4.2.1 Near Field Effects

Three 600-foot long submerged multiport diffusers discharge condenser cooling water to the reservoir. In open mode, the plant pumps water from the reservoir through steam condensers where the cooling water is heated by as much as 26°F before discharge through the diffusers. In helper mode, condenser cooling water is routed to mechanical draft cooling towers before discharge to the diffusers. Helper mode is used whenever the applicable limitations cannot be met in open mode. If the thermal discharge limitations cannot be met in helper mode, the plant output is cut back.

The temperature effects of the BFNP discharge depend on the ambient flow and temperature pattern (mixed or stratified) moving across the diffuser as well as the discharge flow and temperature from the diffuser. The analysis of near field effects is based on observed temperature patterns at downstream monitor stations and on predicted dilution of the diffuser system.

The effects of plant operation on the near field region were studied with regard to the maximum plant induced temperature rise, the maximum river temperature, and the zone of passage.

4.2.1.1 Maximum Plant Induced Temperature Rise (ΔT_{max})

The maximum plant induced temperature rise outside the diffuser mixing zone is presently determined by subtracting a measured representative upstream temperature from a measured representative downstream temperature. The upstream temperature is the average from Stations 4 and 7 at the 5-foot depth and the downstream temperature is the average of 5-foot depth temperatures from Stations 10, 11, and 13, located 1.5 miles downstream of the diffuser. The present ΔT_{max} limitation is 5°F.

Plant induced temperature rise is greatest under conditions of maximum 3-unit load and low river flow. Natural warming conditions can increase the measured temperature rise, especially during low flow, when the travel time between the upstream and downstream monitors is longest.

Ambient conditions of flow across the diffusers can be fully mixed or stratified. The diffuser induced mixing can cause temperatures downstream of the mixing zone to be either fully mixed or stratifed. The diffuser discharge can also add heat without modifying the ambient pattern. Several comparisons of temperatures upstream and downstream of the diffuser will be shown to provide an understanding of the general diffuser performance, viewed in the near field.

4.2.1.1.1 Measured Diffuser Near Field Effects

Station 14 is located in the main channel, 2 miles upstream of the diffuser and provides the ambient temperature pattern. (See Figure 4.1-3 for location of the monitors.) Station 1 is located 0.5 miles downstream of the diffuser and shows the near field diffuser effects. A comparison of temperatures from these two locations provides an estimate of the initial diffuser induced mixing. Flow during the winter and spring of 1981 was very low, and the plant induced temperature rise was correspondingly high. BFNP operated under a temporary ΔT_{max} limitation of 8.5°F during most of this period due to the drought conditions. In January 1981, a transition from 2-unit to 3-unit operation occurred, with a constant river flow of 20,000 cfs. Figure 4.2-1 shows that ambient temperatures were fully mixed, varying from 36 to 46°F during the month. Temperatures at Station 1 were stratified on many days in January, with near surface (including the 5-foot depth) temperatures 2 to 5°F warmer than bottom temperatures. It is evident that some heat was mixed

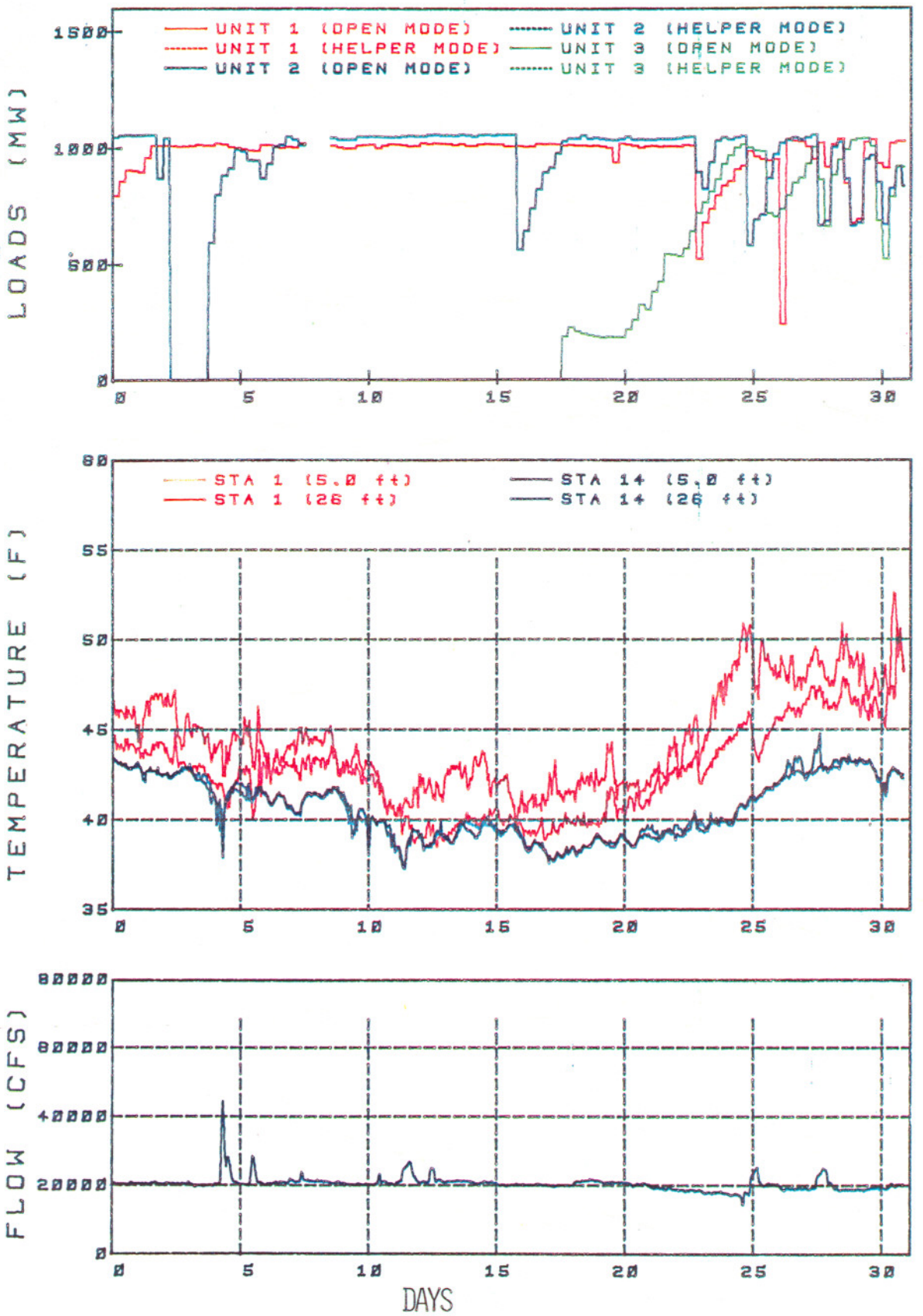

Figure 4.2-1. Hourly BFNP operation, water temperatures at Stations 1 (TRM 293.6) and 14 (TRM 296.1), and river flow during January 1981.

throughout the water column because the bottom temperatures increased 1 to 4°F above the ambient temperatures. The depth of the heated layer, however, cannot be determined from these figures, and may extend almost to the bottom. The 5-foot depth was always within the heated surface layer.

The February 1981 data illustrates the effect of higher river flow (50,000 cfs) on the downstream temperatures. The plant induced temperature rise is less and the stratification is weaker, with a better distribution of heat throughout the water column (Figure 4.2-2). The overriding effect of cooling meteorology can be seen on February 2 and 11. Under these strong cooling conditions, fully mixed temperatures result, even with a full 3-unit load and low flows.

4.2.1.1.2 Predicted Near Field Temperature Effects

The previous section demonstrates the variability of downstream temperatures, which are influenced by both ambient conditions and diffuser discharge characteristics. In order to evaluate alternative temperature rise limitations, a numerical model of the diffuser induced mixing was used to predict the 5-foot depth mixed temperatures, which are utilized for compliance purposes.

Near field temperatures at the edge of the mixing zone, at the 5-foot depth, were predicted on an hourly basis using an analytical model for diffuser mixing developed by the Massachusetts Institute of Technology (Jirka and Harleman, 1973) and TVA. This model has been used in previous TVA submittals (TVA, 1980) and is currently used to schedule operation of the plant to meet thermal limitations under various river flows, water temperatures, meteorology, and anticipated plant loads. Comparison of the predicted downstream temperature with the measured 5-foot depth temperature from Station 1 demonstrates that the analytical results track

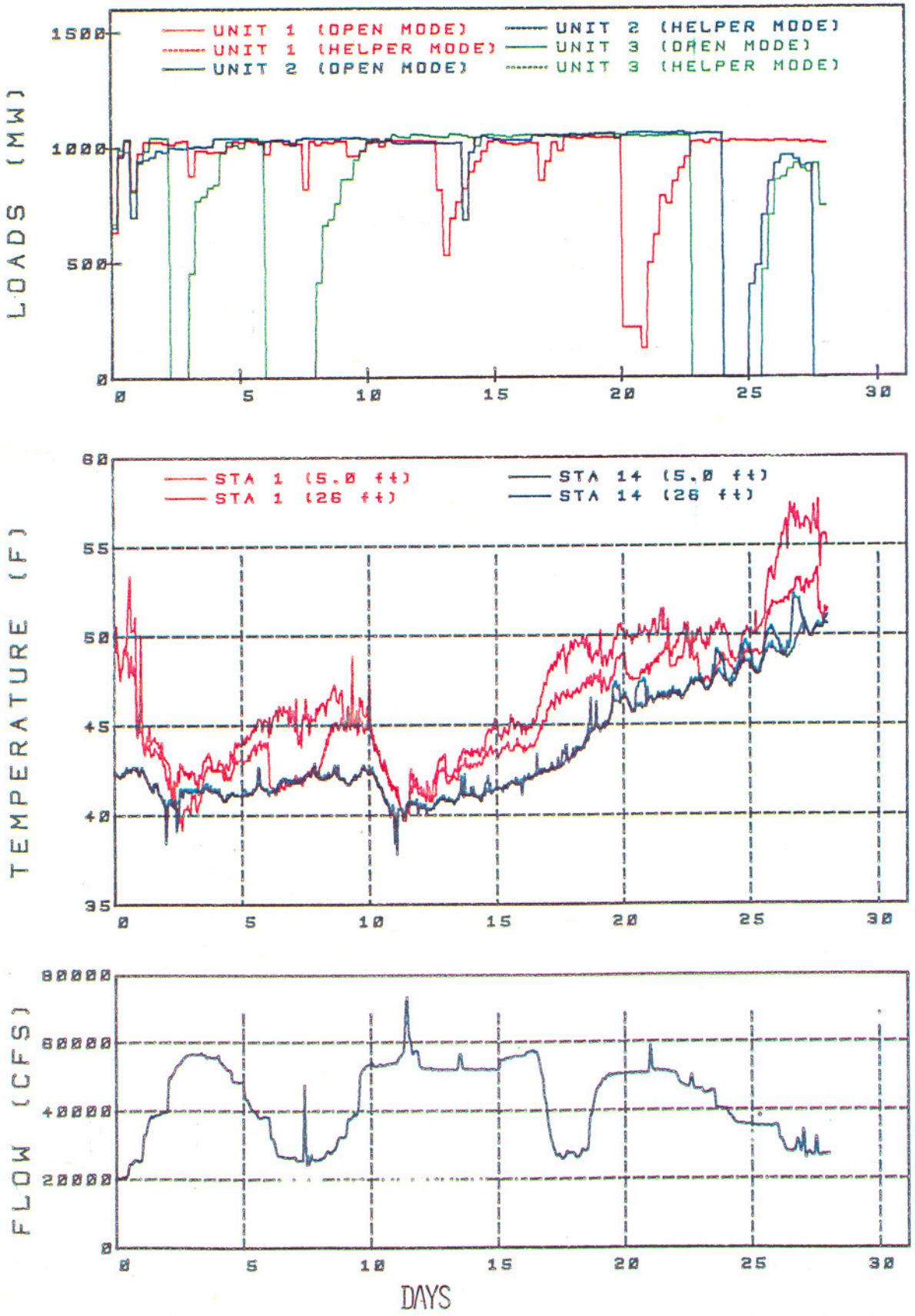

Figure 4.2-2. Hourly BFNP operation, water temperatures at Station 1 (TRM 293.6) and 14 (TRM 296.1), and river flow during February 1981.

the measured temperature pattern quite well. Figures 4.2-3A and 4.2-3B show this comparison for January and February 1981. January was characterized by low flows and variable loads. February was characterized by higher flows of 25,000 to 50,000 cfs and variable loads of 2 or 3 units. The pattern of predicted near field temperatures is quite close to the measured 5-foot depth temperatures at Station 1. The mixing model for calculating downstream temperatures is used to evaluate the near field effects for 12½ years of varying ambient conditions. The analytical model appears to respond properly to river flows, water temperatures, meteorology, and plant conditions, and is sufficiently accurate for the evaluation of alternative temperature rise limitations.

The simulation studies of alternative limitations assumed full 3-unit operation (3,300 MWe) under actual flow and meteorological conditions. The diffuser discharge was assumed to be 1,450 cfs per unit for open mode operation and 1,225 cfs for helper mode. The discharge temperature in open mode was calculated using a condenser temperature rise of up to 26°F, depending on intake water temperature. The condenser temperature rise in helper mode was based on intake water temperature, the number of operating condenser cooling water pumps, and plant load. Cooling tower performance was based on the results of field tests following the recent tower improvements. Temperatures at the 5-foot depth from the upstream main channel Station 4 (TRM 297.8) were used for the ambient water temperature conditions. Wet bulb temperatures from BFNP were used when available, supplemented when necessary with data from the Huntsville, Alabama, weather station. The river flow at the BFNP site was calculated from historical hourly discharges from Guntersville and Wheeler Dams using an unsteady flow model as discussed in Section 4.1.2. Actual flow

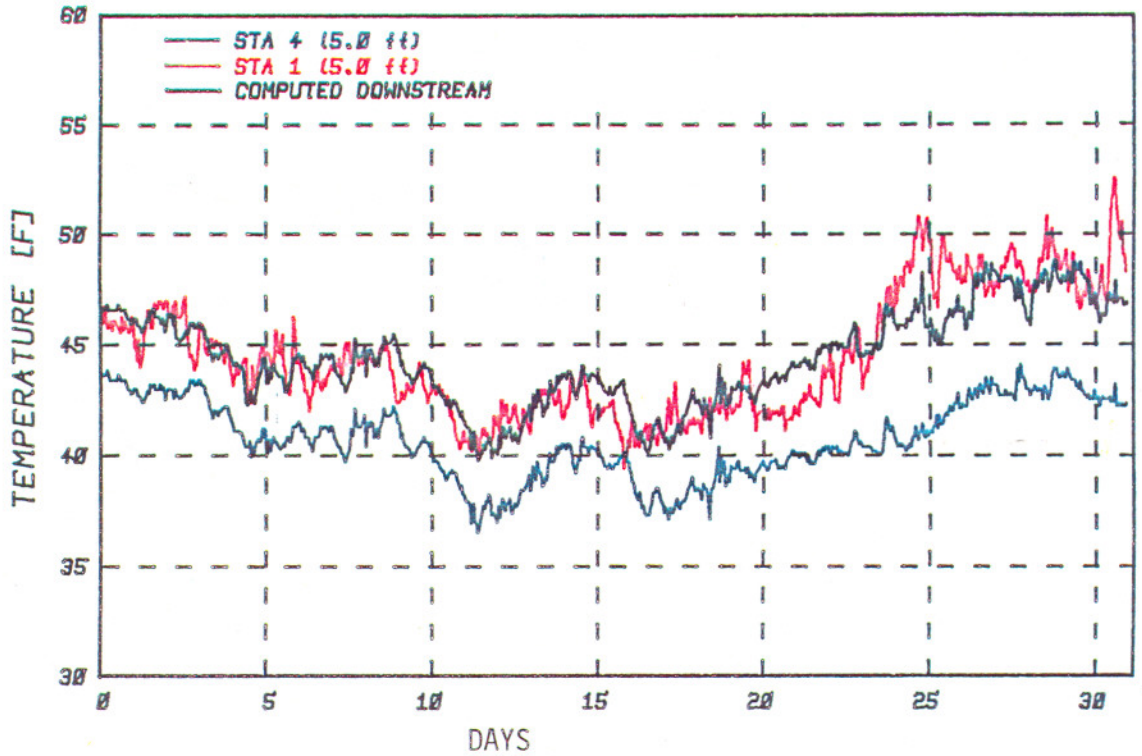

Figure 4.2-3A. Comparison of hourly computed water temperatures versus measured temperatures at Station 1 (TRM 293.6) for January 1981.

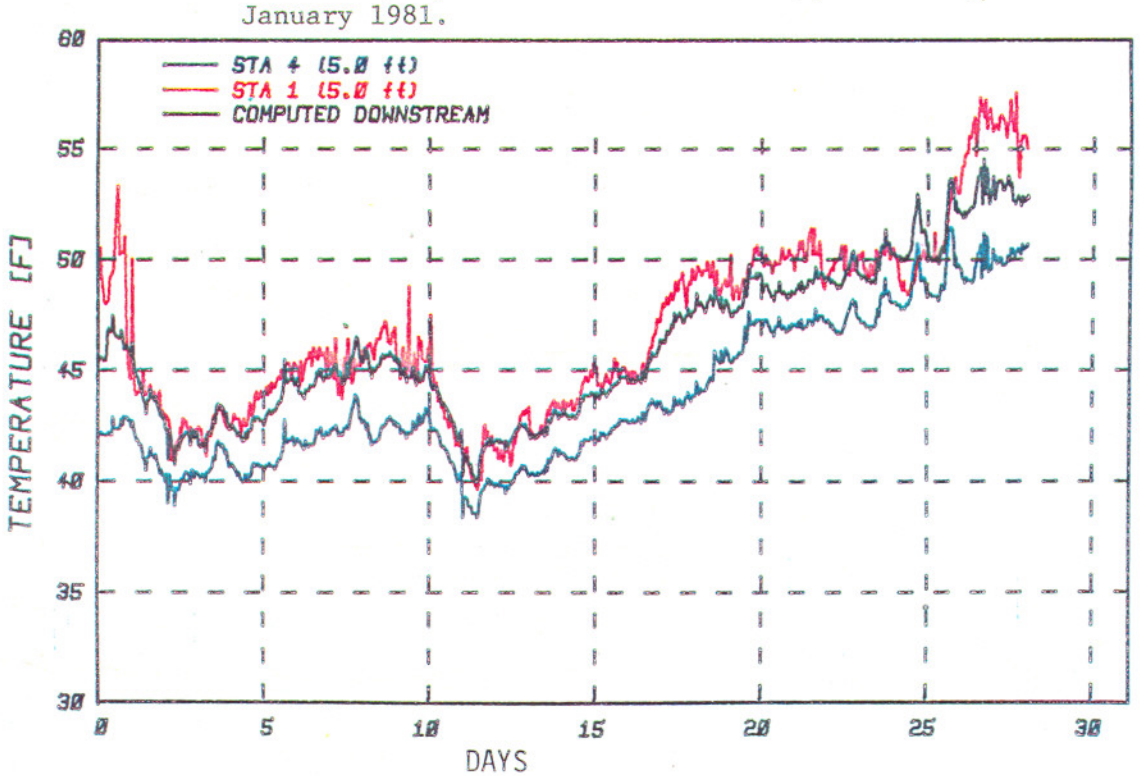

Figure 4.2-3B. Comparison of hourly computed water temperatures versus measured temperatures at Station 1 (TRM 293.6) for February 1981.

conditions were used in the evaluations to analyze both peaking (1969-1976) and maintained minimum flow operations (1977-1981).

The ambient (upstream) temperature was subtracted from the downstream temperature predicted by the near field model to provide the plant induced temperature rise (ΔT) for each hour. Solar heating between the upstream monitor and the mixing zone was not considered because this is a natural phenomenon and not a result of plant operation.

The simulations represent predicted temperatures at the edge of a mixing zone about 2,200 feet downstream of the diffuser. The downstream edge is near Station 1 and represents an area considerably smaller (90 acres) than the present mixing zone which extends to Stations 10, 11, and 13 (490 acres). The total reservoir area downstream of BFNP is about 26,000 acres.

The near field model was used to predict the ΔT for the period January 1969 through May 1981. This provided over 12 years of record for comparison of alternative limitations. Historical dam releases were used. The resulting hourly temperature predictions were compared using (1) the occurrence of various ΔT ranges and (2) the durations of these occurrences. Occurrence is presented over an annual basis as well as by month to show seasonal patterns.

A maximum temperature rise limitation (ΔT_{max}) of 10°F was evaluated. Cooling towers were not operated unless the calculated plant induced ΔT would have exceeded the 10°F ΔT_{max} limitation in open mode. If the cooling towers in helper mode could not keep the plant induced temperature rise below 10°F, the plant output was cut back with continued maximum cooling tower usage until the ΔT_{max} limitation was obtained. During the summer months both the maximum temperature and maximum temperature rise limitations can affect plant operation. The

following results reflect a maximum temperature restriction of 90°F with no use of cooling towers until the downstream temperature would have exceeded 90°F. The maximum temperature limitation would normally be the controlling limit during the summer period.

Table 4.2-1 shows the predicted annual occurrences of various ΔT ranges at the edge of the mixing zone under the 10°F ΔT_{max} limitation. The highest predicted annual occurrence of ΔTs greater than 5°F for the complete years of record was 19.3 percent, with an average of 8.9 percent.

High ΔTs normally occur during specific low flow months. Because of the strong dependency on flow conditions Table 4.2-2 shows predicted occurrence on a monthly basis. The highest monthly predicted occurrences of ΔTs greater than 5°F shown in Table 4.2-2 occurred during the drought starting in late 1980 and continuing through spring 1981 when occurrences of up to 92 percent were predicted on a monthly basis (January 1981). The overall averages for each month are below 15 percent, with the largest monthly averages occurring in spring (April-May) and late fall (October-November), corresponding to the seasonal low flow patterns.

The near field model simulations also provided the duration of occurrences of ΔT greater than 5°F. Table 4.2-3 summarizes this information for the period January 1969 through May 1981. The majority of the occurrences were between 3 and 6 hours in duration, which reflects the significant influence of actual operation of Guntersville and Wheeler Dams for peaking purposes before 1977.

There are significantly long durations of ΔT greater than 5°F during the drought period of late 1980-1981. Table 4.2-4 shows durations greater than 24 hours for the period December 1980 to May 1981,

Table 4.2-1 Predicted annual occurrences (percent of time) of plant-induced temperature rise (ΔT) at edge of diffuser mixing zone (five-foot depth) Browns Ferry Nuclear Plant, with plant operating under a ΔT_{max} limitation of $10^{o}F$.

Range of Temperature Rise (^{o}F)	Year													Max** (Avg)
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981*	
0–3	51.0	52.5	64.3	73.1	73.8	70.7	75.4	60.8	66.3	42.7	81.8	49.6	16.9	81.8 (63.5)
3–5	29.7	31.6	21.7	17.7	18.1	19.6	21.2	24.9	32.0	52.9	18.2	44.0	36.2	52.9 (27.6)
5–8	17.9	15.2	13.8	9.2	8.1	9.7	3.4	14.1	1.6	4.4	0.0	6.4	46.9	17.9 (8.7)
8–10	1.4	0.7	0.3	0.0	<0.1	0.0	0.0	0.3	<0.1	0.0	0.0	0.0	0.0	1.4 (0.2)
>5	19.3	15.9	14.0	9.2	8.1	9.7	3.4	14.4	1.7	4.4	0.0	6.4	46.9	19.3 (8.9)

*1/1/81 - 5/31/81

**Maximum and average do not include 1981 since it was an incomplete year

NOTE: All numbers are percent of time in given period

Table 4.2-2. Predicted monthly occurrences (percent of time) of plant induced temperature rise (ΔT) in the range 5-10°F at the edge of the diffuser mixing zone (five-foot depth) Browns Ferry Nuclear Plant, ΔT_{max} = 10°F.

Month	Year													Max
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	(Avg)
JAN	19.2	4.0	9.7	0	0	0	0	0.4	0	0	0	0	92.1	92.1 (9.7)
FEB	0	2.2	0	0	2.7	0	0	2.3	7.7	0	0	1.2	1.6	7.7 (1.4)
MAR	20.0	5.5	3.9	3.1	2.3	0.4	0	4.0	0	0	0	0.7	52.2	52.2 (7.1)
APR	24.7	11.3	35.6	23.6	13.6	9.3	3.6	31.0	0	0	0	0	16.9	35.6 (13.1)
MAY	25.7	18.0	21.2	12.2	2.8	7.0	3.0	27.3	0	0.1	0	0	66.4	66.4 (14.1)
JUN	25.8	16.8	22.6	18.8	1.4	15.8	6.7	13.8	1.0	0	0	0		25.8 (10.2)
JUL	6.6	17.2	19.5	15.5	7.5	13.0	3.1	10.4	4.2	0	0	0		19.5 (8.1)
AUG	22.7	14.4	13.6	11.3	7.5	11.3	9.5	17.3	7.5	0	0	0		22.7 (9.6)
SEP	29.6	15.7	21.8	19.7	21.0	17.2	9.9	25.4	0.6	0.4	0	5.6		29.6 (13.9)
OCT	23.0	31.0	17.2	6.6	23.9	25.3	3.4	18.5	0	6.6	0	4.7		31.0 (13.4)
NOV	21.7	26.8	2.5	0	14.9	15.7	1.7	22.1	0	43.9	0	6.7		43.9 (13.0)
DEC	11.8	27.2	0.1	0	0	1.2	0.4	0.5	0	2.6	0	56.8		56.8 (8.4)

NOTE: All numbers are percent of time in given period.

Table 4.2-3

Discreet occurrences of durations of plant induced temperatures greater than $5^{o}F$ under a $\Delta T_{max}=10^{o}F$ limitation at edge of mixing zone, BFNP.

	Duration (hrs.)														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13-18	19-24	24+
1969	15	16	18	24	45	52*	45	34	18	7	3	5	3	0	0
1970	22	22	24	48	44	41	24	26	14	2	3	0	3	0	0
1971	10	27	27	34	43	38	25	10	15	2	1	0	4	1	0
1972	17	21	30	31	29	13	14	8	10	5	1	0	0	0	0
1973	14	15	13	26	30	15	17	9	6	4	0	0	0	0	0
1974	25	26	27	27	39	19	15	12	5	3	0	0	0	0	0
1975	17	16	14	27	7	4	5	1	0	0	0	0	0	0	0
1976	18	27	38	50	62	27	21	7	8	4	0	2	5	0	0
1977	8	7	7	10	4	0	2	0	1	0	0	0	0	1	0
1978	9	8	4	6	1	3	4	2	2	1	1	1	12	1	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	8	6	9	5	4	1	2	2	3	0	0	0	3	3	2
1981	4	3	3	1	2	2	3	4	2	1	1	3	9	4	13
Total	167	194	214	289	310	215	177	115	84	29	10	11	39	10	15

*Example: There were 52 occurrences of durations 6 hours in length

Note: Durations are discreet, that is a 6-hour duration was not counted as six 1-hour durations, five 2-hour durations, etc.

Table 4.2-4 Long durations of plant-induced temperature rises greater than 5°F during December 1980 - May 1981, BFNP.

Durations of Each Occurrence (Hours):

December	January	February	March	April	May
41	103(319)*	11(82)*	22	13	11
216(319)*	17		35	13	135
	41		11	13	144
	92		308	12	10
	12			12	12
	296			13	80
	54				13
	71(82)*				33

*Continued from the end of one month into next month.

which were the most severe conditions evaluated. The maximum duration was 319 hours which occurred in December 1980 to January 1981.

4.2.1.2 Maximum River Temperature (T_{max})

A second thermal limitation is the maximum river temperature at the edge of the mixing zone. Measured near field temperatures during periods of high ambient temperatures will be shown. The predictive near field model was used to calculate the effects of plant operation under alternative limitations.

4.2.1.2.1 Near Field Effects at High Ambient Temperatures

The summer of 1977 was quite warm, and ambient water temperatures near BFNP approached 85°F in late June. To meet the maximum temperature limit of 86°F, helper mode and then closed mode operations were used. In early July, the unit outputs were also cut back while operating in the closed mode to meet the plant safety contraints of 95°F maximum intake temperature. During this period, the 5-foot depth temperatures at Station 1 increased 1 to 4°F during the day in response to solar heating and then cooled during the night to the more constant bottom temperature (Figure 4.2-4). Nevertheless, the bottom temperatures rose above 85°F for a period of several days during July 1977. Temperature records from early July demonstrate that Stations 1 and 14 were almost identical without diffuser induced heating and mixing. On July 15, 1977, TVA obtained temporary relief from EPA to operate with a maximum temperature limitation of 90°F with available cooling tower operation required when downstream temperatures were greater than 86°F. This change was reflected in Station 1 temperatures beginning on July 16 when plant load was

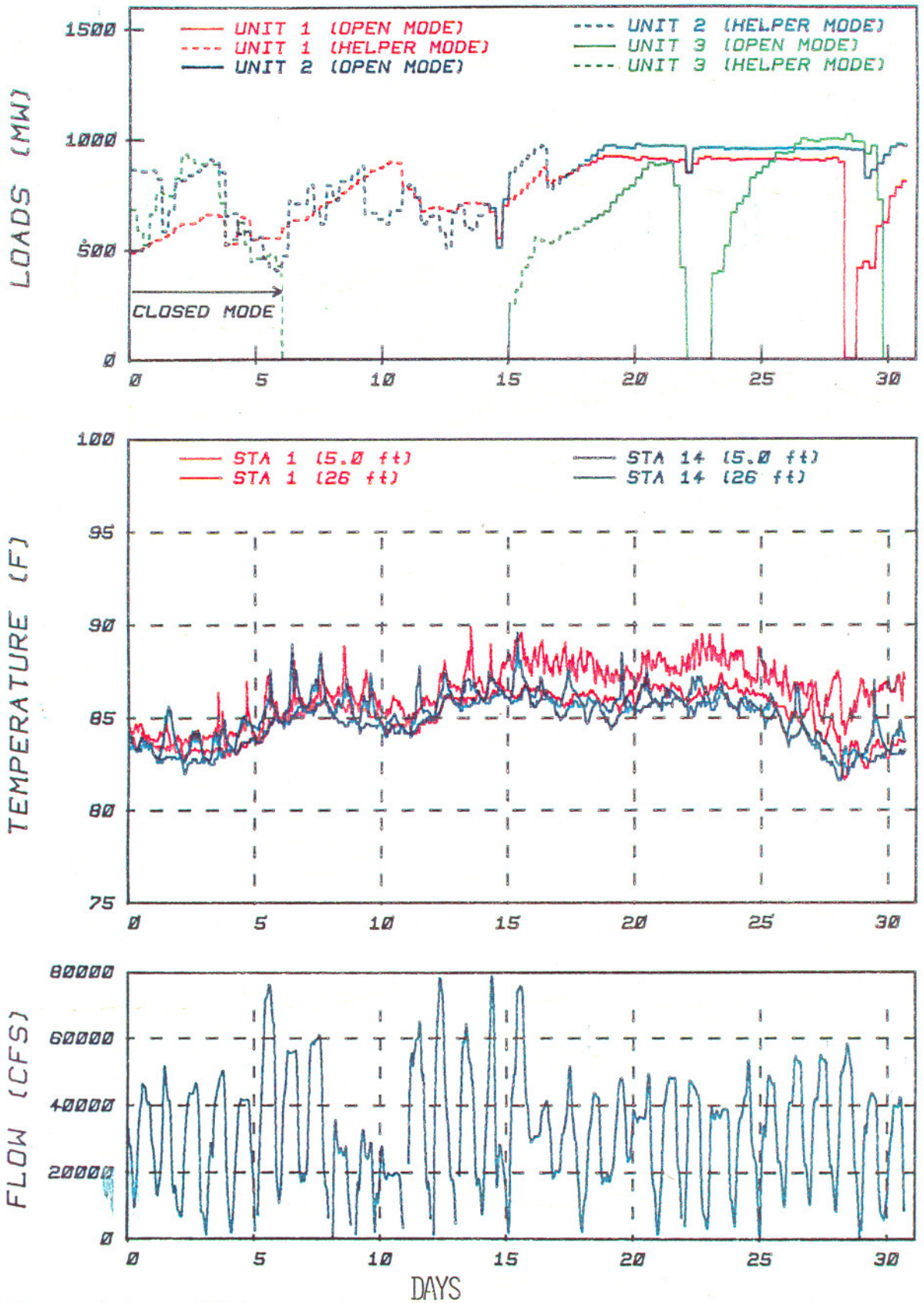

Figure 4.2-4. BFNP operation, water temperatures at Stations 1 (TRM 293.6) and 14 (TRM 296.1), and river flows during July 1977.

increased (Unit 3 brought back on line) and operations were changed from closed to helper mode. On July 19, the operations changed again to open mode due to tower structural failure. Throughout this period bottom temperatures at Station 1 normally remained within 1 or 2°F of upstream conditions.

The summer of 1980 was the warmest period during the recent past. Also, flows were fairly low, which contributed to the most severe environmental conditions experienced at BFNP. The resulting temperature effects became of concern in early July as ambient water temperatures rose rapidly from 80°F to 85°F and reached a maximum of 91.7°F on July 16. It was apparent that continued warm temperatures and 3-unit operation with available cooling tower usage would produce near field temperatures above 90°F. TVA was permitted to use a temporary 93°F T_{max} to operate during this period of excessively high ambient temperature and extreme power demand. Available cooling towers were used through most of July and all of August. Upstream temperatures remained high during August (Figure 4.2-5) often approaching 88 to 89°F. Plant operation under these conditions resulted in downstream near field temperatures close to 90°F for extended periods. Even under these most severe conditions bottom temperatures at Station 1 were significantly lower than at the 5-foot depth.

The most apparent effect of the discharge on near field temperatures is to produce a deeper surface heated layer as compared to the naturally occurring solar heated layer, and to keep the surface layer heated throughout the night. No diurnal variation was apparent at Station 1 during the period when the plant was operating in open mode. During this period the solar energy was being absorbed, but its effect on the deeper surface mixed layer was not apparent.

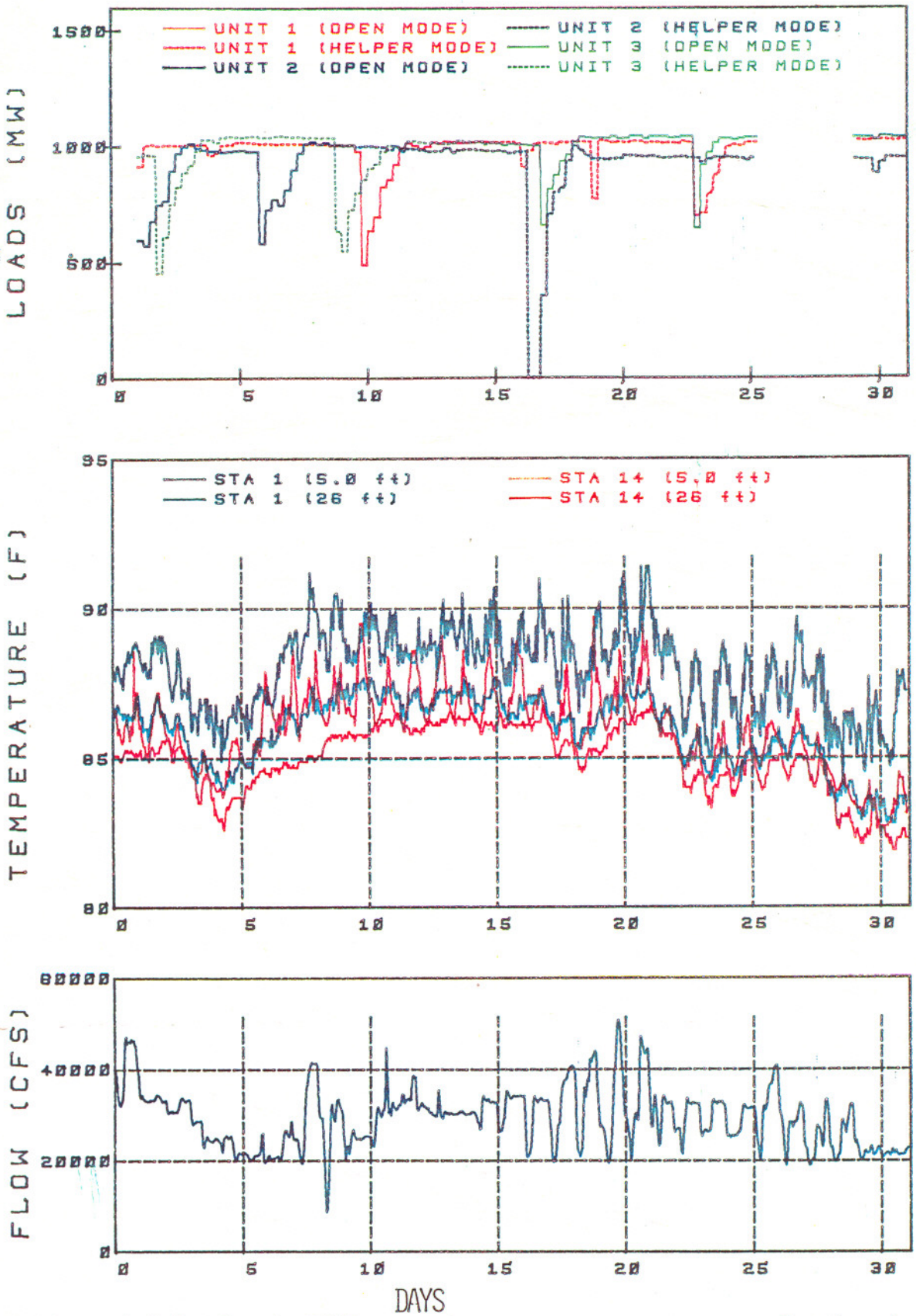

Figure 4.2-5. Hourly BFNP operation, water temperatures at Stations 1 (TRM 293.6) and 14 (TRM 296.1), and river flow during August 1980.

4.2.1.2.2 Predicted Near Field Effects of Alternative T_{max}

The near field model was also used to predict the occurrence of downstream river temperatures under the alternative T_{max} limitation of 90°F and with no cooling tower usage until 90°F was exceeded. If cooling towers in helper mode could not keep the downstream temperature below 90°F, plant output was cut back while continuing maximum helper cooling tower usage. Predictions consider the same mixing zone as used for the ΔT_{max} evaluation discussed earlier. Because high river temperatures occur during the summer months of June, July, and August, these are the only periods analyzed. Figure 4.2-6 shows a comparison of model results with measured data from the 5-foot depth at Station 1 for the month of August 1980. The predicted pattern reflects the diurnal upstream pattern more than the measured data, but the overall discharge effect, incorporating river flow, cooling towers, and plant load fluctuations, is well matched to the data.

Table 4.2-5 shows the predicted occurrence of high downstream river temperatures with no cooling tower usage until 90°F was reached. For comparison, Table 4.2-6 shows the actual occurrence of high ambient river temperatures at the 5-foot depth, upstream of the plant (Station 4, TRM 297.8). Table 4.2-7 provides the predicted downstream river temperatures operating under the present 90°F T_{max} limitation with cooling towers used when downstream temperatures reached 86°F. Table 4.2-8 summarizes the previous tables, displaying the summer averages and maximums, and July averages and maximums for all three cases. The average occurrence of temperatures exceeding 86°F for June, July, and August was 41.1 percent under the alternative limitation, 90°F T_{max} with no cooling towers until 90°F. Downstream river temperatures greater than 86°F

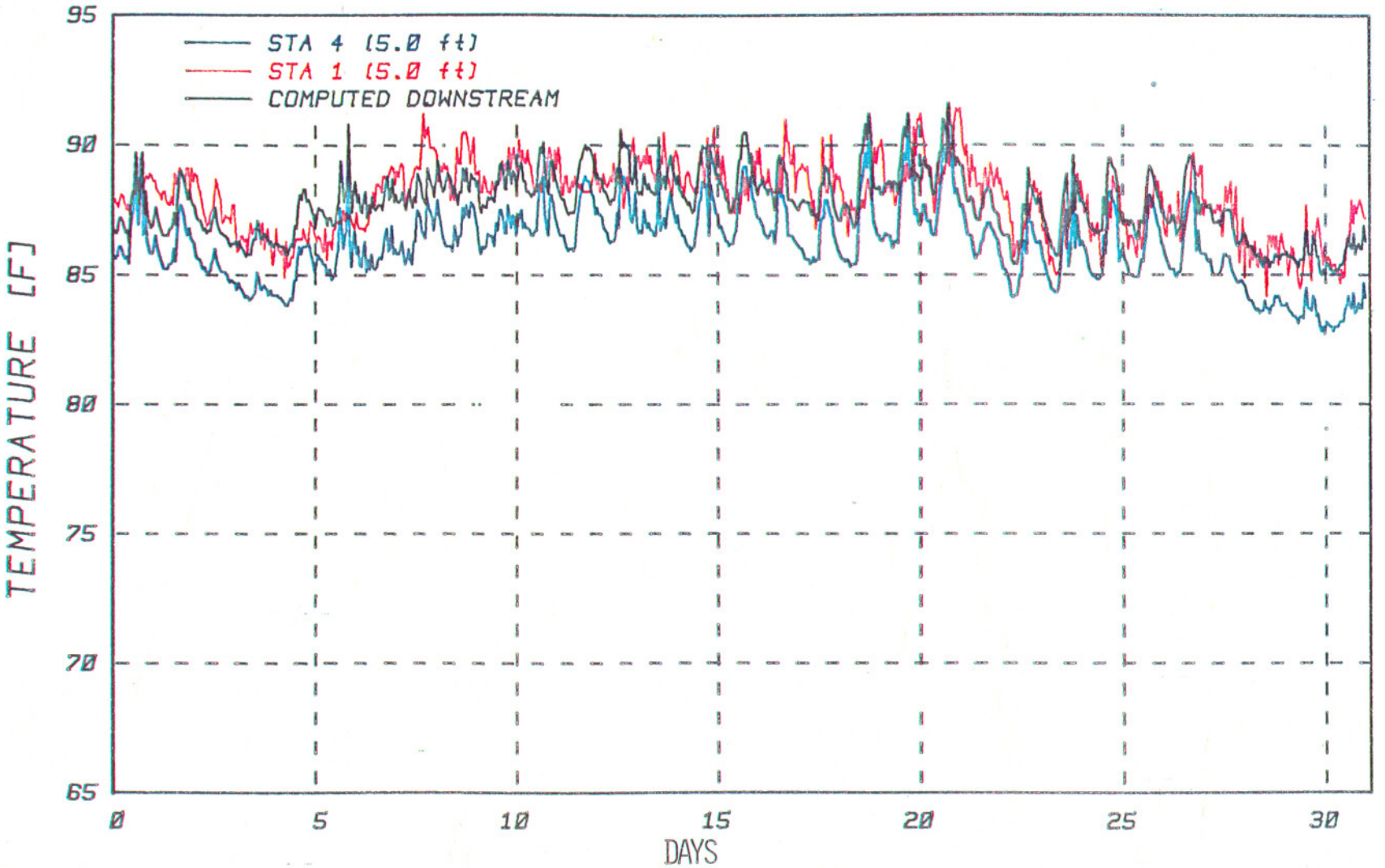

Figure 4.2-6. Comparison of hourly computed water temperatures versus measured temperatures at Station 1 (TRM 293.6) for August 1980.

Table 4.2-5 Predicted occurrences (percent of time) of high downstream river temperatures at edge of diffuser mixing zone (five-foot depth) BFNP, T_{max} = 90°F with no cooling tower usage until downstream temperatures reached 90°F.

	Temperature Range (°F)	Year											
		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
June - August	<86	41.6	45.4	55.9	68.6	69.0	80.7	72.8	85.3	29.8	28.9	93.9	34.9
	>86	58.4	54.6	44.1	31.4	31.0	19.3	27.2	14.7	70.2	71.1	6.1	65.1
	>87	45.6	38.0	24.8	16.4	12.7	6.7	15.5	6.2	58.2	57.9	1.7	62.9
	>88	34.1	29.4	9.6	7.6	3.7	1.4	8.0	2.5	39.0	39.0	0.2	54.5
	>89	20.0	10.9	3.1	3.1	0.5	<0.1	2.9	0.3	21.9	16.0	0.1	38.1
	>90	0	0	0	0	0	0	0	0	0	0	0	1.1*
July Only	<86	0.3	27.0	37.5	64.5	51.8	66.5	73.9	81.2	2.7	0	97.0	6.0
	>86	99.7	73.0	62.5	35.5	48.2	33.5	26.1	18.8	97.3	100.0	3.0	94.0
	>87	93.6	51.9	45.8	19.5	24.6	13.7	8.9	9.7	90.7	96.6	0.5	88.8
	>88	80.1	28.1	23.4	11.8	9.5	3.6	1.9	4.4	75.9	76.4	0	75.7
	>89	50.4	8.9	8.6	5.9	1.5	0.1	0.3	0.4	51.8	38.0	0	47.5
	>90	0	0	0	0	0	0	0	0	0	0	0	2.7*

*Ambient conditions were greater than 90°F.

NOTE: All numbers are percent of time in given period

Table 4.2-6 Frequency of high ambient river temperatures, five foot depth - TRM 297.8.

	Temperature Range (^{o}F)	Year											
		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
June -	<86	82.5	98.3	98.1	99.2	98.5	99.9	97.1	99.8	85.0	91.0	99.8	64.3
	>86	17.5	1.7	1.9	0.8	1.5	0.1	2.9	0.2	15.0	9.0	0.2	35.7
August	>87	4.4	0.3	0.5	0	0.3	0	0.7	0	4.2	2.2	0.1	19.8
	>88	0.5	0	0	0	0	0	0	0	1.6	0.5	0	8.6
	>89	0	0	0	0	0	0	0	0	0.2	0	0	3.3
	>90	0	0	0	0	0	0	0	0	0	0	0	1.1*
July	<86	49.5	96.5	94.9	99.1	95.6	99.6	98.0	99.3	62.6	81.3	100.0	50.4
Only	>86	50.5	3.5	5.1	0.9	4.4	0.4	2.0	0.7	37.4	18.7	0	49.6
	>87	13.0	0.5	1.5	0	0.8	0	0.4	0.1	12.5	4.3	0	31.2
	>88	1.5	0.1	0.1	0	0	0	0	0	4.8	1.1	0	15.3
	>89	0	0	0	0	0	0	0	0	0.5	0	0	6.9
	>90	0	0	0	0	0	0	0	0	0	0	0	2.7*

*Maximum temperature of 91.7^{o}F occurred on July 16, 1980.

NOTE: All numbers are percent of time in given period

Table 4.2-7 Predicted occurrences (percent of time) of high downstream river temperatures at edge of diffuser mixing zone (five-foot depth) BFNP, T_{max} = 90°F, cooling towers used when predicted downstream temperatures reached 86°F.

	Temperature Range (°F)	Year											
		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
June - August	<86	73.9	91.4	94.0	95.7	97.5	99.6	94.8	99.7	71.5	76.4	99.6	52.8
	>86	26.1	8.6	6.0	4.3	2.5	0.4	5.2	0.3	28.5	23.6	0.4	47.2
	>87	15.4	1.2	1.5	0.7	0.7	<0.1	1.5	0.1	11.2	5.4	0.1	30.9
	>88	2.7	0.1	<0.1	<0.1	0	0	0.2	0	2.8	1.3	0	14.6
	>89	<0.1	0	0	<0.1	0	0	0	0	0.4	0.1	0	5.3
	>90	0	0	0	0	0	0	0	0	0	0	0	1.1*
July Only	<86	28.2	91.1	84.1	91.4	92.6	98.9	97.2	99.2	32.9	49.7	100.0	33.5
	>86	71.8	8.9	15.9	8.6	7.4	1.1	2.8	0.8	67.1	50.3	0	66.5
	>87	45.8	2.3	4.4	1.3	2.0	0.1	0.7	0.3	30.9	11.6	0	43.1
	>88	8.1	0.1	0.1	0	0	0	0.1	0	8.3	2.6	0	24.2
	>89	0.1	0	0	0	0	0	0	0	1.2	0.4	0	10.1
	>90	0	0	0	0	0	0	0	0	0	0	0	2.7*

*Ambient conditions were greater than 90°F, plant was shut down during these prediction periods.

NOTE: All numbers are percent of time in given period.

Table 4.2-8 Summary of high ambient and predicted river temperatures at the five-foot depth, near Browns Ferry Nuclear Plant, 1969-1980.

	Temperature Range (^{o}F)	Summer* Maximum (1980)	Summer* Average	July Maximum (1980)	July Average
Ambient River Temperatures	<86	64.3	92.8	50.4	85.6
	>86	35.7	7.2	49.6	14.4
	>87	19.8	2.7	31.2	5.4
	>88	8.6	0.9	15.3	1.9
	>89	3.3	0.3	6.9	0.6
	>90	1.1	0.1	2.7	0.2
Downstream River Temperatures, Present T_{max} Requirements	<86	52.8	87.2	33.5	74.9
	>86	47.2	12.8	66.5	25.1
	>87	30.9	5.7	43.1	11.9
	>88	14.6	1.8	24.2	3.6
	>89	5.3	0.5	10.1	1.0
	>90	1.1	0.1	2.7	0.2
Downstream River Temperature, T_{max} = 90^{o}F, No Towers Until 90^{o}F	<86	34.9	58.9	6.0	42.4
	>86	65.1	41.1	94.0	57.6
	>87	62.9	28.9	88.8	45.4
	>88	54.5	19.1	75.7	32.6
	>89	38.1	9.8	47.5	17.8
	>90	1.1	0.1	2.7	0.2

*Average of June, July, and August

occurred 12.8 percent of the time under the present limitation, 90°F T_{max} with cooling towers usage when the downstream temperature reached 86°F. The average for this period under ambient upstream conditions was 7.2 percent. The hottest summer conditions for the period of record occurred during 1980. The occurrence of temperatures greater than 86°F during summer 1980 under the alternative limitation was 65.1 percent, under the present limitation was 47.2 percent and under ambient upstream conditions was 35.7 percent. For July, normally the hottest month, the average occurence of temperatures greater than 86°F under the alternative limitation was 57.6 percent, under the present limitation was 25.1 percent, and under ambient upstream conditions was 14.4 percent. During July 1980 the maximum monthly occurence of temperatures greater than 86°F under the alternative limitation was 94.0 percent, under the present limitation was 66.5 percent, and under ambient upstream conditions was 49.6 percent. Under average conditions the temperatures are about equally distributed between the range 86 to 88°F and 88 to 90°F. Under the maximum conditions during 1980 a larger percentage was in the range 88 to 90°F.

Durations of these predicted high river temperatures were also evaluated. Tables 4.2-9 and 4.2-10 provide summaries of durations for the summer months during 1969-1980. Table 4.2-9 shows durations in the range 86°F to 88°F. Most occurrences were for durations of less than 4 hours. Table 4.2-10 details durations in the range 88°F to 90°F. Most durations were less than 6 hours; however, several long durations did occur. Table 4.2-11 summarizes the durations greater than 48 hours in length for both ranges. Durations of downstream temperatures at 90°F were all less than 6 hours in length.

Table 4.2-9 Discreet occurrences of durations of downstream river temperatures in the range 86°F to 88°F under a T_{max} limitation of 90°F with no cooling tower usage until 90°F, BFNP.

	Duration (hrs.)														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13-18	19-24	24+
1969	16	4	3	8*	3	1	1	2	2	0	5	5	5	1	6
1970	15	5	2	3	3	6	4	2	2	4	7	7	13	7	14
1971	12	9	9	7	6	14	2	4	4	5	6	5	9	2	4
1972	9	9	3	5	2	6	3	7	2	5	2	8	6	1	4
1973	10	7	7	14	6	6	8	3	15	12	5	3	1	2	3
1974	12	6	5	7	3	4	5	2	4	3	6	3	5	3	0
1975	19	12	8	6	5	2	5	1	5	6	3	1	2	3	2
1976	5	7	4	7	5	2	0	1	5	7	3	2	4	0	0
1977	4	0	2	3	0	2	1	2	0	0	1	2	2	2	0
1978	13	8	6	4	0	3	0	1	2	3	3	1	4	2	5
1979	8	6	6	0	1	1	2	2	0	0	1	0	0	1	1
1980	10	3	2	3	2	0	0	0	0	0	1	0	1	0	1
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	133	76	57	67	36	47	31	27	41	45	43	37	52	24	40

*Example: There were eight occurrences of durations four hours in length.

NOTE: Durations are discreet, that is a 6-hour duration was not counted as six 1-hour durations, five 2-hour durations, etc.

Table 4.2-10 Discreet occurrences of durations of river temperatures in the range 88°Fto 90°F under a T_{max} limitation of 90°F with no cooling tower usage until 90°F, BFNP.

	Duration (hrs.)														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13-18	19-24	24+
1969	11	2	3	3	2	1	2	0	4*	1	6	2	5	1	6
1970	18	10	4	6	9	10	3	7	3	8	8	3	5	1	2
1971	7	6	5	2	7	4	1	1	0	0	2	0	1	3	0
1972	6	3	6	3	4	0	1	1	0	0	3	3	2	0	0
1973	8	1	2	3	3	1	0	1	1	2	0	0	0	0	0
1974	3	0	1	1	1	1	0	0	0	0	1	0	0	0	0
1975	10	7	0	8	5	4	1	1	0	0	1	1	1	3	1
1976	3	4	1	3	3	0	2	0	0	0	0	0	0	0	0
1977	16	12	7	3	5	6	2	2	2	1	2	2	3	7	5
1978	10	6	4	5	5	6	0	1	3	0	2	1	3	7	6
1979	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1980	10	3	2	3	2	0	0	0	0	0	1	0	0	1	1
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	104	54	36	40	47	33	12	14	13	12	26	12	20	23	21

*Example: There were four occurrences of durations nine hours in length.

NOTE: Durations are discreet, that is a 6-hour duration was not counted as six 1-hour durations, five 2-hour durations, etc.

Table 4.2-11 Predicted durations of downstream river temperatures greater than 86°F for periods longer than 48 hours, BFNP.

Number of Hours of Each Occurrence by Year

1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
109	86	71	142	70	0	389	0	639	74	0	1789
764	57	237	86	81				133	1029		
68	62							258	269		
	242							148			
	72							265			
	129										
	61										

Predicted durations of downstream river temperatures greater than 88°F for periods longer than 48 hours, BFNP.

Number of Hours of Each Occurrence by Year

1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
140	0	0	0	0	0	0	0	69	50	0	66
83								266	111		262
118								56	107		66
									132		55
									53		192
											79
											115

The predicted temperatures discussed previously are considered the maximum temperatures at the edge of the mixing zone at the 5-foot depth under the various limitations. As noted previously, measured data show that cooler temperatures are usually found beneath the discharge plume. Temperatures downstream of the mixing zone under most conditions are cooler than the maximums predicted except under severe meteorological conditions as will be discussed under far field effects.

Finally, the plant had very little effect on the seasonal temperature pattern as shown in Figure 4.2-7. The predicted downstream temperatures at the 5-foot depth (maximum plant load and 90°F T_{max} and 10°F ΔT_{max} limitations with no cooling tower usage until plant operation in open mode would have exceeded these limits) are compared with ambient upstream measured temperatures at the 5-foot depth (Station 4). The averages show that over a year slight increases in temperatures (less than 5°F) occur, but these are small when compared to the changes over the annual cycle which are on the order of 50°F.

4.2.1.3 Near Field Zone of Passage

An important concept related to thermal discharge limitations is the maintenance of a zone of passage at natural temperatures for fish to migrate upstream and downstream of the near field mixing zone. As shown previously, the bottom temperatures at Station 1 remain very close (within 1 or 2°F) to the ambient upstream conditions, even during full plant load and low flows. The diffuser does not extend completely across the main channel, and considerable overbank area exists on the left (south) side of the diffuser, as shown in Figure 4.2-8. Data from Station 8 provide a record of temperatures in this overbank region. Figures 4.2-9A and

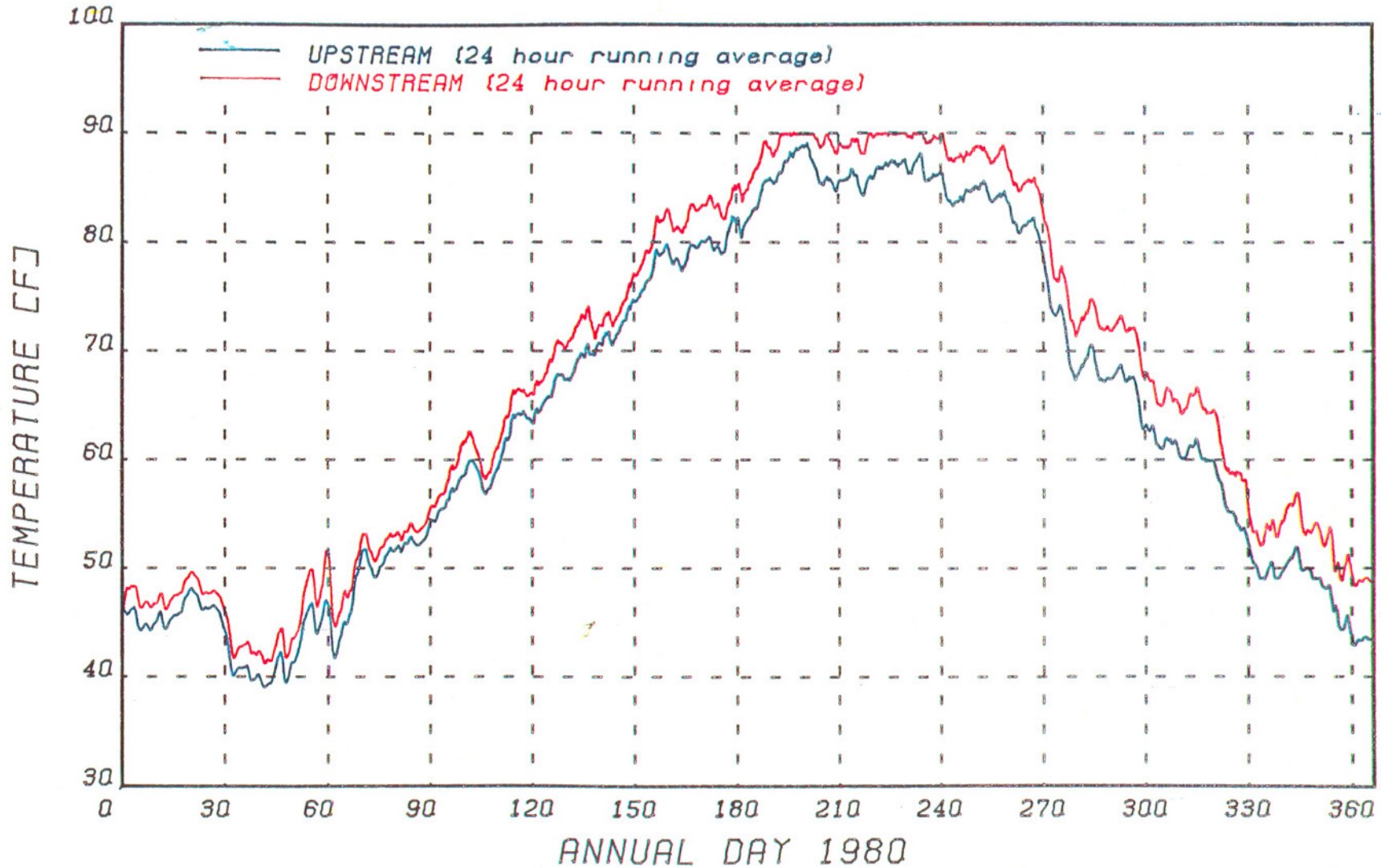

Figure 4.2-7. Effect of BFNP alternative limitations on seasonal temperature pattern, 1980.

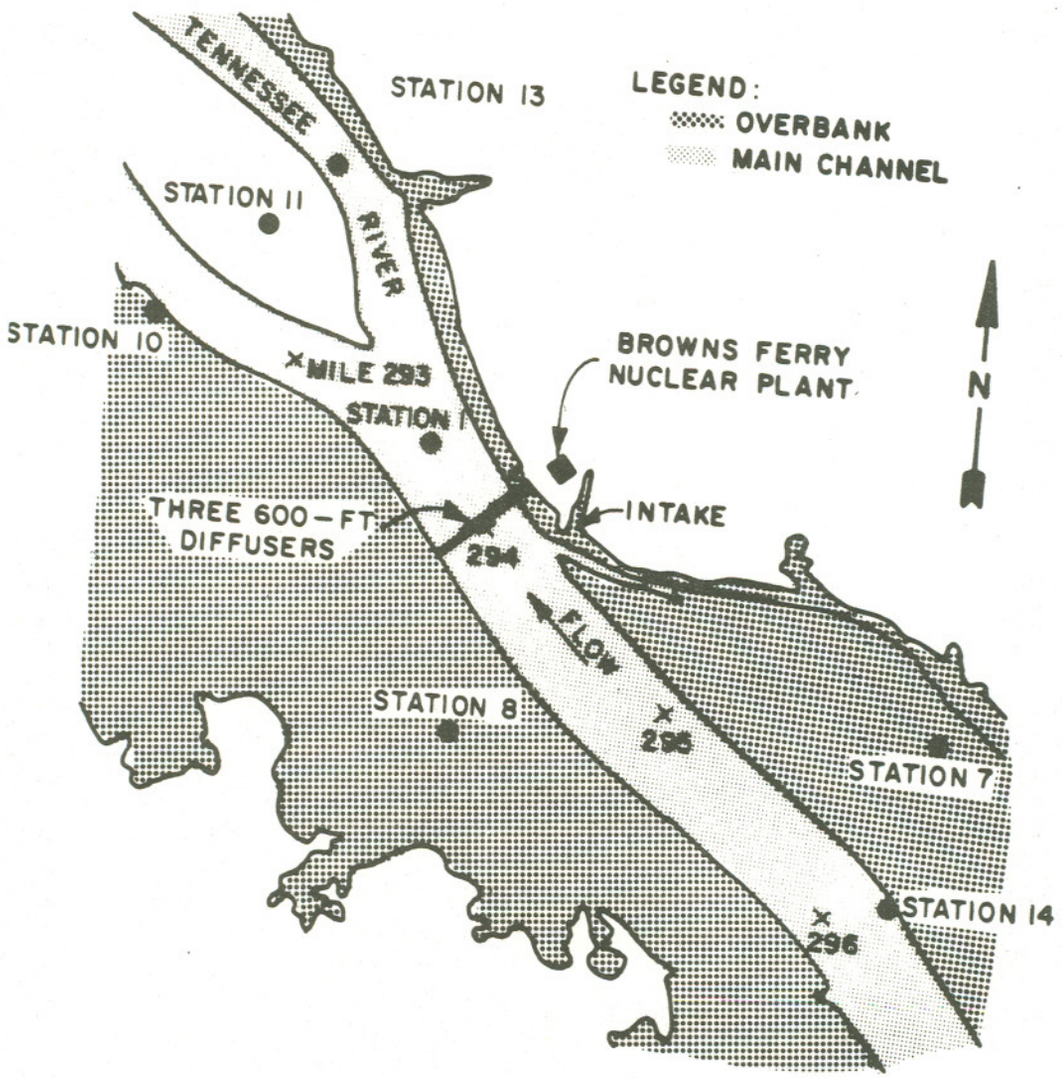

Figure 4.2-8. Wheeler Reservoir in the vicinity of Browns Ferry Nuclear Plant.

4.2-9B show data from Station 8 compared to Station 1 for April and August 1977. These data indicate that Station 8 bottom temperatures remain at ambient, and are slightly less than Station 1 bottom temperatures. But as the August data suggest, the temperature difference is only 1 to 2°F during the warmest part of the year. Nevertheless, the overbank region immediately downstream and to the left of the diffuser remains at ambient temperatures, almost identical to the upstream temperatures.

Stations 10, 11, and 13 provide an accurate picture of all water temperature gradients at this channel location 1.5 miles downstream of the diffuser. Figures 4.2-10A and 4.2-10B shows data from these three stations for April and May 1977. Station 11 is located in shallow water (13 feet) on a submerged island. Temperatures at Station 11 are almost always fully mixed, usually warmer than at Stations 10 and 13, and provide a good approximation of the average temperature of the surface heated layer. Bottom temperatures at Stations 10 and 13, which are about 25 feet deep, are often several degrees cooler than the surface temperatures at 10, 11, or 13. This indicates that the thermal discharge has not fully mixed with the entire river flow, and that a zone of water at ambient temperature is available under the thermal plume. However, there are periods when the entire channel cross section at this downstream location is fully mixed. Thermal changes are minimized in the sense that fully mixed conditions are characterized by cooler maximum temperatures than are stratified conditions. Figures 4.2-11A and 4.2-11B shows temperatures at Stations 10, 11, and 13 during July and August 1977. Although fully mixed conditions exist during most nights, some periods of stratification are evident, with bottom temperature at either Station 10 or 13 remaining

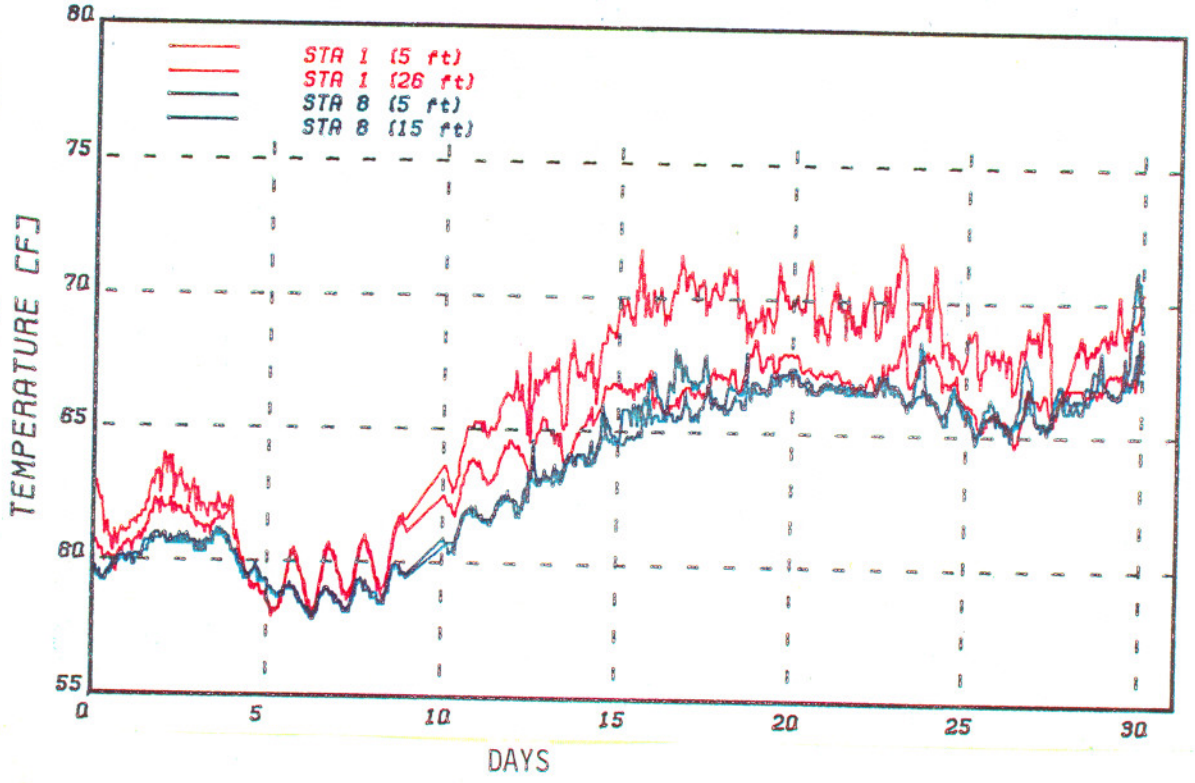

Figure 4.2-9A. Hourly water temperatures at BFNP Stations 1 (TRM 293.6) and 8 (TRM 294.5) during April 1977.

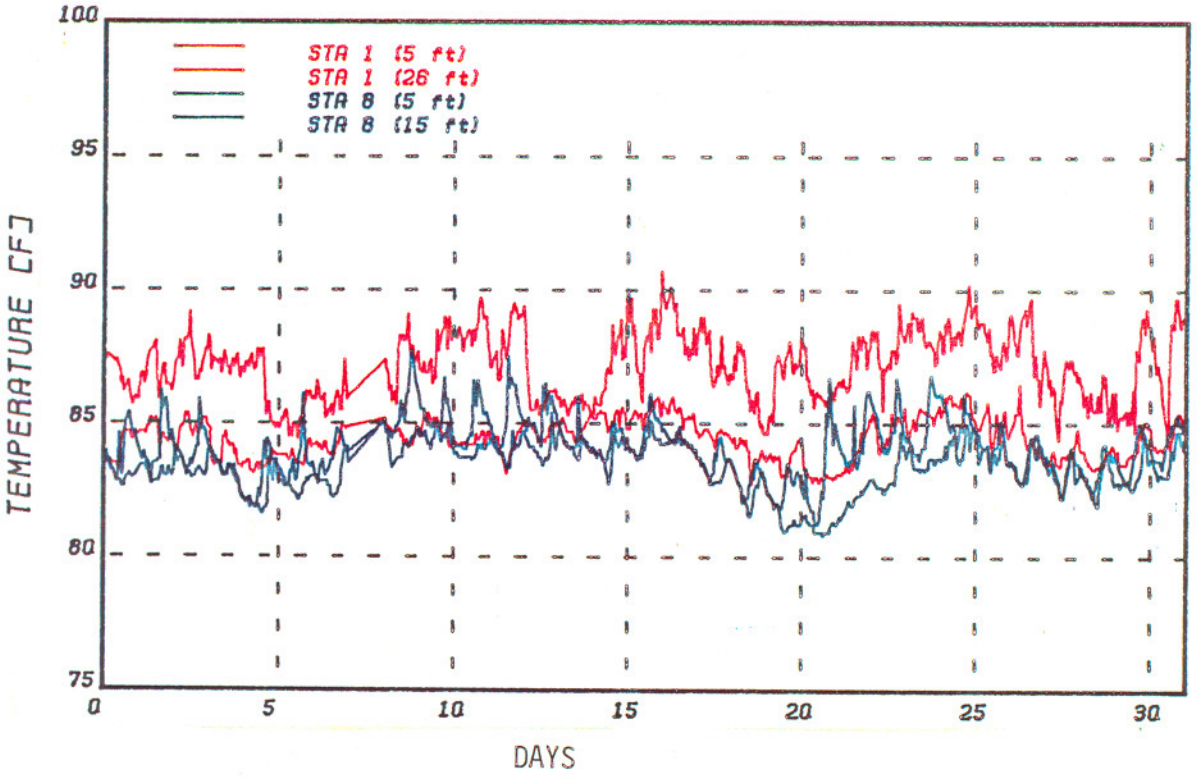

Figure 4.2-9B. Hourly water temperatures at BFNP Stations 1 (TRM 293.6) and 8 (TRM 294.5) during August 1977.

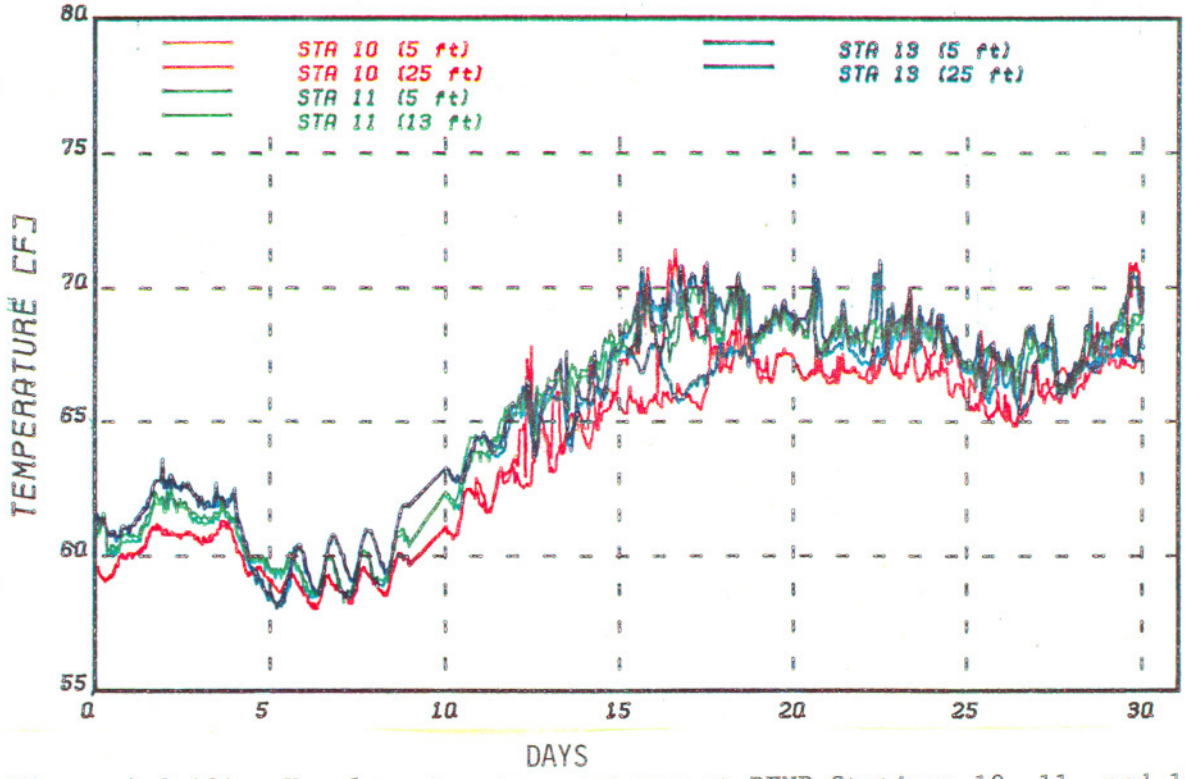

Figure 4.2-10A. Hourly water temperatures at BFNP Stations 10, 11, and 13 (TRM 292.5) during April 1977.

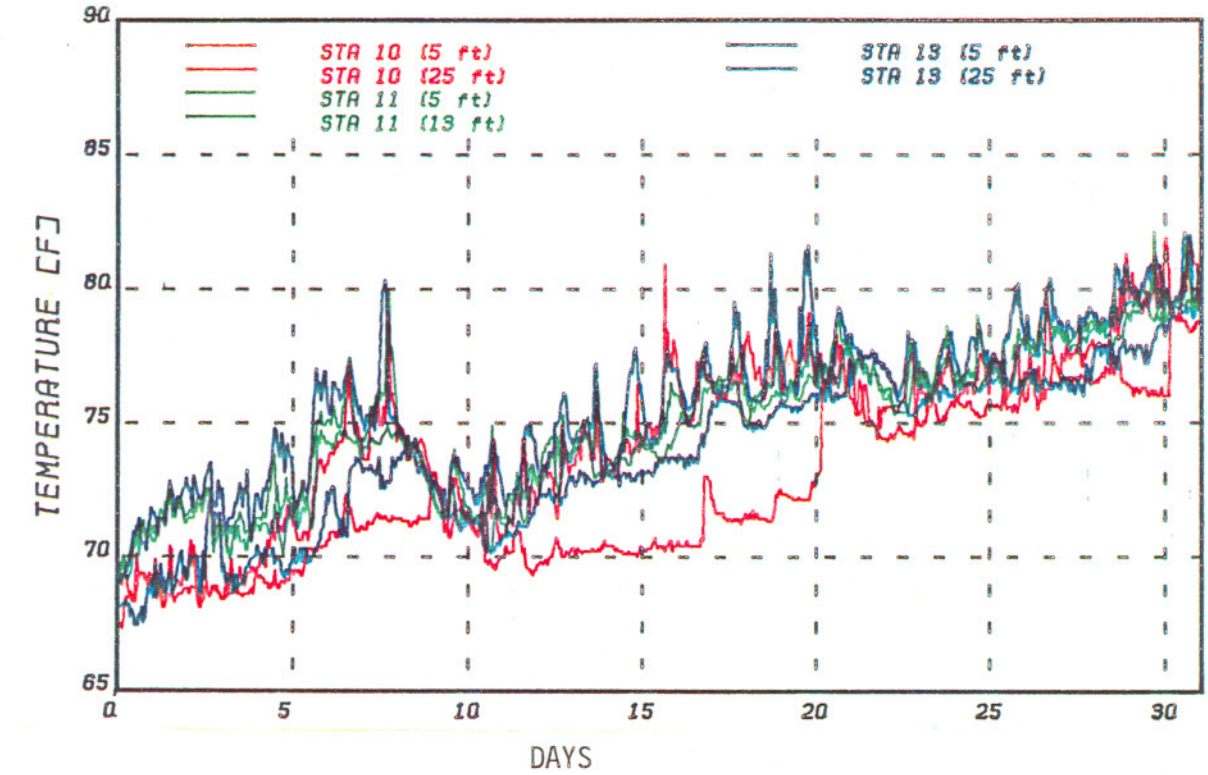

Figure 4.2-10B. Hourly water temperatures at BFNP Stations 10, 11, and 13 (TRM 292.5) during May 1977.

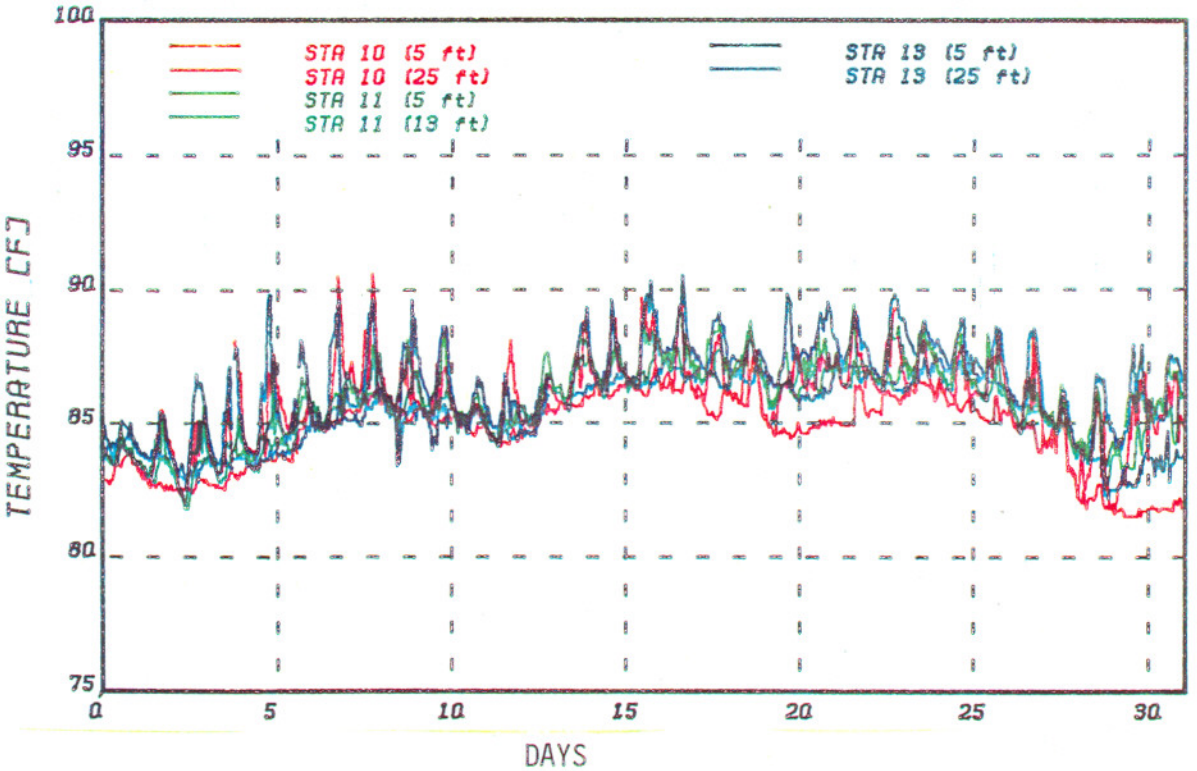

Figure 4.2-11A. Hourly water temperatures at BFNP Stations 10, 11, and 13 (TRM 292.5) during July 1977.

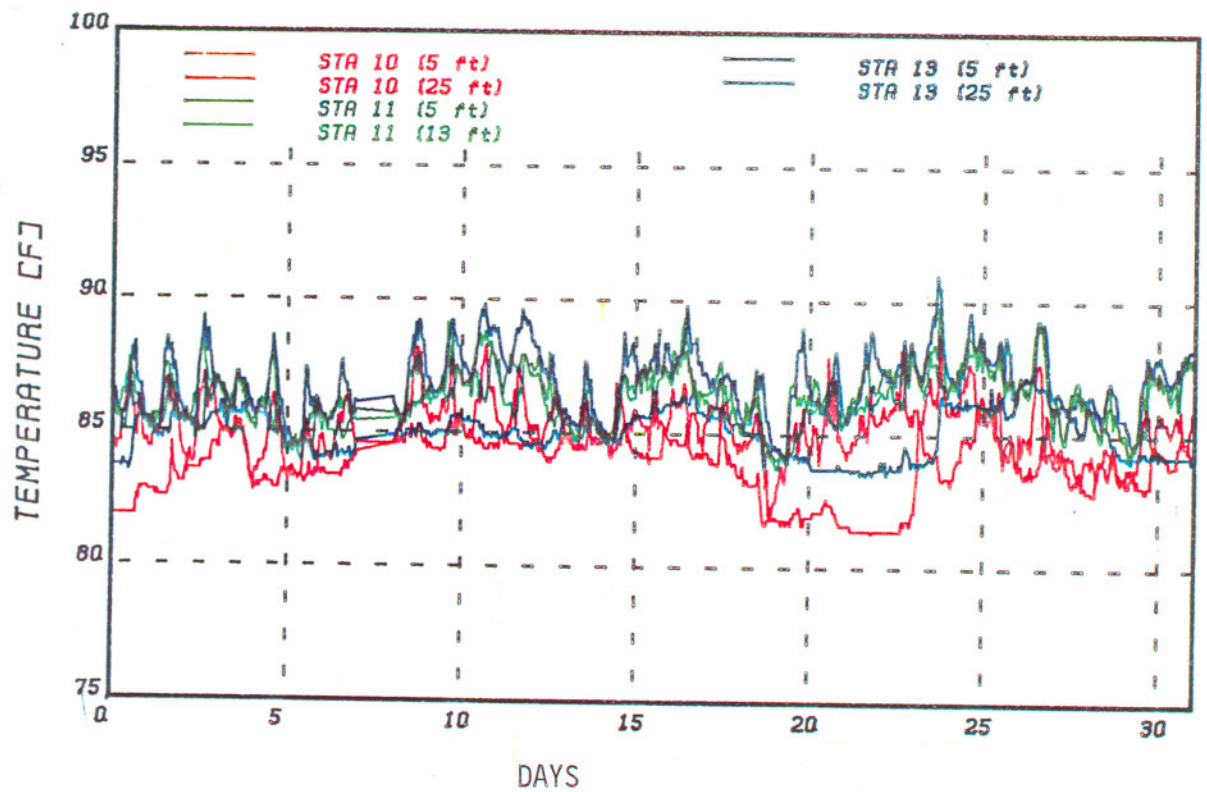

Figure 4.2-11B. Hourly water temperatures at BFNP Stations 10, 11, and 13 (TRM 292.5) during August 1977.

cooler than surface temperatures by 1 to 3°F. During the warmest part of the year, this entire cross section is warmer than ambient, and there is no permanent zone of ambient water temperatures. The summer of 1980 produced a similar situation as shown by the July and August 1980 data in Figures 4.2-12A and 4.2-12B.

4.2.1.4 Summary of Near Field Evaluations

Near field effects from plant operation under alternative limitations were first evaluated using monitoring data from periods when BFNP had temporary thermal variances. Predictive models were then used to characterize effects over a long period of record under constant alternative limitations.

The ΔT_{max} limitation is the overriding limitation during spring, fall, and winter. Monitoring data from these periods show the diffuser often causes a thermal gradient in the near field with surface temperatures approaching the ΔT_{max} limitation and bottom temperature significantly closer to ambient temperature. These conditions are prevalent during low flow periods in winter and spring, and occur under varying flow conditions in the fall. Higher flows during the winter and spring can cause more mixing of the discharge distributing temperatures over the entire vertical depth.

The near field diffuser model predicted increased temperatures due only to the plant discharge at the edge of the mixing zone near Station 1. The ΔT predictions are highly dependent on river flows which affect diffuser mixing. Simulations used an alternative ΔT_{max} of 10°F with no cooling tower operation until the ΔT would have exceeded 10°F.

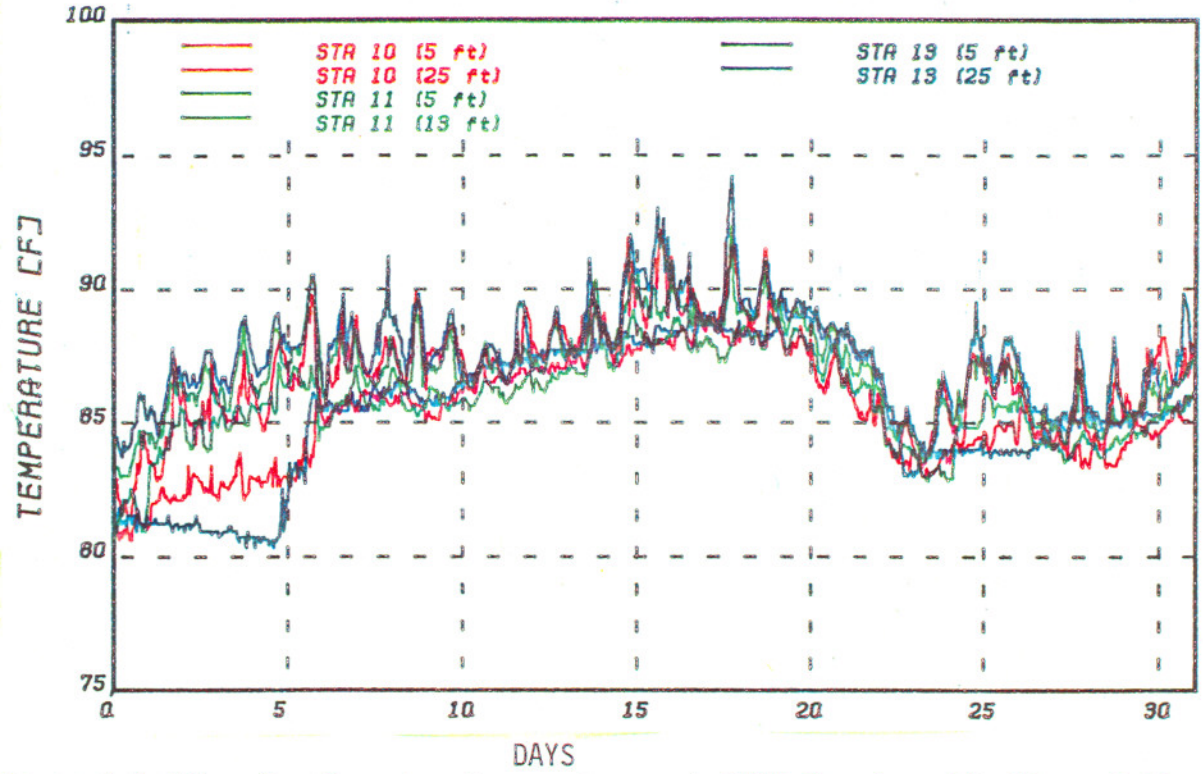

Figure 4.2-12A. Hourly water temperatures at BFNP Stations 10, 11, and 13 (TRM 292.5) during July 1980.

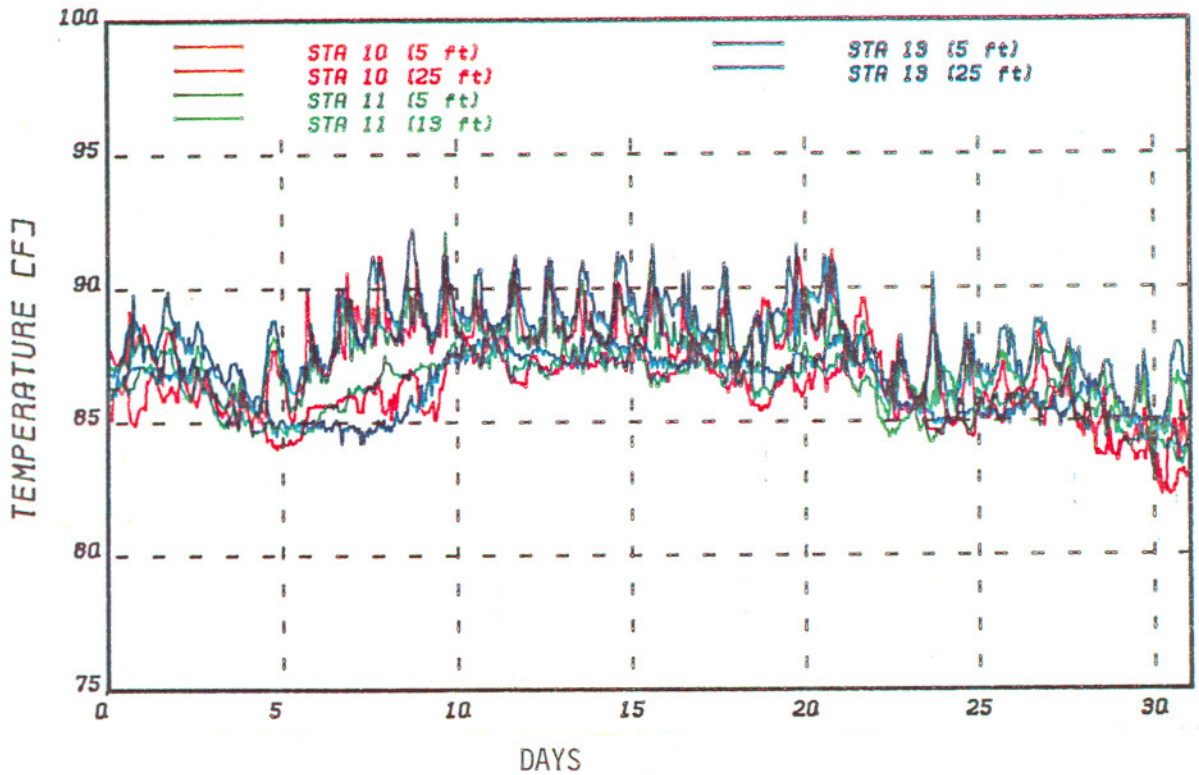

Figure 4.2-12B. Hourly water temperatures at BFNP Stations 10, 11, and 13 (TRM 292.5) during August 1980.

Severe drought conditions during late 1980 and the first half of 1981 showed a dramatic increase in simulated ΔTs greater than 5°F. Predicted ΔTs larger than 5°F occurred greater than 50 percent of the time in December 1980, and during the months of January, March, and May 1981. The longest duration, 319 hours (13 days), occurred during the December-January period. For the 12½ years of record, simulated monthly average occurrences of ΔTs greater than 5°F were less than 15 percent with annual averages less than 9 percent.

The near field simulations showed that the controlling dams could be used for normal peaking operations (as occurred during 1969-1976) and still keep BFNP temperature rises below 10°F. Frequent rises between 5 and 10°F could occur during low flow conditions such as those experienced in late 1980 and 1981.

The T_{max} limitation is important in the months of June through September. The most apparent plant effects on near field temperatures recorded during this period are the production of a deeper surface heated layer (plume) as compared to the naturally occurring solar heated layer, and the continuation of a heated surface layer through the night. Bottom temperatures remain closer to ambient upstream conditions.

The near field diffuser model simulations used an alternative limitation of 90°F with no cooling tower usage until the mixed river temperature would have reached 90°F. Comparisons were made with predictions under the present limitation of 90°F with cooling towers used after the mixed river temperature reached 86°F and with ambient upstream river temperatures. The occurrence of near field temperatures greater than 86°F was used as the basis for comparison.

An average of June, July, and August results over the 12 years of record showed the average occurrence of temperatures greater than 86°F under the alternative limitation was 41.1 percent, under the present limitation was 12.8 percent, and under ambient upstream conditions was 7.2 percent. Under average conditions the occurrences are about equally distributed between the range 86 to 88°F and 88 to 90°F. The most severe conditions occurred during July 1980 when the maximum monthly occurrence of temperatures greater than 86°F under the alternative limitation was 94 percent, under the present limitation was 66.5 percent, and under ambient conditions was 49.6 percent. Under these severe conditions a larger percentage of temperatures were in the 88 to 90°F range.

Long continuous durations of water temperatures greater than 86°F were predicted during the hot summers. The longest duration of 1789 hours (75 days) occurred in the summer of 1980. The longest continuous duration of temperatures greater than 88°F occurred in the summer of 1977 and was 266 hours (11 days) in length.

The plant had little effect on the seasonable temperature pattern. Only slight changes of less than 5°F were predicted.

An evaluation of a zone of passage showed that near the diffuser discharge there are areas of the reservoir which remain at ambient temperatures, especially in the overbank region on the south side. The nearest downstream monitors show bottom temperatures are only slightly higher than ambient. As water travels to the monitors 1.5 miles downstream, deeper water is still normally several degrees cooler than the surface, indicating a zone of water at ambient temperatures is available under the thermal plume. However, there are periods when the entire channel cross section is fully mixed. Fully mixed conditions

normally occur during periods of cooling or high flows, with cooler maximum temperatures than under stratified conditions. However, conditions existed during the summers of 1977 and 1980 when fully mixed warm temperatures were present throughout the cross section.

4.2.2 Far Field Effects

The heat discharged by Browns Ferry Nuclear Plant is mixed in the reservoir by flow and wind induced turbulence and is rejected to the atmosphere by surface heat exchange processes as it is transported downstream. To quantify the far field effect of the heated discharge, both actual data and simulations of ambient and heated conditions resulting from alternative thermal limitations were evaluated. The evaluations included a comparison of the heat output of the plant with solar heat input, the effects of the plant on the release temperatures from Wheeler Dam, and the effects of the plant on thermal stratification and dissolved oxygen depletion in Wheeler Reservoir.

4.2.2.1 Observed Far Field Temperatures

As indicated in Figure 4.1-3, there are two temperature monitors in lower Wheeler Reservoir which provide far field temperature patterns. The interpretation of these observed temperatures must consider that natural and thermal discharge effects are combined in the data. Ambient far field conditions that would exist without BFNP cannot be measured when BFNP is operating. The incremental effect of the discharge must be deducted from observed temperatures. Because the primary consideration is the far field temperature patterns with BFNP operating, observed temperatures from the study periods used in previous sections are discussed.

Station 3 is located near Wheeler Dam in the deepest portion of Wheeler Reservoir. Station 5 is located upstream of the Elk River embayment. Temperatures from Stations 3 and 5 are compared to those from Station 13 which are taken to represent the heated water flowing into the downstream portion of Wheeler Reservoir. Changes that occur between Station 13 and Stations 5 or 3 are the result of far field heating, cooling, and mixing processes.

The daily average surface and bottom temperatures from Stations 13 and 3 are shown in Figure 4.2-13A. Both stations remain fully mixed through March. There is a cooling of water as it moves from Station 13 to 3 because the higher temperatures created by the BFNP discharge cool slightly to the ambient conditions observed at Station 14, upstream of the diffuser. Meteorological conditions determine these ambient temperatures, and sufficient cooling potential is available through evaporation and longwave radiation losses to return the heated water to ambient temperatures. This is illustrated in Figure 4.2-13B, which shows that the incremental heating across the diffuser is almost identical to the incremental far field cooling observed between Stations 13 and 3. During the fall of 1977, when meteorological cooling was dominant, almost no longitudinal temperature differences were observed because plant load was low (1 or 2 units). With higher loads, a similar fully mixed pattern of near field heating and far field cooling will result in the fall.

The far field temperature pattern is more complicated during the spring and summer periods when intermittent stratification develops in the downstream portion of Wheeler Reservoir. The observed patterns can be explained by considering two hydrothermal mechanisms: (1) The far

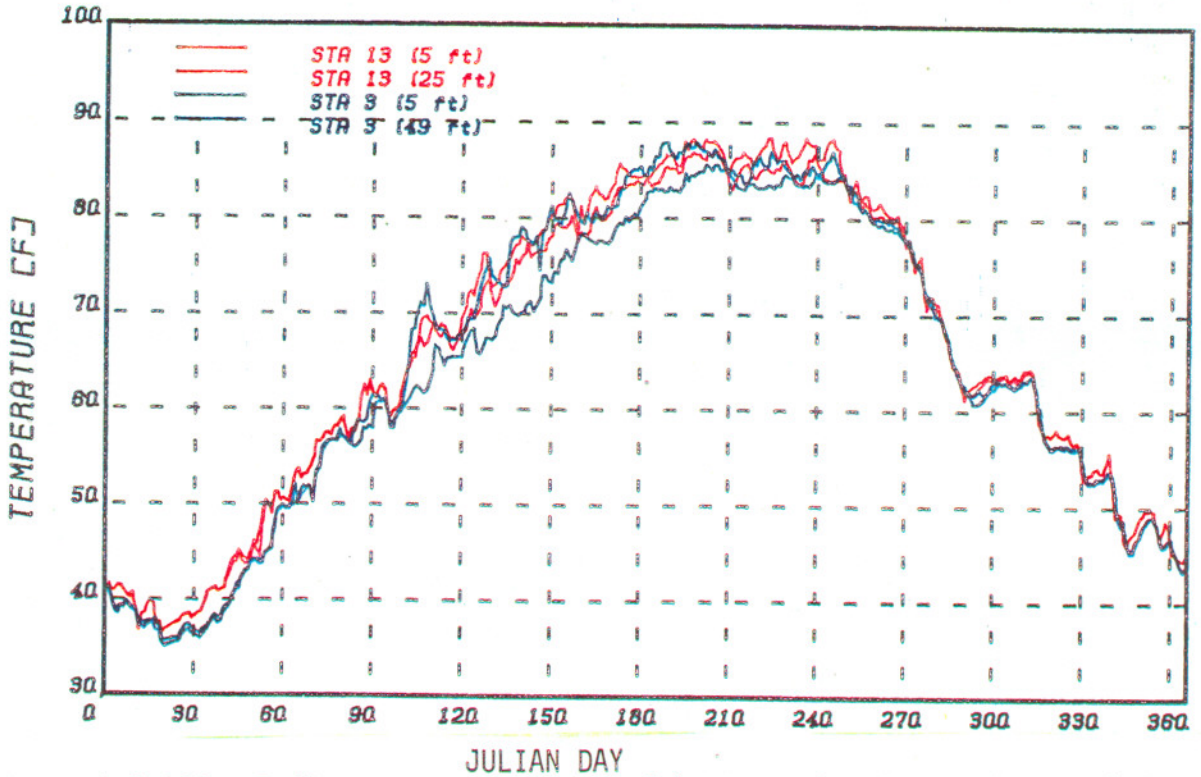

Figure 4.2-13A. Daily average surface and bottom water temperatures at BFNP Stations 13 (TRM 292.5) and 3 (TRM 275.0) during 1977.

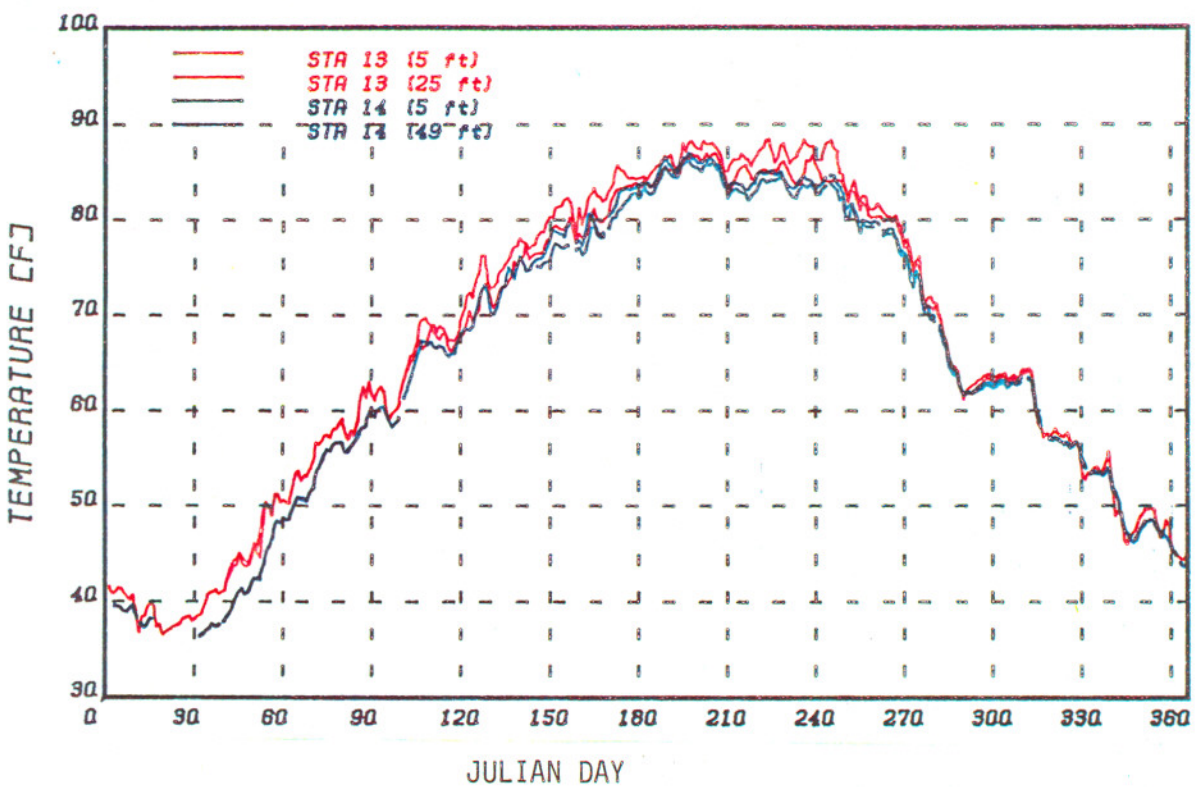

Figure 4.2-13B. Daily average surface and bottom water temperatures at BFNP Stations 13 (TRM 292.5) and 14 (TRM 296.1) during 1977.

field surface temperatures are directly influenced by the meteorological conditions. Both heating and cooling are observed between Stations 13 and 3 at different times. On a seasonal time scale, the longitudinal temperature differences produced by BFNP discharges are small relative to the day-to-day changes due to variable meteorology. (2) The bottom water in lower Wheeler Reservoir is slowly released as part of Wheeler Dam discharge and replenished by water flowing from upstream. When meteorological conditions cause a warming of these inflowing temperatures, as observed at Station 13, this warmer water tends to enter the deep portion of Wheeler Reservoir at mid-depth and leaves the coolest bottom water undisturbed. If meteorological conditions produce a cooling of upstream temperatures, then this inflowing water moves along the main channel and replaces the slightly warmer bottom water near Wheeler Dam. This inflow replacement that occurs during cooling events requires several days, corresponding to the travel time of this cooler water through the downstream portion of Wheeler Reservoir. Detailed effects from these two mechanisms can be better observed from monthly plots of temperature patterns downstream of BFNP.

Figures 4.2-14A and 4.2-14B show temperatures for January 1981. Low flow conditions and a 2 or 3 unit plant load produce a temperature rise of up to 8°F between Stations 14 and 13 (Figure 4.2-14A). Data from Stations 5 and 3, however, show that temperatures have cooled to ambient at Station 5 (Figure 4.2-14B). Temperatures at Station 3 respond slower to the variable meteorology due to the greater depth. There is a several day lag between temperature increases at Station 5 and the corresponding increases at Station 3. The longitudinal temperature gradients produced by changing meteorology are much larger than those caused by the BFNP discharge heating and subsequent far field cooling.

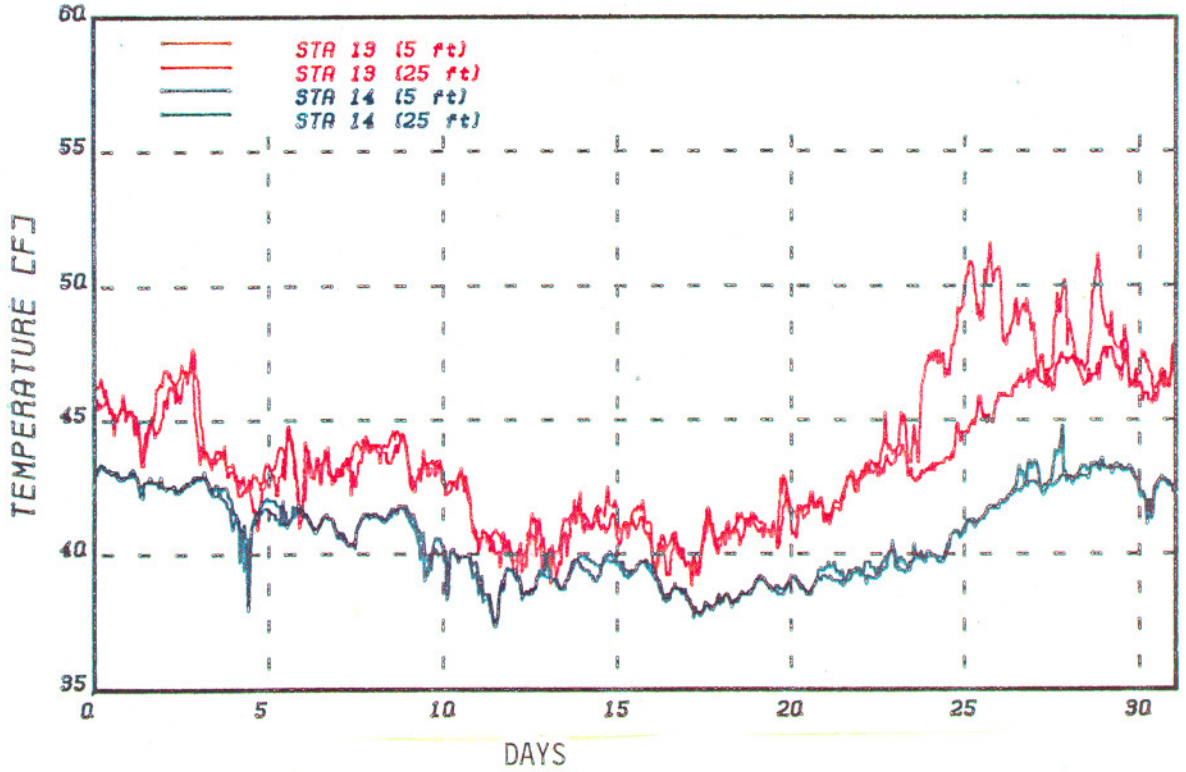

Figure 4.2-14A. Hourly water temperatures at BFNP Stations 13 (TRM 292.5) and 14 (TRM 296.1) during January 1981.

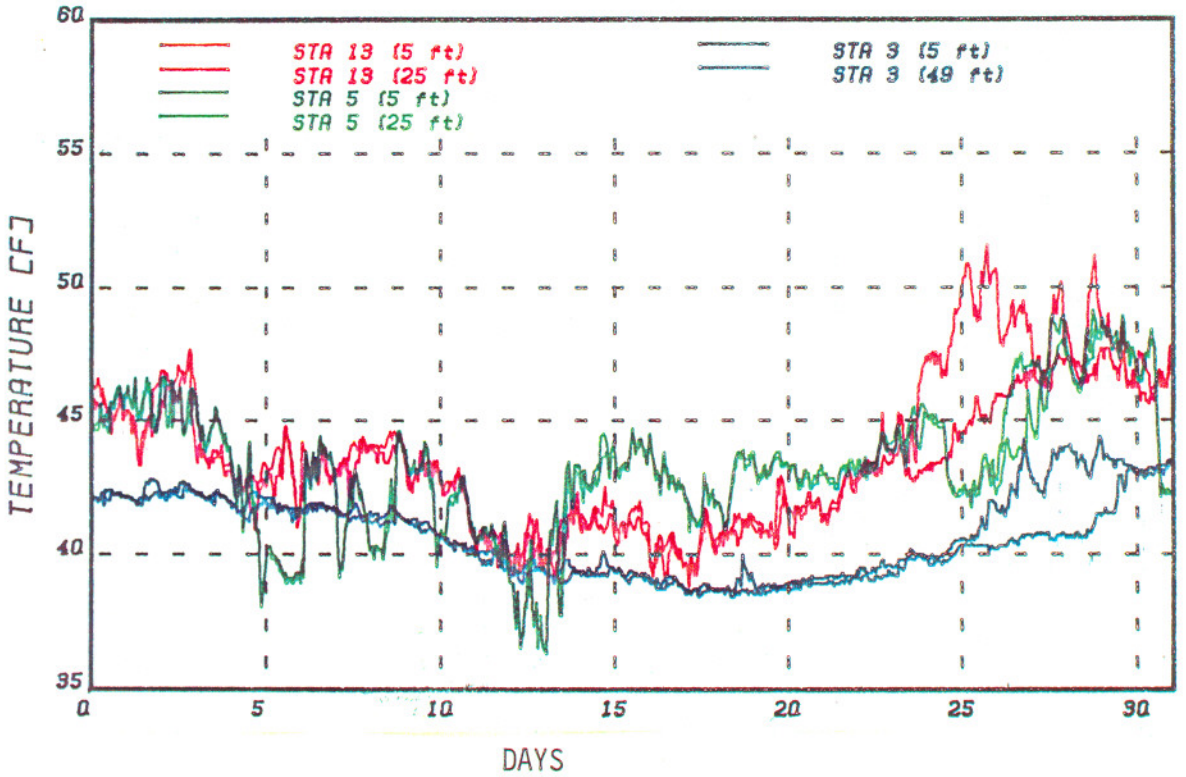

Figure 4.2-14B. Hourly water temperatures at BFNP Stations 13 (TRM 292.5), 5 (TRM 286.2) and 3 (TRM 275) during January 1981.

Figures 4.2-15A and 4.2-15B compare temperature at Stations 13 and 3 during June and July 1977. As the summer temperature maximum is approached, the rate of warming of the ambient upstream temperatures becomes much less, and the stratification at Station 3 is correspondingly weaker. Surface temperatures in the far field are usually slightly less than those at Station 13 during the summer, which indicates that there is a general cooling of the surface temperatures in the far field (1 or 2°F). During late June and the first half of July, BFNP operated in closed mode, and surface temperatures at Station 13 are slightly less than at Station 3, especially at night. This indicates that under natural summer conditions there is a slight surface heating in the far field (1 or 2°F).

Data from the summer of 1980 indicated that the 5-foot depth temperatures in the far field approached 90°F for numerous periods of time as shown in Figures 4.2-16A and 4.2-16B. Temperatures at Station 13 were limited by a 93°F T_{max} during most of the summer. Some stratification occurred at Station 3 following the cooling events prior to July 1 and during late July. Relatively cool water persisted near Wheeler Dam and presumably up the Elk River embayment for many days, but a brief period of 88°F in the entire far field region occurred on July 21. The five-foot depth temperatures in the far field during July and August 1980 were almost identical to temperatures at Station 13. The data suggest that ambient temperatures would have continued to increase in the far field due to the extreme meteorological conditions. The BFNP diffuser produced the same temperature increase in the near field which persisted in the far field.

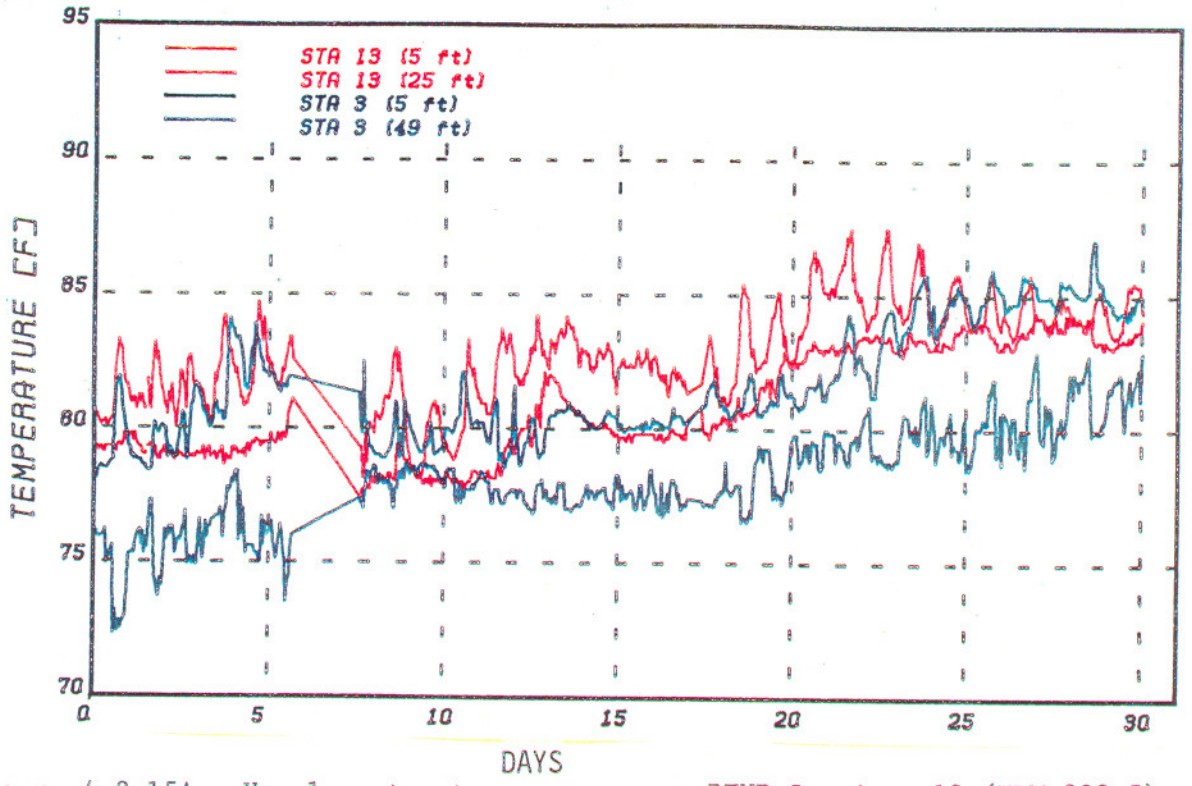

Figure 4.2-15A. Hourly water temperatures at BFNP Stations 13 (TRM 292.5) and 3 (TRM 275.0) during June 1977.

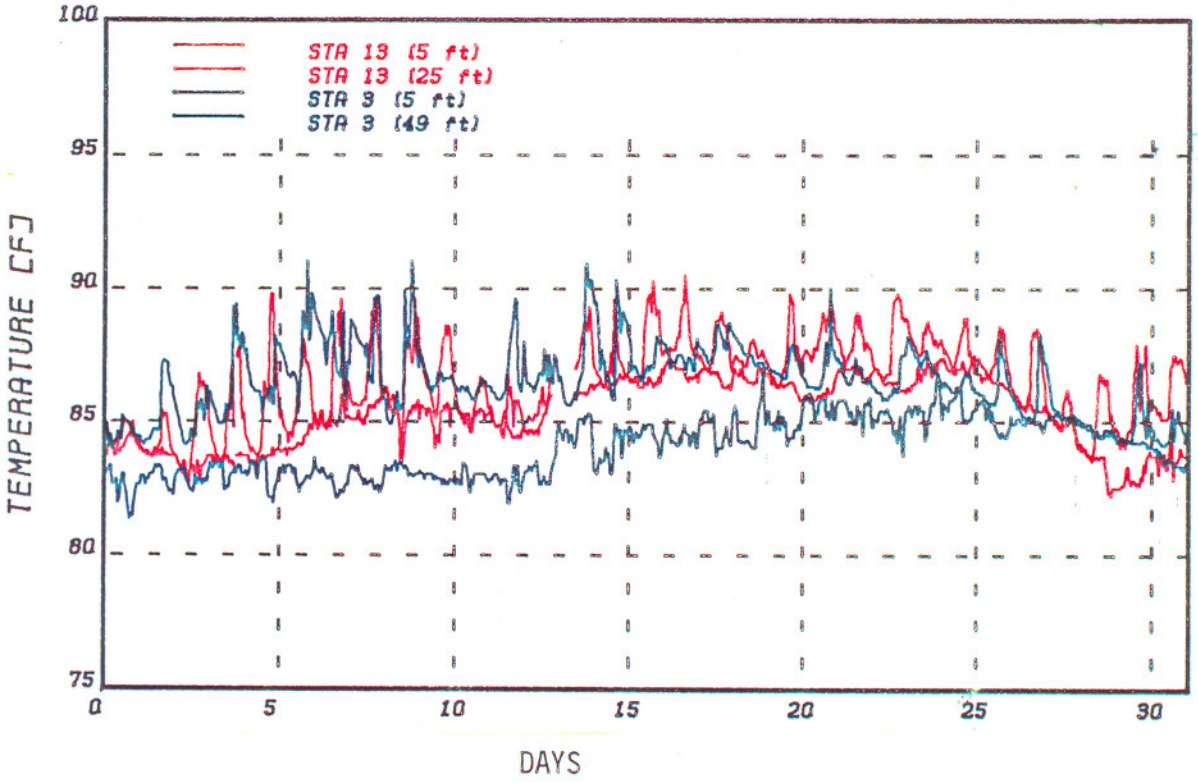

Figure 4.2-15B. Hourly water temperatures at BFNP Stations 13 (TRM 292.5) and 3 (TRM 275.0) during July 1977.

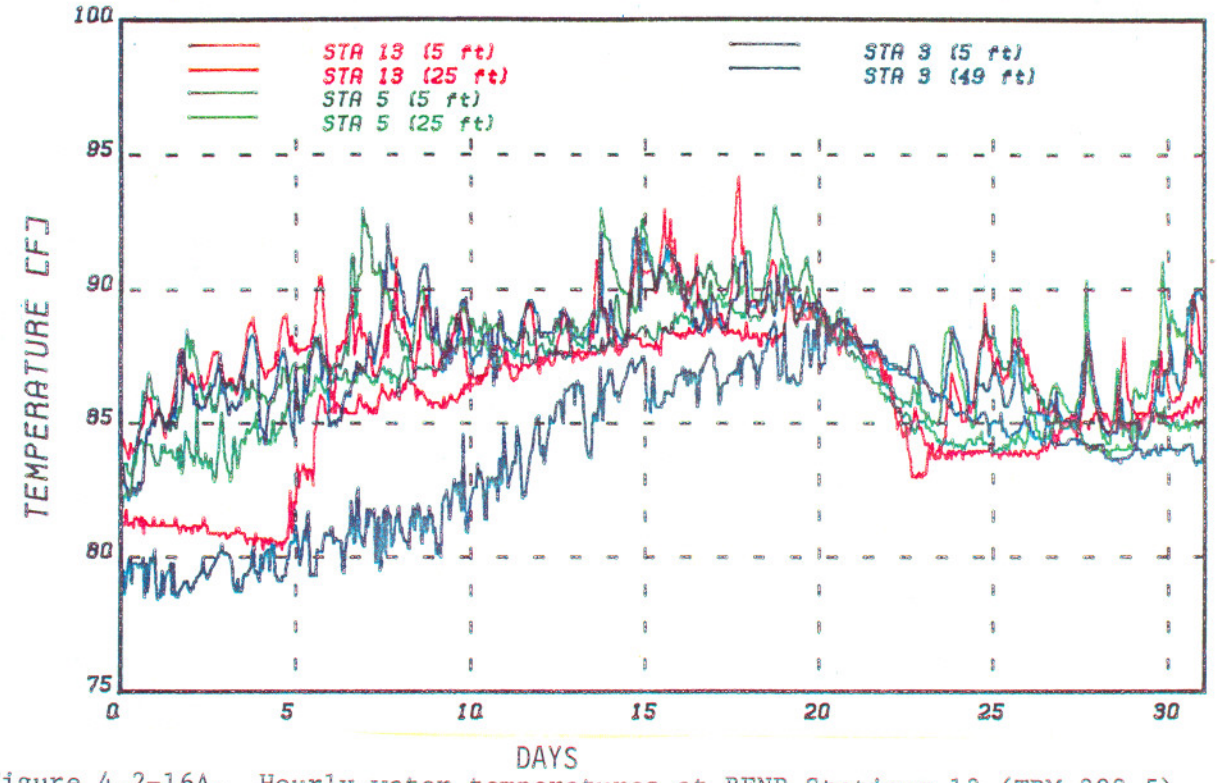

Figure 4.2-16A. Hourly water temperatures at BFNP Stations 13 (TRM 292.5), 5 (TRM 286.2) and 3 (TRM 275) during July 1980.

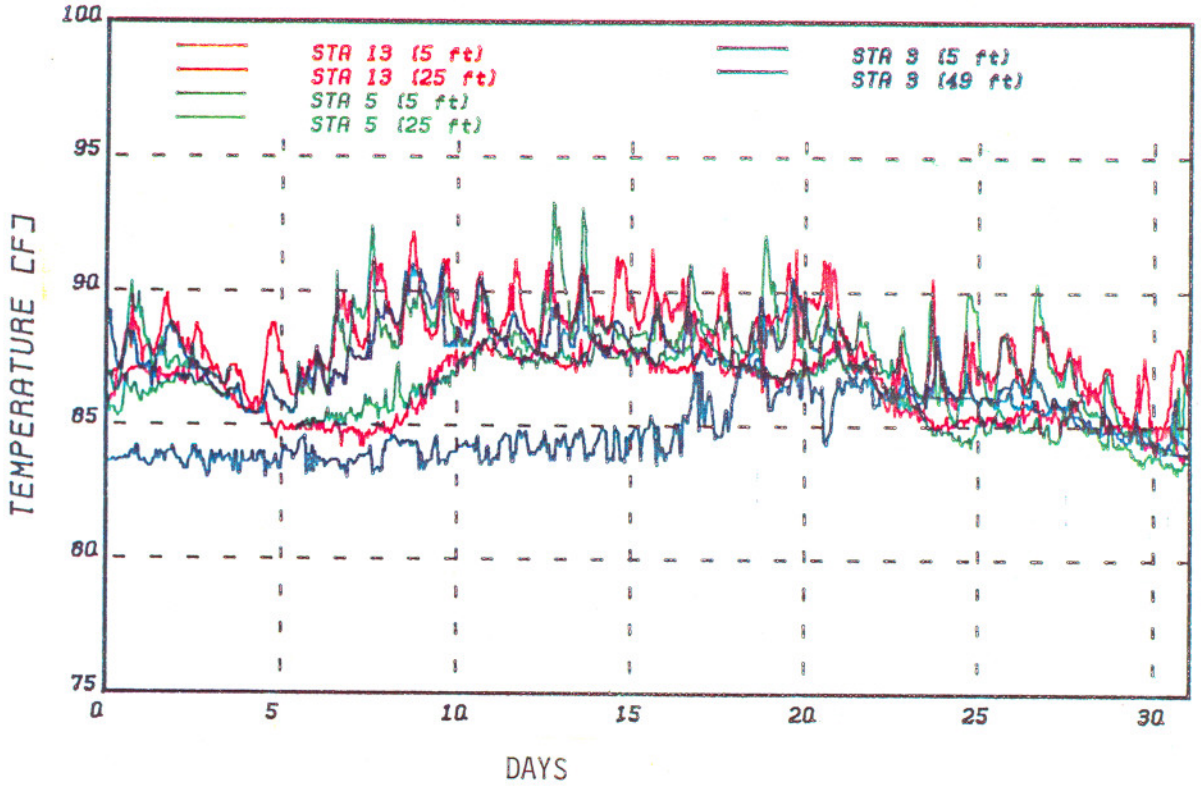

Figure 4.2-16B. Hourly water temperatures at BFNP Stations 13 (TRM 292.5), 5 (TRM 286.2) and 3 (TRM 275) during August 1980.

The previous data show that thermal stratification in Wheeler Reservoir is usually weak and of short duration. Relatively short transit time (1 to 2 weeks), the fact that the turbine intakes in Wheeler Dam withdraw water from the entire vertical depth of the reservoir, and the effect of storm events mixing the entire water body all prevent the development of long periods of strong stratification.

Two additional far field temperature issues which cannot be directly supported by data should be considered. (1) Because flow in the Elk River embayment moves slowly into the main channel of Wheeler Reservoir, it is very difficult for the BFNP discharge to influence temperatures in this major embayment. Temperature dynamics will be dominated by natural meteorological conditions and the effects of cool Elk River inflows. (2) If temperatures downstream of the BFNP are uniformly heated by some increment, then the proceeding discussion suggests that bottom temperatures in the downstream far field region would be warmed by that same increment. In reality, the coolest upstream temperatures are not warmed by the average plant induced increment. Some cool ambient water moves around and under the discharge plume, as discussed previously. In addition, the cooling events that produce short periods of cool upstream temperatures are strong enough to cool the heated discharge plume to almost the same temperature as the upstream water.

4.2.2.2 Predicted Far Field Effects of Ambient Conditions and Plant Operation Under Alternative Limitations

The purpose of the far field modeling was to compare the worst case conditions that could occur in lower Wheeler Reservoir under alternative limitations on the heated discharge. It was necessary to model

ambient conditions for comparison since the plant was operating during the chosen period of study. The modeling period selected was April 9, 1980 through May 31, 1981, which included the severe environmental conditions of hot temperatures during the summer of 1980 and low flows during late 1980 and spring 1981.

A two-dimensional, laterally averaged, unsteady numerical model was used to determine velocity distributions and thermal stratification in lower Wheeler Reservoir. The governing equations of motion and thermal energy were solved by an unsteady finite difference scheme. Details of the model were provided by Waldrop, Ungate, and Harper, (1980).

Surface heat flux and wind shear, upstream and lateral inflow, and downstream withdrawal were treated as time varying boundary conditions and were updated for each hour of the simulation period. Meteorological conditions for the surface boundary inputs were obtained from data taken at the meteorological tower at BFNP. Data from the Huntsville, Alabama, weather station were used when BFNP data were missing. The upstream boundary inflow was determined from the flow routing model described in Section 4.1.2. Lateral inflows included specific inputs from the Elk River, based on Tims Ford Dam discharges, and distributed inputs from other small sources. The downstream withdrawal was determined from the discharge at Wheeler Dam.

The model was verified using actual data from 1977 at instream monitoring station 3 near the confluence of the Elk River at TRM 286.2, 9 miles downstream of the plant, and Station 5 near Wheeler Dam at TRM 275.0, 19 miles downstream. A lateral average of monitoring Stations

10, 11, and 13 data provided the vertical temperature profile used as the upstream boundary conditions. Figure 4.1-3 shows the location of the previously mentioned monitors. Typical results are shown in Figures 4.2-17A, 4.2-17B, 4.2-18A, and 4.2-18B which compare periods in July 1977 at both monitoring stations. The model does a remarkable job in tracking the observed data at various depths. During periods of large solar heating the modeled surface temperatures down to the 5-foot depth reproduce the actual diurnal pattern. Some spikes in the modeled data, above observed conditions, are considered to be the result of using BFNP site meteorology for the 19 miles of modeled reservoir length. Increased wind mixing effects would decrease the diurnal flucuations. Modeled bottom temperatures follow the general trend of monitored data. The model could not be expected to match the short term fluctuations caused by mixing events at the monitors. The ability of the model to reproduce representative temperature at both the surface and the bottom provided confidence for the later work.

Except for the upstream inflow temperatures, all boundary conditions were the same for both the ambient and alternative limitations simulations. For the ambient case, vertical temperature profiles from the nearest upstream monitor, Station 14, TRM 296.1, were used for time varying upstream boundary conditions. The simulations of alternative limitations used results from the previously discussed near field model as upstream boundary conditions. Maximum plant load was considered under 90°F T_{max} and 10°F ΔT_{max} limitations with no cooling tower usage until plant operation in open mode would have exceeded these limits (90/10 simulation). The heated discharge was in most cases fully mixed over the upstream cross section in the alternative limitations case. Actual

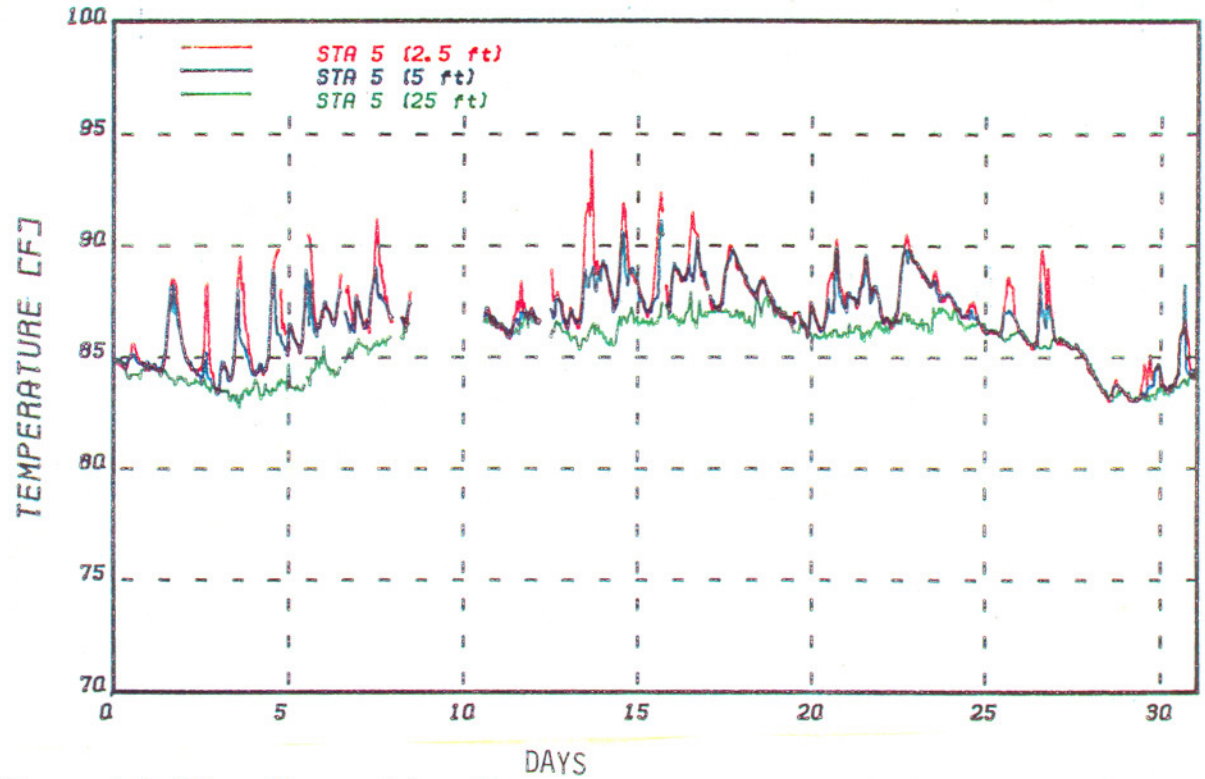

Figure 4.2-17A. Observed hourly water temperatures at BFNP Station 5 (TRM 275) during July 1977.

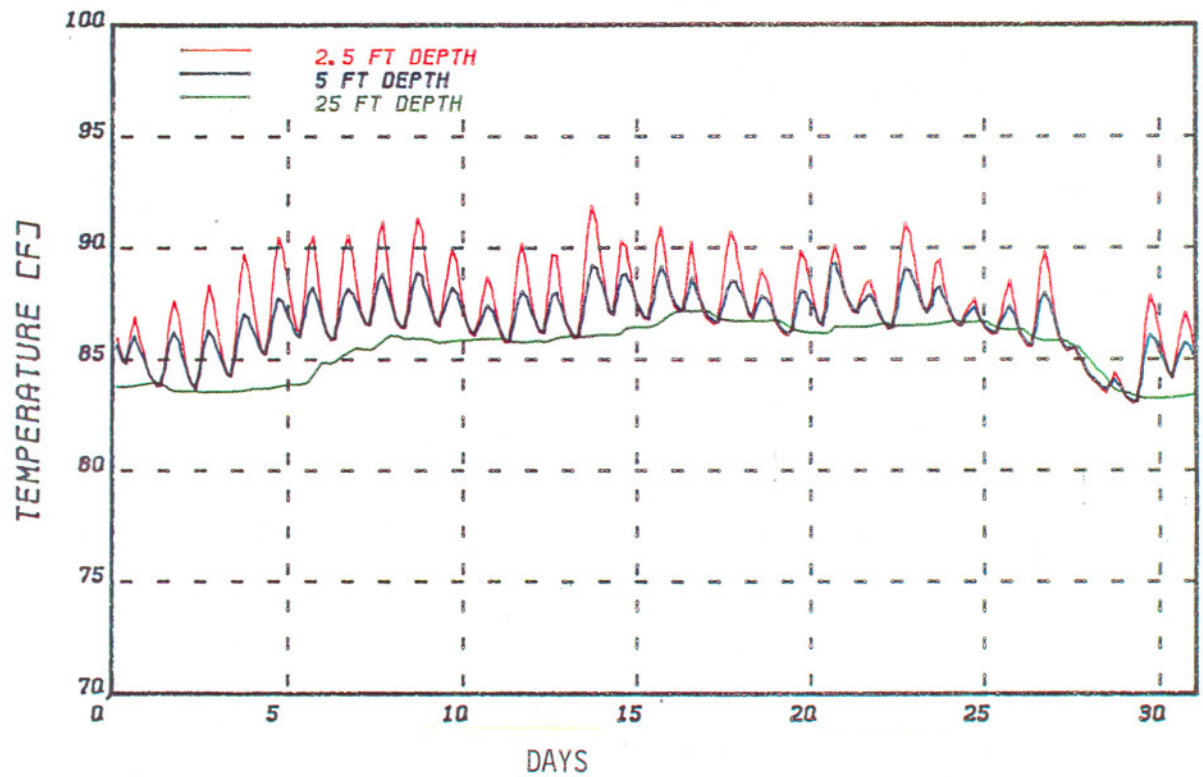

Figure 4.2-17B. Modeled hourly water temperatures at BFNP Station 5 (TRM 275) during July 1977.

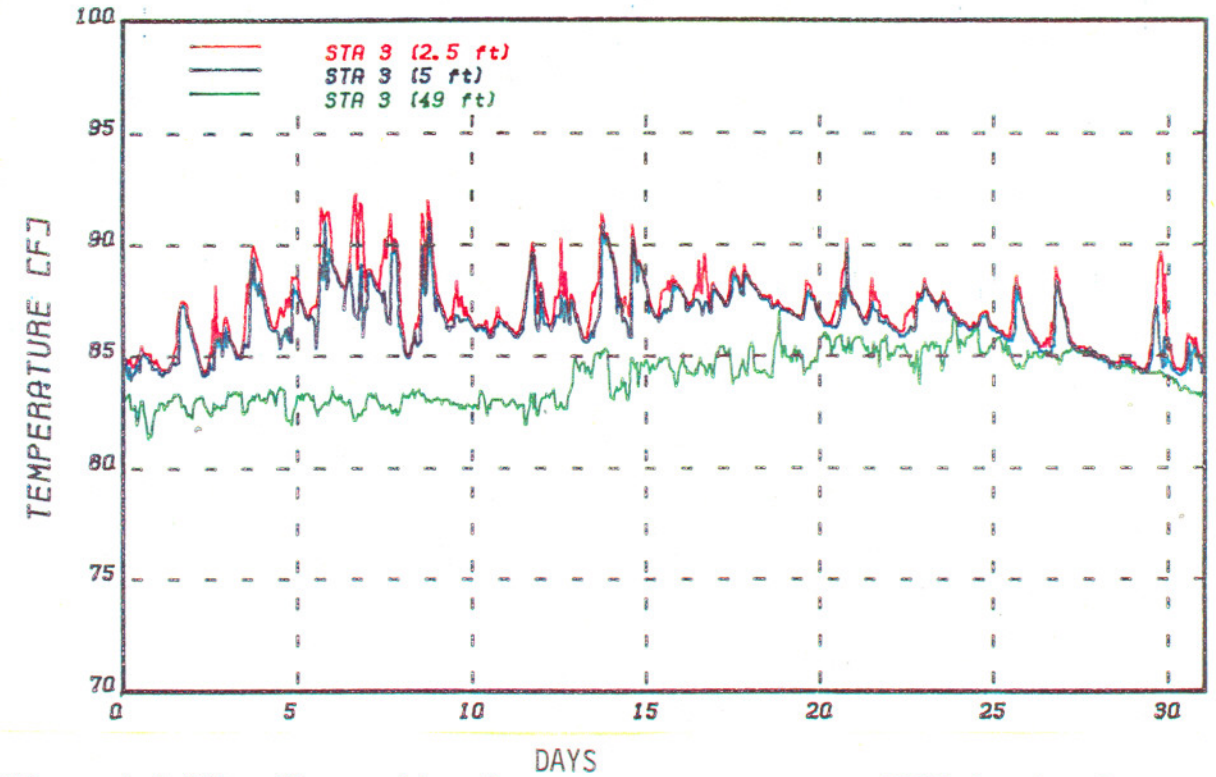

Figure 4.2-18A. Observed hourly water temperatures at BFNP Station 3 (TRM 286.2) during July 1977.

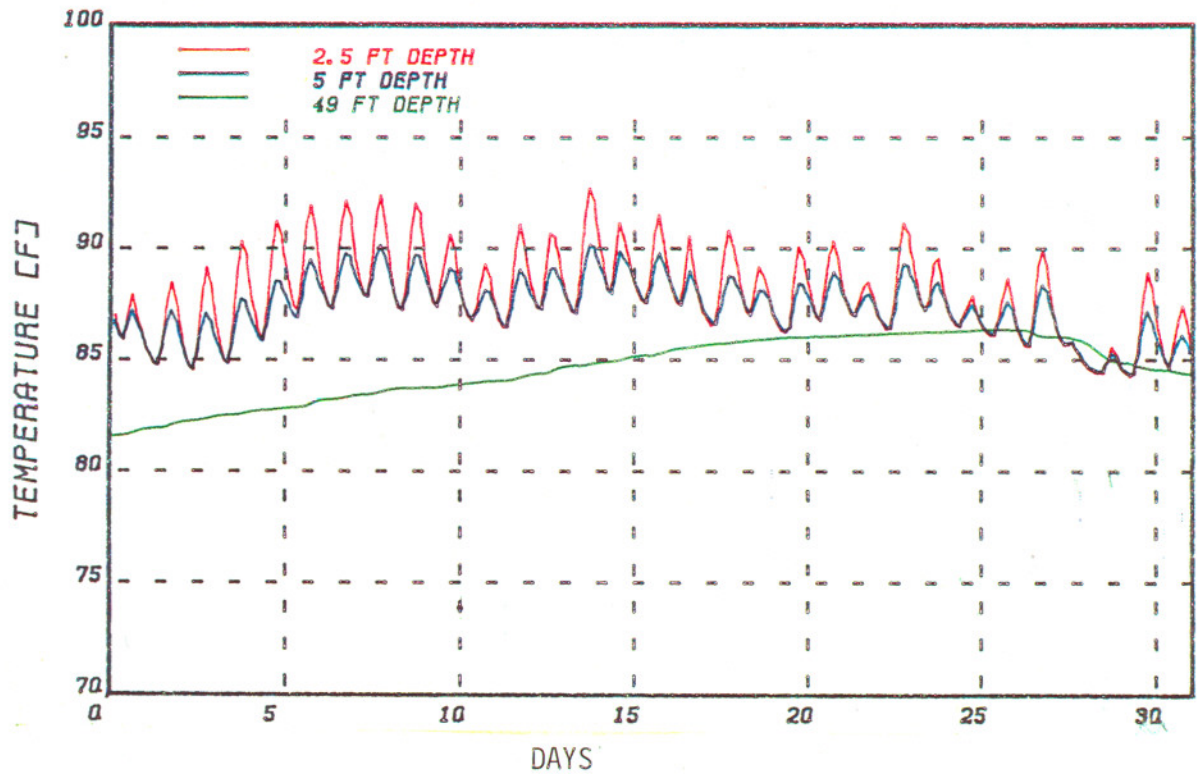

Figure 4.2-18B. Modeled hourly water temperatures at BFNP Station 3 (TRM 286.2) during July 1977.

conditions during October through March are well represented by this approach because fully mixed conditions normally occur at the downstream monitoring Stations 10, 11, and 13 during this period (see Section 4.2.1). The fully mixed assumption provided the worst case conditions in the deeper portions of the reservoir during April through September. Actual conditions in the deeper portions of the reservoir during this period may be closer to ambient if "cool" water travels around the ends and around the individual jets of the diffuser. Downstream stratification then acts to prevent mixing of heated surface temperatures with lower depths. The plant effect would therefore not be as evident in deeper portions of the resevoir as modeled under this worst case conditions which did not allow any water at ambient temperature to enter the lower reach of Wheeler Reservoir.

The modeling results are presented using (1) time series of the volume of the reservoir downstream of BFNP in various temperature ranges, (2) the time series of temperatures at specific points in the reservoir, and (3) vertical isotherms in the reservoir at specific times during the study period. The time series information provides overall trends in the reservoir dynamics while the isotherm plots show the specific effects on the vertical reservoir structure at a single point in time.

One of the most apparent effects of the alternative limitations in the plots of downstream reservoir volume temperature distributions was the lengthening of the period the reservoir was above a certain temperature. Figures 4.2-19A and 4.2-19B provide time series of the downstream reservoir volume at certain temperatures during 1980 for the alternative limitations and ambient conditions. In April the 90/10

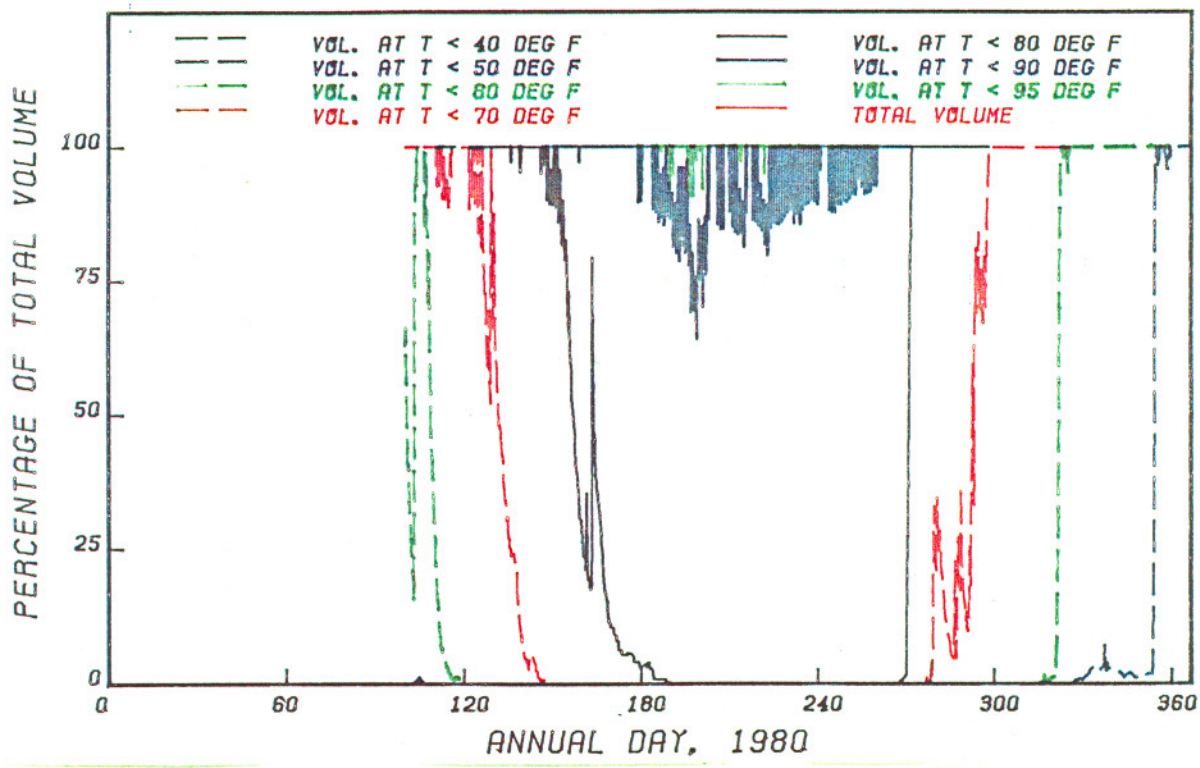

Figure 4.2-19A. Predicted water temperature volumes in Wheeler Reservoir downstream of BFNP under 90/10 limitations during 1980.

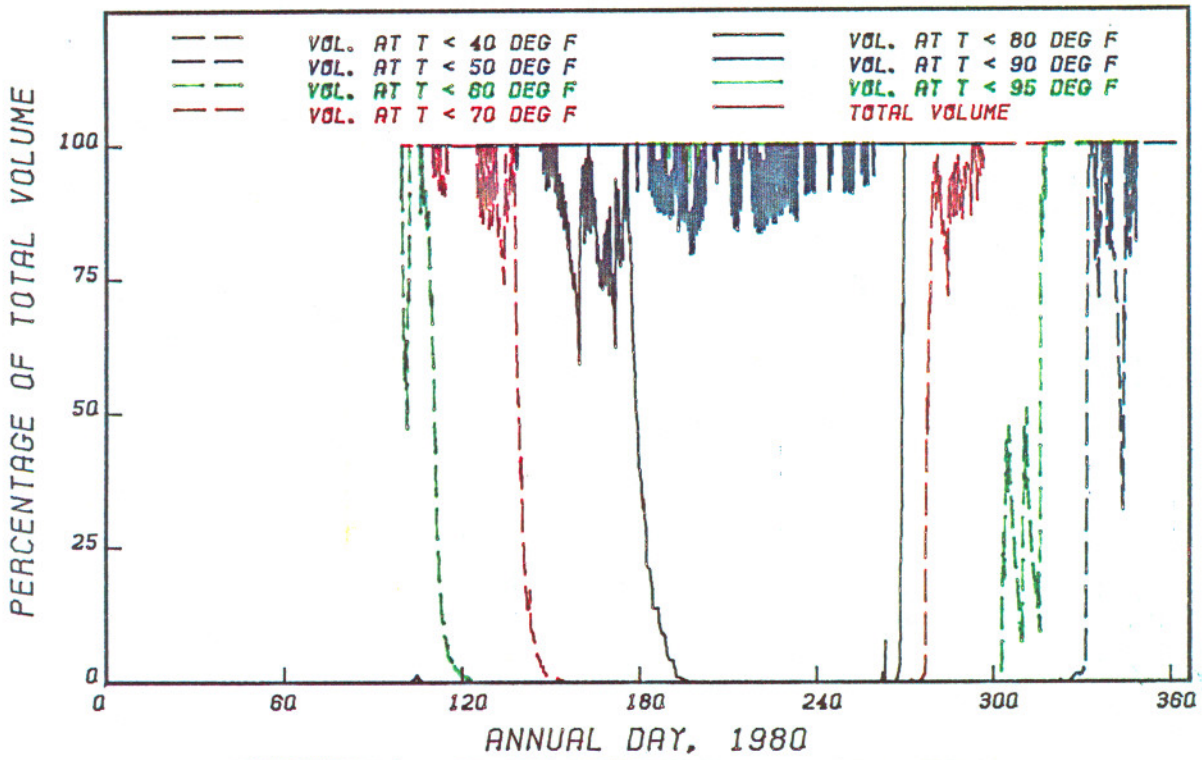

Figure 4.2-19B. Predicted ambient conditions in Wheeler Reservoir downstream of BFNP during 1980.

simulation showed most of the reservoir reached 60°F a couple of days before the ambient case. Temperatures near 70°F were reached in May about a week earlier than ambient, and 80°F temperatures in June occurred two to three weeks before ambient conditions. These advances will be compared with 1981 results later in this section.

More detail is provided by expanding the time series plots of downstream volume temperatures for July 1980. Figures 4.2-20A and 4.2-20B show that high temperatures covering large reservoir volumes in the 90/10 simulation are found in the ambient case as well. That is, the reservoir would have reached these high temperatures without the plant in operation. The plant discharge under worst case conditions advanced the occurrence of warm temperatures or increased the volumes of warm water already present. For example, 86°F temperatures occurred in the downstream reservoir about five days earlier than in the ambient case. Under ambient conditions, up to 50 percent of the reservoir volume had temperatures in the range of 88° to 90°F. The 90/10 simulation showed an increase to 90 percent of the reservoir volume in this same temperature range. As discussed in the preceding section, actual monitored temperatures in the entire downstream reservoir reached 88°F on July 21, 1980.

Temperatures near the surface of the reservoir were not significantly altered by the plant discharge during these severe meteorological conditions. Reservoir volumes having temperatures greater than 90°F resulted from solar inputs since the plant did not discharge temperatures greater than 90°F. These volumes were increased less than 15 percent in the 90/10 simulation. The surface temperatures are therefore moderated by the natural heating and cooling pocesses. This can also be seen in the isotherms of July 15, 1980. Figures 4.2-21A and 4.2-21B show that the

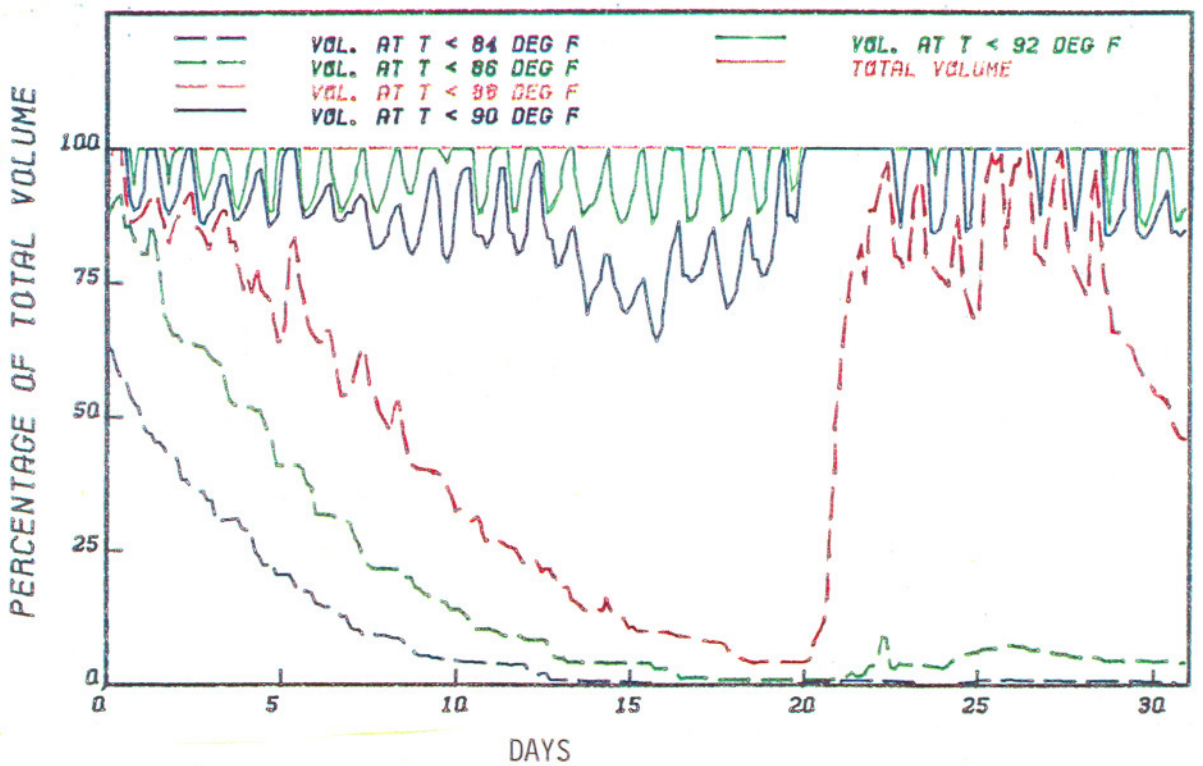

Figure 4.2-20A. Predicted reservoir volumes downstream of BFNP under 90/10 limitations during July 1980.

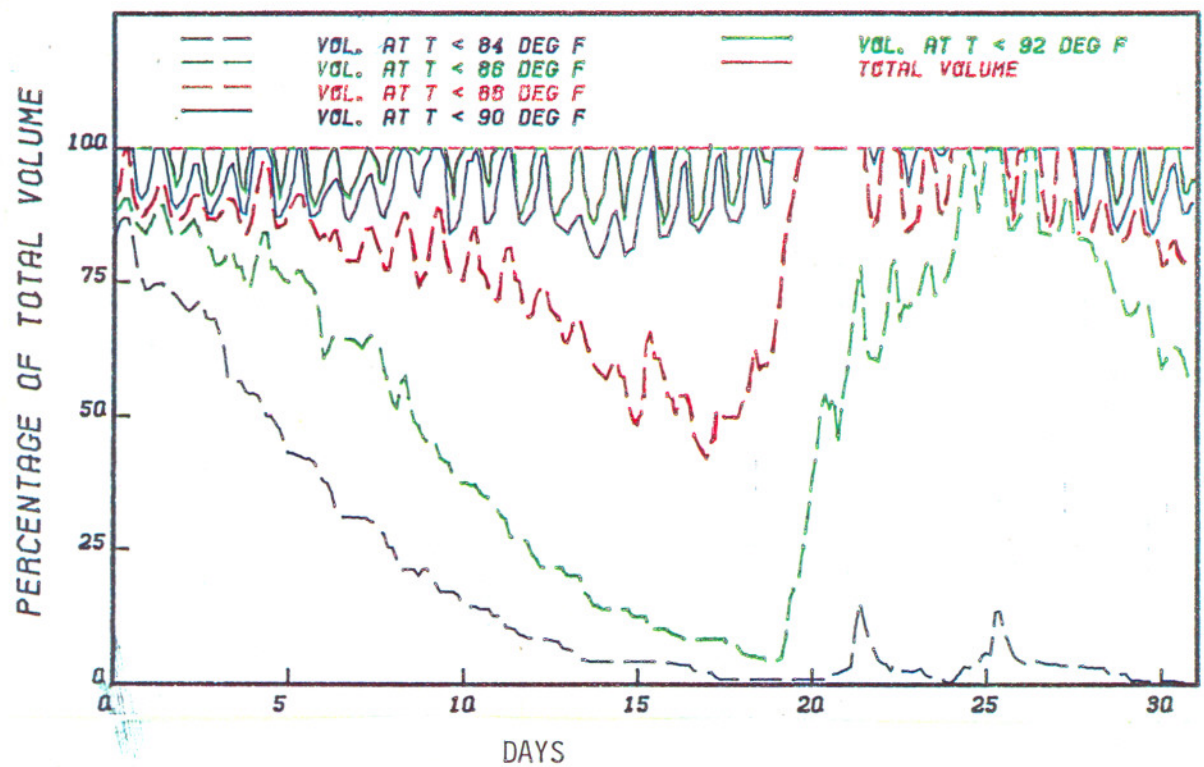

Figure 4.2-20B. Predicted reservoir volumes downstream of BFNP under ambient conditions during July 1980.

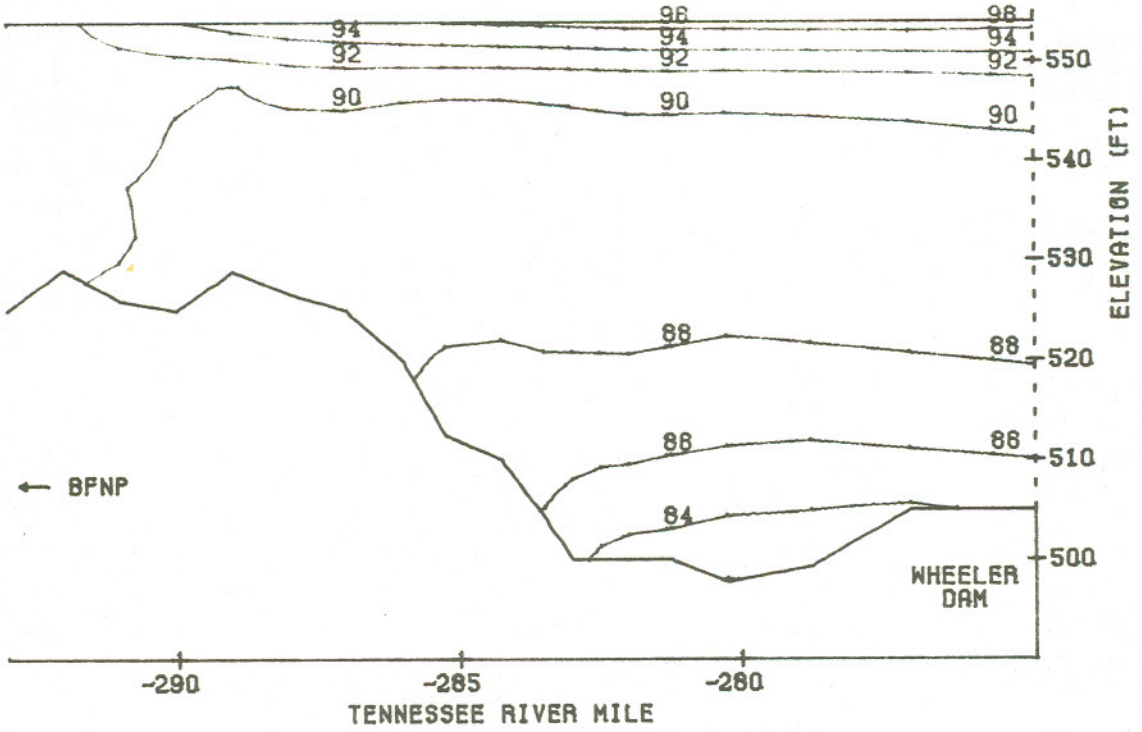

Figure 4.2-21A. Predicted water temperatures in Wheeler Reservoir downstream of BFNP on July 15, 1980 (1800) under 90/10 limitations.

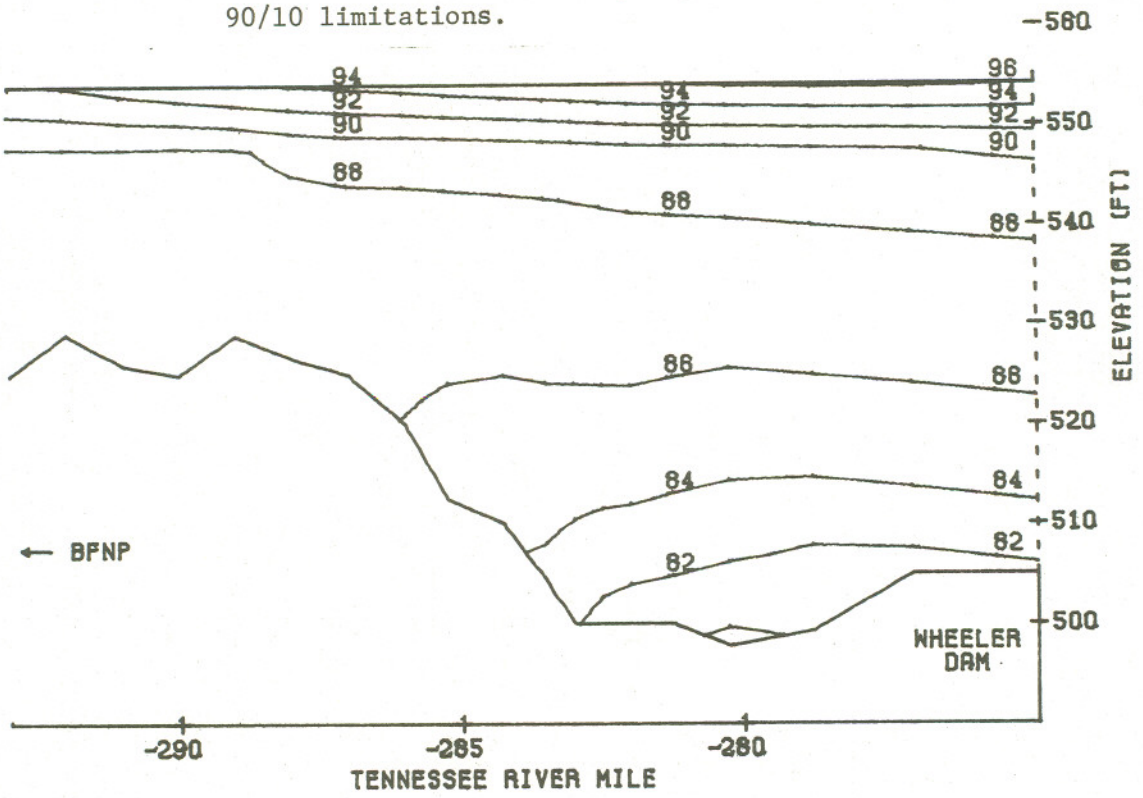

Figure 4.2-21B. Predicted water temperatures in Wheeler Reservoir downstream of BFNP on July 15, 1980 (1800) under ambient conditions.

surface temperatures were less affected by the BFNP heated discharge than deeper portions of the reservoir. The surface temperatures warm as they approach the dam, indicating the significant effect of natural solar heating under these conditions. In most summers surface cooling would be more evident as discussed in previous sections on actual conditions during 1977.

Overall temperatures in the lower portion of the reservoir were raised on the order of 1.5 to 3.0°F under worst case conditions as shown in the isotherms in Figures 4.2-21A and 4.2-21B. The volume time series for July 1980 (both Figures 4.2-20A and 4.2-20B) also show the 90/10 simulation lines coincide closely with the ambient condition lines that represent 2°F cooler temperatures.

Cooling periods caused by meteorological conditions had a significant effect in mixing the reservoir for both the ambient and 90/10 simulations. Figures 4.2-22A and 4.2-22B show time series of modeled reservoir temperatures at various depths near Elk River. This is near Station 3 discussed in the previous section. On July 21, 1980, a cold front passed over the reservoir creating air temperatures that caused surface cooling and wind mixing which distributed the cooler temperatures throughout the reservoir depths. This event brought temperatures in the 90/10 simulation within 1°F of the ambient case throughout the reservoir. Hence, these cooling events can distribute cooler temperatures in the reservoir regardless of the plant discharge effects.

These figures also show the previously mentioned weak stratification was not significantly altered by plant operation under alternative limitations. Bottom temperatures are slightly higher than the ambient case with similar surface temperatures.

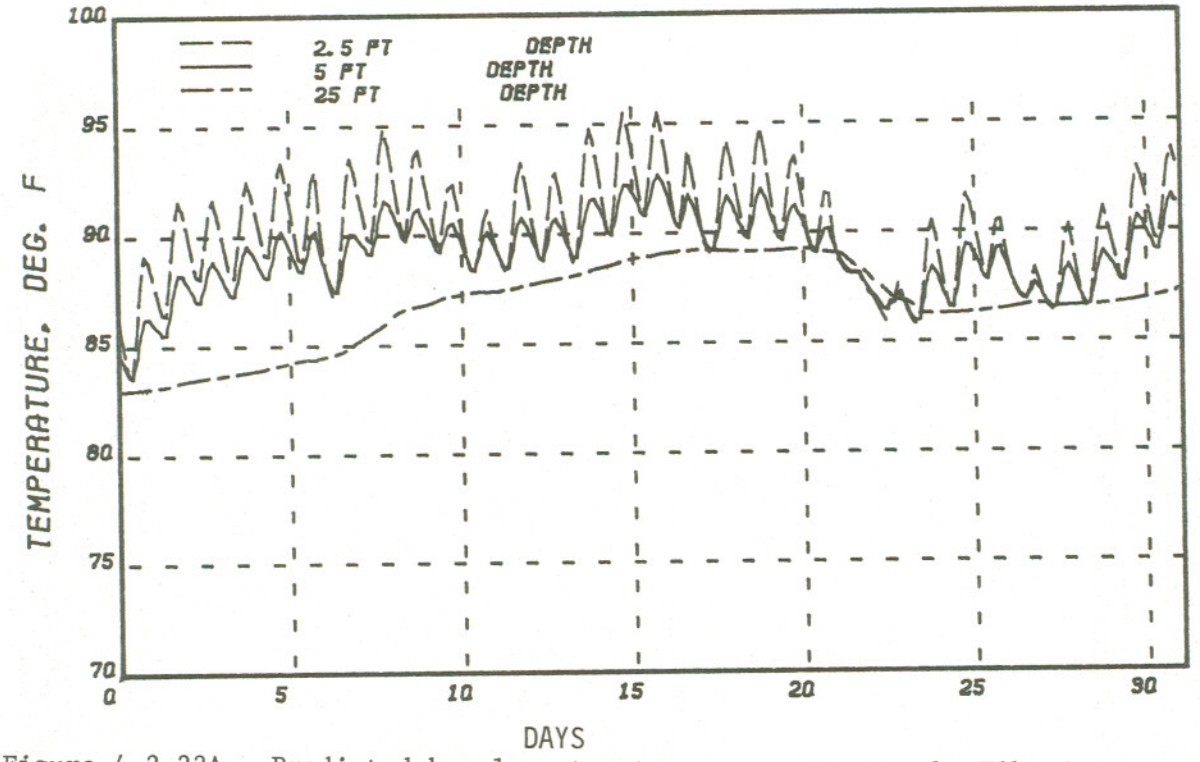

Figure 4.2-22A. Predicted hourly water temperatures near the Elk River (TRM 284.6) during July 1980 under 90/10 limitations.

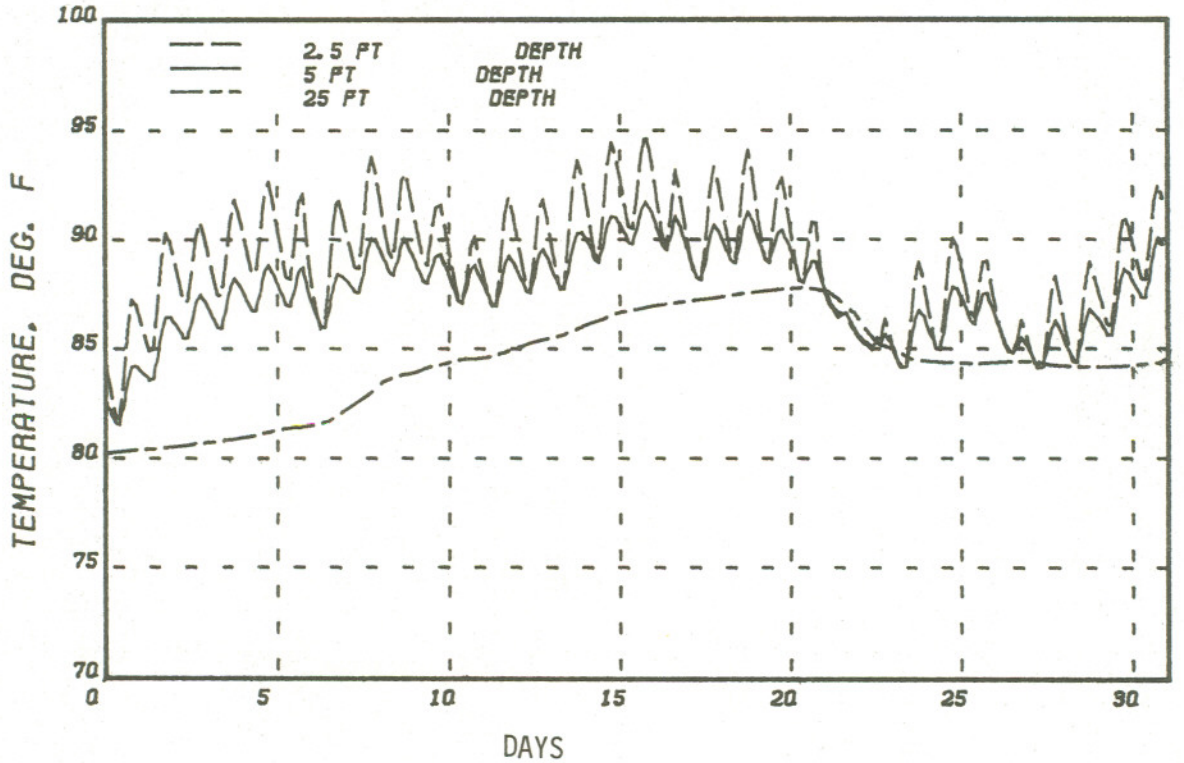

Figure 4.2-22B. Predicted hourly water temperatures near the Elk River (TRM 284.6) during July 1980 under ambient conditions.

The plant discharge can also delay the cooling of the downstream reservoir as shown in Figures 4.2-19A and 4.2-19B. In these general volume time series the cooling to 80°F is delayed about 3 days in the 90/10 simulation over the ambient case. Likewise cooling to 70°F was delayed 10 days to 2 weeks; 60°F was delayed a week; and 50°F was delayed 3 weeks.

Modeled results for the first five months in 1981 show the characteristic advance in downstream reservoir temperatures as experienced in spring of 1980. Figures 4.2-23A and 4.2-23B show that 50°F temperatures in the 90/10 simulation were advanced in February and March about two weeks before the modeled ambient results. However, 60°F and 70°F temperatures were advanced on the order of a week or less. The advance of 60° and 70°F temperatures were very similar to conditions found in 1980.

Isotherms from the 1981 simulations show the same 1.5 to 3.0°F increase in overall reservoir temperatures at any point in time as found in the 1980 simulations. Figures 4.2-24A and 4.2-24B present representative results for March 15, 1981.

4.2.2.3 Far Field Solar Heating

Far field temperature data shown in the previous section illustrate the effect of solar heating on downstream surface temperatures. Solar heating can be a significant influence at Stations 10, 11, and 13 when flow induced turbulent mixing is reduced and there is sufficient travel time between the diffuser and Stations 10, 11, and 13 to absorb a full day of solar heating. As shown in Table 4.1-5, the travel time between the diffuser and the compliance Stations 10, 11, and 13 is greater than 12 hours for flows less than 40,000 cfs. Figure 4.2-25A shows temperature data from Stations 1 and 13 for May 1977. The

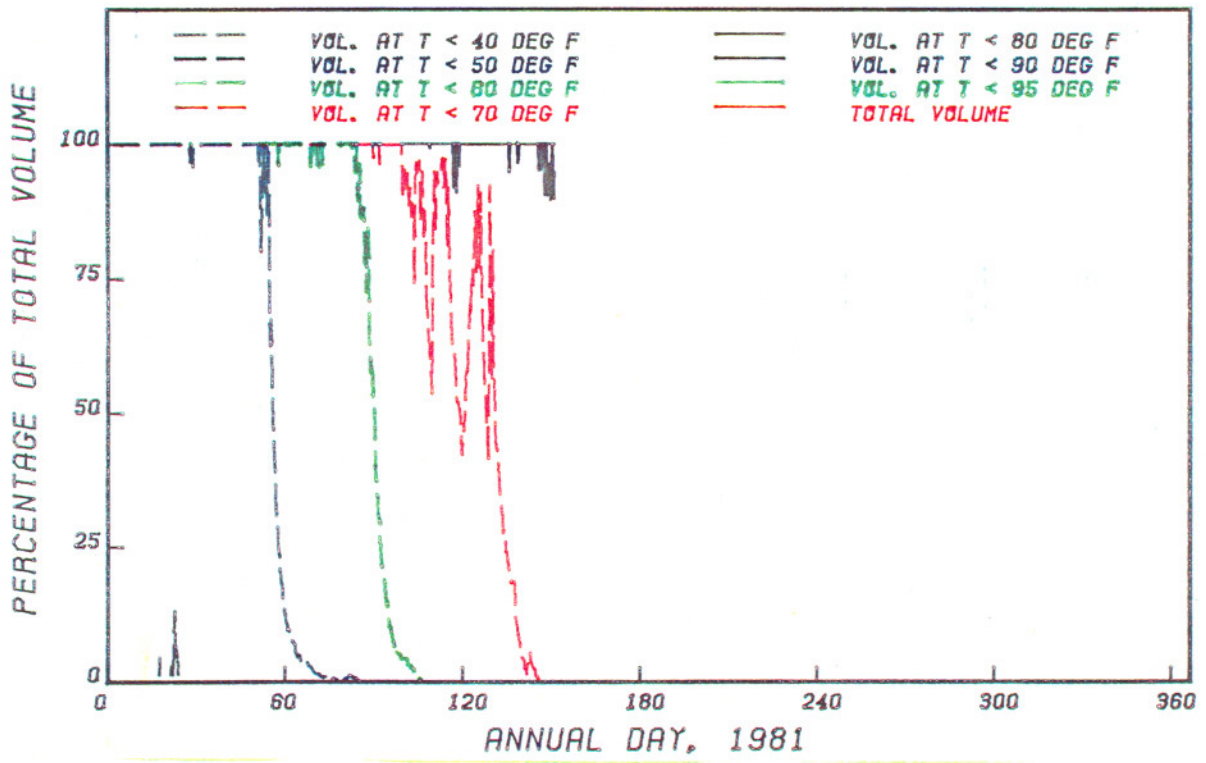

Figure 4.2-23A. Predicted water temperature volumes in Wheeler Reservoir downstream of BFNP during 1981 under 90/10 limitations.

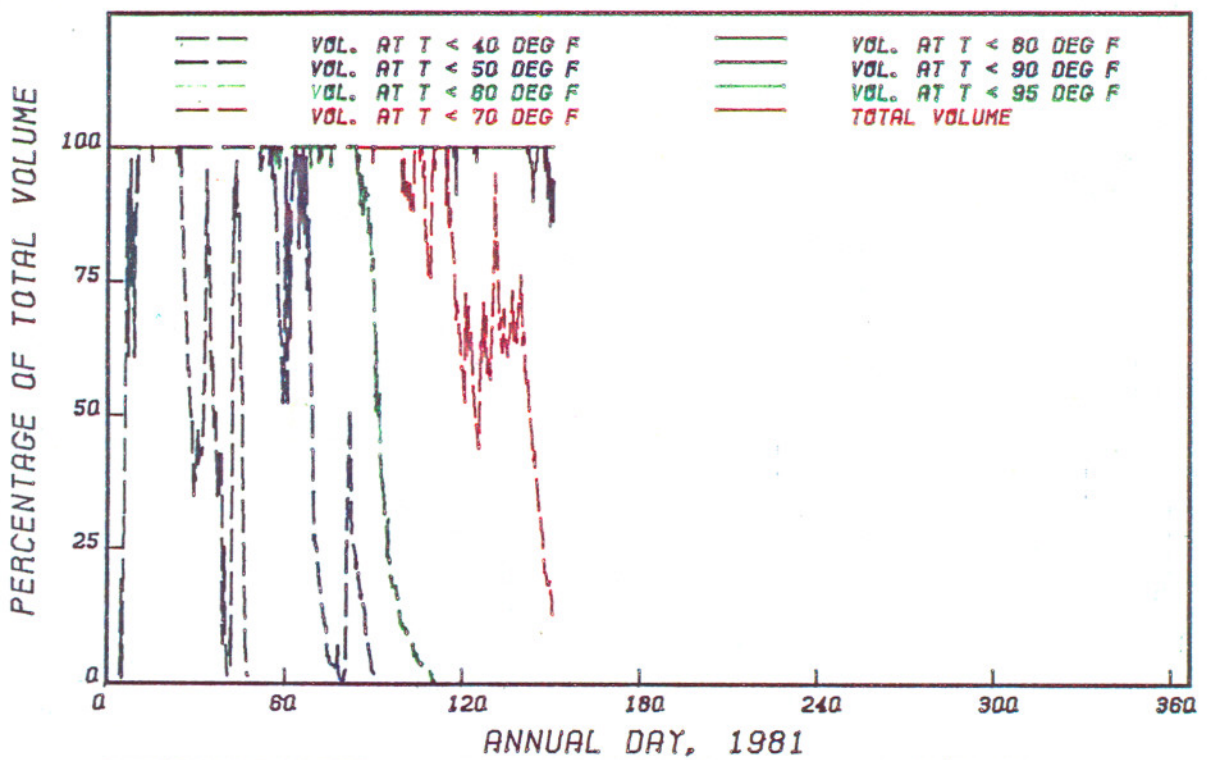

Figure 4.2-23B. Predicted water temperature volumes in Wheeler Reservoir downstream of BFNP during 1981 under ambient conditions.

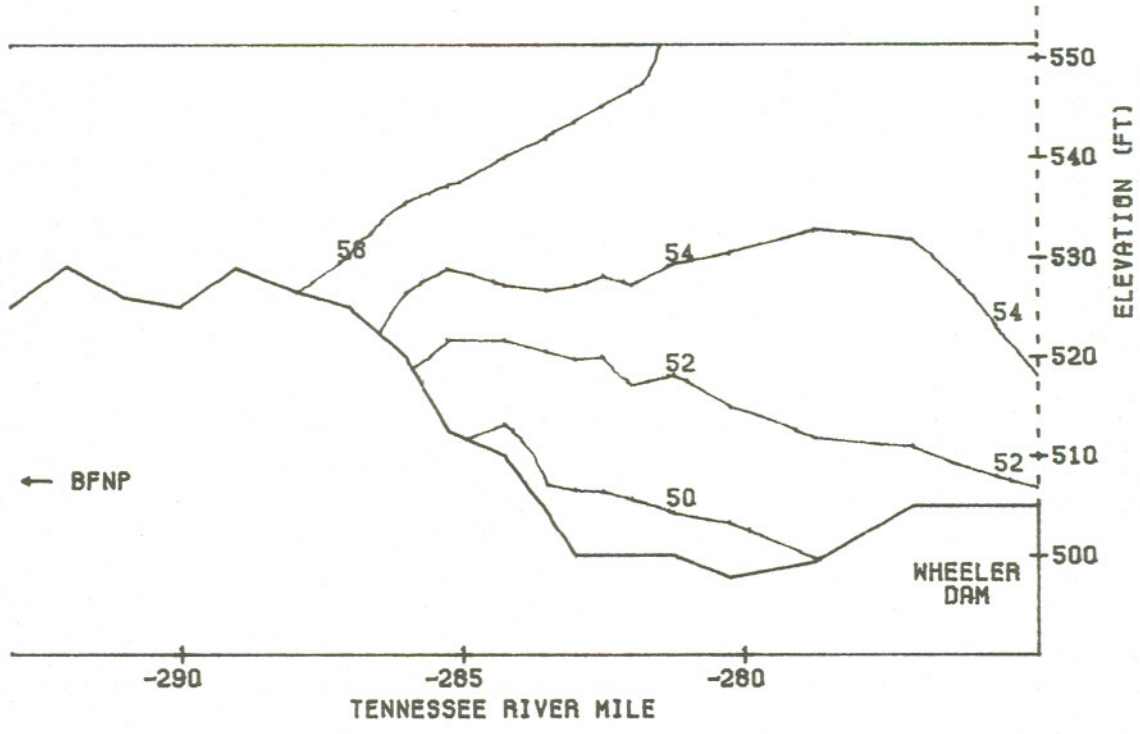

Figure 4.2-24A. Predicted water temperatures in Wheeler Reservoir downstream of BFNP on March 15, 1981 (1800) under 90/10 limitations.

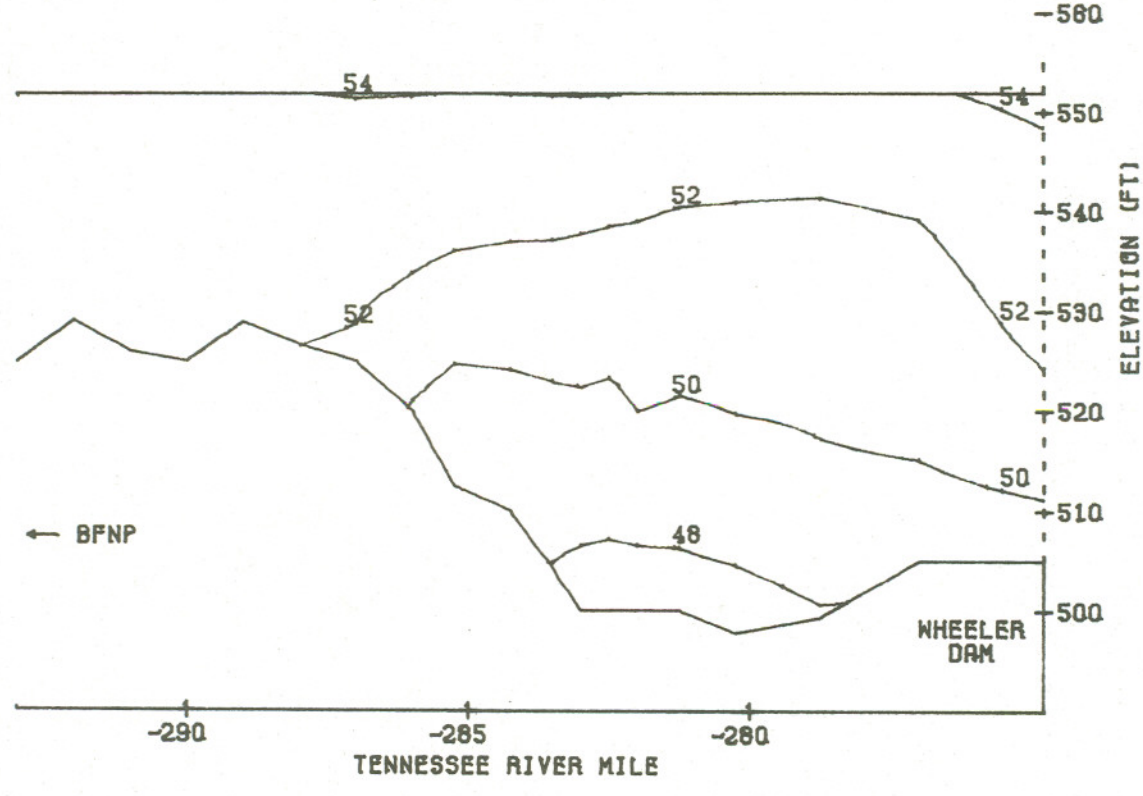

Figure 4.2-24B. Predicted water temperatures in Wheeler Reservoir downstream of BFNP on March 15, 1981 (1800) under ambient conditions.

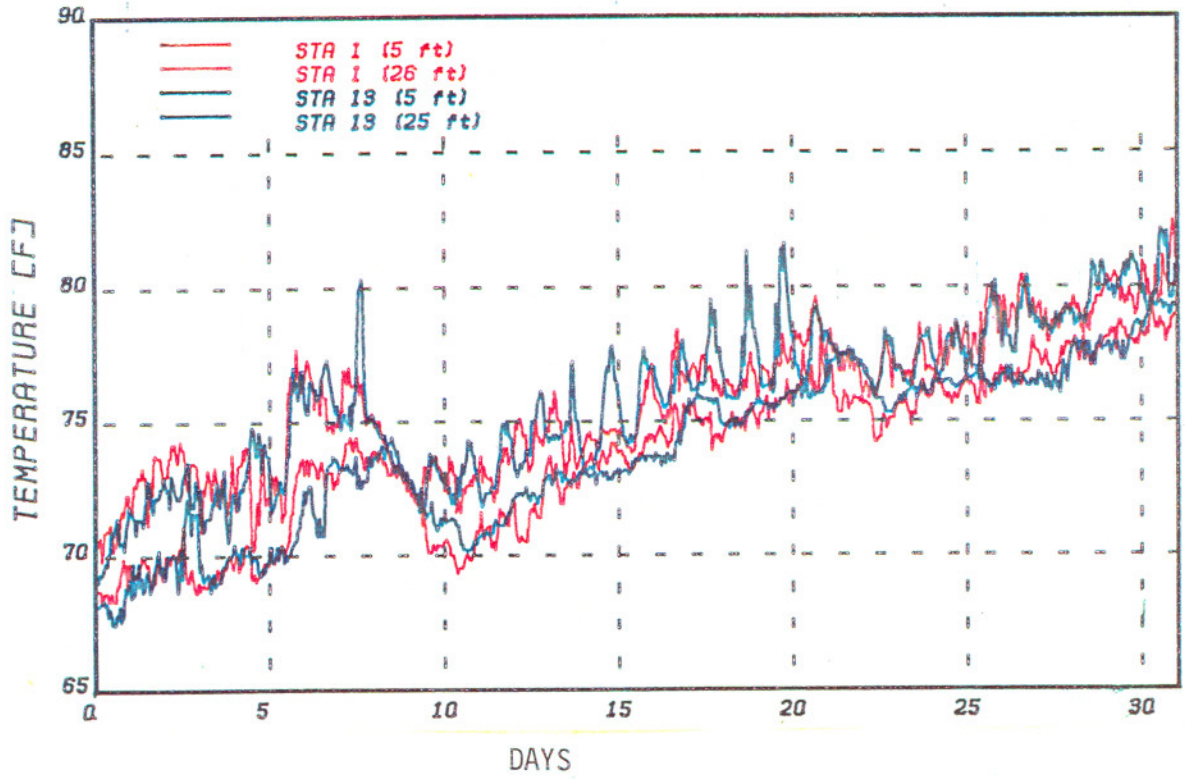

Figure 4.2-25A. Hourly water temperatures at BFNP Stations 1 (TRM 293.6) and 13 (TRM 292.5) during May 1977.

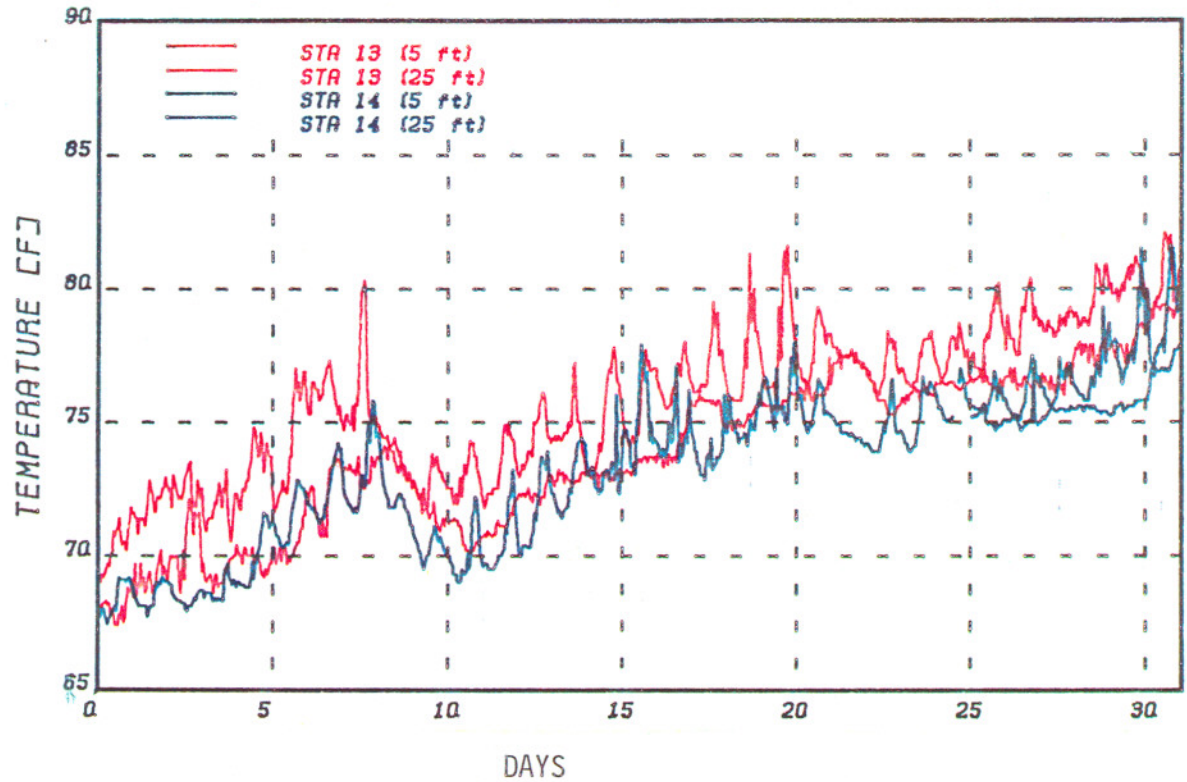

Figure 4.2-25B. Hourly water temperatures at BFNP Stations 13 (TRM 292.5) and 14 (TRM 296.1) during May 1977.

diurnal fluctuation due to solar heating is dominant at Station 13 but much weaker on most days at Station 1, which is much closer to the direct effects of the diffuser. The diurnal variation at Station 13 is very similar to that observed upstream at Station 14 (Figure 4.2-25B), although Station 13 temperatures are 2 to 5°F warmer. Difficulties are encountered when using upstream and downstream measured temperatures for compliance, because slight differences in surface mixing patterns can produce relatively large differences in the 5-foot depth temperatures.

Most of the solar heat is transferred to the atmosphere during the evening and night. Much of the BFNP heat discharged to the surface layers is transferred to the atmosphere in a similar way. Because water temperatures are influenced by both sources of heat, a comparison of their magnitudes is of interest.

Daily average solar heating can vary from near zero (cloudy winter days) to over 100 Btu/ft^{2}hr (sunny summer days). Sunny days between May and August are characterized by 95 Btu/ft^{2}hr (daily average) or 190 Btu/ft^{2}hr during the day (12 hours). BFNP discharges approximately 22×10^9 Btu/hr at full load. An area of 5435 acres is required to capture an equivalent solar heat load on a daily average basis, but only half this area is required to match the plant load during the daytime (2718 acres). This is equal to the surface area between the diffuser and the downstream compliance Stations 10, 11, and 13. For a travel time of one day (20,000 cfs) the solar heat on a sunny spring or summer day between the diffuser and the downstream monitors is equal to the plant discharged heat. This explains why diurnal fluctuations in surface temperatures are often observed at the downstream monitors. The heating and mixing from the diffuser dominates at Station 1 but is more nearly balanced by solar heat at the compliance Station 10, 11, and 13.

The effect of solar heating on the entire downstream reservoir can also be compared with the amount of waste heat produced by the plant. The reservoir surface area downstream of BFNP is approximately 26,000 acres. On a sunny summer day the downstream reservoir receives a daily average solar input of 105×10^9 Btu/hr. During the daytime hours the reservoir receives 210×10^9 Btu/hr. These values can be compared with the full load plant discharge of 22×10^9 Btu/hr.

This discussion is only a statement of the relative significance of solar heating and full load heat discharge from BFNP. Several additional factors are necessary to predict surface temperature fluctuations due to the combination of plant discharge and solar input. The effects of turbulent and wind induced mixing cannot be described well enough to predict near surface temperatures when solar heating is significant. The downstream compliance monitors are actually in the far field region where natural heating, cooling, and mixing processes are important. Predictions of BFNP discharge effects can be better matched closer to the diffuser.

4.2.2.4 Effects of Heated Discharge from BFNP on Releases at Wheeler Dam

A specific concern that arose during the review of TVA's previous evaluation of thermal limitations (TVA, 1980) was the possible effect on releases from Wheeler Dam. The turbine intakes on Wheeler Dam withdraw water from the entire vertical depth of the reservoir. Therefore, the releases from the dam are an average of temperatures found over the vertical depth of the reservoir. Figure 4.2-24B shows the vertical profile of simulated ambient conditions during the spring of 1981 (March 15). By comparing the vertical profile under an alternative ΔT_{max} limitation of 10°F, Figure 4.2-24A, the downstream releases should

be affected at the most 1.5 to 3.0°F over ambient conditions. Figures 4.2-21B and 4.2-21A show simulated ambient profiles and the effect of plant operation profiles for a summer period under the 90°F T_{max} limitation with no cooling tower usage until 90°F. Under the worst case conditions downstream temperature could be raised 1.5°F to 3.0°F.

Two significant mechanisms can act to lessen the downstream effect at Wheeler Dam. Meteorological conditions can cause cooling throughout the reservoir regardless of the plant discharge. These major cooling, and associated mixing, events can bring temperatures close to what would have occurred under ambient conditions. Periods of cooling would cause lower temperatures to persist for several days. The second mechanism is the status of actual plant operation which is not consistently three units at full load. At lower loads less heat would be added creating lower temperatures in the downstream portion of the reservoir.

4.2.2.5 Temperature Stratification - Dissolved Oxygen Depletion

Wheeler Reservoir does not exhibit the long periods of stable stratification necessary to produce significant oxygen depletion. As discussed in Section 4.2.2.2, stratification is limited to short periods of up to a few days interspersed among periods of complete mixing. Such periods of stratification should be more pronounced in the spring when surface temperatures are increasing rapidly in response to meteorological conditions while inflow temperatures remain low. By summer, inflows will have warmed sufficiently to greatly reduce any temperature gradients, making long periods of stable stratification impossible.

Wheeler Reservoir also has a rather short hydraulic residence time as do all the mainstem Tennessee River reservoirs. The mean hydraulic residence time in Wheeler Reservoir is approximately 11 days. This indicates that reservoir volume is small relative to inflow rates. As a result, the reservoir waters are constantly and rapidly replaced by upstream sources. This constant replenishment results in reservoir water quality which is more heavily influenced by inflow quality than by processes occurring within the reservoir. Consequently, little dissolved oxygen depletion should occur unless very large additions of oxygen-demanding material are introduced into the reservoir.

The previous discussion of far field temperature effects indicates that the ambient thermal regime characterized by occasional brief periods of weak stratification will not be altered by BFNP operation. Figure 4.2-26 depicts a summer dissolved oxygen distribution during a period of severe meteorological conditions. The figure indicates the presence of a mild dissolved oxygen gradient in the lower reservoir due to reduced reaeration with increasing reservoir depth; no significant oxygen depletion is observed.

4.2.2.6 Summary of Far Field Evaluations

The far field effects of BFNP on lower Wheeler Reservoir were evaluated using observed monitoring data during severe conditions and predictive model results. Data from monitors just downstream of the plant and monitors near Elk River and Wheeler Dam provided observed temperatures during 1977, 1980, and 1981. A laterally-averaged two-dimensional hydrothermal reservoir model was used to predict the worst case effects on Wheeler Reservoir under alternative limitations.

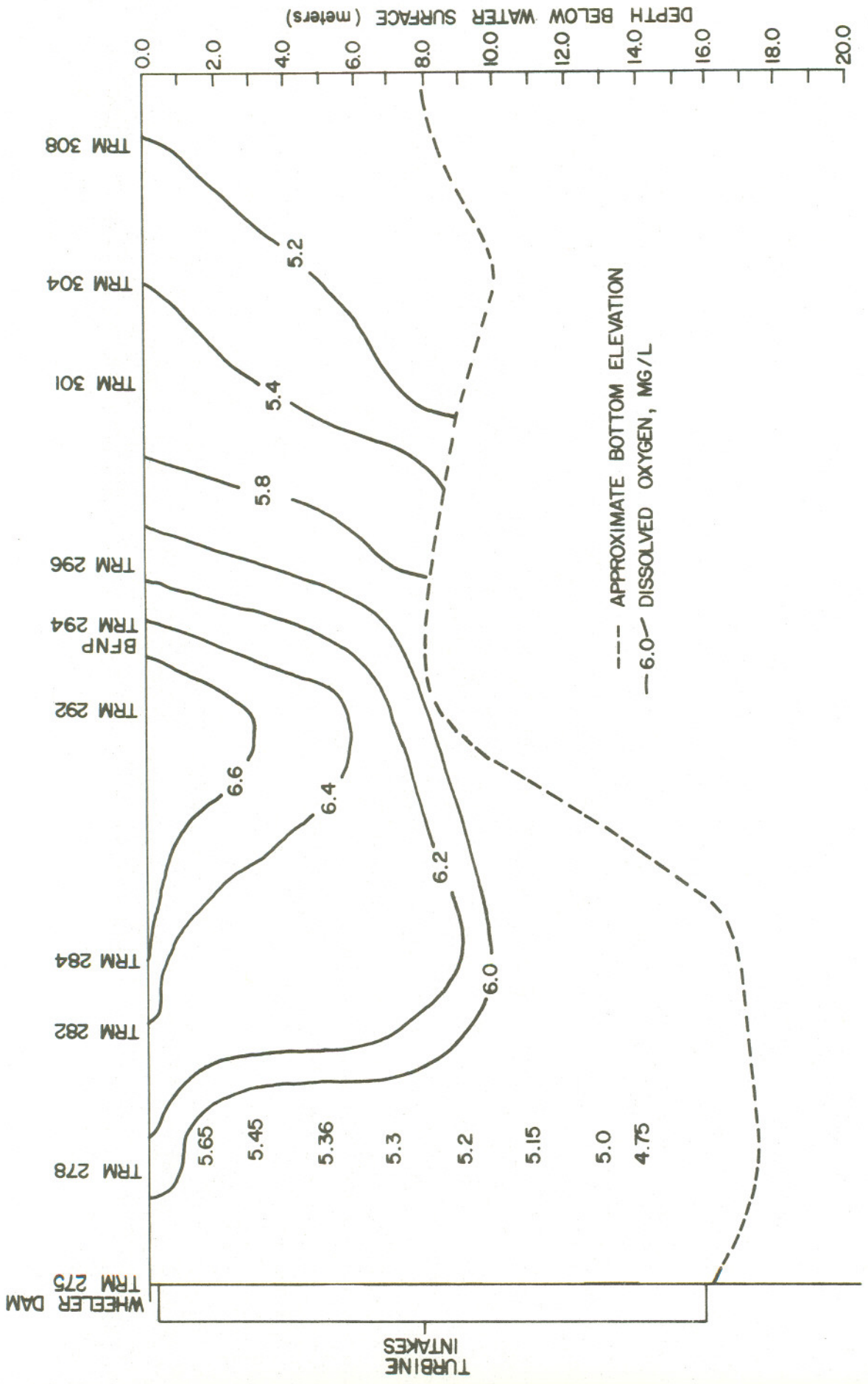

FIGURE 4.2-26 DISSOLVED OXYGEN PROFILE - WHEELER RESERVOIR
SURVEY DATE : AUGUST 25, 1980

Observed temperature changes between the plant discharge and the far field monitors result from far field heating, cooling and mixing processes. During fall and winter there is usually a cooling of heated discharge temperatures, with temperatures near the Elk River close to those found upstream of the plant.

The far field temperature pattern during spring and summer periods is complicated when intermittent stratification develops. Meteorological conditions and releases from Wheeler Dam influence the observed data. The longitudinal temperature gradients produced by changing meteorology are much larger than those caused by the BFNP discharge heating and subsequent far field cooling. When meteorological conditions cause a warming of inflow temperatures, this warmer water tends to enter the deep portion of Wheeler Reservoir at mid-depth and leaves the coolest bottom water undisturbed. If meteorological conditions produce a cooling of upstream temperatures, then this inflowing water moves along the main channel and replaces the slightly warmer bottom water near Wheeler Dam.

During the summer there is generally a slight cooling of surface temperatures in the far field. However, during extremely warm conditions, far field surface temperatures can remain the same or increase downstream to Wheeler Dam.

Elk River temperatures near Wheeler Reservoir are dominated by natural meteorology and the effects of cool Elk River inflows. BFNP discharge does not influence Elk River embayment temperatures.

The observed data show that some cool ambient water moves around and under the discharge plume. This cool water can cause bottom temperatures in Wheeler Reservoir to be cooler than if temperatures

downstream of BFNP were uniformly heated by the discharge. Major cooling events can rapidly cool the heated discharge plume and allow near-ambient temperatures to flow into the bottom layers of Wheeler Reservoir.

The modeling of the far field showed that the effects of alternative limitations (90°F T_{max} and 10°F ΔT_{max} with no cooling towers until the limits are reached) would advance warming and delay cooling throughout the reservoir. During the April through September period, the model results are worse case evaluations since water at ambient temperatures may travel around the diffuser into the lower reservoir.

Even under these worst case fully mixed boundary conditions the high temperatures predicted in the alternative limitations simulation are not higher than those found in the ambient evaluation. The BFNP discharge did cause increased volumes of water at high temperatures. Isotherms from alternative limitation simulations showed increases in reservoir temperatures at any particular time of 1.5 to 3.0°F.

Far field temperature data illustrate the result of solar heating on downstream surface temperatures. A comparison between the effects of solar heating and the plant discharge showed the solar heat on a sunny spring or summer day between the diffuser and the monitors 1.5 miles downstream to be equal to the plant discharged heat during the 12 hours of solar heating.

Effects of the heated discharge from BFNP on releases at Wheeler Dam are estimated from the far field modeling to be at most 1.5°F to 3.0°F. This is significantly lower than the 10°F alternative ΔT_{max} limitation evaluated or the present 5°F ΔT_{max} limit. The effects

will be much less during a cooling period, when the meteorological conditions will produce far field temperatures very close to ambient.

Wheeler Reservoir does not exhibit the characteristics associated with extensive hypolimnetic dissolved oxygen depletion. The transient nature of thermal stratification and the rapid replacement of reservoir waters by inflows should preclude significant dissolved oxygen depletion. Operation of BFNP should not alter the occurrence of temperature stratification; therefore, no significant impact on dissolved oxygen is expected.

The modeling results showed the previously mentioned weak stratification was not significantly altered. The short residence time, full depth turbine intake, and the effects of cooling events are overriding factors preventing significant changes in stratification patterns.

A SUPPLEMENTAL 316(a) DEMONSTRATION FOR ALTERNATIVE THERMAL DISCHARGE LIMITS FOR BROWNS FERRY NUCLEAR PLANT, WHEELER RESERVOIR, ALABAMA

APPENDIX 5

THERMAL LIMITATION COMPLIANCE MONITORING TECHNIQUES

Tennessee Valley Authority
February 1983

A SUPPLEMENTAL 316(a) DEMONSTRATION FOR ALTERNATIVE THERMAL DISCHARGE LIMITS FOR BROWNS FERRY NUCLEAR PLANT, WHEELER RESERVOIR, ALABAMA

APPENDIX 5

THERMAL LIMITATION COMPLIANCE MONITORING TECHNIQUES

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A SUPPLEMENTAL 316(a) DEMONSTRATION FOR ALTERNATIVE THERMAL DISCHARGE LIMITS FOR BROWNS FERRY NUCLEAR PLANT, WHEELER RESERVOIR, ALABAMA

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THERMAL LIMITATION COMPLIANCE MONITORING TECHNIQUES

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APPENDIX 5 THERMAL LIMITATION COMPLIANCE MONITORING TECHNIQUES

5.0 Introduction

Compliance with thermal limitations at BFNP must be verified using instream measurements or a calculated method which models discharge and mixing processes.

This appendix reviews past difficulties in measuring plant induced temperature effects with upstream and downstream monitor stations and suggests improvements that will allow the plant induced effects to be more accurately assessed. It is proposed that compliance with the thermal limitations be based on a 24-hour running average of measured or calculated temperatures.

5.1 Difficulties with Measured Compliance

As discussed in a previous report (Ungate, 1978), several incidents of measured temperature differences between the upstream and downstream 5-foot depth temperatures exceeding 5°F have occurred. In most cases these events were associated with short time scale fluctuations of the upstream or downstream 5-foot depth temperatures caused by solar heating and wind mixing that was not synchronous at the upstream and downstream stations. Several changes in the method of measuring compliance have been made to minimize the influence of these short term fluctuations.

The original upstream monitor was located near Decatur, approximately 15 miles upstream of the BFNP intake. Table 4.1-4 in Appendix 4 indicates that the travel time between these points was 2 days, even with a flow of 40,000 cfs. Analysis indicated that longitudinal temperature changes of 1 or 2°F were common in the spring

(warming) and fall (cooling). The actual plant induced temperature rise, when combined with the natural longitudinal gradient, occasionally produced a measured difference of 5°F. To alleviate the longitudinal problem, the upstream monitor used for compliance was moved downstream 12 miles, to a location only 3 miles upstream of BFNP (Station 4). As discussed in Appendix 4, this upstream monitor is in the region of the reservoir characterized by significant overbanks and much lower velocities and associated turbulence. Near surface stratification is much more significant at Station 4 than it was at Station 6, and lateral variations are correspondingly greater because of the differences in mixing at various locations across the reservoir. To minimize the effect of these lateral variations at the 5-foot depth, two upstream stations are used for the ambient compliance temperature. A station located in the overbank region upstream of BFNP (Station 7) is combined with Station 4 in a weighted average to account for the spatial differences in short term heating and mixing.

The downstream compliance monitors are located 1.5 miles downstream of the BFNP diffuser. As discussed in Appendix 4, there is usually sufficient travel time between the diffuser and the monitors for significant solar heating and associated cooling and mixing to occur. The resulting short term fluctuations in temperature at the 5-foot depth are measured by the monitors in addition to the more constant thermal plume effects. Both temporal and spatial averaging are used to minimize the effects of these short-term fluctuations and to obtain a temperature that is more representative of the cross section. The downstream compliance temperature is determined by a two-hour running average (updated at 15-minute intervals) of the 5-foot depth temperatures averaged spatially using the three downstream

stations located laterally across the reservoir. The upstream and downstream monitors remain separated by a considerable travel time at normal or low flows, so small longitudinal gradients, probably less than 1°F may exist. A greater problem is simply that short term fluctuations between the upstream and downstream compliance temperatures remain which are not synchronous. During periods of constant flow and plant load, the measured plant induced temperature rise fluctuates from hour to hour, even with the averaging between stations and the averaging of eight 15-minute measurements at each station that is employed to reduce these fluctuations.

As many of the figures showing measured data have shown, the daytime temperatures in the upper layers of the reservoir are highly variable because of solar heating and flow or wind induced mixing. Because these fluctuations are short term and limited to the near surface layers, they do not indicate BFNP discharge effects. If BFNP discharge has an effect on the 5-foot depth temperatures, it will be persistent and not fluctuate widely from hour to hour except as river flow or plant load conditions change.

One appropriate method for minimizing the compliance measurement difficulties is to utilize a time averaging that eliminates the hourly fluctuations and provides a record of the more slowly varying plant induced effects that are of ultimate concern. As an example, a 24-hour running average technique (updated hourly) was used to eliminate the short term variations in the upstream 5-foot depth temperatures from Station 4. Figures 5.1-1A and 5.1-1B show the results for May and June 1980 when there were considerable fluctuations due to meteorological conditions, including large diurnal variations associated with solar heating and cooling.

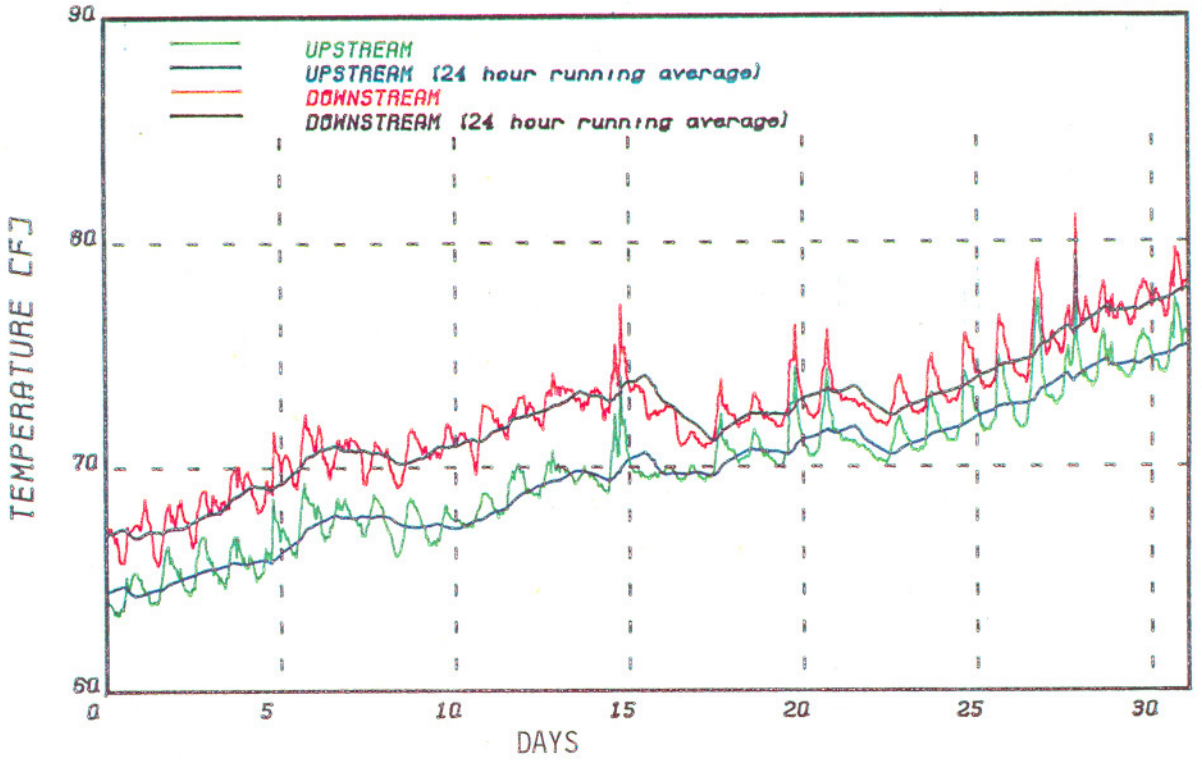

Figure 5.1-1A. Predicted dompliance temperatures at BFNP under hourly and 24-hour running average measurement periods, May 1980.

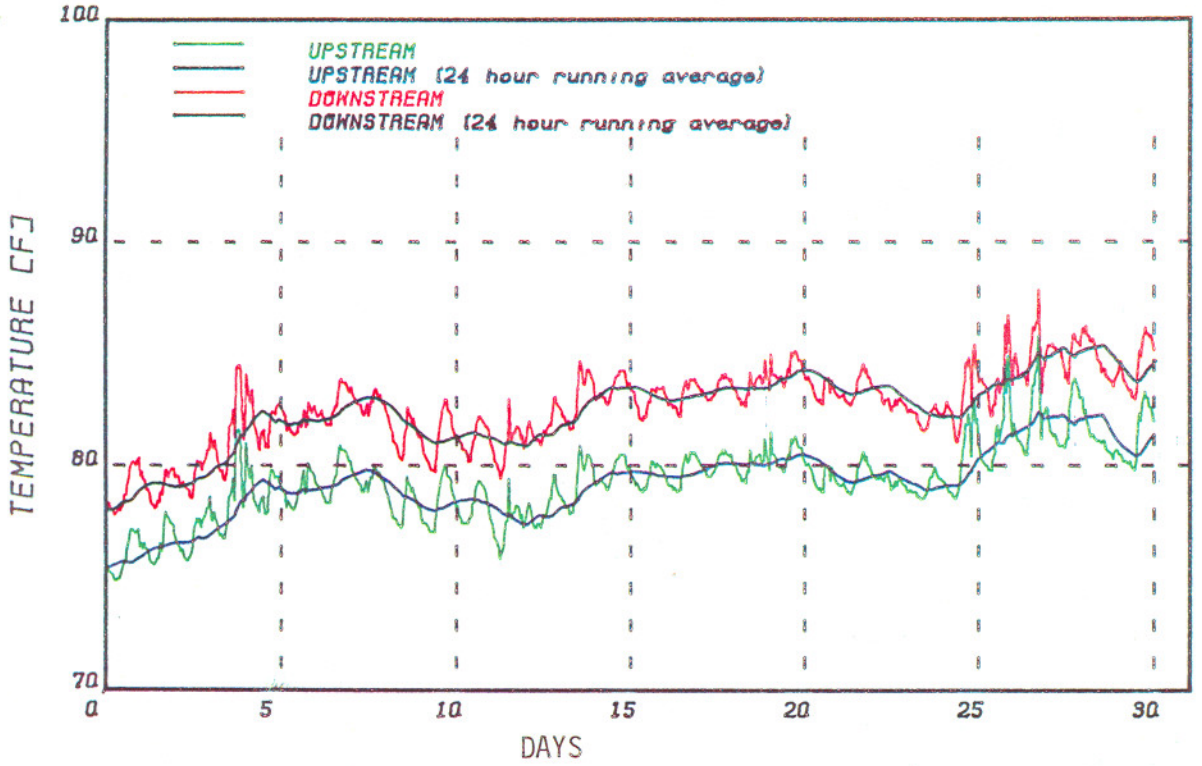

Figure 5.1-1B. Predicted compliance temperatures at BFNP under hourly and 24-hour running average measurement periods, June 1980.

The near field model was used to calculate the downstream temperatures that would result with a full 3-unit load for the river flows at each hour. These plant induced ΔTs produce a downstream temperature that follows closely the upstream temperature, since the flows were very steady during this period. The 24-hour running average temperatures (updated hourly) for this period are also shown. The diurnal variations are smoothed out and the plant induced temperature rise is more clearly apparent. The temperature rise is largest during the first half of May when flows were 25,000 to 50,000 cfs, and decreased in the middle of May when flows increased to 75,000 cfs. Flows in late May and through June were consistently in the 25,000 to 50,000 cfs range.

As ambient temperatures approach the maximum temperature limitation, the short term fluctuations produce a corresponding fluctuation in the remaining allowable plant induced temperature rise. A nuclear power plant simply cannot be operated efficiently to comply with such a variable thermal limitation and the plant load would be reduced conservatively so that the afternoon peaks in downstream compliance temperatures, due to solar heating, would not exceed the maximum limitation. Figure 5.1-2 shows the ambient temperatures for July 1980 as hourly and 24-hour running average values. During this period, it would be necessary to completely shut down the BFNP discharge if hourly temperatures were used for compliance. The plant could have a small but fairly steady ΔT of 1 or 2°F during this period if 24-hour averaging of the ambient temperatures was used. The maximum temperature limitation should not be applied to the short term fluctuations in the near field surface temperatures.

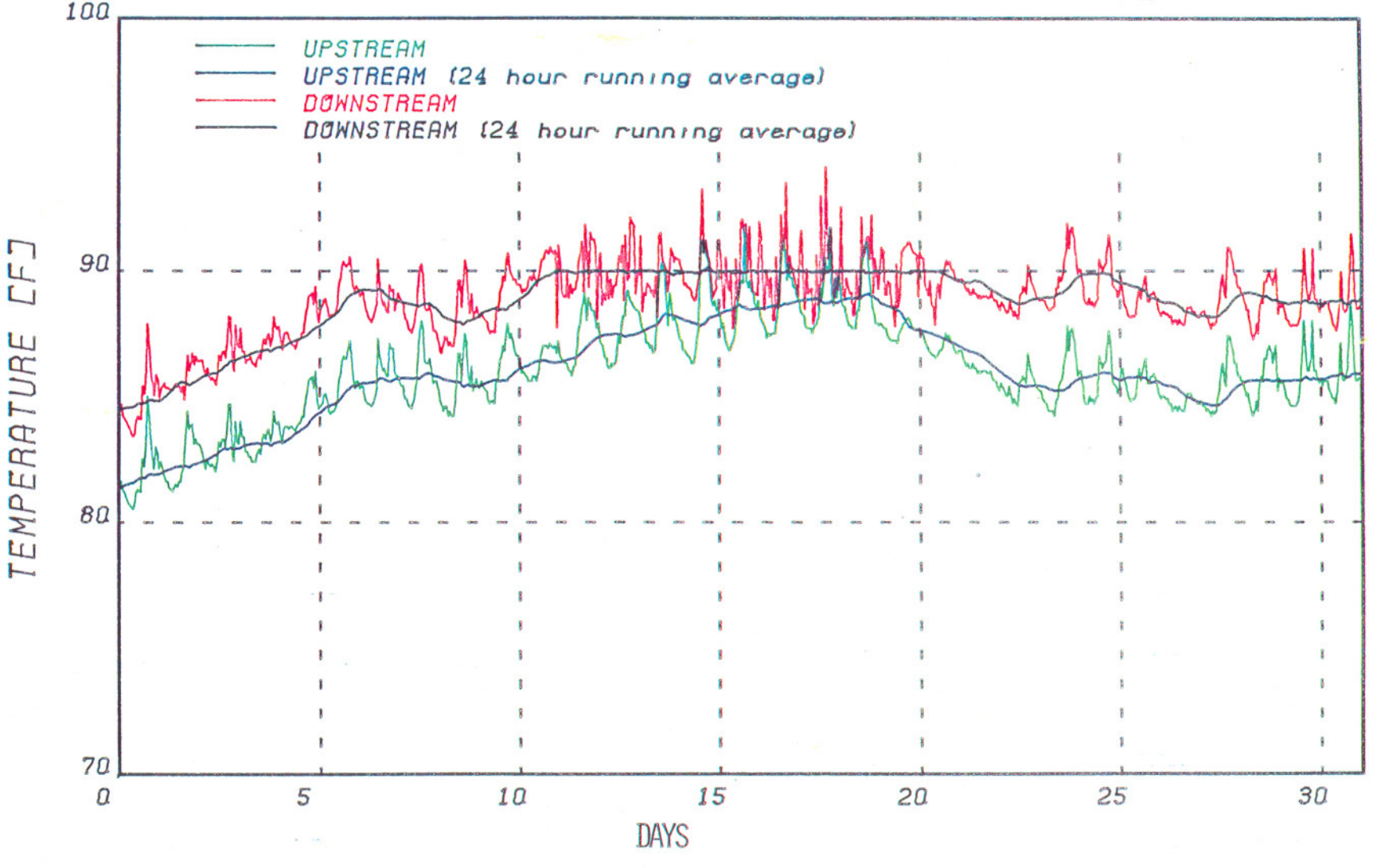

Figure 5.1-2. Predicted compliance temperatures at BFNP under hourly and 24-hour running average measurement periods, July 1980.

The use of 24-hour averaging would have no significant effect on seasonal temperature patterns. The previous annual cycle temperature plot (Figure 4.2-7 from Appendix 4) shows 24-hour average temperatures for both ambient and alternative standards cases. A slight increase in temperatures exists, but this does not change the overall annual temperature pattern.

Use of 24-hour running averaged temperatures for compliance with thermal limitations would allow some instantaneous temperatures to exceed the 90°F T_{max} and 10°F ΔT_{max} limits. Table 5.1-1 shows that the 24-hour averaging would cause few instantaneous (hourly) ΔTs greater than 10°F. The highest predicted occurrence was 6.6 percent of the time in January 1969. Only 6 out the 149 months studied showed any ΔTs greater than 10°F. Increases in the predicted instantaneous maximum temperatures are shown in Table 5.1-2. The average occurrence of summer (June, July, and August) temperatures greater than 90°F for the 12 years studied was 3.4 percent of the time.

The maximum monthly occurrence of temperatures greater than 90°F was 28.6 percent of the time in July 1969. The maximum instantaneous temperature predicted during the entire study period was 93.2°F. Durations of temperatures greater than 90°F were never longer than 24 hours because the 24-hour running average temperature would have exceeded the thermal limitation. Under these circumstances, the plant would use cooling towers or cut back plant load to stay within the limits. For completeness, Table 5.1-3 shows the predicted occurrences of 24-hour running average temperatures using 90°F T_{max} and 10°F ΔT_{max} limitations. The only occurrence of 24-hour running average temperatures greater than 90°F was due entirely to the high-ambient temperatures

Table 5.1-1. Predicted monthly occurrences of instantaneous (hourly) plant induced temperature rise (ΔT) greater than $10^{o}F$ at the edge of the diffuser mixing zone (five-foot depth) Browns Ferry Nuclear Plant, $\Delta T_{max} = 10^{o}F$, 24-hour running average.

Month	Year													Max
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	(Avg)
JAN	6.6	1.8	0.4	0	0	0	0	0	0	0	0	0	0	6.6 (0.7)
FEB	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0.4 (<0.1)
MAR	1.3	0	0	0	0	0	0	0	0	0	0	0	0	1.3 (0.1)
APR	0	0	0	0	0	0	0	0	0	0	0	0	0	
MAY	0	0	0	0	0	0	0	0	0	0	0	0	0	
JUN	0	0	0	0	0	0	0	0	0	0	0	0		
JUL	0	0	0	0	0	0	0	0	0	0	0	0		
AUG	0	0	0	0	0	0	0	0	0	0	0	0		
SEP	0	0	0	0	0	0	0	0	0	0	0	0		
OCT	0	0	0	0	0	0	0	0	0	0	0	0		
NOV	0	0	0	0	0	0	0	0	0	0	0	0		
DEC	1.1	0	0	0	0	0	0	0	0	0	0	0		1.1 (0.1)

NOTE: All numbers are percent of time in given period

Table 5.1-2 Predicted occurrences of instantaneous downstream river temperatures at edge of diffuser mixing zone (five-foot depth) Browns Ferry Nuclear Plant, $\Delta T_{max} = 10^{o}F$, $T_{max} = 90^{o}$, 24-hour running average

	Temperature Range (^{o}F)	Year											
		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
June - August	<86	41.6	45.4	55.9	68.6	69.0	80.7	72.8	85.3	29.8	28.9	93.9	34.9
	>86	58.4	54.6	44.1	31.4	31.0	19.3	27.2	14.7	70.2	71.1	6.1	65.1
	>87	45.6	38.0	24.8	16.4	12.7	6.7	15.5	6.2	58.2	57.9	1.7	62.9
	>88	33.9	21.9	9.7	7.6	3.8	1.4	8.0	2.5	38.8	39.0	0.2	55.4
	>89	20.3	8.7	3.2	3.0	0.5	<0.1	2.9	0.3	21.8	15.9	0.1	38.1
	>90	10.1	1.4	0.8	0.5	0	0	<0.1	0	7.3	3.4	0	16.7*
July Only	<86	0.3	27.0	37.5	64.5	51.8	66.5	73.9	81.2	2.7	0	97.0	6.0
	>86	99.7	73.0	62.5	35.5	48.2	33.5	26.1	18.8	97.3	100.0	3.0	94.0
	>87	93.6	51.9	45.8	19.5	24.6	13.7	8.9	9.7	90.7	96.6	0.5	88.8
	>88	79.4	28.1	23.7	11.8	9.5	3.6	1.9	4.4	75.5	76.3	0	77.6
	>89	51.3	8.9	8.9	5.9	1.5	0.1	0.3	0.4	51.3	37.2	0	48.0
	>90	28.6	1.6	2.6	1.6	0	0	0	0	21.2	8.3	0	20.8*

NOTE: All numbers are percent of time in given period

*A maximum temperature of $93.2^{o}F$ occurred on July 15, 18, and August 21, 1980.

Table 5.1-3 Predicted 24-hour average occurrence of downstream river temperatures at edge of diffuser mixing zone (five-foot depth) Browns Ferry Nuclear Plant, $\Delta T_{max} = 10^{o}F$, $T_{max} = 90^{o}F$. No cooling tower usage until the 24-hour average downstream temperature or plant induced ΔT reached the limits.

	Temperature Range (^{o}F)	Year											
		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
June - August	<86	42.4	41.7	57.0	68.9	73.6	84.1	77.2	88.3	26.8	27.1	95.9	36.0
	>86	57.6	58.3	43.0	31.1	26.4	15.9	22.8	11.7	73.2	72.9	4.1	64.0
	>87	46.3	42.2	18.5	14.4	8.8	3.1	11.6	1.0	58.9	58.9	0.7	62.3
	>88	36.3	13.8	8.7	7.4	1.7	0	7.2	0	38.6	38.9	0	58.2
	>89	22.1	2.2	2.7	0	0	0	0.5	0	20.8	12.7	0	44.1
	>90	0	0	0	0	0	0	0	0	0	0	0	0.6*
July Only	<86	0	25.0	29.7	68.0	52.6	67.7	81.7	78.1	0	0	100.0	7.9
	>86	100.0	75.0	70.3	32.0	47.5	32.3	18.3	21.9	100.0	100.0	0	92.1
	>87	100.0	53.9	39.4	19.6	23.9	8.1	2.8	3.1	92.2	97.6	0	86.8
	>88	93.6	15.9	22.9	15.7	5.1	0	0	0	79.3	81.0	0	82.4
	>89	62.1	3.8	8.2	0	0	0	0	0	60.9	32.9	0	50.7
	>90	0	0	0	0	0	0	0	0	0	0	0	1.8*

NOTE: All numbers are percent of time in given period

*A maximum 24-hour average temperature of $90.2^{o}F$ occurred on July 15, 1980, as a result of high ambient temperatures (The plant was not operating during this prediction period.)

(the plant was shut down when ambient temperatures exceeded the thermal limitations).

Utilization of temperature average is consistent with EPA's (1976) recommendations for setting appropriate thermal discharge limits which are based on maximum weekly average temperature (see Appendix 3, section 3.2.1). Because the purpose of the 90°F limit is to prevent adverse impacts on growth, short-term excursions above 90°F during a 24-hour period would not have a significant effect on sauger or smallmouth bass, particularly as these temperatures would be confined to surface strata.

Based on the data and analyses in this report, a 24-hour temporal averaging of data is recommended for compliance purposes, to remove the effects of short term near surface fluctuations, and to obtain a better representation of plant induced temperature effects in Wheeler Reservoir.

5.2 Calculated Compliance Method

On November 21, 1978, TVA requested that compliance with thermal limitations at Browns Ferry Nuclear Plant be based on calculations as outlined in the report, "Assessment of Water Temperature Monitoring at the Browns Ferry Nuclear Plant," Report No. WM28-1-67-101, August 1978 (Ungate 1978). A summary of this proposal appears as Exhibit 1 to this appendix. The proposed computed compliance method provides a precise way of determining the rise in temperature produced by the plant. This would overcome the significant problems experienced in the past when natural solar heating adversely affected the monitored results. TVA has implemented a demonstration of the proposed computer

method. At the end of a one-year demonstration period, an evaluation of the computed method will be provided for regulatory approval. Field studies will be used as the basis for establishing the precision of the computed compliance method.

5.3 Refinement to the Calculated Compliance Method

The present measured method of compliance uses instream temperature measurements at 15-minute intervals which are averaged over a 2-hour period. This temporal averaging was adopted to prevent compliance from being determined by instantaneous jumps in water temperature that are not representative of true conditions. In Section 5.1 the effects of solar heating and flow or wind-induced mixing were discussed. Because these fluctuations are short term and limited to the near surface layers they do not indicate BFNP discharge effects, which will be persistent and not fluctuate widely from hour to hour except as river flow or plant load conditions change.

In Section 5.1 it was mentioned that study periods used to develop biological data on adverse effects were on the order of 24 hours to a week. Using a longer averaging time in compliance would provide a method that is more consistent with biological support information.

Therefore, it is recommended that the thermal limitations be based on a 24-hour average of measured or computed temperatures. The 24-hour average compliance will be included in the one-year study period discussed in Section 5.2. After the study, the final method, location of instream monitors, number of measurements, and temporal averaging of the results will be provided for final approval.

EXHIBIT 1

TEMPERATURE MONITORING

BROWNS FERRY NUCLEAR PLANT

On November 21, 1978, TVA requested that compliance with thermal limitations at Browns Ferry Nuclear Plant be based on calculations as outlined in a report, "Assessment of Water Temperature Monitoring at the Browns Ferry Nuclear Plant," Report No. WM28-1-67-101, August 1978. EPA approved the planned demonstration of the computed method in a letter to TVA dated March 25, 1981. The demonstration period will continue for up to one year. During this period, TVA will conduct tests necessary to verify and calibrate the computed method. Compliance parameters using the present measured method will continue to be transmitted to plant operators and reported to EPA during this period. At the end of the demonstration period, data from continuous temperature monitors and from special water temperature and velocity surveys will be used to evaluate the computed compliance method. Details on the computed compliance method are presented in the following discussion.

Measured Information

The computed method will utilize the following measurements:

1. Mixed temperature: Three new temperature monitors will be situated about 2,200 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 15

minutes at the 1-, 1½-, and 2-meter depths at each monitor and transmitted to the plant site. Data at the 1-, 1½-, and 2-meter depths will be averaged to give temperature at the 1.5-meter (/5-foot) depth. Temperatures at each monitor will be temporally averaged using the current temperature and the previous four 15-minute observations. The mixed river temperature will be computed by averaging the temperature data associated with the operating diffuser legs.

2. Dam discharges: Discharges from Guntersville and Wheeler Dams will be transmitted to the plant site.

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 position (open-closed) of the appropriate gate structure will be monitored on site.

Calculated Information

The previous measurements will be received by a computer which will calculate the following information:

1. Discharge flow will be computed from a number of condenser cooling water pumps in operation. The position of gate structures will allow determination of the operating diffusers and cooling mode. If cooling towers are in use, the average evaporation rate will be subtracted from the computed discharge flow; this approximation will cause an error of less than 0.1°F in temperature calculations.

2. River flow will be computed using an unsteady flow routing model. The dam releases at Guntersville and Wheeler will be updated every time step (15 minutes).

3. The temperature rise will be computed using the theory of diffuser mixing discussed in report No. WM28-1-67-101. 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 as described previously.

Upon approval of this method, the river flow, temperature rise, and mixed temperature will be sent to the plant control room. A permanent record will be stored for compliance purposes.

A SUPPLEMENTAL 316(a) DEMONSTRATION FOR ALTERNATIVE THERMAL DISCHARGE LIMITS FOR BROWNS FERRY NUCLEAR PLANT, WHEELER RESERVOIR, ALABAMA

APPENDIX 6

ECONOMIC EVALUATION OF ALTERNATIVE THERMAL LIMITATIONS AND ALTERNATIVE MONITORING METHOD

Tennessee Valley Authority
February 1983

A SUPPLEMENTAL 316(a) DEMONSTRATION FOR ALTERNATIVE THERMAL DISCHARGE LIMITS FOR BROWNS FERRY NUCLEAR PLANT, WHEELER RESERVOIR, ALABAMA

APPENDIX 6

ECONOMIC EVALUATION OF ALTERNATIVE THERMAL LIMITATIONS AND ALTERNATIVE MONITORING METHOD

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A SUPPLEMENTAL 316(a) DEMONSTRATION FOR ALTERNATIVE THERMAL DISCHARGE LIMITS FOR BROWNS FERRY NUCLEAR PLANT, WHEELER RESERVOIR, ALABAMA

APPENDIX 6

ECONOMIC EVALUATION OF ALTERNATIVE THERMAL LIMITATIONS AND ALTERNATIVE MONITORING METHOD

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APPENDIX 6 ECONOMIC EVALUATION OF ALTERNATIVE THERMAL LIMITATIONS AND ALTERNATIVE MONITORING METHOD

6.0 Introduction

TVA is firmly committed to environmental protection and considers this protection a necessary part of providing power to its customers. However, due to the significant penalties and costs resulting from measures taken at BFNP to comply with thermal limitations, it is important that these limitations not be established at levels that are more stringent than necessary to provide adequate protection. This appendix presents the type of penalties involved in complying with thermal limitations and savings that can be realized under alternate limitations.

6.1 Methods and Penalties Associated With Meeting Thermal Limitations

During most of the year, reservoir thermal limitations at BFNP can be met by operating in the open mode of cooling (no cooling towers). When reservoir flows drop or when ambient reservoir temperatures increase to high levels, actions must be taken to either reduce the amount of heat being rejected to the reservoir or to increase the water flow past the plant.

Operating the cooling towers at BFNP to reduce the heat rejected to the reservoir requires a large power demand on the TVA system. Operating all cooling tower pumps and fans for a 24-hour period requires about 1 million kWh of electricity. To put this in perspective, the annual average daily usage of electricity by a home in the TVA region is about 40 kWh. Thus, when the six towers are operating, electrical usage is equivalent to the requirements of about 25,000 average homes in the TVA region. This power requirement is

also approximately equivalent to the 1981 average daily residential usage of power in the Decatur, Alabama, area. Operating the cooling towers is equivalent to the addition of an increased power demand on the TVA power system. Supplying this additional power results in increased generation from more expensive power generation since lower cost generation is utilized first on the system. If this energy were replaced by coal-fired generation, it would require approximately 450 tons of coal to be burned over a 24-hour period. If the generation were replaced by generation from oil-fired gas turbines, which could occur during peak summer conditions, approximately 55,000 gallons of oil would be consumed over a 24-hour period.

If operating the cooling towers does not provide sufficient cooling to meet thermal limitations, the amount of heat discharged to Wheeler Reservoir can be reduced by reducing the plant electrical output (load reductions). The magnitude of load reductions can vary from only a few megawatts of power to a full plant shutdown depending on the initial plant load, number of generating units operating, reservoir temperature and flow, and ambient air temperature. Reducing load to meet thermal limitations also requires power to be replaced by more expensive sources of power, and can result in even higher cost penalties due to the periods of time in which they usually occur. Load reductions instituted to comply with the maximum downstream temperature limitation occur during summer conditions when TVA power system loads are also at a peak. Replacement energy during these periods of time is very expensive since most generating units are already operating at maximum output and additional capacity is limited. During some summers, large amounts of power have been both generated

from TVA's gas turbines and purchased from other utilities to meet peak system load requirements. Presently, TVA's oil-fired gas turbines cost over ten times more per kWh generated to operate than BFNP. The amount of fuel oil necessary to generate power to replace a relatively low load reduction can be substantial. For example, a load drop of 10 percent (roughly 330 megawatts) would require a consumption of approximately 18,000 gallons of fuel oil per hour. During the extreme conditions of the summer of 1980 when neighboring utilities were also in emergency operating procedures, TVA's power needs approached the point where any additional load demand could not have been met, even when power was curtailed to certain classes of customers.

Load reductions to comply with the ΔT_{max} limitation are possible during periods of low reservoir flows. Although this condition usually occurs during the spring and fall seasons when power demands typically are not as high, replacement power costs can still be significant. Due to the normally lower power demands, TVA takes advantage of the spring and fall periods to perform scheduled preventive maintenance on many of its power plants. This reduces the amount of system capacity available for replacing lost power which can result in relatively high replacement power costs.

An alternate method of complying with thermal limitations (ΔT_{max} primarily) which would prevent possible load reductions and minimize cooling tower usage is to maintain higher reservoir flows past the plant by depleting storage in the TVA hydro system. This action however can reduce the effectiveness of TVA's reservoir level control for multipurpose operation. Because hydropower is a limited energy resource, higher flows for cooling can also reduce the volume

of water available for peaking power from hydro units during the summer months. This results in the depletion of hydro generation capability during the summer months when replacement costs are even higher as discussed above. The decision of whether to meet reservoir thermal limitations by operating cooling towers, reducing load, altering reservoir flows, or a combination of these efforts is made on a case-by-case basis depending on economics and the condition of the overall power system at the time.

The closed mode of cooling was included as part of the cooling tower retrofit program at Browns Ferry as an alternate method of complying with thermal limitations. However, operating in the closed mode has been found to not be a practical method of operating the plant. Although TVA has implemented modifications to correct problems with the cooling system, there are still substantial risks associated with the operation of the retrofitted cooling tower system in the closed mode.

Changing to closed mode operation subjects the plant systems to two distinct and abrupt changes in the quality of the intake water. The first change is associated with the slug of quiescent water contained in the tower return channel. Accumulated biotic material in the channel can enter the plant and obstruct the flow of cooling water to various pieces of critical equipment. The second abrupt change is associated with the sudden temperature increases in the cooling water entering the plant since the temperature of the water exiting the towers during closed mode exceeds the ambient reservoir temperature under almost all conditions. The responses and stresses to the primary cooling water systems associated with these abrupt changes in plant

intake water result in increased risk of system failure and subsequent loss of generation from the entire plant. This risk is compounded during the summer months since the water temperature exiting the towers during helper mode already approaches the maximum allowable water temperature for various nuclear safety cooling systems.

In summary, load reductions and power required for cooling tower operation result in the need to replace large amounts of power with much more costly generation especially during the summer months. Although closed mode operation may be a possible means of reducing load reductions during periods when ambient temperature conditions are not excessive, it is not a practical means of operating the plant. The potential to adversely affect nuclear safety systems which depend on water from the cooling tower circuit and the potential consequences of a complete plant shutdown resulting from closed mode operation far outweighs the benefits of such operation. Any increases in thermal limitations which still provide for environmental protection or improvements in compliance methods which would reduce cooling tower operation would be of substantial economic benefit to TVA and ultimately the ratepayer.

6.2 Economics of Alternative Thermal Limitations

The following sections compare the net savings of alternative thermal limitations with a base case of 90°F T_{max} and 5°F ΔT_{max} with cooling tower operation whenever downstream temperatures would have reached 86°F in open mode.

6.2.1 Savings with 90°F T_{max} and 5°F ΔT_{max} Limitation with Cooling Tower Operation Whenever Downstream Temperature Reaches 90°F in Open Mode

Extensive cooling tower operation would be needed to meet a thermal limitation requirement to operate the towers whenever the mixed downstream reservoir temperature would have reached 86°F in open mode. In addition, with cooling tower operation, internal safety related temperature constraints of the plant can require load reductions to be taken whenever tower return temperatures approach 94°F. The critical period for the internal plant constraint corresponds with the periods of high ambient water temperatures during the summer season. Thus operation of the cooling towers to satisfy the 86°F tower operating requirement would result in significant load reductions due to internal constraints. However, in most cases, cooling tower operation would not be required to meet a 90°F T_{max} during summer periods since a ΔT on the order of 1° to 2°F is normally experienced during the summer months when operating in open mode. Annual average savings associated with decreased tower operation and load reductions due to the internal temperature constraint under this limitation are estimated to be about $2 million. However, in an extreme year, savings of about $5 million could be realized.

6.2.2 Savings with 90°F T_{max} and 10°F ΔT_{max} Limitations with Cooling Tower Operation Whenever Downstream Temperature Reaches 90°F in Open Mode

Under this case, additional savings would be realized during periods of low flow conditions (typically fall and spring) past the

plant. As previously discussed, the hydro system could then be operated to enhance other system requirements without having to provide additional flow past BFNP. Average annual savings from the base for this change in thermal limitations are estimated to be about $3.5 million. However, a saving of $10 million would be possible for an extreme year.

6.3 Economics of Alternative Monitoring Methods

6.3.1 Advantages of 24-Hour Running Average

A 24-hour running average of reservoir temperatures provides much more flexibility in operating the plant and removes many short term effects over which the plant has no control. At present, the plant must take actions to reduce downstream temperatures several hours before an excursion is predicted to occur due to the distance (and travel time) between the upstream and downstream monitor locations. If the plant waits until an excursion is about to occur to take action, the action will be futile in keeping the downstream temperature within the applicable limitation. In some instances, plant actions can turn out to be unneeded due to changes in reservoir flow or temperature or weather conditions which result in downstream temperatures lower than predicted. Another complicating factor is solar heating which can significantly affect downstream temperatures. The present monitoring system measures the total thermal addition and cannot distinquish between the solar and plant induced increments. Under these conditions, the plant has been required to modify operations for conditions which were not totally plant induced. The 24-hour averaging method would dampen out the effects of distance (travel time) and solar heating thereby allowing more uniform operation of the plant to achieve compliance with the thermal limitations.

The total savings associated with 24-hour averaging in conjunction with alternative thermal limitations are briefly discussed in the following subsections and are summarized in Figure 6.1. An evaluation of the 24-hour averaging method with the thermal limitations currently being met by TVA (90°F T_{max} and 5°F ΔT_{max} and with tower operation when temperatures reach 86°F in open mode) has been included for completeness.

6.3.2 Savings with 24-Hour Averaging with 90°F T_{max} and 5°F ΔT_{max} Limitations with Cooling Tower Operation whenever Downstream Temperature Reaches 86°F in Open Mode

Under this case, annual savings on the order of $2 million annually would be expected, and in an extreme year, annual savings of $8 million could be realized. However, significant costs would still be incurred due to operating the towers whenever the downstream temperature would approach 86°F.

6.3.3 Savings with 24-Hour Averaging with 90°F T_{max} and 5°F ΔT_{max} Limitations with Cooling Tower Operation Whenever Downstream Temperature Reaches 90°F in Open Mode

Additional savings for this case would be realized due to the reduced cooling tower usage associated with the removal of the 86°F temperature constraint in conjunction with a longer averaging period. Annual average savings on the order of $3.5 million would be expected. In an extreme year, savings on the order of $12 million could be realized.

6.3.4 Savings with 24-Hour Averaging with 90°F T_{max} and 10°F ΔT_{max} Limitations with Cooling Tower Operation Whenever Downstream Temperature Reaches 90°F in Open Mode

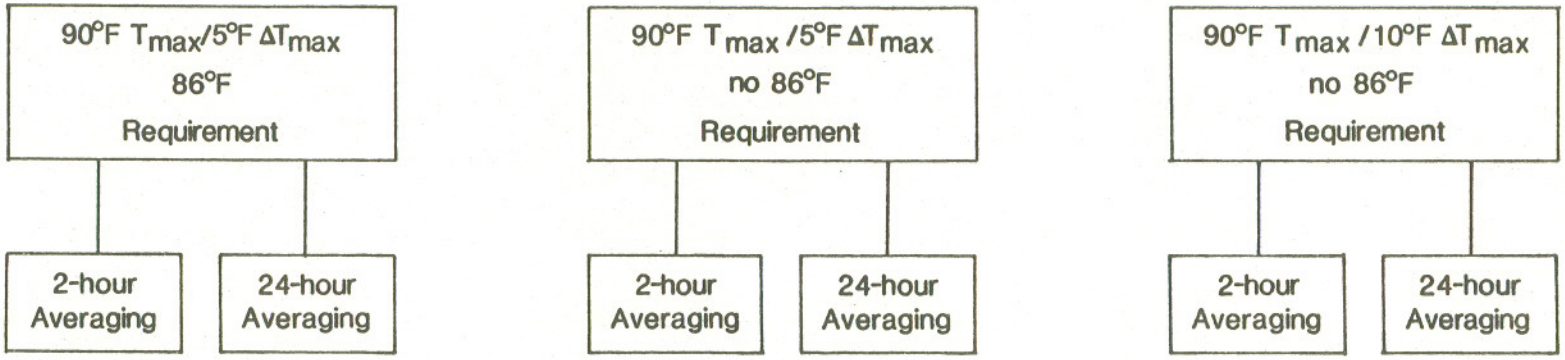
Cooling tower usage would be reduced further in this case. On an annual average basis, savings of about $4 million would be expected. In a severe year, however, an annual savings of about $14 million could be realized.

6.4 Summary of Economics of Alternative Thermal Criteria and Monitoring

The total annual savings for the various cases referenced to the base case of 90°F T_{max} and 5°F ΔT_{max} with cooling tower operation whenever the downstream temperature would exceed 86°F in open mode, and 2-hour running average compliance monitoring, are shown in Figure 6.1. Annual average savings for the alternatives evaluated range from $2 million to $4 million. However, in an extreme year, savings ranging from $5 million to $14 million could be realized. Under a 24-hour averaging compliance method, annual average savings of $4 million and extreme savings of $14 million could be realized under a 90°F T_{max} and 10°F ΔT_{max} limitation if the towers are not required to operate to minimize excursions above 86°F.

FIGURE 6.1

INCREMENTAL ANNUAL AVERAGE AND EXTREME SAVINGS OF ALTERNATIVE THERMAL LIMITATIONS AND COMPLIANCE MONITORING



AVERAGE ANNUAL SAVINGS	Base	$2 million	$2 million	$3.5 million	$3.5 million	$4 million
EXTREME ANNUAL SAVINGS	Base	$8 million	$5 million	$12 million	$10 million	$14 million

A SUPPLEMENTAL 316(a) DEMONSTRATION FOR ALTERNATIVE THERMAL DISCHARGE LIMITS FOR BROWNS FERRY NUCLEAR PLANT, WHEELER RESERVOIR, ALABAMA

APPENDIX 7

REFERENCES FOR THE REPORT AND TECHNICAL APPENDIXES

Tennessee Valley Authority
February 1983

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