WM-28-1-67-101

327 A
1/22/79

ASSESSMENT OF WATER TEMPERATURE MONITORING AT THE BROWNS FERRY NUCLEAR PLANT

TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER MANAGEMENT
WATER SYSTEMS DEVELOPMENT BRANCH
NORRIS, TENNESSEE

7901260151

Tennessee Valley Authority
Division of Water Management
Water Systems Development Branch

ASSESSMENT OF
WATER TEMPERATURE MONITORING AT THE
BROWNS FERRY NUCLEAR PLANT

WM28-1-67-101

Prepared by
Christopher D. Ungate
Norris, Tennessee
August 1978

CONTENTS

LIST OF FIGURES

SYNOPSIS

TVA's experience with water temperature standards as they apply to the Browns Ferry Nuclear Plant situated in the State of Alabama are summarized. The monitoring system used in obtaining data is described, and an analysis of spatial and temporal changes in the Wheeler Reservoir in the vicinity of the plant are presented. Results from a one-dimensional temperature model of the reservoir in the vicinity of the plant are also included.

As a result of the experience with this monitoring technique, a new approach to compliance with the applicable temperature standards is proposed.

INTRODUCTION

The Browns Ferry Nuclear Plant, situated on the right bank of Wheeler Lake near Decatur, Alabama, at Tennessee River Mile (TRM) 294 (Figure 1), consists of three 1152 megawatt generating units. The main steam condensers are cooled by water pumped from the reservoir. The plant was originally designed for once-through cooling of the condensers, utilizing three large multiport diffusers (perforated pipes) partially imbedded in the old river channel adjacent to the plant. This cooling water system is now supplemented with six mechanical draft cooling towers that were installed to help meet the more stringent water temperature standards adopted by the State of Alabama in 1972. This modified condenser cooling system can be operated in either open, helper or closed modes, depending on plant loads, river flows and ambient temperatures.

This report summarizes the Tennessee Valley Authority's (TVA) experience with monitoring water temperatures in the vicinity of the Browns Ferry Nuclear Plant for the purpose of showing compliance with applicable water temperature standards. A description of the monitoring system and a history of changes to the monitoring system is given. An analysis of spatial and temporal changes in water temperature in Wheeler Reservoir near the plant is presented. Results of temperature studies presented in this report include the application of a one-dimensional temperature model to the reservoir in the vicinity of the plant, statistical analyses of the monitors, and field studies of spatial and temporal changes of water temperatures near the monitors. After

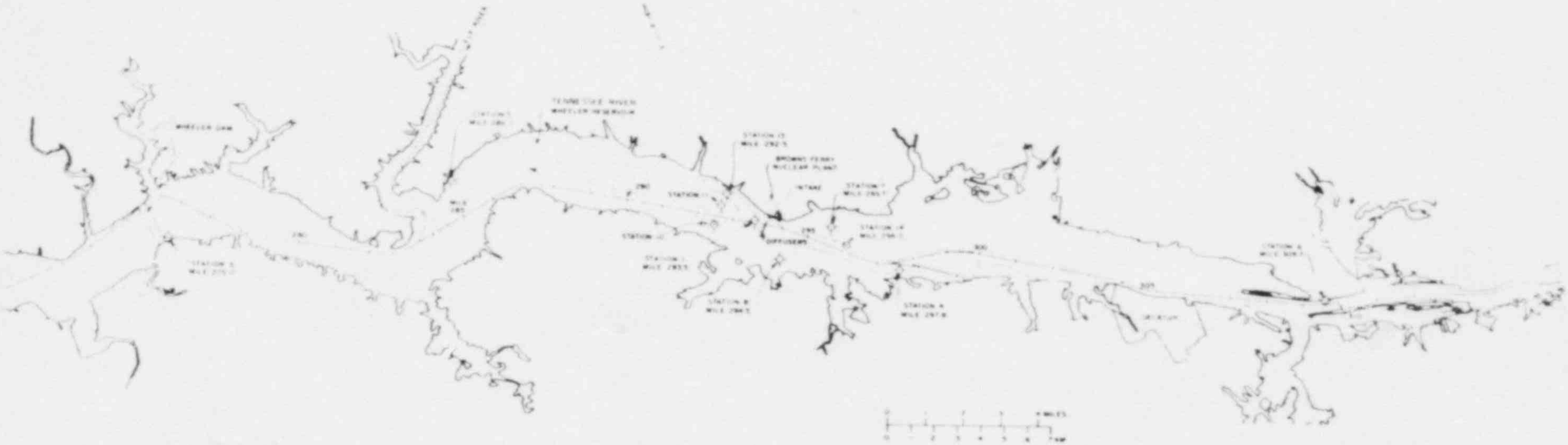


Figure 1 : Browns Ferry Vicinity Map and Temperature Monitor Locations

summarizing the problems encountered with the present monitoring system, a new approach to showing compliance with applicable temperature standards will be proposed. The types of physical measurements and calculations to be used in the new system will be outlined. Justification for the new approach will be discussed, drawing on the experience with the present monitoring system and other studies of plant induced thermal effects.

HISTORY OF PRESENT MONITORING SYSTEM

This history of the present monitoring system details the location of temperature measurements and the method of calculation of compliance parameters. Temperature standards are outlined and plant operation is noted. Considerable difficulty is shown in determining whether temperatures measured with the present monitoring system indicate actual plant-induced thermal effects or natural temperature variations. Changes in the present monitoring system were therefore made to make temperature measurements and compliance calculations more indicative of plant-induced thermal effects.

Applicable temperature standards, unless modified, limit the maximum temperature rise to 5°F above natural temperatures before the addition of artificial heat and the maximum water temperature to 86°F (Reference 1). (The maximum mixed temperature standard at Browns Ferry was increased on an interim basis to 90°F on July 15, 1977). Temperatures should be measured at a depth of five feet in waters 10 feet or greater in depth and should be measured only after reasonable opportunity for mixing with receiving waters has been afforded.

The temperature monitoring system at Browns Ferry Nuclear Plant was designed to measure an ambient temperature upstream of the plant which was not influenced by the thermal discharge and a mixed temperature downstream of the plant after all diffuser induced mixing had occurred. Compliance with the maximum temperature rise standard is determined by comparing the difference between the mixed and ambient temperatures. Compliance with the maximum temperature standard is determined by the mixed temperature measurement.

During closed mode operation, the maximum temperature standard of 86°F may be exceeded if ambient temperatures approach or exceed 86°F provided the discharge of blowdown and waste heat is minimized (Reference 2).

The location of all past and present Browns Ferry Nuclear Plant water temperature monitors, with the exception of monitor No. 9, is shown in Figure 1. Monitor No. 9 was situated at TRM 292.5 between the right bank and monitor No. 13. Monitor Nos. 1, 3, 4 and 5 were installed in 1968 and 1969 to provide preoperational water temperature data. With the advent of operation of the first unit at Browns Ferry in late 1973, monitor Nos. 6-11 were installed between April and September 1973. Figure 1 shows that most monitors were installed in overbank areas or on the edge of the main river channel to avoid interference with navigation on the reservoir.

Figure 2 gives a summary of the history of water temperature monitoring for the Browns Ferry Nuclear Plant. Plant operation has occurred since late 1973, with the first several months consisting of intermittent operation and testing before the commercial operation of Unit 1 in August 1974. All plant operation was discontinued for approximately a year and a half because of redesign and repairs of plant safety features following a fire on March 22, 1975. Figure 2 shows when particular monitors were in service, which monitors were used for compliance calculations and when changes in the method for determining compliance were made.

Compliance with applicable temperature standards was initially based on hourly instantaneous temperature measurements at the five-foot depth at downstream monitor Nos. 9, 10 and 11 and upstream

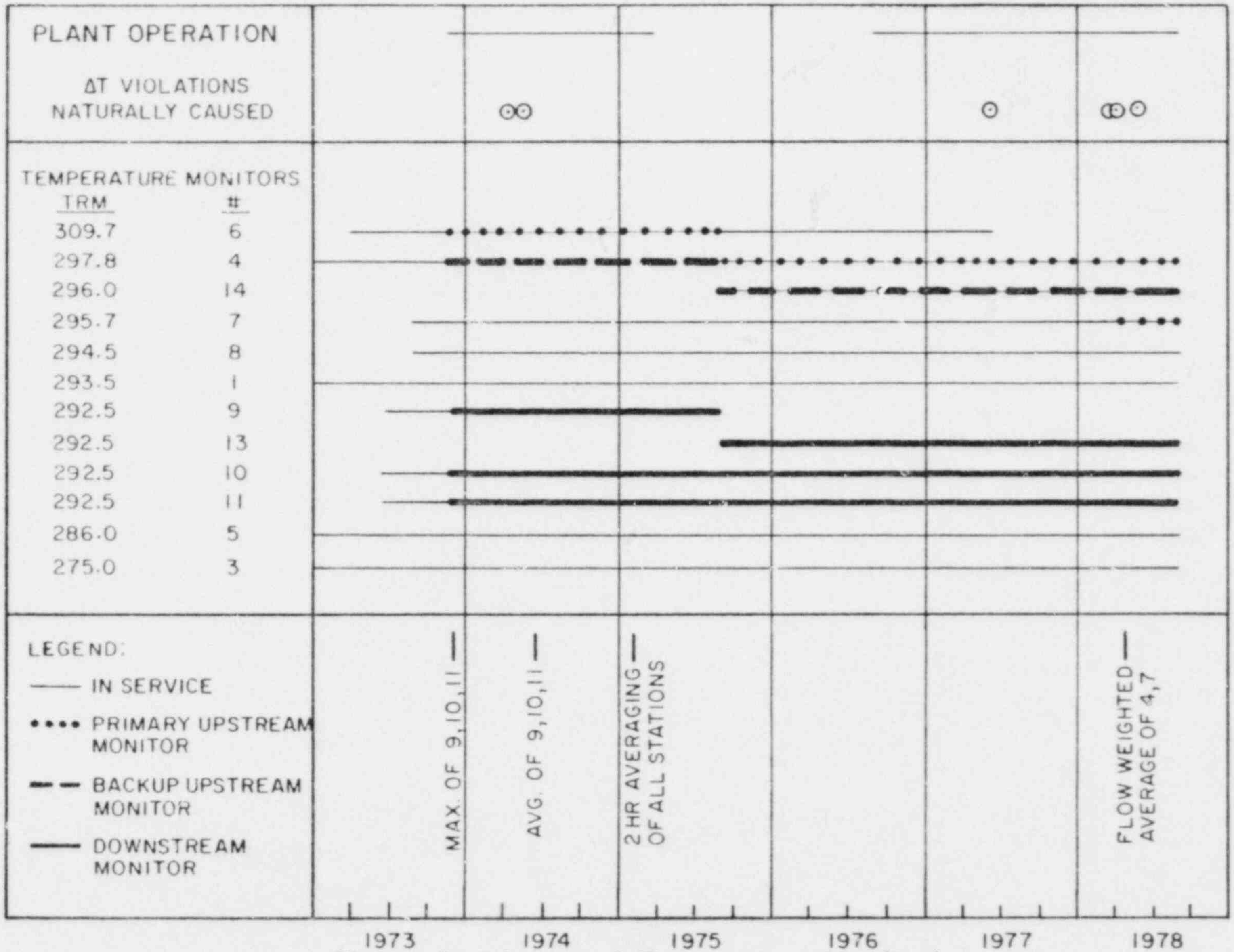


Figure 2: History of Temperature Monitoring
Browns Ferry Nuclear Plant

monitor No. 6. Thus the monitoring system utilized about a mile stretch of Wheeler Reservoir for measuring plant thermal effects and about 1.5 miles for mixing of the plant discharge. The travel time of water through the 15-mile stretch is about 1-3 days depending on river flow while the travel time through the "mixing zone" is 3-10 hours depending on river flow. The temperature rise was computed as the maximum of temperatures at monitor Nos. 9-11 less the temperature at monitor No. 6. The maximum of temperatures at monitor Nos. 9-11 was used to determine compliance with the maximum temperature standard.

Two instances when the temperature rise standard was exceeded during the spring of 1974 (one with the plant not in operation) were found to be caused by natural temperature variations (see Figure 2 and Table 1). The monitoring system was changed so that the temperature rise and maximum temperatures were computed as the spatial average of measurements at monitor Nos. 9-11. In addition, temperatures were measured every 15 minutes to provide more frequent compliance information to plant operators. Further experience with the monitoring system resulted in a change during January 1975 to computing the upstream and downstream temperatures as an average of temperatures over the previous two hours.

In early 1975 just before the March 22, 1975, fire, TVA proposed to the Nuclear Regulatory Commission (NRC) revisions in the environmental technical specifications for the plant to change the location of monitors used to determine compliance with applicable temperature standards. NRC approved the changes in July 1975. Monitor No. 9 was removed because it was found to be relatively more affected by natural heating near the right bank. Monitor No. 13 was placed in the

TABLE 1

MONITORED TEMPERATURE RISES EXCEEDING 5°F CAUSED BY NATURAL CONDITIONS

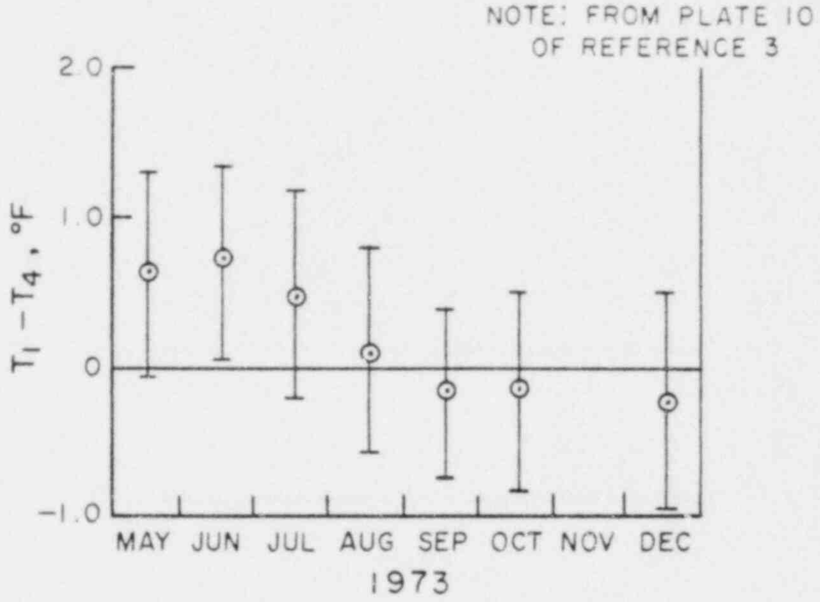
Date	Time	Maximum Rise (°F)
1974		
4/29	1600	5.3
5/19[1]	2115, 1300	5.9
1977		
5/8	1400-1600	5.7
1978		
3/31	1444-1629	5.4
4/2	1514-1959	5.9
5/15	1614-1929	5.3

1. Plant not in operation.

right side river channel at TRM 292.5 in line with monitor Nos. 10 and 11 to provide downstream temperatures. Monitor No. 4 was designated as the primary upstream monitor and monitor No. 14 was placed at TRM 296.0 as a backup. This change brought the upstream and downstream monitors closer together, further minimizing natural temperature variations and reducing the effective length of Wheeler Reservoir for measuring plant thermal effects to about five miles (travel time of about 9-24 hours).

Plant operation resumed in the fall of 1976 with all three units eventually in service. One occasion when the temperature rise exceeded 5°F in the spring of 1977 was attributed to natural temperature variations. Attention regarding reservoir water temperatures was drawn to the maximum temperature standard in the early summer of 1977 because of the occurrence of record high natural temperatures of about 88°F, the poor performance and later structural failure of the plant's mechanical draft cooling towers and resulting plant deratings to meet temperature standards.

Two occurrences of the temperature rise standard being exceeded in the spring of 1978 resulted in a change in the method of computation of the upstream ambient temperature. The ambient temperature was changed to a flow weighted average of a main channel monitor (No. 4) and an overbank monitor (No. 7) in an effort to account for lateral temperature variations in Wheeler Reservoir. Velocity studies indicated that about 0.7 of the river flow occurred in the main channel and 0.3 in the overbanks. An additional temperature rise greater than 5°F attributable to natural temperature variations after the monitoring change and further plant deratings prompted the proposal of a new approach to showing compliance with thermal standards discussed in this report.



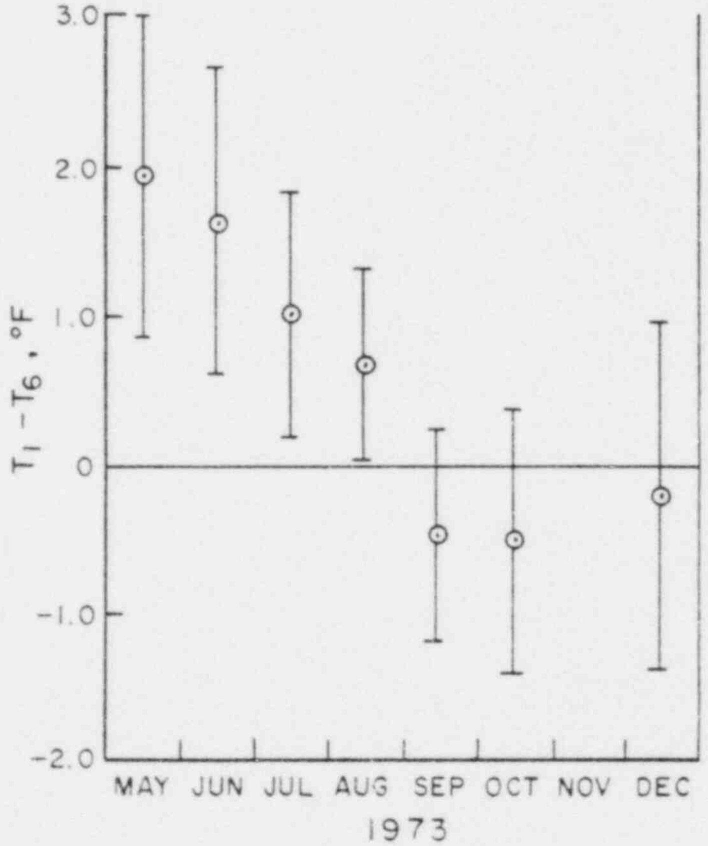


Figure 3: Average Temperature Differences Between Monitor Numbers 1–6 and 1–4

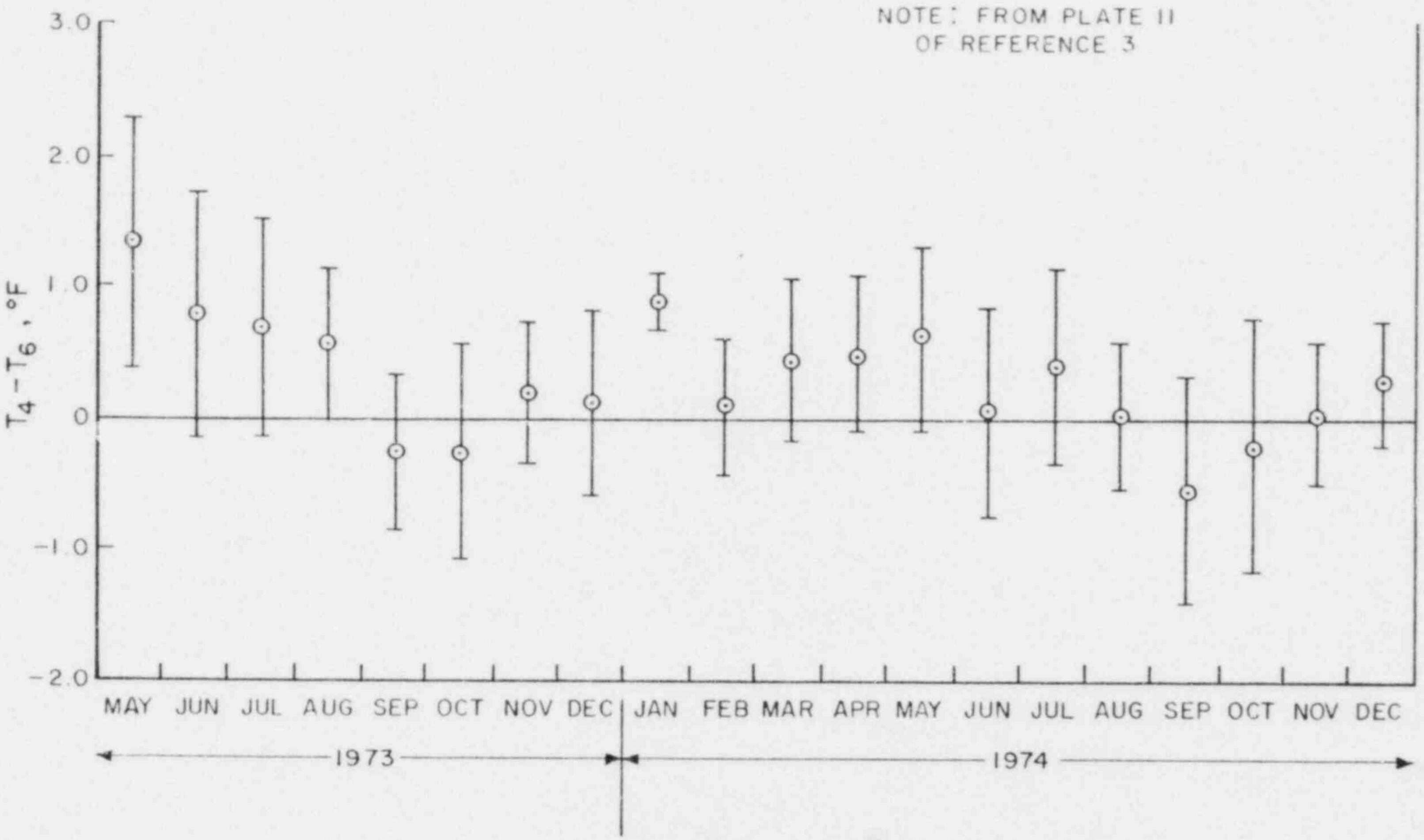


Figure 4: Average Temperature Differences
Between Monitor Numbers 4-6

Computer modeling of natural longitudinal temperature differences using temperature data from the monitors and meteorological data during the plant outage in 1975 and 1976 has been carried out by researchers at the Massachusetts Institute of Technology (MIT) (Reference 4). A one-dimensional (longitudinal) cross-sectionally averaged model was used. A plot of the comparison of model predictions with measured data is given in Figure 5. The measured data were computed as the difference between a 49 hour running average of five-foot and bottom temperatures at monitor Nos. 1 and 6. This choice of time scales averages out hourly temperature variations which are due to cross-sectional temperature variations and the diurnal cycle and shows "storm cycles", or wide temperature swings persisting up to a week which are probably associated with weather patterns. Also visible in Figure 5, though less clearly, is the weak annual cycle of natural longitudinal temperature differences noted in Figures 3 and 4.

Figure 5 shows that the one-dimensional model gives a reasonable prediction of average longitudinal temperature differences. Agreement is better in the spring than in the fall. Spring heating is a relatively steady process which induces very little turbulence as stratification builds up. Autumn cooling is a complex process, however, in which the cooled surface water sinks due to its greater density, causing turbulence and non-one-dimensional mixing. Figure 6 shows the temperature difference between the model predictions and measured data. The seasonal variation of this temperature residual indicates that non-one-dimensional effects are also causing temperature variations in Wheeler Reservoir.

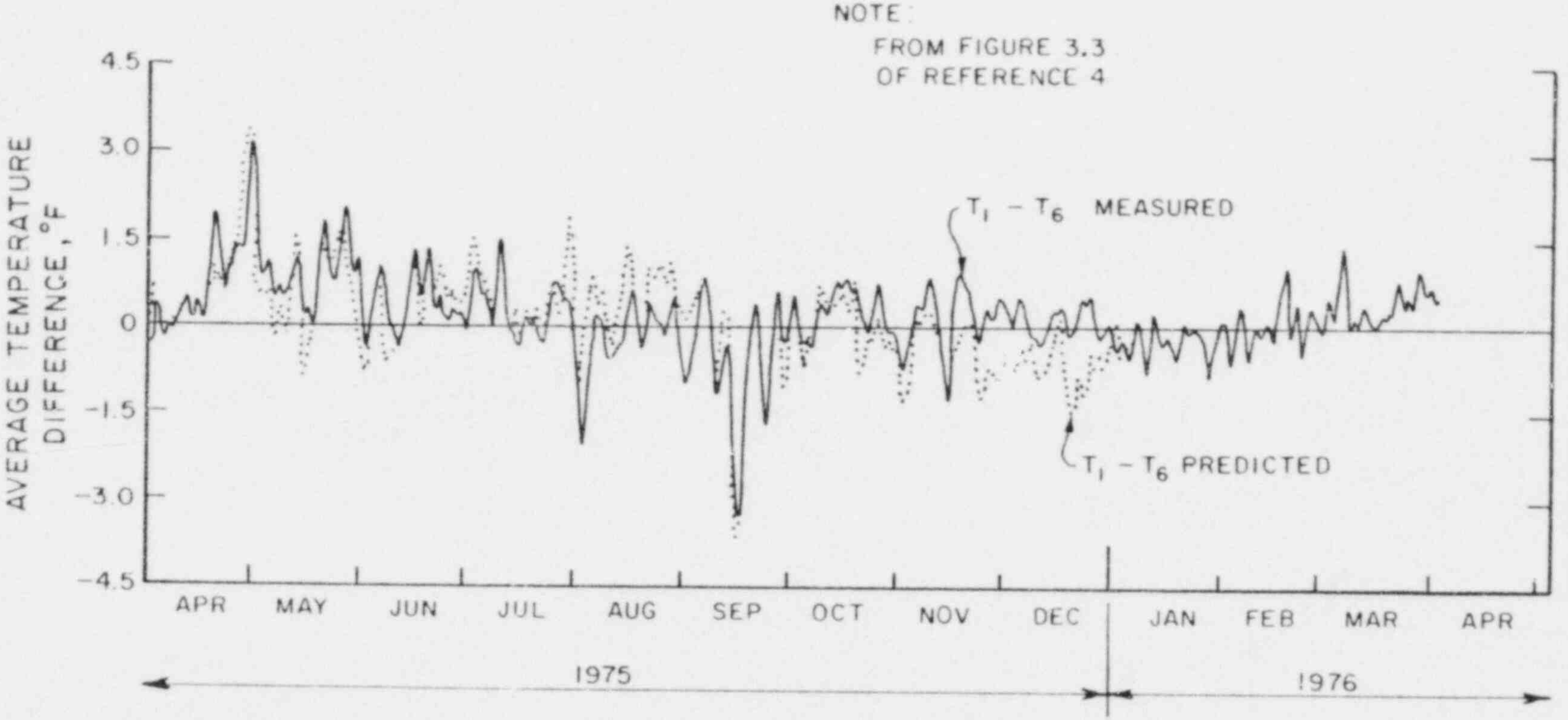
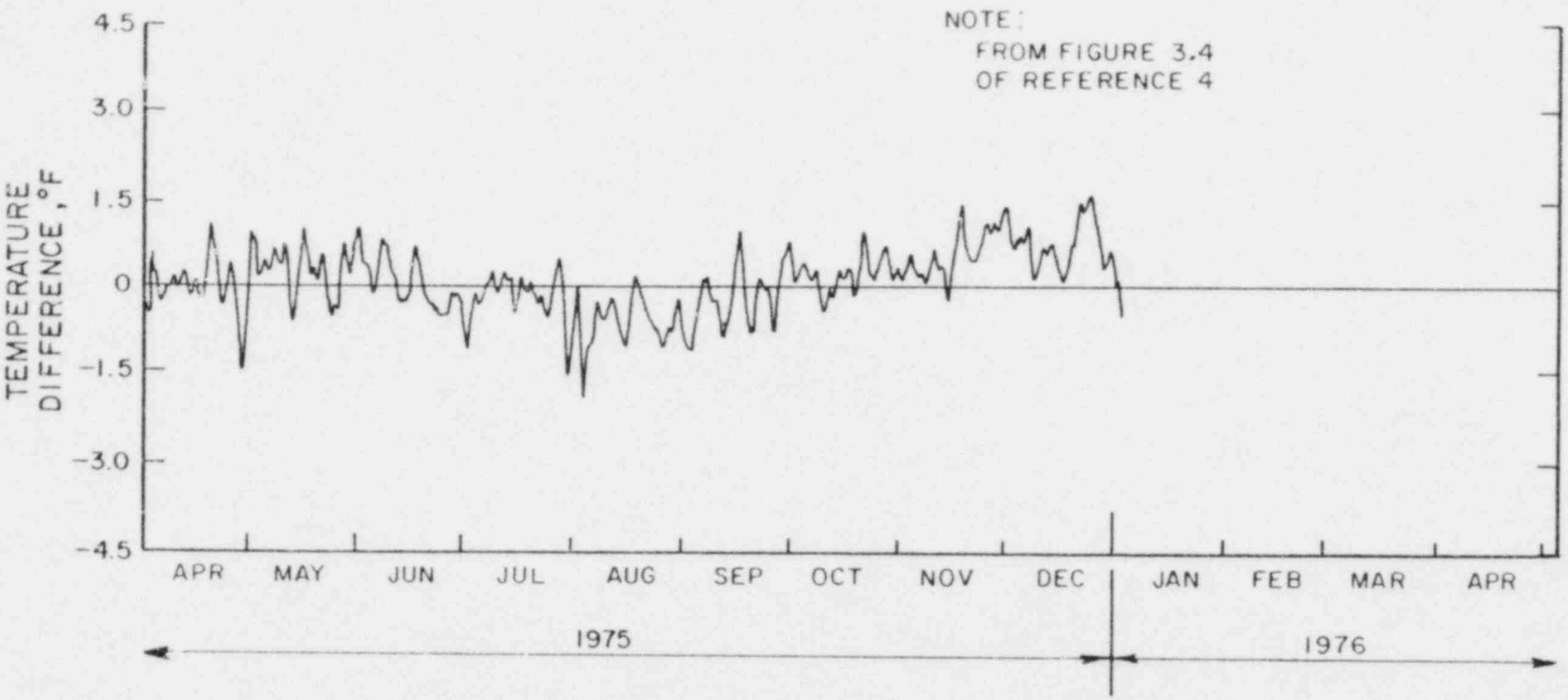


Figure 5: Comparison of Measured Temperature Difference Between Monitor Numbers 1 - 6 With Model Predictions

WM28-1-67-101.6



NOTE:
FROM FIGURE 3.4
OF REFERENCE 4

Figure 6: Difference Between Predicted and Measured Temperature Difference Between Monitor Numbers 1-6

ANALYSES OF NATURAL TEMPERATURE PATTERNS

Longitudinal Variations

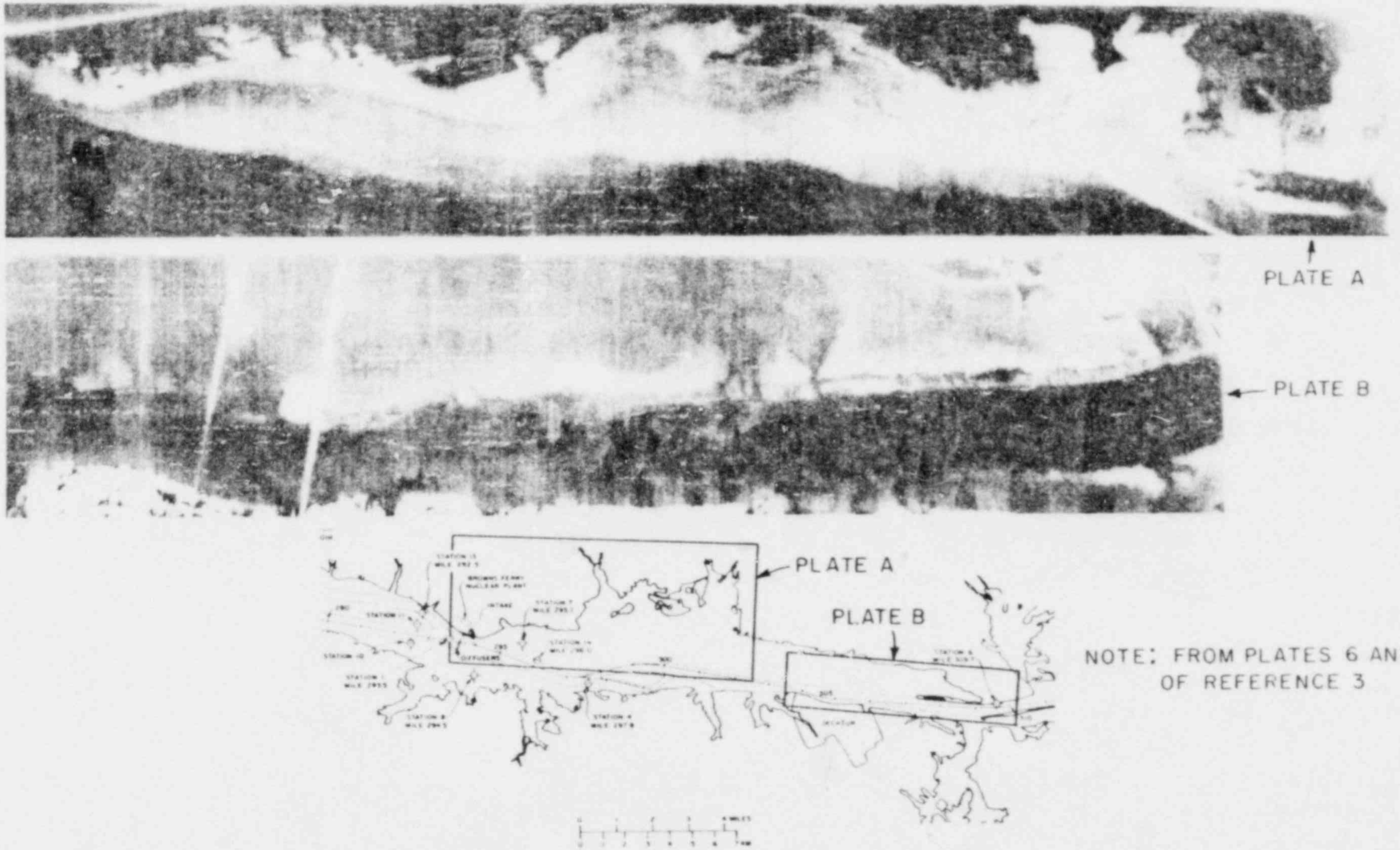
Natural longitudinal temperature variations have been shown by analyses of monitor Nos. 6, 4 and 1 during periods of plant inactivity (Reference 3). Figures 3 and 4 show that the monthly mean temperature at the five-foot depth at upstream monitors can be as much as 1° - 2°F higher than the temperature at the downstream monitor. Instantaneous temperature differences greater than 3°F are possible between monitor Nos. 1 and 6. Mean downstream temperatures are greater than upstream temperatures primarily in the spring and summer months when the reservoir water is being heated by solar radiation. Mean downstream temperatures can be as much as 1°F cooler than upstream temperatures at the five-foot depth in the fall and winter months as the reservoir cools.

These seasonal longitudinal temperature differences as detected by the Browns Ferry monitors effectively change the maximum temperature rise standard applied to the effects of plant discharge. Spring heating conditions reduce the maximum allowable plant-induced temperature rise by the amount of the natural longitudinal temperature increases. Autumn cooling conditions increase the maximum allowable plant-induced temperature rise by the amount of natural longitudinal temperature decreases. Thus temperature rises exceeding 5°F caused by natural temperature variations have always occurred in the spring months when the effective maximum allowable temperature rise is less than 5°F (Table 1); conversely, temperature rises exceeding 5°F are very unlikely to occur in the autumn months even though plant-induced temperature rises could have been greater than 5°F.

Cross-sectional Variations

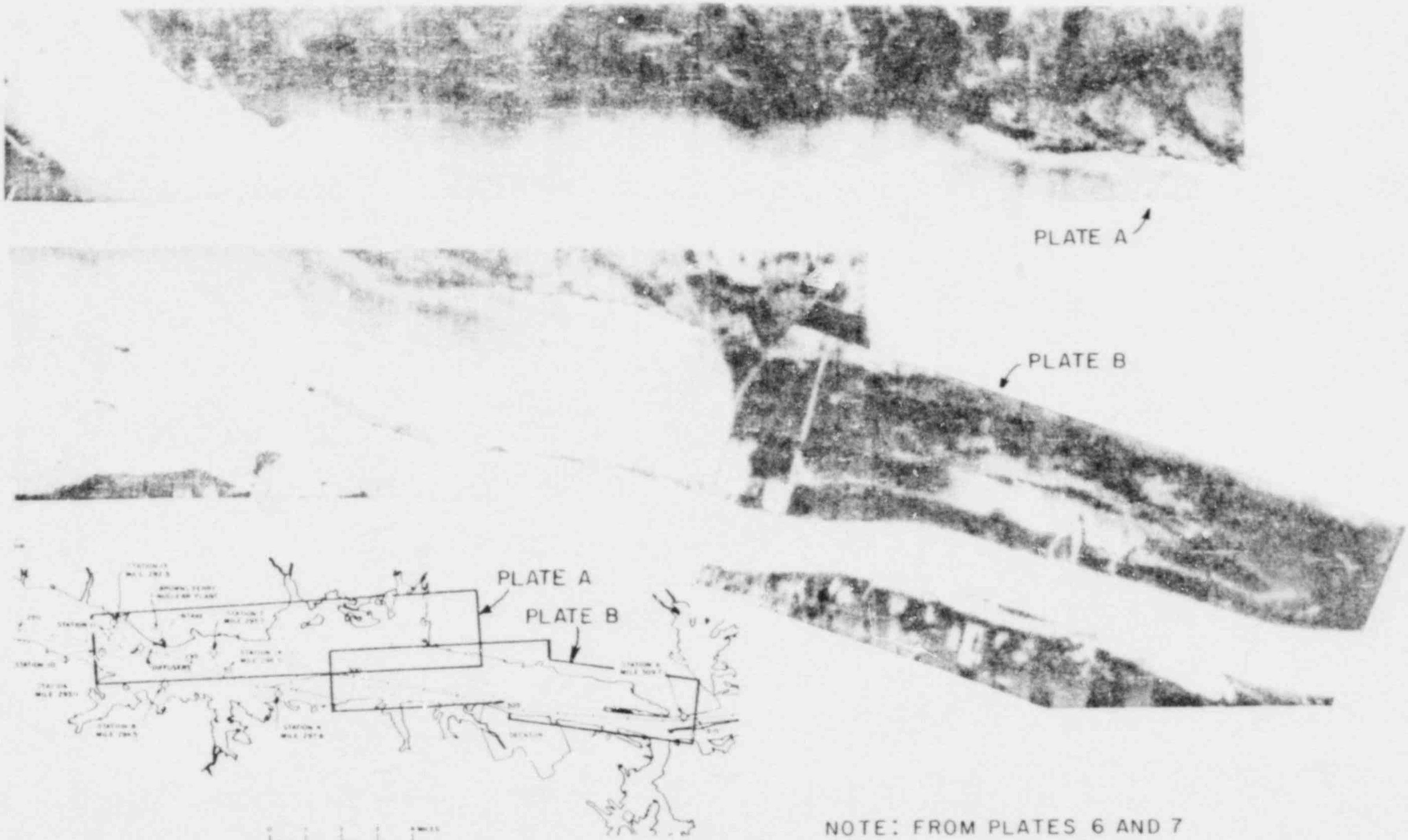
A major cause of lateral and vertical temperature variations is the interaction of seasonal heating and cooling trends with varying reservoir hydrography and resulting flow distributions. Figures 7 and 8 give an indication of these effects in Wheeler Reservoir upstream of Browns Ferry during spring heating and autumn cooling conditions, respectively (References 4 and 5). In the infrared imagery of Figures 7 and 8, warmer surface water temperatures are indicated by the lighter areas. The index maps on each figure shows the 25-30 foot deep main channel and the shallower 5-15 foot deep overbank areas covered by each infrared picture. Figures 7 and 8 show that spring heating and autumn cooling occur primarily in the overbank areas, which in turn affect the water temperatures in the main river channel. The overbank areas are affected earlier than the main channel because of their shallower depth, larger area and smaller proportion of the total river flow which passes through them relative to the main channel. Figures 7 and 8 show that flow from the right overbank area is mixed with the main channel flow in the vicinity of Browns Ferry Nuclear Plant.

Field studies were conducted on June 2-4, 1978, to observe the lateral and vertical temperature variations in the vicinity of the upstream and downstream monitors used for showing compliance with thermal standards. The river flow and plant load during the survey are shown on Figure 9. One unit was in operation on helper mode during most of the survey period; discussion of diffuser thermal effects will be made later in this report. Figures 10-13 show water temperature profiles in the vicinity of the upstream monitor Nos. 4, 14 and 7,



NOTE: FROM PLATES 6 AND 7
OF REFERENCE 3

Figure 7: Spring Heating Upstream of Browns Ferry



NOTE: FROM PLATES 6 AND 7
OF REFERENCE 3

Figure 8: Autumn Cooling Upstream of Browns Ferry

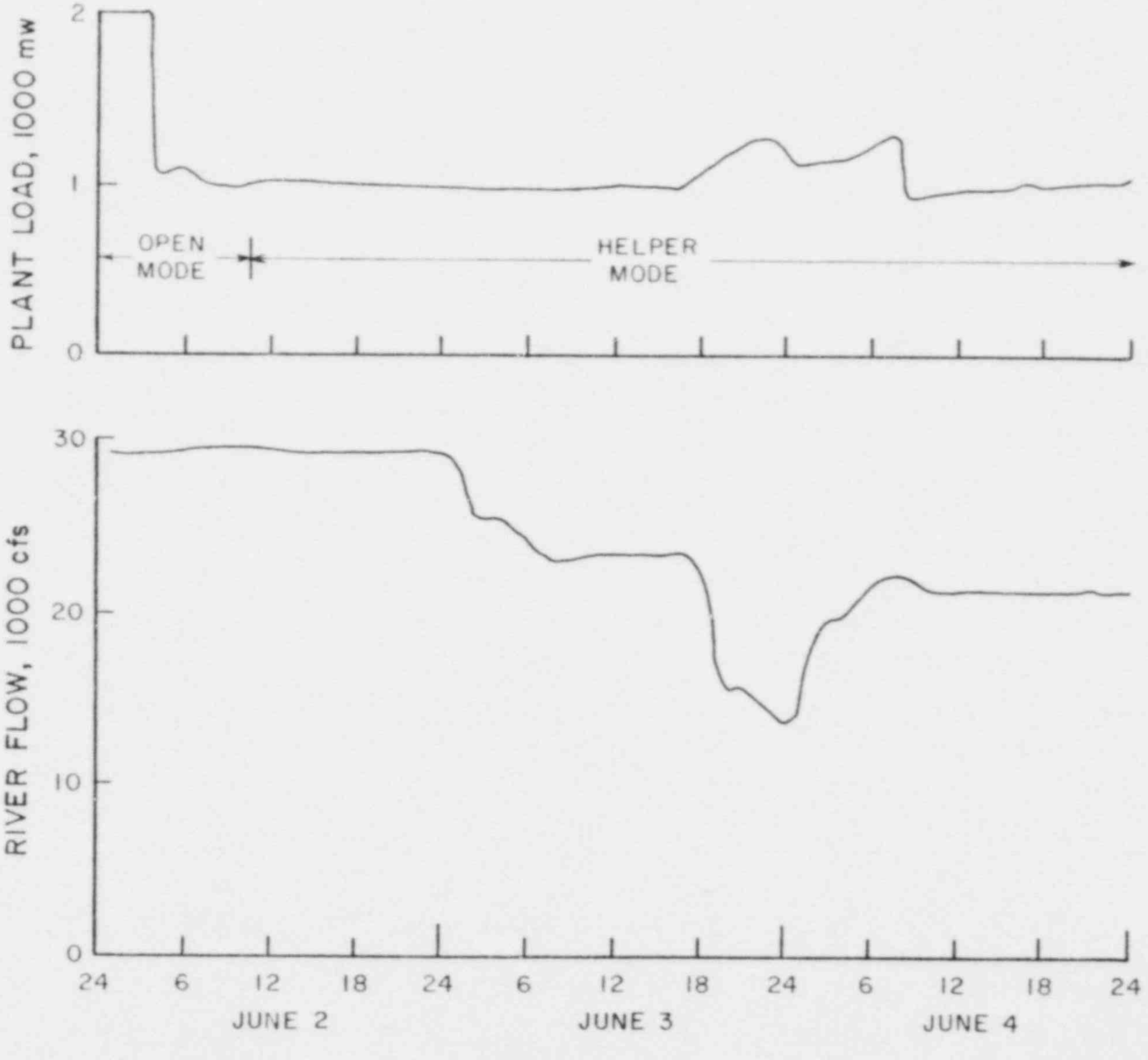
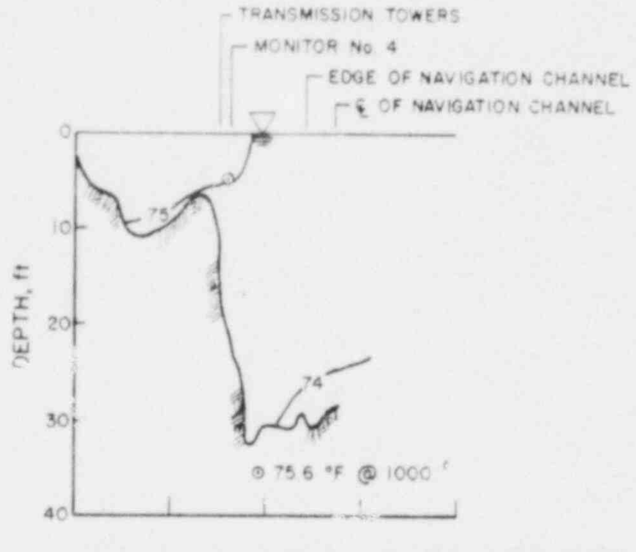
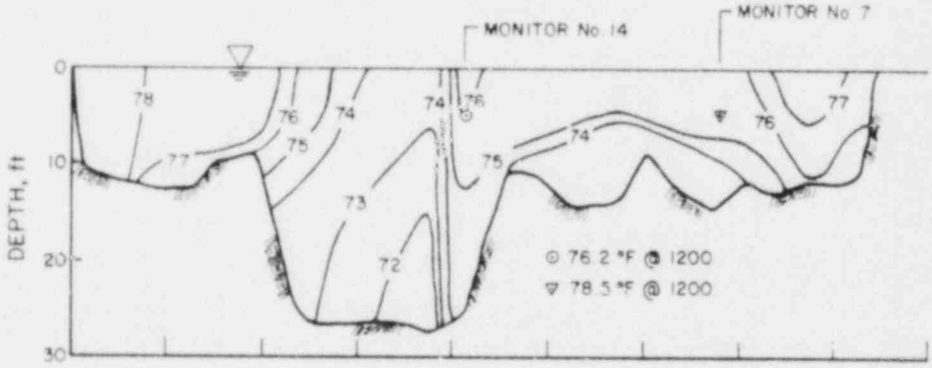


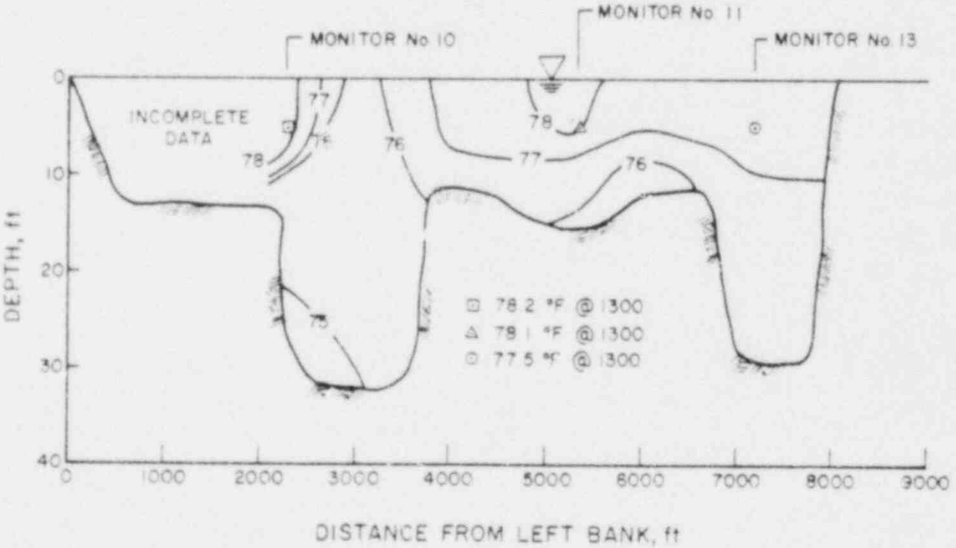
Figure 9: Field Survey Conditions, June 2-4, 1978



a) TRM 297.8 AT MONITOR #4, 1024-1056 HOURS

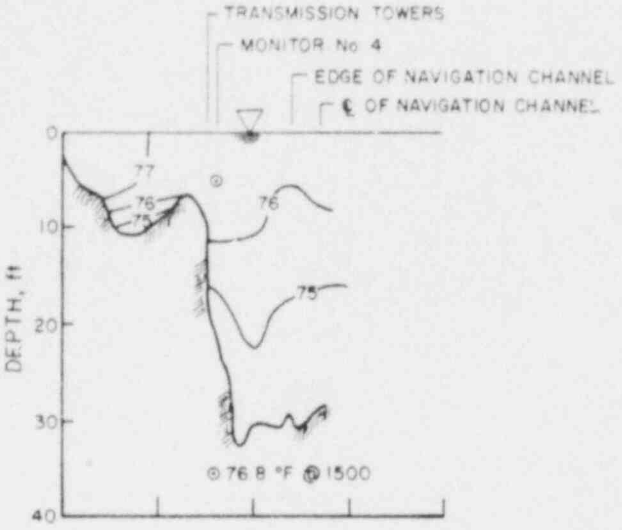


b) TRM 295.7 NEAR MONITORS #14 AND #7, 1120-1159 HOURS

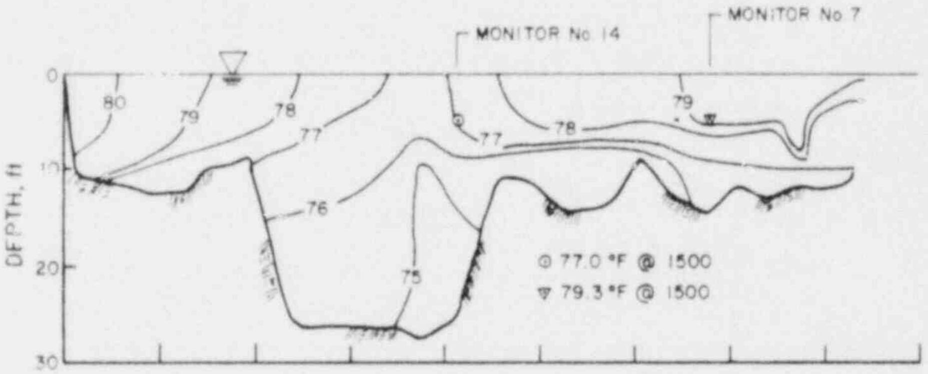


c) TRM 292.5 AT MONITORS #10, #11 AND #13, 1232-1245 HOURS

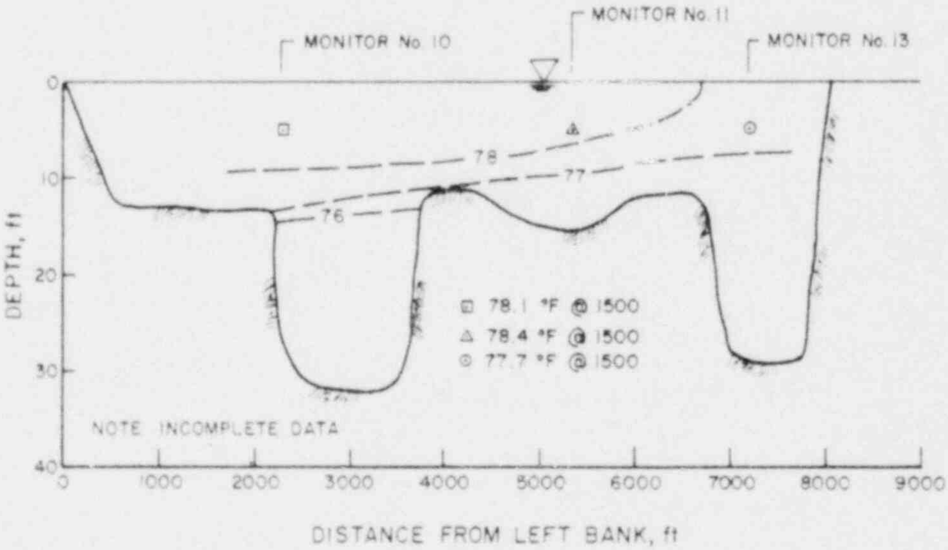
Figure 10. Water Temperature Profiles near Permanent Monitors
Morning of June 3, 1978



a) TRM 297.8 AT MONITOR #4, 1441 - 1516 HOURS

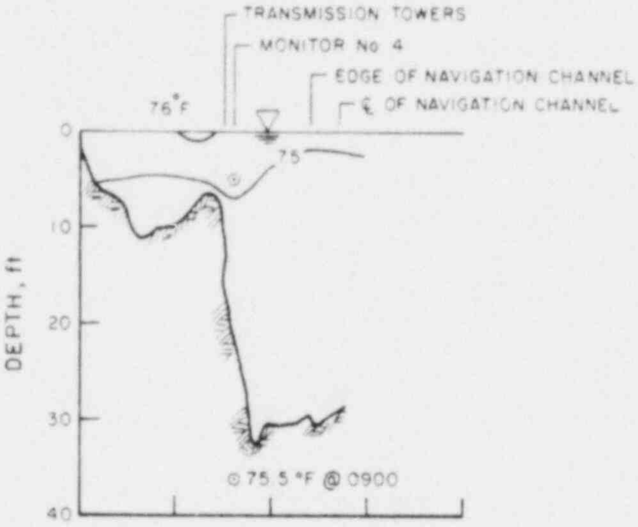


b) TRM 295.7 NEAR MONITORS #14 AND #7, 1435 - 1558 HOURS

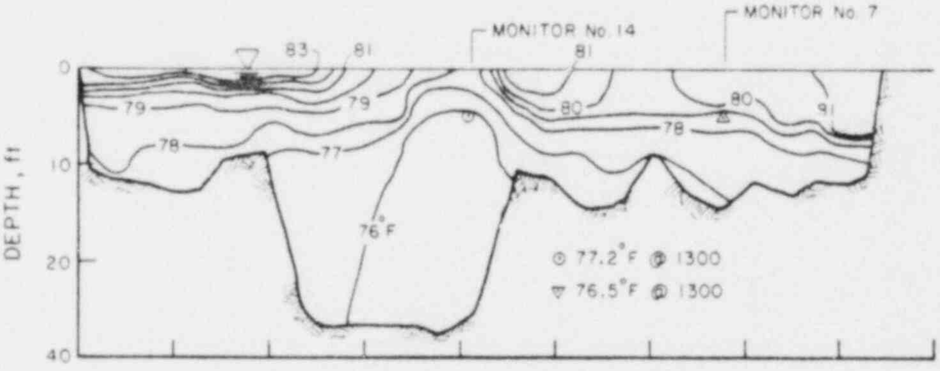


c) TRM 292.5 AT MONITORS #10, #11 AND #13, 1500 HOURS

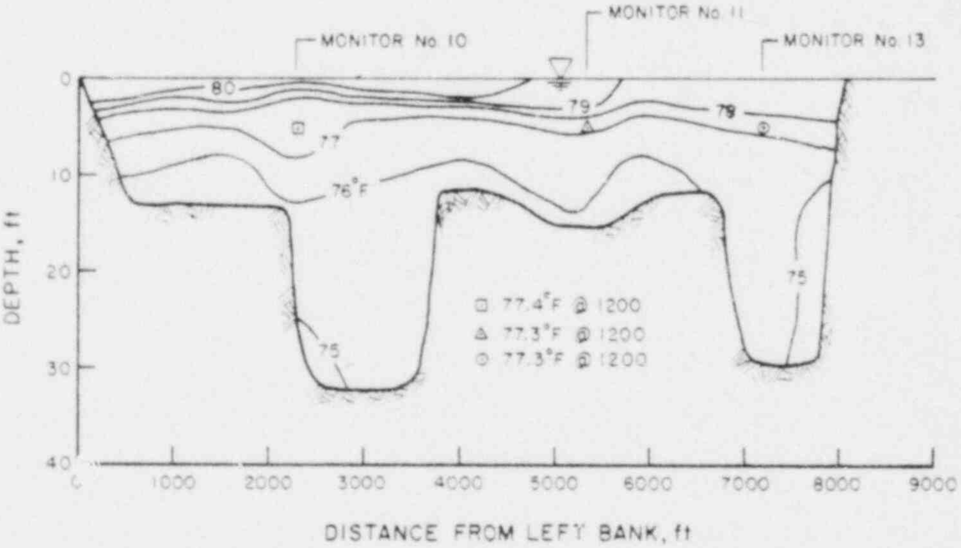
Figure 11. Water Temperature Profiles near Permanent Monitors
Afternoon of June 3, 1978



a) TRM 297.8 AT MONITOR #4, 0911 - 0936 HOURS

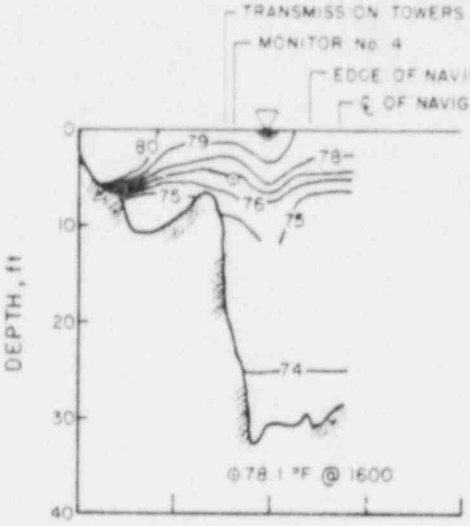


b) TRM 295.7 NEAR MONITORS #14 AND #7, 1025 - 1342 HOURS

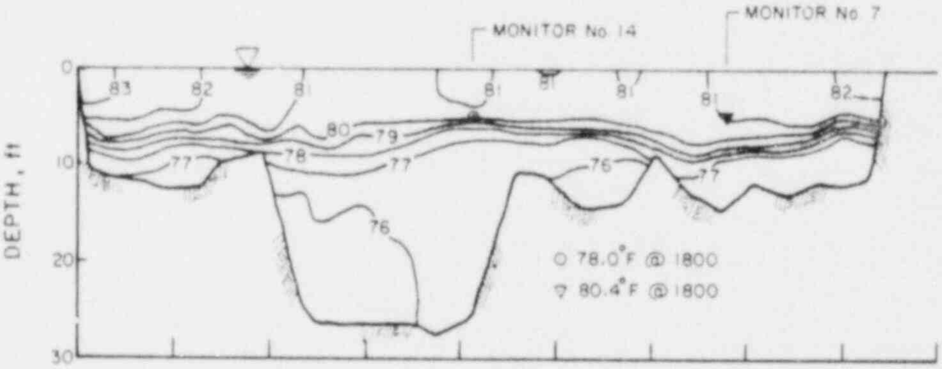


c) TRM 292.5 AT MONITORS #10, #11 AND #13, 1147 - 1222 HOURS

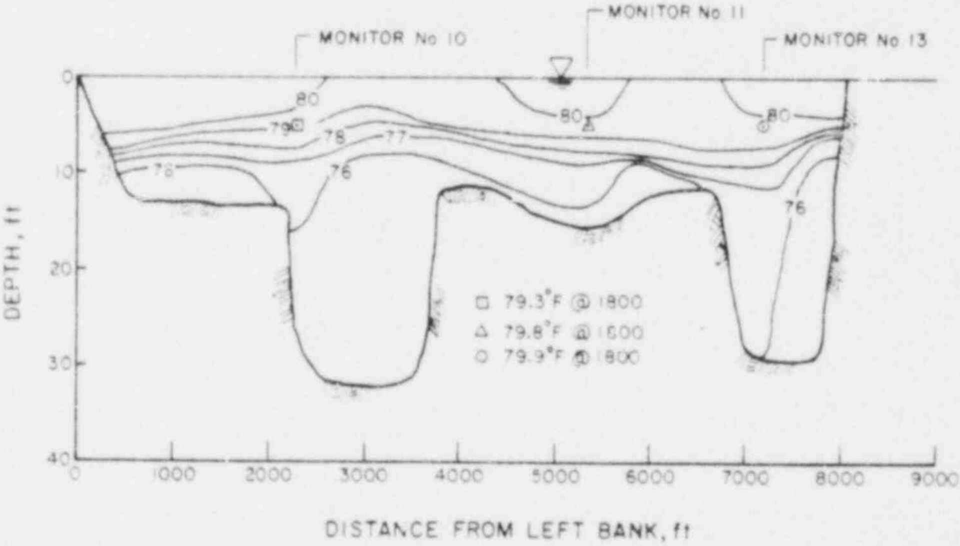
Figure 12. Water Temperature Profiles near Permanent Monitors
Morning of June 4, 1978



a) TRM 297.8 AT MONITOR #4, 1548-1610 HOURS



b) TRM 295.7 NEAR MONITORS #14 AND #7, 1547-1817 HOURS



c) TRM 292.5 AT MONITORS #10, #11 AND #13, 1728-1751 HOURS

Figure 13: Water Temperature Profiles near Permanent Monitors Afternoon of June 4, 1978

and the downstream monitor Nos. 10, 11 and 13 on the morning and afternoon of June 3-4, 1978.

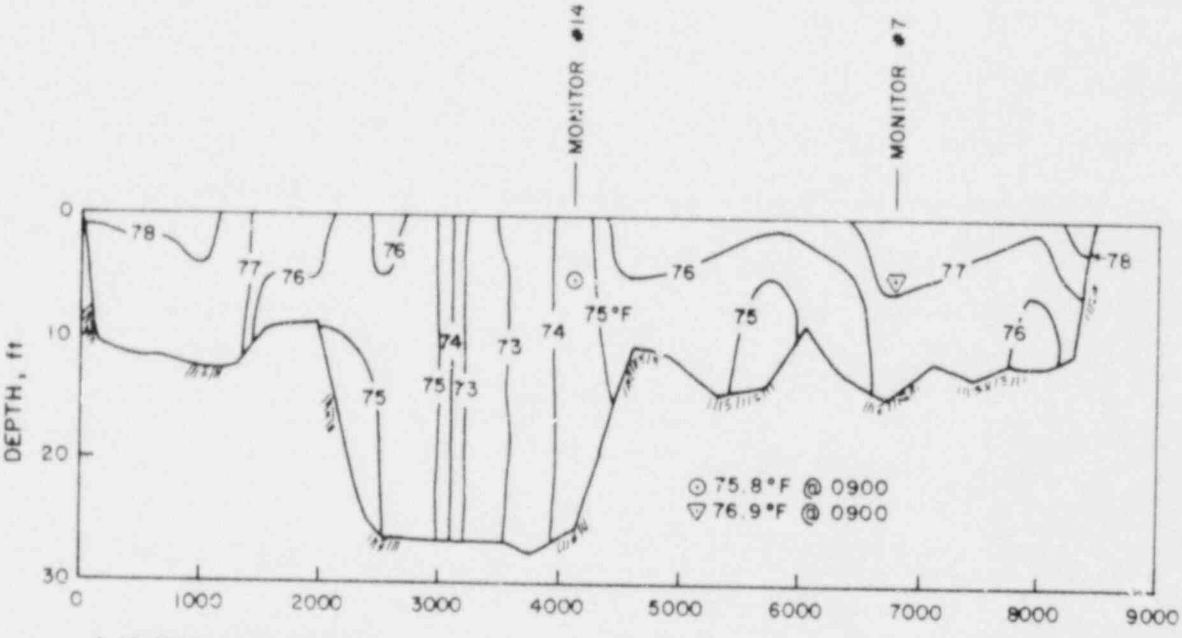
River flows of about 30,000 cfs, partly cloudy skies and little wind prevailed on June 3, 1978. Figure 10 shows that some stratification was present during the morning survey that day. The presence of water in the main channel which was 5-6°F colder than in the overbank areas caused an area of large lateral temperature gradients near the point of intersection of the channel and the right overbank in the vicinity of monitor No. 14. This water was released from Guntersville Reservoir and remained relatively cool because of the lack of overbank areas and riverine characteristics of the Tennessee River between Gunversville Dam and Decatur, Alabama. During the afternoon survey of June 3, 1978 (Figure 11), additional stratification developed in the overbank areas. Temperatures in the overbanks were still as much as 5°F warmer than the water in the main channel, although main channel temperatures had increased 1-3°F. Warmer temperatures were noted in the lower depths of the right side channel at the downstream monitors due to the effect of operation of unit three diffuser near the right bank. This effect is clearer in the June 4, 1978, survey results and will be noted later.

River flows of about 21,000 cfs and clear skies characterized the June 4, 1978, survey. Figures 12 and 13 show similar temperature variations as those noted for June 3, 1978, in Figures 10 and 11. Stratification was much stronger on June 4, 1978, with the area of largest temperature gradients near the five-foot depth at which compliance temperature measurements were made.

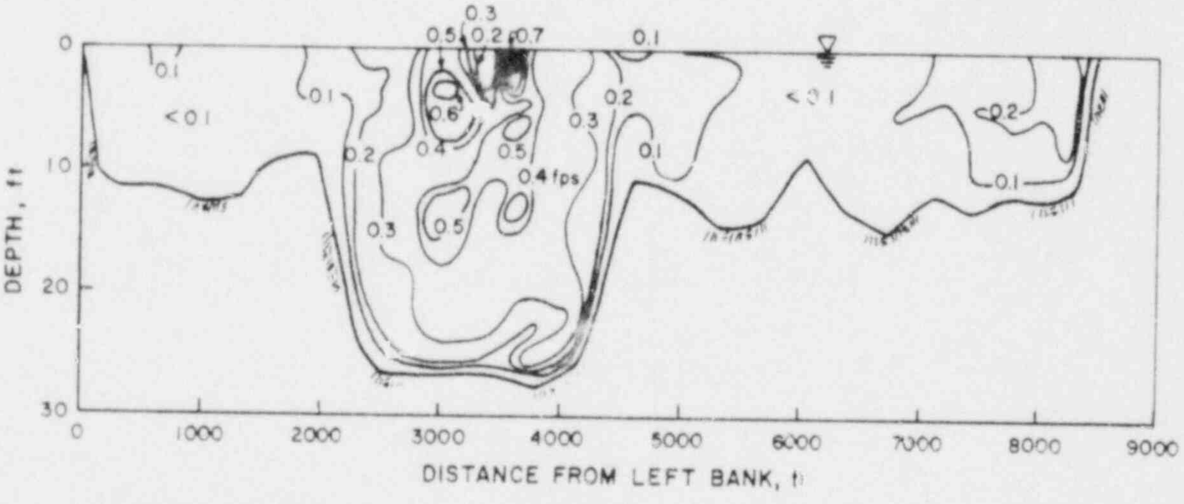
Velocity data at the cross-section near monitor Nos. 7 and 14 at TRM 295.7 upstream of the plant was also measured during the surveys. High winds on June 3, 1978, prevented the collection of accurate velocity data on that day. Velocity data taken prior to the morning survey of June 4, 1978, and velocity data taken during the morning survey of June 4, 1978, are shown in Figures 14 and 15, respectively. Data in Figure 15 corresponds to the temperature survey presented in Figure 12. Calm winds prevailed during the survey presented in Figures 14 and 15, although higher winds during the afternoon survey of June 4, 1978, (Figure 13) prevented the collection of accurate velocity data.

Figure 14 shows that about 85 percent of the flow at TRM 295.7 in the early morning hours of June 4, 1978, consisted of the cooler water in the main channel which had been released earlier from Guntersville Dam. Dead zones occurred in the left overbank and the middle of the right overbank with a flow of warmer water near the right bank in the vicinity of an impounded creek bed. As stratification developed later in the morning, both the velocity and temperature profiles changed dramatically. A dead zone still was present in the left overbank but was smaller in area. Flow as well as temperature in the right overbank was fairly uniform in the lateral direction. Approximately 75 percent of the river flow was present in the main channel, which was still as much as 5-8°F cooler than areas of the overbank regions.

These field data clearly illustrate that temperatures measured at the five-foot depth are often situated in areas of large vertical and lateral temperature gradients. When compliance monitor measurements are situated in areas of large temperature gradients, they are subject

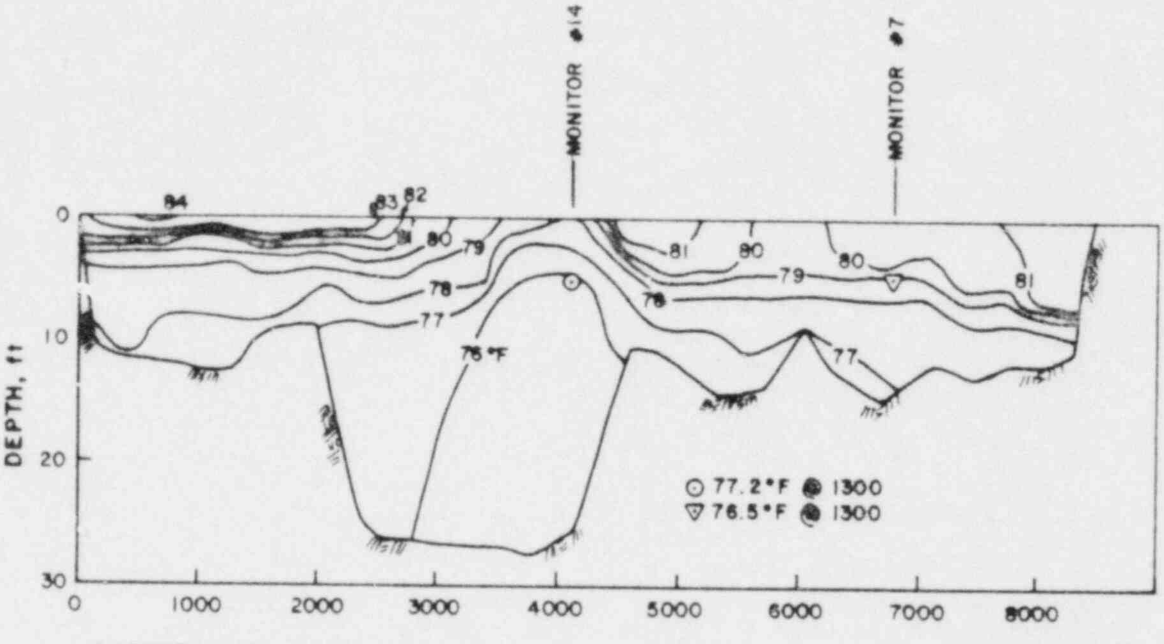


a) TEMPERATURE PROFILE

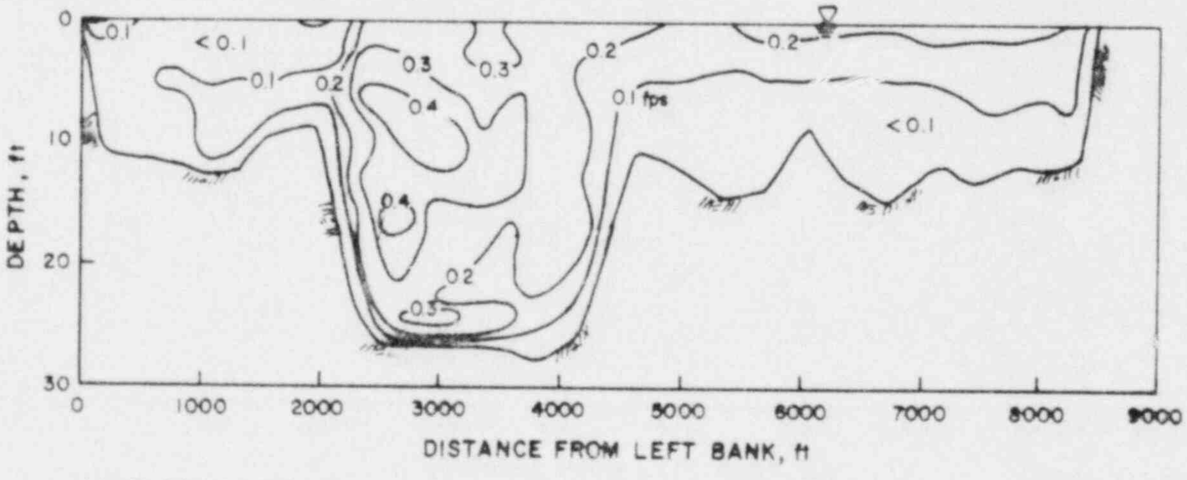


b) VELOCITY PROFILE

Figure 14: Temperature and Velocity Profiles at TRM 295.7
June 4, 1978, 0600-0935 Hours



a) TEMPERATURE PROFILE



b) VELOCITY PROFILE

Figure 15: Temperature and Velocity Profiles at TRM 295.7
June 4, 1978, 1010 – 1318 Hours

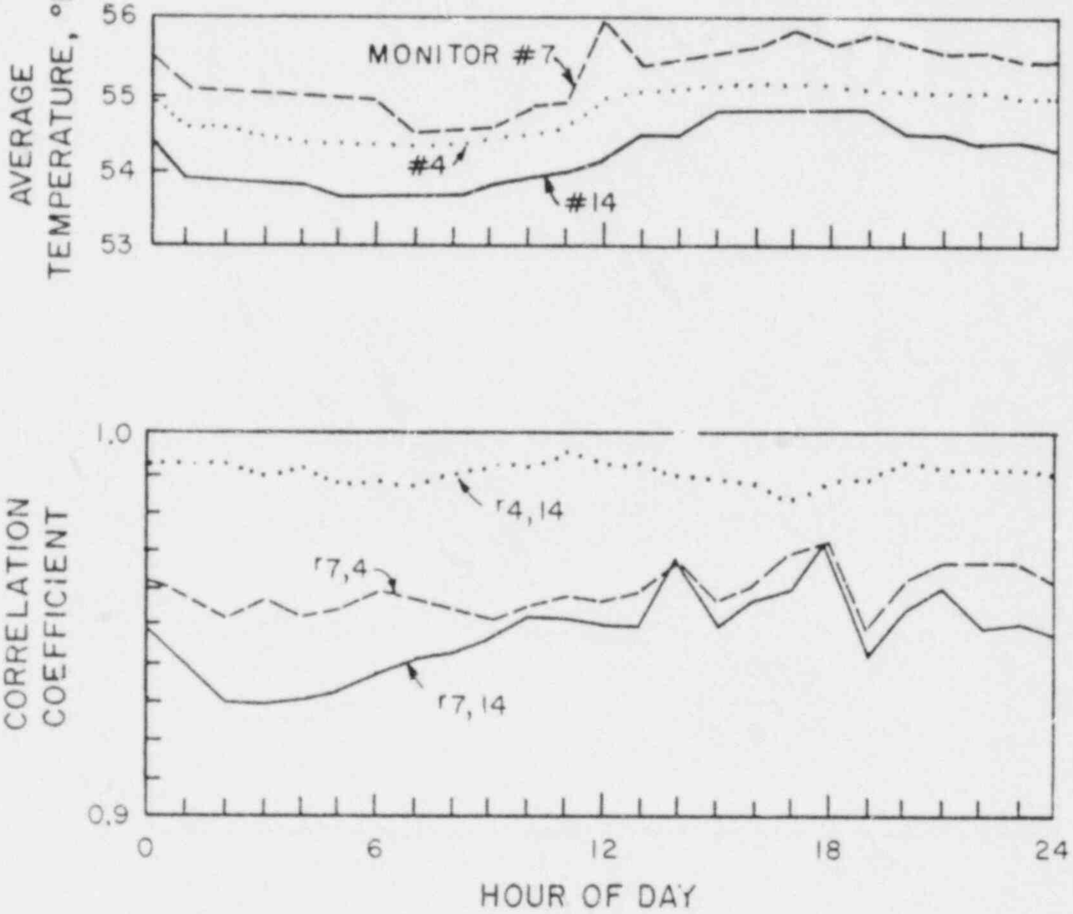
to considerable fluctuations due to wind, river flow, solar radiation and other phenomena which could shift the location of the temperature gradients.

Temporal Variations

Studies of the stochastic properties of natural water temperatures have noted variations with seasonal time scales; weather-induced, short term time scales on the order of days; and diurnal time scales (Reference 6). In addition, hourly variations induced by changes in wind, river flow, solar radiation or cloud cover are possible.

Seasonal temperature and temperature difference variations have been noted in Figures 3 and 4 in which the natural longitudinal temperature difference between monthly mean temperatures at various monitors was presented. Both seasonal and "storm cycle" variations were noted in connection with the application of a one-dimensional model to natural longitudinal temperature differences given in Figures 5 and 6. An indication of diurnal temperature changes can be seen in the field data from the June 2-4, 1978, survey given in Figures 10-15.

Diurnal as well as hourly temperature variations have been studied in statistical analyses of water temperatures at monitor Nos. 7, 4 and 14 during 1977. Figures 16-18 show the diurnal variation of temperatures and correlation coefficients between monitors during an average day in March, May and July 1977, respectively. The statistics at each hour were based upon all data collected at that hour during each month. The correlation coefficient is a measure of the linear variation of the temperatures measured at the same time at different monitors. By definition, the correlation coefficient can vary between -1



WM28-1-67-101.16

Figure 16: Statistical Analysis of Upstream Monitors for March 1977

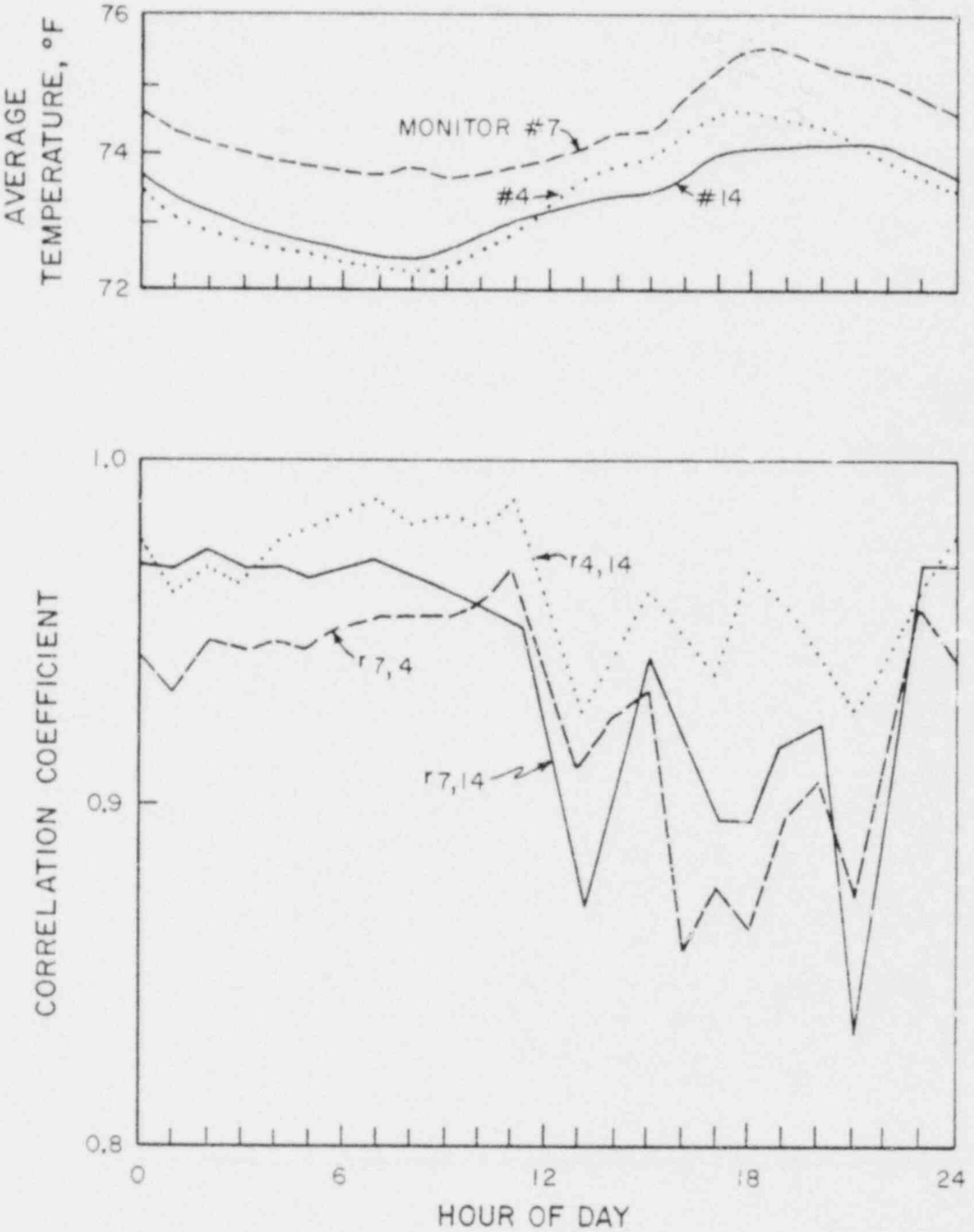


Figure 17: Statistical Analysis of Upstream Monitors for May 1977

WM28-1-67-101.17

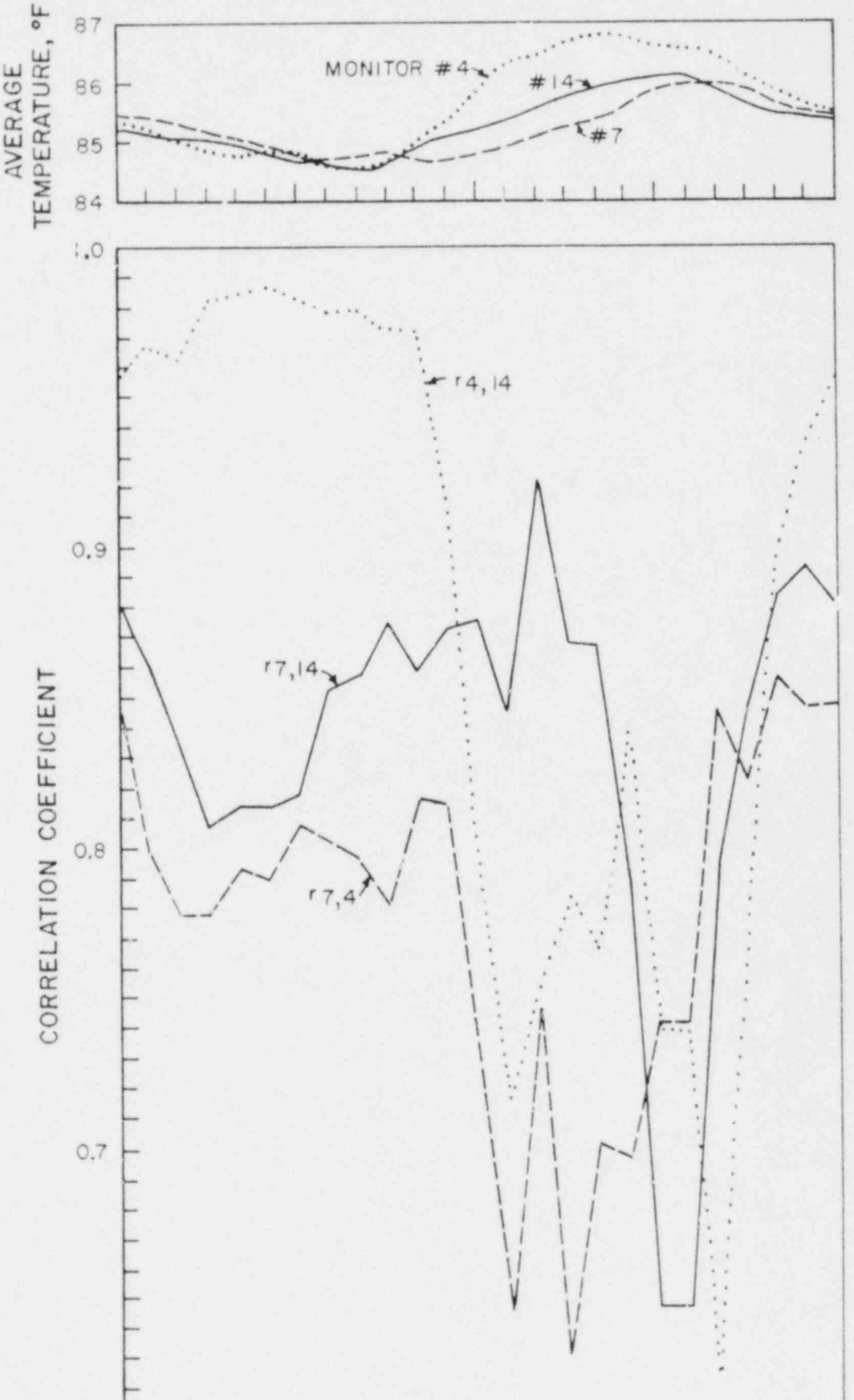


Figure 18. Statistical Analysis of Upstream Monitors for July 1977

and 1; a coefficient near 1 indicates that high (low) temperatures at one monitor occur when high (low) temperatures occur at another monitor, and a correlation coefficient near -1 indicates that high (low) temperatures at one monitor occur when low (high) temperatures occur at another monitor. A correlation coefficient near zero indicates that the temperatures at the monitors are not linearly correlated.

Figure 16 shows that monitor No. 7 was 0.5 - 1.0 °F warmer on the average than the main channel monitor Nos. 4 and 14 during March 1977. The main channel monitors were more linearly correlated than the overbank monitor and either channel monitor. These observations are indicative of the beginning of spring heating in the overbank areas of Wheeler Reservoir upstream of the plant. Figure 17 shows that monitor No. 7 was about 1°F warmer than the main channel monitor Nos. 4 and 14 during May 1977. The main channel monitors were more linearly correlated than the overbank and either channel monitor; however, from late morning until late evening, all of the correlation coefficients were lower and showed more fluctuations. This behavior indicates that solar heating affected the monitors in a more uneven manner than the radiational cooling during the early morning hours. This pattern is even more pronounced in July 1977, shown in Figure 18. The variation of correlation coefficients show a similar pattern in July, except that the magnitude of the fluctuations is greater. Monitor No. 7 in the right overbank was generally cooler than the main channel monitor Nos. 4 and 14, particularly in the afternoon hours. Apparently the process of reservoir cooling began during July 1977 shortly after the summer solstice.

The effect of non-linear temporal changes between monitors is demonstrated in Figure 19, which shows the diurnal temperature records at compliance monitors on May 8, 1977, when the temperature rise exceeded 5°F from 1400 to 1600 hours. While all monitored temperatures generally increase and decrease in a similar manner, the rates of temperature change and the time of peak temperature varied among monitors. The timing of the temperature rise excursion above 5°F at Browns Ferry on May 8, 1977, (1400-1600 hours) agrees with the timing of the decrease in correlation coefficients from late morning to late evening shown in Figures 16-18. In fact, Table 1 shows that all Browns Ferry temperature rise excursions above 5°F caused by natural temperature variations have occurred during this period of the day.

Summary

The preceding analysis of natural temperature patterns in Wheeler Resrvoir near Browns Ferry Nuclear Plant poses the following problems which must be addressed in the design of a system to show compliance with applicable temperature standards:

1. Definition of Ambient Temperature: Lateral and temporal variations in temperature upstream of Browns Ferry which are uninfluenced by plant thermal discharges are of the same order of magnitude as the applicable temperature rise standard. Data presented in this report clearly show the difficulty in determining the "ambient" temperature in the presence of such large variations.

2. Longitudinal Distance Between Compliance Monitors: The longitudinal distance between compliance monitors is presently about five miles. Natural longitudinal differences between the present Browns

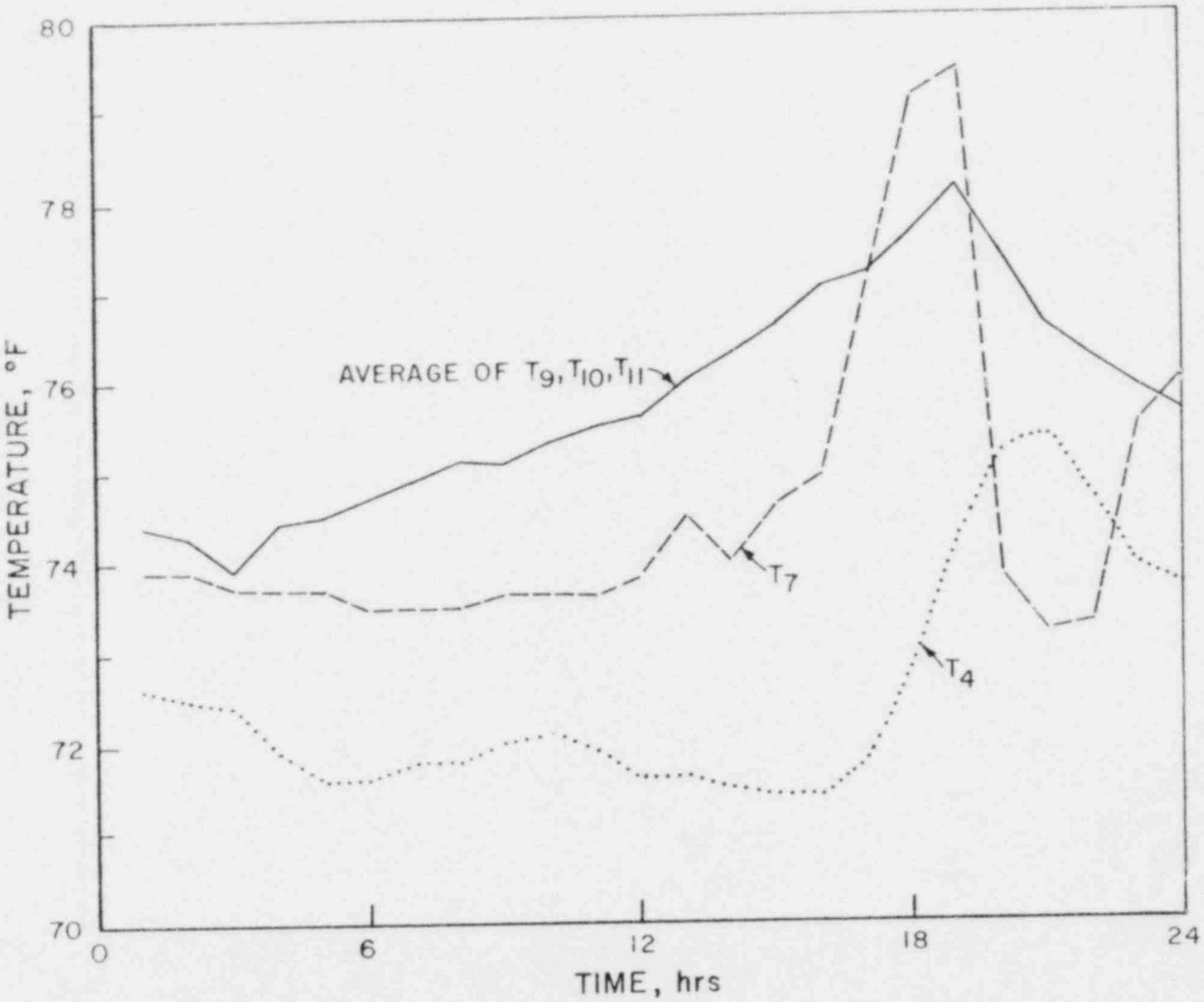


Figure 19: Water Temperatures Near Browns Ferry Nuclear Plant
May 8, 1977

Ferry monitors can effectively reduce the maximum allowable temperature rise standard in the spring and increase the maximum allowable rise in the fall as applied to plant discharges.

3. Vertical Location of Temperature Measurements: Temperatures measured at the five-foot depth are often situated in areas of large vertical temperature gradients. Navigation constraints restrict the location of temperature monitors such that temperatures are often measured at the points of intersection between overbank and main channel areas. These locations are often subject to large lateral temperature gradients. Temperature measurements in areas of large temperature gradients are subject to considerable fluctuation.

4. Determination of Mixing Zone Size: The present "mixing zone" for plant discharges is about 1.5 miles long over the entire reservoir cross-section. The presence of natural temperature variations at the downstream monitors indicates that the thermal effects of plant-induced mixing are not clearly detectable so far downstream of the plant diffusers.

PROPOSED SYSTEM FOR DEMONSTRATING COMPLIANCE WITH TEMPERATURE STANDARDS

To provide for a reliable means of showing compliance with applicable temperature standards, a system utilizing measured environmental and plant parameters and a model of diffuser mixing is proposed for the Browns Ferry Nuclear Plant. The essential features of the system are described and an outline of the necessary measurements and calculations for the system is provided. The effects and advantages of the proposed system are briefly discussed.

Essential Features of the System

The proposed system for demonstrating compliance with temperature standards utilizes operational monitoring to measure the parameters used in mathematical modeling of the mixing of plant discharges. The mathematical model can then be used to calculate plant-induced temperature effects.

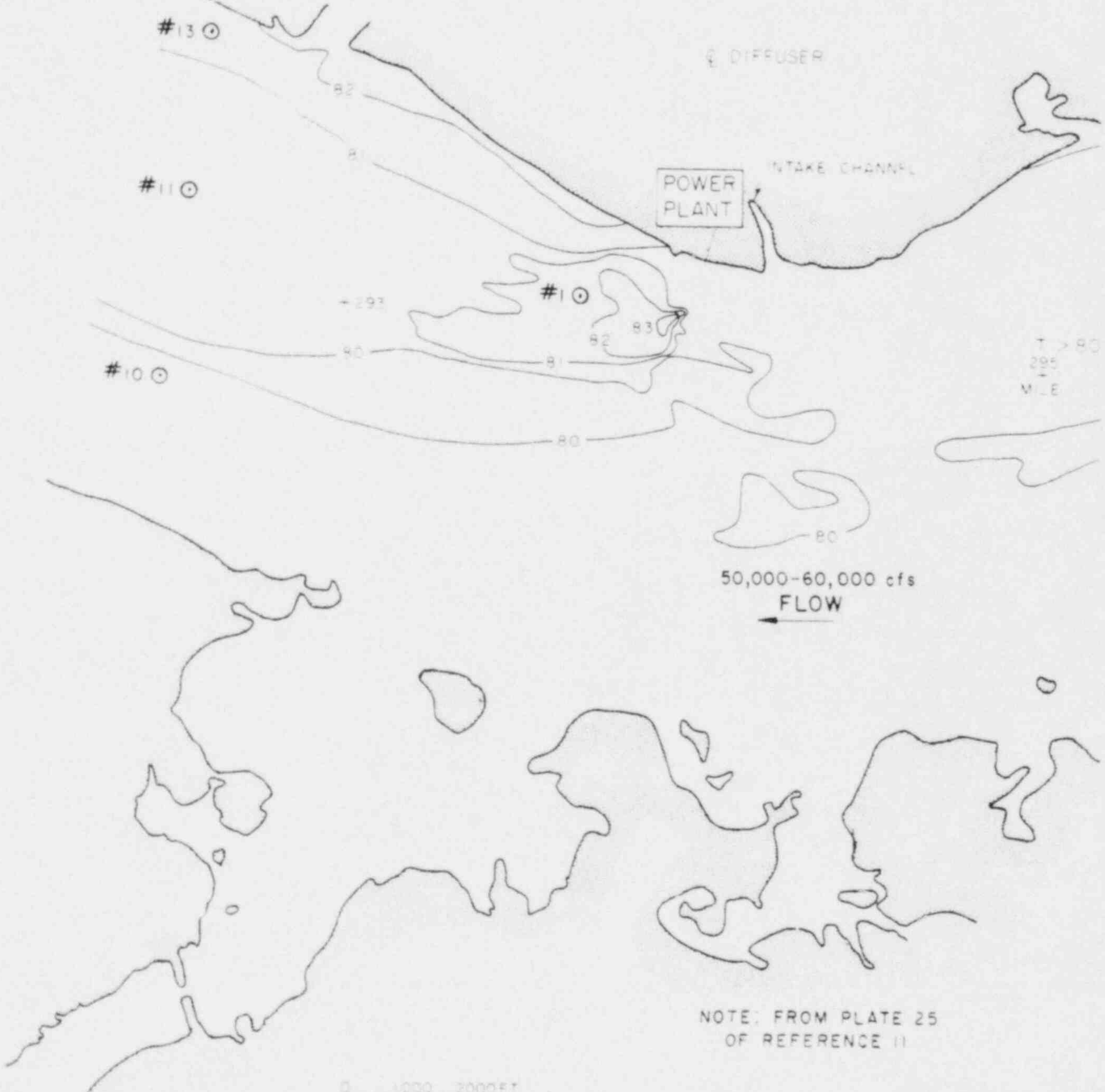
An approach which is basically similar to the proposed system is suggested in Reference 7. This reference states that "The best approach available for demonstrating compliance with this type of regulation" (temperature rise standard on the order of natural temperature variations) "is one where operational monitoring is not aimed at measuring temperature rises directly but, rather, at verifying that the physical parameters used in mathematical modeling of hydrothermal conditions were correctly evaluated." Because river flows, plant discharge rate and discharge temperature can easily be obtained at Browns Ferry, a computer program can calculate the plant-induced temperature rise on a real-time basis based on downstream mixed temperature measurements.

Such monitoring, the real-time calculation of plant-induced temperature effects, and continuous refinement of mathematical modeling techniques based on operating experience, offers the most reliable means available for demonstrating compliance with applicable temperature standards at Browns Ferry.

The model of diffuser mixing is basically described in References 8 and 9 and has been verified in physical model studies and field tests (Reference 10). As discussed in Reference 8, the model is used daily to predict the optimal cooling mode at Browns Ferry. Necessary inputs to the model include plant discharge rate, discharge temperature, river flow and ambient temperature.

Ambient river temperature is used in the model to determine the buoyancy of the discharge relative to the receiving water and the temperature difference between the discharge and the river. The proposed compliance system will not measure the ambient temperature because of the natural temperature variations discussed previously. Instead, the computer model will iteratively compute the temperature rise and ambient temperature based upon a measured downstream mixed temperature until the solutions converge. Thus the only river temperature measurement will be made downstream of the diffuser in an area where plant-induced temperature effects can be reliably measured.

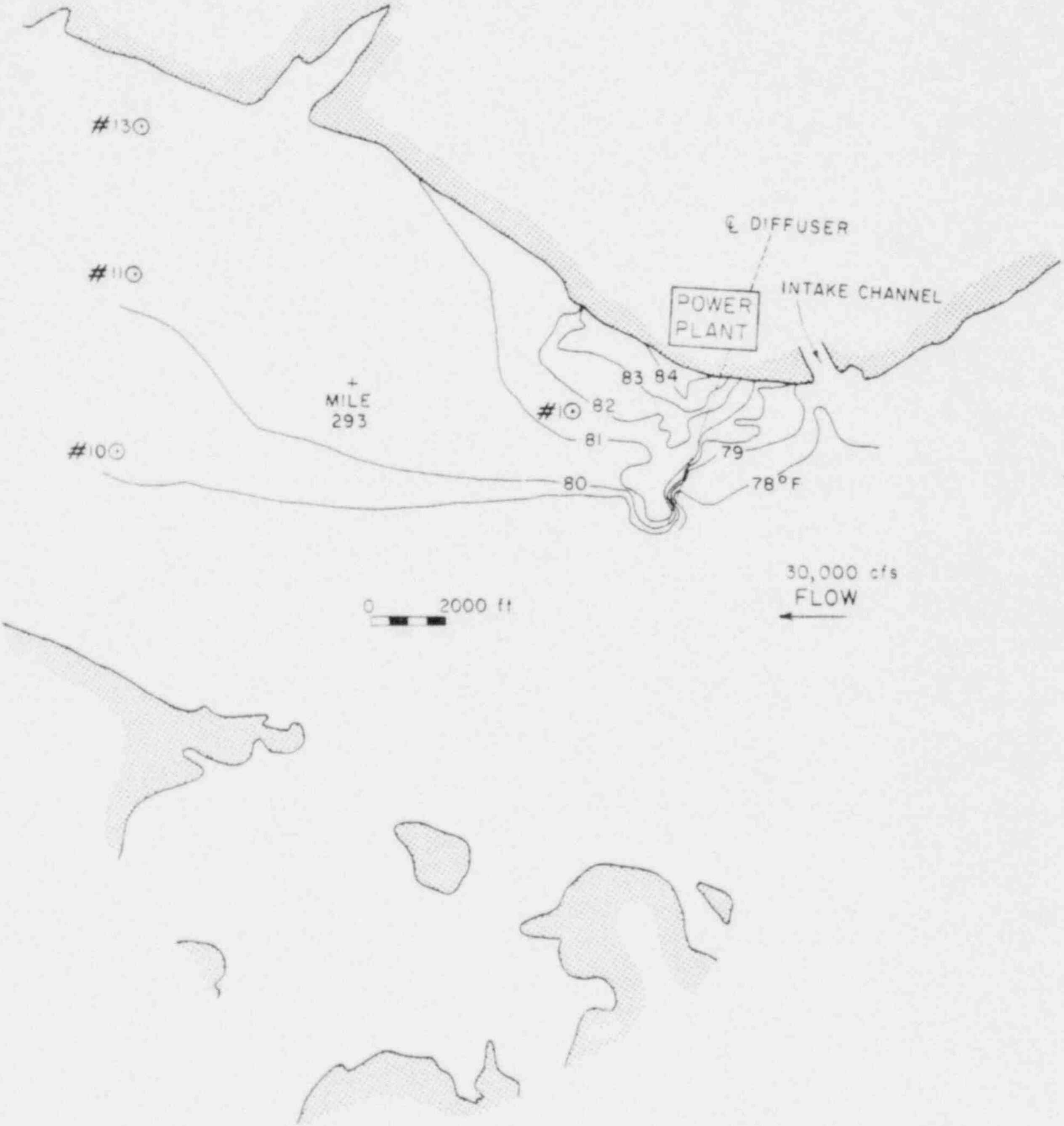
Field measurements and diffuser performance analyses indicate that diffuser-induced mixing takes place within one to two diffuser lengths downstream of the discharge point. Figures 20 and 21 show examples of isotherms at the five-foot depth for full one and three unit operation, respectively, at Browns Ferry using open mode cooling (References 11 and 10). The majority of diffuser-induced mixing takes



NOTE: FROM PLATE 25
OF REFERENCE 11

Figure 20: Isotherms at the Five-Foot Depth
One Unit Open Mode Cooling at Browns Ferry
August 15, 1974

WM28-1-67-101.20



WM28 - 1 - 67 - 101.21

Figure 21: Isotherms at the Five-Foot Depth
Three Unit Open Mode Cooling at Browns Ferry
June 9, 1977

place between the diffuser and monitor No. 1 which is about one diffuser length (1800 feet) downstream of the discharge point. Therefore, consistent with navigation constraints, the proposed system will utilize temperature measurements at three monitors situated one to two diffuser lengths downstream of the mid-channel (unit one) diffuser, the left side (unit two) diffuser and the right side (unit three) diffuser, to determine the downstream mixed temperature. By positioning the monitors at the edge of an area primarily affected by diffuser mixing, temperature fluctuations associated with large lateral temperature gradients near the point of intersection between the main channel and left overbank can be avoided. The effective mixing zone for the plant under the proposed compliance system extending one to two diffuser lengths (1800-3600 feet) downstream in the main river channel over the entire depth is compared to the present mixing zone which occupies approximately 1.5 miles downstream of the diffusers.

As discussed in Reference 10, the temperature distribution downstream of the diffuser during normal open mode discharges may be either stratified or well mixed in the vertical direction. If the discharge plume stratifies, the depth of the stratified layer is estimated at one-sixth the water depth (Reference 12). At a water depth of about 30 feet, the bottom of the stratified layer (a zone of large temperature gradients) would be situated very near the normal depth for compliance measurement of five feet. Under the proposed compliance system, measurements at the repositioned downstream temperature monitors will be made at the one-meter and two-meter depths and averaged to give a temperature at the five-foot (actually 4.92 foot) depth. This method will bracket the area of large vertical temperature gradients associated with stratified diffuser plumes and average out fluctuations in the position of large vertical temperature gradients or in well-mixed flow regimes.

Measurements and Calculations

The proposed compliance system will utilize the following measurements for:

1. Mixed temperature: Three monitors will be situated approximately one to two diffuser lengths (1800-3600 feet) downstream of the diffusers. One will be situated at the left side of the navigation channel, one near the right side of the navigation channel, and one between the navigation channel and the right bank. Measurements will be made every 5 minutes at one-meter and two-meter depths at each monitor and transmitted to the plant site.

2. River flow: Discharges from Guntersville and Wheeler Dams will be transmitted to the plant site at least hourly.

3. Discharge temperature: A monitor at the diffuser gate structure will measure the temperature of water entering each diffuser and transmit the data to the plant site.

4. Discharge flow: The number of condenser cooling water pumps in operation and the position (open-closed) of appropriate gate structure will be monitored on site.

These measurements will be received by a dedicated computer which will calculate the following information:

1. Discharge flow will be computed from the number of condenser cooling water pumps in operation. The position of gate structures will allow determination of the operating diffusers.

2. River flow will be computed using an unsteady flow routing model and the previous 48 hours of Guntersville and Wheeler Dam discharges.

3. The temperature rise will be computed using the theory of diffuser mixing discussed previously. The temperature rise and ambient river temperature will be calculated by an iterative procedure until the difference between successive calculations is small.

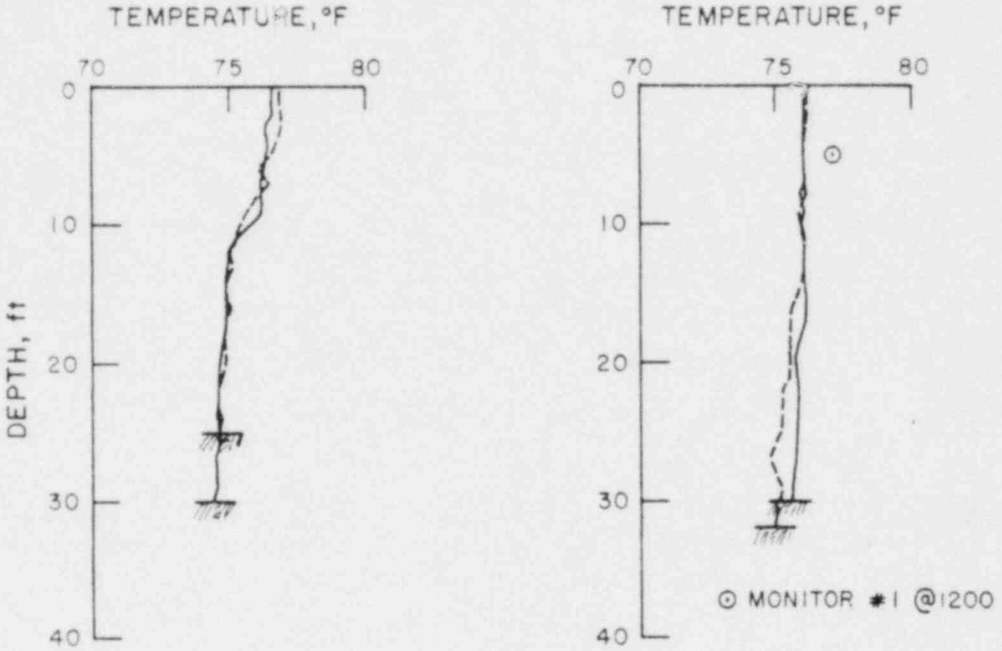
4. The ambient river temperature will be initially calculated as the present downstream temperature less the temperature rise of the previous hour. The ambient river temperature will be recalculated through successive iterative computations of the temperature rise.

5. The mixed temperature will be calculated using temperature data from the downstream monitor associated with the appropriate operating diffuser. Data at the one- and two-meter depths will be averaged to give temperature at the 1.5-meter (~ 5-foot) depth. Temperatures at each monitor will be temporarlly averaged using the current temperature and the previous four 15-minute observations.

The river flow, temperature rise, and the mixed and ambient river temperatures will be transmitted to the plant control room. A permanent record will be stored for compliance purposes.

Discussion

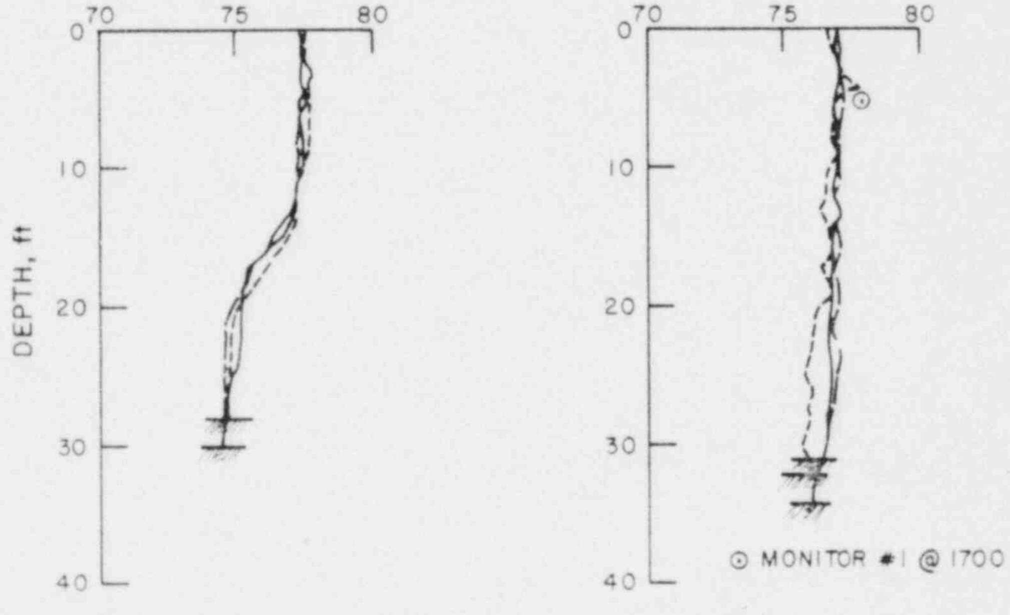
The proposed compliance system is expected to provide a more accurate value of the plant-induced temperature rise. The mathematical model of diffuser mixing has been verified to give reasonable predictions of diffuser mixing. Figures 22 and 23 show the effect of diffuser mixing for one-unit helper mode operation at Browns Ferry during the



900-1000 ft. UPSTREAM

500 ft. DOWNSTREAM

a) 1202-1259 HOURS

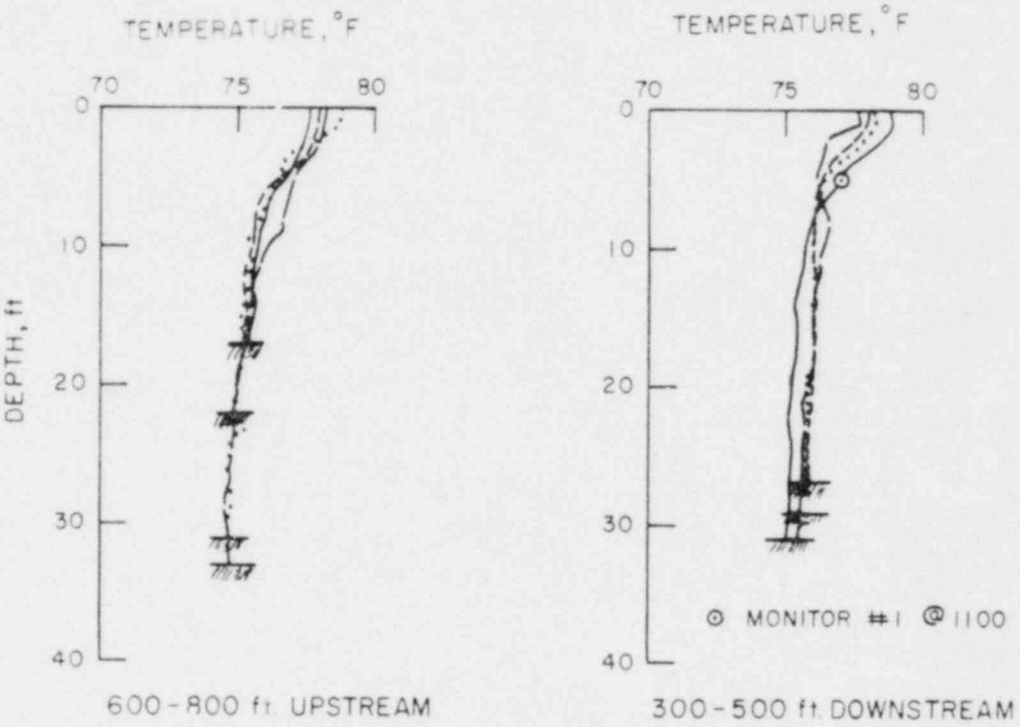


900 - 1100 ft. UPSTREAM

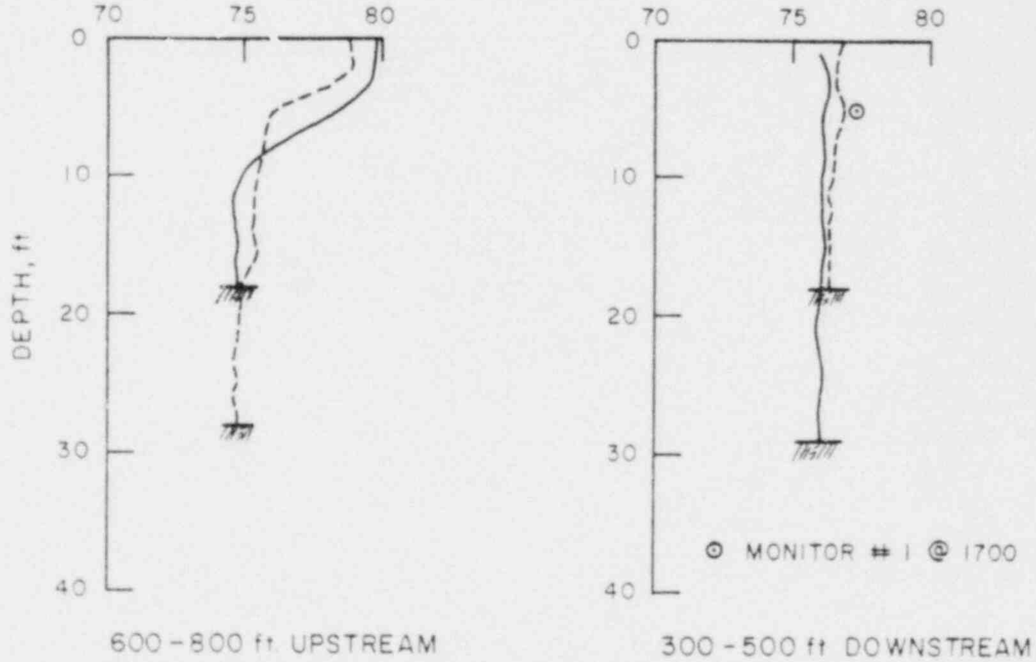
300-500 ft. DOWNSTREAM

b) 1612 -1648 HOURS

Figure 22: Water Temperature Profiles in the Vicinity of the Diffuser, June 3, 1978



a) 1023-1134 HOURS



b) 1652-1713 HOURS

Figure 23: Water Temperature Profiles in the Vicinity of the Diffuser, June 4, 1978

June 2-4, 1978, field survey. Prior to mixing, the diffuser discharge was 4-7°F above the "ambient" temperature. As shown in Figures 22 and 23, the diffuser entrained stratified water from upstream and produced a well mixed temperature profile downstream in most cases. Comparison of upstream and downstream temperatures at the five-foot depth would give a negative temperature rise; however, the plant-induced effect was to vertically mix waste heat and the heat contained in the entrained stratified layer for a temperature increase of about 1°F in the lower layer. The calculated plant-induced temperature rise is shown in Figure 24 to be about 0.6°F for helper mode cooling during the survey, implying that about 0.4°F of the temperature rise in the lower layer was caused by the distribution of the stratified upstream layer over the entire depth. An earlier period of one and two unit open mode operation has a calculated temperature rise of 2.5°F in Figure 24. The present monitoring system showed temperature rises of 0-3.6°F during the period. A time lag of 6-8 hours and natural temperature variations resulted in erroneous measurements of the plant-induced thermal effect by the present monitoring system.

The proposed compliance system is also expected to provide a more reliable calculation of plant-induced effects. Measurements of plant parameters can be readily scanned for accuracy and downstream temperature measurements are expected to be primarily affected by diffuser-induced mixing. The compliance system should be relatively unaffected by natural temperature variations.

The compliance system will also provide hourly updates to the predictive computer model for cooling modes at Browns Ferry (References 8 and 9). This will permit more accurate forecasting of the effect of plant operation on plant-induced thermal effects.

Conference on Verification of Mathematical and Physical Models in Hydraulic Engineering, College Park, Maryland, August 9-11, 1978.

11. Johnson, B. E. and B. J. Clift, "Browns Ferry Nuclear Plant, Water Temperature Surveys," TVA Division of Water Control Planning, Engineering Laboratory, Report No. 63-49, October 1974.

12. Jirka, G. and D.R.F. Harleman, "Mechanics of Submerged Multiport Diffuser for Buoyant Discharges in Shallow Water," Massachusetts Institute of Technology, Ralph M. Parsons Laboratory, Report No. 169, March 1973.

WM28-1-67-101.24

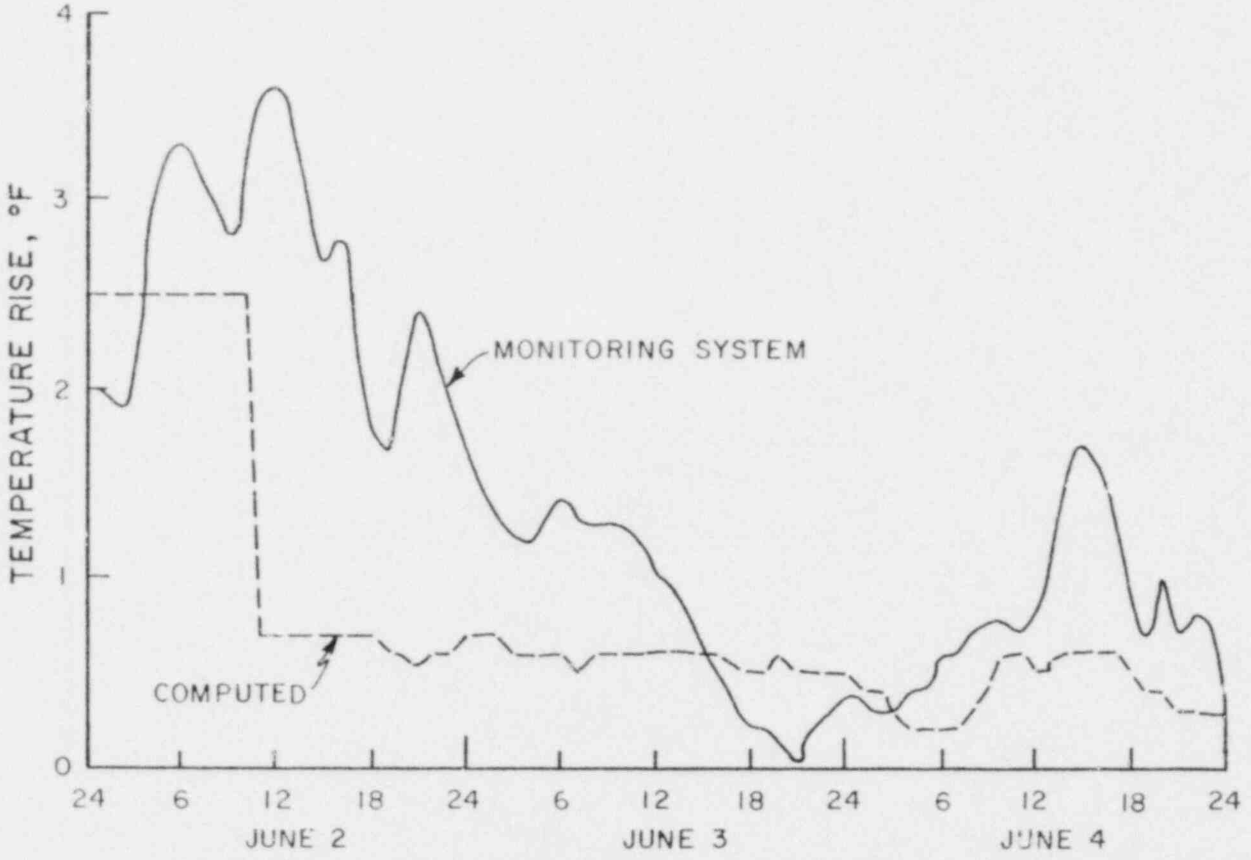


Figure 24: Plant - Induced Temperature Rise During Field Surveys
June 2-4, 1978

REFERENCES

1. State of Alabama Water Improvement Commission, Water Quality Criteria, adopted May 5, 1967, amended June 13, 1972; July 17, 1972; and February 26, 1973.

2. Environmental Protection Agency, National Pollutant Discharge Elimination System Permit No. AL0022080, Browns Ferry Nuclear Plant.

3. Waldrop, W. R., "Natural Heating and Cooling in the Wheeler Reservoir Approach to the Browns Ferry Nuclear Plant," TVA Division of Water Control Planning, Engineering Laboratory, Report No. 63-50, March 1975.

4. Massachusetts Institute of Technology, Energy Laboratory, "Waste Heat Management in the Electric Power Industry: Issues of Energy Conservation and Station Operation Under Environmental Constraints, Interim Report for Subtask 2: Development of Control Technologies for Supplementary Control Technology, Office of the Assistant Secretary for Environment, U. S. Department of Energy, under Contract No. EY-76-S-02-4114.A001, June 1978.

5. Stolzenbach, K. D., "Monitoring of Water Temperatures in Wheeler Reservoir to Determine Compliance of Browns Ferry Nuclear Plant with Water Temperature Standards," TVA Division of Water Control Planning, Engineering Laboratory, Report No. 63-45, May 1974.

6. Song, C.C.S. and C. Chien, "Stochastic Properties of Daily Temperatures in Rivers," American Society of Civil Engineers, Journal of the Environmental Engineering Division, Vol. 103, No. EE2, April 1977, pp 217-231.

7. Markofsky, M., "Preoperational and Operational Hydrothermal Field Data Acquisition and Analysis," American Society of Civil Engineers, Journal of the Hydraulics Division, Vol. 102, No. HY12, December 1976, pp 1711-1721.

8. Harper, W. L. and W. R. Waldrop, "An Operational Procedure for Predicting the Most Economical Use of Condenser Cooling Modes," Proceedings of the First Waste Heat Management and Utilization Conference, Vol. 2, Miami Beach, Florida, 1977.

9. Harper, W. L. and W. R. Waldrop, "A Technique for Determining the Optimum Mode of Cooling at the Browns Ferry Nuclear Plant," TVA Division of Water Management, Water Systems Development Branch, Report No. 63-53, November 1975.

10. Almquist, C. W., C. D. Ungate and W. R. Waldrop, "Field and Model Results for Multiport Diffuser Plume," to be presented at the American Society of Civil Engineers Hydraulic Division Specialty