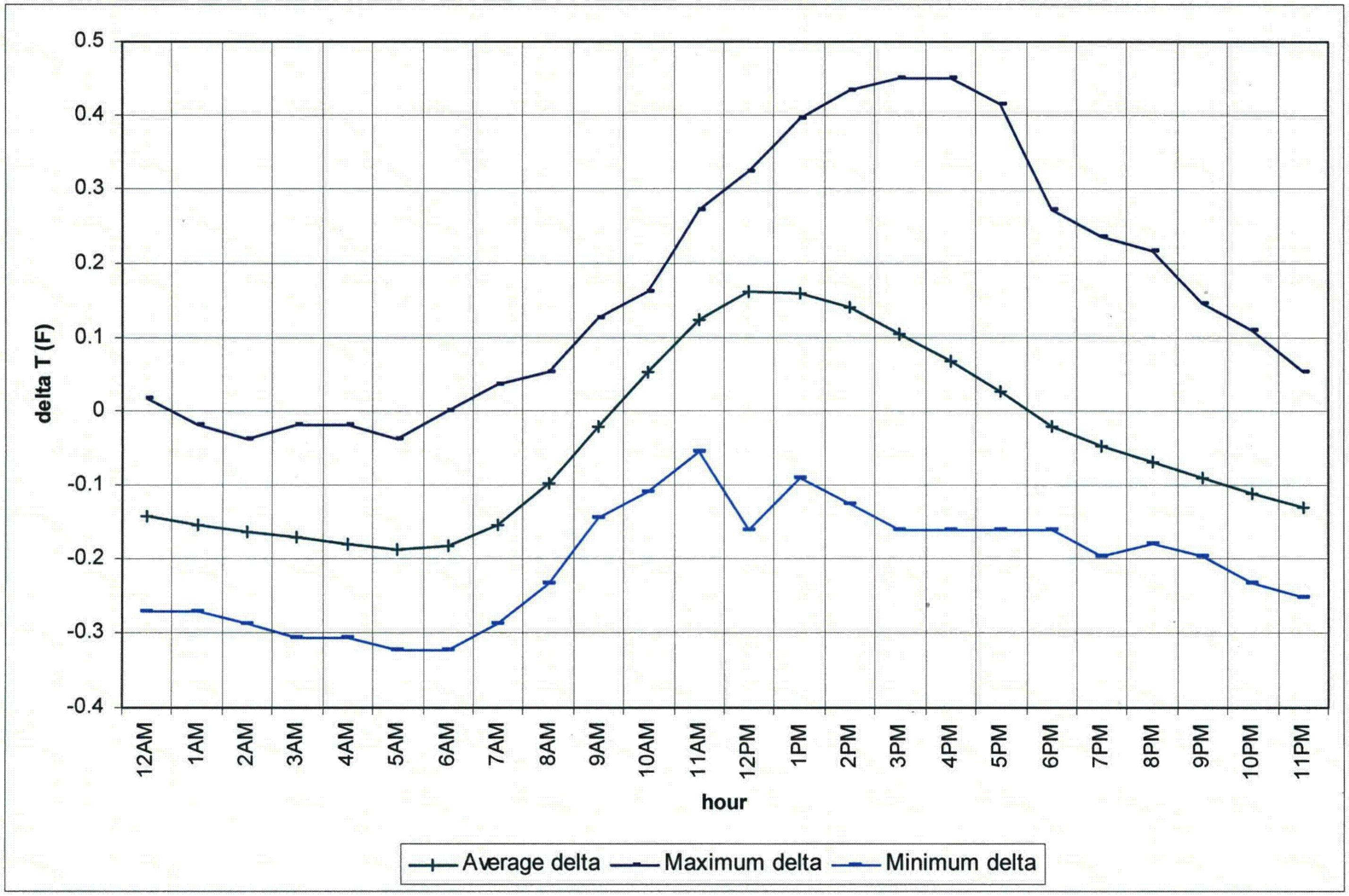

Figure 5-37 Overall change in temperature from reduced depth for Sonde 1 (Goose Island, shallow)

The ΔT is positive for increases and negative for decreases when applied to sonde data; nominal depth for Sonde 1 is 15 in.

Figure 5-38 Overall change in temperature from reduced depth for Sonde 3 (Environmental lab, shallow)

The ΔT is positive for increases and negative for decreases when applied to sonde data; nominal depth for Sonde 3 is 9 in.

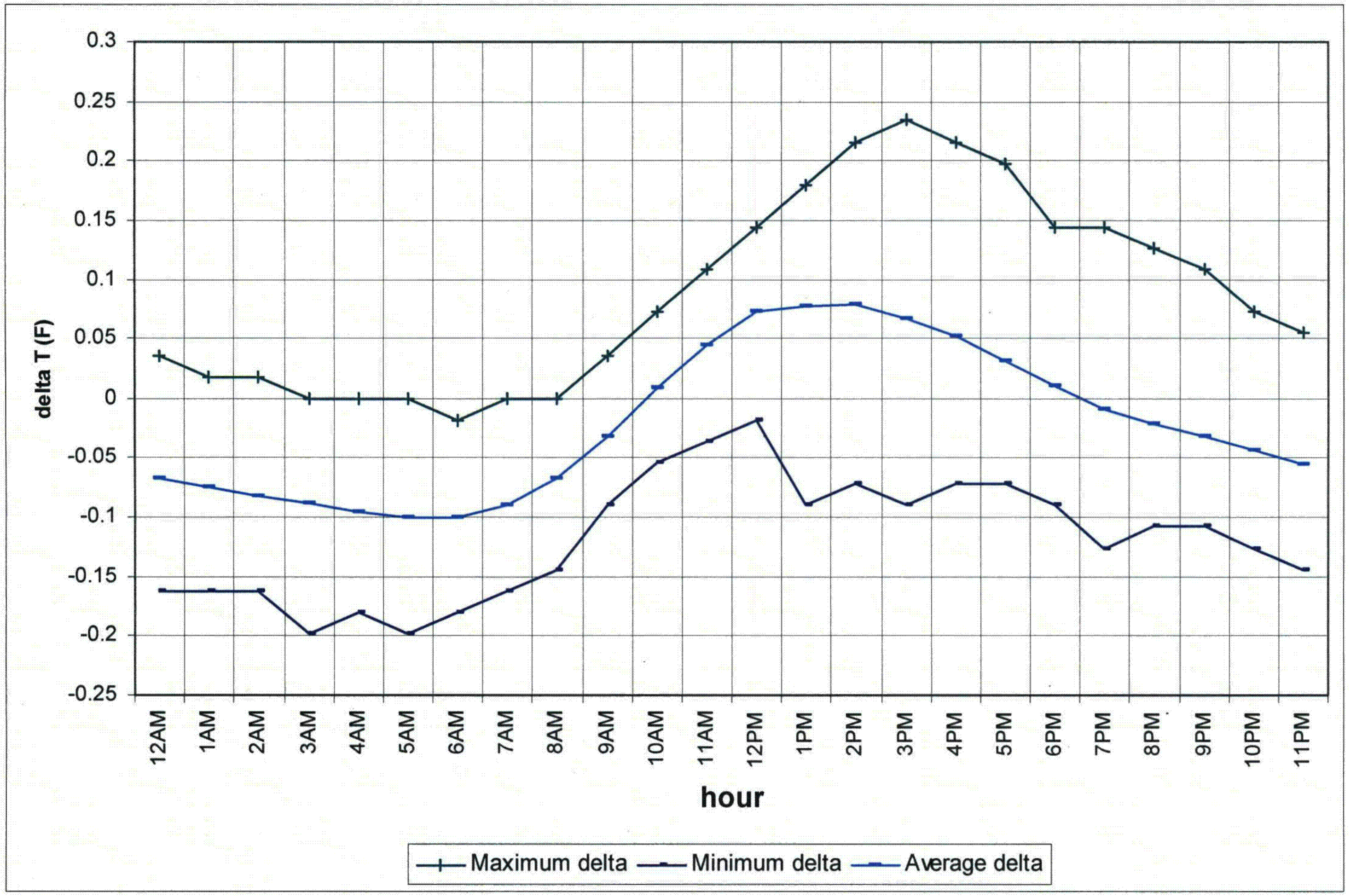

Figure 5-39 Overall change in temperature from reduced depth for Sonde 6 (downstream from Test Track, shallow)

The ΔT is positive for increases and negative for decreases when applied to sonde data; nominal depth for Sonde 6 is 21 in.

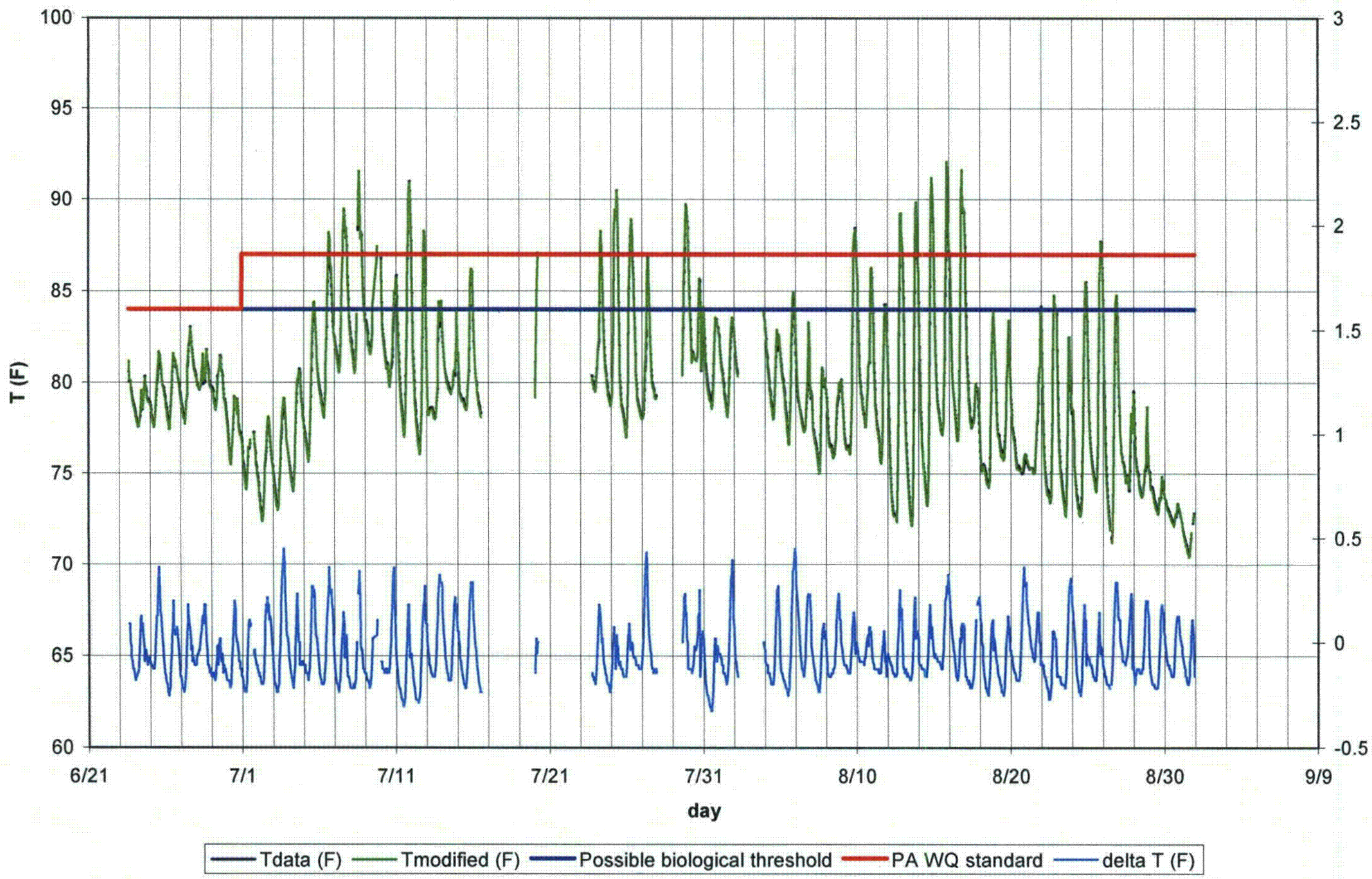

Figure 5-40 Sonde 1 (Goose Island, shallow) observed and modified temperatures series and computed change in temperature from depth effect (ΔT) shown in light blue below on right hand y-axis

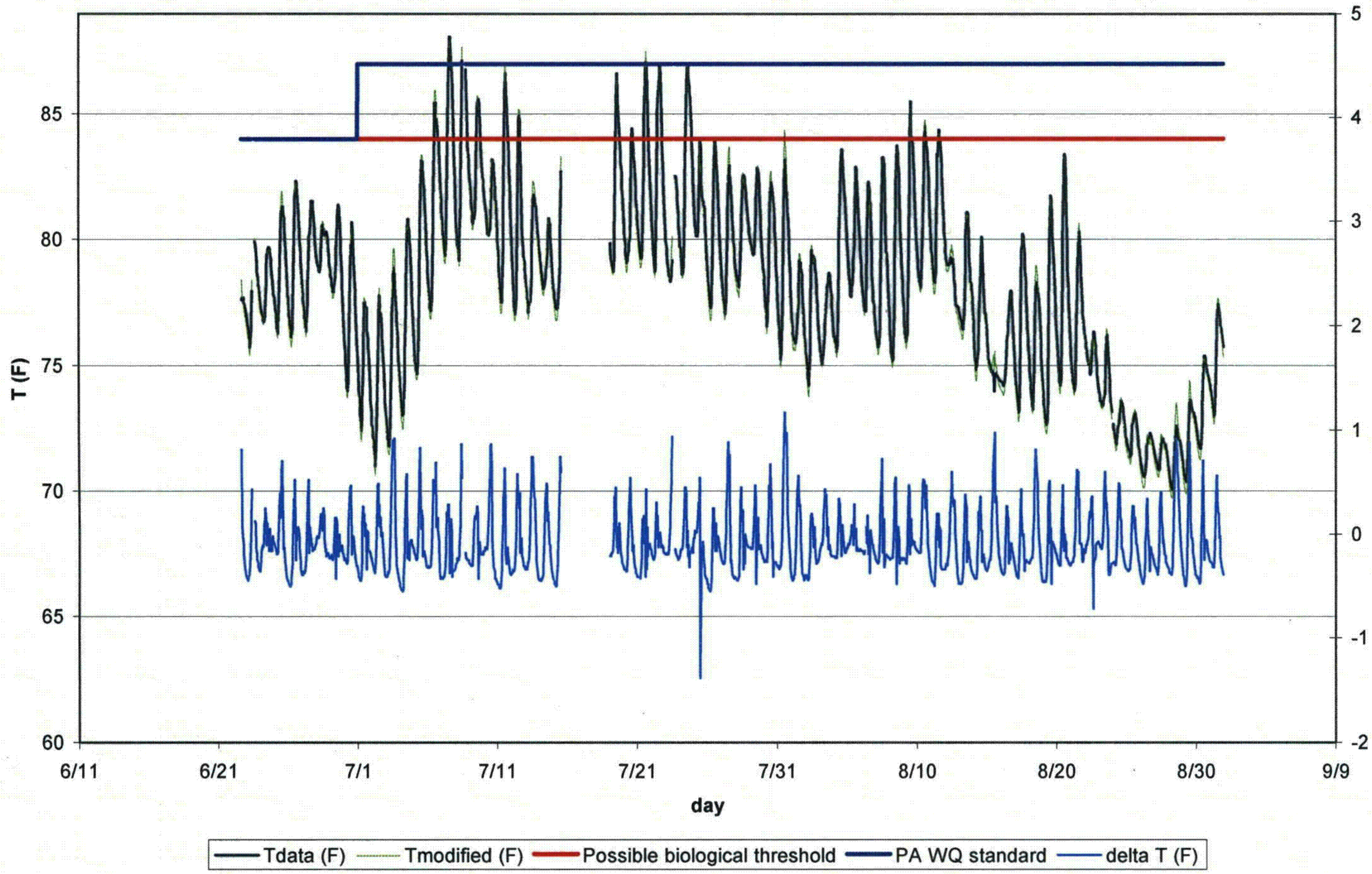

Figure 5-41 Sonde 3 (Environmental lab, shallow) observed and modified temperatures series and computed change in temperature from depth effect (ΔT) shown in light blue below on right hand y-axis

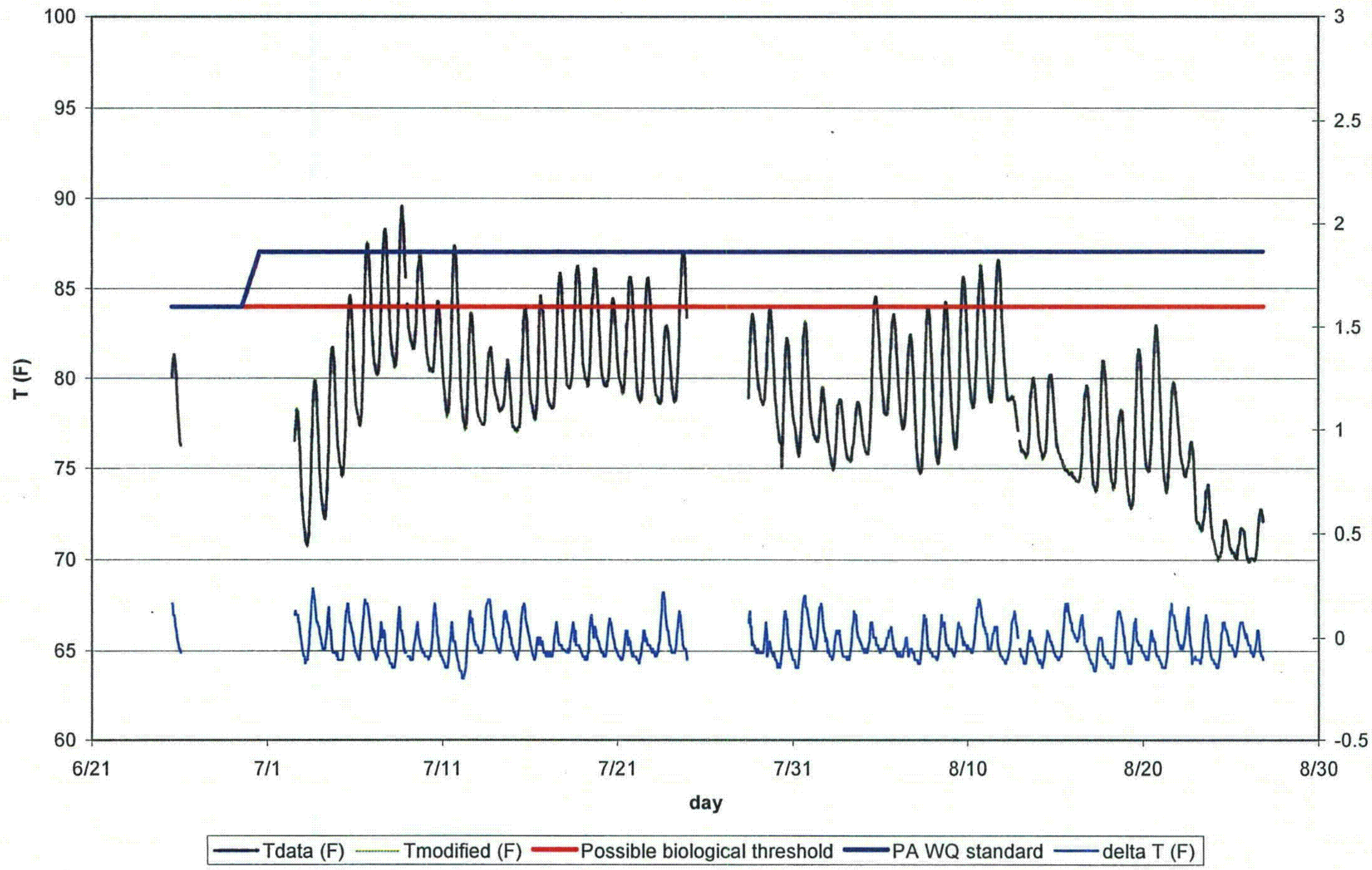

Figure 5-42 Sonde 6 (Downstream of Test Track, shallow) observed and modified temperatures series and computed change in temperature from depth effect (ΔT) shown in light blue below on right hand y-axis

Table 5-4 Thermal analysis summary

	Sonde 1 (Goose Island)	Sonde 3 (Environmental lab)	Sonde 6 (Test Track)
Sonde data period (2010)	23 June – 3 September	22 June – 3 September	25 June – 3 September
Depth used for thermal response calculation (inches)	15	9	21
Comparison to PA WQ Standard			
2010 data: hours above PA WQ standard	81	7	19
With ΔT applied: hours above PA WQ standard	81	8	19
Added hours	0	1	0
2010 data: number of events above PA WQ standard	18	3	6
With ΔT applied: number of events above PA WQ standard	18	4	6
New events	0	1	0
2010 data: average event duration (hours)	4.50	2.33	3.17
With ΔT applied: average event duration (hours)	4.50	2.33	4.25
Comparison to possible biological threshold			
2010 data: hours above 84°F	185	85	133
With ΔT applied: hours above 84°F	185	90	133
Added hours	0	5	0
2010 data: number of events above 84°F	34	16	22
With ΔT applied: number of events above 84°F	34	17	22
New events	0	1	0
2010 data: average event duration (hours)	5.44	5.31	6.05
With ΔT applied: average event duration (hours)	5.44	5.31	6.05

5.12. CONCLUSIONS

Based on field observations, SMB successfully spawned throughout the study area in late May and early June 2010. As the fry developed throughout June, they tended to disperse from the schools, but remained along the shoreline in aquatic vegetation at the river banks and the islands. However, by the time water temperature consistently exceeded 84-85° F these fry had grown to juvenile size and migrated from the shoreline habitat into deeper river water. In early July, shoreline water temperatures were approaching 90° F. At this time, YOY SMB were not observed in these areas.

Based on field observations and during naturally occurring flow events, some smallmouth bass juveniles appeared to suffer in 2010 from the same bacterial disease (*Flavobacterium*) experienced in 2005.

Collected water quality data indicates that during the summer low flow months there are natural occurrences of water quality not meeting the Pennsylvania State criteria for warm water fisheries, primarily for water temperature and DO and to a much lesser extent pH. These naturally occurring variations from the Pennsylvania Water Quality Criteria in water temperature and dissolved oxygen, independent of consumptive use, were of short duration and were limited to the shallow, inshore areas both upstream and downstream of the proposed BBNNP discharge location.

The thermal response analysis shows that the 0.5 inch reduction in depth has no appreciable effect on the magnitude, the duration or the frequency of events greater than or equal to a possible biological threshold of 84°F nor on the magnitude, the duration or the frequency of events greater than the PA WQ Standard.

Therefore, we conclude that the proposed consumptive use of the Bell Bend Project will have no appreciable effect on the condition for SMB spawning, fry emergence, rearing, and nursery.

6. *ASSESSMENT OF POTENTIAL IMPACTS ON DOWNSTREAM USERS*

Users of the waters of the Susquehanna River downstream of BBNPP can be classified as either direct withdrawers of water or dischargers that depend on the dilution and assimilative capacities of the Susquehanna. For direct withdrawers (e.g., municipal water utilities) the primary issue is availability of water and the functionality of intake structures at low water surface elevations. For dischargers, end-of-pipe concentration limits may depend on a specific flow rate used in calculations and models (e.g., PENTOXSD).

6.1. METHODS

The following evaluation of potential impacts on downstream water intakes and treated wastewater dischargers covers the area downstream of the BBNPP site as far as Danville and Riverside, PA (just over 30 miles distance from BBNPP), as stated in the Study Plan. For each group (withdrawers, dischargers), we sought to understand the scope of impacts (physical, chemical, and regulatory) that might occur for the group, divided into large (1 mgd or more) and small (less than 1 mgd) withdrawal or discharge rates. Inquiries were made by telephone and email, with repeated calls to facilities that did not respond, to attempt to ensure that each known withdrawer and discharger had the opportunity to respond. Contacts with water withdrawers focused on defining impacts on their ability to serve their customer base and/or their ability to maintain suitable intake velocities because of potential reduced water availability, decreased river stage, or changed water quality. Other concerns included potentially increased chemical usage due to reduced river flow. Discussions with treated wastewater dischargers focused on potential reductions of effluent limits driven by decreased dilution based upon a seven-day, ten-year low flow in the Susquehanna River reduced by a maximum of 48 cfs of added consumptive water use arising from the installation of a new generating unit at the BBNPP. The 48 cfs value was used for the interviews because the downstream user survey was begun prior to the change to 43 cfs in PPL Bell Bend's application to the SRBC. The 7Q10 at Bell Bend is 843 cfs; at Bloomsburg, it is estimated at 942 cfs; at Danville, it is estimated to be 1,010 cfs per http://paapps.er.usgs.gov/flowstats.

The list in Table 6-1of water withdrawers in excess of 0.1 mgd is based on internet research on local water suppliers and telephone contacts with the withdrawers. While three of the withdrawers are extracting from wells, rather than directly from the Susquehanna River, these withdrawers were included because of their wells' proximity to the river.

Table 6-1 Downstream water withdrawals

Facility/Location	Type	Design flow (mgd)	Distance downstream of the BBNPP intake (mi)	Expected Impact
PA-American Water Company (serves Berwick and Nescopeck)	Water supply - wells	4.6	6.5	No impact, reserves the right to reassess in the future (e-mail R. Schnitzler, 5/15/2011)
Mifflin Township Water Authority	Water supply - wells[16]	0.223 (typ.) 0.432 (max.)	11	No impact (e-mail P. Hartzell, 5/11/2011)
Catawissa Borough Municipal Authority	Water supply - wells[17]	0.12 (avg.) 0.2 (max.)	22	None expected (telecon C. Bachman, 5/3/11)
Danville Municipal Authority	Water supply	2 (avg.)	30	Potential impact on treatability (including chemical usage) of Authority's raw water and quantity of treatment residuals requiring disposal (e-mail D. Marks, Gannett-Fleming, 5/11/2011)
Cherokee Pharmaceuticals, Riverside	Process water supply	34.392	31.2	Could potentially impact the facility, but still under evaluation (e-mail J. Brenchley, 5/9/2011)

The list in Table 6-2 of downstream sanitary and industrial wastewater dischargers to the Susquehanna is based on a USEPA Envirofacts search (last updated in 2006) of all dischargers to the Susquehanna River having greater than 0.1 mgd flow. This flow cutoff was based on our assumption that flows smaller than this would not be impacted by the 43 cfs maximum BBNPP consumptive use, given that an 0.1 mgd discharge is less than 0.1% of the 7Q10 for the Susquehanna River at the point of discharge.

[16] within ¼ mi of river

[17] wells ½ mi upstream along Catawissa Creek; the surface intake (not usually used) on Catawissa Creek

Table 6-2 Downstream treated wastewater dischargers

Facility/Location	Type	Design flow (mgd)	Distance downstream of the SSES intake (mi)	Expected Impact
Nescopeck Borough	POTW	0.11	6.5	None (e-mail from J. Hendricks, Herbert, Rowland, & Grubic, Inc. for Nescopeck Borough, 4/28/2011)
Berwick Area Joint Sewer Authority	POTW	3.7	6.5	Little to no effect on BAJSA's effluent limits and their ability to meet them (e-mail and letter from E. Threet, Herbert Rowland & Grubic Inc., 5/16/2011)
Bloomsburg Municipal Authority	POTW	4.29	18	Based upon a check of PENTOX and a discussion with PADEP, no significant impact on Bloomsburg's WWTP discharge is anticipated (voice mail T. Jones, Gannett-Fleming, 5/22/2011)
Danville Municipal Authority	POTW	3.62	30	Authority suggests that PADEP be asked to rerun its models for effluent limit development based upon reduced Q7,10 (e-mail R. Jager, Gannett-Fleming, 5/10/2011)
Wise Foods, Berwick	Indust.	0.59	7.3	NPDES permit undergoing renewal at present; therefore, comment at this time would be premature. Wise Foods reserves the right to comment in the future on this matter (e-mail R. Wolfe, 5/6/2011).
DelMonte Corp., Bloomsburg	Indust.	0.671	12.9	No response after multiple calls
Cherokee Pharmaceuticals, Riverside	Indust.	12.2	31.7	Could potentially impact the facility, but still under evaluation (e-mail J. Brenchley, 5/9/2011)

6.2. Evaluation of Potential Impacts

Downstream Water Withdrawals

As provided in Table 6-1 three downstream withdrawal facilities (PA American Water, Mifflin Township Water Authority, and Catawissa Borough Municipal Authority) indicated no expected impact on their well water withdrawals as a result of the project consumptive water use. The Danville Municipal Authority indicated a potential impact on raw water treatability and the quantity of treatment residuals requiring disposal. Cherokee Pharmaceuticals, Riverside indicated a general concern for potential impacts.

Generally, the BBNPP consumptive use will only result in a very small change in water level (less than 0.5 inch at the BBNPP intake) which is unlikely to have any impact on either the

Danville Municipal Authority or Cherokee Pharmaceuticals' ability to withdraw water from the river 30 miles downstream from BBNPP. Small water level changes are also unlikely to have any impacts on nearby municipal well water levels, confirming the no expected impact response from PA American Water, Mifflin Township and Catawissa Borough.

In terms of raw water treatability the discharge from BBNPP is typically about 1% of the average river flow increasing to about 5% at 7Q10 conditions. The BBNPP discharge must meet PADEP NPDES permit discharge standards. In addition, this ratio illustrates only minimal potential changes to stream water quality (T, DO, pH) in areas immediately below the BBNPP discharge. These small changes are unlikely to even be detectable at the location of these downstream facilities. As a result, no treatability impacts would be expected.

Downstream Treated Wastewater Discharges

The principal issue with respect to regulated downstream wastewater discharges is the owner's ability to meet effluent limits under an assumption that the BBNPP consumptive use will alter (reduce) the rate of flow used by PADEP for calculating the discharge limits that treatment standards imposed in their NPDES permits are based on.

Three of the seven wastewater treatment dischargers as listed in

Table 6-2 indicated little or no expected impact due to the proposed BBNPP consumptive water use. One discharger did not respond to phone inquiries, while three dischargers indicated either that they could be potentially impacted or that additional analysis is required.

Normally, when effluent limitations in an NPDES discharge permit are set by the PADEP, the PADEP performs modeling using PENTOXSD[18]. PENTOXSD uses a mass-balance water quality analysis model that includes consideration for mixing, first-order decay and other factors to determine recommended water quality-based effluent limits. The primary purpose of the model is to assist PADEP permit engineers in determining appropriate NPDES permit limits for toxics and certain other substances. For each parameter evaluated, the program:

- Computes a Wasteload Allocation (WLA) on a single discharge basis (i.e., without the consideration of multiple source interactions) for each applicable criterion.
- Determines a recommended maximum water quality-based effluent limitation (WQBEL) for each parameter.
- Compares the recommended WQBEL with the entered discharge concentration to determine which is more stringent.
- Recommends average monthly and maximum daily effluent limitations.

PENTOXSD uses two different design stream flows to compute the Wasteload Allocations (WLAs). They are the 7Q10 and Qh (harmonic mean flow). The 7Q10 stream flow is specified in the Water Quality Standards, Pa. Code Title 25 Section 96.4(g) Table 1. This stream flow is used in the application of three of the four water quality criteria:

- Acute Fish Criteria (AFC), also referred to as Criteria Maximum Concentration
- Chronic Fish Criteria (CFC), also referred to as Criteria Continuous Concentration
- Threshold Human Health (THH)

The Qh flow is specified by regulation in the Water Quality Standards, Pa. Code Title 25 Section 96.4(g) Table 1. Section 93.8a(e) specifies that "*...for carcinogens, the design conditions result in a lifetime – 70 years – average exposure...*" DEP has determined that Qh meets this requirement.

Consumptive water use at BBNPP is less than one percent of harmonic mean flow and is unlikely to impact any effluent limitations for carcinogens. Flow analyses separately performed by PPL[19] suggest that existing operation of the Cowanesque and Whitney Point Reservoirs during low flow periods (flows equal to or less than 7Q10) would be expected to offset any flow reduction associated with the BBNPP consumptive use. These reservoir operations are not currently reflected in the historical flow record used in this analysis and as a result are not

[18] Technical Reference Guide (TRG) PENTOXSD for Windows PA Single Discharge Wasteload Allocation Program for Toxics, Version 2.0, Commonwealth of Pennsylvania, Department of Environmental Protection.

[19] "Modification And Use Of the Oasis Model to Evaluate Sources of Flow Augmentation For PPL Consumptive Water Use Mitigation in the Susquehanna River Basin, Document JCP-BB-1, Rev. 0, March 7, 2012"

reflected in the statistical derivation of the 7Q10 flow or any PENTOXSD modeling that has been performed in setting downstream discharge effluent limitations. In this section of the Susquehanna River down to and including the location of the

Table 6-2 listed treated wastewater discharges, these reservoir operations result in enhanced streamflow conditions during low flow periods that appear to effectively offset any potential flow reductions due to BBNPP consumptive use. As a result, no net change to the statistically derived 7Q10 is expected, and no impacts to downstream effluent limitations would be expected to occur once these flows enhancements are accounted for. Since the 7Q10 will be maintained there is no need to recalculate effluent limitations with PENTOXSD.

6.3. Conclusions

One large downstream water user expressed concern about consumptive use impact on its activities; several downstream dischargers and one water user expressed interest in further evaluation of quantitative impacts, but none voiced immediate objections. One large discharger anticipated little to no effect; two large dischargers anticipated no significant impact after running models and/or consulting with PADEP. The smaller entities that responded do not anticipate any impacts from the proposed consumptive use, although one smaller discharger reserves the right of future comment. Separate analysis suggests that a BBNPP consumptive use will not alter water chemistry at any downstream withdrawal or discharge point and is therefore unlikely to have any impact on water treatability. When the BBNPP consumptive water use is considered in combination with existing flow enhancements in this section of the river due to operation of the Cowanesque and Whitney Point reservoirs, no impact on downstream effluent limitations would be expected.

7. *STUDY CONCLUSIONS*

Potential effects of the requested level of the BBNPP consumptive water use were investigated using the procedures and methods identified in the Study Plan. These procedures and methods relied as much as possible on field programs in which data directly useful in addressing the study questions were obtained. Analysis of the data was supplemented with calculations and models as appropriate.

This study benefited from the opportunity to measure the characteristics and behavior of the Susquehanna River over the range of flows that occurred in 2010 including a period of sustained low flows.

For all five study questions, either minimal or no impacts due to 43 cfs of BBNPP consumptive water use were found. This result is largely due to the small fraction of the 7Q10 that consumptive water use represents (5%) and the consequent small reduction in water surface elevation (<0.5 in.) that is expected to occur.

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