TENNESSEE VALLEY AUTHORITY
River System Operations & Environment
River Scheduling

WINTER 2006 COMPLIANCE SURVEY FOR WATTS BAR NUCLEAR PLANT OUTFALL 113 PASSIVE MIXING ZONE

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EXECUTIVE SUMMARY

The National Pollutant Discharge Elimination System (NPDES) Permit No. TN0020168 for Watts Bar Nuclear Plant (WBN) identifies the discharge of water to the Tennessee River from the Supplemental Condenser Cooling Water (SCCW) System as Outfall 113. Furthermore, the permit identifies that when there is no flow released from Watts Bar Dam (WBH), the effluent from Outfall 113 shall be regulated based on a passive mixing zone extending in the river from bank-to-bank and 1,000 feet downstream from the outfall. Compliance with the requirements for the passive mixing zone is to be made by two annual instream temperature surveys: one for winter conditions and one for summer conditions. Summarized in this report are the measurements, analyses, and results for the passive mixing zone survey conducted for 2006 winter conditions. The survey was conducted on March 22, 2006, and included the collection of temperature data at eleven temporary monitoring stations deployed across the downstream edge of the passive mixing zone during a period of no flow in the river. Despite some problems with some of the temperature stations, sufficient valid data were collected to compute the three compliance parameters specified in the NPDES permit: the one-hour average temperature at the downstream edge of mixing zone, T_d; the one-hour average temperature rise from upstream to the downstream edge of the mixing zone, ΔT; and the one-hour average temperature rate-of-change at the downstream edge of the mixing zone, TROC. The measured parameters were compared to predicted values from a thermal plume model used by TVA to verify the operation of Outfall 113. The results of the comparisons, in terms of maximum values observed during the no flow event, were as follows:

Parameter	Predicted	Measured	NPDES Limit
Maximum T_d	55.6°F	54.5°F	86.9°F
Maximum ΔT	3.2 F°	1.8 F°	5.4 F°
Maximum TROC	+0.4°/hour	+0.6°/hour	±3.6 F°

As shown, values predicted by the model were higher than those measured in the survey for the maximum temperature, T_d, and the maximum temperature rise, ΔT. Thus, for these parameters, the model is considered conservative for predicting the impact of Outfall 113. That is, because the model overpredicted the observed values for these parameters, it will tend to enforce the operation of Outfall 113 at levels of T_d and ΔT below the NPDES limits. The model underpredicted the TROC at the downstream end of the passive mixing zone. This difference is likely due to phenomena in the river that are not represented in the thermal plume model, such as unsteady sloshing in the reservoir and the impact of wind. For the survey of March 22, a passing tow and lock operations at Watts Bar Dam also may have been factors. Based on a survey conducted in 2005, a factor of safety of 0.3F°/hour is currently used in the model for predicting the maximum value of the TROC. That is, the safe operation of Outfall 113 for the passive mixing zone is evaluated based on a maximum value of TROC of ±3.3 F°/hour rather than ±3.6 F°/hour. The results of the survey summarized herein confirm the ongoing need to apply 0.3F°/hour as a factor of safety for predicting TROC with the thermal plume model.

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INTRODUCTION

Outfall 113 for the Watts Bar Nuclear Plant (WBN) includes the discharge of water to the Tennessee River from the Supplemental Condenser Cooling Water (SCCW) system. Due to the dynamic behavior of the thermal effluent in the river, the National Pollutant Discharge Elimination System (NPDES) Permit No. TN0020168 for the plant specifies two mixing zones for Outfall 113: one for active operation of the river and one for passive operation of the river (TDEC, 2004). The passive mixing zone corresponds to periods when operations at Watts Bar Dam (WBH) produce no flow in the river (i.e., hydropower and/or spillway releases). The dimensions of the passive mixing zone extend from bank-to-bank and downstream 1,000 feet from the outfall. The active mixing zone applies to all other river flow conditions. The dimensions of the active mixing zone include the right-half of the river (facing downstream) and extend downstream 2,000 feet from the outfall. The passive and the active mixing zones are illustrated in Figure 1.

Table 1 summarizes the NPDES temperature limits for Outfall 113. The limits apply to both the active and passive mixing zones. Compliance for the active mixing zone is monitored by permanent instream water temperature stations situated in the right-half of the river. Due to limitations in placing permanent stations across the river, a thermal plume model is used to determine the safe operation of Outfall 113 for the passive mixing zone. To verify the thermal plume model, the NPDES permit specifies that two instream temperature surveys shall be conducted each year – one for winter conditions and one for summer conditions. The purpose of this report is to present the results for the passive mixing zone temperature survey conducted for winter 2006 conditions. The survey was conducted on March 22, 2006, and included the deployment of temporary temperature stations across the downstream edge of the passive mixing zone. Data from these and other monitoring stations were analyzed to obtain measured values for the compliance parameters listed in Table 1 and to compare these with the corresponding values predicted from the SCCW thermal plume model. Summarized herein are descriptions of the survey method, results, and conclusions.

Table 1. Temperature Criteria for SCCW Mixing Zones

Maximum Temperature, Downstream Edge of Mixing Zone, T_d	Running 1-hr	86.9°F
Maximum Temperature Rise, Upstream to Downstream, ΔT	Running 1-hr	5.4 F°
Maximum Temperature Rate-of-Change, TROC	Running 1-hr	±3.6 F°/hr

INSTREAM SURVEY

The method of conducting the instream survey is the same as that used for the first such survey, conducted for winter conditions on May 6, 2005 (McCall and Hopping, 2005). Table 2 provides a summary of the sources of data for the survey. The WBN Environmental Data Station (EDS) provided measurements from existing permanent monitoring stations, including the upstream (ambient) river temperature, river water surface elevation, SCCW effluent temperature, SCCW effluent flow, and air temperature. WaterView®, a hydroplant monitoring system, was used to provide measurements for the discharge from WBH.

The effluent plume for Outfall 113 was monitored by deploying temporary monitoring stations at roughly equal intervals across the downstream edge of the passive mixing zone. The temporary water temperature monitoring stations recorded temperature profiles using HOBO water temperature sensors positioned at depths of 0.5, 3, 5, and 7 feet below the water surface. Shown in Figure 2 is a schematic of the temporary monitoring stations, which included an assembly containing a tire float, a string of HOBO water temperature sensors, and anchor weights. The water temperature sensors have an accuracy of about ±0.4 F° and resolution of about 0.04 F°, which is consistent with other temperature measurements used for TVA hydrothermal compliance. The HOBO devices include an internal data acquisition unit and were programmed to collect measurements once every minute. A Global Positioning System (GPS) tracking device was used position the stations along the downstream edge of the passive mixing zone, as shown in Figure 3. For this study, the GPS location of Station WB1 was out of the water due to the seasonally low stage of Chickamauga Reservoir (see Figure 3). As such, eleven temporary stations were deployed for the survey described herein (i.e., Stations WB2 through WB12).

Table 2. Sources of Data for Passive Mixing Zone Survey

Data	Source	Frequency
River Discharge from Watts Bar Dam	WaterView®	5 min
River Water Surface Elevation	WBN EDS Station 30 (Tailwater at WBH)	15 min
River Ambient Water Temperature	WBN EDS Station 30 (Tailwater at WBH)	15 min
SCCW Effluent Discharge	WBN EDS Station 32 (Outfall 113)	15 min
SCCW Effluent Temperature	WBN EDS Station 32 (Outfall 113)	5 min
Air Temperature	WBN EDS Met Tower	15 min
Passive Mixing Zone Downstream Temperatures	Temporary HOBO Monitors	1 min

RESULTS

River Conditions

Shown in Figure 4 are the measured conditions of the river for the day of the survey. Included are the river discharge, water surface elevation, and upstream (ambient) water temperature. To provide a period of no flow in the river, releases from Watts Bar Dam were suspended between about 07:00 CST and 16:00 CST. Within this period, a small release was inadvertently made at 15:00 CST, as shown by the spike in Figure 4. When the releases were suspended at 07:00 CST, the river water surface below WBH dropped in the first three hours, but then slowly increased throughout most of the remainder of the survey, due to filling from downstream. Before the start of the survey, when water was being released from WBH, the ambient river temperature was steady at about 51.8°F (i.e., before 07:00 CST). At about 09:00 CST, about two hours after releases were suspended, the ambient temperature began to climb, reaching a peak of 53.2°F at about 12:30 CST. Afterwards, the ambient temperature trended downward. At 15:00 CST the ambient temperature dropped suddenly by about 0.5°F due to cooler water in the small release made at that time.

SCCW Conditions

During the survey, the SCCW system was thermally loaded and operating in "summer" mode. Shown in Figure 5 are the measured conditions of the WBN SCCW system for the day of the survey. Included are the discharge and temperature of the SCCW effluent. In the initial four hours of the survey, the SCCW discharge was about 151 cfs. Around 11:00 CST, adjustments were made in the SCCW system to maintain a proper balance of flow at WBN. This, in turn, increased the SCCW discharge to about 163 cfs (8 percent increase). The average discharge for the entire survey was about 159 cfs. In the initial hours of the survey the temperature of the SCCW effluent was about 59°F. After 09:00 CST, the temperature began to increase, due to the diurnal increase in air temperature passing through the cooling tower, reaching about 64°F by the end of the survey (see Figure 5 for the observed air temperature). The temperature of the SCCW effluent relative to the ambient river temperature also is shown in Figure 5. At the beginning of the survey, the effluent from the SCCW system was about 7°F warmer than the river. At the end of the survey the effluent from the SCCW system was about 12°F warmer than the river.

Effluent Behavior

Shown in Figure 6 are the readings from the HOBO temperature stations at the downstream end of the passive mixing zone. The stations are labeled consecutively from WB2 to WB12, with WB2 situated near the left shoreline of the river and WB12 situated near the right shoreline of the river (see Figure 3). As previously emphasized, Station WB1 was not deployed due to the stage of Chickamauga Reservoir. In the survey, a number of problems were encountered with the stations. These include the following:

- Due to difficulties with initializing the clock for the HOBO data acquisition units, two sensors for Station WB5 (5-foot and 7-foot), all of the sensors for Station WB6, two sensors for Station WB7 (0.5-foot and 5-foot), and one sensor for Station WB9 (0.5-foot) all failed to collect data throughout the survey.

- Due to a bad connection, one sensor for Station WB10 became separated from the HOBO string and was lost (3-foot depth).

- Also, prior to the beginning of the survey, many stations drifted from their waypoint, due to anchor problems (i.e., the stations were deployed the day before the survey). Data collection for these stations was delayed until after 08:30 CST, due to the time required to reposition the stations to their original waypoint.

- At about 09:30 CST, a tow passed through the survey area, running over Station WB3 and disturbing many nearby stations, all which again had to be repositioned.

In general, the temperature at each sensor increased throughout the survey, due to solar heating and the Outfall 113 effluent. Other notable behavior of the data presented in Figure 6 includes the following:

- The temperature at the 0.5-foot depth for Stations WB3, WB4, and WB5 was very erratic in the morning hours of the survey. This was because of the aforementioned tow, which apparently created patches of warm water in the surface layer of the river. These patches also could have been created by operation of the navigation lock at Watts Bar Dam. Water in the lock, which is released when moving tows past the dam, tends to be warmer than the ambient river water if it has resided in the lock for a significant period of time. Also, the release from the lock would have caused extra mixing in the river, and perhaps in the portion containing these stations.

- The temperature at Stations WB2, WB3, WB4, and WB5 increases significantly at about 12:30 CST, about 5½ hours after the beginning of the no-flow event. This likely corresponds to the arrival of the leading edge of the thermal plume from Outfall 113. For no-flow events, the thermal plume often traverses across the river and spreads in the half of the river across from the outfall. That is, in the part of the river containing WB2, WB3, WB4, and WB5. Although the temperature of the water in the half of the river near Outfall 113 also increases (i.e., Stations WB7 through WB12) it does not exhibit a leading edge as shown by Stations WB2, WB3, WB4, and WB5. This is likely because the plume resided in the near-half of the river prior to the beginning of the no flow event (i.e., the antecedent conditions of the near-half of the river already included heat from Outfall 113; whereas, the far-half of the river was initially undisturbed by heat from Outfall 113).

- The temperature of the water at 0.5-foot depth at Stations WB10, WB11, and WB12 was, at times, cooler than the temperature of the water at larger depths (e.g., 3-foot and 5-foot depths). This is because during the survey, the air temperature was cooler than the water temperature. For example, at 10:00 CST, the ambient water temperature upstream of the mixing zone was about 52°F (Figure 4), whereas the air temperature was only about 35°F (Figure 5). As a result, the temperature of the water in the near surface layer of the river is cooled below that of the water below.

- The inadvertent, small release made at 15:00 CST caused unwanted mixing at many of stations. Overall, the release would tend to move the plume from the far-half of the river to the near-half of the river. Thus, at Stations WB3, WB4, and WB5 the water temperature is observed to drop, and at Stations WB10, WB11, and WB12 the water temperature is observed to increase.

Compliance Parameters

At each HOBO station, the temperature at the 5-foot compliance depth was determined by averaging the measurements for the sensors at depths 3, 5, and 7 feet. Plotted in Figure 7 is the resulting temperature variation across the downstream end of the passive mixing zone, measured at the top of each hour from the available HOBO stations. As previously noted, problems were encountered at several stations. Results for hours 07:00 CST and 08:00 CST are not shown because the data are corrupted by stations drifting off their waypoint. Results for 16:00 CST are not shown because the data are corrupted by the inadvertent release from Watts Bar Dam at 15:00 CST. For the remaining hours, dashed lines in the temperature profiles are shown aside stations that encountered problems with one or more of the 3-foot, 5-foot, and 7-foot sensor readings. In particular: (1) the temperature at Station WB5 is based on the sensor at the 3-foot depth, (2) the temperature at WB7 is based on the average of the sensors at the 3-foot and 7-foot depths, and (3) the temperature at Station WB10 is based on the sensor at the 5-foot depth. No data are shown for WB1 because the station was not deployed, and no data are shown for Station WB6 because all the sensors for this station failed to collect readings.

Despite the loss of data at some of the temperature stations, the remaining valid readings provide a suitable indication of the distribution of heat across the mixing zone. As shown in Figure 7, the heat is rather evenly distributed across the river as the effluent spreads from Outfall 113. For example, at each hour, the change in temperature between any two stations across the mixing zone is usually less than 1°F. At 11:00 CST and 12:00 CST, the temperature is slightly more pronounced along the right bank, indicating the conveyance of a large patch of warmer water in the period spanning these hours. Since heat from the outfall is distributed across the full width of the river, data from all of the HOBO stations were used in computing the NPDES compliance parameters, which is consistent with the dimensions of the passive mixing zone (e.g., as shown in Figure 1).

The compliance parameters examined include those summarized in Table 1: the temperature at the downstream edge of mixing zone, T_d; the temperature rise from upstream to the downstream edge of the mixing zone, ΔT; and the temperature rate-of-change at the downstream edge of the mixing zone, TROC. Following the criteria specified in the NPDES permit, the fundamental equations used to compute the compliance parameters are provided in Appendix A. The temperature at the downstream end of the mixing zone was determined from the HOBO measurements (i.e., average of sensors at depths 3, 5, and 7 feet for all eleven HOBO stations). The temperature rise was computed as the difference between the temperature at the downstream end of the mixing zone and the upstream temperature measured at Station 30. The temperature rate-of-change was determined by the change in the temperature at the downstream end of the mixing zone from one reading to the next. The data were averaged over a period of one hour using 15-minute readings, as specified in the NPDES permit, and compared with the WBN thermal plume model. The results are presented in Figure 8. For the HOBO measurements, it takes at least one hour before enough data is available to compute one-hour averages as specified in the NPDES permit. In Figure 8, the "spin-up" period, wherein averages are computed with fewer data than specified in the permit, is represented by a dashed line. The following comments are provided.

- Temperature at the downstream edge of the passive mixing zone, T_d: The maximum 1-hour average T_d predicted by the thermal plume model was 55.6°F, whereas the maximum measured value was 54.5°F. Thus, the model overpredicted the maximum measured T_d by 0.9°F. Also, the increase in river temperature due to the no flow event was predicted to occur much more rapidly in the model. This is because the model assumes that impacts due to changes in the operating conditions of the river and/or Outfall 113 occur within one hour (i.e., the model time-step); whereas in reality, the time for such impacts to develop is much longer, at least for events with little or no river flow.

- Temperature rise, ΔT: The maximum 1-hour average ΔT predicted by the plume model was 3.2 F°, whereas the maximum measured value was about 1.8 F°. Thus, the model overpredicted the temperature rise by about 1.4 F°. In part, this is due to the variation of the upstream ambient water temperature assumed in the model. To be conservative, the model assumes that the upstream temperature remains constant, whereas in reality, the temperature experiences diurnal changes due to solar heating and mixing. In the survey of March 22, the upstream ambient water temperature increased by as much as 1.2 F° during the survey (e.g., see Figure 4). For the reason cited above (i.e., computational time-step of one hour), the model predicted the temperature rise to develop much sooner than that found by the measurements. For example, the model predicted a temperature rise of about 2 F° after the first hour of the survey, whereas the actual temperature rise did not approach 2 F° until the end of the survey (see Figure 8).

- Temperature rate-of-change, TROC: The maximum 1-hour average TROC predicted by the plume model was +0.4 F°/hour, whereas the maximum measured was +0.6 F°/hour. Thus, the model underpredicted the maximum TROC by 0.2 F°/hour. The exact reason for this difference is not apparent from the available data. In contrast to the surveys conducted in 2005, the maximum measured TROC occurred early in the survey rather than near the end of the survey (see McCall and Hopping, 2005, or McCall and Hopping, 2006). As before, the difference is likely due to dynamic phenomena in the river not included in the model formulation. In this case, the operation of the navigation lock and passing tow (at about 09:30 CST) may have accelerated the movement and/or spreading of the thermal plume beyond that predicted by the calm, steady conditions assumed in the model.

CONCLUSIONS

The survey of March 22, 2006, was successful in measuring the NPDES water temperature parameters for wintertime conditions of the Outfall 113 passive mixing zone. The measurements were compared with values predicted by the thermal plume model currently used to determine the safe operation of the SCCW system when there is no flow in the river from WBH. Overall, the model was found to be conservative for predicting the impact of Outfall 113 on the temperature, T_d, and temperature rise, ΔT, at the downstream end of the passive mixing zone. This is because the model overpredicted the maximum value measured for these parameters, and hence will tend to enforce the operation of Outfall 113 at levels of T_d and ΔT below the NPDES limits. The thermal plume model, however, was not conservative in predicting the temperature rate-of-change, TROC. This is because the model underpredicted the measured maximum TROC by 0.2 F°/hour (i.e., +0.6 F°/hour measured vs. +0.4 F°/hour predicted). This difference is likely due to phenomena in the river that are not represented in the thermal plume model, such as unsteady sloshing in the reservoir and the impact of wind. For the survey of March 22, a passing tow and lock operations at Watts Bar Dam also may have been factors. Under these conditions, until further notice, a factor of safety of 0.3 F°/hour shall continue to be used in the model for predicting the maximum value of TROC. This factor of safety was first implemented in response to the results of the summer test conducted in 2005 (see Hopping and McCall, 2006). Thus, the safe operation of Outfall 113 for the passive mixing zone will be evaluated based on a maximum value of TROC of ±3.3 F°/hour rather than ±3.6 F°/hour. In general, this action will have only a minimum impact on the operation of the SCCW, since the operation of the SCCW tends to be controlled primarily by the NPDES limit for ΔT, not the limit for TROC.

REFERENCES

McCall, Michael J., and P.N. Hopping, "Winter 2005 Compliance Survey for Watts Bar Nuclear Plant Outfall 113 Passive Mixing Zone," TVA River Operations, Report No. WR2005-2-85-151, October 2005.

McCall, Michael J., and P.N. Hopping, "Summer 2005 Compliance Survey for Watts Bar Nuclear Plant Outfall 113 Passive Mixing Zone," TVA River Operations, Report No. WR2005-2-85-152, February 2006.

TDEC, *State of Tennessee NPDES Permit No. TN0020168*, Tennessee Department of Environment and Conservation, November 2004.

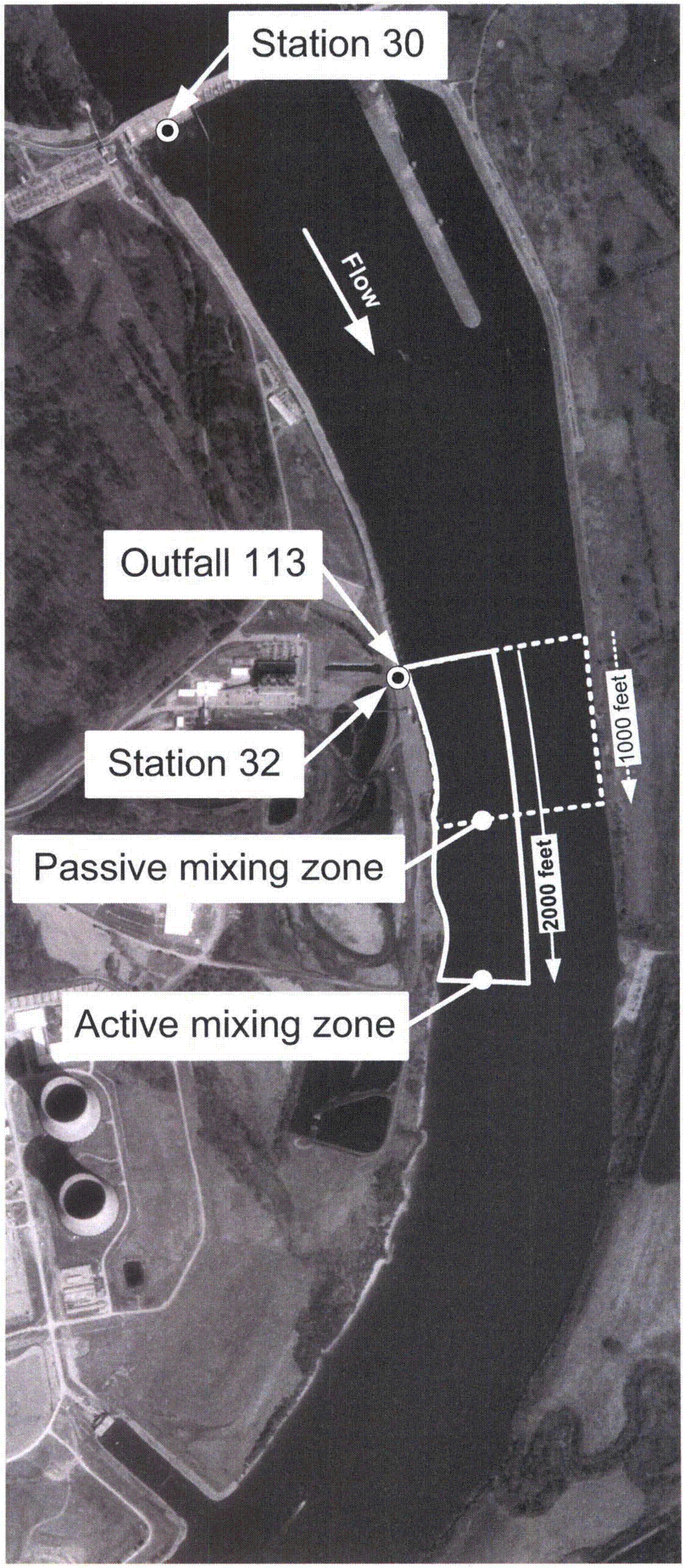

Figure 1. Watts Bar Nuclear Plant Outfall 113 (SCCW) Mixing Zones

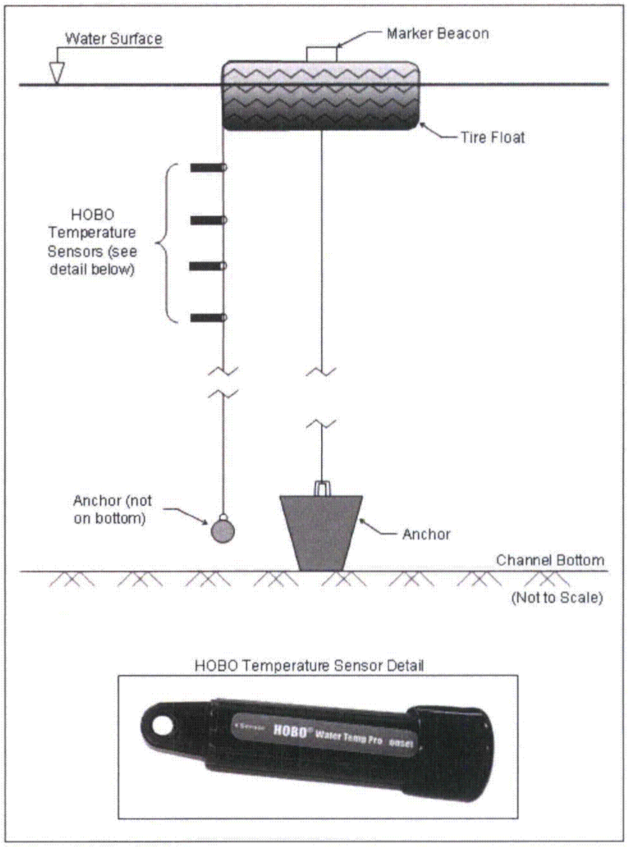

Figure 2. Schematic of HOBO Water Temperature Monitoring Stations

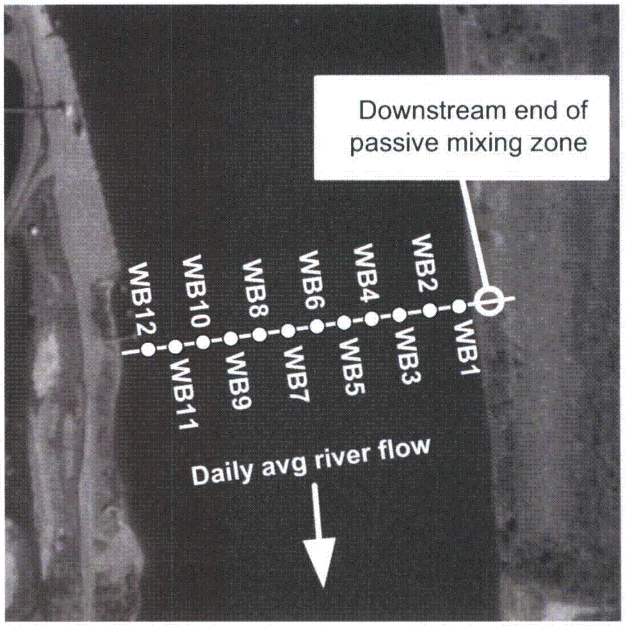

Figure 3. Location of HOBO Monitoring Stations

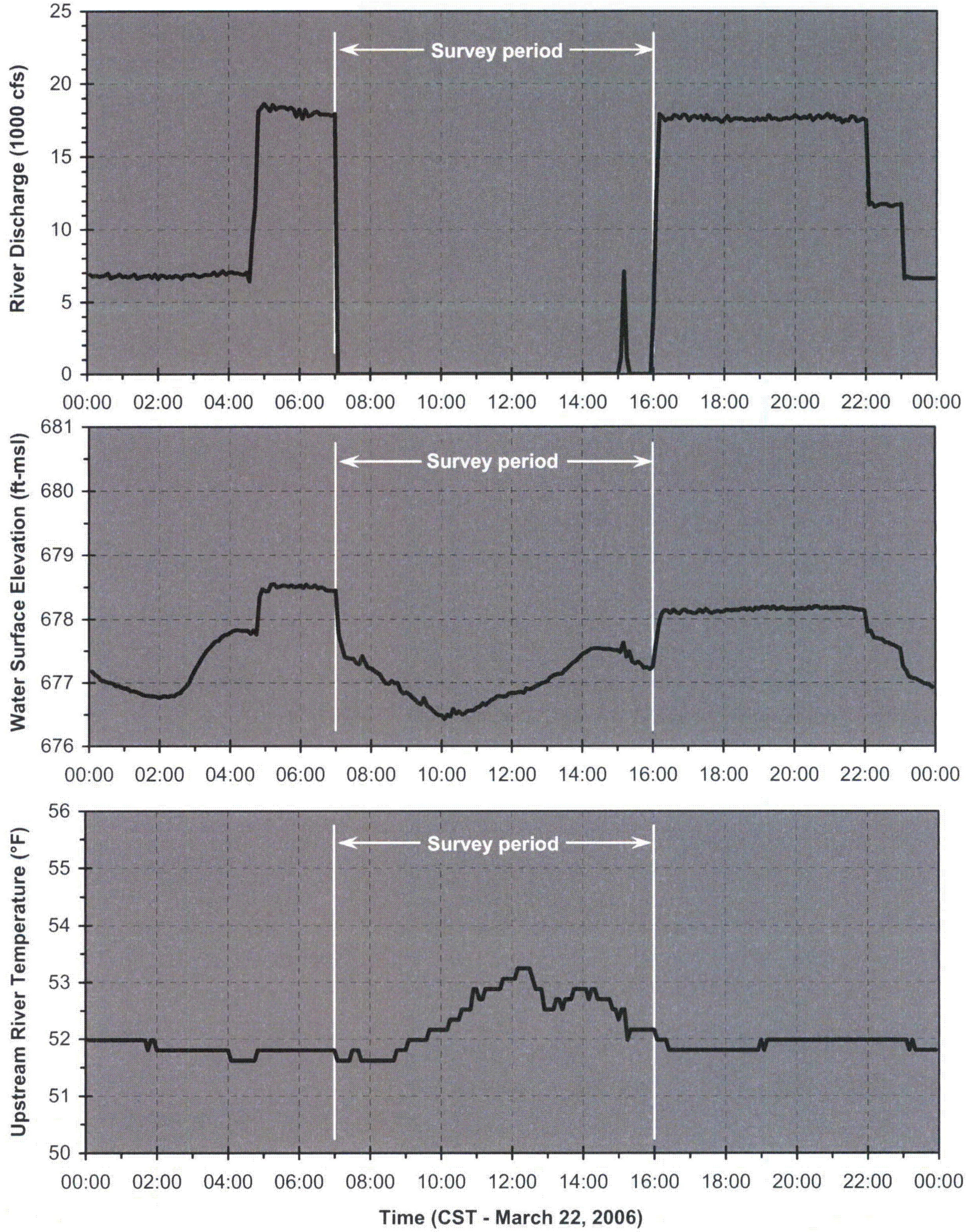

Figure 4. River Conditions

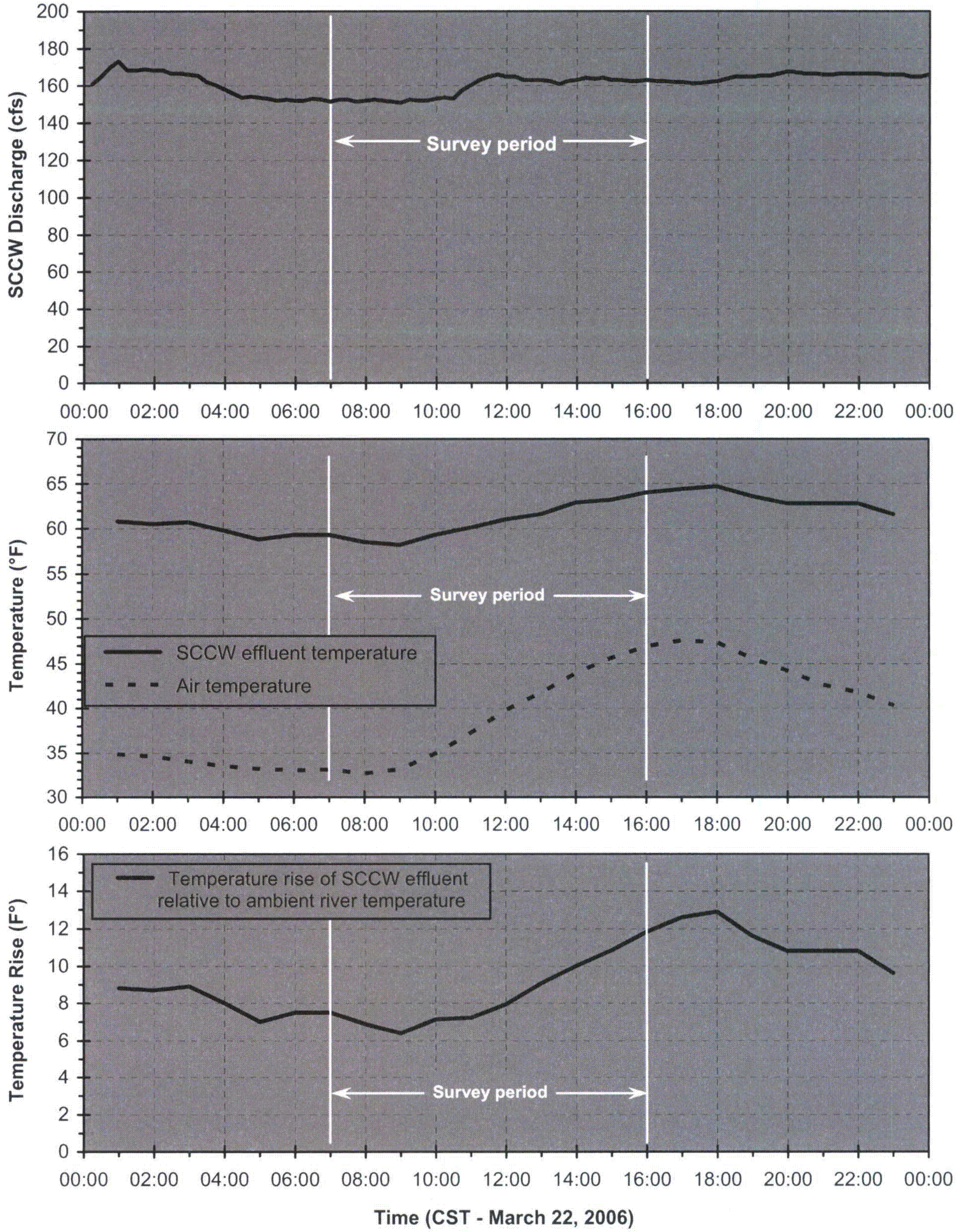

Figure 5. SCCW Conditions

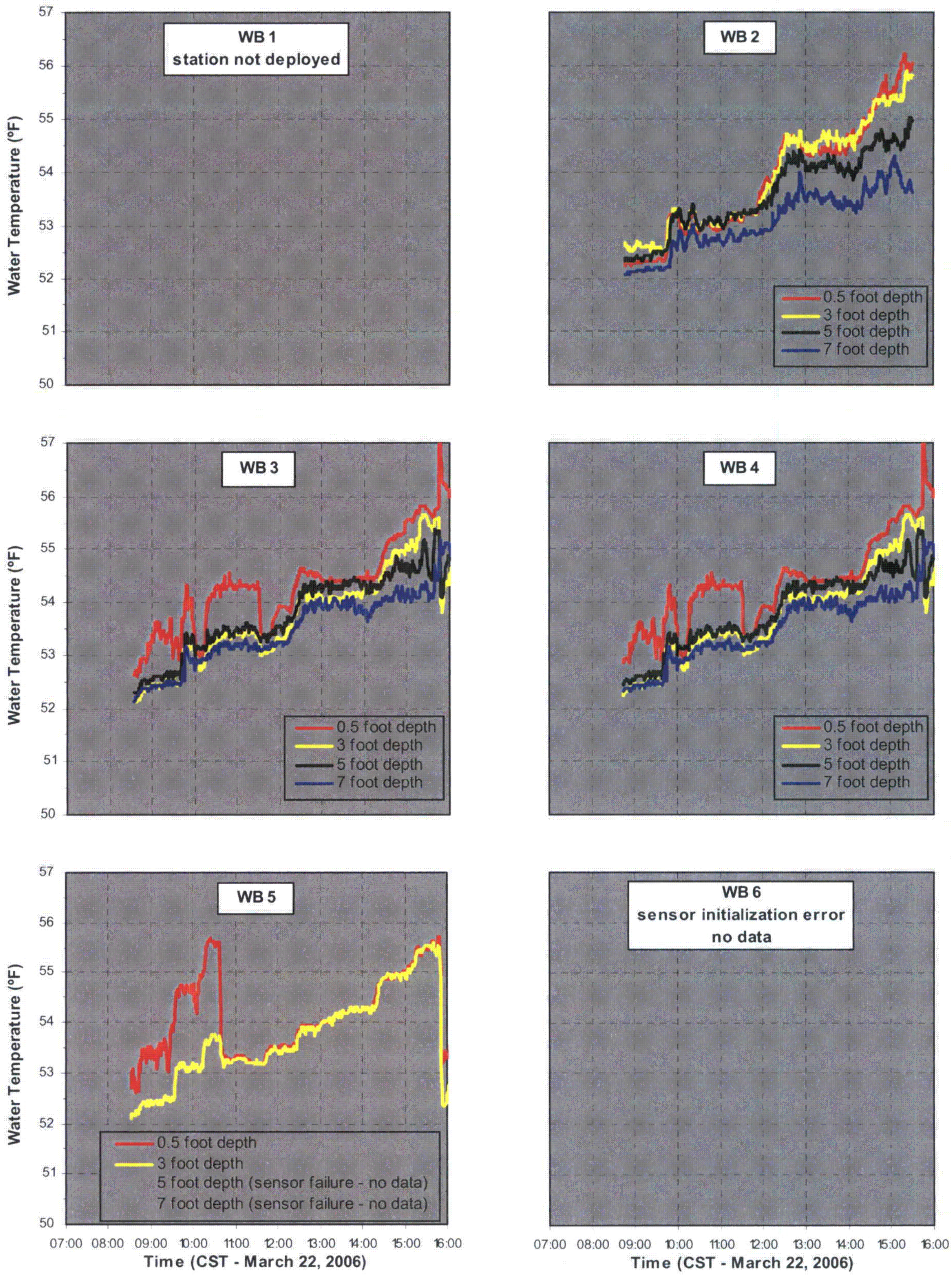

Figure 6. HOBO Water Temperature Measurements During Survey

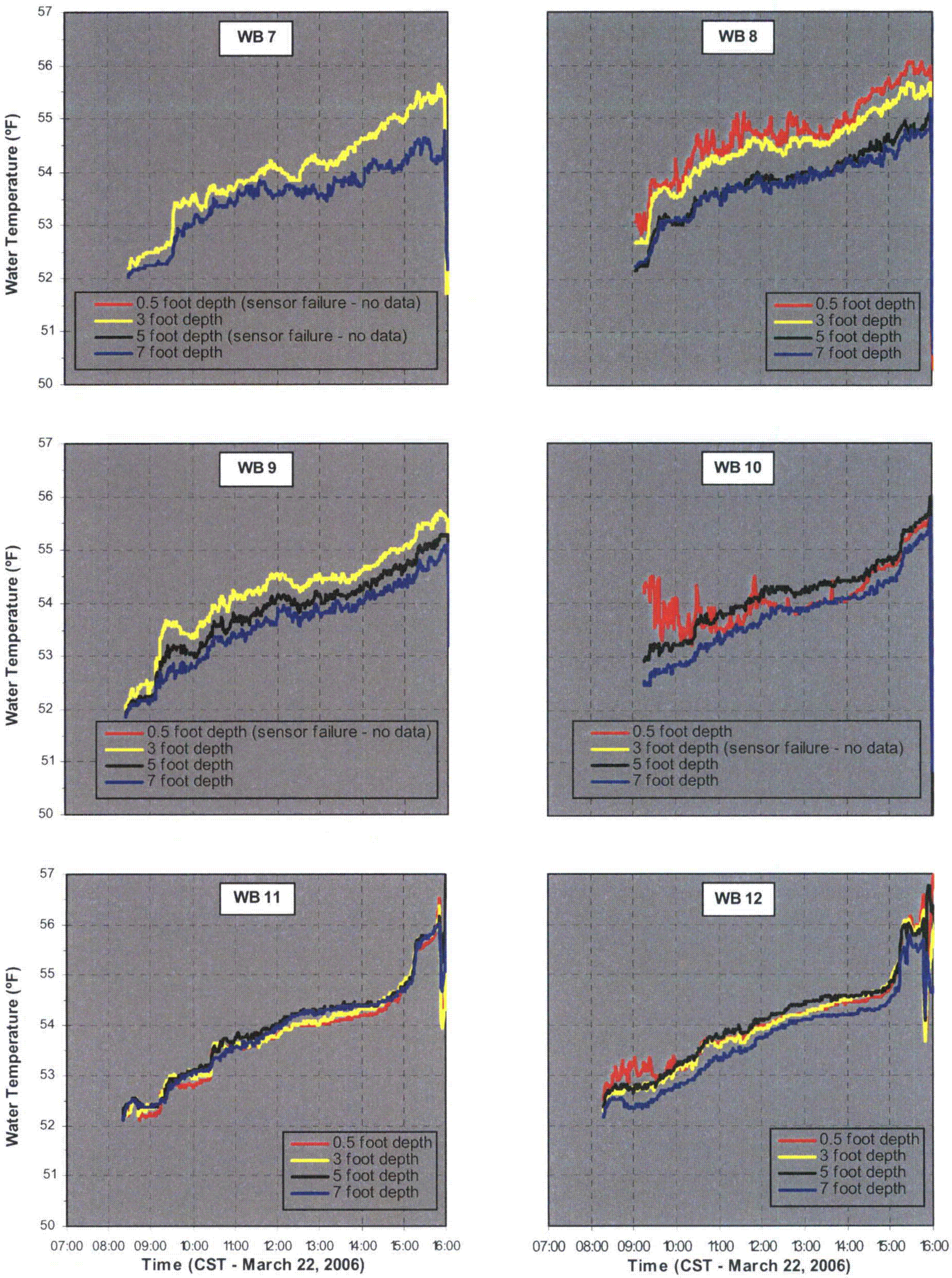

Figure 6 (Continued). HOBO Water Temperature Measurements During Survey

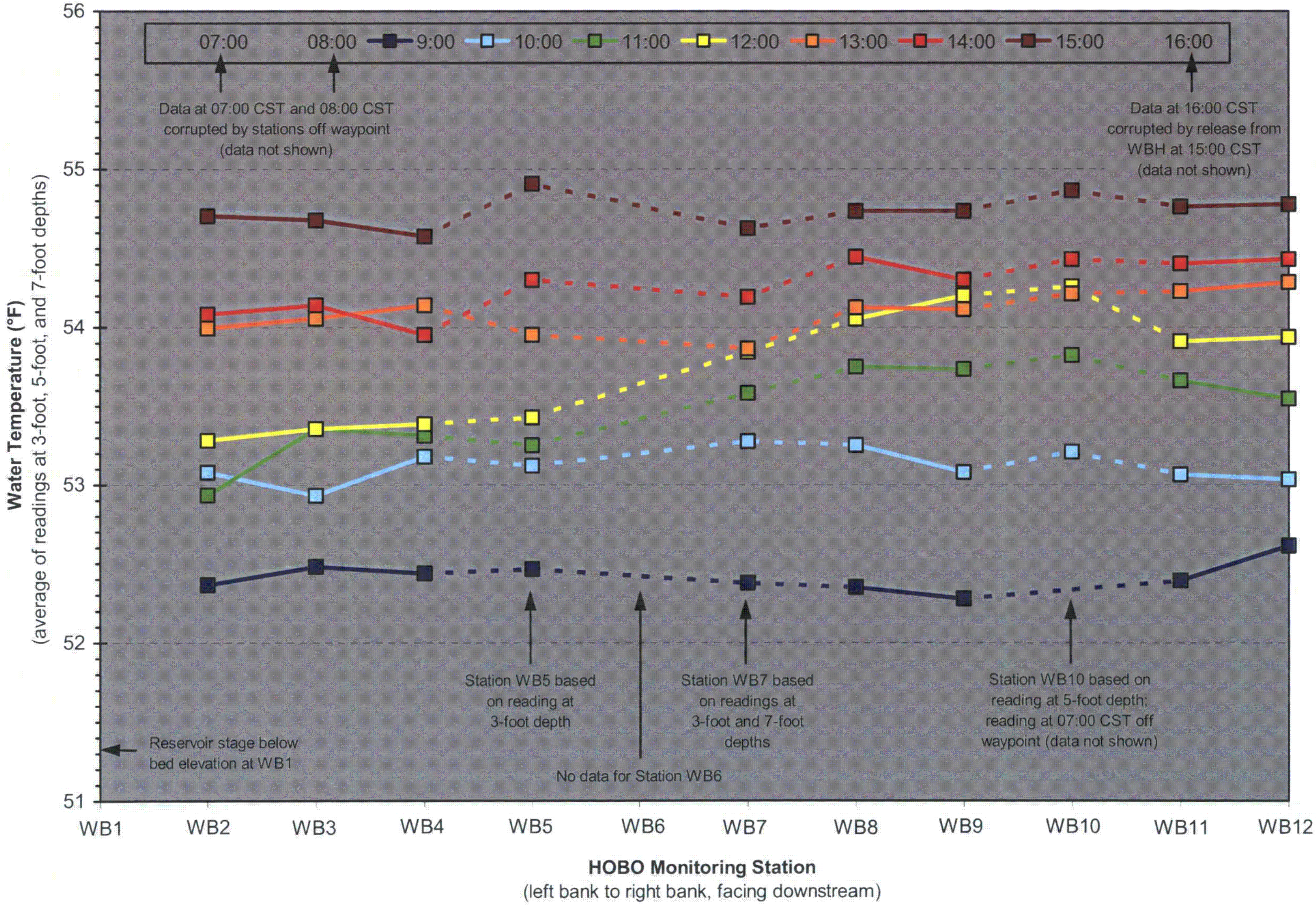

Figure 7. Profiles of Instantaneous Compliance Temperature Across Downstream End of Passive Mixing Zone

(Average of Readings at 3-, 5-, and 7-Foot Depths, Except as Noted)

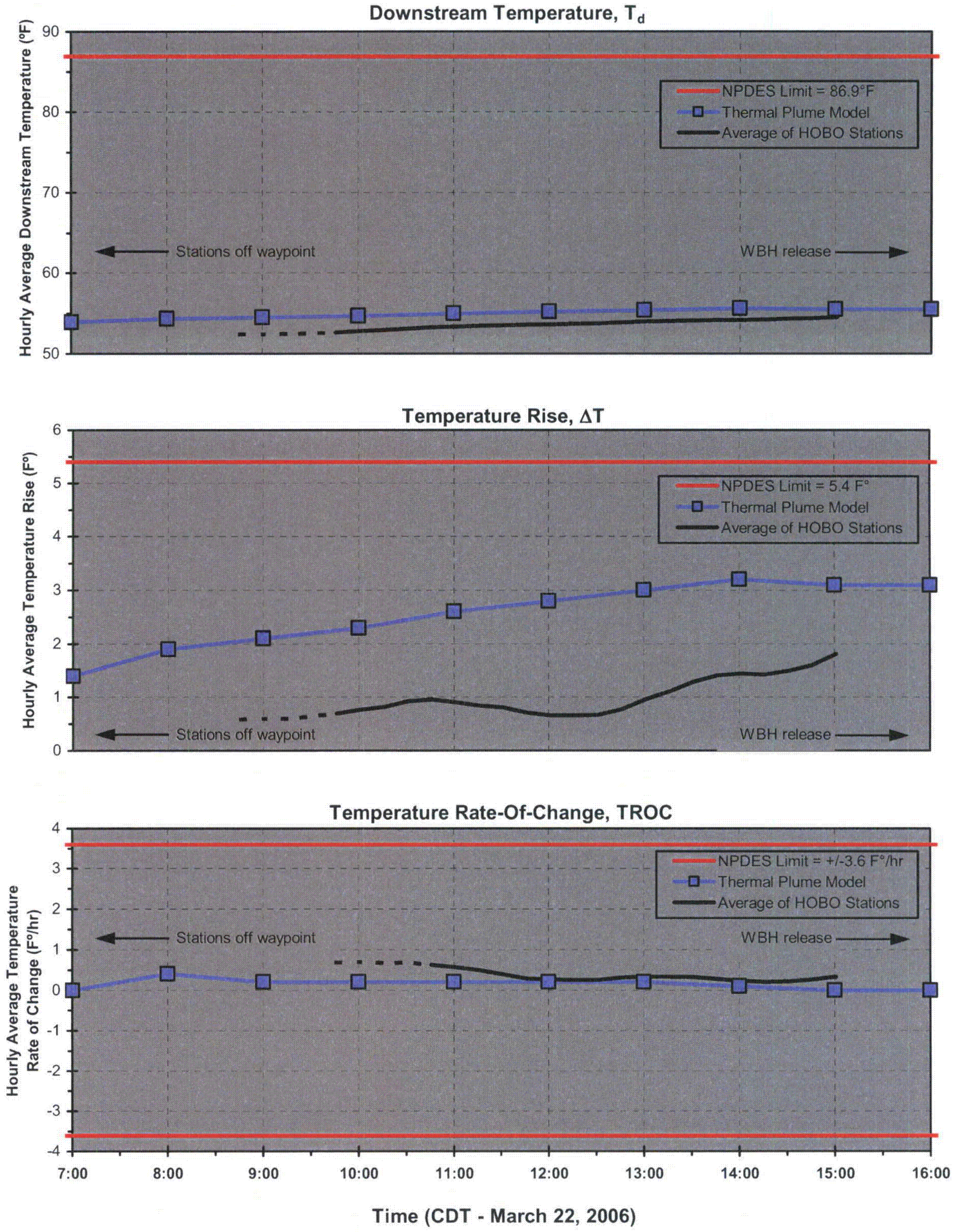

Figure 8. Measured and Computed Compliance Parameters for Passive Mixing Zone

APPENDIX A

WBN Outfall 113 NPDES Compliance Parameters

- Current Instantaneous Upstream Temperature:

  Tu_i (measured at EDS Station 30 by the first sensor below a depth of 5 feet)

- Current 1-Hour Average Upstream Temperature:

  $$Tu1_i = \frac{Tu_i + Tu_{i-1} + Tu_{i-2} + Tu_{i-3} + Tu_{i-4}}{5},$$

  where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of Tu

- Current Instantaneous Downstream Temperature:

  $$Td_i = \frac{Td3_i + Td5_i + Td7_i}{3},$$

  where $Td3_i$, $Td5_i$, and $Td7_i$ denote the current measurements of river temperature at the downstream end of the mixing zone at water depths of 3 feet, 5 feet, and 7 feet, respectively

- Current 1-Hour Average Downstream Temperature:

  $$Td1_i = \frac{Td_i + Td_{i-1} + Td_{i-2} + Td_{i-3} + Td_{i-4}}{5},$$

  where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of Td

- Current Instantaneous Temperature Rise:

  $$\Delta T_i = Td_i - Tu_i$$

- Current 1-Hour Average Temperature Rise:

$$\Delta T1_i = \frac{\Delta T_i + \Delta T_{i-1} + \Delta T_{i-2} + \Delta T_{i-3} + \Delta T_{i-4}}{5},$$

where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of ΔT

- Current Temperature Rate-of-Change:

$$TROC_i = \frac{Td_i - Td_{i-4}}{1\,\text{hour}},$$

- Current 1-Hour Average Temperature Rate-of-Change:

$$TROC1_i = \frac{TROC_i + TROC_{i-1} + TROC_{i-2} + TROC_{i-3} + TROC_{i-4}}{5},$$

where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of TROC

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Parameter	Model	Measured	NPDES Limit
Maximum T_d	65.6°F	64.8°F	86.9°F
Maximum ΔT	3.4 F°	2.0 F°	5.4 F°
Maximum TROC	1.2 F°/hour	0.7 F°/hour	±3.6 F°/hr

As shown, the values predicted by the model were all larger than the measured values from the survey data. Therefore, based on the winter 2005 survey, the thermal plume model is considered conservative for estimating the potential maximum impact of Outfall 113 on the river. As such, the model currently is considered adequate for making decisions regarding the safe operation of Outfall 113 for the passive mixing zone.

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WINTER 2005 COMPLIANCE SURVEY FOR WATTS BAR NUCLEAR PLANT OUTFALL 113 PASSIVE MIXING ZONE

INTRODUCTION

Outfall 113 for the Watts Bar Nuclear Plant (WBN) includes the discharge of water to the Tennessee River from the Supplemental Condenser Cooling Water (SCCW) system. Due to the dynamic behavior of the thermal effluent in the river, the National Pollutant Discharge Elimination System (NPDES) Permit No. TN0020168 for the plant specifies two thermal mixing zones for Outfall 113: one for active operation of the river and one for passive operation of the river (TDEC, 2004). The passive mixing zone corresponds to periods when the operation at Watts Bar Dam (WBH) is producing no flow in the river (i.e., hydropower and/or spillway releases). The dimensions of the passive mixing zone extend from bank-to-bank and downstream 1,000 feet from the outfall. The active mixing zone applies to all other river flow conditions. The dimensions of the active mixing zone include the right-half of the river and extends 2,000 feet downstream from the outfall. The passive and the active mixing zones are illustrated in Figure 1 (Hopping, 2004).

Table 1 summarizes the NPDES temperature limits for Outfall 113. The limits apply to both the active and passive mixing zones. Compliance for the active mixing zone is monitored by permanent instream water temperature stations. Due to limitations in placing permanent stations across the full width of the river, a thermal plume model is used to estimate the dilution of the Outfall 113 effluent for the passive mixing zone. This study addresses the NPDES requirements for the passive mixing zone. In particular, the permit specifies that two instream temperature surveys shall be conducted per year to ensure compliance for the passive mixing zone, one for winter conditions and one for summer conditions. The surveys are to be performed while the SCCW system is thermally loaded and with little or no flow in the river. Temperature profiles are to be taken at a sufficient number of locations across the downstream edge of the passive mixing zone to locate the effluent plume. The measurements are to be used to compute the thermal compliance parameters listed in Table 1 and to compare these parameters with those estimated by the thermal plume model.

Table 1. Temperature Criteria for SCCW Mixing Zones

Maximum Temperature, Downstream Edge of Mixing Zone, T_d	Running 1-hr	86.9°F
Maximum Temperature Rise, Upstream to Downstream, ΔT	Running 1-hr	5.4 F°
Maximum Temperature Rate-of-Change, TROC	Running 1-hr	±3.6 F°/hr

The purpose of this report is to summarize the results for the passive mixing zone temperature survey for the 2005 winter conditions. The survey was conducted on May 6, 2005. It is important to note that in terms of the impact of Outfall 113 on river temperature, peak winter conditions usually prevail from about March through May. In this period, the combination of cool ambient river conditions and warm Outfall 113 effluent conditions can create a large temperature rise in the river. The May 6 survey included the deployment of temporary temperature stations at predetermined locations along the downstream edge of the passive mixing zone. Data from these and other monitoring stations were analyzed to obtain measured values for the compliance parameters listed in Table 1 (i.e., T_d, ΔT, and TROC) and to compare these with the corresponding values estimated from the SCCW thermal plume model.

INSTREAM SURVEY

Data Collection

The effluent plume for Outfall 113 was monitored by deploying twelve temporary monitoring stations, spaced at roughly equal intervals along the downstream edge of the passive mixing zone. The temporary water temperature monitoring stations recorded temperature profiles using HOBO water temperature sensors positioned at depths of 0.5, 3, 5, and 7 feet below the water surface. Shown in Figure 2 is a schematic of the temporary monitoring stations, which included an assembly containing a tire float, a string of HOBO water temperature sensors, and anchor weights. The water temperature sensors have an accuracy of about ±0.4 F° and resolution of about 0.04 F°, which is consistent with other temperature measurements used for TVA hydrothermal compliance. The HOBO devices include an internal data acquisition unit that can be programmed to establish the desired frequency and duration of measurements. For the May 6 survey, the water temperature sensors were programmed to take measurements once every minute. The twelve temporary stations were deployed and retrieved, respectively, at the beginning and end of the survey. A Global Positioning System (GPS) tracking device was used to position the stations along the downstream edge of the passive mixing zone, as shown in Figure 3.

Real-Time Monitoring of Survey Conditions

The HOBO water temperature sensors do not provide real-time measurements. Thus, to ensure that the NPDES compliance limits are not threatened during the survey, real-time measurements were made using a string of sensors deployed from a boat. The sensors on the "spot-check" string were located at the same depths as those of the HOBO water temperature stations. Data for the upstream temperature, needed to compute and check the temperature rise ΔT, was obtained by cell phone communication with personnel having access to real-time measurements. Although the downstream edge of the passive mixing zone crosses the river navigation channel, no disturbances from tows or other large vessels were experienced during the survey.

Ambient River and WBN Conditions

Table 2 provides a summary of the sources and frequencies of data collection during the survey. The WBN Environmental Data Station (EDS) provided measurements from existing permanent monitoring stations, including the upstream (ambient) river temperature, river water surface elevation, SCCW effluent temperature, SCCW effluent flow, and air temperature. WaterView, a hydroplant monitoring system, was used to provide measurements for the discharge from Watts Bar Dam.

Table 2. Source and Frequency of Passive Mixing Zone Data

Data	Source	Frequency
River Discharge from Watts Bar Dam	WaterView	5 min
River Water Surface Elevation	WBN EDS Station 30 (Tailwater at Watts Bar Dam)	15 min
River Ambient Water Temperature	WBN EDS Station 30 (Tailwater at Watts Bar Dam)	15 min
SCCW Effluent Discharge	WBN EDS Station 32 (Outfall 113)	15 min
SCCW Effluent Temperature	WBN EDS Station 32 (Outfall 113)	5 min
Air Temperature	WBN EDS Met Tower	15 min
Passive Mixing Zone Downstream Temperatures	Temporary HOBO Monitors	1 min

Figure 4 shows the measured river discharge, water surface elevation, and upstream (ambient) river temperature for May 6, 2005. To provide a period of no flow in the river, hydropower operations at WBH were suspended between approximately 9:00 CDT and 15:00 CDT. The spillway was already idle because WBH was not in a flood operation. When WBH was discontinued (i.e., at 9:00 CDT), the water surface elevation below the dam first dropped, but then slowly increased throughout the survey due to filling from water downstream in the river. The ambient river temperature, measured below WBH as well, was steady while WBH was in operation (i.e., before 9:00 CDT). However, after WBH was discontinued, the ambient temperatures increase throughout the survey period.

During the survey, the SCCW system at WBN was operating in "summer mode" to provide full, thermally loaded conditions. As shown in Figure 5, the SCCW effluent discharge remained consistent over the survey period until approximately 13:45 CDT, when the SCCW discharge was increased by WBN to reduce the volume of water in the cooling tower basins. The effluent discharge remained at the increased level for the remainder of the survey. Also shown in Figure 5 is the SCCW effluent temperature, which increased from approximately 74°F to 77°F over the course of the test. This increase is directly related to the diurnal increase in air temperature, also shown in Figure 5. Together, the increase in the discharge and temperature of the SCCW effluent increased the thermal load on the river during the latter part of the survey.

Results and Conclusions

Shown in Figure 6 are the readings from the HOBO temperature stations at the downstream end of the passive mixing zone. The stations were labeled consecutively from WB1 to WB12, with WB1 situated near the left shoreline of the river and WB12 situated near the right shoreline of the river (i.e., facing downstream—see Figure 3). In general, the temperature at each sensor increased throughout the survey period. This increase is due to the Outfall 113 effluent and due to diurnal solar heating. Note that the temperature increase is larger for sensors near the water surface. For example, the increase from the beginning to the end of the survey period is of magnitude 6 F° for sensors at a depth of 0.5 foot, but only of magnitude between 1 F° and 2 F° for sensors at a depth of 7 feet. The larger increase at shallower depths is due primarily to two factors. First, warm water is lighter than cool water, yielding positive buoyancy. As a result, the heated effluent from Outfall 113 tends to spread, or float, in the upper part of the water column. Second, heating by solar activity is largest at the water surface. Together, these factors help provide a zone of cool water in the bottom of the river to protect aquatic wildlife.

At each HOBO station, the temperature at the 5-foot compliance depth was determined by averaging the measurements for the sensors at depths 3, 5, and 7 feet. Plotted in Figure 7 is the resulting 5-foot compliance temperature across the downstream end of the passive mixing zone at the top of each hour of the survey, from 9:00 CDT to 15:00 CDT. As was observed in previous studies (e.g., Smith et al., 2001), there appears to be a very subtle shift in the concentration of heat from the right (SCCW) side of the river to the left (opposite) side of the river as the influence of the Outfall 113 effluent and solar activity spreads in the river. At the same time, it appears that outfall-induced circulation patterns and slow-moving, random eddies in the river carry pockets of effluent to other parts of the river outside the subtle areas of concentrated heat. For example, at 13:00 CDT and afterwards, there is buildup of heat on both sides of the river. Specifically, at 13:00 CDT, there is a significant spike in the temperature at WB9. Since there is no consistent, clearly defined plume, and to account for all of the pockets of effluent crossing the downstream edge of the mixing zone, it is considered best for all of the HOBO stations to be included in computing the Outfall 113 compliance parameters.

The compliance parameters to be examined for passive mixing zone survey include those summarized in Table 1—the temperature at the downstream edge of mixing zone, Td; the temperature rise from upstream to the downstream edge of the mixing zone, ΔT; and the temperature rate-of-change at the downstream edge of the mixing zone, TROC. Following the criteria specified in the NPDES permit, the fundamental equations used to compute the compliance parameters are provided in Appendix A. The temperature at the downstream end of the mixing zone was determined from the HOBO measurements (i.e., average of sensors at depths of 3, 5, and 7 feet for all twelve HOBO stations). The temperature rise was computed as the difference between the temperature at the downstream end of the mixing zone and the upstream temperature measured at Station 30. The temperature rate-of-change was determined by the change in the temperature at the downstream end of the mixing zone from one reading to the next. The data were averaged over a period of one hour using 15-minute readings, as specified in the NPDES permit, and compared with the WBN thermal plume model. The results are presented in Figure 8. The following comments are provided.

- One-hour averaging: For the HOBO measurements, it takes at least one hour before enough data is available to compute one-hour averages as specified in the NPDES permit. In Figure 8, the "spin-up" period wherein averages are computed with fewer data than specified in the permit is represented by a dashed line.

- Temperature at the downstream edge of the passive mixing zone, T_d: The maximum T_d estimated by the thermal plume model was 65.5°F, whereas the maximum measured value was 64.8°F. Thus, the model overestimated the maximum downstream temperature for the no flow event. Compared to the actual measurements, the response of the river temperature to the no flow event was estimated to occur much more rapidly in the model. For example, for the actual measurements, T_d is essentially unchanged between 9:00 and 10:00 CDT, whereas in the model, T_d increases from 63.8°F to 65.0°F within the first hour. This is because the model is formulated in a quasi-unsteady manner, wherein the computed river temperature is assumed to change from one steady-state condition to the next within one hour, in response to the changes in the operation of the river and/or Outfall 113. That is, the model assumes that impacts due to operational changes in the river and/or Outfall 113 are fully realized within one hour, whereas in reality, the actual time for the development of such impacts is much longer, at least for events with little or no river flow.

- Temperature rise, ΔT: The maximum estimated by the plume model was 3.4 F°, whereas the maximum measured value was 2.0 F°. Thus, the model overestimated the temperature rise. For the reason cited above, the model also overestimated the response of the no flow event. That is, the model estimated the temperature rise to occur sooner than that found by the actual measurements.

- Temperature rate-of-change, TROC: The maximum TROC estimated by the plume model was 1.2 F°/hour, whereas the maximum measured was 0.7 F°/hour. Thus, like T_d and ΔT, the model overestimated the temperature rate-of-change. Because of the computed early onset of the temperature rise, as identified above, the maximum temperature rate-of-change also occurred earlier in the model than that found by the actual measurements.

There are several factors that perhaps contribute to the overestimated values of Td, ΔT, and TROC. First is the issue of timing. If the no flow event lasted longer, the temperature measured at the downstream end of the passive mixing zone may have eventually climbed to the same level as that estimated by the model. Second, the actual spreading/dilution of the thermal plume may be larger than that estimated by the model. As a result, the actual temperature would be lower than values obtained by the model. Third is the issue of atmospheric heat exchange. Although the model assumes a loss of heat to the atmosphere, the actual loss may be larger, which again would result in actual temperatures being lower than model values. And finally, for the computation of temperature rise, the model assumes the initial value of the upstream temperature persists throughout the forecast period. Whereas this generally holds true while WBH is discharging water from the hydroturbines, it is not necessarily true for no flow events, where diurnal solar heating and other mechanisms can cause the upstream temperature to increase. If the upstream temperature increases, as observed in the survey of May 6, the actual temperature rise will be lower than that estimated by the thermal plume model.

Overall, based on the survey of May 6, 2005, the thermal plume model was conservative for estimating the impact of Outfall 113 on the river, since it overestimated the maximum values of all the compliance parameters (i.e., Td, ΔT, and TROC). As such, the model currently is considered adequate for making decisions regarding the safe operation of Outfall 113 for the passive mixing zone.

REFERENCES

Hopping, Paul N., "Proposed Modifications to Water Temperature Effluent Requirements for Watts Bar Nuclear Plant Outfall 113," TVA River Operations, Report No. WR2004-3-85-149, October 2004.

McCall, Michael J., and P.N. Hopping, "Workplan for Watts Bar Nuclear Plant Passive Mixing Zone NPDES Compliance," TVA River Operations, Report No. WR2005-3-85-150, March 2005.

Smith, Brennan T., P.N. Hopping, W.L. Harper, and M. Lee, "Hydrothermal Data for Watts Bar Nuclear Plant SCCW Outfall," TVA River Operations, Report No. WR2001-4-85-145, September 2001.

TDEC, *State of Tennessee NPDES Permit No. TN0020168*, Tennessee Department of Environment and Conservation, November 2004.

"Watts Bar Steam Plant Water Temperature Surveys – Watts Bar Steam Plant Advance Report No. 1," TVA Division of Water Control Planning, Engineering Laboratory, Report No. 9-1105, Norris, TN, April 1974.

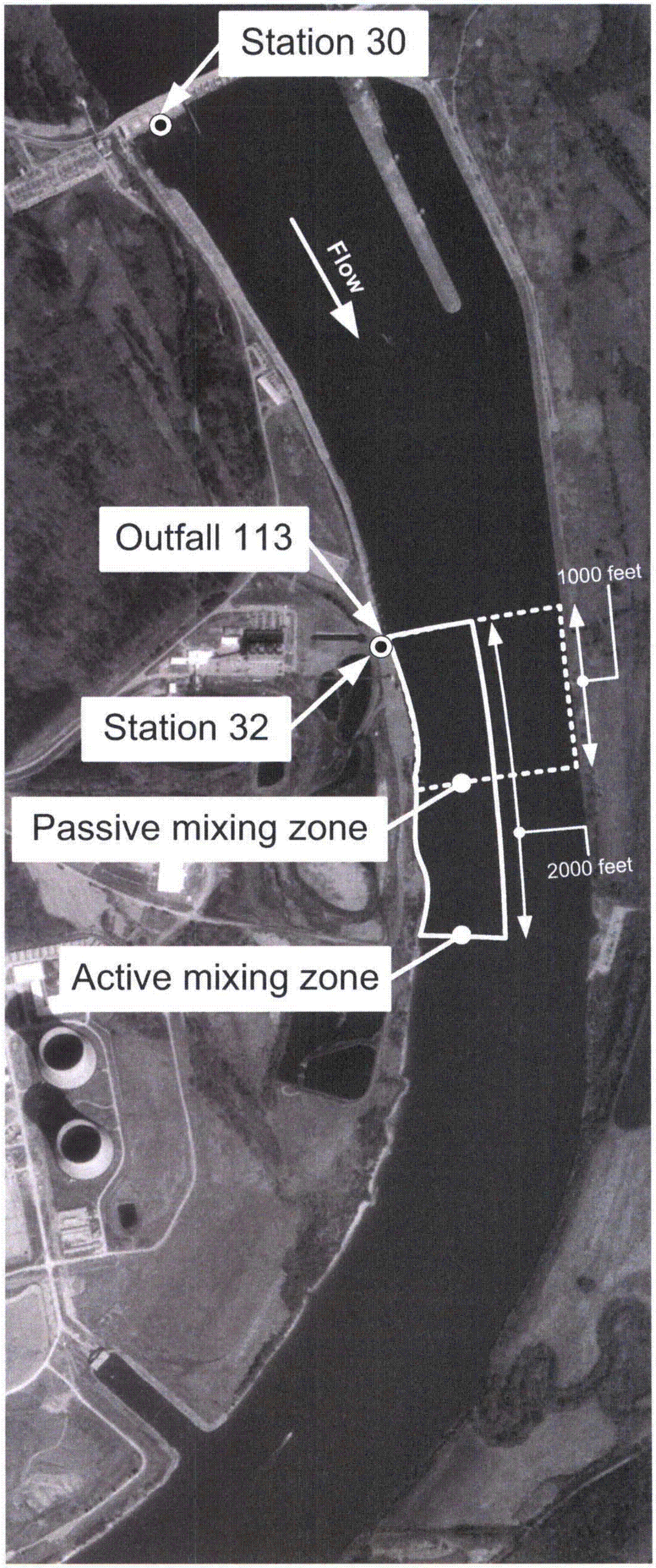

Figure 1. Watts Bar Nuclear Plant Outfall 113 (SCCW) Mixing Zones

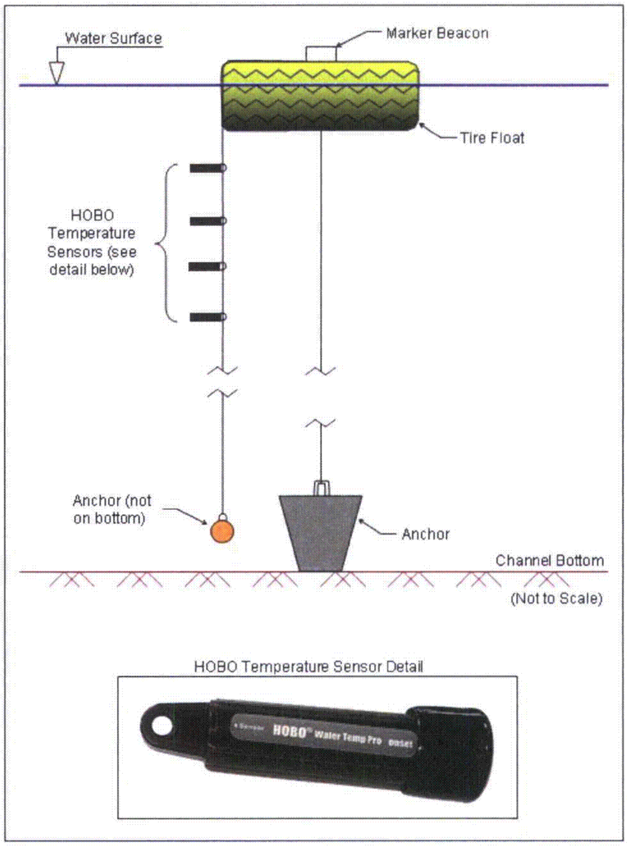

Figure 2. Schematic of HOBO Water Temperature Monitoring Stations

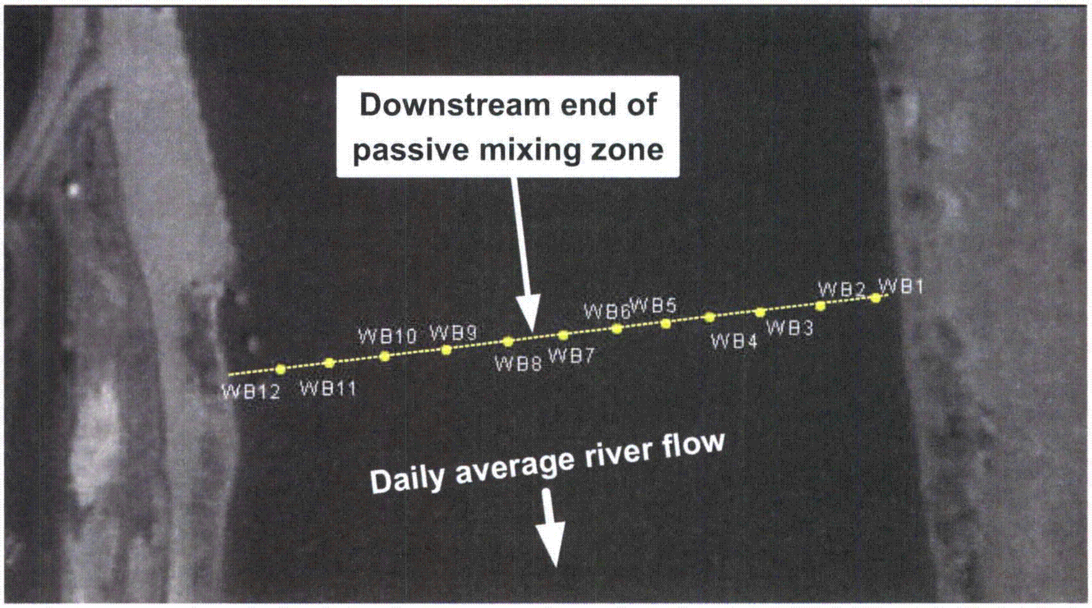

Figure 3. Location of HOBO Monitoring Stations

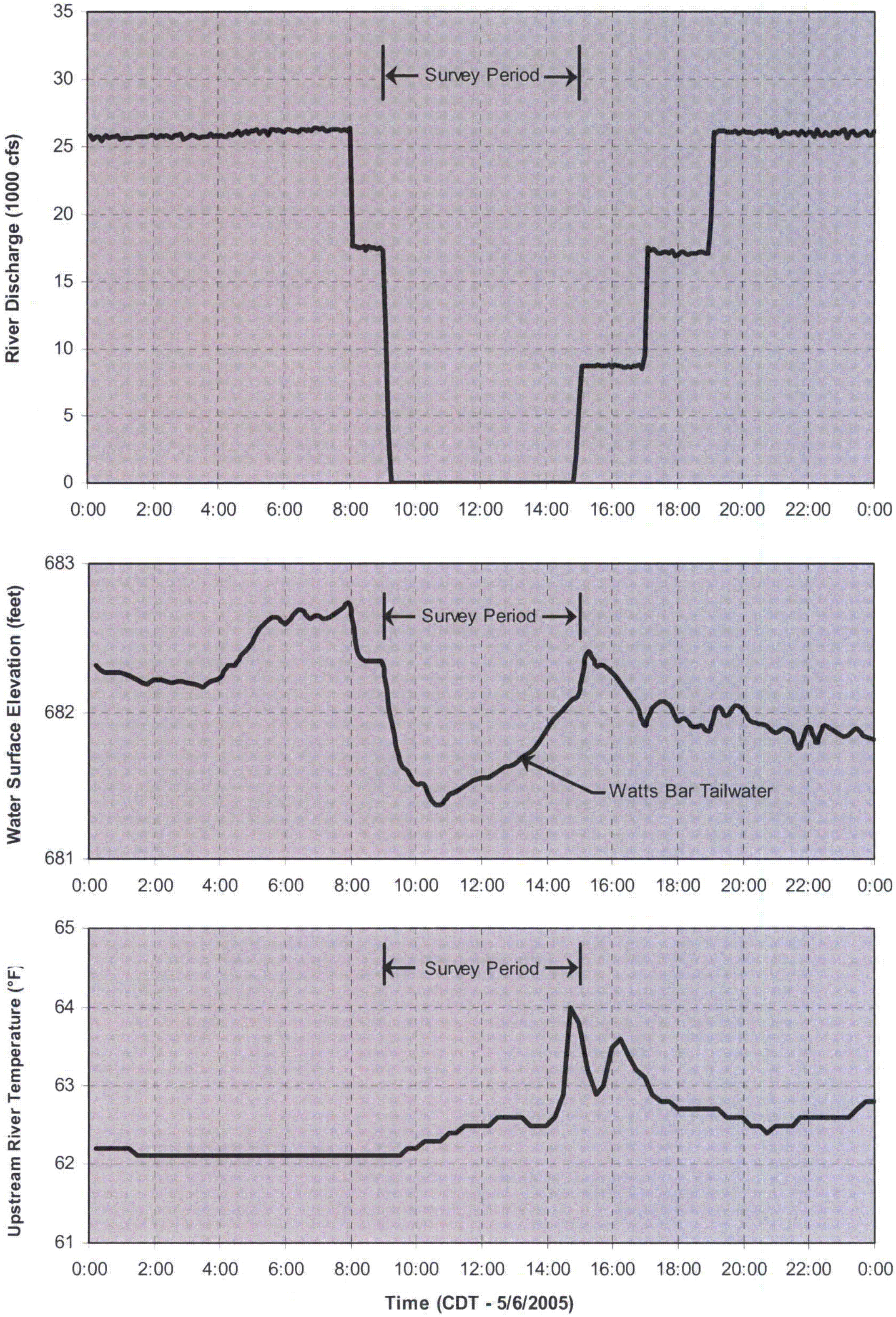

Figure 4. Ambient River Conditions During Survey

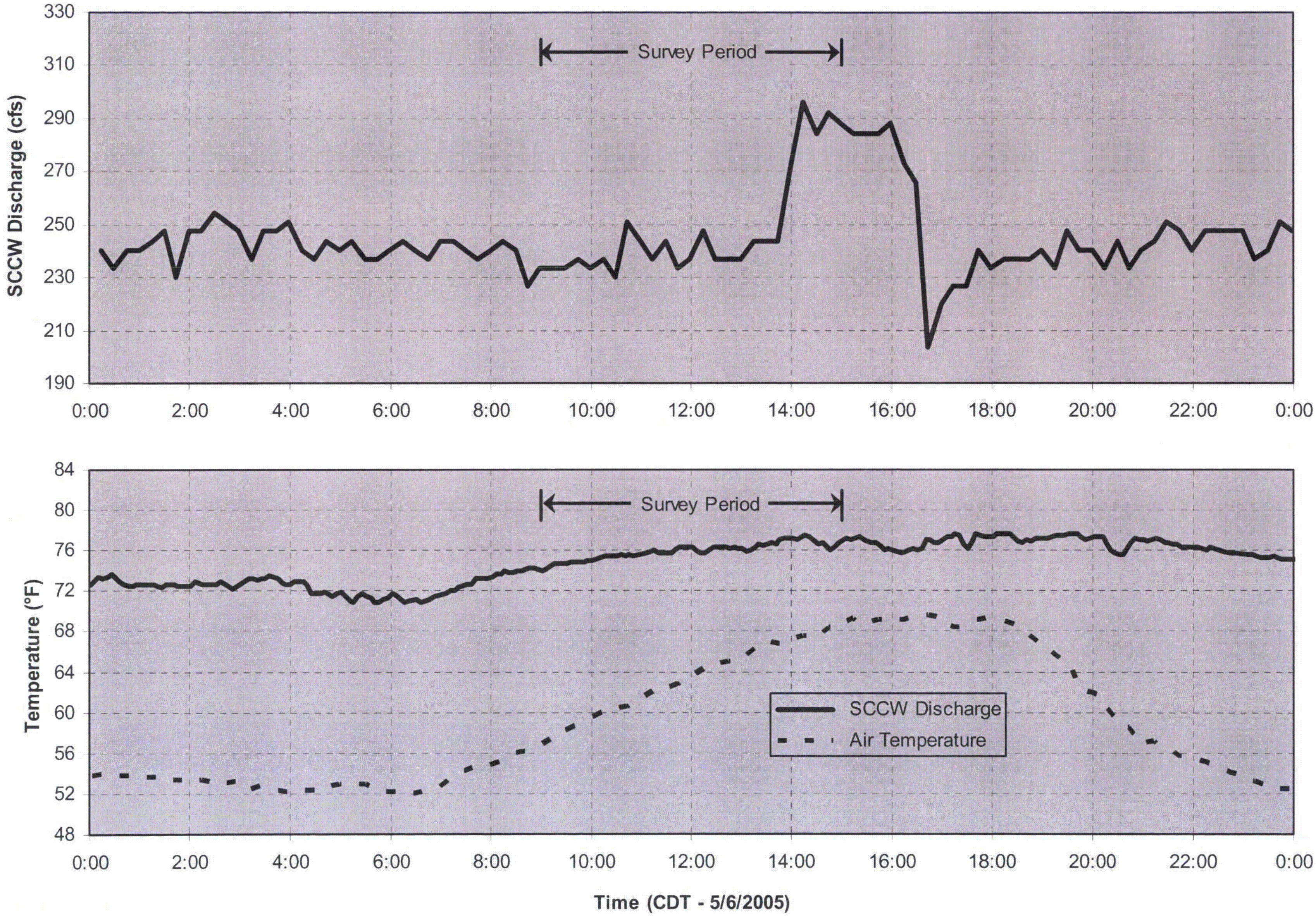

Figure 5. SCCW Conditions and Air Temperature During Survey

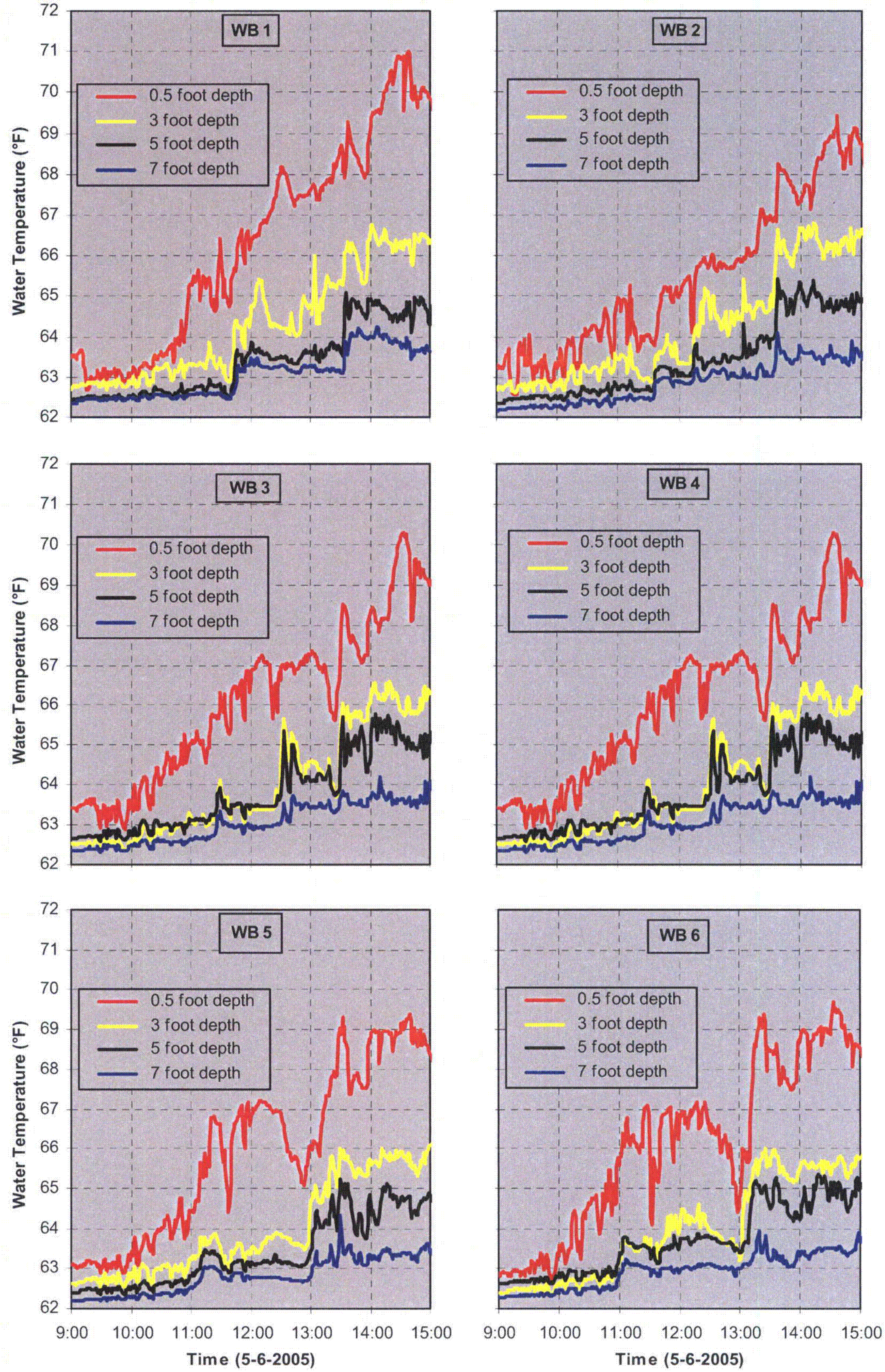

Figure 6. HOBO Water Temperature Measurements During Survey

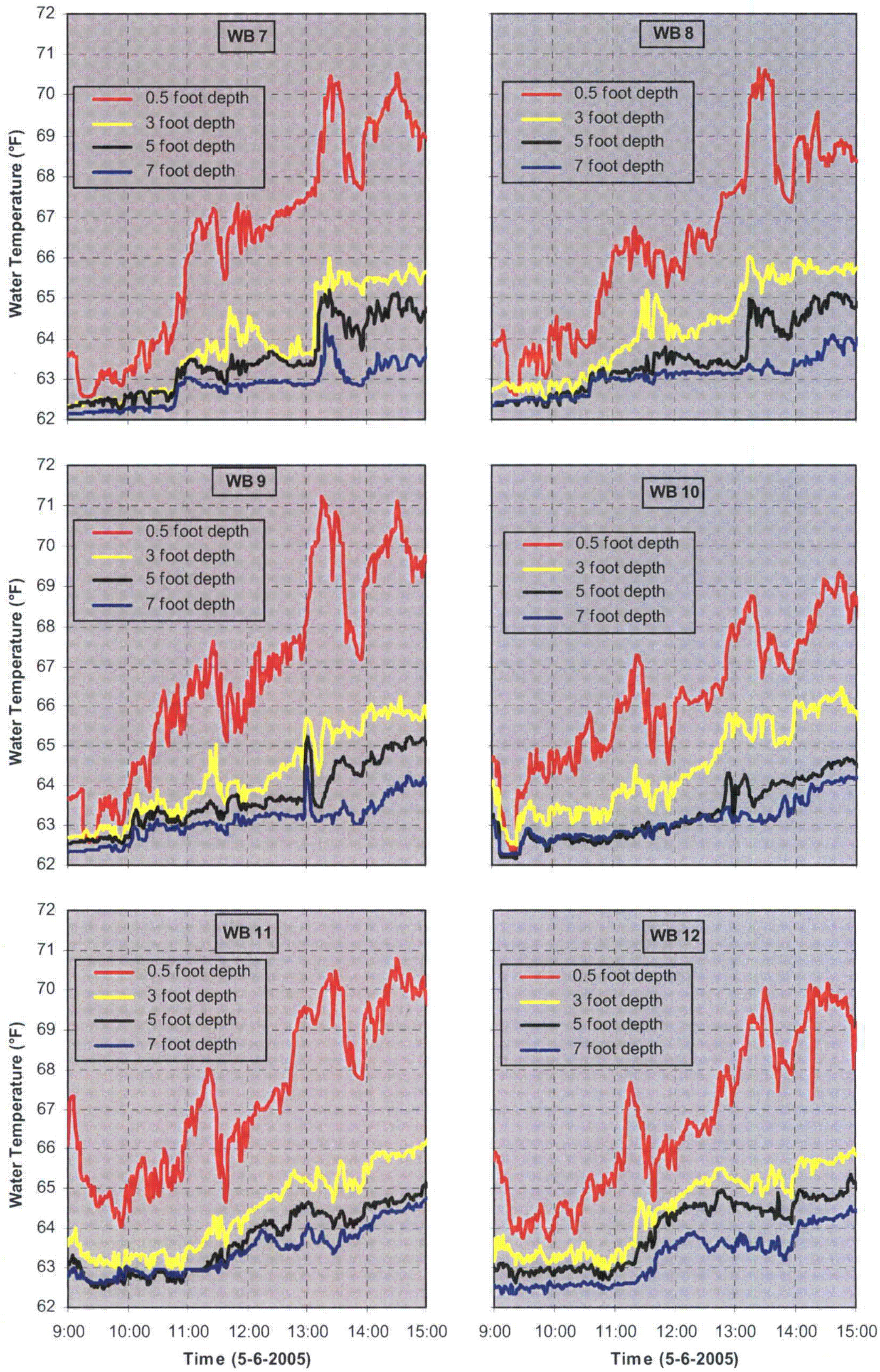

Figure 6 (Continued). HOBO Water Temperature Measurements During Survey

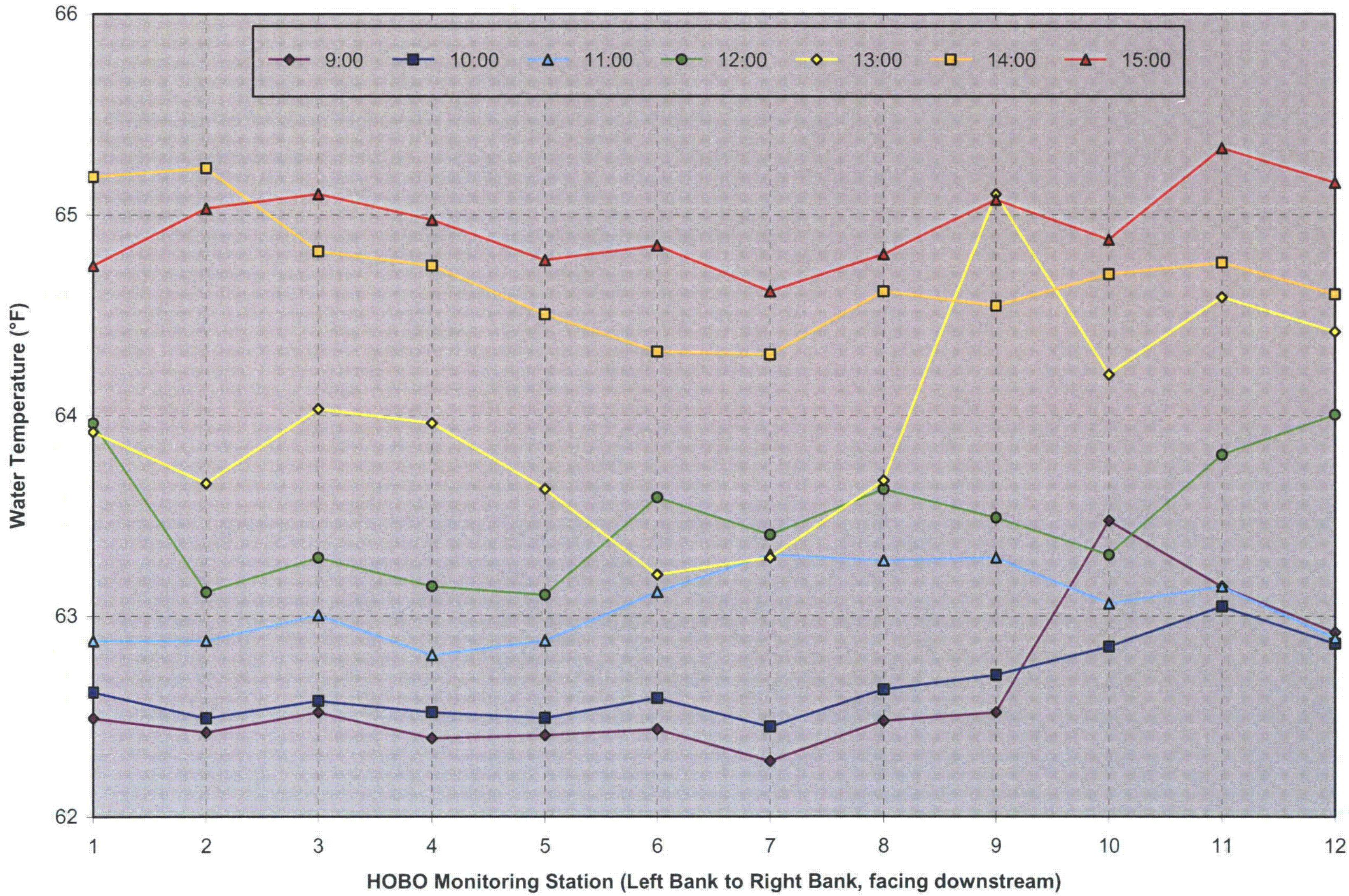

Figure 7. Profiles of Measured 5-foot Compliance Temperature Across Downstream End of Passive Mixing Zone

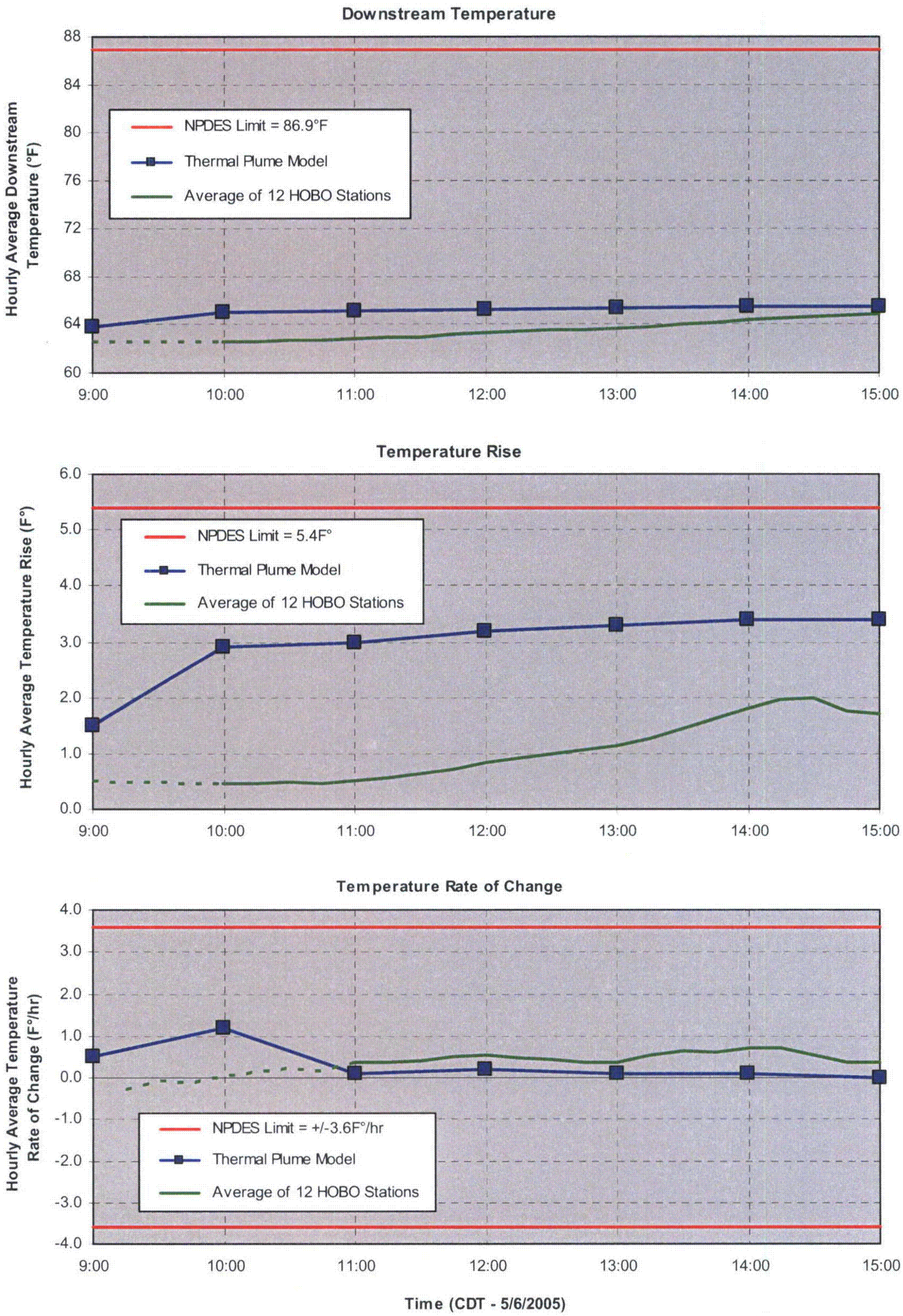

Figure 8. Measured Compliance Parameters for Passive Mixing Zone

APPENDIX A

WBN Outfall 113 NPDES Compliance Parameters

- Current Instantaneous Upstream Temperature:

  Tu_i (measured at EDS Station 30 by the first sensor below a depth of 5 feet)

- Current 1-Hour Average Upstream Temperature:

  $$Tu1_i = \frac{Tu_i + Tu_{i-1} + Tu_{i-2} + Tu_{i-3} + Tu_{i-4}}{5},$$

  where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15 minute (0.25 hour) values of Tu

- Current Instantaneous Downstream Temperature:

  $$Td_i = \frac{Td3_i + Td5_i + Td7_i}{3},$$

  where $Td3_i$, $Td5_i$, and $Td7_i$ denote the current measurements of river temperature at the downstream end of the mixing zone at water depths 3 feet, 5 feet, and 7 feet, respectively

- Current 1-Hour Average Downstream Temperature:

  $$Td1_i = \frac{Td_i + Td_{i-1} + Td_{i-2} + Td_{i-3} + Td_{i-4}}{5},$$

  where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15 minute (0.25 hour) values of Td

- Current Instantaneous Temperature Rise:

  $$\Delta T_i = Td_i - Tu_i$$

- Current 1-Hour Average Temperature Rise:

$$\Delta T1_i = \frac{\Delta T_i + \Delta T_{i-1} + \Delta T_{i-2} + \Delta T_{i-3} + \Delta T_{i-4}}{5},$$

where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15 minute (0.25 hour) values of ΔT

- Current Temperature Rate-of-Change:

$$TROC_i = \frac{Td_i - Td_{i-1}}{0.25\ \text{hour}},$$

- Current 1-Hour Average Temperature Rate-of-Change:

$$TROC1_i = \frac{TROC_i + TROC_{i-1} + TROC_{i-2} + TROC_{i-3} + TROC_{i-4}}{5}$$

where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15 minute (0.25 hour) values of TROC

TENNESSEE VALLEY AUTHORITY
River System Operations & Environment
River Scheduling

SUMMER 2006 COMPLIANCE SURVEY FOR WATTS BAR NUCLEAR PLANT OUTFALL 113 PASSIVE MIXING ZONE

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TVA

EXECUTIVE SUMMARY

The National Pollutant Discharge Elimination System (NPDES) Permit No. TN0020168 for Watts Bar Nuclear Plant (WBN) identifies the discharge of water to the Tennessee River from the Supplemental Condenser Cooling Water (SCCW) System as Outfall 113. Furthermore, the permit identifies that when there is no flow released from Watts Bar Dam (WBH), the effluent from Outfall 113 shall be regulated based on a passive mixing zone extending in the river from bank-to-bank and 1,000 feet downstream from the outfall. Compliance with the requirements for the passive mixing zone is to be made by two annual instream temperature surveys: one for winter conditions and one for summer conditions. Summarized in this report are the measurements, analyses, and results for the passive mixing zone survey conducted for 2006 summer conditions. The survey was conducted on September 3, 2006, and included the collection of temperature data at twelve temporary monitoring stations deployed across the downstream edge of the passive mixing zone during a period of no flow in the river. The data were analyzed to compute three compliance parameters: the 1-hour average temperature at the downstream edge of mixing zone, T_d; the 1-hour average temperature rise from upstream to the downstream edge of the mixing zone, ΔT; and the 1-hour average temperature rate-of-change at the downstream edge of the mixing zone, TROC. The measured parameters were compared to predicted values from the thermal plume model used by TVA to help determine the safe operation of Outfall 113. The results of the comparisons, in terms of maximum values observed during the no flow event, are as follows:

Parameter	Model	Measured	NPDES Limit
Maximum T_d	82.1°F	81.0°F	86.9°F
Maximum ΔT	1.4 F°	0.4 F°	5.4 F°
Maximum TROC	+0.6 F°/hour	+0.2 F°/hour	±3.6 F°/hr

As shown, values predicted by the model were larger than those measured in the survey for all the compliance parameters. Thus, for the conditions of September 3, 2006, the plume model is conservative. That is, the model would enforce the operation of Outfall 113 at levels of T_d, ΔT, and TROC below the NPDES limits. For T_d and ΔT, these results are consistent with those of all the previous surveys for the passive mixing zone. The same is not true, however, for TROC. Previous surveys have revealed that the model is capable of underpredicting measured values for TROC by as much as 0.3 F°/hour (e.g., see McCall and Hopping, 2006). Under these conditions, a factor of safety of 0.3 F°/hour is currently used in the plume model for predicting the maximum value of TROC. In this manner, the safe operation of Outfall 113 for the passive mixing zone is evaluated based on a maximum value of TROC of ±3.3 F°/hour rather than ±3.6 F°/hour. This practice will continue until further notice.

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SUMMER 2006 COMPLIANCE SURVEY FOR WATTS BAR NUCLEAR PLANT OUTFALL 113 PASSIVE MIXING ZONE

INTRODUCTION

Outfall 113 for the Watts Bar Nuclear Plant (WBN) includes the discharge of water to the Tennessee River from the Supplemental Condenser Cooling Water (SCCW) system. Due to the dynamic behavior of the thermal effluent in the river, the National Pollutant Discharge Elimination System (NPDES) Permit No. TN0020168 for the plant specifies two mixing zones for Outfall 113: one for active operation of the river and one for passive operation of the river (TDEC, 2004). The passive mixing zone corresponds to periods when operations at Watts Bar Dam (WBH) produce no flow in the river (i.e., hydropower and/or spillway releases). The dimensions of the passive mixing zone extend from bank-to-bank and downstream 1,000 feet from the outfall. The active mixing zone applies to all other river flow conditions. The dimensions of the active mixing zone include the right-half of the river (facing downstream) and extend downstream 2,000 feet from the outfall. The passive and the active mixing zones are illustrated in Figure 1.

Table 1 summarizes the NPDES temperature limits for Outfall 113. The limits apply to both the active and passive mixing zones. Compliance for the active mixing zone is monitored by permanent instream water temperature stations situated in the right-half of the river. Due to limitations in placing permanent stations across the river, a thermal plume model is used to determine the safe operation of Outfall 113 for the passive mixing zone. To verify the thermal plume model, the NPDES permit specifies that two instream temperature surveys shall be conducted each year—one for winter conditions and one for summer conditions. The purpose of this report is to present the results for the passive mixing zone temperature survey conducted for summer 2006 conditions. The survey was conducted on September 3 and included the deployment of temporary temperature stations at twelve locations across the downstream edge of the passive mixing zone. Data from these and other monitoring stations were analyzed to obtain measured values for the compliance parameters listed in Table 1 and to compare these with the corresponding values estimated from the SCCW thermal plume model. Summarized herein are descriptions of the survey method, results, and conclusions.

Table 1. Temperature Criteria for SCCW Mixing Zones

Maximum Temperature, Downstream Edge of Mixing Zone, T_d	Running 1-hr	86.9°F
Maximum Temperature Rise, Upstream to Downstream, ΔT	Running 1-hr	5.4 F°
Maximum Temperature Rate-of-Change, TROC	Running 1-hr	±3.6 F°/hr

INSTREAM SURVEY

The method of conducting the instream survey is the same as that used for the first such survey, conducted for winter conditions on May 6, 2005 (McCall and Hopping, 2005). Table 2 provides a summary of the sources of data for the survey. The WBN Environmental Data Station (EDS) provided measurements from existing permanent monitoring stations, including the upstream (ambient) river temperature, river water surface elevation, SCCW effluent temperature, SCCW effluent flow, and air temperature. WaterView®, a hydroplant monitoring system, was used to provide measurements for the discharge from WBH.

The effluent plume for Outfall 113 was monitored by deploying twelve temporary monitoring stations at roughly equal intervals across the downstream edge of the passive mixing zone. The temporary water temperature monitoring stations recorded temperature profiles using HOBO water temperature sensors positioned at depths of 0.5, 3, 5, and 7 feet below the water surface. Shown in Figure 2 is a schematic of the temporary monitoring stations, which included an assembly containing a tire float, a string of HOBO water temperature sensors, and anchor weights. The water temperature sensors have an accuracy of about ±0.4 F° and resolution of about 0.04 F°, which is consistent with other temperature measurements used for TVA hydrothermal compliance. The HOBO devices include an internal data acquisition unit and were programmed to collect measurements once every minute. Most of the temporary monitoring stations were deployed on September 2, 2006. All of the stations were retrieved at the end of the survey. A Global Positioning System (GPS) device was used to position the stations along the downstream edge of the passive mixing zone, as shown in Figure 3.

Table 2. Sources of Data for Passive Mixing Zone Survey

Data	Source	Frequency
River Discharge from Watts Bar Dam	WaterView®	5 min
River Water Surface Elevation	WBN EDS Station 30 (Tailwater at WBH)	5 min
River Ambient Water Temperature	WBN EDS Station 30 (Tailwater at WBH)	5 min
SCCW Effluent Discharge	WBN EDS Station 32 (Outfall 113)	5 min
SCCW Effluent Temperature	WBN EDS Station 32 (Outfall 113)	5 min
Air Temperature	WBN EDS Met Tower	15 min
Passive Mixing Zone Downstream Temperatures	Temporary HOBO Monitors	1 min

RESULTS

River Conditions

Figure 4 shows the measured river conditions for the day of the survey, including the discharge, water surface elevation, and upstream (ambient) river temperature. To provide a period of no flow in the river, releases from Watts Bar Dam were suspended between about 06:00 CDT and 14:00 CDT, a total of eight hours. When the releases were suspended, the river water surface elevation below WBH first dropped, but then slowly increased, due to filling from the river downstream. The ambient river temperature was about 80.7°F before the beginning of the survey. After the releases from WBH were suspended, the ambient river temperature decreased slightly, reaching 80.4°F after about six hours, but then increased back to 80.7°F at the end of the survey period.

SCCW Conditions

During the survey, the SCCW system at WBN was thermally loaded and operating in "summer" mode. Shown in Figure 5 are the measured conditions of the SCCW system for the day of the survey. Included are the discharge and temperature of the SCCW effluent. The SCCW discharge fluctuated between approximately 330 cfs and 380 cfs. The average discharge during the survey was about 355 cfs. The SCCW effluent temperature increased from about 80°F at the beginning of the survey to about 85°F at the end of the survey. This increase is due to the diurnal increase in air temperature, also shown in Figure 5. The temperature of the SCCW effluent relative to the ambient river temperature also is shown in Figure 5. At the beginning of the survey, the temperature of the effluent from the SCCW system was actually cooler than the river temperature, due to the action of the WBN cooling towers. This is because when the ambient river temperature is warm, as was the case in this survey, the cooling towers are more effective in reducing the temperature of the plant condenser cooling water, especially in the cool hours of the morning. At the end of the survey the effluent from the SCCW system was about 4°F warmer than the river.

Effluent Behavior

Individual Temperature Stations

Shown in Figure 6 are the readings from the HOBO temperature stations at the downstream end of the passive mixing zone. The stations are labeled consecutively from WB1 to WB12, with WB1 situated near the left shoreline of the river and WB12 situated near the right shoreline of the river (i.e., facing downstream—see Figure 3). The following behaviors are noted:

- In general, the temperature at each sensor increased throughout the survey. This increase is due to the effluent from Outfall 113 and due to solar heating.

- The temperature increase is larger for sensors near the water surface, in particular the sensor at 0.5-foot depth. This behavior is due to buoyancy, which causes the warm water to drift primarily in the upper part of the water column.

- The temperature differences among the 3-foot, 5-foot, and 7-foot sensors are small, typically less than 0.5 F°, and often less than 0.25 F°. This indicates that for these depths, the flow is fairly well-mixed. When this occurs, it is common to see a behavior wherein the measured temperature at larger depths is warmer than the measured temperature at shallower depths, in contrast to the action of buoyancy. A good example is the 7-foot sensor for station WB2 (Figure 6). In this case, the measured temperature at the 7-foot depth is warmer than that at both the 3-foot and 5-foot depths. This behavior is due to the accuracy of the temperature sensors and usually is artificial. As previously noted, the accuracy of the HOBO sensors is ±0.4 F°. Thus, it is possible for the measured difference in temperature between two sensors to be as large as 0.8 F° even though the sensors are immersed in a sample of uniform temperature. This behavior occurred not only at WB2, but also at WB3, WB5, WB6, WB7, WB8, and WB11. Most, if not all, of these occurrences of "negative" buoyancy are likely unreal.

- Many of the stations exhibited a temperature excursion of about 0.5 F°, primarily at the 0.5-foot depth, between 09:00 CDT and 10:00 CDT, about three to four hours after the beginning of the no flow event. The mechanisms responsible for the movement of these patches of warm water across the downstream end of passive mixing zone are not fully understood, but they likely are due to sloshing in the reservoir caused by the no flow event. For example, the time of travel for a gravity wave between Watts Bar Dam and Chickamauga Dam is about three hours.

- The temperature for all stations, and at most depths, increased in a more lasting manner between 12:00 CDT and 13:00 CDT, about six to seven hours after the beginning of the no-flow event. This likely corresponds to the leading edge of the central part of the thermal plume from Outfall 113. That is, for this no-flow event, it took between six to seven hours for the warmest part of the thermal plume to spread to the downstream edge of the passive mixing zone.

Distribution Across The Mixing Zone

At each HOBO station, the instantaneous compliance temperature was determined by averaging the measurements for the sensors at the 3-foot, 5-foot, and 7-foot depths. Plotted in Figure 7 are the resulting temperature profiles across the downstream end of the passive mixing zone, measured at the top of each hour from 06:00 CDT to 14:00 CDT. Note that the temperature profile is shown as a dashed line between Station WB1 and Station WB5 for the 06:00 CDT reading. This is because the HOBO sensors for Stations WB1 through WB4 were not deployed until about 06:30 CDT, 30 minutes after the survey had begun. Because of this, the 06:00 CDT temperatures at Stations WB1 through WB4 were estimated based on the readings at two nearby stations—WB5 and WB6. The following behaviors are noted in Figure 7:

- Although the maximum variation in temperature across the river for any one profile is slight, typically less than 0.5 F°, there appears to be mild concentrations of heat in the region between Stations WB1 and WB5 and in the region between Stations WB7 and WB10. This behavior persists throughout the duration of the survey.

- At the beginning of the survey, between 06:00 CDT and 07:00 CDT, the temperature across the river decreases slightly, perhaps due to the nighttime cooling that typically occurs in the early hours of the morning.

- After 07:00 CDT, the temperature tends to increase from hour to hour at all the stations across the river. That is, heat from Outfall 113 is distributed across the full width of the river. It also is noted that the increase in temperature is higher on the left side of the river, between Stations WB1 and WB7. This is consistent with the expected behavior of the Outfall 113 effluent. In no-flow events, the effluent tends to spread across the river and build in the left side of the waterway—in this case, in the region between Stations WB1 and WB7.

- Between 12:00 CDT and 13:00 CDT the temperature of all stations across the river increased by about 0.25°F. As emphasized earlier, this likely corresponds to the time when the warmest part of the plume from Outfall 113 reaches the downstream edge of the passive mixing zone.

Compliance Parameters

Since heat from the outfall is distributed across the full width of the river, data from all of the HOBO stations were used to compute the NPDES compliance parameters, which is consistent with the dimensions of the passive mixing zone (e.g., as shown in Figure 1). The compliance parameters examined include those given in Table 1: the temperature at the downstream edge of mixing zone, T_d; the temperature rise from upstream to the downstream edge of the mixing zone, ΔT; and the temperature rate-of-change at the downstream edge of the mixing zone, TROC. Following the criteria specified in the NPDES permit, the fundamental equations used to compute the compliance parameters are provided in Appendix A. The temperature at the downstream end of the mixing zone was determined from the HOBO measurements (i.e., average of sensors at depths 3, 5, and 7 feet for all twelve HOBO stations). The temperature rise was computed as the difference between the temperature at the downstream end of the mixing zone and the upstream temperature measured at Station 30. The temperature rate-of-change was determined by the change in the temperature at the downstream end of the mixing zone from one hour to the next. The data were averaged over a period of one hour using 15-minute readings, as specified in the NPDES permit, and compared with the WBN thermal plume model. The results are presented in Figure 8. The following comments are provided.

- Temperature at the downstream edge of the passive mixing zone, T_d: The maximum 1-hour average T_d estimated by the thermal plume model was 82.1°F, whereas the maximum measured value was about 81.0°F. Thus, the model overpredicted the maximum measured T_d by 1.1°F. Compared to the measurements, the increase in river temperature due to the no flow event was predicted to occur much more rapidly by the model. This is because the model assumes that impacts due to changes in the river and/or Outfall 113 are fully realized within one hour (i.e., the model time-step); whereas in reality, the actual time for the development of such impacts is much longer, at least for events with little or no river flow. Both the predictions from the model and measurements from the survey were well below the NPDES limit of 86.9°F.

- Temperature rise, ΔT: The maximum 1-hour average ΔT predicted by the plume model was 1.4 F°, whereas the maximum measured value was about 0.4 F°. Thus, the model overpredicted the maximum measured temperature rise by 1.0 F°. For the reason cited above (i.e., computational time-step of one hour), the model predicted the temperature rise to occur sooner than that found by the measurements. Both the predictions from the model and measurements from the survey were well below the NPDES limit of 5.4 F°.

- Temperature rate-of-change, TROC: The maximum 1-hour average TROC predicted by the plume model was +0.6 F°/hour, whereas the maximum measured value was about +0.2 F°/hour. Thus, the model overpredicted the temperature rate-of-change by 0.6 F°/hour. For the reason cited above (i.e., computational time-step of one hour), the model predicted the maximum TROC to occur sooner than that found by the actual measurements. Both the predictions from the model and measurements from the survey were well below the NPDES limit of ±3.6°F.

CONCLUSIONS

The survey of September 3, 2006, was successful in measuring the NPDES water temperature parameters for summertime conditions for the Outfall 113 passive mixing zone. The measurements were compared with values predicted by the thermal plume model that is currently used to determine the safe operation of the SCCW system. Overall, for the conditions of September 3, 2006, the model was found to be conservative in estimating the impact of Outfall 113 on the temperature, T_d, temperature rise, ΔT, and temperature rate-of-change, TROC, at the downstream end of the passive mixing zone. This is because the model overpredicted the maximum value measured for all these parameters, and hence would tend to enforce the operation of Outfall 113 at levels of T_d, ΔT, and TROC below the NPDES limits. For T_d and ΔT, these results are consistent with those for all of the previous surveys for the passive mixing zone. The same is not true, however, for TROC. Previous surveys have revealed that the model is capable of underpredicting measured values for TROC by as much as 0.3 F°/hour (e.g., see McCall and Hopping, 2006). Under these conditions, and despite the results summarized herein, a factor of safety of 0.3 F°/hour is used in the plume model for predicting the maximum value of TROC. That is, the safe operation of Outfall 113 for the passive mixing zone will continue to be evaluated based on a maximum value of TROC of ±3.3 F°/hour rather than ±3.6 F°/hour. In general, this action will have only a very slight impact on the SCCW, since the operation of the SCCW tends to be controlled primarily by the NPDES limit for ΔT, not the limit for TROC.

REFERENCES

McCall, Michael J., and P.N. Hopping, "Summer 2005 Compliance Survey for Watts Bar Nuclear Plant Outfall 113 Passive Mixing Zone," TVA River Operations, Report No. WR2006-2-85-152, February 2006.

McCall, Michael J., and P.N. Hopping, "Winter 2005 Compliance Survey for Watts Bar Nuclear Plant Outfall 113 Passive Mixing Zone," TVA River Operations, Report No. WR2005-2-85-151, October 2005.

TDEC, *State of Tennessee NPDES Permit No. TN0020168*, Tennessee Department of Environment and Conservation, November 2004.

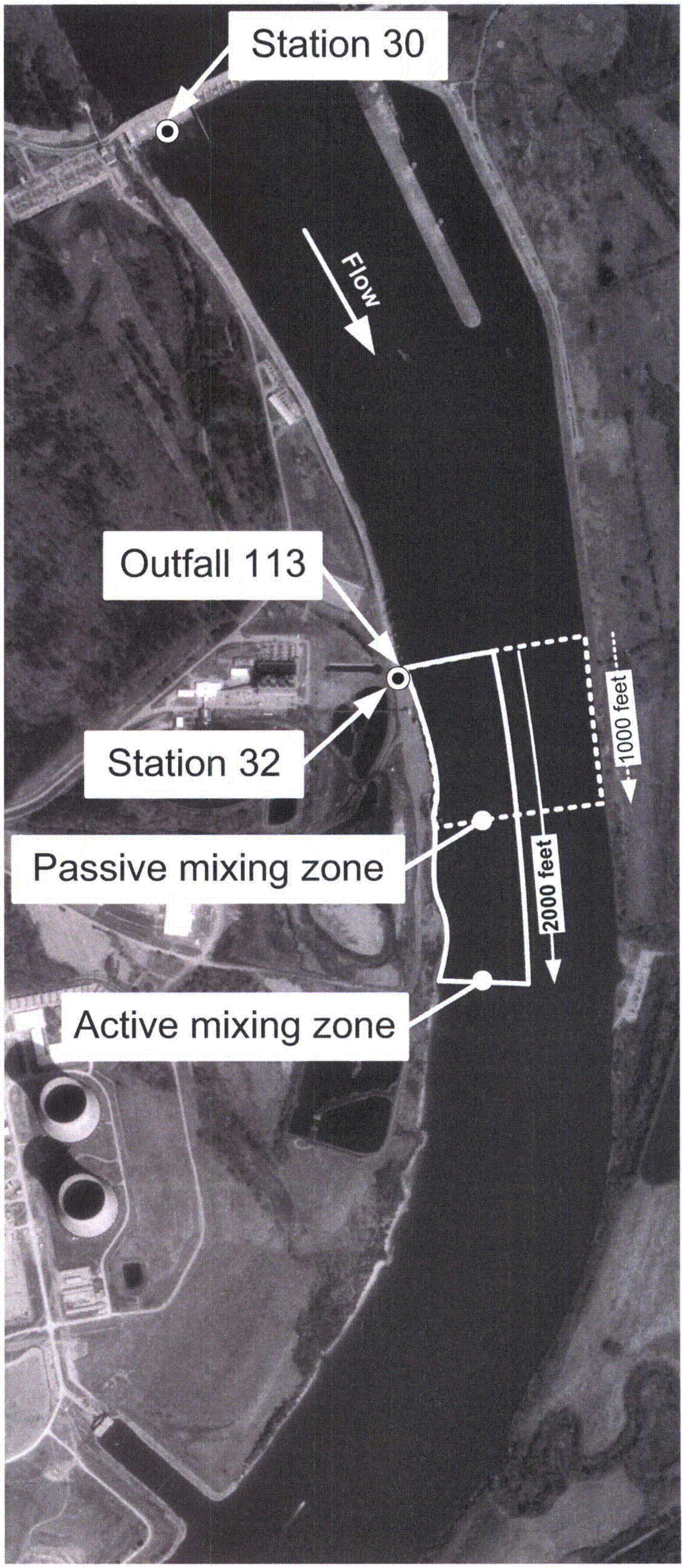

Figure 1. Watts Bar Nuclear Plant Outfall 113 (SCCW) Mixing Zones

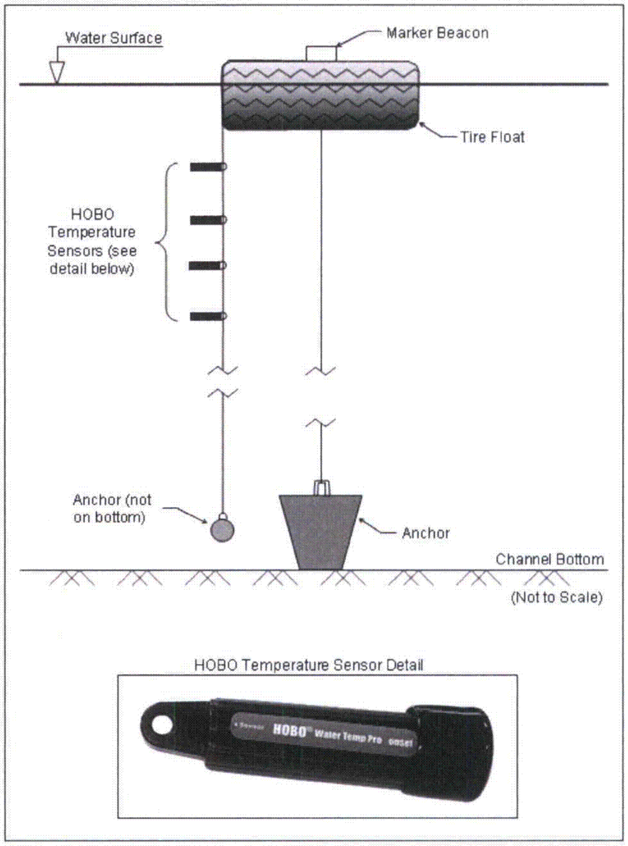

Figure 2. Schematic of HOBO Water Temperature Monitoring Stations

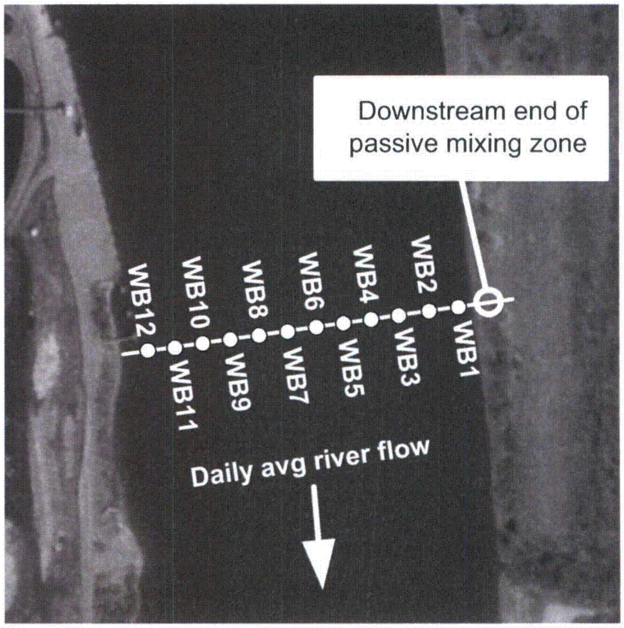

Figure 3. Location of HOBO Monitoring Stations

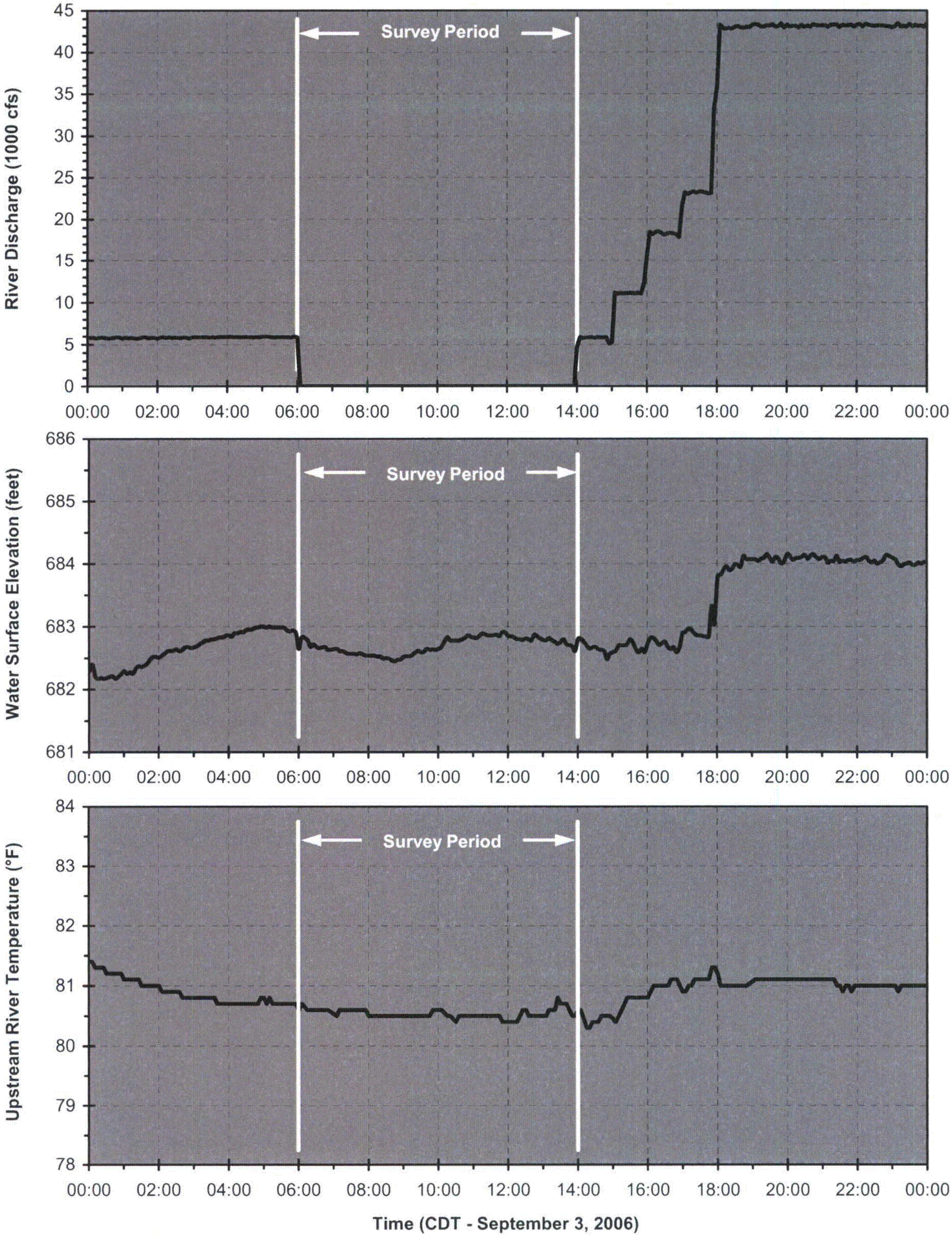

Figure 4. River Conditions

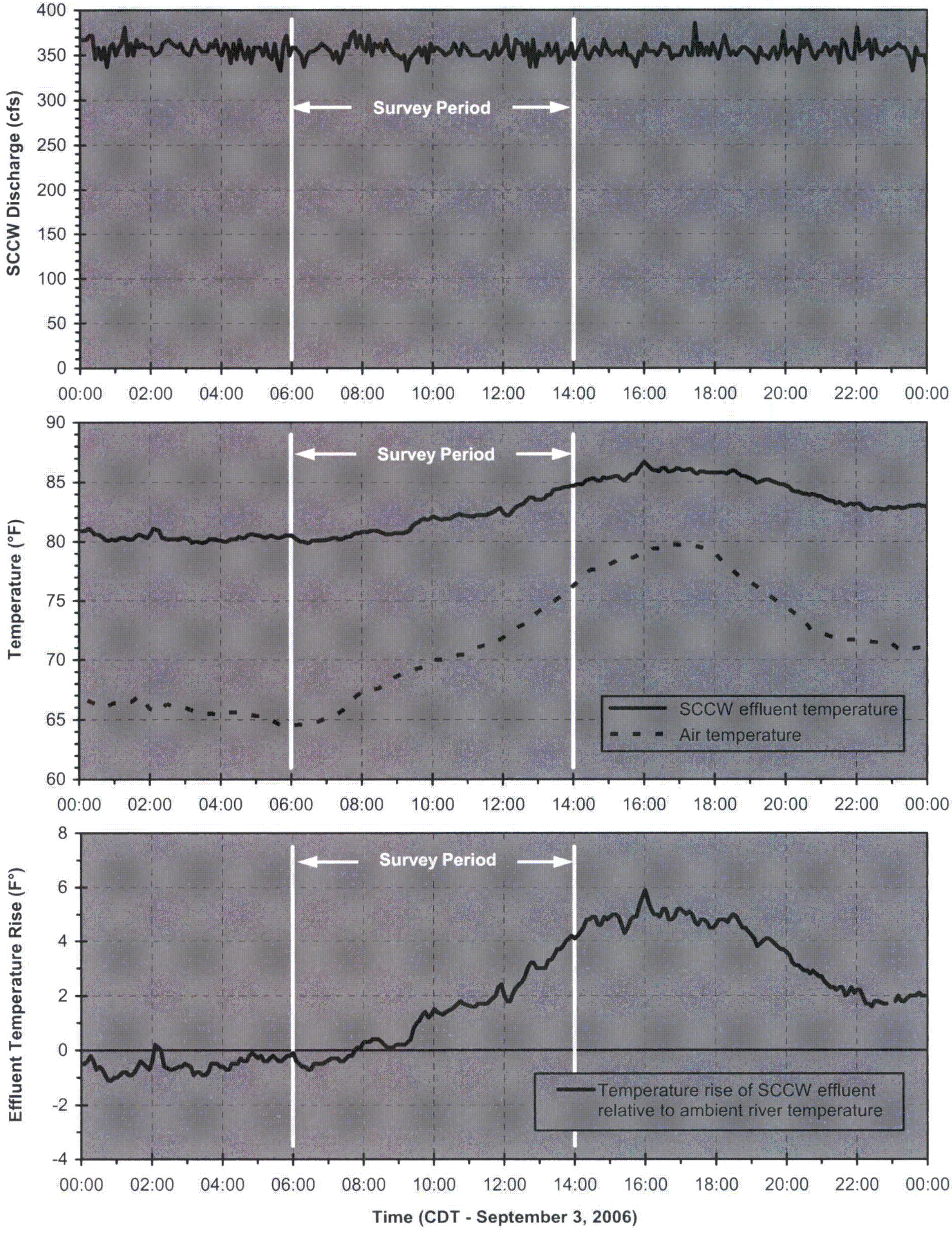

Figure 5. SCCW Conditions

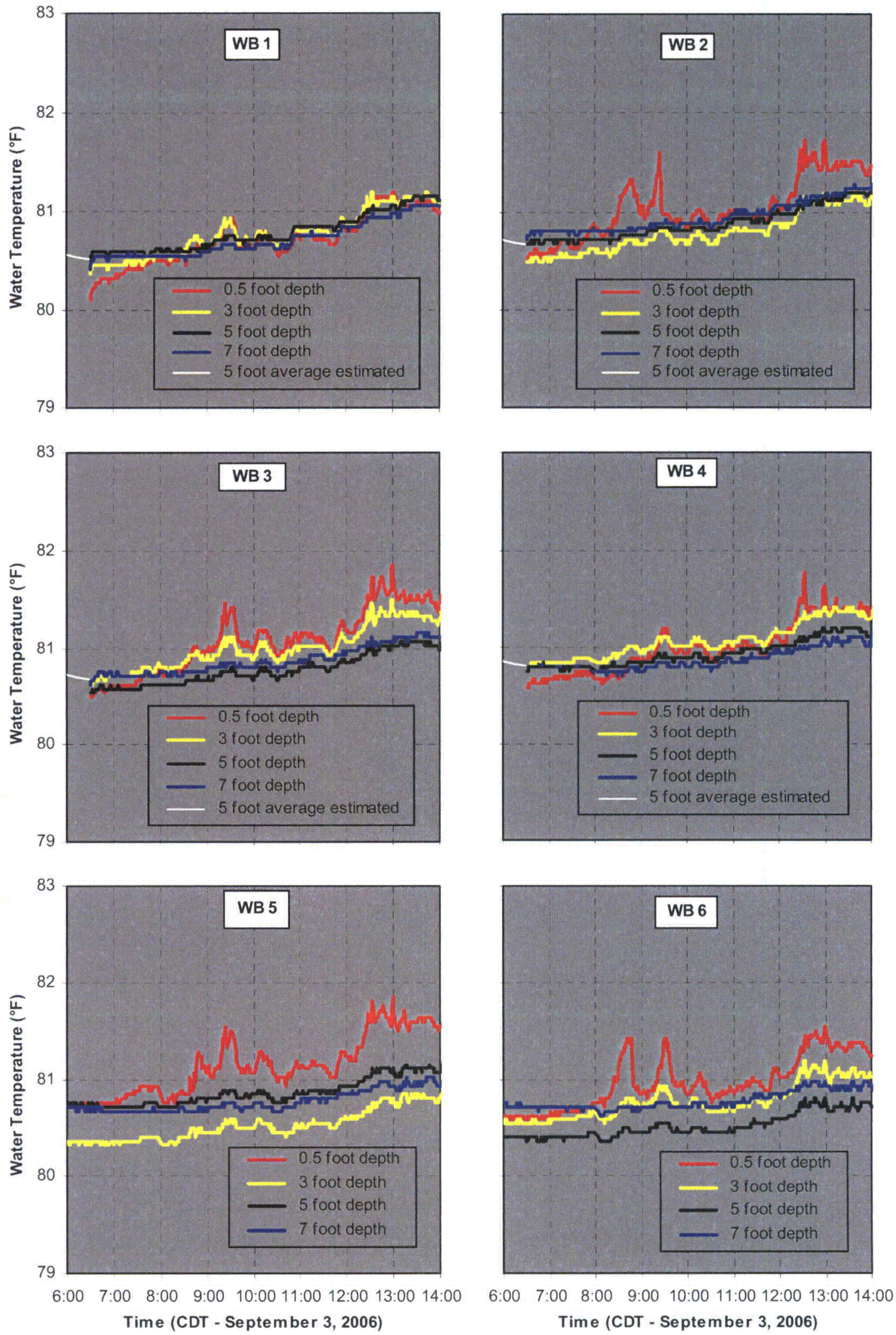

Figure 6. HOBO Water Temperature Measurements During Survey

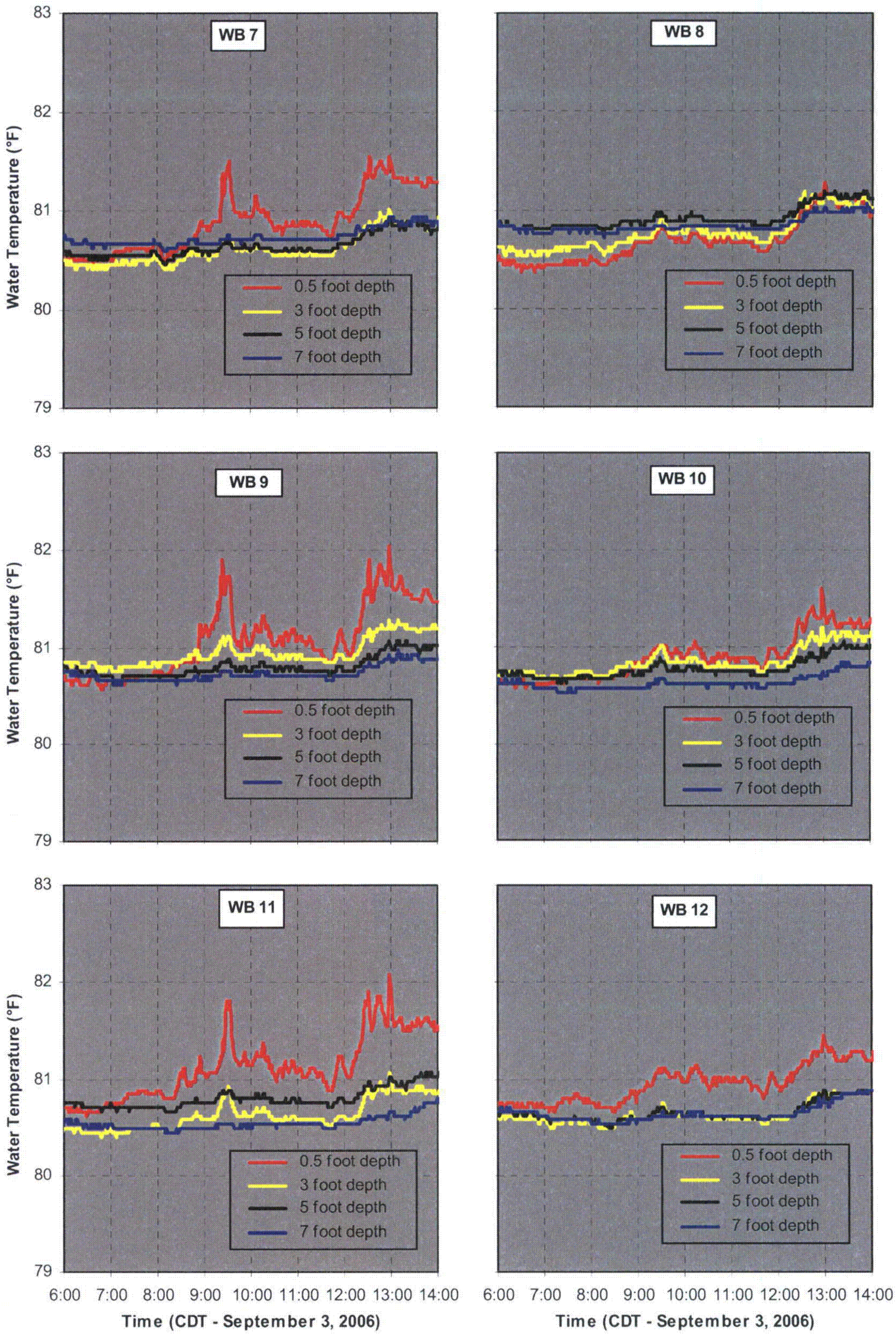

Figure 6 (Continued). HOBO Water Temperature Measurements During Survey

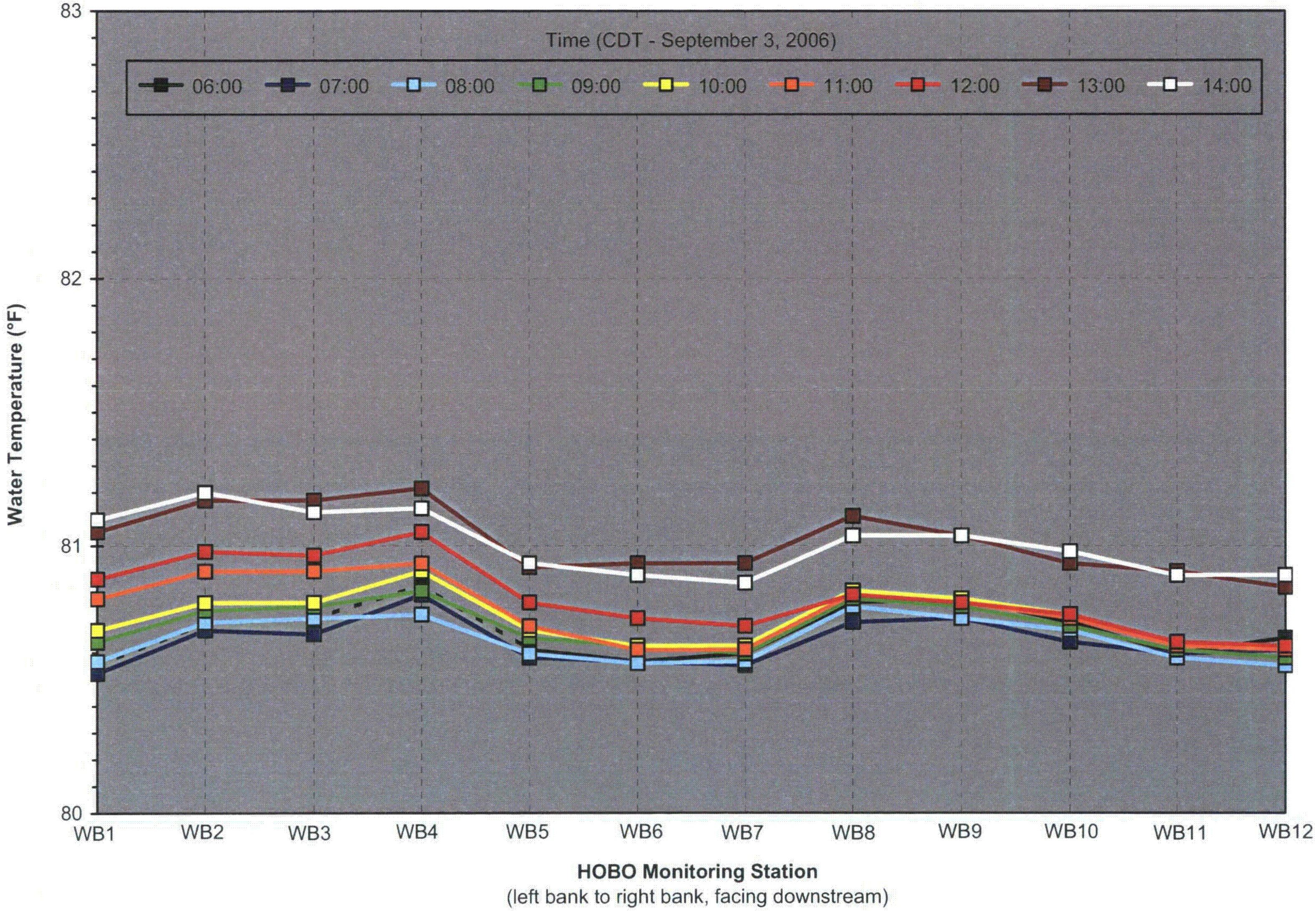

Figure 7. Profiles of Instantaneous Compliance Temperature across Downstream End of Passive Mixing Zone
(Average of Readings at 3-Foot, 5-Foot, and 7-Foot Depths)

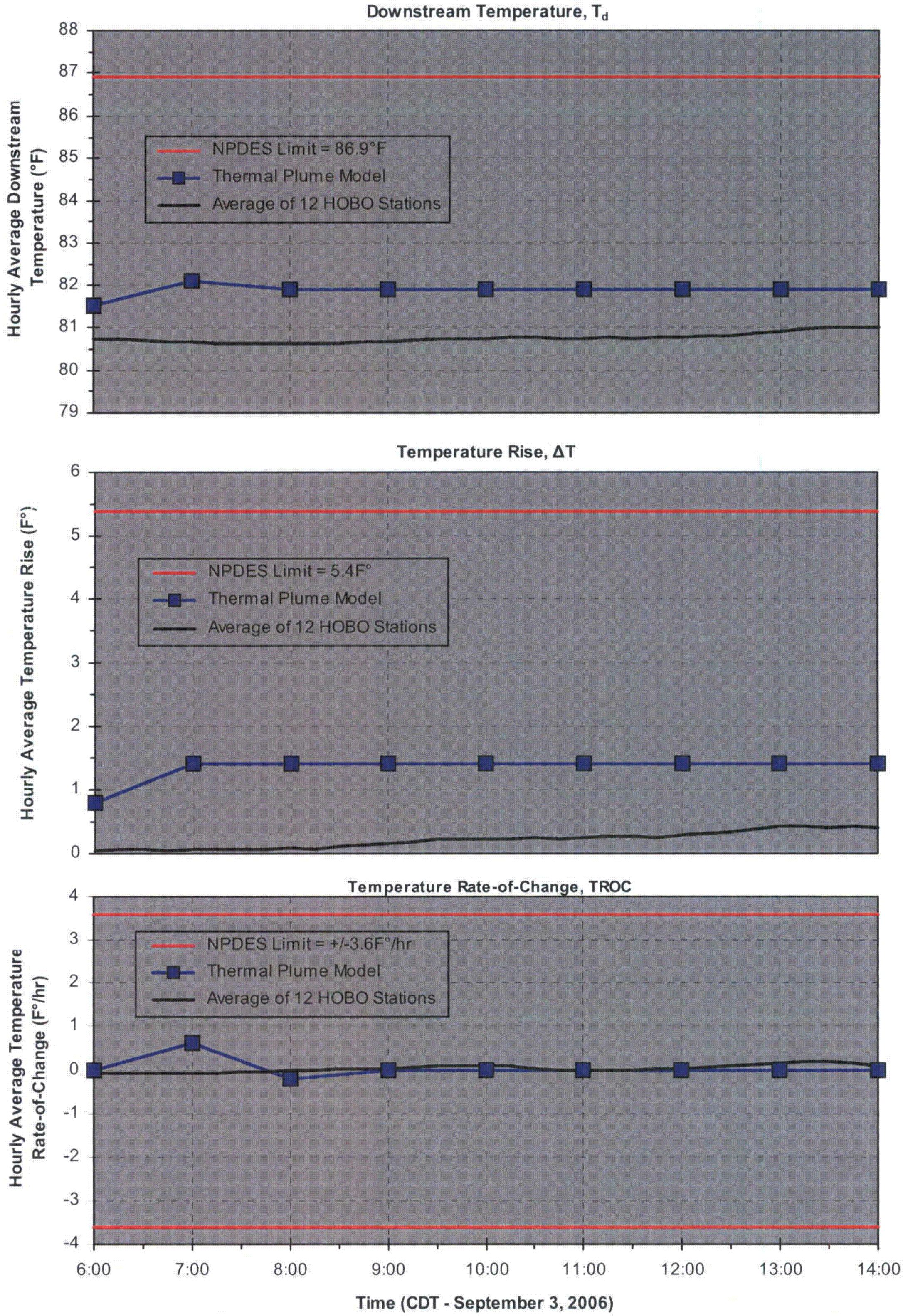

Figure 8. Measured and Computed Compliance Parameters for Passive Mixing Zone

APPENDIX A

WBN Outfall 113 NPDES Compliance Parameters

- Current Instantaneous Upstream Temperature:

  Tu_i (measured at EDS Station 30 by the first sensor below a depth of 5 feet)

- Current 1-Hour Average Upstream Temperature:

  $$Tu1_i = \frac{Tu_i + Tu_{i-1} + Tu_{i-2} + Tu_{i-3} + Tu_{i-4}}{5},$$

  where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of Tu

- Current Instantaneous Downstream Temperature:

  $$Td_i = \frac{Td3_i + Td5_i + Td7_i}{3},$$

  where $Td3_i$, $Td5_i$, and $Td7_i$ denote the current measurements of river temperature at the downstream end of the mixing zone at water depths 3 feet, 5 feet, and 7 feet, respectively

- Current 1-Hour Average Downstream Temperature:

  $$Td1_i = \frac{Td_i + Td_{i-1} + Td_{i-2} + Td_{i-3} + Td_{i-4}}{5},$$

  where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of Td

- Current Instantaneous Temperature Rise:

  $$\Delta T_i = Td_i - Tu_i$$

- Current 1-Hour Average Temperature Rise:

$$\Delta T1_i = \frac{\Delta T_i + \Delta T_{i-1} + \Delta T_{i-2} + \Delta T_{i-3} + \Delta T_{i-4}}{5},$$

where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of ΔT

- Current Temperature Rate-of-Change:

$$TROC_i = \frac{Td_i - Td_{i-4}}{1\ \text{hour}},$$

- Current 1-Hour Average Temperature Rate-of-Change:

$$TROC1_i = \frac{TROC_i + TROC_{i-1} + TROC_{i-2} + TROC_{i-3} + TROC_{i-4}}{5}$$

where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of TROC

TENNESSEE VALLEY AUTHORITY
River System Operations & Environment
River Scheduling

SUMMER 2005 COMPLIANCE SURVEY FOR WATTS BAR NUCLEAR PLANT OUTFALL 113 PASSIVE MIXING ZONE

WR2005-2-85-152

Prepared by

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Knoxville, Tennessee
February 2006

TVA

EXECUTIVE SUMMARY

The National Pollutant Discharge Elimination System (NPDES) Permit No. TN0020168 for Watts Bar Nuclear Plant (WBN) identifies the discharge of water to the Tennessee River from the Supplemental Condenser Cooling Water (CCW) System as Outfall 113. Furthermore, the permit identifies that when there is no flow released from Watts Bar Dam (WBH), the effluent from Outfall 113 shall be regulated based on a passive mixing zone extending in the river from bank-to-bank and 1,000 feet downstream from the outfall. Compliance with the requirements for the passive mixing zone is to be made by two annual instream temperature surveys: one for winter conditions and one for summer conditions. Summarized in this report are the measurements, analyses, and results for the passive mixing zone survey conducted for 2005 summer conditions. The survey included the collection of temperature data at twelve temporary monitoring stations deployed across the downstream edge of the passive mixing zone during a period of no flow in the river. The data were analyzed to compute three compliance parameters: the one-hour average temperature at the downstream edge of mixing zone, T_d; the one-hour average temperature rise from upstream to the downstream edge of the mixing zone, ΔT; and the one-hour average temperature rate-of-change at the downstream edge of the mixing zone, TROC. The measured parameters were compared to predicted values from a thermal plume model used by TVA to verify the operation of Outfall 113. The results of the comparisons, in terms of maximum values observed during the no flow event, are as follows:

Parameter	Model	Measured	NPDES Limit
Maximum T_d	79.8°F	79.5°F	86.9°F
Maximum ΔT	2.0 F°	1.0 F°	5.4 F°
Maximum TROC	+0.4 F°/hour	+0.7 F°/hour	±3.6 F°/hr

As shown, values predicted by the model were larger than those measured in the survey for the maximum temperature, T_d, and maximum temperature rise, ΔT, at the downstream end of the passive mixing zone. Thus, for these parameters, the model is considered conservative for estimating the impact of Outfall 113. That is, because the model overestimated the observed values for these parameters, it will tend to enforce the operation of Outfall 113 at levels of T_d and ΔT below the NPDES limits. The value predicted by the thermal plume model, however, was smaller than that measured in the survey for the maximum temperature rate-of-change, TROC (i.e., +0.7 F°/hour measured vs. +0.4 F°/hour predicted). This discrepancy is likely due to phenomena in the river that are not represented in the thermal plume model, such as unsteady sloshing in the reservoir and/or the impact of wind. Under these conditions, until further notice, a factor of safety of 0.3 F°/hour will be used in the model for estimating the maximum value of TROC. That is, the safe operation of Outfall 113 for the passive mixing zone will be evaluated based on a maximum value of TROC of ±3.3 F°/hour rather than ±3.6 F°/hour. In general, this action will only have a minimum impact on the operation of the SCCW, since the operation of the SCCW tends to be controlled primarily by the NPDES limit for ΔT and not the limit for TROC.

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SUMMER 2005 COMPLIANCE SURVEY FOR WATTS BAR NUCLEAR PLANT OUTFALL 113 PASSIVE MIXING ZONE

INTRODUCTION

Outfall 113 for the Watts Bar Nuclear Plant (WBN) includes the discharge of water to the Tennessee River from the Supplemental Condenser Cooling Water (SCCW) system. Due to the dynamic behavior of the thermal effluent in the river, the National Pollutant Discharge Elimination System (NPDES) Permit No. TN0020168 for the plant specifies two mixing zones for Outfall 113: one for active operation of the river and one for passive operation of the river (TDEC, 2004). The passive mixing zone corresponds to periods when operations at Watts Bar Dam (WBH) produce no flow in the river (i.e., hydropower and/or spillway releases). The dimensions of the passive mixing zone extend from bank-to-bank and downstream 1,000 feet from the outfall. The active mixing zone applies to all other river flow conditions. The dimensions of the active mixing zone include the right-half of the river (facing downstream) and extend downstream 2,000 feet from the outfall. The passive and the active mixing zones are illustrated in Figure 1.

Table 1 summarizes the NPDES temperature limits for Outfall 113. The limits apply to both the active and passive mixing zones. Compliance for the active mixing zone is monitored by permanent instream water temperature stations situated in the right-half of the river. Due to limitations in placing permanent stations across the river, a thermal plume model is used to determine the safe operation of Outfall 113 for the passive mixing zone. To verify the thermal plume model, the NPDES permit specifies that two instream temperature surveys shall be conducted each year—one for winter conditions and one for summer conditions. The purpose of this report is to present the results for the passive mixing zone temperature survey conducted for summer 2005 conditions. The survey was conducted on July 29 and included the deployment of temporary temperature stations at twelve locations across the downstream edge of the passive mixing zone. Data from these and other monitoring stations were analyzed to obtain measured values for the compliance parameters listed in Table 1 and to compare these with the corresponding values estimated from the SCCW thermal plume model. Summarized herein are descriptions of the survey method, results, and conclusions.

Table 1. Temperature Criteria for SCCW Mixing Zones

Maximum Temperature, Downstream Edge of Mixing Zone, T_d	Running 1-hr	86.9°F
Maximum Temperature Rise, Upstream to Downstream, ΔT	Running 1-hr	5.4 F°
Maximum Temperature Rate-of-Change, TROC	Running 1-hr	±3.6 F°/hr

INSTREAM SURVEY

The method of conducting the instream survey is the same as that used for the first such survey, conducted for winter conditions on May 6, 2005 (McCall and Hopping, 2005). Table 2 provides a summary of the sources of data for the survey. The WBN Environmental Data Station (EDS) provided measurements from existing permanent monitoring stations, including the upstream (ambient) river temperature, river water surface elevation, SCCW effluent temperature, SCCW effluent flow, and air temperature. WaterView, a hydroplant monitoring system, was used to provide measurements for the discharge from WBH.

The effluent plume for Outfall 113 was monitored by deploying twelve temporary monitoring stations, spaced at roughly equal intervals across the downstream edge of the passive mixing zone. The temporary water temperature monitoring stations recorded temperature profiles using HOBO water temperature sensors positioned at depths of 0.5, 3, 5, and 7 feet below the water surface. Shown in Figure 2 is a schematic of the temporary monitoring stations, which included an assembly containing a tire float, a string of HOBO water temperature sensors, and anchor weights. The water temperature sensors have an accuracy of about ±0.4 F° and resolution of about 0.04 F°, which is consistent with other temperature measurements used for TVA hydrothermal compliance. The HOBO devices include an internal data acquisition unit and were programmed to collect measurements once every minute. The twelve temporary stations were deployed and retrieved, respectively, at the beginning and end of the survey. A Global Positioning System (GPS) tracking device was used position the stations along the downstream edge of the passive mixing zone, as shown in Figure 3.

Table 2. Sources of Data for Passive Mixing Zone Survey

Data	Source	Frequency
River Discharge from Watts Bar Dam	WaterView	5 min
River Water Surface Elevation	WBN EDS Station 30 (Tailwater at WBH)	15 min
River Ambient Water Temperature	WBN EDS Station 30 (Tailwater at WBH)	15 min
SCCW Effluent Discharge	WBN EDS Station 32 (Outfall 113)	15 min
SCCW Effluent Temperature	WBN EDS Station 32 (Outfall 113)	5 min
Air Temperature	WBN EDS Met Tower	15 min
Passive Mixing Zone Downstream Temperatures	Temporary HOBO Monitors	1 min

RESULTS

River Conditions

Figure 4 shows the measured river conditions for the day of the survey, including the discharge, water surface elevation, and upstream (ambient) river temperature. To provide a period of no flow in the river, releases from Watts Bar Dam were suspended between about 7:30 CDT and 13:00 CDT. When the releases were suspended, the river water surface elevation below WBH first dropped, but then slowly increased throughout the survey, due to filling from downstream in the river. While water was being released, the ambient river temperature was steady at about 77.8°F (i.e., before 7:30 CDT). After releases were suspended, the ambient river temperature remained at 77.8°F for about three hours, but then slowly increased, reaching about 78.6°F at the end of the survey period.

SCCW Conditions

During the survey, the SCCW system at WBN was operating in "summer mode" to provide full, thermally loaded conditions. As shown in Figure 5, the SCCW discharge fluctuated between approximately 270 cfs and 310 cfs. The average discharge was about 290 cfs. Also shown in Figure 5 is the SCCW effluent temperature, which increased from approximately 84°F to 88°F over the course of the survey. This increase is due to the diurnal increase in air temperature, also shown in Figure 5.

Effluent Behavior

Shown in Figure 6 are the readings from the HOBO temperature stations at the downstream end of the passive mixing zone. The stations are labeled consecutively from WB1 to WB12, with WB1 situated near the left shoreline of the river and WB12 situated near the right shoreline of the river (i.e., facing downstream—see Figure 3). In general, the temperature at each sensor increased throughout the survey. This increase is due to the Outfall 113 effluent and due to solar heating. The temperature increase is larger for sensors near the water surface. For example, the increase from the beginning to the end of the survey period is of magnitude 5 F° for sensors at a depth of 0.5 foot, but only of magnitude between 1 F° and 2 F° for sensors at a depth of 7 feet. This behavior is due to buoyancy, which causes the warm water from Outfall 113 and solar heating to drift primarily in the upper part of the water column. It also is noted that the temperature for all stations increases significantly between 11:00 CDT and 12:00 CDT, about 3½ to 4½ hours after the beginning of the no-flow event. This corresponds to the leading edge of the central part of the thermal plume from Outfall 113. That is, for this no-flow event, it took between 3½ and 4½ hours for the warmest part of the thermal plume to spread and/or drift to the downstream edge of the passive mixing zone.

At each HOBO station, the temperature at the 5-foot compliance depth was determined by averaging the measurements for the sensors at depths 3, 5, and 7 feet. Plotted in Figure 7 is the resulting 5-foot temperature across the downstream end of the passive mixing zone, measured at the top of each hour from 7:00 CDT to 13:00 CDT. Note that the temperature profiles are shown as a dashed line between Station 9 and Station 11. This is because the temperature at Station 10 is based solely on the reading at the 5-foot depth, rather than an average of readings from sensors at the 3, 5 and 7-foot depths. The exception at Station 10 was necessary because of a connection failure, which caused the 3-foot sensor to float up to a level near that of the 0.5-foot sensor (see Station WB10 in Figure 6 and note that the measurements for the 3-foot sensor are about the same as those for the 0.5-foot sensor).

As shown in Figure 7, there is a shift in the concentration of heat from the right (SCCW) side of the river to the left (opposite) side of the river as the discharge spreads outward from Outfall 113. This is due to the momentum of the effluent jet from the outfall (i.e., in the absence of river flow). The aforementioned increase in temperature between 11:00 CDT and 12:00 CDT is apparent. Since heat from the outfall is distributed across the full width of the river, data from all of the HOBO stations were used in computing the NPDES compliance parameters, which is consistent with the dimensions of the passive mixing zone (e.g., as shown in Figure 1).

The compliance parameters examined include those summarized in Table 1: the temperature at the downstream edge of mixing zone, T_d; the temperature rise from upstream to the downstream edge of the mixing zone, ΔT; and the temperature rate-of-change at the downstream edge of the mixing zone, TROC. Following the criteria specified in the NPDES permit, the fundamental equations used to compute the compliance parameters are provided in Appendix A. The temperature at the downstream end of the mixing zone was determined from the HOBO measurements (i.e., average of sensors at depths 3, 5, and 7 feet for all twelve HOBO stations). The temperature rise was computed as the difference between the temperature at the downstream end of the mixing zone and the upstream temperature measured at Station 30. The temperature rate-of-change was determined by the change in the temperature at the downstream end of the mixing zone from one reading to the next. The data were averaged over a period of one hour using 15-minute readings, as specified in the NPDES permit, and compared with the WBN thermal plume model. The results are presented in Figure 8. For the HOBO measurements, it takes at least one hour before enough data is available to compute one-hour averages as specified in the NPDES permit. In Figure 8, the "spin-up" period, wherein averages are computed with fewer data than specified in the permit, is represented by a dashed line. The following comments are provided.

- Temperature at the downstream edge of the passive mixing zone, T_d: The maximum T_d estimated by the thermal plume model was 79.8°F, whereas the maximum measured value was 79.5°F. Thus, the model slightly overestimated the maximum T_d for the no flow event. Compared to the actual measurements, the response of the river temperature to the no flow event was estimated to occur much more rapidly in the model. This is because the model is formulated in a quasi-unsteady manner, wherein the river is assumed to change from one steady-state condition to the next within one hour, in response to the changes in operation of the river and/or Outfall 113. That is, the model assumes that impacts due to changes in the river and/or Outfall 113 are fully realized within one hour; whereas in reality, the actual time for the development of such impacts is much longer, at least for events with little or no river flow.

- Temperature rise, ΔT: The maximum ΔT estimated by the plume model was 2.0 F°, whereas the maximum measured value was about 1.0 F°. Thus, the model overestimated the temperature rise. This primarily is due to the fact that the model does not include heating of the upstream ambient water. In reality, the upstream ambient water temperature increased by about 0.8 F° in the span of the survey (e.g., see Figure 4). For the reason cited above (i.e., quasi-unsteady formulation), the model estimated the temperature rise to occur sooner than that found by the actual measurements.

- Temperature rate-of-change, TROC: The maximum TROC estimated by the plume model was +0.4 F°/hour, whereas the maximum measured was +0.7 F°/hour. Thus, the model underestimated the temperature rate-of-change. The exact reason for this discrepancy cannot be fully discerned from the available data. It is known that the maximum TROC occurred in connection with the rapid change in downstream temperature observed between 11:00 CDT and 12:00 CDT. This change likely was due to dynamic phenomena in the river not included in the model. For example, between 11:00 CDT and 12:00 CDT, the 10-meter wind speed dropped from over 5 mph to below 2.5 mph. This, perhaps in connection with other unsteady "sloshing' in the reservoir, accelerated the movement and/or spreading of the thermal plume beyond that estimated by the calm, quiescent conditions assumed in the model. The maximum TROC also occurred earlier in the model than that observed by the actual measurements. Both were well below the NPDES limit of ±3.6 F°/hour.

CONCLUSIONS

The survey of July 29, 2005, was successful in measuring the NPDES water temperature parameters for summertime conditions of the Outfall 113 passive mixing zone. The measurements were compared with values estimated by the thermal plume model currently used to determine the safe operation of the SCCW system when there is no flow in the river from WBH. Overall, the model was found to be conservative for estimating the impact of Outfall 113 on the temperature, T_d, and temperature rise, ΔT, at the downstream end of the passive mixing zone. This is because the model overestimated the maximum value measured for these parameters, and hence will tend to enforce the operation of Outfall 113 at levels of T_d, and ΔT below the NPDES limits. The thermal plume model, however, was not conservative in estimating the temperature rate-of-change, TROC. This is because the model underestimated the measured maximum TROC by 0.3 F°/hour (i.e., +0.7 F°/hour measured vs. +0.4 F°/hour predicted). This discrepancy likely is due to phenomena in the river that are not represented in the thermal plume model, such as unsteady sloshing in the reservoir and/or the impact of wind. Under these conditions, until further notice, a factor of safety of 0.3 F°/hour will be used in the model for estimating the maximum value of TROC. That is, the safe operation of Outfall 113 for the passive mixing zone will be evaluated based on a maximum value of TROC of ±3.3 F°/hour rather than ±3.6 F°/hour. In general, this action will have only a minimum impact on the operation of the SCCW, since the operation of the SCCW tends to be controlled primarily by the NPDES limit for ΔT, not the limit for TROC.

REFERENCES

McCall, Michael J., and P.N. Hopping, "Winter 2005 Compliance Survey for Watts Bar Nuclear Plant Outfall 113 Passive Mixing Zone," TVA River Operations, Report No. WR2005-2-85-151, October 2005.

TDEC, *State of Tennessee NPDES Permit No. TN0020168*, Tennessee Department of Environment and Conservation, November 2004.

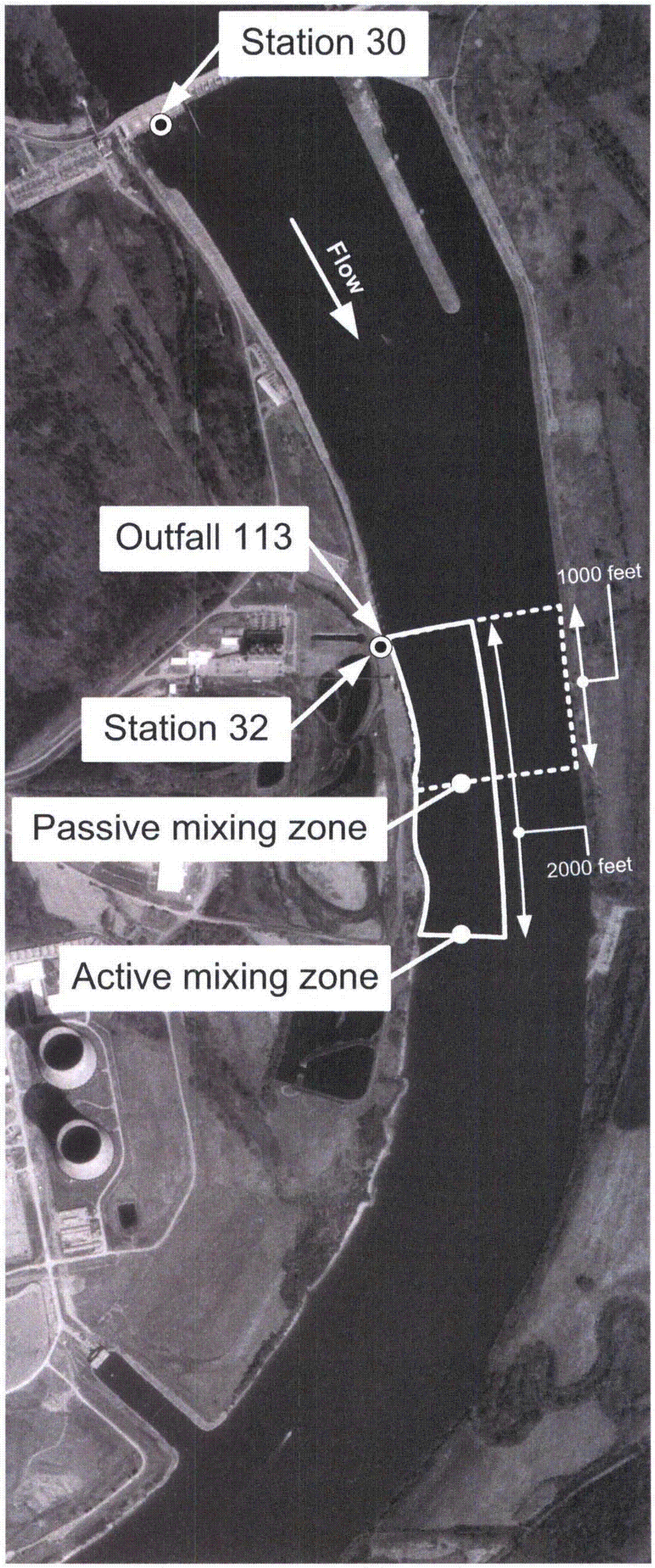

Figure 1. Watts Bar Nuclear Plant Outfall 113 (SCCW) Mixing Zones

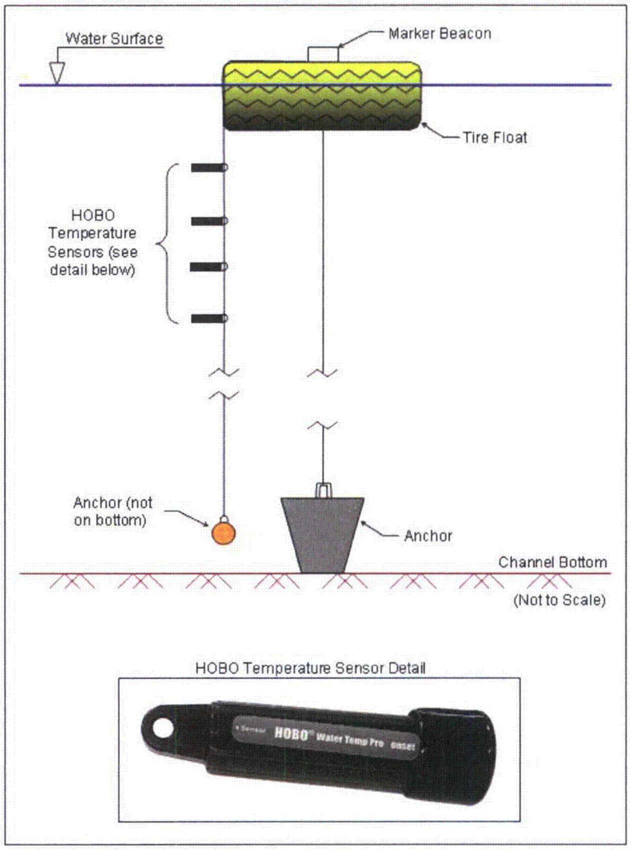

Figure 2. Schematic of HOBO Water Temperature Monitoring Stations

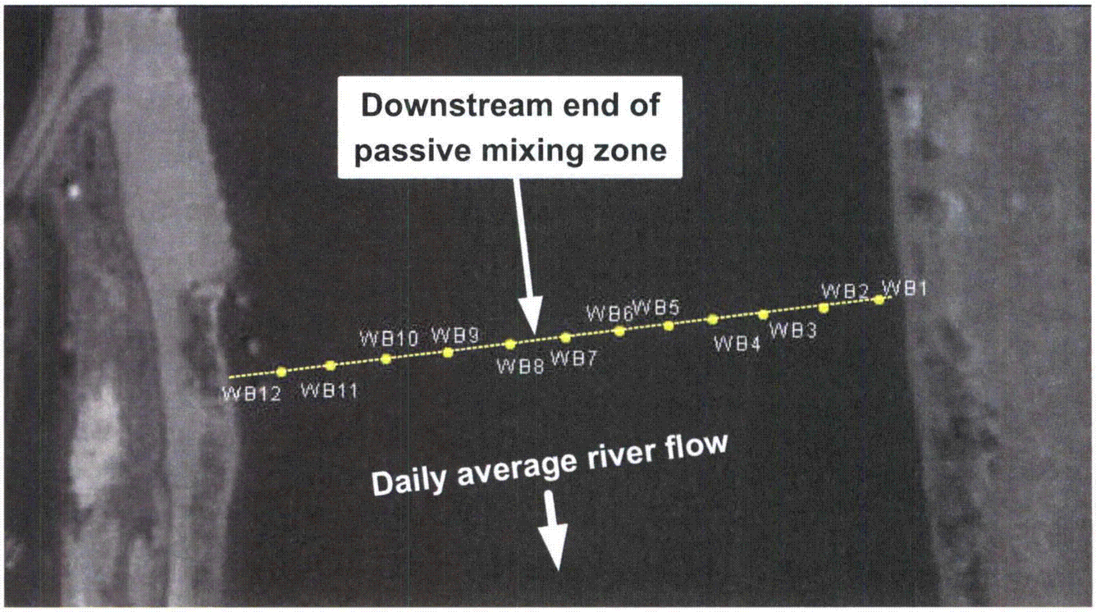

Figure 3. Location of HOBO Monitoring Stations

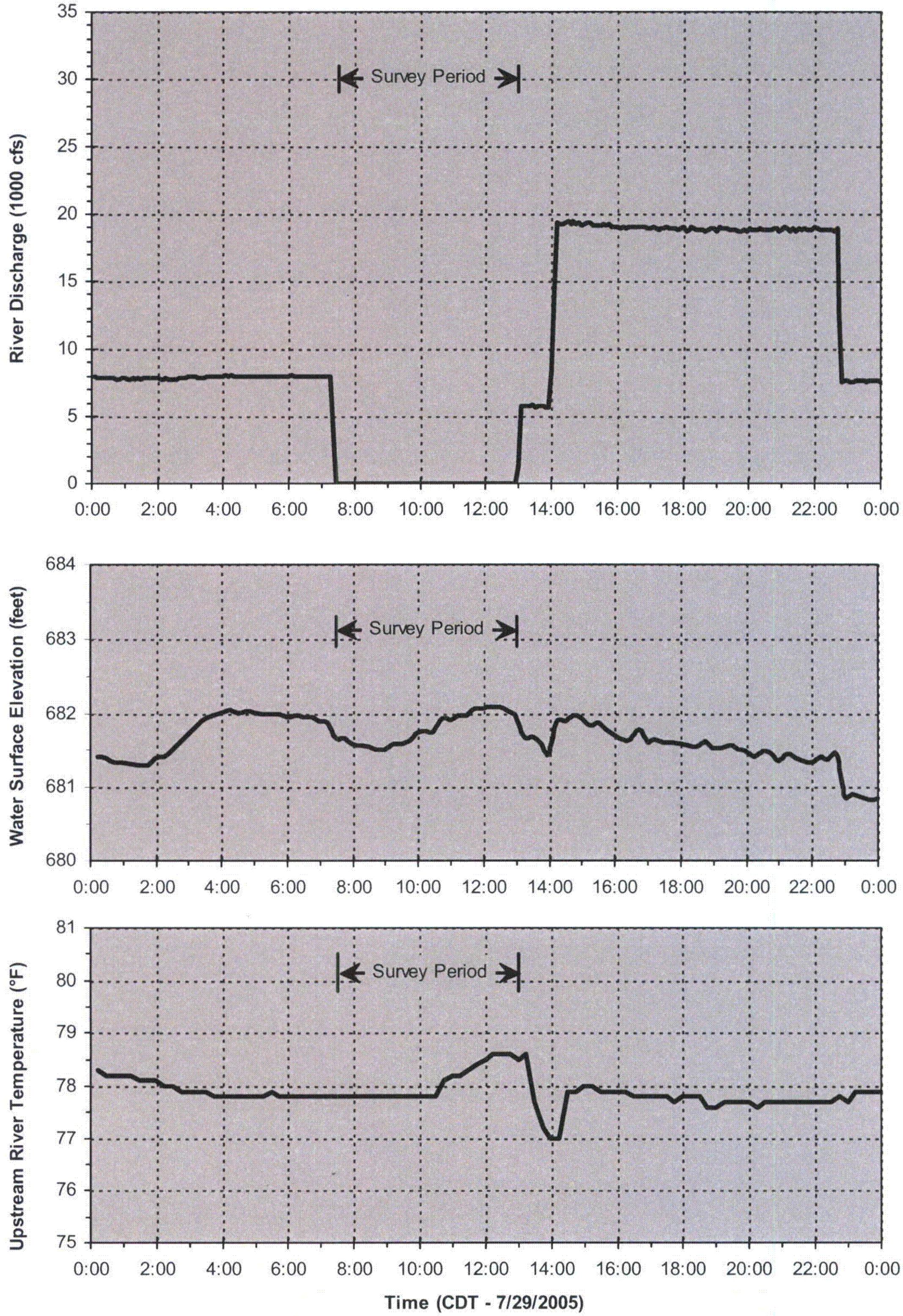

Figure 4. River Conditions

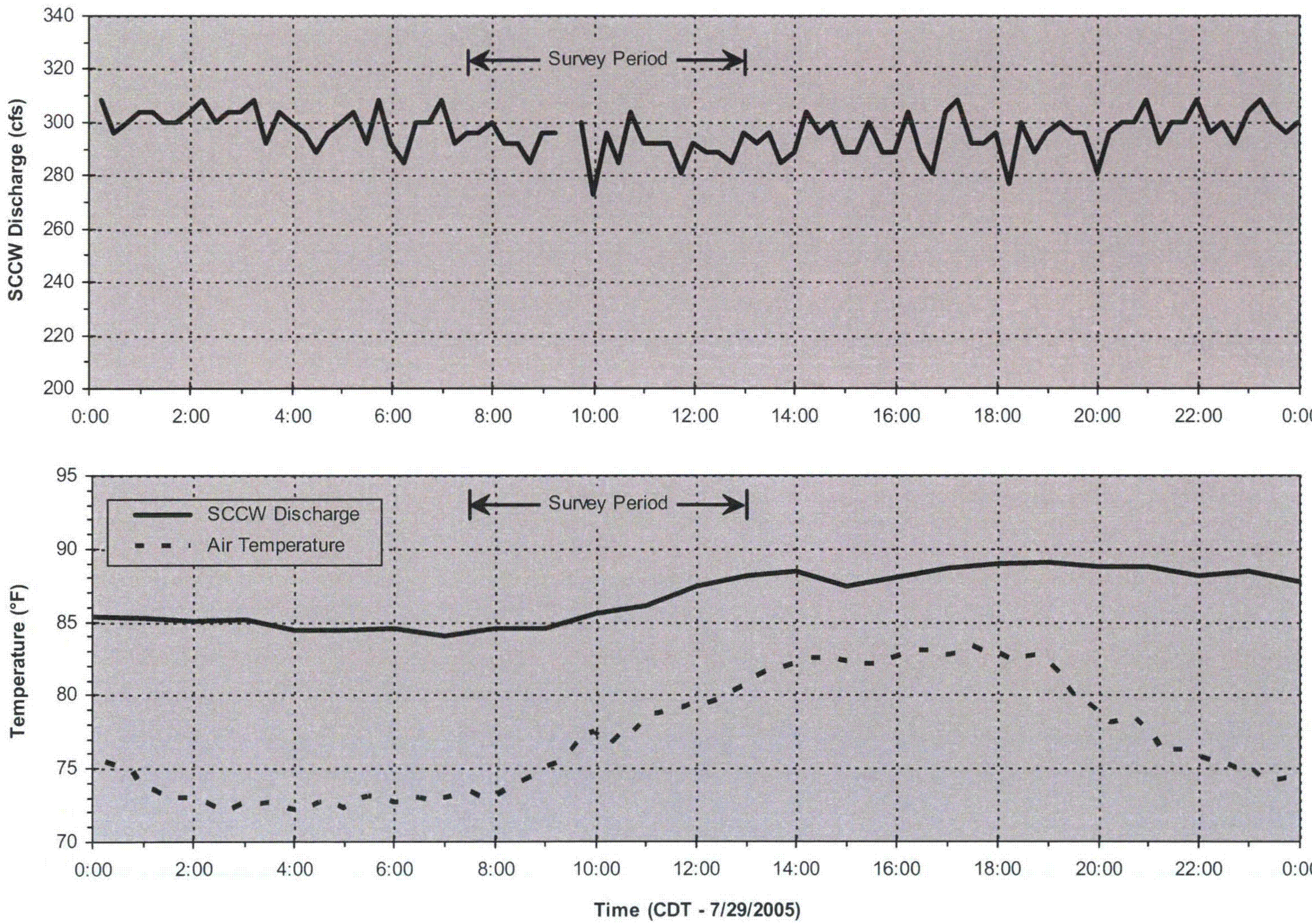

Figure 5. SCCW Conditions and Air Temperature

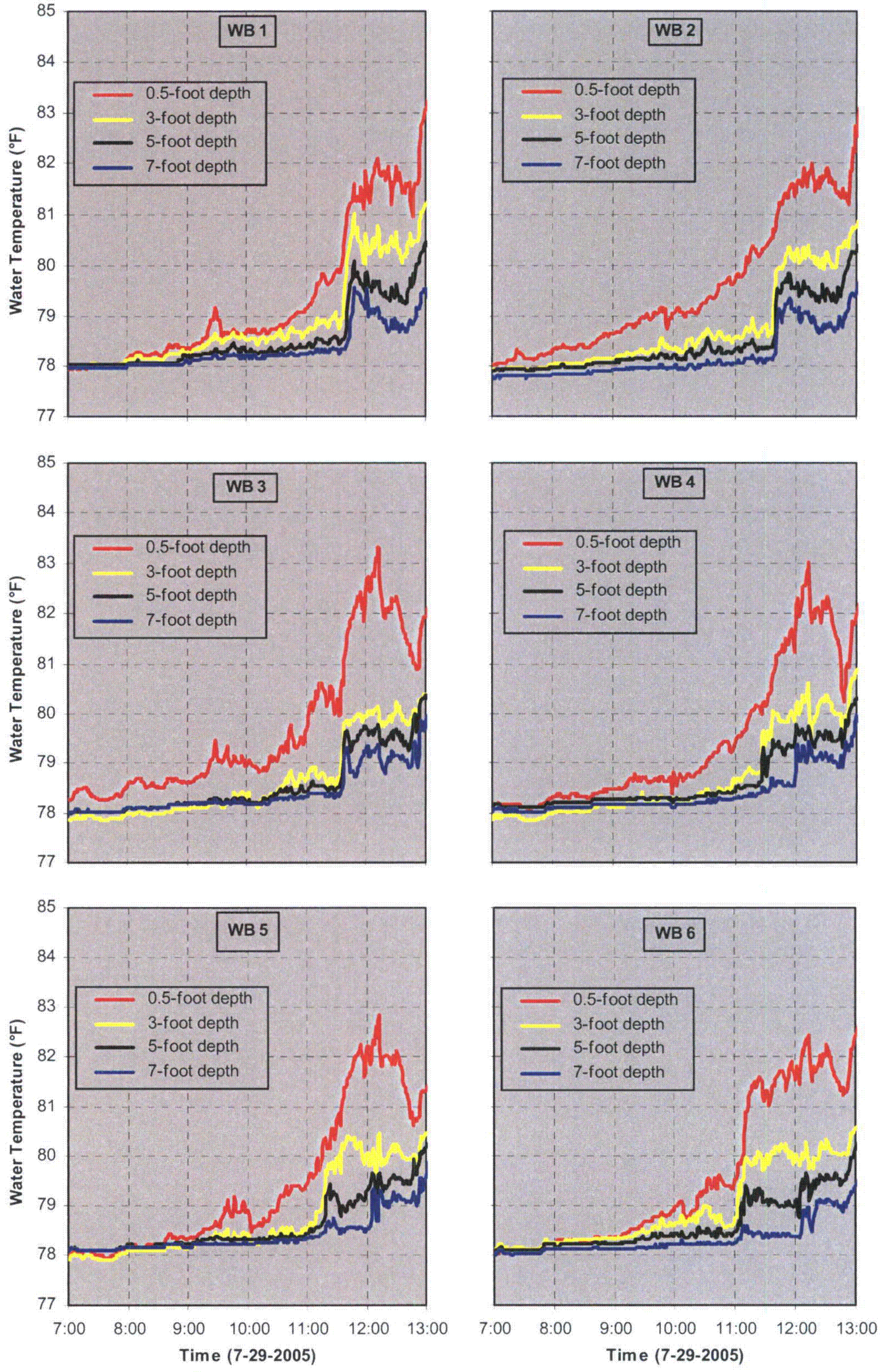

Figure 6. HOBO Water Temperature Measurements during Survey

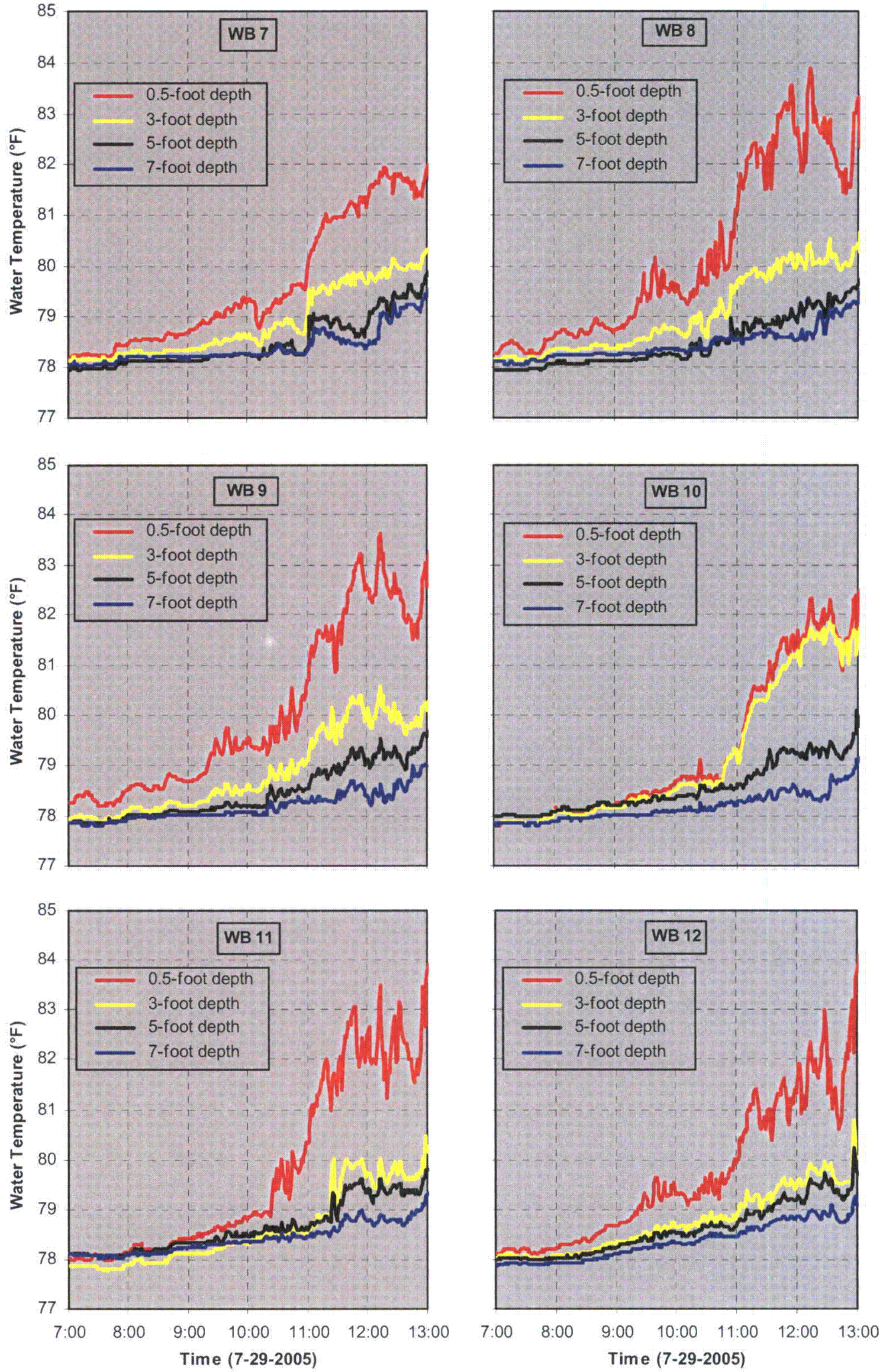

Figure 6 (Continued). HOBO Water Temperature Measurements during Survey

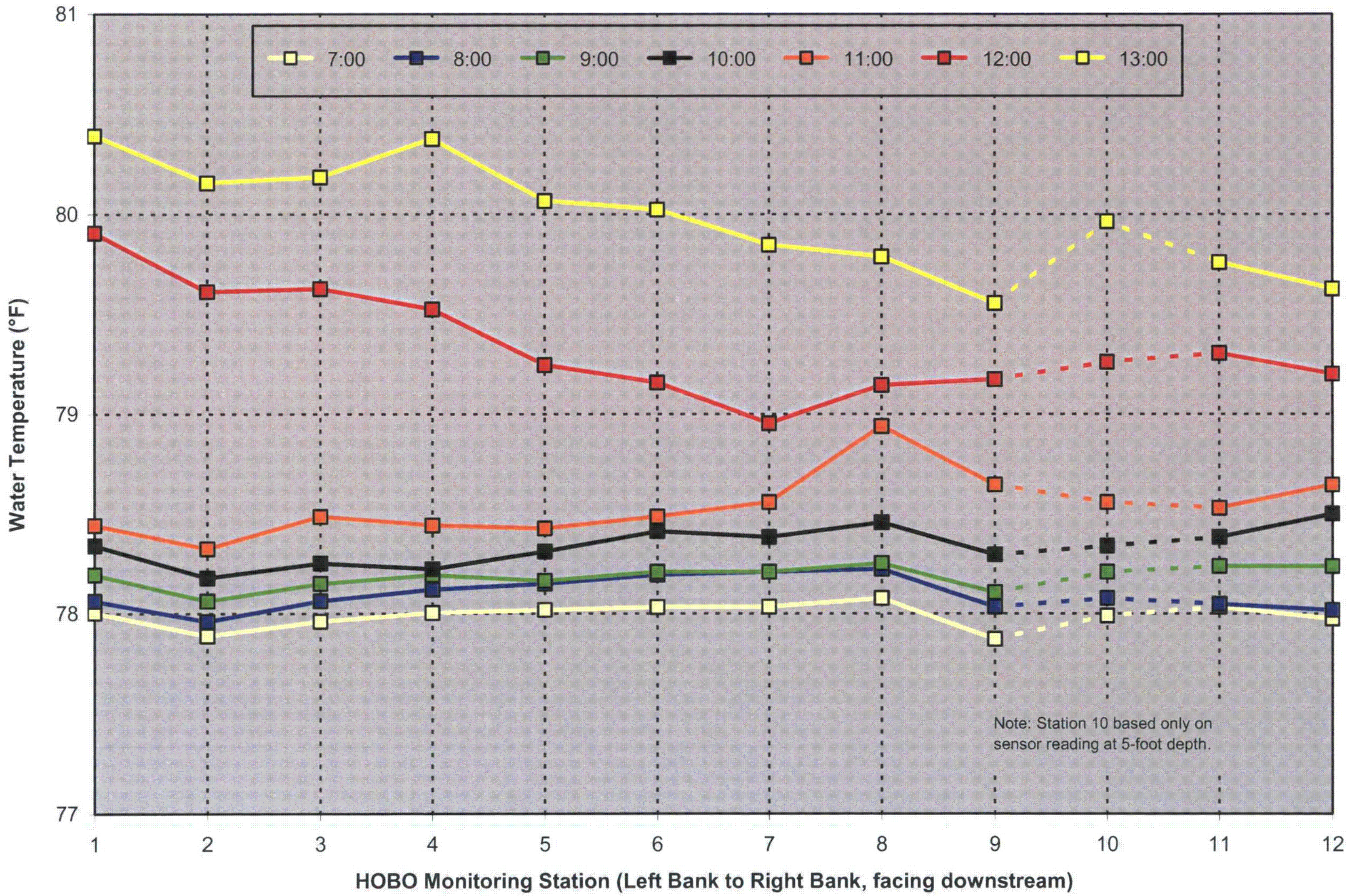

Figure 7. Profiles of Average Temperature at 5-Foot Compliance Depth across Downstream End of Passive Mixing Zone

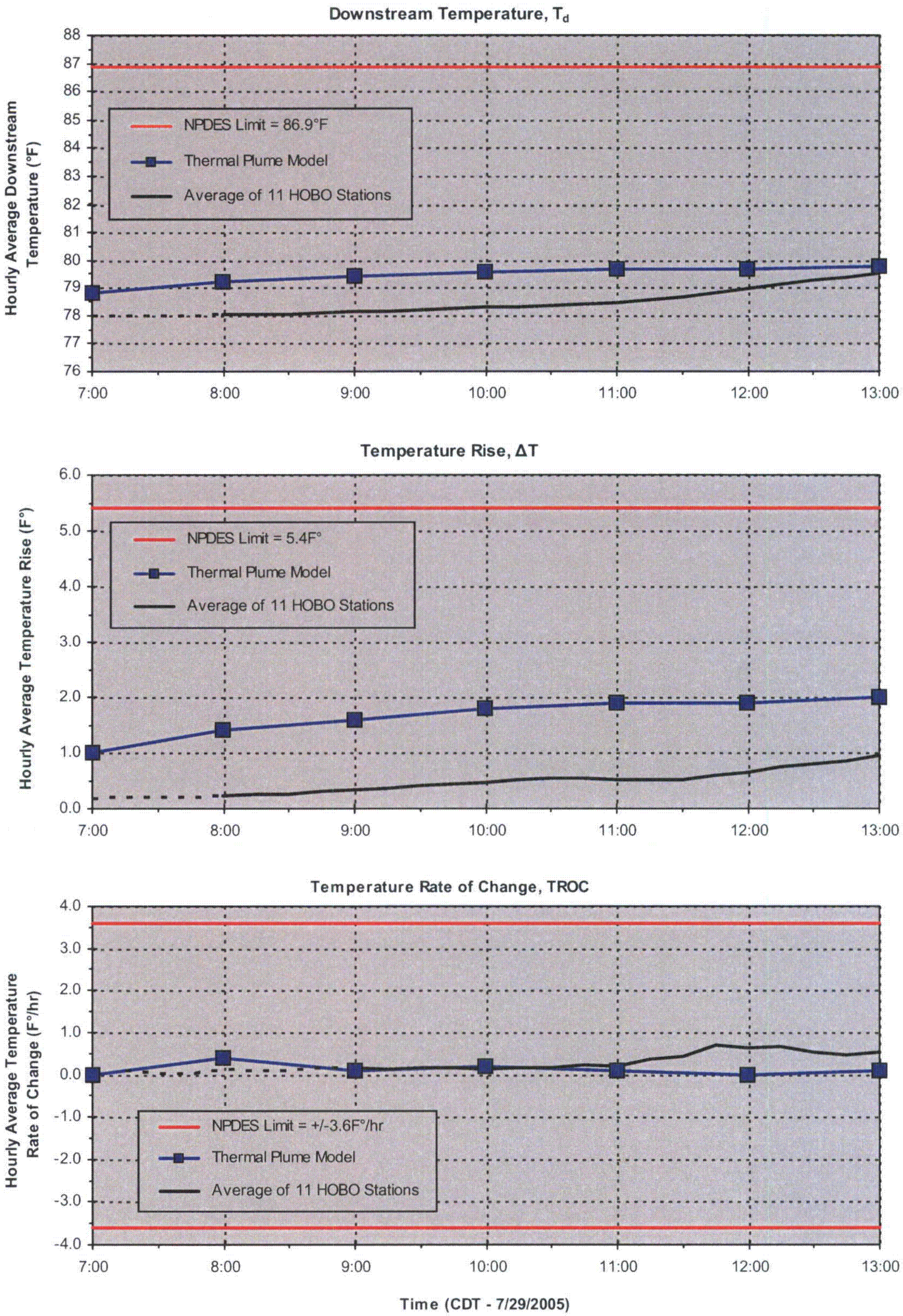

Figure 8. Measured and Computed Compliance Parameters for Passive Mixing Zone

APPENDIX A

WBN Outfall 113 NPDES Compliance Parameters

- Current Instantaneous Upstream Temperature:

  Tu_i (measured at EDS Station 30 by the first sensor below a depth of 5 feet)

- Current 1-Hour Average Upstream Temperature:

  $$Tu1_i = \frac{Tu_i + Tu_{i-1} + Tu_{i-2} + Tu_{i-3} + Tu_{i-4}}{5},$$

  where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of Tu

- Current Instantaneous Downstream Temperature:

  $$Td_i = \frac{Td3_i + Td5_i + Td7_i}{3},$$

  where $Td3_i$, $Td5_i$, and $Td7_i$ denote the current measurements of river temperature at the downstream end of the mixing zone at water depths 3 feet, 5 feet, and 7 feet, respectively

- Current 1-Hour Average Downstream Temperature:

  $$Td1_i = \frac{Td_i + Td_{i-1} + Td_{i-2} + Td_{i-3} + Td_{i-4}}{5},$$

  where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of Td

- Current Instantaneous Temperature Rise:

  $$\Delta T_i = Td_i - Tu_i$$

- Current 1-Hour Average Temperature Rise:

$$\Delta T1_i = \frac{\Delta T_i + \Delta T_{i-1} + \Delta T_{i-2} + \Delta T_{i-3} + \Delta T_{i-4}}{5},$$

where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of ΔT

- Current Temperature Rate-of-Change:

$$TROC_i = \frac{Td_i - Td_{i-1}}{0.25\ \text{hour}},$$

- Current 1-Hour Average Temperature Rate-of-Change:

$$TROC1_i = \frac{TROC_i + TROC_{i-1} + TROC_{i-2} + TROC_{i-3} + TROC_{i-4}}{5}$$

where the subscripts i, i-1, i-2, i-3, and i-4 denote the current and previous four 15-minute (0.25 hour) values of TROC

TENNESSEE VALLEY AUTHORITY
RIVER SYSTEM OPERATIONS & ENVIRONMENT

July 1999 Verification Study of Thermal Discharge for Watts Bar Nuclear Plant Supplemental Condenser Cooling Water System

WR99-2-85-143

Prepared by
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Engineering Laboratory
Norris, Tennessee

November 1999

EXECUTIVE SUMMARY

To protect aquatic habitat from waste heat discharged in freshwater receiving systems by industrial operations, water quality criteria for the state of Tennessee specifies limits for three instream thermal parameters, all defined from water temperatures at the 5-foot depth at the end of a mixing zone. As specified in the National Pollutant Discharge Elimination System (NPDES) Permit No. TN0020168[1] for Watts Bar Nuclear Plant, these limits are:

- Maximum increase in river temperature from ambient ΔT = 5.4 F° (3.0 C°),
- Maximum downstream river temperature T_d = 86.9°F (30.5°C), and
- Maximum rate-of-change of river temperature dT_d/dt = 3.6 F°/hour (2.0 C°/hour).

For Watts Bar Nuclear Plant (WBN), TN0020168 also requires that the river bottom temperature at the outside edge of a mussel relocation zone (MRZ), a rectangular region extending 150 feet from the right bank and 75 feet upstream and downstream of the centerline of Outfall 113, not exceed 33.5°C (92.3°F), and that the flow direction near the river bottom at the upstream edge of this zone be continuously monitored. In general, the overall extent of the mixing zone created by the waste heat shall provide a safe zone of passage for fish and other aquatic wildlife.

To help verify compliance with these criteria, the results of a field survey of the thermal discharge from Outfall 113 of the Watts Bar Nuclear Plant are summarized in this report. This outfall includes the WBN supplemental condenser cooling water (SCCW) system discharge channel at TRM 529.2. The measurements were performed in accordance to a request by the Tennessee Department of Environment and Conservation (TDEC) that a survey be conducted during the initial startup of the WBN SCCW system.

The survey was conducted on July 19, 1999. The objectives of the survey were to:

- Determine the three-dimensional configuration of the thermal plume,
- Substantiate the dispersion modeling,
- Assure conformance with the assigned thermal mixing zones, and
- Evaluate locations for upstream and downstream temperature monitors.

For each of these objectives, the following results and conclusions are given.

Three-Dimensional Configuration of Thermal Plume

The field survey was successful in documenting the three-dimensional configuration of the plume in the surface layer of the river (i.e., upper 2.0 meters/6.6 feet) for the ambient field conditions of July 19, 1999.

The configuration of the plume indicates that the WBN SCCW discharge is effectively mixed with the ambient river water for the conditions of July 19, 1999. This is demonstrated by the measured values of ΔT and T_d, both of which were well within the limits established by state water quality criteria.

Dispersion Modeling

The computed instream temperature rise, ΔT, and downstream temperature, T_d, are in good agreement with actual measurements.

Conformance with Assigned Thermal Mixing Zones

For Outfall 113, the longitudinal dimensions of 1,000 feet downstream of the discharge appears to encompass a sufficient volume of the river to dilute the thermal discharge from WBN to below the instream limits for ΔT and T_d.

For the ambient conditions on July 19, 1999, the near-field configuration of the discharge plume lies near the right side (looking downstream) of the assigned thermal mixing zone, allowing a substantial portion of the river for passage of aquatic wildlife.

Evaluate Locations for Upstream and Downstream Temperature Monitors

Based on observed and anticipated water flow patterns in the tailrace of Watts Bar Dam, the best location for the upstream temperature monitor was determined to be between the 2nd and 3rd discharge bay (looking downstream) of the Unit 3 draft tube.

Based on observed data and modeling results, the best location for a single downstream monitor was determined to be at the end of the mixing zone, 1000 feet downstream of Outfall 113, and between 300 to 400 feet from the right bank (looking downstream).

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JULY 1999 VERIFICATION STUDY OF THERMAL DISCHARGE FOR WATTS BAR NUCLEAR PLANT SUPPLEMENTAL CONDENSER COOLING WATER SYSTEM

1.0 INTRODUCTION

The National Pollutant Discharge Elimination System (NPDES) Permit No. TN0020168 for Watts Bar Nuclear Plant (WBN) provides effluent limitations and monitoring requirements for Outfall 101 (Diffuser Pipe at TRM 527.9), Outfall 102 (Emergency Overflow to TRM 527.2), and Outfall 113 (SCCW Discharge at TRM 529.2). The permit specifies that the Tennessee Valley Authority (TVA) shall conduct temperature modeling studies to determine appropriate daily average discharge temperatures from these outfalls to assure compliance with the state water quality criteria for instream temperature. The instream criteria, defined at the end of the mixing zone at a depth of 5 feet, are:

- Maximum increase in river temperature from ambient ΔT = 5.4 F° (3.0 C°),
- Maximum downstream river temperature T_d = 86.9°F (30.5°C), and
- Maximum rate-of-change of river temperature dT_d/dt = 3.6 F°/hour (2.0 C°/hour).

For Outfall 113, these limits are to be applied at the downstream end of a mixing zone, which extends the width of the river and 1000 feet downstream of the Outfall 113 centerline. In addition to these limits, TN0020168 requires that the river bottom temperature at the outside edges of a mussel relocation zone (MRZ), a rectangular region extending 150 feet from the right bank and 75 feet upstream and downstream of the centerline of Outfall 113, not exceed 33.5°C (92.3°F), and that the flow direction near the river bottom at the upstream edge of this zone be continuously monitored.

The supplemental condenser cooling water (SCCW) system of Watts Bar Nuclear Plant, which discharges heated water from Outfall 113, began operation on July 19, 1999. This report presents the results of a water temperature field survey of the Outfall 113 thermal discharge conducted on July 19, 1999. The objectives of the survey were to:

- Determine the three-dimensional configuration of the thermal plume,
- Substantiate the dispersion modeling for the environmental assessment of this discharge,
- Assure conformance with the assigned thermal mixing zones, and
- Evaluate locations for upstream and downstream temperature monitors.

Summarized herein are the results of the field survey. The hydrothermal conditions of the survey are presented first. Subsequent discussions are given for the test procedures, analysis of data, and results of model comparisons. The conclusions provide summary interpretations of the survey results relative to each of the objectives listed above.

2.0 HYDROTHERMAL CONDITIONS

The hydrothermal conditions for the survey period are shown in Figure 1. The release from Watts Bar Hydro (WBH) was constant at about 33,000 cfs for the entire period. The ambient river temperature, measured at the WBN Unit 1 intake, slowly increased through the survey period from about 76.1°F to 76.7°F. Air temperatures were measured at the WBN meteorological data tower. The dry bulb temperature ranged from 79.0°F to 86.5°F during the survey period, with wet bulb temperature ranging from 71.7°F to 79.8°F.

3.0 TEST PROCEDURE

The primary device used to measure water temperature in the field survey was an array of resistance temperature detectors (RTDs) mounted on a streamlined support at depths of 0.5 m, 1.0 m, 1.5 m, and 2.0 m (1.6 ft, 3.3 ft, 4.9 ft, and 6.6 ft). This RTD array, suspended in the water from TVA's hydrothermal survey boat (Figure 2), collects temperature data at approximately 25-foot intervals along the path of the vessel. The location of the measurements is obtained with a global positioning system (GPS) receiver.

During the field survey of July 19, 1999, measurements from the RTD array were collected as the survey boat moved along a series of transects in the region including the Outfall 113 discharge mixing zone.

Vertical profiles of water temperature were measured at the upstream and downstream edges, and at the center of the mussel relocation zone (MRZ). This required an extra effort to accurately position the boat during each profile measurement. For this reason, the winch-mounted S4 multi-function probe, shown in Figure 2, was replaced with an anchor in an attempt to maintain the position of the survey boat in the river current. The electronically controlled winch was used to raise and lower the anchor, and to control the length of the anchor cable. The vertical temperature profiles were obtained with a Hydrolab DataSonde 4 multi-parameter probe, manually deployed from the hydrothermal survey boat. The Hydrolab probe also was used to gather temperature profiles at other selected locations in the mixing zone. Temperature, depth, and time of measurement were recorded automatically as the probe was raised from the bottom to the surface at each measurement point. The horizontal position of each profile was obtained from the GPS receiver on the survey boat.

Vertical profiles of river velocity in the mussel relocation zone were measured with an acoustic-doppler current profiler (ADCP) at the same locations as the vertical profiles of water temperature. While transversing the mixing zone with the RTD array, the ADCP also was used to obtain backup measurements of the total river flow.

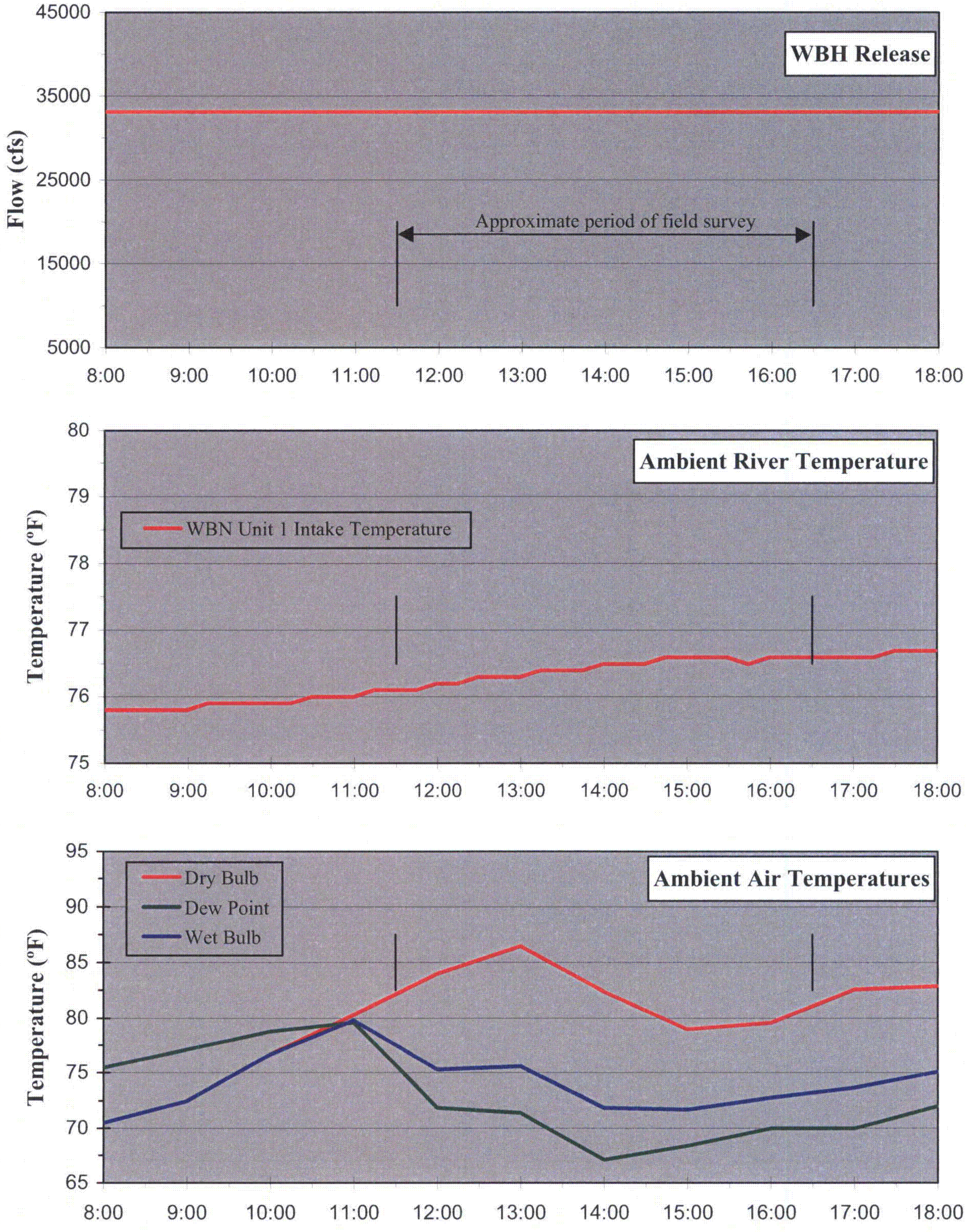


Figure 1. Ambient Conditions on July 19, 1999

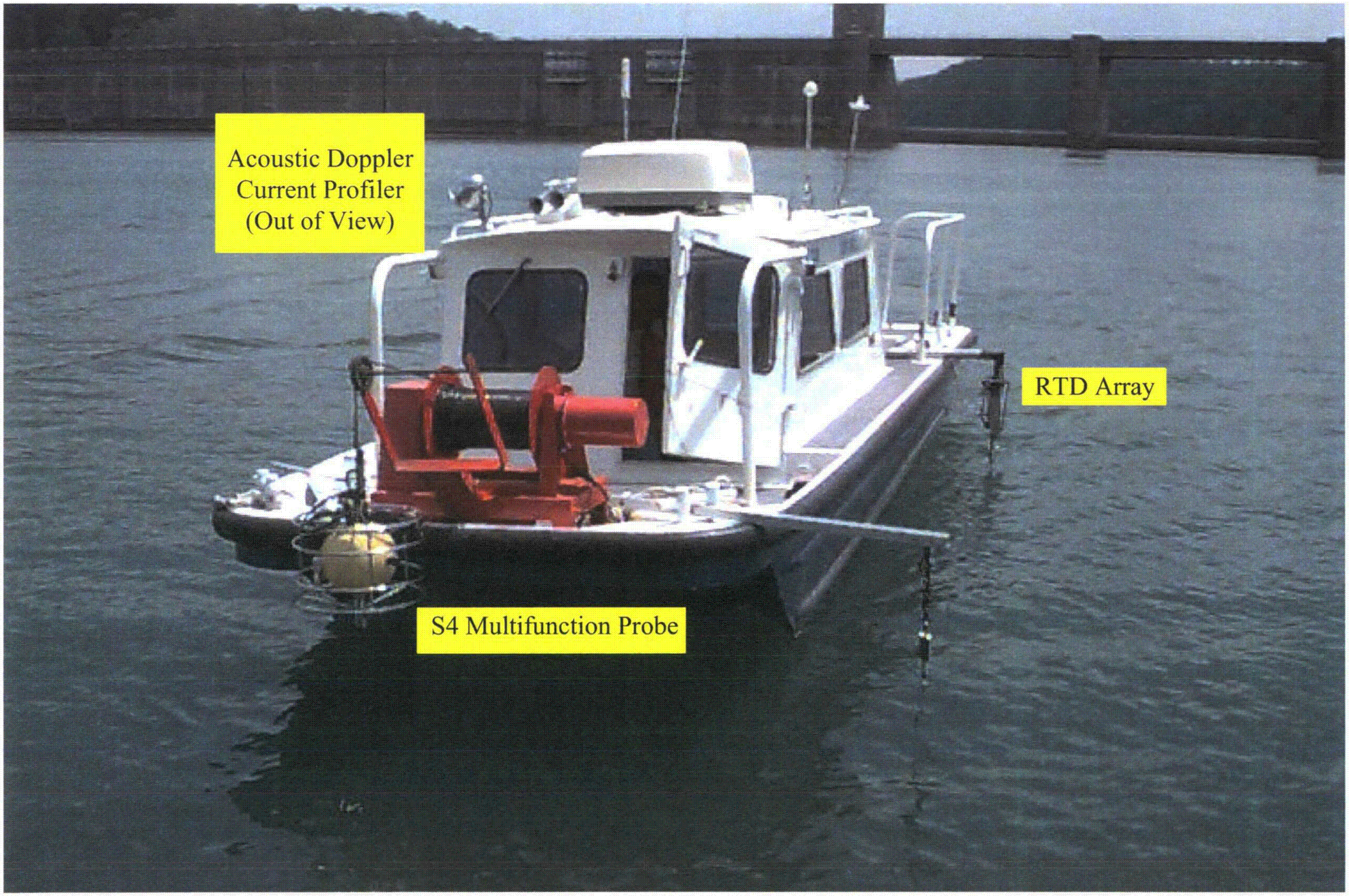


Figure 2. TVA Hydrothermal Survey Boat

4.0 FIELD CONDITIONS

Field conditions during the time of the survey are summarized in Table 1.

TABLE 1

Field Conditions on July 19, 1999 - 1100 a.m. - 1700 p.m. EDT

River Flow[a]	33,000 cfs
River Elevation[a]	683.3 ft
Watts Bar Headwater Elevation[a]	740.8 ft
Wind Speed (avg)[b]	3.0 mph
Wind Direction (avg)[b]	131 deg
Dry Bulb Air Temperature (max)[b]	86.5°F
Dry Bulb Air Temperature (avg)[b]	82.1°F
Dew Point (max)[b]	79.6°F
Dew Point (avg)[b]	71.2°F
Intake Temperature (max)[c]	76.6°F
Intake Temperature (avg)[c]	76.4°F
SCCW Discharge Flow[d,e]	204 cfs
SCCW Discharge Temperature (max)[e]	86.9°F

[a]River flow and elevations computed from River System Operations data for Watts Bar and Chickamauga Dams and verified by measurement with acoustic doppler profiler.
[b]From recorded WBN met data. Wind direction is measured clockwise from the north, and represents the direction from which the wind is blowing.
[c]From recorded WBN thermal compliance data.
[d]SCCW discharge flow was less than the expected value of 278 cfs due to air temporarily trapped in discharge piping.
[e]Data provided by WBN System Engineering, for conditions during period of full heat load.

The condition of the SCCW system during the survey is illustrated in Figure 3. Flow through the system was initiated shortly after 1000 by opening the bypass connecting the SCCW supply and discharge conduits. Shortly after 1300 the discharge valve from the Unit 1 cooling tower basin was slowly opened to begin adding heat to the flow. At about 1425, the bypass was closed so that the SCCW discharge was fully supplied by heated water from the plant. Shortly

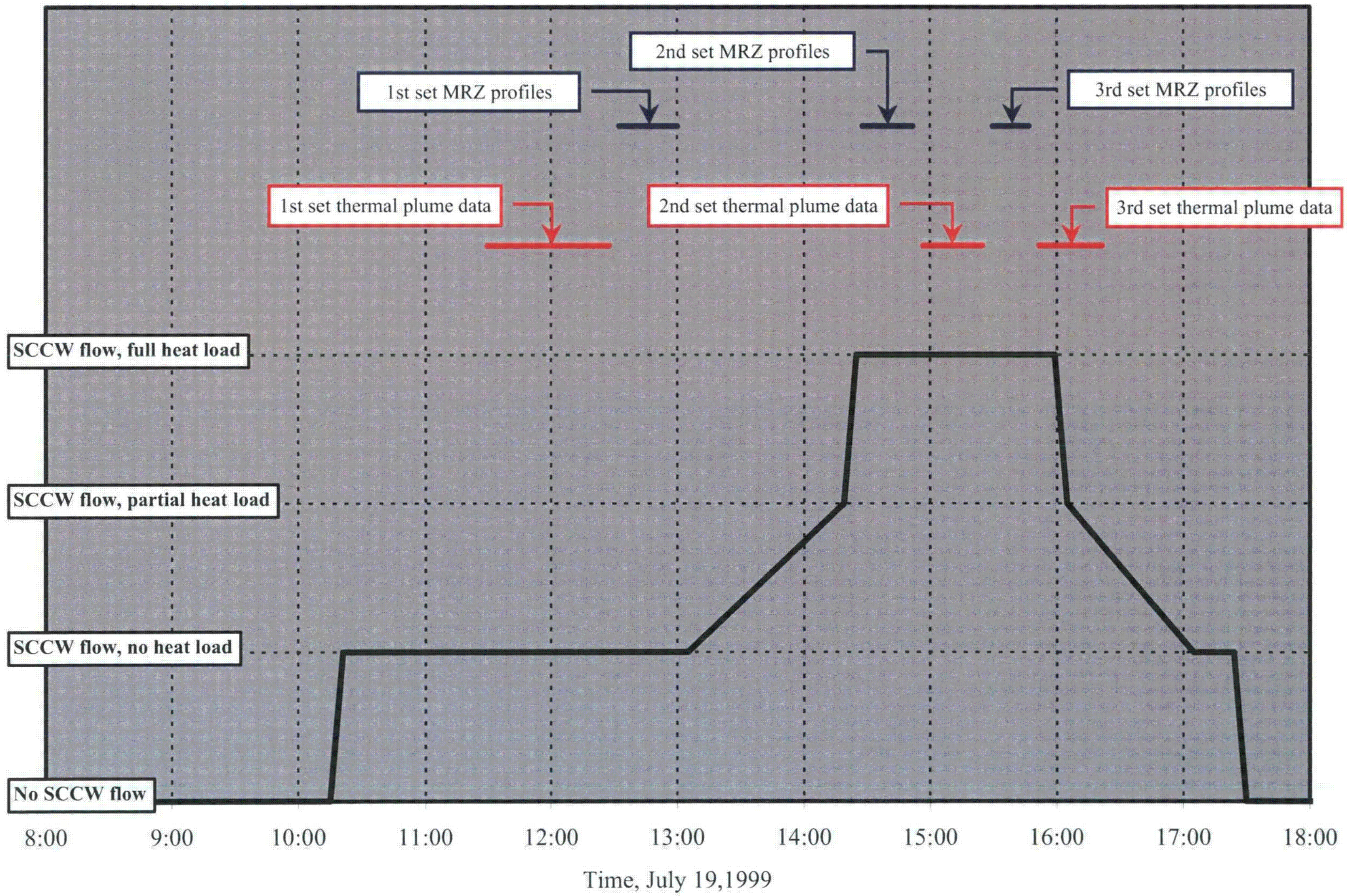


Figure 3. Operation of SCCW System During Survey Period

after 1600 the bypass was opened, thereby diluting the heated flow in the same manner as between 1300 and 1425. Shortly after 1700 the discharge valve from the Unit 1 cooling tower basin was closed so that the SCCW discharge was supplied solely by the cool bypass flow. At 1730 the bypass was closed, suspending all flow through the SCCW system.

5.0 DATA ANALYSIS AND RESULTS

Hydrothermal data were collected throughout the survey period. Relative to the condition of the SCCW system, the intervals of data collection are shown in Figure 3. Three sets of measurements with the RTD array were taken to map the thermal plume. For the first, taken around noon, the SCCW system was operating with no heat added to the discharge. In the second, beginning shortly before 1500, the SCCW discharge was fully supplied by heated flow from the plant. In the third, beginning shortly before 1600, the SCCW discharge initially was fully supplied by heated flow from the plant, but later was diluted by the bypass. It is noted that despite this reduction in the heat load, the "transient" operation of the SCCW system in the third set of measurements was not detected by the RTD array. This appears to be due to the fact that the measurements were taken upstream to downstream in advance of the "front" created by the change in thermal loading.

Using the Hydrolab probe and ADCP, three sets of data were also taken of full-depth temperature and velocity profiles in the MRZ. Each set was collected with the same SCCW conditions, respectively, as in the first, second, and third sets of the aforementioned measurements for the thermal plume. In the third set of MRZ profiles, the data were collected before the SCCW discharge was diluted by bypass flow.

The instream temperature rise for the first set of measurements with the RTD array is shown in Figure 4. Recall that these measurements were taken after startup of the SCCW system, but before heat was added to the flow. The data were taken at depths of 0.5, 1.0, 1.5, and 2.0 meters (1.6, 3.3, 4.9, and 6.6 feet). The instream temperature rise for the second and third sets of measurements with the RTD array is shown in Figure 5. These data sets were both collected with the SCCW discharge fully supplied by heated flow from the plant. For this reason, they have been combined to create a single image of the temperature rise for fully heated conditions. The following comments are provided.

- The temperature rise at each measurement point is computed as the difference between the measured temperature and an upstream reference temperature. The upstream reference temperature was computed by averaging the temperature measurements in the right-most 150 feet of the upstream-most transect. For both the pre- and post-heated discharge conditions, the reference temperature is 77.5°F.

- Before heat was added to the SCCW discharge, there was a transverse temperature gradient in the river, with the right side (facing downstream) measuring approximately 1 F° warmer than the left side (Figure 4). This indicates that the flow through the WBH

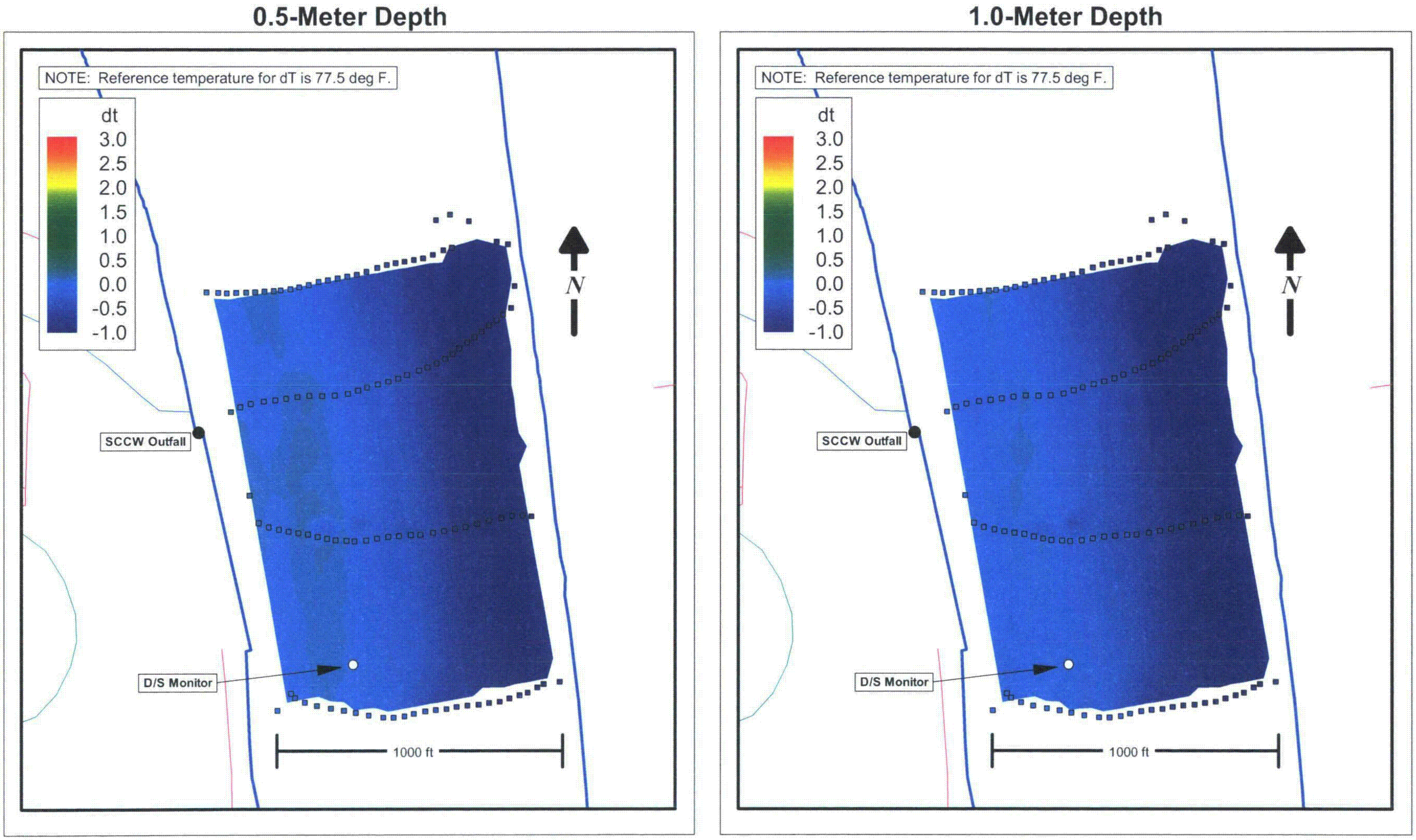
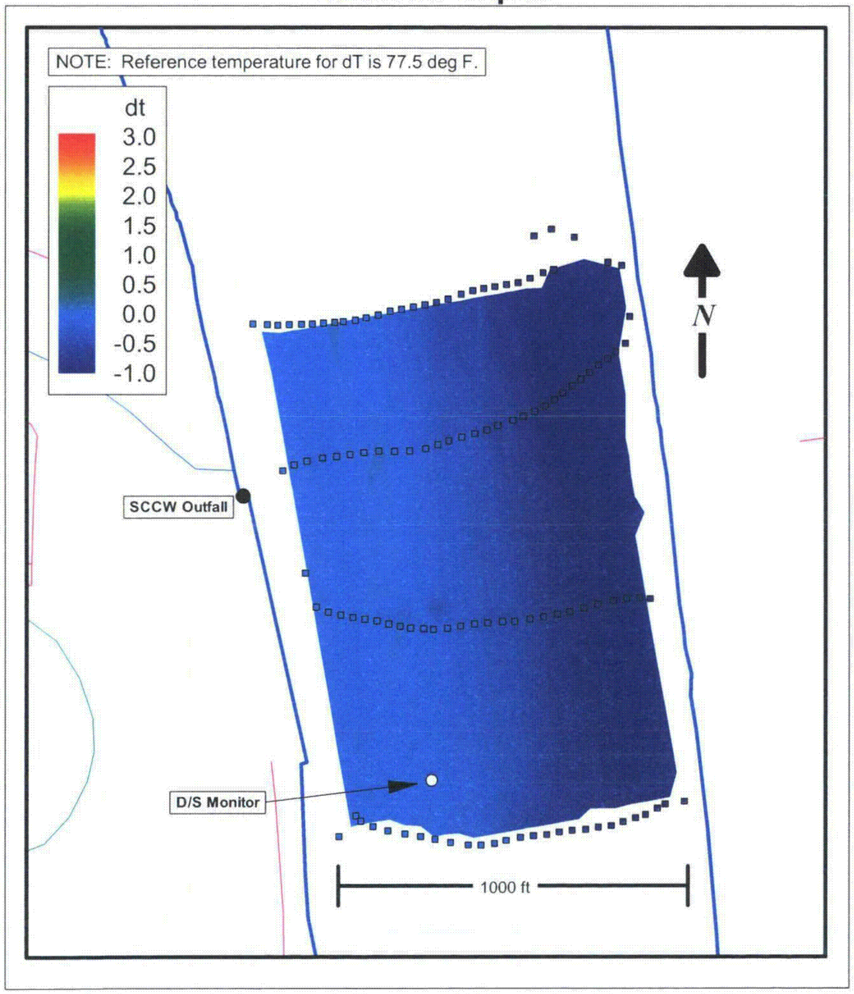


Figure 4. Measured Instream Temperature Rise Before Addition of Heat to SCCW Discharge

1.5-Meter Depth



2.0-Meter Depth

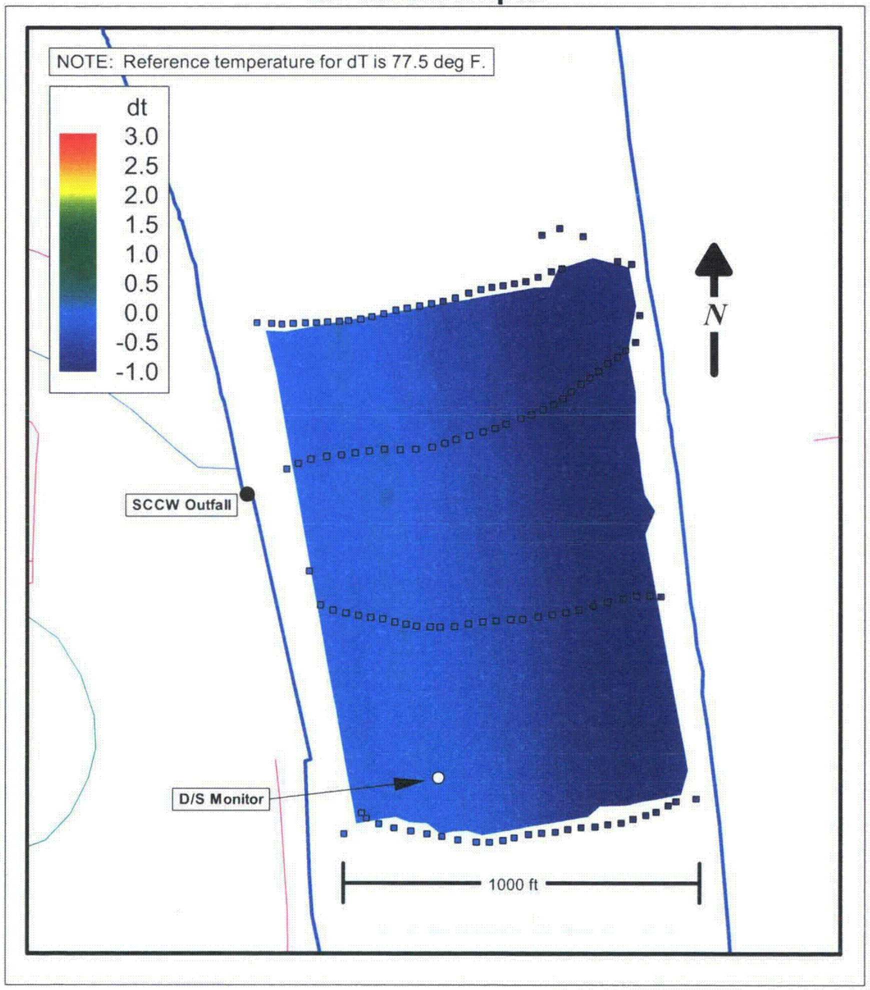


Figure 4 (continued). Measured Instream Temperature Rise Before Addition of Heat to SCCW Discharge

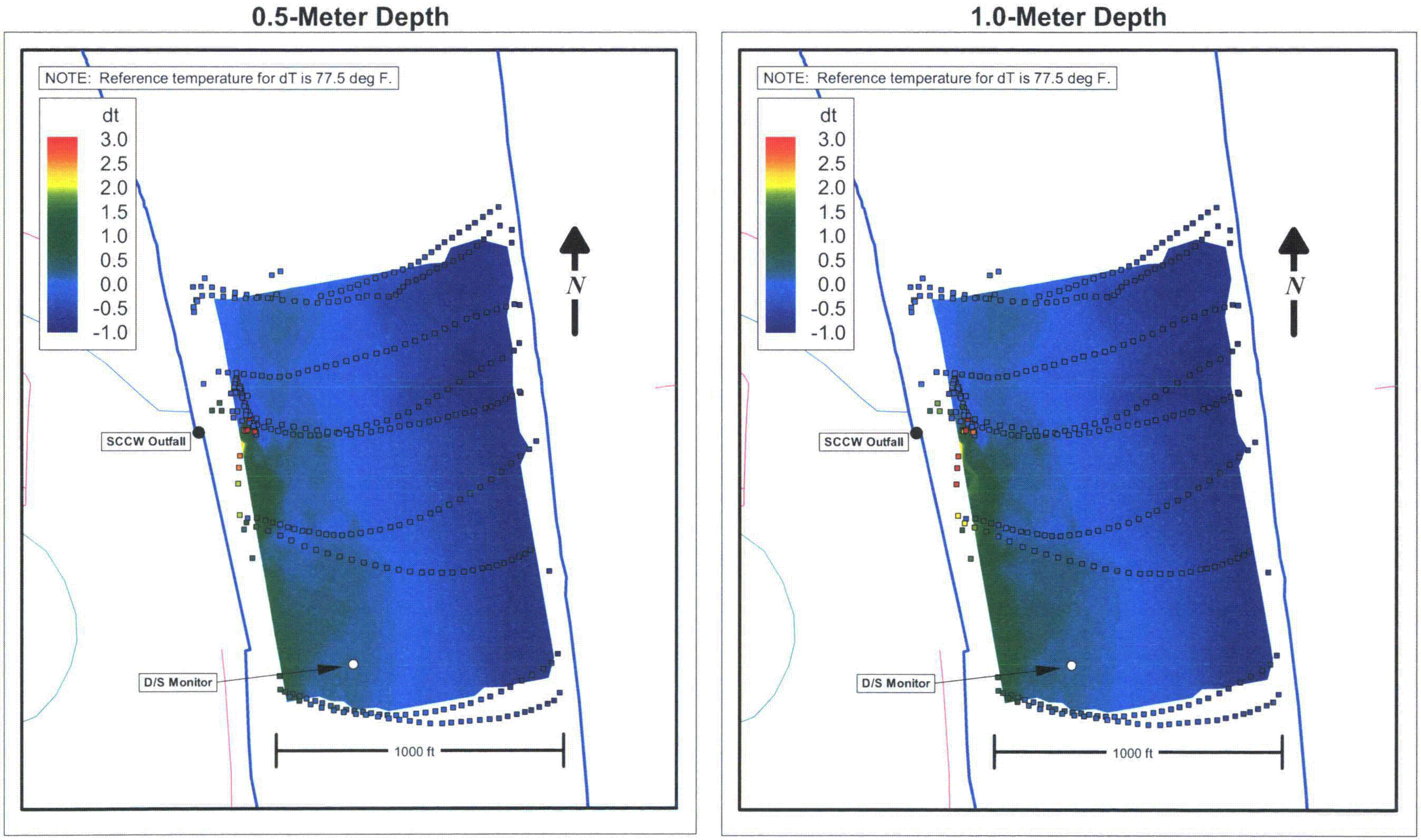


Figure 5. Measured Instream Temperature Rise After Addition of Heat to SCCW Discharge

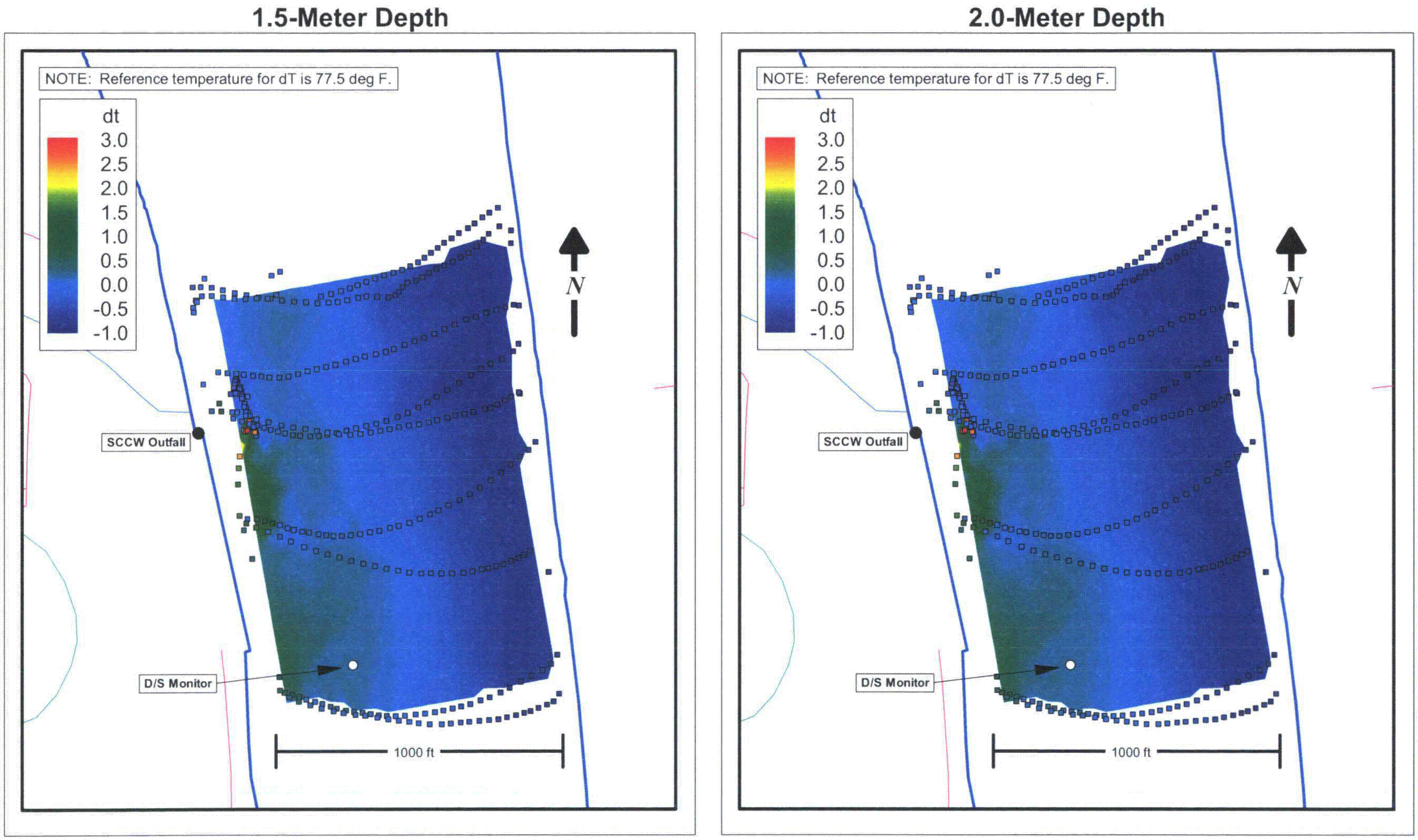


Figure 5 (continued). Measured Instream Temperature Rise After Addition of Heat to SCCW Discharge turbines was slightly warmer than the receiving water in Chickamauga Reservoir on the day of the survey.

- After heat was added to the SCCW discharge, the thermal plume from the Outfall 113 discharge followed the right river bank and spread transversely approximately 1/3 of the width of the river at the end of the 1,000-foot mixing zone (Figure 5). Within the plume, there was little variation in the vertical temperature distribution within the top 2 meters (6.6 feet) of the water column.

It is emphasized that the plots in Figures 4 and 5 represent "smeared" rather than "clear" images of the water temperature. A clear image would include the temperature at an instant in time. In contrast, the data in Figures 4 and 5 were collected over periods of at least 30 minutes (see Figure 3). In this manner, the figures represent "likely" rather than "exact" images of the thermal structure of the flow. For the conditions of Figure 5, if additional data sets were collected, the general location of the SCCW thermal plume would remain unchanged. The shape of the plume, however, would probably be different. This is due to turbulent eddies in the flow, which constantly contort the boundary between the warm SCCW discharge and the cool river flow. The same is true for Figure 4; however, due to the "mild" temperature and velocity gradients, a shifting boundary probably would not be discernible in additional data sets.

At the same time, it also is emphasized that Figures 4 and 5 should not be construed as "average" temperatures, as would be computed by numerical models such as CORMIX or PHOENICS. To obtain a distribution of the average temperature, long-term measurements would be required for each sampling station in the mixing zone. In contrast, the images in Figures 4 and 5 were obtained by a one-time measurement at each sampling station. The required duration of measurements to obtain a "good" average depends on the duration of temperature fluctuations. In Figure 4, the observed temperature fluctuations were insignificant, and hence these images probably strongly mimic average conditions. In Figure 5, however, measurements in the vicinity of the SCCW outfall indicate that the duration of temperature fluctuations created by turbulent eddies were of magnitude one minute. In this case, data collection would be required for perhaps as long thirty minutes. Although long-duration field measurements over large-scale areas are impractical with current instrumentation, data such as that shown in Figures 4 and 5 are good for providing integral properties of the SCCW thermal plume. For example, measurements at the 1.5-meter (5-foot) depth at the downstream end of the mixing zone will yield a good estimate of the instream compliance temperature. Even though the temperature distribution at this section will vary due to turbulence, the average across the plume will remain essentially constant, providing a good data for verifying integral properties obtained by numerical models.

The approximate locations of the MRZ profiles are shown in Figure 6. For each set of measurements, an attempt was made to collect data at fixed stations along the upstream edge, midpoint, and downstream edge of the MRZ. However, due to flow-induced movements of the MRZ buoys and the survey boat, the location of the measurement stations shifted between each set of profiles. Despite these movements, the stations were, for the most part, near the upstream, midpoint, and downstream edges of the MRZ. As shown, the second set of profiles was located closest to the shore, followed by the first set, and then the third set.

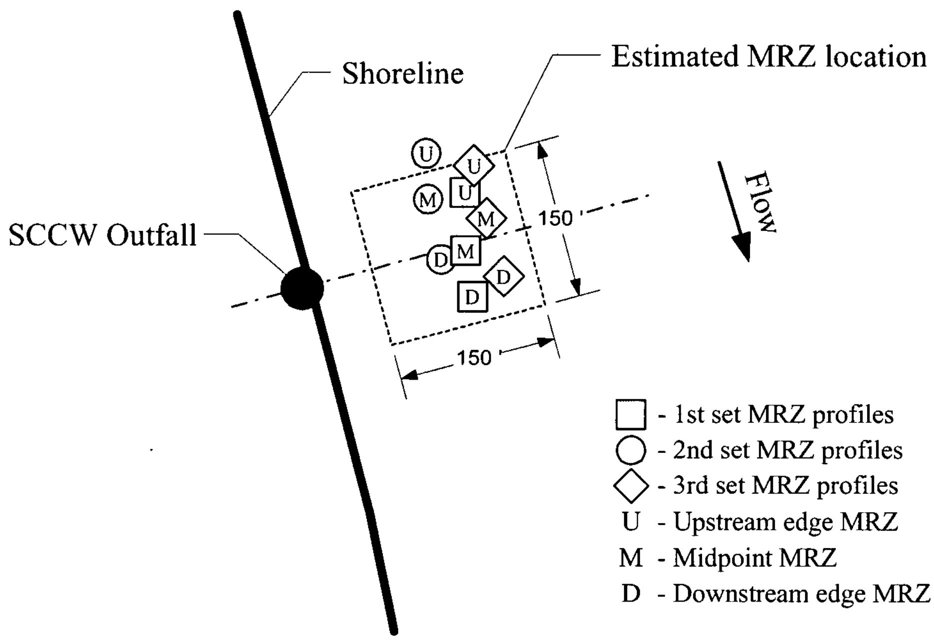


Figure 6. WBN Outfall 113 Mussel Relocation Zone Measurement Stations

Velocity measurements were collected only for the third set of MRZ profiles. The results are shown in Figure 7. Since the SCCW and river discharges did not change significantly over the period of the survey, the velocities for the first and second sets of profiles are expected to be much the same. The following comments are provided.

- The magnitude of the water velocity ranged from 0.6 to 1.0 ft/s near the bottom, increasing to 1.0 to 1.5 ft/s near the surface.

- The direction of the water velocity ranged from 165° to 180° clockwise from the North. The downstream direction of the river at this location is approximately 170° clockwise from the North, hence all the measured velocities were in the downstream direction.

Temperature profiles measured in the MRZ are shown in Figure 8. The profiles are plotted based on whether the measurements were taken before or after heat was added to the SCCW discharge. As summarized earlier, the first set of measurements was collected before heat was added, whereas the second and third sets were collected after heat was added. The following comments are provided.

- In the first set of profiles, the measured water temperatures were near uniform at 77.5°F for all stations—upstream, midpoint, and downstream.

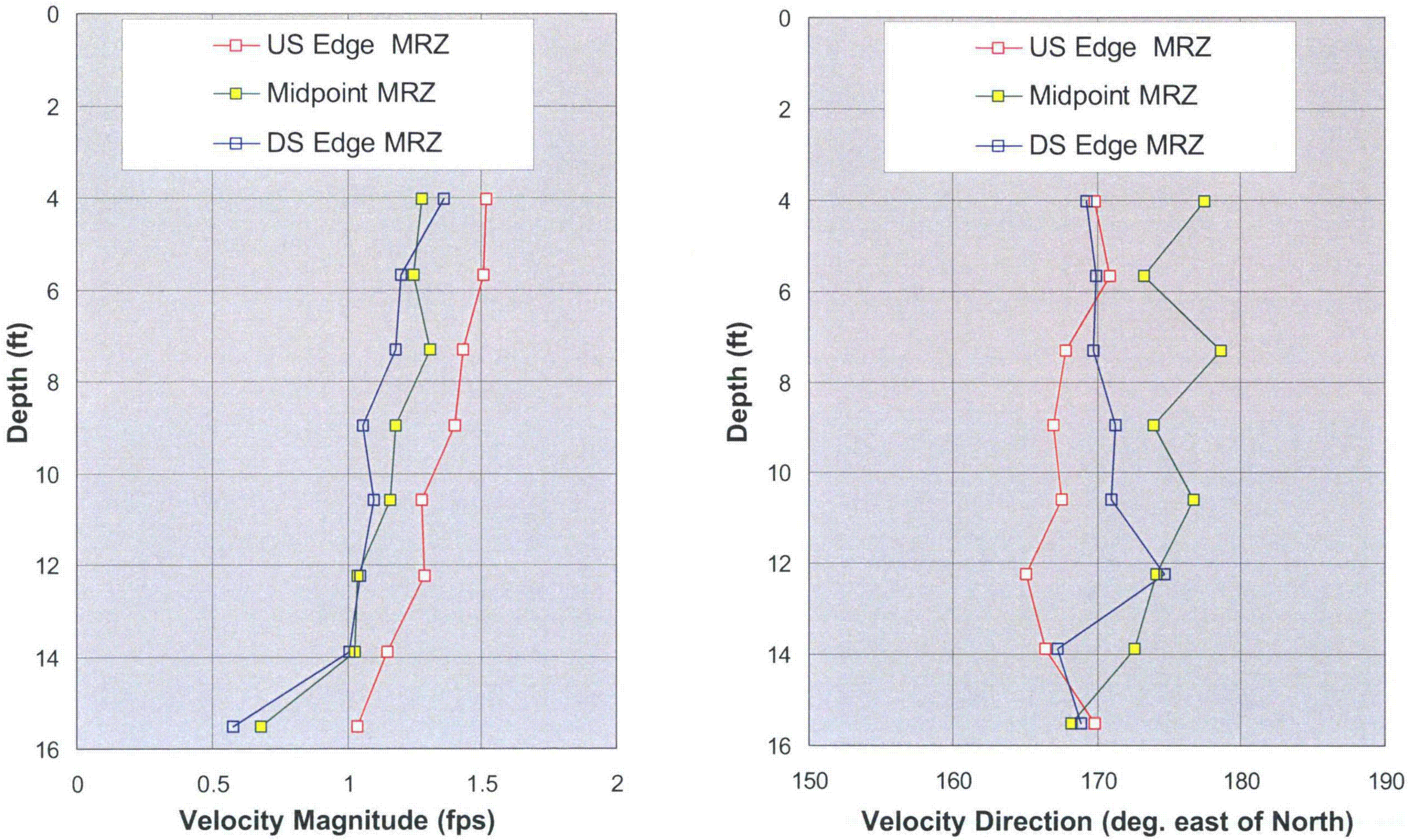


Figure 7. Measured River Velocity Magnitude and Direction in WBN Outfall 113 Mussel Relocation Zone

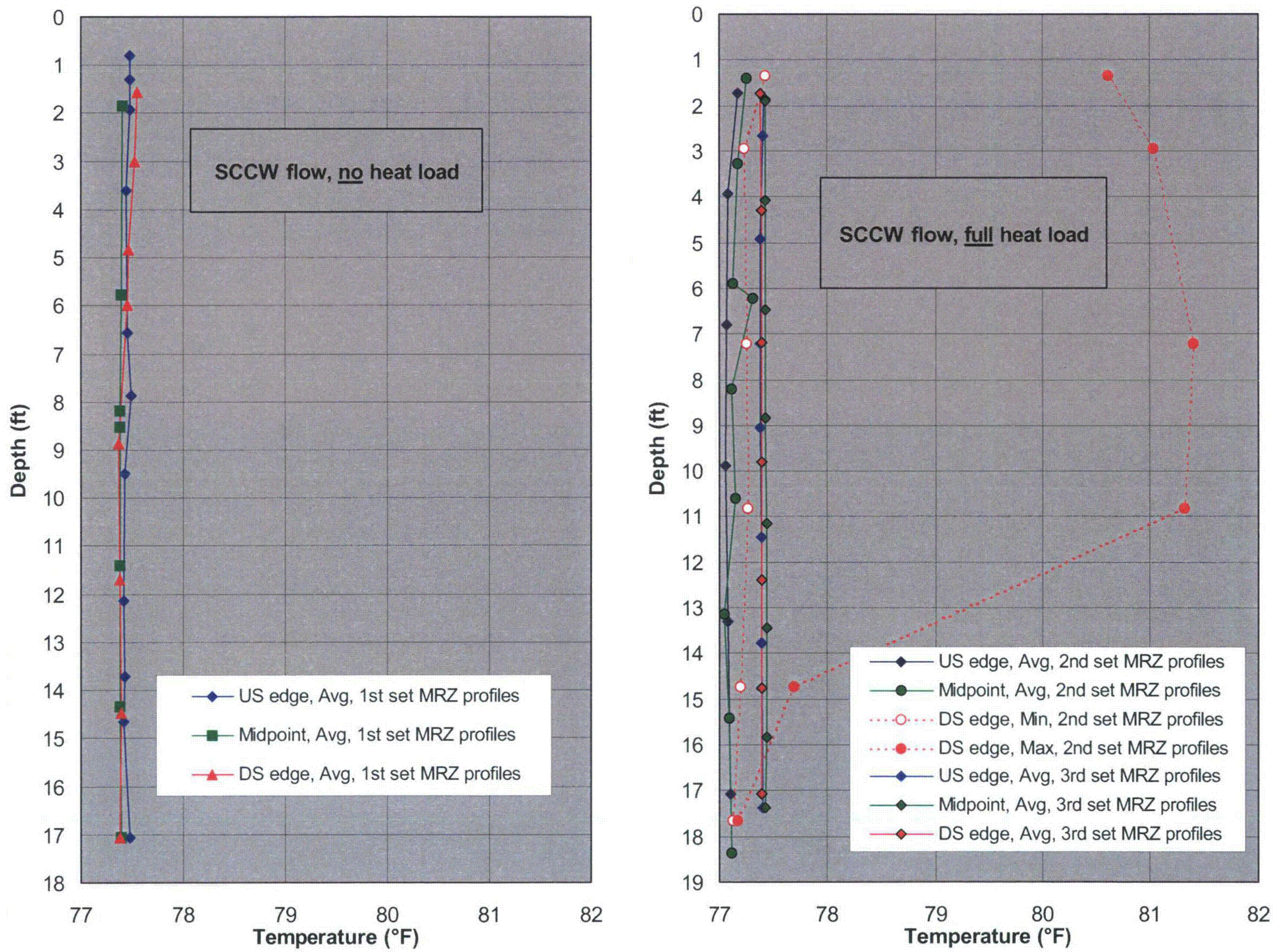


Figure 8. Measured Temperature Profiles in the WBN Outfall 113 Mussel Relocation Zone

- In the second set of profiles, the temperatures at the upstream and midpoint stations also were near uniform, but at a slightly lower temperature—between 77.1°F and 77.2°F. The reason for the lower temperature is unclear (i.e., 0.3 to 0.4 F° lower than the first set of profiles). Although the flow from Watts Bar Dam was unchanged, it may be possible that a "patch" of slightly cooler water was passing through the hydroturbines during the measurements for the second set of profiles. It also is noted that this deviation is roughly equivalent to the accuracy of the temperature sensor in the Hydrolab probe, ±0.3 F°. Despite this question, it is evident that for the field conditions of Table 1 that the thermal plume does not spread significantly upstream of the outfall.

  At the downstream station (i.e., second set of profiles), the observed behavior of the temperature suggests that this station was located in the shifting boundary-region of the SCCW plume. In the measurements, intermittent burst of heated water from the SCCW discharge caused the temperature to vary between the ambient conditions measured upstream, and values that were as much as 4 F° higher. In general, for all MRZ temperature profiles, the duration of data collection for each measurement point was typically between 30 seconds and 1 minute. In most cases this allowed good average temperatures to be computed. However, due to the long duration of the intermittent temperature fluctuations, such was not the case for the downstream station. As such, in Figure 8, the observed maximum and minimum temperatures are plotted for the downstream station. If the average temperature were midway between these extremes, the observed temperature excursion above ambient would be of the same order of magnitude as that measured in the same location by the RTD array, about 2 F° (see Figure 5).

- In the third set of profiles, the water temperature was near uniform at 77.5°F for all measurement stations—upstream, midpoint, and downstream. These measurements show no evidence of the SCCW thermal plume, even though the stations were only about 25 feet further from the outfall than the stations in the second set of profiles (see Figure 6). This indicates that for the field conditions of Table 1, the plume is sharply "bent over" by the ambient discharge—so much so that, at the location of the outfall, no significant heat reaches the outer boundary of the MRZ.

- Comparing the MRZ temperature profiles before and after heat was added to the SCCW discharge, it is evident that the thermal plume did not reach the bottom of the MRZ, at least for the field conditions of July 19. The bottom temperature remained well below the 92.3°F limit.

6.0 MODEL COMPARISON

Ambient conditions recorded for July 19, 1999, at 1600 EDT were input into a TVA computer model entitled WBSCH, used to simulate WBN effects on river temperature[2,3]. This model uses dam releases and headwater elevations at Watts Bar and Chickamauga Dams, ambient air and river temperatures, WBN unit loads and pump operations, SCCW system valve positions, and a table of results of numerous CORMIX[4] model runs to compute WBN discharge flowrates and temperatures for the diffuser and SCCW discharges, and the resulting temperatures in the river at the downstream end of the diffuser and Outfall 113 mixing zones. The results of the model, shown in Table 2, agree very well with the measured instream data shown in Figure 5.

The ambient and discharge conditions were also input into CORMIX. The resulting computed horizontal and vertical plume geometry is shown in Figures 9 and 10. The CORMIX results show horizontal and vertical temperature distributions similar to that measured during the survey. Both the measured and computed plumes remain attached to the right bank under the ambient and discharge conditions existing during the survey. The computed instream temperature rise (ΔT) on the plume centerline is shown in Figure 11. The computed ΔT at the end of the mixing zone of 0.9 F° compares well with the measured value of 1.0 F°.

7.0 EVALUATION OF DOWNSTREAM TEMPERATURE MONITOR LOCATION

NPDES Permit TN0020168 requires measurement of the river temperature at the downstream end of the mixing zone at a depth of five feet. Under low river flow conditions, the thermal plume is expected to spread transversely across the entire river width before it reaches the downstream end of the mixing zone[3]. Under the relatively high river flow conditions of this survey, the thermal plume remained attached to the right bank as it was conveyed downstream. Due to the presence of commercial barge traffic on both sides of the river, it is not feasible to locate a floating monitor in the river in a position which would guarantee that the plume is always intercepted. However, "worst case" conditions for instream temperature rise can reasonably be expected to involve low river flow and thus more plume spreading. Therefore, a floating monitor located 1/4 to 1/3 of the river width off the right bank should be sufficient to give ample warning to prevent any violations of the instream thermal limits. In accordance with normal practice for downstream monitors, there should be three measurement depths (3, 5, and 7 feet). The temperature measurements at these depths would be averaged to obtain the measured downstream temperature.

TABLE 2

WBSCH Run for July 19, 1999, 1600 EDT Field Survey Conditions

```
Output from wbsch version #1.50


 river flow (cfs), velocity (fps):          33000     1.867
 river elevation (ft):                          681.90
 dry bulb temperature (F):                        86.5
 wet bulb temperature (F):                        71.9
 relative humidity (%):                           49.7
 ambient river temperature (F):                   77.4
 supplemental ccw intake temperature (F):         80.0
 unit condenser cleanliness (%):               85          85
 tower capabilities (%):                     105.0       85.0
 unit ccw pumps:                                4           0
 unit ercw pumps:                               2           0
 unit ercw bypass (%):                       0.00        0.00
 unit rcw pumps:                                2           0
 unit loads (MWe):                           1240           0
 supplemental ccw flow (cfs):                    226.5
 supplemental ccw bypass flow (%):                 0.0
 diffuser mode:                                    3

 intake temperature (skimmer wall) (F):           78.4
 unit ccw inlet temperatures (F):            86.3         0.0
 unit ccw outlet temperatures (F):          125.7         0.0
 unit turbine back-pressure (in.-hg):          5.7         0.0
 tower flows (cfs, inlet):                    943           0
 tower blowdown flows (cfs):                 44.6         0.0
 total tower blowdown discharge (cfs):            44.6
 tower discharge temperatures (F):           87.2        78.4
 pond elevation (ft):                            707.0
 pond temperature (F):                            87.2
 diffuser legs:                                      2
 diffuser discharge temperature (F):              87.2
 unit diffuser discharges (cfs):             64.2        83.2
 total diffuser discharge (cfs):                 147.4
 supplemental discharge flow (cfs):              204.1
 supplemental discharge temperature (F):          87.2
 overflow weir discharge (cfs):                    0.0
 upstream temperature (F):                        77.4
 downstream temperature (F):                      78.6
 delta T below SCCW discharge (F):                 1.0
 delta T below diffuser (F):                       1.2
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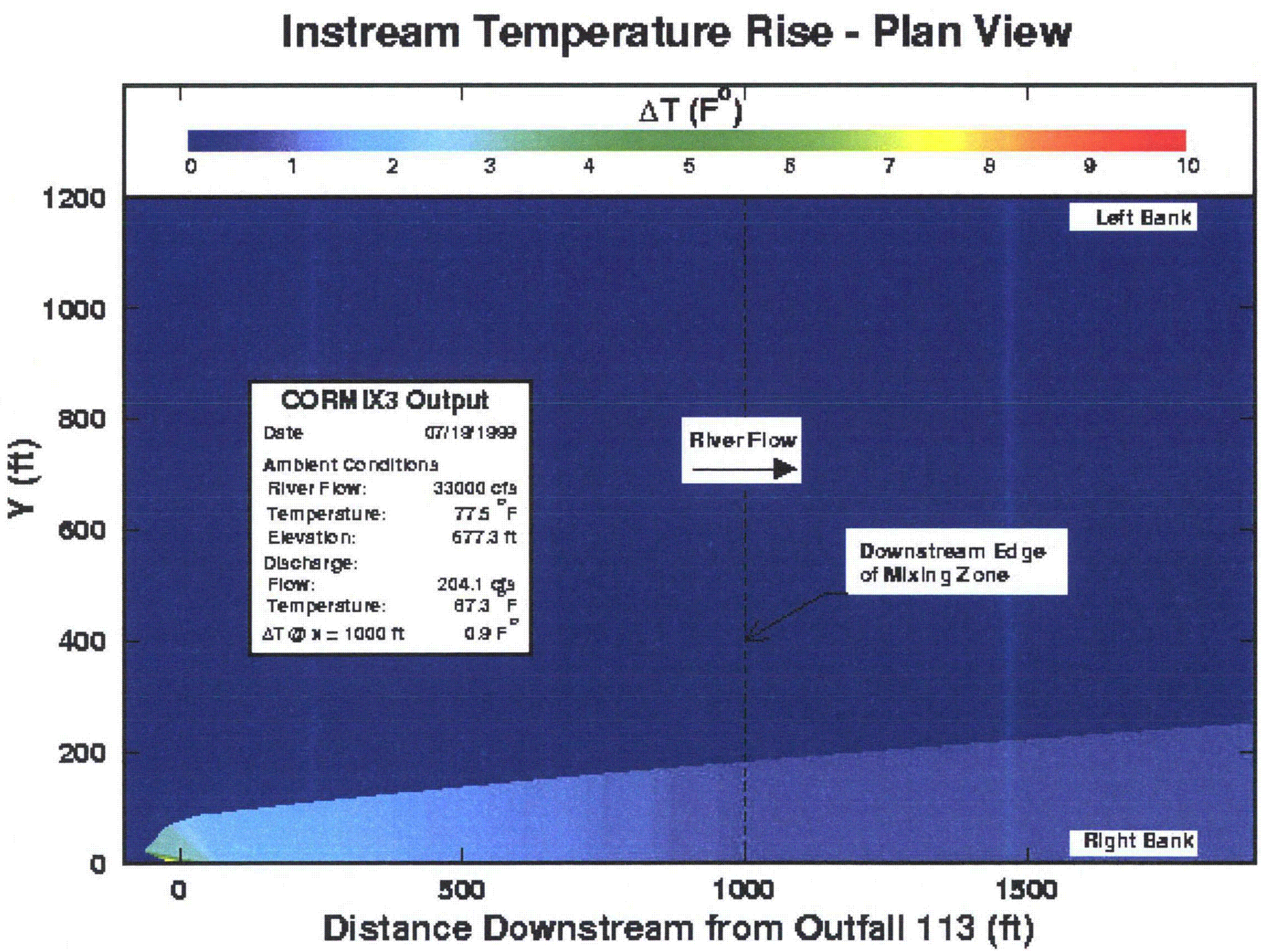

Figure 9. Plan View of Thermal Plume Predicted by CORMIX, Based on Ambient and Discharge Conditions at 07/19/1999, 1600 EDT

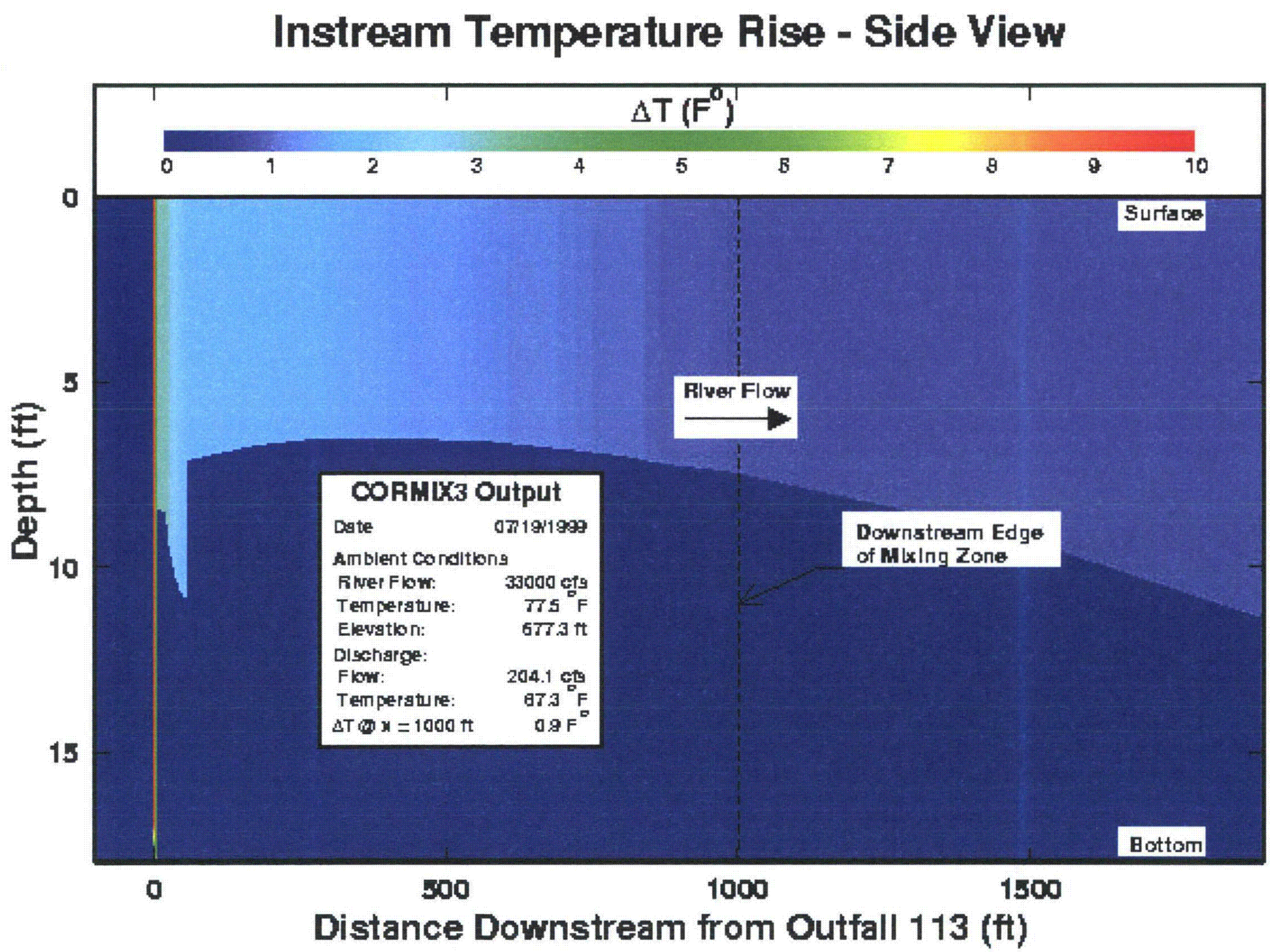

Figure 10. Side View of Thermal Plume Predicted by CORMIX, Based on Ambient and Discharge Conditions at 07/19/1999, 1600 EDT

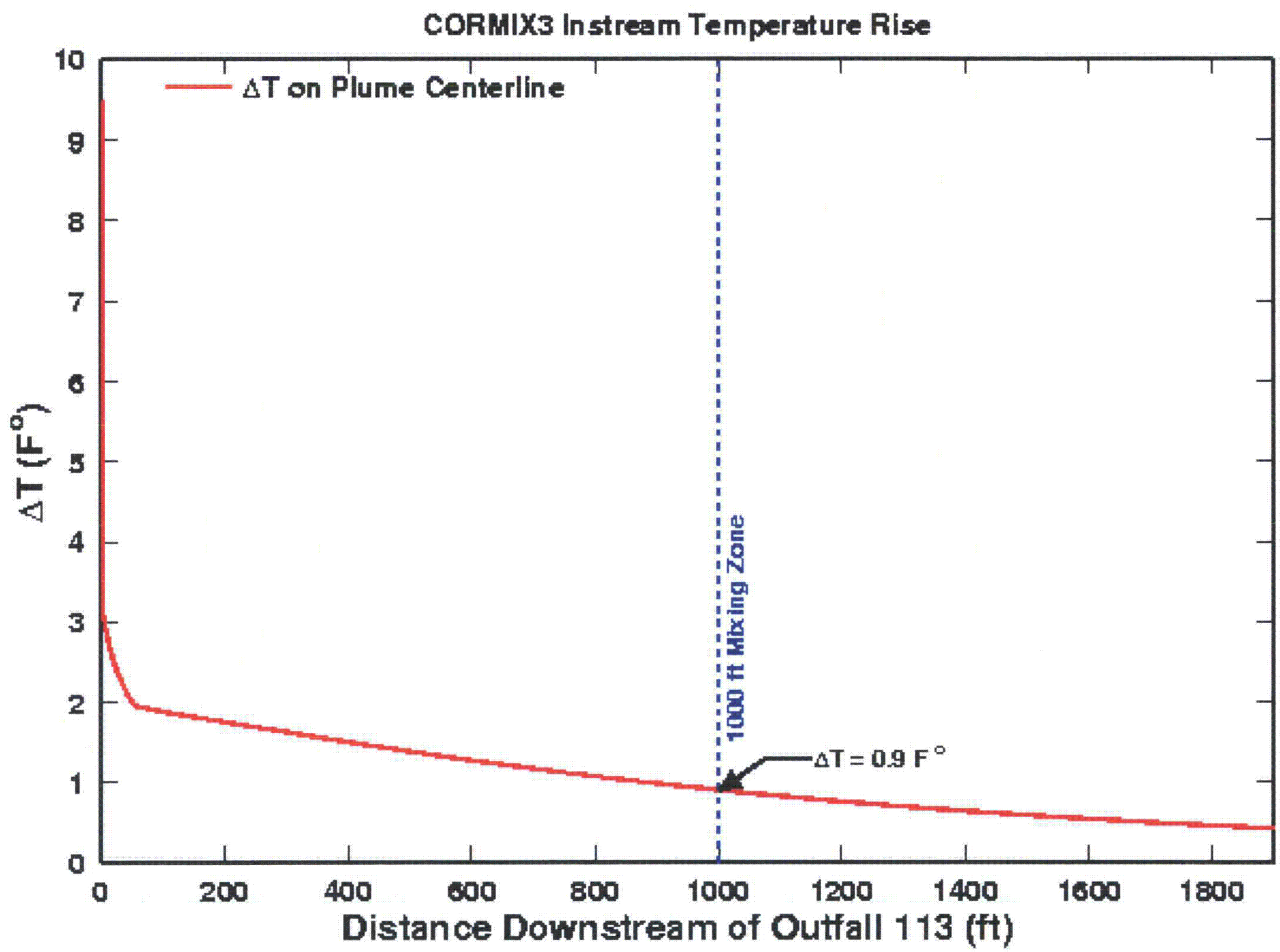

Figure 11. CORMIX Computed Instream Temperature Rise at Plume Centerline

8.0 EVALUATION OF UPSTREAM TEMPERATURE MONITOR LOCATION

For upstream temperature, the normal practice is to locate a monitor in the river at a location sufficiently far upstream of the outfall to be outside the influence of the thermal plume under all conditions. For the Watts Bar SCCW project, however, this is not feasible for several reasons:

- The close proximity of Watts Bar Dam limits the distance the monitor can be located upstream.

- Given the narrow confines of the river at this location, and the rapid and turbulent river velocities under high flow conditions, a floating monitor would be a serious obstacle to river traffic below the dam.

- The high river velocities and variation of river elevation with flow would make it extremely difficult to securely anchor a monitor to the river bottom between the dam and Outfall 113. A monitor which has broken loose from its anchor point could pose a serious safety hazard for the public and commercial river users.

Based on visual observation of the flow distribution in the tailwater of the Watts Bar Dam powerhouse, it was decided that the best location for the upstream temperature monitor would be on the downstream face of the taildeck, between the 2nd and 3rd discharge bays of the Unit 3 draft tube (looking downstream). This places the monitor in the approximate center of the powerhouse discharge. The temperature sensor should be located five feet below the water surface at the minimum flat pool elevation of Chickamauga Reservoir, which has a normal operating range of 675 feet in the winter to 683 feet in the summer. Due to the large amount of turbulent mixing, there is little or no stratification in the tailrace when water is discharged through the hydro turbines, and hence no need for sensors at multiple depths. The upstream measurement depth would be no less than the five-foot depth of the downstream measurement, and may be as much as eight feet deeper. Any thermal stratification that may occur under conditions of no turbine discharge would result in a measured upstream temperature the same or cooler than the actual temperature at the five-foot depth. Therefore, the resulting measured instream temperature rise (ΔT) could perhaps be larger than the actual five-foot value, which will result in a conservative operation of the SCCW system.

9.0 CONCLUSIONS

As requested by the Tennessee Department of Environment and Conservation, a hydrothermal survey was performed on July 19, 1999, for Outfall 113 of Watts Bar Nuclear Plant upon startup of the WBN Supplemental Condenser Cooling Water system. The survey was conducted to examine the increase in river temperature above ambient, ΔT, and the maximum downstream temperature T_d. The objectives of the tests were to: (1) determine the three-dimensional configuration of the thermal plume, (2) substantiate the dispersion modeling, and (3) evaluate locations for upstream and downstream temperature monitors. In regard to these objectives, the following conclusions are provided.

Three-Dimensional Configuration of Thermal Plume

In the surface layer of the river (i.e., upper 2.0 meters/6.6 feet), the three-dimensional configuration of the plume was documented for summer conditions on July 19, 1999 (Figure 5).

As expected for the SCCW and river flows on the day of the survey, the plume did not spread across the full width of the river. However, measured temperatures indicate that the SCCW discharge is effectively mixed with the ambient river water, at least for the conditions examined. The measured ΔT and T_d, summarized in Table 3, are both well within the limits established by state water quality criteria.

Table 3. Summary of Measured Instream Water Temperature Parameters

Parameter	State Limit	Measured July 19, 1999
ΔT	5.4 F°	1.0 F°
T_d	86.9°F	78.5°F
MRZ Bottom Temp	92.3°F	77.5°F

Dispersion Modeling

The values of instream temperature rise, ΔT, and downstream temperature, T_d computed by the model WBSCH agree well with measurements for the ambient and discharge conditions of the survey.

Monitor Locations

The downstream monitor should be positioned between 300 and 400 feet off the right bank (looking downstream). The monitor should measure temperatures at the 3-, 5-, and 7-foot depths. These temperatures will be averaged to determine the downstream temperature.

The upstream monitor should be located on the downstream face of the taildeck for the Watts Bar Dam powerhouse, near the center of the turbine discharge bays. The monitor should measure tailrace temperature at elevation 670 feet, which is five feet below the normal minimum flat pool elevation of Chickamauga Reservoir.

10.0 REFERENCES

[1]TDEC, 1999. "NPDES Permit No. TN0020168," State of Tennessee, Tennessee Department of Environment and Conservation (TDEC), Division of Water Pollution Control, NPDES Permit No. TN0020168, Nashville, Tennessee.

[2]Lee, M., W. Harper, P. Ostrowski, M. C. Shiao, and N. Sutherland, 1993. "Discharge Temperature Limit Evaluation for Watts Bar Nuclear Plant," Tennessee Valley Authority, Engineering Laboratory Report No. WR28-1-85-137, Norris, Tennessee.

[3]Harper, Walter L., 1997. "Watts Bar Nuclear Plant Supplemental Cooling Water Project Thermal Plume Modeling," Tennessee Valley Authority Engineering Laboratory, Norris, Tennessee.

[4]Jirka, G. H., R. L. Doneker, and W. W. Hinton, 1996. "User's Manual for CORMIX: A Hydrodynamic Mixing Zone Model and Decision Support System for Pollutant Discharges into Surface Waters," Office of Science and Technology, U.S. Environmental Protection Agency, Washington, DC.