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DISCHARGE TEMPERATURE LIMIT EVALUATION FOR WATTS BAR NUCLEAR PLANT

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EXECUTIVE SUMMARY

The Tennessee Valley Authority (TVA) anticipates one unit at Watts Bar Nuclear Plant
to begin operation in 1994/1995. Watts Bar Fossil Plant is currently mothballed with no present
. 3 schedule for unit start up. Both the fossil and nuclear plants rely on the Tennessee River
downstream of Watts Bar Hydro for dispersing thermal effluent from condenser cooling. Due
. 4 to the uncertainty in Watts Bar Fossil Plant future operation, TVA has evaluated the thermal
effects of operating the hydro, fossil, and nuclear plants under various operating scenarios. The
. 5 goal is to ensure that operations do not violate the State of Tennessee instream water quality
criteria for temperature.

.6

. 8 Watts Bar Hydro Plant is generally operated to provide peaking power. The normal
maximum duration of zero discharge is 15 hours. Historically, continuous zero releases
14 associated with special operations or repairs have not exceeded 20 hours in duration.

16 Previous field studies showed a worst case maximum fossil plant-induced instream
17 temperature rise of 3 F° (1.7 C°). This occurred after 12 hours of zero release from the hydro
plant.

19

Water temperatures and flows, and meteorological records from 1976 to 1993, were used with a computer model to simulate Watts Bar Nuclear Plant operation with and without fossil plant operation. The results showed that under all simulated historical conditions the maximum downstream temperature (85.6°F, 29.8°C) was below 86.9°F (30.5°C), allowed by the State of Tennessee. The maximum nuclear plant-induced temperature rise (1.8 F°, 1.0 C°) was below both the State criteria for temperature rise of 5.4 F° (3.0 C°) and for rate of temperature change of 3.6 F°/hour (2.0 C°/hour). The combined worst-case temperature rise from both fossil and nuclear plant operation was 4.8 F° (2.7 C°). The maximum hourly nuclear plant discharge temperature, only dependent on meteorology, was 97.3°F (36.3°C). The worst case conditions evaluated at steady-state showed that even with a discharge of 100.9°F (38.3°C) the maximum downstream temperature was 86.4°F (30.2°C).

Based on the extensive simulations of historical conditions, the worst case steady-state results, and a small margin of safety, TVA proposes a daily average discharge limit of 95°F (35°C). The diffuser mixing zone remains (as previously permitted) 240 feet wide and extends 240 feet downstream. TVA also proposes a pond emergency overflow temperature limit of 104°F (40°C), which would be measured by grab sample once a day during overflow at the overflow weir. A proposed mixing zone for the overflow weir discharge should be 1,000 feet wide and extend 3,000 feet downstream. Due to the location and length of the diffuser (less than 1/4 of the river width) and small effect from surface overflow discharge, ample space exists for fish to pass by the plant during all operations.

The operation of Watts Bar Fossil and Nuclear Plants are not anticipated to cause problems with Sequoyah Nuclear Plant's ability to meet safety or environmental temperature limits. The combined effects of Watts Bar Fossil and Nuclear Plants on Sequoyah Nuclear Plant are expected to be small, with an average increase in bottom temperature of about 0.4 F° (0.2 C°) under low flow conditions.

Watts Bar Nuclear Plant has continuous discharge temperature and flowrate monitors. TVA proposes a daily average discharge temperature limit on the flow weighted average of hourly temperature values (based on the actual hours of discharge). TVA will calibrate the plant temperature sensors, flowrate monitors, and transfer electronics at least annually. TVA proposes to field survey thermal conditions in stages, as heated discharges are added at the Watts Bar site, to verify computer modeling assumptions.

I. INTRODUCTION

The Tennessee Valley Authority is constructing a two-unit 2,540 Megawatt (MWe) nuclear plant in Rhea County, Tennessee, on the right bank of Chickamauga Reservoir at Tennessee River Mile (TRM) 528. One nuclear unit is anticipated to begin operation in 1994/1995. The location, shown in Figure A.1 (all figures have been placed in the Appendix), is adjacent to the Watts Bar Dam Reservation. Watts Bar Nuclear Plant is situated about two miles downstream of Watts Bar Hydro Plant (TRM 529.9) and about one mile downstream of the four-unit Watts Bar Fossil Plant, located on the right bank of Chickamauga Reservoir at TRM 529.

The State of Tennessee instream water quality criteria for temperature are a maximum downstream temperature of 86.9°F (30.5°C), a maximum temperature rise of 5.4 F° (3.0 C°), and a maximum rate of temperature change of 3.6 F°/hour (2.0 C°/hour). The standards are applicable at the edge of a mixing zone.

State-of-the-art mathematical models together with available data are used to simulate the environmental impact of plant operations from 1976 through 1993. The primary goal of the evaluation is to provide a maximum daily average discharge temperature for the nuclear plant that will ensure meeting the instream State of Tennessee temperature standards, yet provide flexibility for plant operation. Experience at other fossil and nuclear plants has shown that daily average limits provide plant operating flexibility without adverse effects on the water body. Combined fossil and nuclear plant operation was also evaluated.

This report provides details of the operating characteristics of each of the generating plants (hydro, fossil, and nuclear). Thermal characteristics for the fossil plant and the nuclear plant are presented. The hydro-thermal effects of worst case operation of the fossil plant are identified. Computer models of nuclear plant operation are used for various operating scenarios. A daily average discharge temperature and maximum pond overflow temperature are proposed, based on the findings. The "mixing zone" and "zone of passage" for nuclear plant thermal discharges are addressed. The combined effects of Watts Bar Fossil and Nuclear Plant operation on Sequoyah Nuclear Plant are evaluated. Finally, proposed limits, monitoring, reporting, and field verification for thermal compliance at Watts Bar Nuclear Plant are discussed.

II. PLANT OPERATING CHARACTERISTICS

A. Watts Bar Hydro Plant

Watts Bar Hydro Plant (WBH) has five units with a total capacity of 166.5 MWe. The hydro plant releases about 9,000 cubic feet per second (cfs) per unit and is normally used for peaking operations. Peaking operations entail storing water at night and releasing water during the day when there is the greatest demand for electricity.

Hourly WBH discharge records have been archived since January 1, 1976. The average discharge at the hydro plant has been 26,300 cubic feet per second (cfs), with about 24,200 cfs during the summer months and about 35,100 cfs during the winter months. The normal discharge through each of the five turbines at the hydro plant ranges from 7,500 to 10,000 cfs. The minimum flow at which the turbines can operate is 3,500 cfs; however, for maximum efficiency, the flow seldom falls below 8,000 cfs per unit.

WBH is operated to provide peaking power and the normal maximum duration of zero discharge is 15 hours. When special operations are planned, the period of zero discharge historically has not exceeded 20 hours. Tables 1 and 2 show low river flow (less than 3,500 cfs) occurrences and durations by month and by year. The low river flow occurrences were divided into periods of 5-hour duration. The longest period of low flow ever recorded was between 16-20 hours and the largest number of occurrences for this duration was nine, occurring in 1988. Within the 18 years, there were 1826 occurrences for the 6- to 10-hour duration, 1390 for the 1- to 5-hour duration, 396 for the 11- to 15-hour duration and 26 for the 16- to 20-hour duration.

Headwater elevation at Chickamauga Dam along with the discharge from WBH determines the water surface elevations downstream of WBH in the vicinity of the plant sites. Chickamauga Reservoir elevations vary from a normal maximum elevation of 683.0 feet in the summer months to a normal minimum elevation of 675.0 feet in the winter months. Table 3 shows the approximate stage-discharge relationship below WBH at minimum pool conditions in the winter.

B. Watts Bar Fossil Plant

Watts Bar Fossil Plant (WBF) is currently mothballed with no scheduled start-up date. When operated at full capacity, WBF generated 240 MWe, used a once-through cooling system requiring 626 cfs of cooling water, and elevated the cooling water temperatures up to 10 F° (5.6 C°). The fossil plant heated discharge was continuous regardless of WBH operation.

Ungate and Howerton (1977) described the plant water usage as follows. The once-through cooling water is supplied by gravity from WBH through a conduit system approximately 3,600 feet long. The centerline of the intake opening is located at elevation 716 feet and is contiguous with the upstream face of Watts Bar Dam at the right abutment of the dam. The

TABLE 1

Watts Bar Hydro Plant Releases (1976 - 1993[1])

Low River Flow Occurrence And Duration
Broken Down By Year For All Months

Number of times flows < 3,500 cfs persisted for indicated duration

Year	Total hours per year[2]	Duration (hours)				
		1-5	6-10	11-15	16-20	21+
1976	1422	134	112	8	1[3]	0
1977	1386	123	98	18	0	0
1978	1775	136	145	19	0	0
1979	448	58	29	1	0	0
1980	1548	98	145	9	0	0
1981	2520	176	238	14	0	0
1982	56	14	2	0	0	0
1983	6	3	0	0	0	0
1984	454	39	39	3	0	0
1985	1886	79	140	39	3	0
1986	2817	113	189	73	4	0
1987	2408	117	189	44	2	0
1988	2814	121	169	74	9	0
1989	540	25	50	5	0	0
1990	523	22	34	13	1	0
1991	551	24	47	9	0	0
1992	1119	53	78	20	5	0
1993	1763	55	122	47	1	0
Total Occurrences		1,390	1,826	396	26	0

Notes:

1. Does not include November 29 through December 31, 1993.
2. There are 8760 hours in a non-leap year.
3. For example, there was 1 occurrence in 1976 when the WBH release was less than 3,500 cfs for between 16 and 20 continuous hours.

TABLE 2

Watts Bar Hydro Plant Releases (1976 - 1993[1])

Low River Flow Occurrence And Duration
Broken down By Month For All Years

Number of times flows < 3,500 cfs persisted for indicated duration

Month	Total hours per year	Duration (hours)				
		1-5	6-10	11-15	16-20	21+
Jan	870	117	66	1	1[2]	0
Feb	800	128	53	1	0	0
Mar	1241	118	109	3	2	0
Apr	2266	147	196	16	3	0
May	3018	110	222	58	10	0
Jun	3952	68	175	106	4	0
Jul	2553	59	196	62	1	0
Aug	1947	80	148	39	2	0
Sep	2762	75	181	81	3	0
Oct	2465	143	239	17	0	0
Nov	1867	186	158	9	0	0
Dec	1195	159	83	3	0	0
Total Occurrences		1,390	1,826	396	26	0

Notes:
1. Does not include November 29 through December 31.
2. For example, there was 1 occurrence in all Januarys, 1976-1993, when WBH release was less than 3,500 cfs for between 16 and 20 continuous hours.

TABLE 3

Approximate Stage Discharge Relationship
Immediately Below Watts Bar Dam

(Ungate and Howerton, 1977)

Water Surface Elevation (feet)	Watts Bar Dam Discharge (cfs)
675	0
677	12,500
679	25,000
681	37,500
683	50,000
696	190,000

heated water from the condensers is discharged into the river through a rectangular culvert 7 feet wide and 10 feet deep. The top elevation of the culvert outlet is 675.0 feet, which coincides with the minimum pool level of Chickamauga Reservoir. Topography in the vicinity of the discharge is given in Figure A.2.

C. Watts Bar Nuclear Plant

Watts Bar Nuclear Plant (WBN) operates in closed-mode using one natural draft cooling tower per nuclear unit. The blowdown from closed-mode operation is discharged into the Tennessee River through a multiport diffuser system. WBN is designed to route the blowdown water either to the diffusers or to a yard holding pond. The current National Pollutant Discharge Elimination System (NPDES) Permit for WBN stipulates that the discharge diffusers may operate only when discharge from WBH is greater than 3,500 cfs.

1. Plant Design

WBN is a two-unit nuclear plant, with one unit nearing the end of construction. It is located on the right bank of the Tennessee River at TRM 528. When operated at full capacity, it will produce 2,540 MWe (1,270 MWe per unit) of electricity. WBN utilizes a closed-cycle heat dissipation system consisting of two natural draft cooling towers and a blowdown system. The water losses due to evaporation and blowdown are replenished with the makeup water which is supplied via an intake channel and pumping station at TRM 528.0. The average and maximum intake flow rates are 133 cfs and 143 cfs, with a dilution ratio of twice that of the blowdown.

2. Intake and Discharge Design

The cooling tower blowdown flow is directed through the blowdown diffuser system to the Tennessee River. The blowdown system consists of two multiport diffusers (at TRM 527.8) and the 190 acre-feet capacity yard holding pond. Presently, whenever less than 3,500 cfs is discharged from the WBH, the two diffuser legs are closed and blowdown flow is diverted to the holding pond for storage. An overflow weir on the south side of the pond allows discharge to the Tennessee River (TRM 527.2) should the pond capacity be exceeded in an emergency. The blowdown system is depicted in Figure A.3.

The diffuser system consists of two pipes branching from a central conduit at the right bank of Chickamauga Reservoir and extending in a direction perpendicular to Tennessee River flow. Each pipe is controlled by a 54-inch diameter butterfly valve located a short distance downstream of the central conduit wye. A physical description of the diffusers is given in Table 4 and depicted in Figure A.4.

TABLE 4

Dimensions of Constructed Diffusers
Watts Bar Nuclear Plant

		Upstream Leg	Downstream Leg	Total
DIFFUSER	Pipe Length (ft) (unpaved corrugated steel pipe)	80.0	160.0	240.0
	Pipe Diameter (ft)	3.5	4.5	
	Port Diameter (in)	1.0	1.0	
	Number of Port Per Corrugation	2	2	
	Port Spacing Normal to Corrugation (in)	3.0	3.0	
	Port Spacing Parallel to Corrugation (in)	3.0	3.0	
	Friction Factor	0.0948	0.0841	
APPROACH PIPE	Pipe Length (ft) (paved corrugated steel pipe)	447.0	297.0	744.0
	Pipe Diameter (ft)	3.5	4.5	
	Friction Factor	0.0191	0.0148	

The downstream leg is composed of two segments of 4.5-foot diameter pipe. The approach pipe is made of paved corrugated steel approximately 297 feet long, while the diffuser pipe is made of unpaved corrugated steel 160 feet long. The diffuser pipe section is half buried in the river bottom and has two 1-inch diameter ports per corrugation. The centerline of the ports is oriented at a 45° angle from the horizontal in a downstream direction.

The upstream leg is composed of two segments of 3.5-foot diameter pipe. The approach pipe is made of paved corrugated steel approximately 447 feet long, while the diffuser pipe is made of unpaved corrugated steel 80 feet long. The upstream diffuser pipe section is half buried in the river bottom and extends its entire length of 80 feet beyond the dead end of the downstream diffuser pipe section. The port diameter, spacing, and orientation of the upstream leg is the same as that of the downstream leg.

The location of the diffuser system at TRM 527.8 is given in Figure A.5. Both the upstream and downstream legs are located beneath the navigation channel. For a detailed description of the diffuser design and operation see Ungate (1976). For results of hydrothermal model tests of the diffusers see Ungate (1977).

3. Blowdown Discharge Rates

To maintain the concentration of dissolved solids in the cooling tower basins at approximately twice that found in the Tennessee River, blowdown discharge from the cooling tower basins is between 44.6 cfs and 85.0 cfs. During periods of zero release from WBH, blowdown is routed into a yard holding pond of approximately 190 acre-feet capacity. When discharge from WBH is greater than 3,500 cfs, discharge of blowdown through the diffusers into the river is resumed. The yard holding pond discharge rate is between 60.2 and 85.0 cfs. Combined blowdown and holding pond discharge can range between 44.6 and 170 cfs.

4. Operating Characteristics of the Diffuser Legs

Table 5 contains the operating characteristics of the diffuser legs such as maximum and minimum flows, the average jet exit velocity, approach pipe velocity, and the required head. It shows that the average jet exit velocity varies from 6.8 to 17.3 feet per second (fps) for all operations.

TABLE 5

Design Characteristics of Blowdown Diffusers
for Normal Operation

OPERATING PARAMETERS	Minimum	Maximum
Blowdown Discharge Rate	44.6 cfs 28.8 Mg/d	170.0 cfs 109.9 Mg/d
Port Velocity (fps)	6.8	17.3
Appeoach Pipe Velocity (fps)	2.3	5.9
Dead End Head (ft)	1.6	10.4
Diffuser Head Required (ft)	1.7	11.1
Total Head Required from Wye (ft)	1.8	12.1

III. HYDROTHERMAL ANALYSES

Due to the unique configuration of having a dam, a fossil plant, and a nuclear plant located in close proximity to each other, the effects of the individual and combined fossil and nuclear discharges on the river temperature (near-field) are evaluated.

A. Watts Bar Fossil Plant Thermal Discharge

1. Future Watts Bar Fossil Plant Operation

Currently Watts Bar Fossil Plant is mothballed. There are no schedules for unit start up. The units are being considered for a solid waste burning facility. However, the project is only in the initial exploration stage. A waste-fired plant is not anticipated to have a higher heat discharge than the previous coal-fired operation.

2. Watts Bar Fossil Plant 316a Variance

The Environmental Protection Agency granted TVA a 316a variance for WBF once-through cooling operation in 1975 (Zeller, 1975). The variance was based in part on water temperature surveys (Tennessee Valley Authority, 1974). The WBF NPDES permit issued in 1984 (with continued 316a variance) has a daily average discharge limit of 90°F (32.2°C).

3. Effects of Watts Bar Fossil Plant on Water Temperatures

Although WBF is not currently on-line, there is a possibility of some form of renewed operation in the future. Because the thermal discharge characteristics of any future fossil plant operation are unknown, predictive modeling efforts utilize the cooling water flow and temperature rise of the past operation. Thus, the discharge analyzed conforms to the previous full load fossil plant discharge of 626 cfs with a 10 F° (5.6 C°) temperature rise, which equates to adding 1.4×10^9 Btu/hr heat to the river.

4. River Temperature Analysis

Ungate and Howerton (1977) provide the most complete analysis of the fossil plant discharge together with field measurements. Using the surface jet model of Shirazi and Davis (1974), Ungate and Howerton analyzed the initial mixing zone of the discharge. The initial mixing zone extended between 300 and 800 ft downstream of the discharge depending on the ambient flowrate. At the edge of the initial mixing zone, calculated temperature rises for the plume centerline were between 1 and 5 F° (0.6 and 2.8 C°), and for the average of the whole plume were between 0.5 and 3 F° (0.3 and 1.7 C°).

At higher ambient flows and higher pool elevations, the calculated temperature rises were smaller. Temperatures beyond the initial mixing zone were not presented. **B.**

Additionally, Ungate and Howerton (1977) described field observations of the fossil plant discharge during and immediately following a prolonged period of zero river flow. Periods of zero flow can extend 12 hours or longer as WBH operates for peaking power purposes. Under zero flow conditions, the heated discharge is not advected downstream. The river in the fossil plant vicinity is gradually heated as the discharge re-entrains itself.

The field observations made on October 30, 1977, included studies of the river during and after a 12-hour flow shutdown, while all four WBF units were operating. The observed longitudinal excess water temperature is shown in Figure A.6, along with measurements made during a 6-hour shutdown on March 16, 1974. The effect of the extended duration is to increase the longitudinal extent, but not the maximum value, of the excess temperature of the warm water slug. The downstream edge of the warm water slug proceeded downstream as a stratified surface layer, causing less than a 1.0 F° (0.6 C°) temperature rise in the vicinity of the nuclear plant discharge at TRM 527.8. Upstream of the discharge, no significant difference in the excess temperature distribution was observable for the two shutdown durations. Apparently the excess temperature distribution upstream of the discharge attains a steady-state condition after six hours of zero river flow.

Once flow at WBH is resumed after a shutdown, the warm water slug is advected downstream. Figure A.7 shows field measurements and model predictions of the river temperature presented by Ungate and Howerton (1977) for resumed flow following the October 30, 1977, shutdown. The field survey and model predictions show that after an extended period of no flow (12 hours), the discharge from WBF caused a temperature rise of almost 3.0 F° (1.7 C°) at the WBN diffuser location. During the critical summer months the temperature rise would be less because the discharge is submerged and, in rising to the surface, the discharge entrains a greater volume of the ambient water.

5. Summary of Effects for Combined Evaluation

A conservative approach was taken to estimate the downstream impact of the discharge for the combined operation of the fossil and nuclear plants. A 3.0 F° (1.7 C°) temperature increase over the ambient was used to quantify the impact of the fossil operation at the nuclear diffuser. The 3.0 F° (1.7 C°) increase is greater than the observed increase after a 12-hour shutdown. In mid-summer, the increase should be less than 3.0 F° (1.7 C°) due to the higher pool and the associated discharge submergence which provides a greater available volume of water for dilution.

B. Watts Bar Nuclear Plant Thermal Discharge

1. Near-Field Effects of Diffuser Discharge on River Temperature

The thermal effects of the WBN discharge on Chickamauga Reservoir depend on the ambient river flow temperature and surface elevation and the discharge flow and temperature through the WBN diffusers. A computer model was used to simulate the thermal effects of WBN under several scenarios for WBF and WBN plant operations for the ambient river and atmospheric conditions of the period from January 1, 1976 through October 15, 1993. River flows and elevations, WBN discharge temperatures and flows, and the resulting downstream river temperatures were calculated for each hour of this period.

2. Computer Model Inputs

a. Meteorological Data

Hourly wet-bulb and dry-bulb temperatures were obtained from National Weather Service meteorological records at Chattanooga airport for January 1, 1976, through October 15, 1993. The Chattanooga airport is the closest airport south (conservative meteorology) of the Watts Bar site. The airport at Knoxville is closer to the Watts Bar site but is north of the site, and may be cooler.

b. Watts Bar and Chickamauga Hydro Releases and Chickamauga Headwater Elevation

Hourly releases from Watts Bar and Chickamauga Hydros, and the headwater elevation at Chickamauga Hydro, were obtained from TVA records for January 1, 1976 through October 15, 1993.

c. Reservoir Elevations at WBN Site

The discharge flowrate through the WBN diffusers depends on the difference in elevation between the river surface at WBN and the water surface in the WBN holding pond. During periods of discharge from WBH, the river elevation at WBN can be lower than WBH tailwater elevation (Figure A.8). Therefore, river flow and river elevations at WBN were calculated on an hourly basis using an explicit one-dimensional unsteady numerical flow routing model (Ferrick and Waldrop, 1977). Hourly discharges from WBH and Chickamauga Hydro and the headwater elevation at Chickamauga Hydro were used as boundary conditions. The model was calibrated using field measurements of river elevation at WBN for the month of August 1993 (Figure A.8).

d. River Temperatures Upstream of the Nuclear Plant Site

WBH release temperatures were generated by TVA's System Temperature (SYSTEMP) model (Alavian and Ostrowski, 1991) using the above meteorological data. The SYSTEMP model has previously been used to estimate probable extreme intake temperatures at WBN (Alavian and Potter, 1992). An example of computed versus measured WBH release temperatures from that study is shown in Figure A.9. The computed WBH release temperatures were used as the ambient river temperature at WBN for the scenarios with no WBF operation. For scenarios where WBF was assumed operational, these temperatures were incremented by the estimated maximum river temperature rise of 3.0 F° (1.7 C°) due to the WBF discharge (Section III.A.5).

e. WBN Blowdown Flow and Temperature

The diffuser discharge flow and temperature depend on the reactor power levels of each unit; the flowrates and temperatures of the condenser cooling water (CCW), essential raw cooling water (ERCW), and raw cooling water (RCW) systems; the surface elevations of the yard holding pond and Chickamauga Reservoir; the ambient wet-bulb and dry-bulb temperatures; and the intake temperature of the ERCW and RCW systems.

Hourly values of tower blowdown flow and temperature were computed using steam turbo-generator and cooling tower performance calculation methods (Benton, 1992). Two-unit WBN operation at full design load was assumed. In cases where the turbine backpressure limit of 5.5 inches of mercury would be exceeded, the unit loads were reduced to meet the backpressure limit. Cooling tower capabilities of 89 percent were assumed for both towers. Condenser cleanliness factors of 85 percent were assumed for both units.

ERCW pump flowrates were assumed to be 21.7 cfs (9,740 gal/min) per pump. RCW pump flowrates were assumed to be 10.3 cfs (4,610 gal/min) per pump. These flowrates assume 10 percent degradation from design capacity as indicated in the ERCW Design Criteria and RCW System Description (TVA Engineering Design, 1993; TVA Engineering Design, 1988). ERCW and RCW system intake temperatures were assumed equal to the ambient river temperature.

The diffuser discharge was computed with a pipe flow routing program which distributes the flow between diffuser legs by balancing the head between the pond and the river. The program simulates the operation of the yard holding pond in a manner such that flow conservation is maintained for all discharges entering the blowdown system from the cooling towers. It was assumed that both diffuser legs were operated whenever diffuser discharge was permitted.

3. Model Results

The heated effluent dilution caused by the interaction between WBN submerged diffusers and the river was computed using an analytical expression (Adams, 1972) described in Ungate and Howerton (1977). Two operational scenarios were investigated. For both scenarios, hourly WBN discharge temperature and flow, and downstream river temperature, temperature rise, and rate of change were calculated for the period from January 1, 1976 through October 15, 1993. Results of simulation for each scenario are given below:

a. Scenario 1 - Operation of WBN under the current discharge restrictions (no WBN diffuser discharge when WBH discharge is less than 3,500 cfs) and no WBF plant operation.

   In this scenario, WBF is not operating and no discharge from the WBN diffusers is allowed if the WBH discharge is less than 3,500 cfs (one-half unit operation). During periods when the WBH discharge is below this level, cooling tower blowdown flow is routed into the yard holding pond. The pond can accumulate blowdown water for approximately 30 hours before overtopping the overflow weir. The actual time available before overflow varies with plant pump operation, the percentage of cooling tower flow which is lost to evaporation, river elevation, and the initial level of water in the pond.

   The maximum pond elevation which occurred under this scenario was 708.05 feet on September 26, 1988 at 1200 hours, corresponding to an overflow weir discharge of 60 cfs (Figure A.10). The maximum diffuser discharge of 165 cfs, a combination of 65 cfs blowdown from the towers and 100 cfs flow from the yard holding pond, occurred on September 26, 1988 at 1300 hours. The maximum total discharge from the plant occurred at the same time, with an additional 25 cfs being discharged from the overflow weir for a total discharge rate of 190 cfs (Figure A.11).

   The maximum upstream river temperature for this scenario was 82.5°F (28.1 C°) on July 29, 1993. The maximum downstream river temperature of 82.6°F (28.1 C°) occurred on the same date (Figure A.12). The maximum downstream river temperature rise was 1.8 F° (1.0 C°) on February 3, 1986 (Figure A.13). The maximum diffuser discharge temperature was 97.3°F (36.3 C°) on July 13, 1980 (Figure A.14). Minimum, average, and maximum monthly values for the downstream temperature rise, downstream temperature, and discharge temperature are shown in Table 6.

b. Scenario 2 - Operation of WBN under the current discharge restrictions (no WBN diffuser discharge when WBH discharge is less than 3,500 cfs) but with WBF plant operation.

TABLE 6

Summary of Results (Scenario 1)
Downstream Temperature, January 1, 1976 to October 15, 1993

Assumptions: No WBF operation, no WBN discharge when WBH release is < 3,500 cfs

Month	Temperature Rise F°			River Temperature °F			Discharge Temperature °F		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Jan	0.0	1.6	0.2	34.9	58.4	42.0	43.0	80.6	64.3
Feb	0.0	1.8	0.3	35.1	51.3	41.9	50.8	83.5	66.6
Mar	0.0	1.7	0.3	37.7	56.7	47.7	51.3	87.0	70.8
Apr	0.0	1.4	0.3	48.7	65.6	56.7	59.1	88.1	75.1
May	0.0	1.0	0.2	57.8	72.4	64.5	64.9	91.5	79.9
Jun	0.0	0.9	0.2	62.3	79.1	70.7	70.1	94.0	84.5
Jul	0.0	0.7	0.1	66.2	82.6	74.9	76.2	97.3	86.8
Aug	-0.1	0.4	0.1	70.8	81.8	76.5	74.5	95.4	86.0
Sep	-0.2	0.7	0.1	67.5	81.2	75.0	67.2	93.0	82.5
Oct	-0.3	0.9	0.1	58.2	76.8	68.0	59.1	90.3	75.5
Nov	-0.1	1.2	0.1	47.6	68.3	58.8	54.7	86.0	70.9
Dec	0.0	1.5	0.2	39.8	59.5	48.7	46.8	85.1	66.4

In this scenario, WBF is assumed to be operational, and the same restrictions on WBN diffuser discharge apply as in Section III.B.3.a. The upstream river temperature for this scenario, incremented by the estimated maximum river temperature rise due to WBF operation (3 F°, 1.7 C°), resulted in a maximum upstream river temperature of 85.5°F (29.7 C°) on July 28, 1993. The maximum downstream river temperature of 85.6°F (29.8 C°) occurred on the same date (Figure A.15).

The maximum downstream river temperature rise for this scenario was 1.7 F° (0.9 C°) on February 3, 1986 (Figure A.16). The discharge temperature from a closed cycle plant is primarily determined by air temperature and plant load, and is relatively independent of the intake water temperature. Thus, the maximum diffuser discharge temperature for this scenario was the same as Scenario 1 (97.3°F, 36.3 C°, on July 13, 1980). Minimum, average, and maximum monthly values for the downstream temperature rise, downstream temperature, and discharge temperature are shown in Table 7.

4. Worst Case Combination of Ambient River and Air Temperatures and WBN Diffuser Operation

The WBN diffuser operation was analyzed for the combined worst case ambient river, air, and yard holding pond temperatures. The maximum value of upstream river temperature for full load operation of WBF was used (85.5°F, 29.7°C). The air temperature values at the time of maximum discharge temperature in the previous runs were used [dry- and wet-bulb temperatures of 102°F (38.9°C) and 85.0°F (29.4°C)]. A yard holding pond temperature of 104°F (40.0°C) was used (details are provided in Section III.B.6).

When WBN diffuser discharge is not permitted (WBH discharge is less than 3,500 cfs), the worst case discharge condition would occur at the beginning of a 3,500 cfs release from WBH after a period when the WBN pond has reached its maximum elevation. The resulting discharge from WBN was a combination of tower blowdown flow of 83.8 cfs at 97.3°F (36.3°C) and flow from the pond through the diffusers of 98.6 cfs at 104°F (40.0°C). The diffuser discharge flow of 182.4 cfs at 100.9°F (38.3°C) resulted in a river temperature rise of 0.9 F° (0.5 C°) and a downstream river temperature of 86.4°F (30.2°C) (Table 8).

If the maximum WBN-induced temperature rise (1.8 F°, 1.0 C°) is added to the 3 F° (1.7 C°) increase from WBF operation after resumed releases from WBN, the combined worst case temperature rise is 4.8 F° (2.7 C°).

TABLE 7

Summary of Results (Scenario 2)
Downstream Temperatures, January 1 to October 1993

Assumptions: WBF operation, no WBN discharge when WBH release is < 3,500 cfs

Month	Temperature Rise F°			River Temperature °F			Discharge Temperature °F		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Jan	0.0	1.5	0.2	37.9	54.8	45.0	43.0	80.6	64.3
Feb	0.0	1.7	0.2	38.1	54.3	44.9	50.8	83.5	66.6
Mar	0.0	1.6	0.2	40.7	59.5	50.7	51.3	87.0	70.8
Apr	0.0	1.2	0.3	51.7	68.5	59.7	59.1	88.1	75.1
May	-0.1	0.9	0.2	60.8	75.3	67.5	64.9	91.5	79.9
Jun	-0.1	0.7	0.1	65.3	82.0	73.7	70.1	94.0	84.5
Jul	-0.1	0.6	0.1	69.2	85.6	77.9	76.2	97.3	86.8
Aug	-0.2	0.3	0.1	73.8	84.7	79.5	74.5	95.4	86.0
Sep	-0.3	0.6	0.1	70.4	84.2	78.0	67.2	93.0	82.5
Oct	-0.4	0.8	0.1	61.2	79.7	71.0	59.1	90.3	75.5
Nov	-0.2	1.0	0.1	50.6	71.2	61.8	54.7	86.0	70.9
Dec	0.0	1.4	0.1	42.8	62.5	51.7	46.8	85.1	66.4

TABLE 8

Summary of Results - Watts Bar Nuclear Plant Thermal Discharge
Worst Case Steady-State Conditions with Continuous Discharge

Assumptions: Worst case meteorology, upstream, and pond temperatures; Loads adjusted for 5.5 in.-Hg limit; Maximum diffuser discharge flow

	Unit 1	Unit 2	Units 1 & 2
River flow (cfs)	--	--	3500
Velocity (fps)	--	--	0.227
Elevation (ft)	--	--	680.0
Dry-bulb temperature (°F)	--	--	102.0
Wet-bulb temperature (°F)	--	--	85.0
Relative humidity (%)	--	--	50.3
Intake temperature (°F)	--	--	85.5
Condenser cleanliness (%)	95.0	95.0	95.0
Tower capabilities (%)	89.0	89.0	89.0
CCW pumps	4	4	8
ERCW pumps	2	2	4
ERCW bypass (cfs)	0.0	0.0	0.0
RCW pumps	3	3	6
Loads (MWe)	960	960	1920
CCW inlet temperature (°F)	98.0	98.0	98.0
CCW outlet temperature (°F)	130.2	130.2	130.2
Turbine backpressure (in.-Hg)	5.5	5.5	5.5
Tower flows (cfs)	935	935	1870
Tower blowdown flows (cfs)	41.9	41.9	83.8
Tower discharge temperature (°F)	97.3	97.3	97.3
Pond elevation (ft)	--	--	708.1
Pond temperature (°F)	--	--	104.0
Diffuser discharge temperature (°F)	--	--	100.9
Diffuser discharge (cfs)	70.1	112.3	182.4
Overflow weir discharge (cfs)	--	--	65.9
Upstream temperature (°F)	--	--	85.5
Downstream temperature (°F)	--	--	86.4
Temperature Rise (F°)	--	--	0.9

5. Daily Average Discharge Temperature Limit

Experience with thermal discharges at TVA's other nuclear and fossil plants has shown that a daily average limit offers plant flexibility without adversely affecting the receiving water body. Changes in plant operations, adverse short-term weather patterns, and other factors can often cause unexpected spikes in water temperatures. Such temperatures are not representative of the effect of the thermal discharge on the water environment. All of TVA's fossil plants in Tennessee have a daily average discharge limit.

The modeling discussed in the previous section showed that even a steady-state discharge (up to 100.9°F, 38.3°C) under worst case conditions (worst meteorology on record, full load WBF Operation, and no WBH Operation) guarantees that the discharge after mixing will meet the State of Tennessee's thermal water quality criteria.

Table 9 shows the worst daily average discharge temperature in the two scenario simulations. Also shown is the maximum hourly discharge temperature. Based on these results and providing for a small margin of safety, TVA proposes a daily average discharge limit for WBN of 95°F (35°C).

6. Yard Holding Pond Temperature - Maximum Temperature Limit

During a period of zero discharge from the WBH, the blowdown is stored in the yard holding pond. The following assumptions were used to calculate the rise of pond water temperature:

a. zero discharge from WBH for 12 hours,
b. worst meteorological conditions (July 1952),
c. pond surface elevation at 707.0 feet,
d. pond bottom elevation at 688.0 feet,
e. no advection to cool the water, and
f. maximum blowdown temperature of 97.3°F (36.3°C).

The analysis results show that the pond water temperature could reach 104.0°F (40.0°C), and the water would discharge through the pond overflow weir if the pond elevation should reach above 707.0 feet (Figure A.17).

7. Thermal Impact of Yard Holding Pond Overflow on the River Temperature

CORMIX (Cornell Mixing Zone Expert System, NCASI, 1992), was used to model the mixing of the pond discharge through the overflow weir into the river. The following assumptions were used:

TABLE 9

Effects of Watts Bar Nuclear Plant Operation on River Temperature
Summary Results of Scenario Simulations

Scenario	Scenario Characteristics	Maximum Upstream Temperature (°F)	Maximum Downstream Temperature (°F)	Maximum Temperature Rise* (F°)	Maximum Hourly Discharge Temperature (°F)	Maximum Daily Average Discharge Temperature (°F)
1	No WBF operation, no WBN discharge when WBH release < 3500 cfs	82.5	82.6	1.8	97.3	93.3
2	WBF operation, no WBN discharge when WBH release < 3500 cfs	85.5	85.6	1.7	97.3	93.3

* Temperature rise due only to WBN thermal discharge

a. river at summer pool elevation of 682.0 feet,
b. ambient temperature of 84.5°F (29.2°C),
c. river at the low flow of 0.3 feet per second velocity,
d. pond discharge temperature of 104.0°F (40.0°C), and
e. pond flow of 60 cfs.

The modeling results indicate that a steady state was reached at about 3,000 feet, fully laterally mixed to the depth of 1.2 feet. The temperature rise in the plume is 1.3 F° (0.7 C°) which is lower than the State criteria of 5.4 F° (3.0 C°).

8. Nuclear Plant Mixing Zones and Zone of Passage

The permitted diffuser mixing zone at WBN extends 240 feet downstream over the entire river depth and diffuser system width (240 feet) for all discharge operations (Ungate and Howerton, 1977). Figure A.5 (from Ungate and Howerton, 1977) shows the diffuser location. The width of the Tennessee River at the nuclear plant site is about 1,000 feet. Previous studies of diffuser mixing considered river flows as low as 3,500 cfs.

The diffuser mixing zone will be confirmed by field observations for one-unit operation and later for two-unit operation. As shown in Figure A.5, there should be ample area for fish movement on the left (looking downstream) side of the river under all operating conditions. The navigation lock is also located on the left side of the river for fish movement past the dam (see Figure A.1).

The discharge from overflowing the yard holding pond takes longer to mix than the diffuser discharge. The proposed mixing zone for the surface discharge is 1,000 feet wide and extends 3,000 feet downstream. Because of the surface discharge, there should be ample area for fish movement below the surface plume.

9. Summary of Watts Bar Nuclear Plant Thermal Effects

Table 9 summarizes the results of the two operational scenarios evaluated. The maximum hourly downstream temperature was 85.6°F (29.8°C) and the maximum temperature rise was 1.8 F° (1.0 C°). Because the maximum hourly temperature rise is below 3.6 F° (2.0 C°), the plant-induced rate of temperature change will always meet the State rate of temperature change criteria of 3.6 F°/hour (2.0 C°/hour). The maximum hourly discharge temperature (97.3 F°, 36.3 C°), only dependent on meteorology, was the same in both scenarios.

The worst case conditions evaluated at steady-state showed that, even with a discharge of 100.9°F (38.3°C), the maximum downstream temperature of 86.4°F (30.2°C) is below the State criteria of 86.9°F (30.5°C). Based on the worst case steady-state results, the maximum daily averages shown in Table 9, and a small margin of safety, TVA proposes a daily average discharge limit of 95°F (35°C). TVA also proposes a pond overflow temperature limit of 104°F (40°C), which would be measured by grab sample once a day at the overflow weir during an emergency overflow.

The previously defined diffuser mixing zone is 240 feet wide and extends 240 feet downstream. Due to the location and width of the diffuser, ample space exists for fish to pass by the plant during all operations. The proposed mixing zone for the overflow discharge is 1,000 feet wide and extends 3,000 feet downstream. These evaluations will be confirmed by field investigations.

IV. THE COMBINED EFFECT OF WATTS BAR NUCLEAR AND FOSSIL PLANT DISCHARGES ON SEQUOYAH NUCLEAR PLANT

Sequoyah Nuclear Plant (SQN) is located about 45 river miles downstream of the Watts Bar facilities. A reservoir water quality model was used to determine the potential effects of the Watts Bar facilities on SQN intake temperatures and subsequent operation.

The impact of thermal discharges from WBN (TRM 527.8) and WBF (TRM 529.0) on SQN (TRM 484.5) operation was examined using the two-dimensional Chickamauga Box Exchange Transport Temperature and Ecology of a Reservoir (BETTER) model. The Chickamauga BETTER model was calibrated with three years of field surveys (1985, 1986, and 1987) and was verified using field data collected in 1988. A detailed description of the model and discussions on model calibration and verification can be found in Butkus, et al. (1990). The following worst case was selected to evaluate the effects of thermal discharges from WBN and WBF under 1986 (dry year) hydrology and meteorology, assuming the two units at SQN are in operation with a total condenser circulating water flow of about 3,000 cfs.

Both nuclear units were assumed in operation plus yard holding pond discharge at WBN and surface discharge at WBF. The maximum blowdown rate is about 85 cfs. Combined with the yard holding pond discharge, the maximum worst case total discharge amounts to 182.4 cfs (Table 8). The blowdown temperature is a function of the wet-bulb temperature and can be computed (from a curve fit of model results) as:

$$T_b = 17.1777 + 0.230339 T_d - (0.463474 \times 10^{-2}) T_d^2 + 0.250133 T_w \\ - (0.127615 \times 10^{-2}) T_w^2 + (0.94504 \times 10^{-2}) T_d T_w$$

where T_b is the blowdown temperature in °C, T_d is the dry bulb temperature in °C, and T_w is the wet-bulb temperature in °C. No ambient heating or cooling is assumed for the yard holding pond discharge. The blowdown and the yard holding pond discharge enter the river via two multiport diffusers with a combined length of about 240 ft.

When WBF is operated at rated capacity, the plant requires 626 cfs of cooling water and raises the temperature of water withdrawn through Watts Bar Dam by up to 10 F° (5.6 C°) (Ungate and Howerton, 1977). Because the elevation of the centerline of the turbines (elevation 676 feet, approximately 60 feet deep) is 40 feet below the fossil plant intake, water temperatures entering the fossil plant could theoretically be higher than water temperatures entering the turbines. A study of withdrawal thickness at WBH indicates that water from all depths enter the turbines, even when a warm surface layer is present in the summer months (TVA, 1972). The temperature difference between the fossil plant intake and the turbine discharge is, therefore, not considered to be significant. In this study, the temperature of water entering the fossil plant is assumed equal to the release temperature at WBH.

The combined effects of WBN and WBF thermal discharges can be evaluated by comparing water temperatures at the SQN intake (TRM 483.7-484.8) against that of a base run which does not include thermal discharges from WBN and WBF. As shown in Figure A.18, below the WBN and WBF thermal discharges (TRM 527.4-529.0), the average differences in the surface and bottom temperatures are about 1.3 F° (0.7 C°) and 0.5 F° (0.3 C°) even under extremely low flow conditions. A large increase in surface temperature of about 4.5 F° (2.5 C°) occurs in early July under reverse flow conditions. This reverse flow was computed based on the flat pool assumption and might not actually happen in the field. The temperature increase dissipates quickly as it flows downstream. At the SQN intake (Figure A.19), there is essentially no difference in the surface temperature, and the average difference in the bottom temperature is reduced to about 0.4 F° (0.2 C°). Immediately below the SQN diffuser (TRM 483.0-483.7), the average difference in the bottom temperature (Figure A.20) is reduced to about 0.2 F° (0.1 C°). With higher river flows, the combined impacts of WBN and WBF are expected to be less pronounced as the temperature increase would quickly dissipate due to dilution with larger flows. At Chickamauga Dam, the effect of WBN and WBF is almost indiscernible as demonstrated by the difference in release temperatures in Figure A.21.

The combined effects of WBN and WBF thermal discharges on SQN operation are expected to be small with an average increase in bottom temperature of about 0.4 F° (0.2 C°) under low river flow conditions. With higher river flows, the impact is expected to be less pronounced as the temperature increase would quickly dissipate due to dilution with larger flows. Therefore, operations of Watts Bar Fossil and Nuclear Plants are not anticipated to cause problems with Sequoyah Nuclear Plant's ability to meet safety or environmental temperature limits.

V. PROPOSED THERMAL LIMITS FOR WATTS BAR NUCLEAR PLANT

A. Proposed Diffuser Discharge and Overflow Pond Temperature Limits

TVA proposes a daily average thermal discharge limit of 95°F (35°C). TVA also proposes a pond overflow temperature limit of 104°F (40°C), measured at least once per day at the overflow weir. The 240-foot wide diffuser mixing zone extends 240 feet downstream. The proposed surface overflow mixing zone should be 1,000 feet wide and extend 3,000 feet downstream.

B. Monitoring and Reporting

WBN has continuous temperature and flowrate sensors to monitor the discharge before it enters the multiport diffusers. Plant instrumentation can record the hourly-averaged values of temperature and flowrate measurements. TVA proposes a daily average discharge temperature limit based on the flow-weighted average of the hourly temperature values measured during diffuser discharge. Flow weighting provides a true representation of the amount of heat being discharged. Daily reporting would include both average temperature and flowrate. Should the yard holding pond overflow, measurements of the discharge flowrate and temperature will be made by water level measurement and grab sample at least once per day at the overflow weir. Monthly Discharge Monitoring Reports would provide the maximum and mean daily average temperature and flowrate values.

TVA will calibrate the plant temperature sensors, flowrate monitors, and transfer electronics at least annually. Calibration records will be kept on-site for review.

C. Staged Field Verifications

TVA proposes to conduct field surveys of thermal conditions in stages as heated discharges are added at the Watts Bar site. Near-field surveys of one-unit WBN operation will be used to verify mathematical modeling assumptions used in this report. The near-field surveys will attempt to cover both worst-case summer (maximum downstream temperature) and winter (maximum temperature rise) conditions. Surveys will include steady one-unit releases (7,500 to 10,000 cfs) from WBH. Peaking operations will also be tested where WBH releases are curtailed at night for up to 16 hours, followed by one-unit hydro plant operation until steady-state conditions are reached. Appropriate conditions for these surveys may only be available during periods of normal to low rainfall. Heavy rainfall years may provide too much river flow in the system to schedule low WBH operations. TVA will attempt to finish the surveys within a year after full load operation.

The results of all field surveys will be sent to the State of Tennessee within six months of the survey. Reports will summarize the thermal surveys in tabular and visual formats. The surveys will be compared with mathematical model results to verify the assumptions used in this report. The surveys will also document the mixing zone and zone of passage.

Any field surveys that show exceptions to the assumptions used in this report will be documented. Revised mathematical models will then be used to re-create the evaluations in this report.

As units at WBF or the second unit at WBN are added, new near-field surveys of the combined thermal effects of plant operations will be made. Similar near-field surveys to those described above will be conducted during the summer and the winter of the first year of full load operation. Addition of other heat discharges will also be studied in a similar manner under worst-case summer and winter conditions.

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VII. APPENDIX

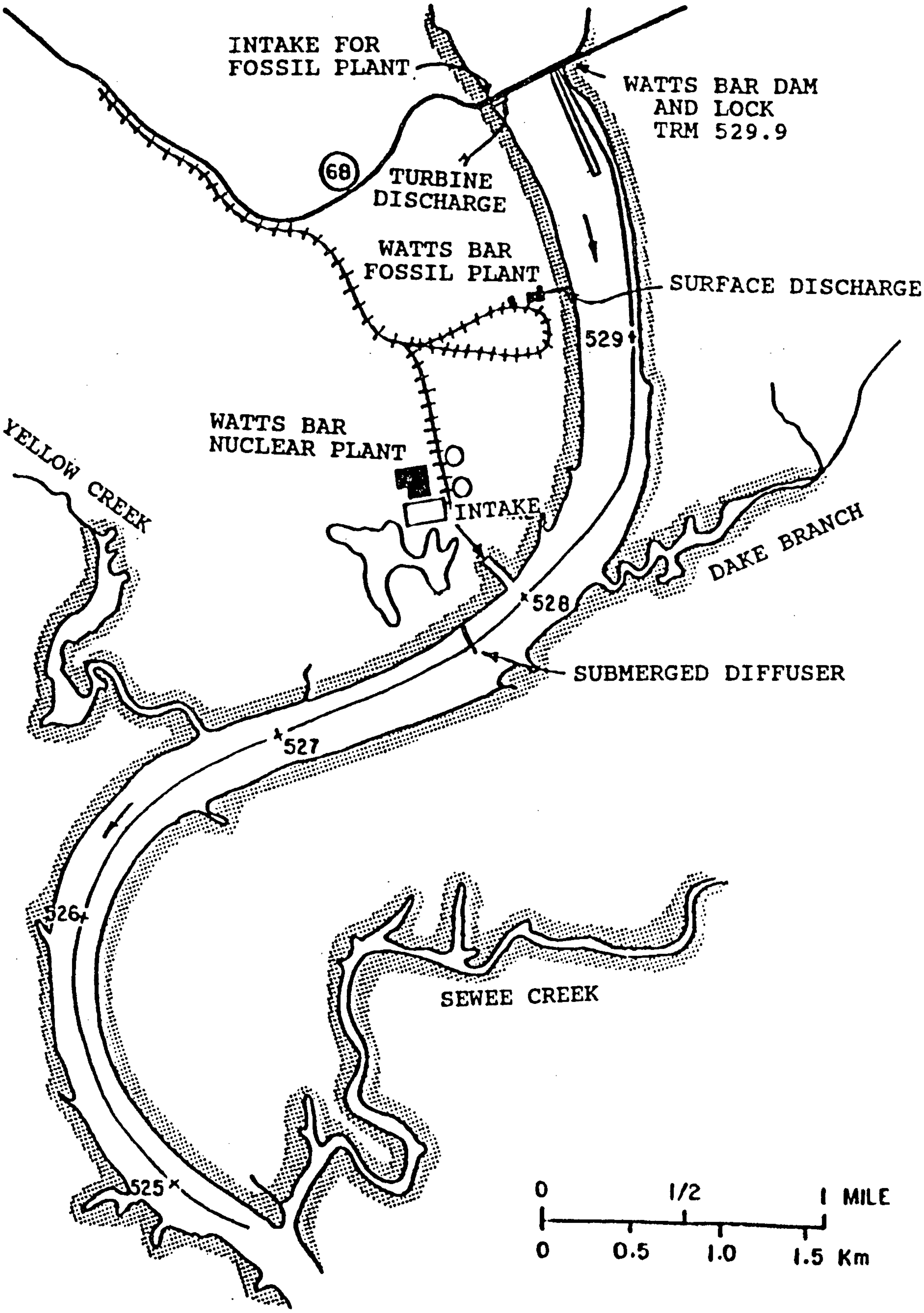


Figure A.1 Tennessee River Near Watts Bar Hydro Plant
(Ungate and Howerton, 1977)

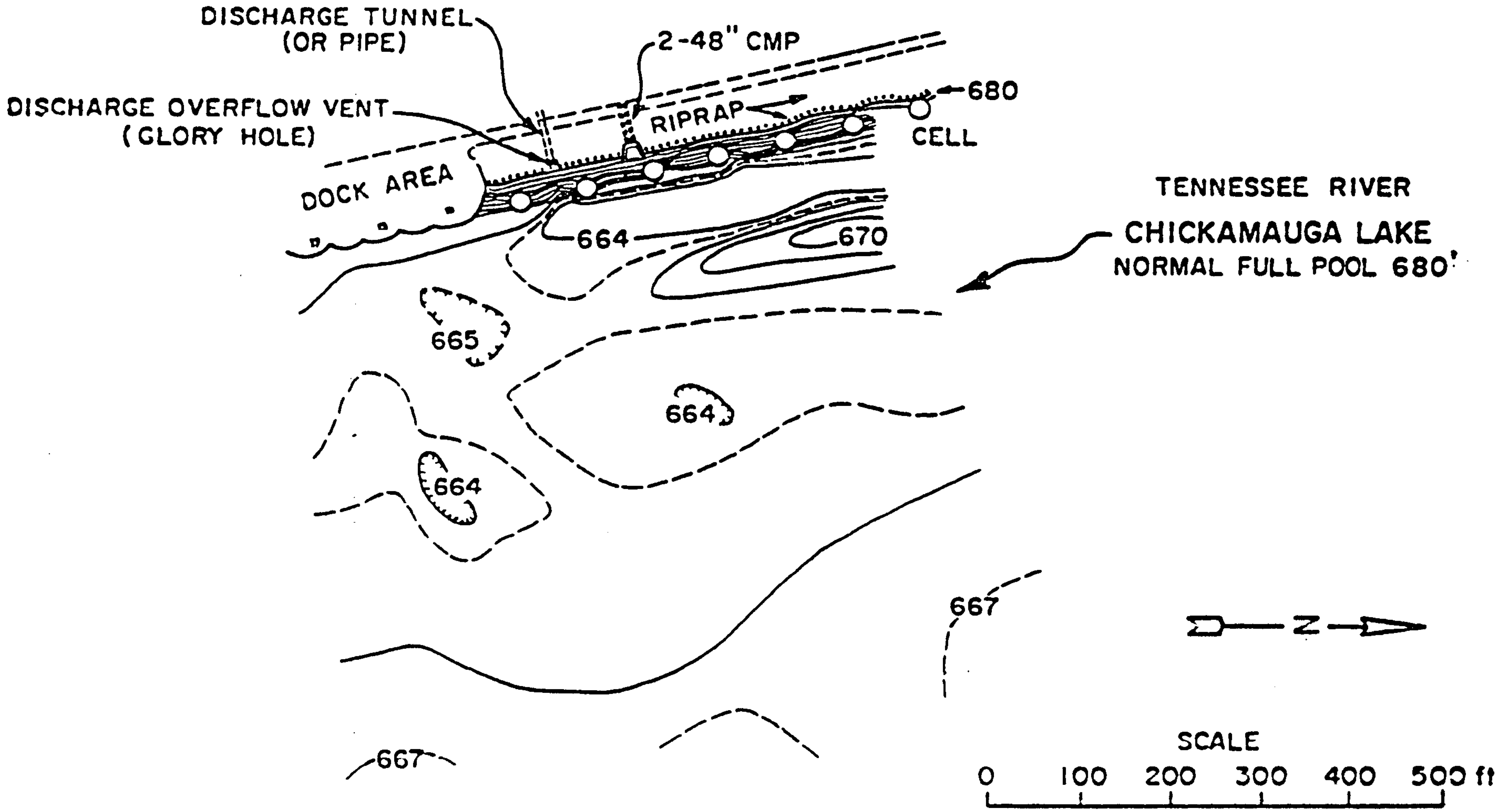


Figure A.2 WBF Condenser Water Discharge Area (Ungate and Howerton, 1977)

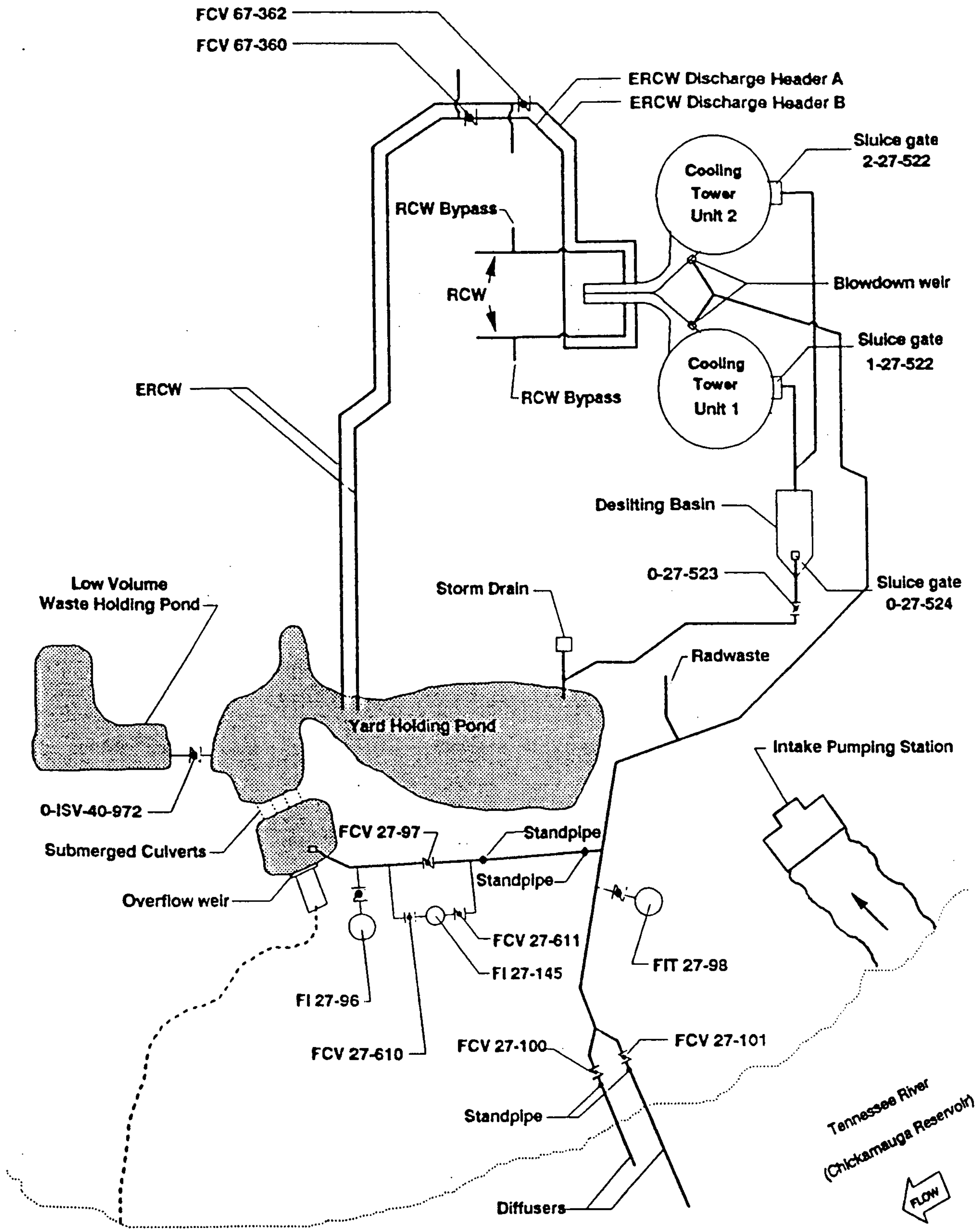


Figure A.3 WBN Cooling Tower Blowdown System

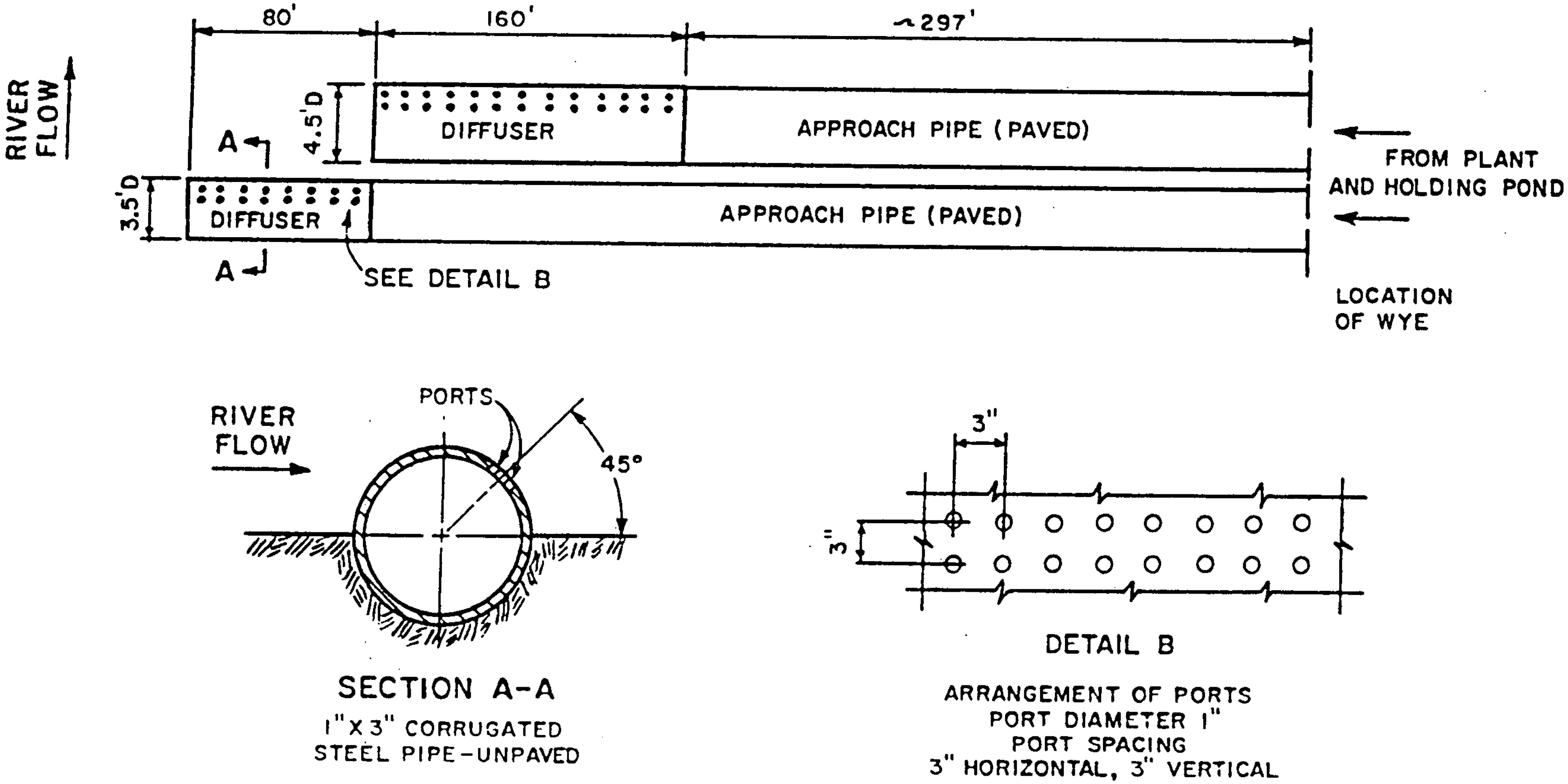


Figure A.4 Description of WBN Multiport Diffuser System (Ungate and Howerton, 1977)

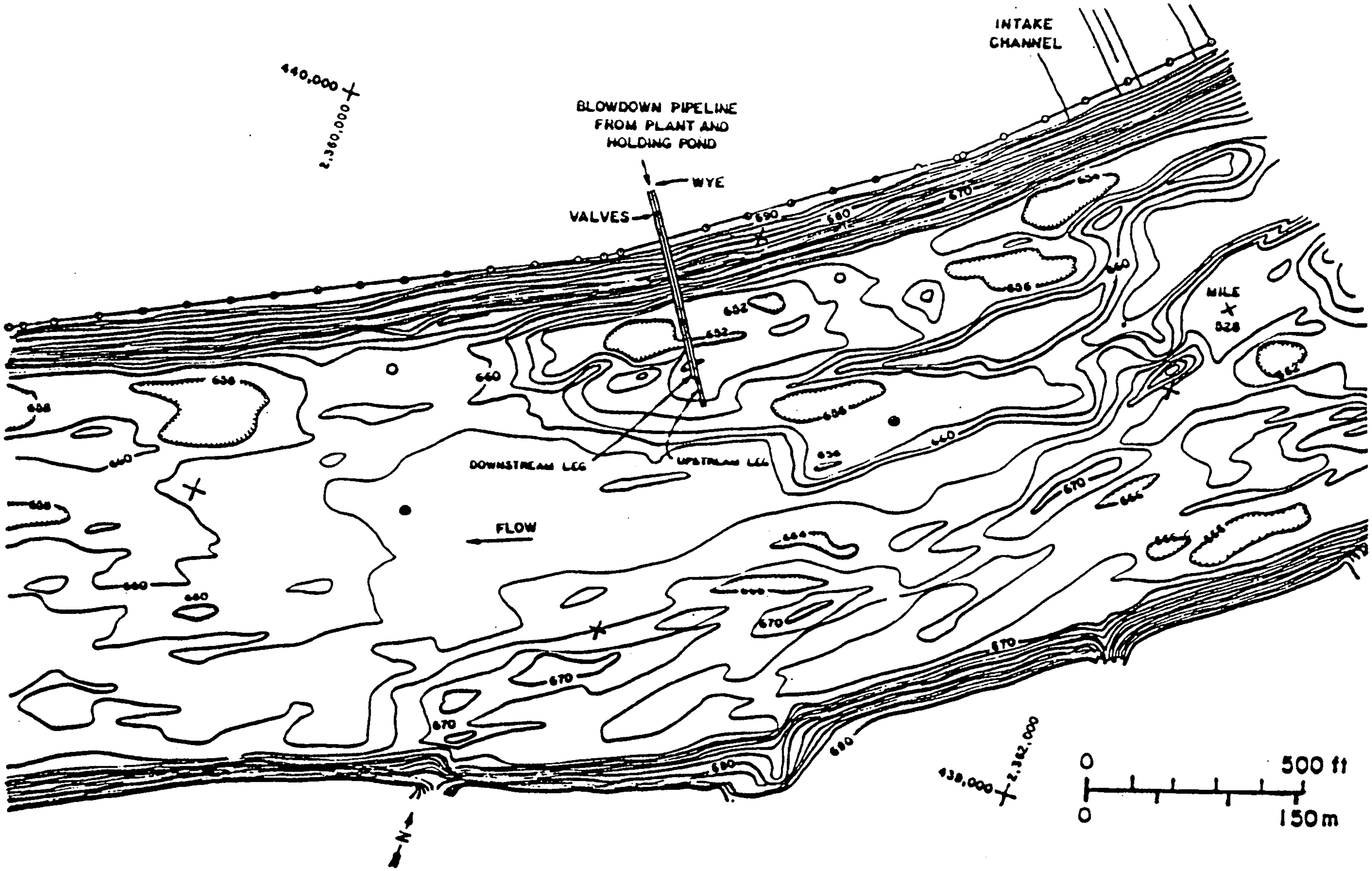


Figure A.5 Location of WBN Multiport Diffuser System, Tennessee River (Ungate and Howerton, 1977)

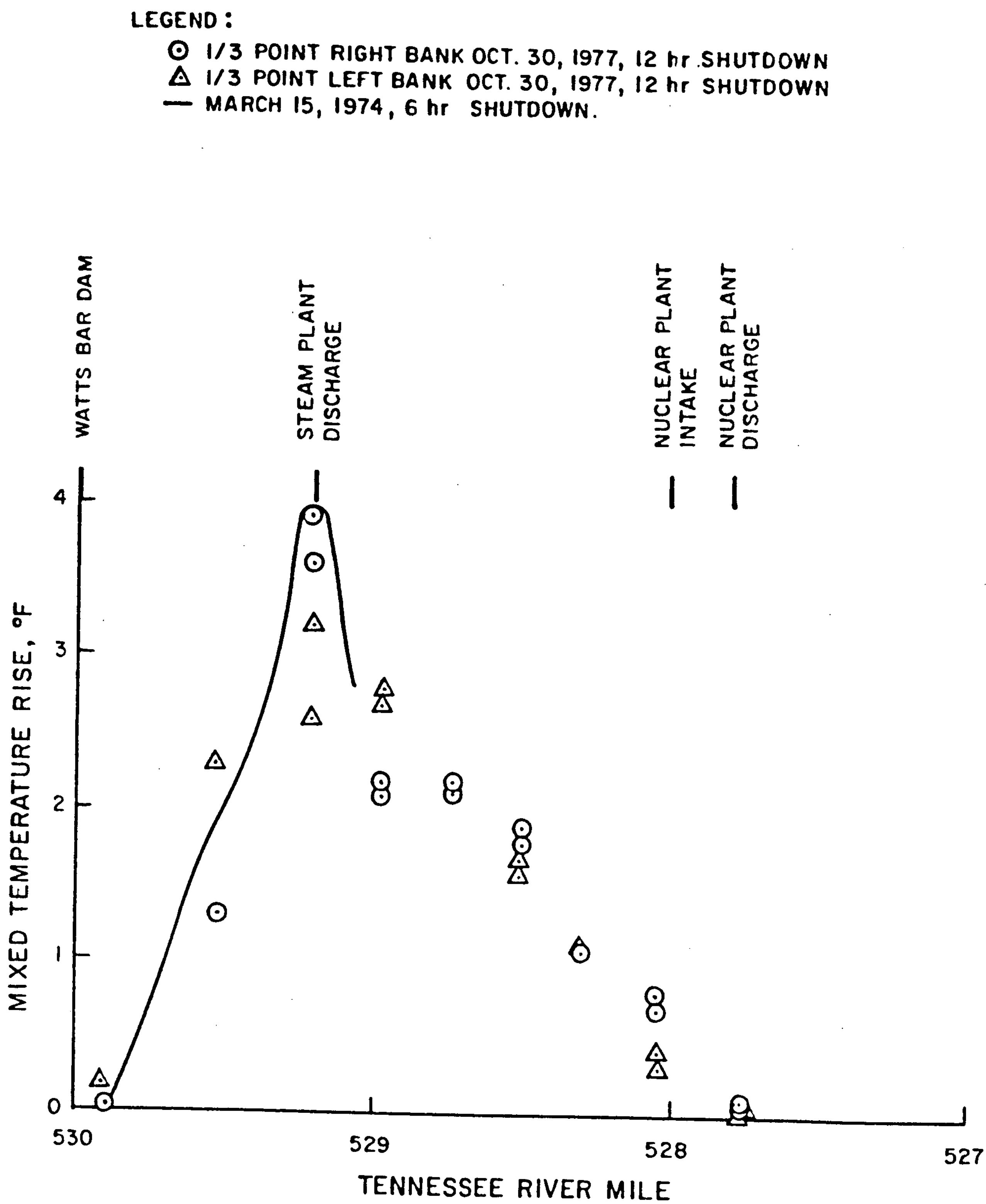


Figure A.6 Longitudinal Excess Temperature Distribution Below WBH After Periods of WBF Discharge and Zero River Flow (Ungate and Howerton, 1977)

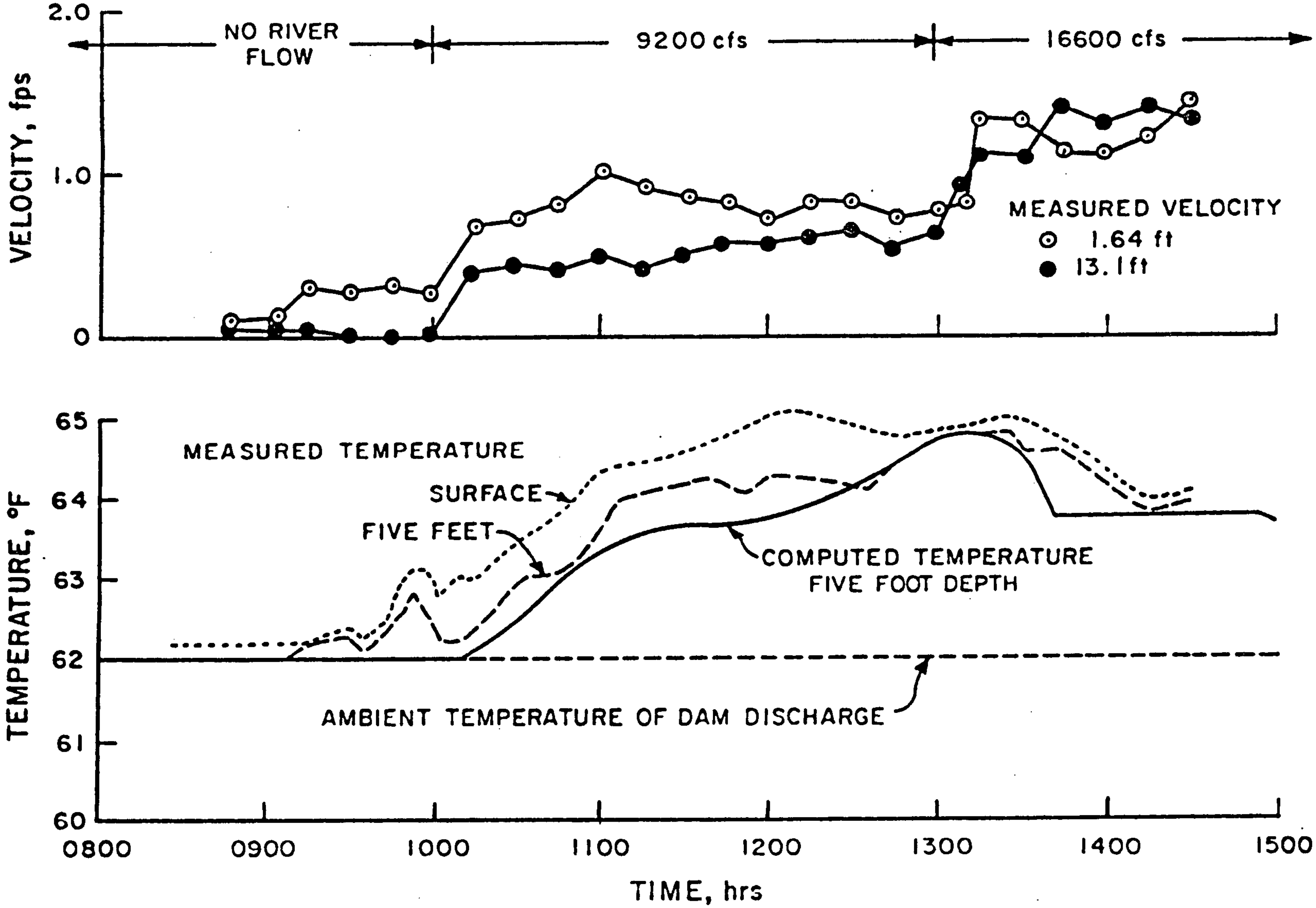
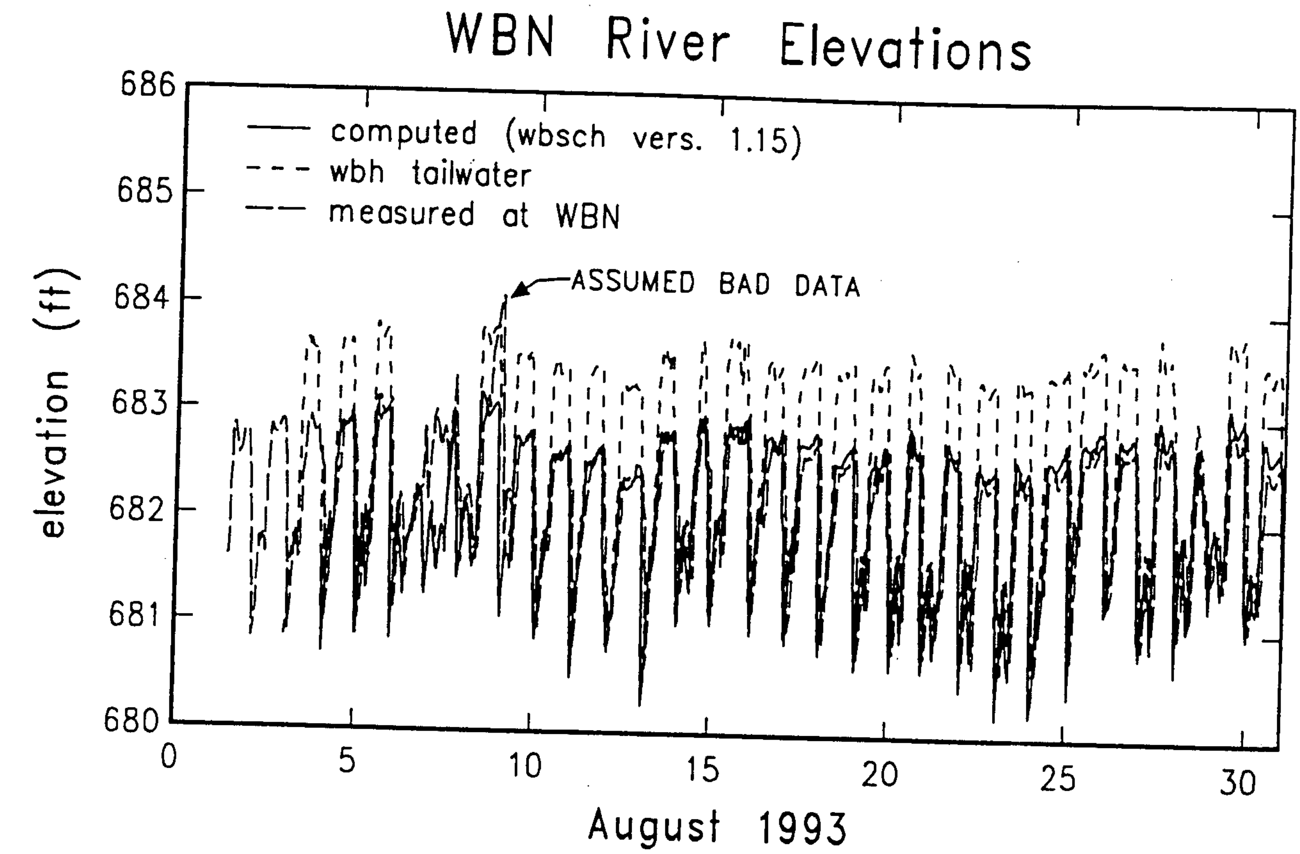


Figure A.7 Velocity and Temperature at TRM 527.8, October 30, 1977, After 12 Hours of Zero Flow from WBH (Ungate and Howerton, 1977)



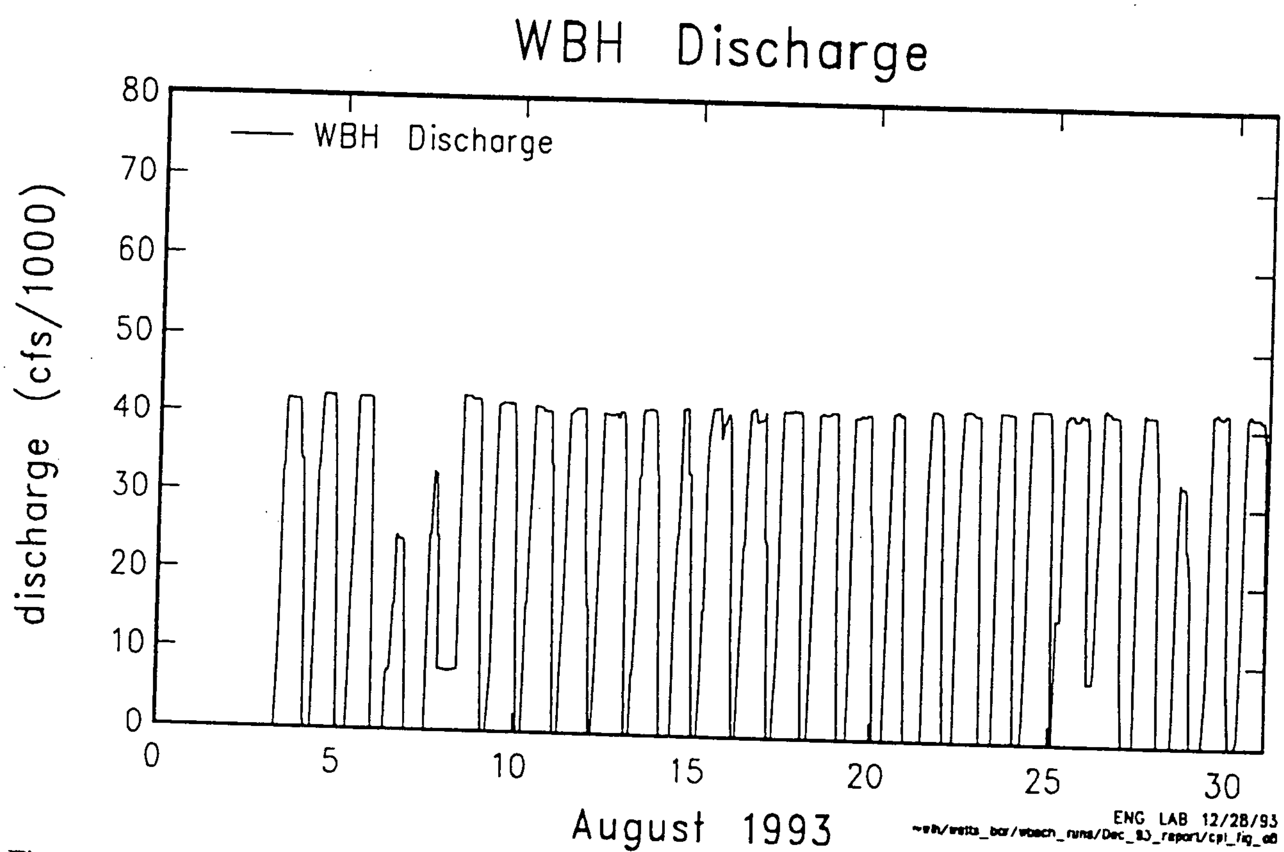


Figure A.8 Measured and Computed River Elevations in the Vicinity of WBN, and WBH Discharges During August 1993.

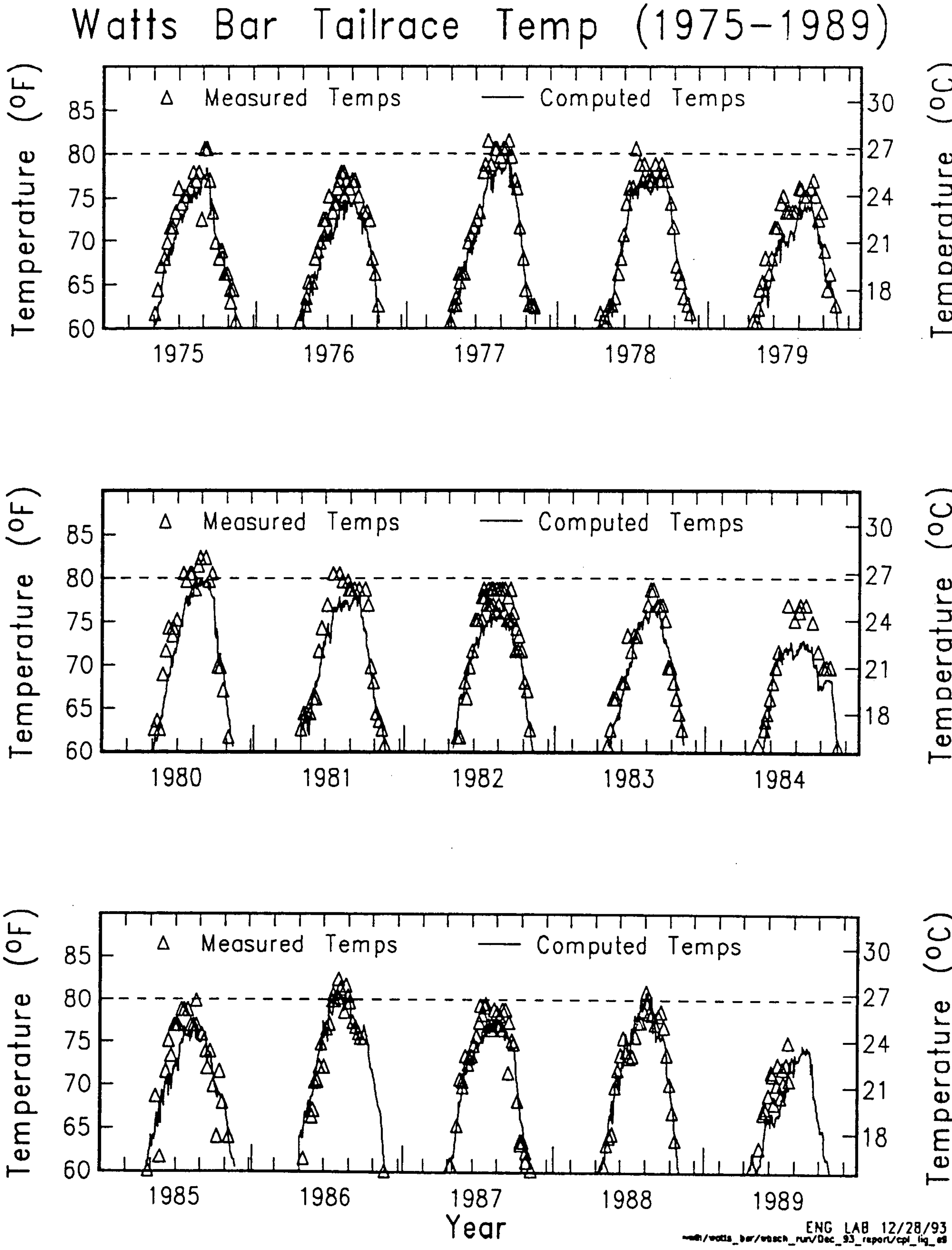


Figure A.9 Measured and Computed WBH Tailrace Temperatures, 1975-1989 (Alavian and Potter, 1992).

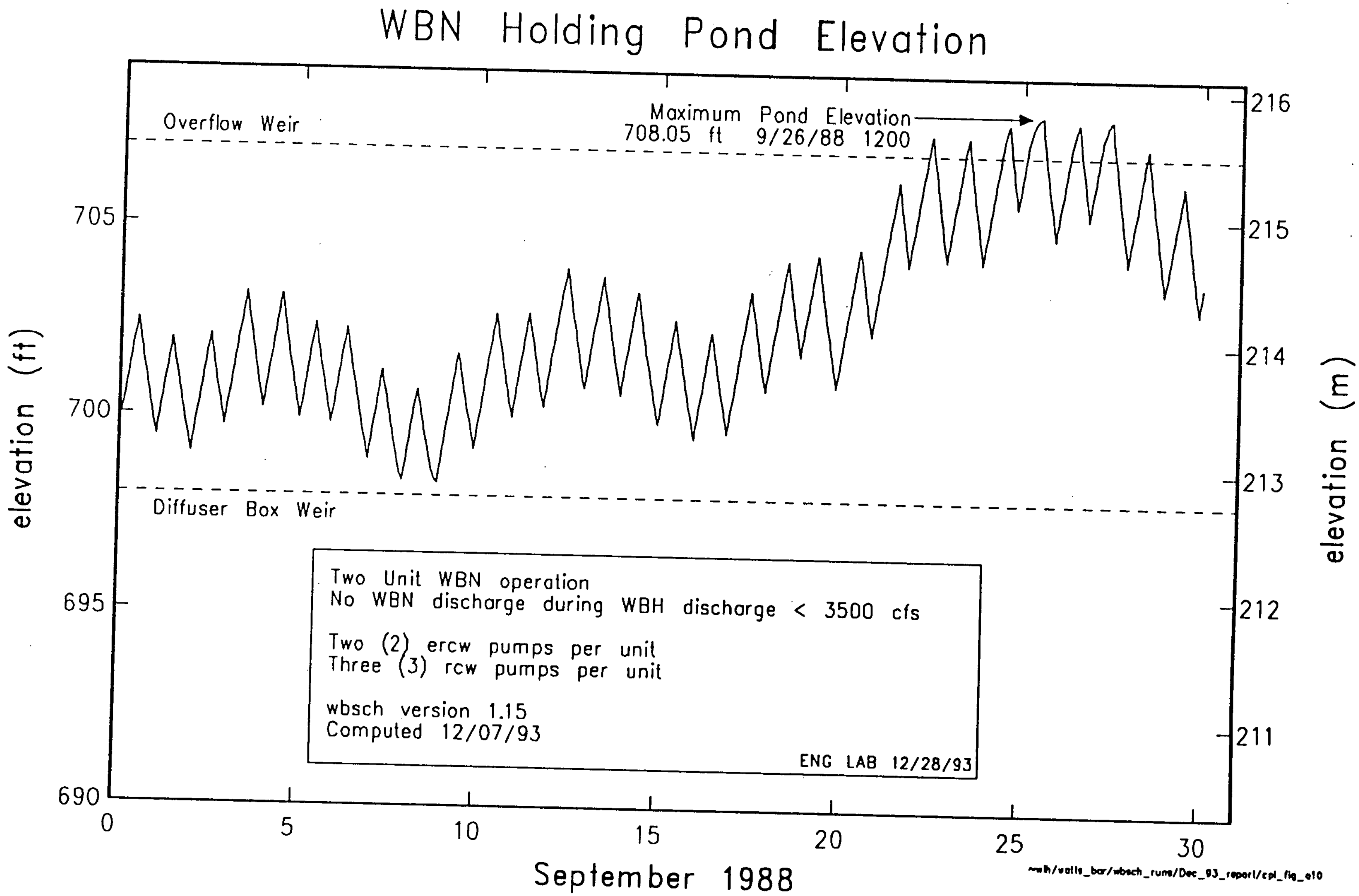


Figure A.10 WBN Yard Holding Pond Elevations During Month of Maximum Pond Elevation.

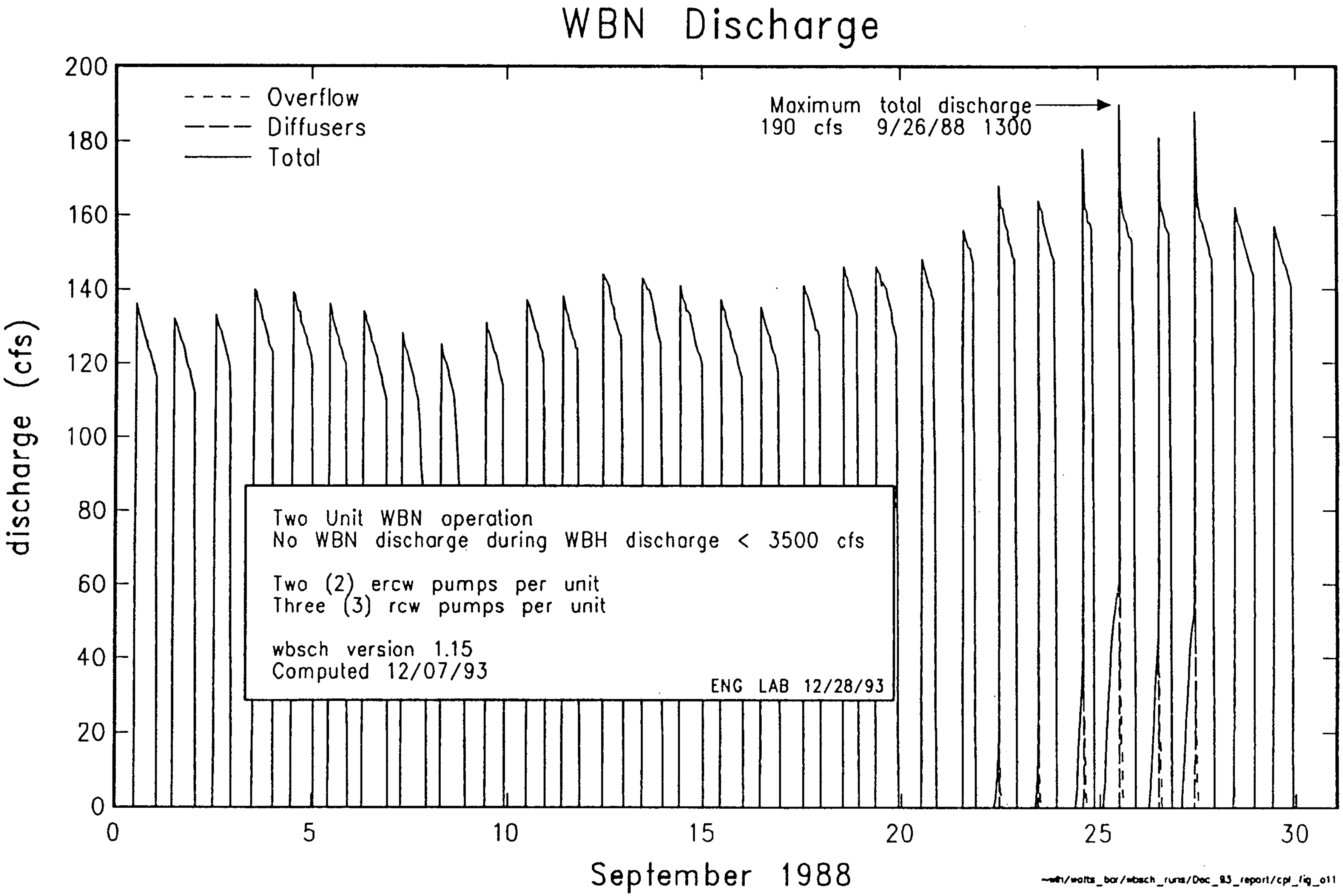


Figure A.11 WBN Thermal Discharge Flows During Month of Maximum Total Discharge With No WBN Discharge Permitted When WBH Release < 3500 cfs.

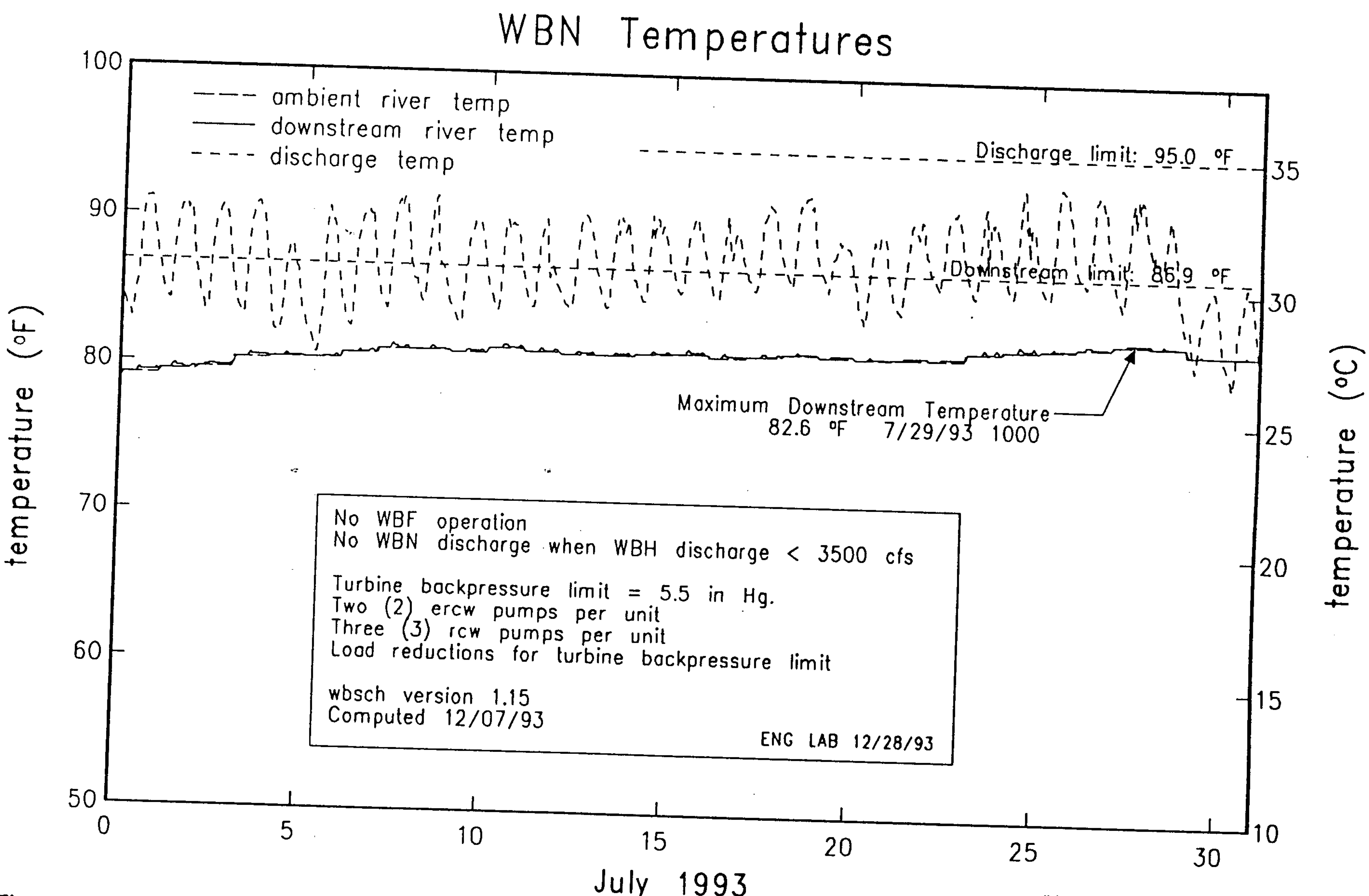


Figure A.12 WBN Temperatures During Month of Maximum Downstream Temperature With No WBF Operation and No WBN Discharge Permitted When WBH Release < 3500 cfs.

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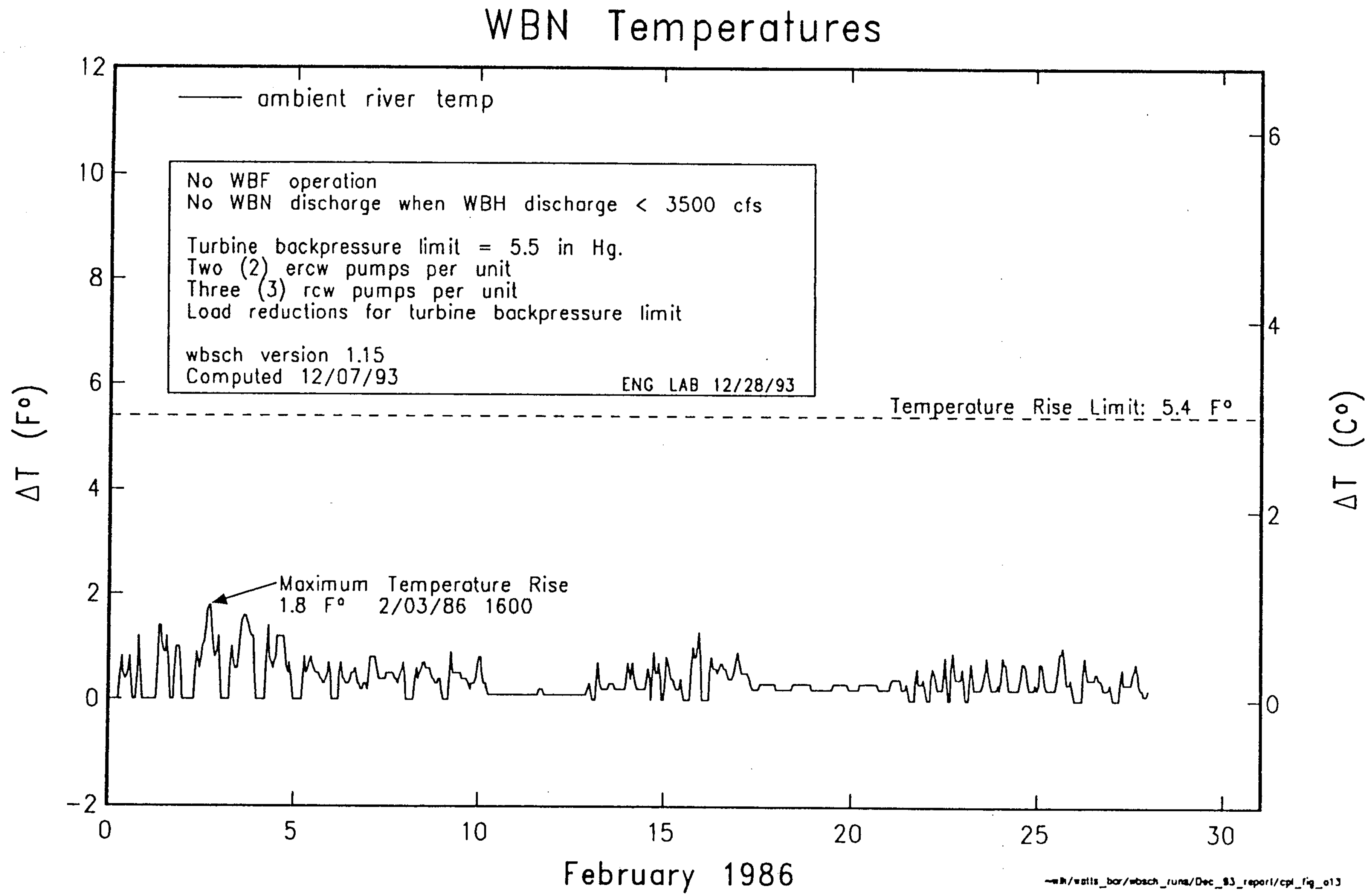
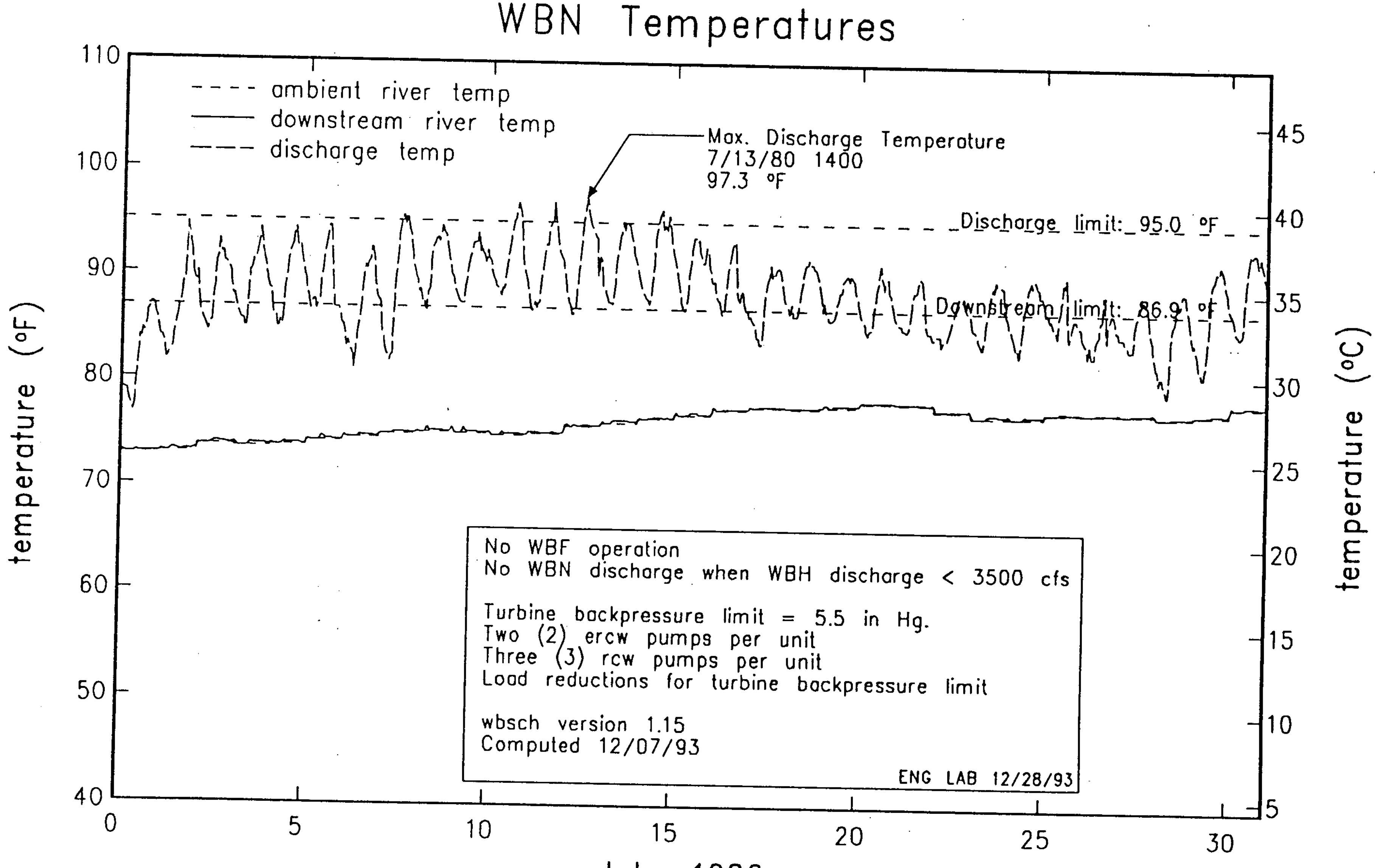


Figure A.13 WBN Downstream Temperature Rise During Month of Maximum Downstream Temperature Rise With No WBF Operation and No WBN Discharge Permitted When WBH Release < 3500 cfs.



~wh/watts_bar/wbsch_runs/Dec_93_report/cpt_fig_a14

Figure A.14 WBN Temperatures During Month of Maximum Discharge Temperature With No WBF Operation and No WBN Discharge Permitted When WBH Release < 3500 cfs.

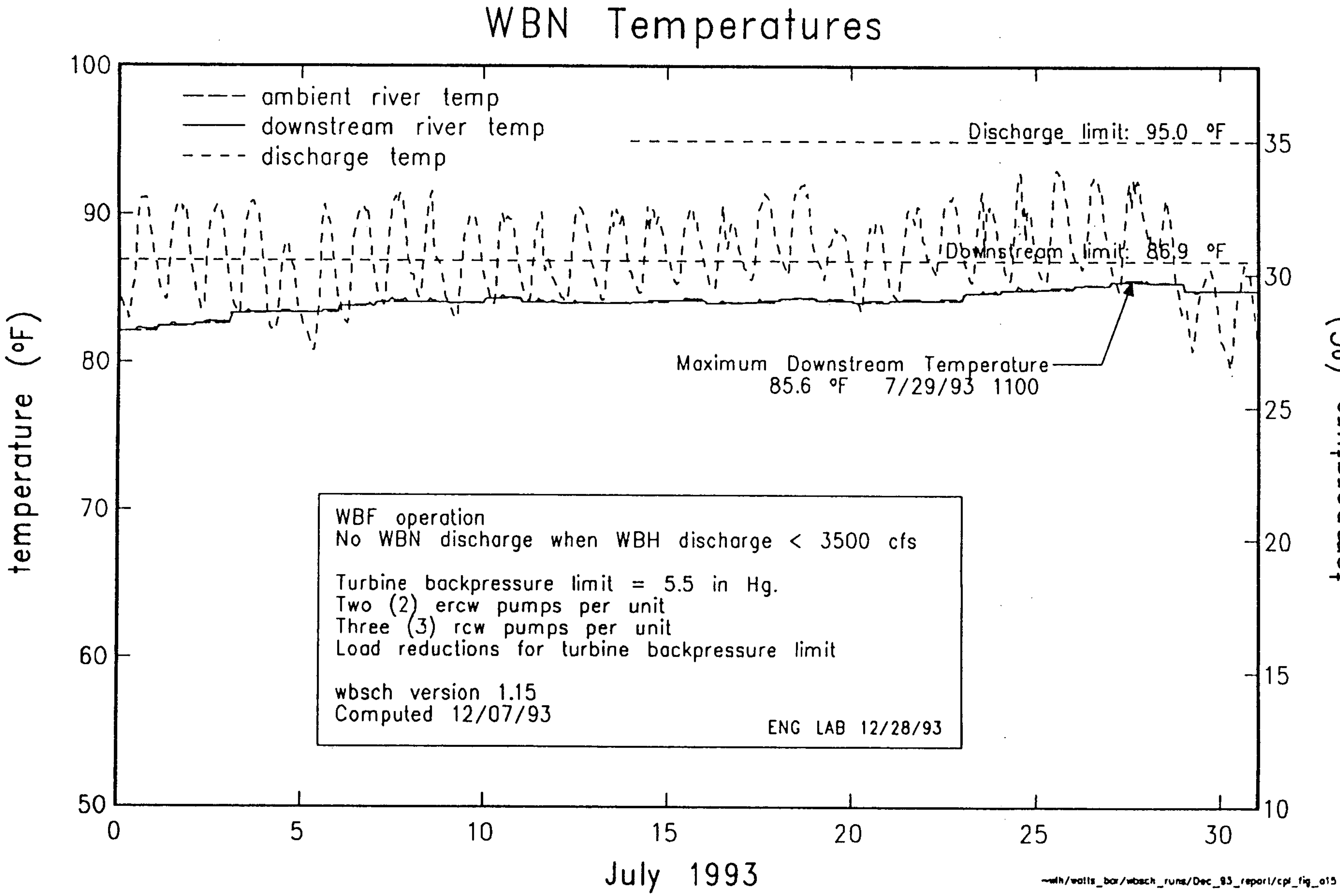


Figure A.15 WBN Temperatures During Month of Maximum Downstream Temperature With Full Load WBF Operation and No WBN Discharge Permitted When WBH Release < 3500 cfs.

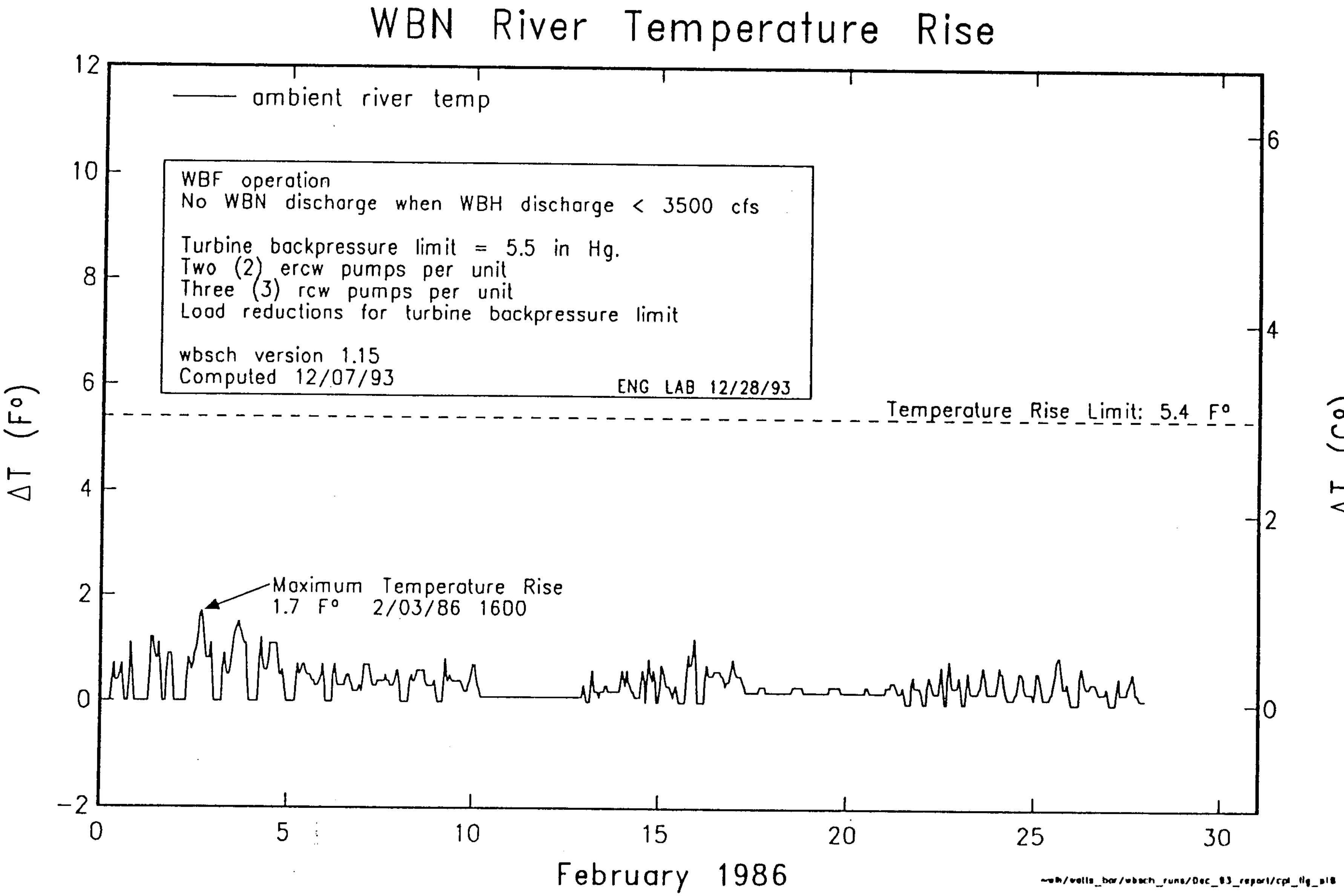


Figure A.16 WBN River Temperature Rises During Month of Maximum Temperature Rise With Full Load WBF Operation and No WBN Discharge Permitted When WBH Release < 3500 cfs.

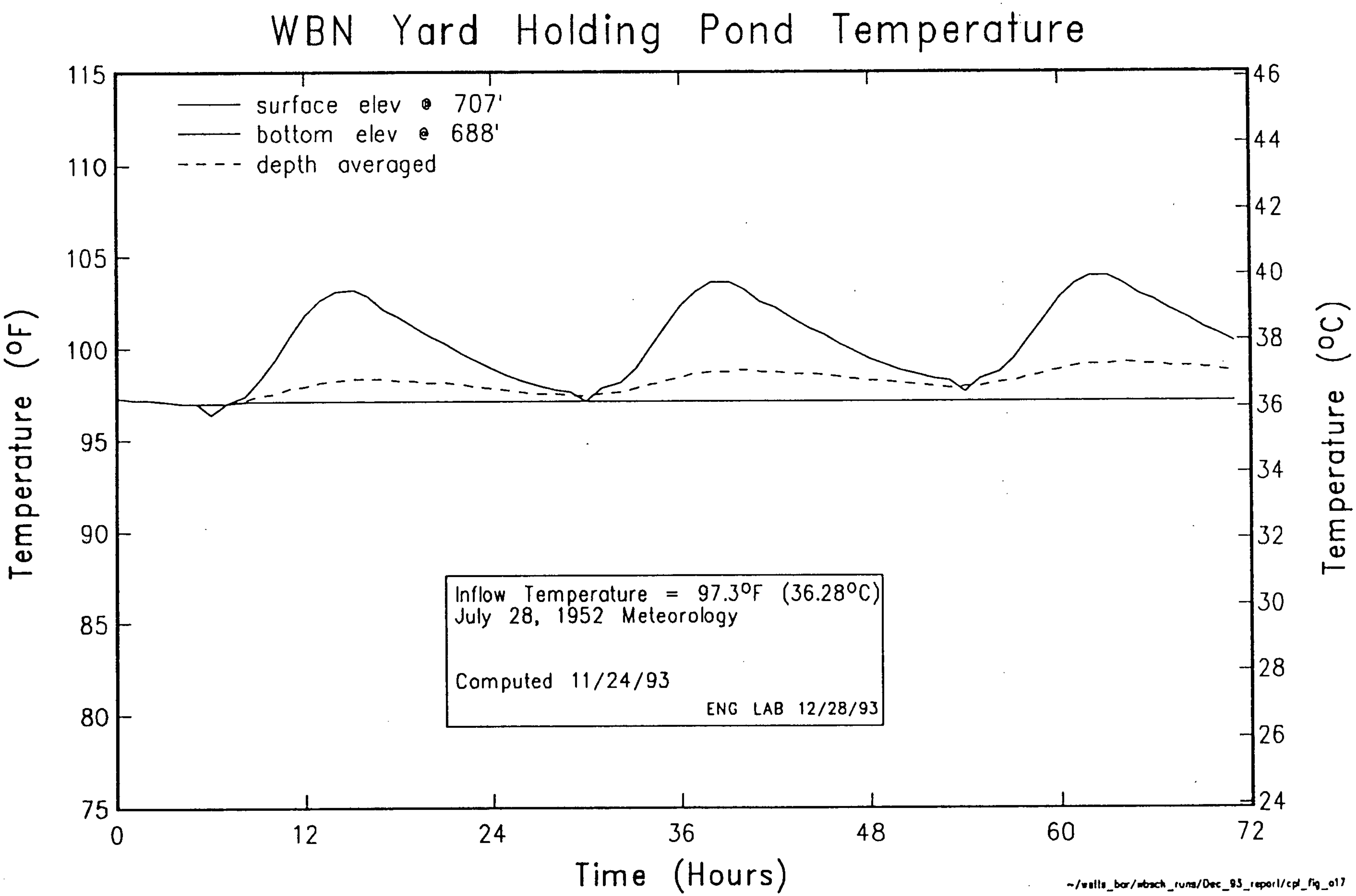


Figure A.17 WBN Yard Holding Pond Temperatures Using July 28, 1952 Meteorology

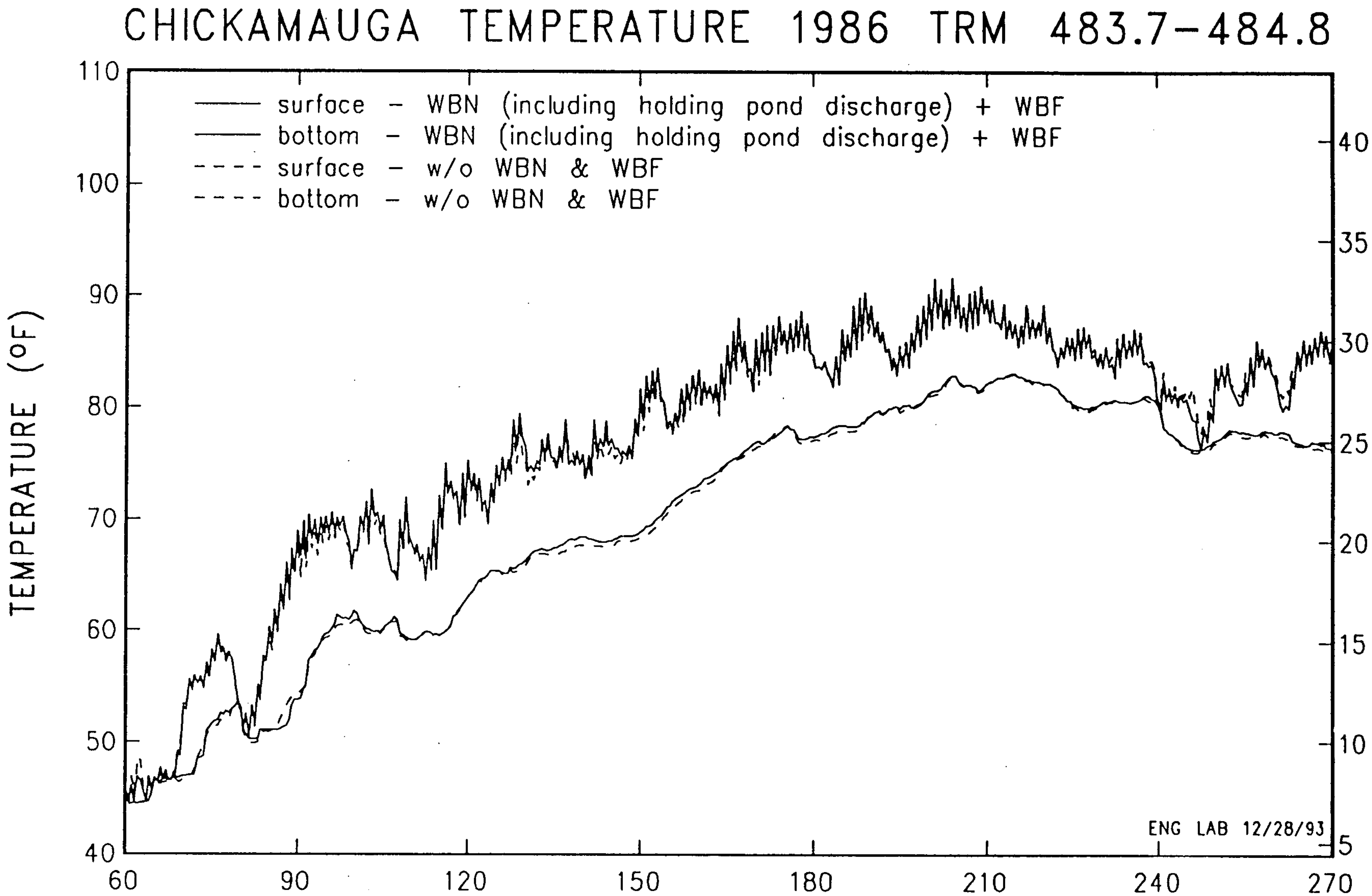


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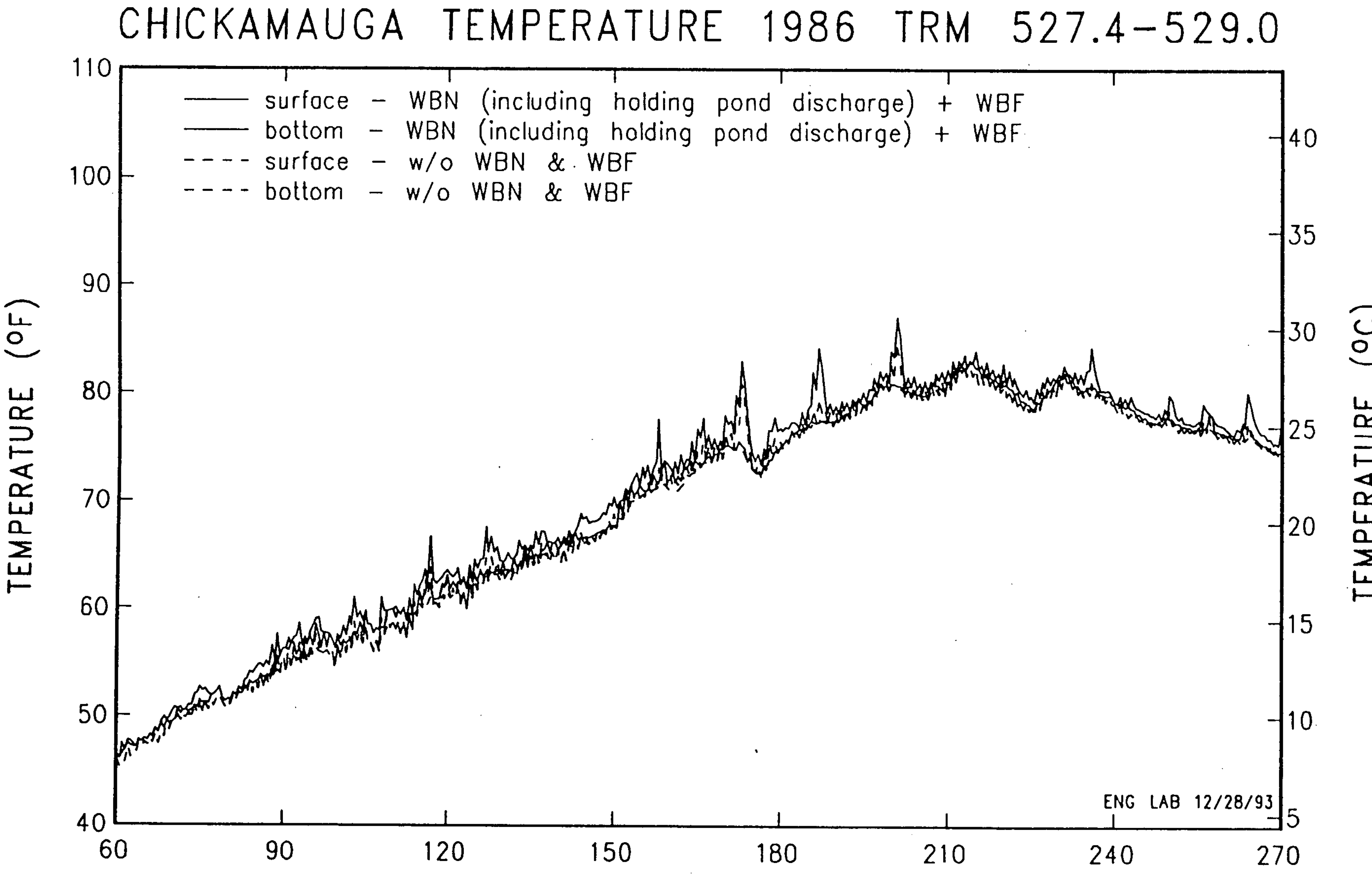
Figure A.18 Effects of WBN & WBF Thermal Discharges on Water Temperature Below WBH - 1986



~wfh/watts_bar/wbsch_runs/Dec_93_report/cpl_fig_a19

Figure A.19 Effects of WBN & WBF Thermal Discharges on Water Temperature at SQN Intake - 1986

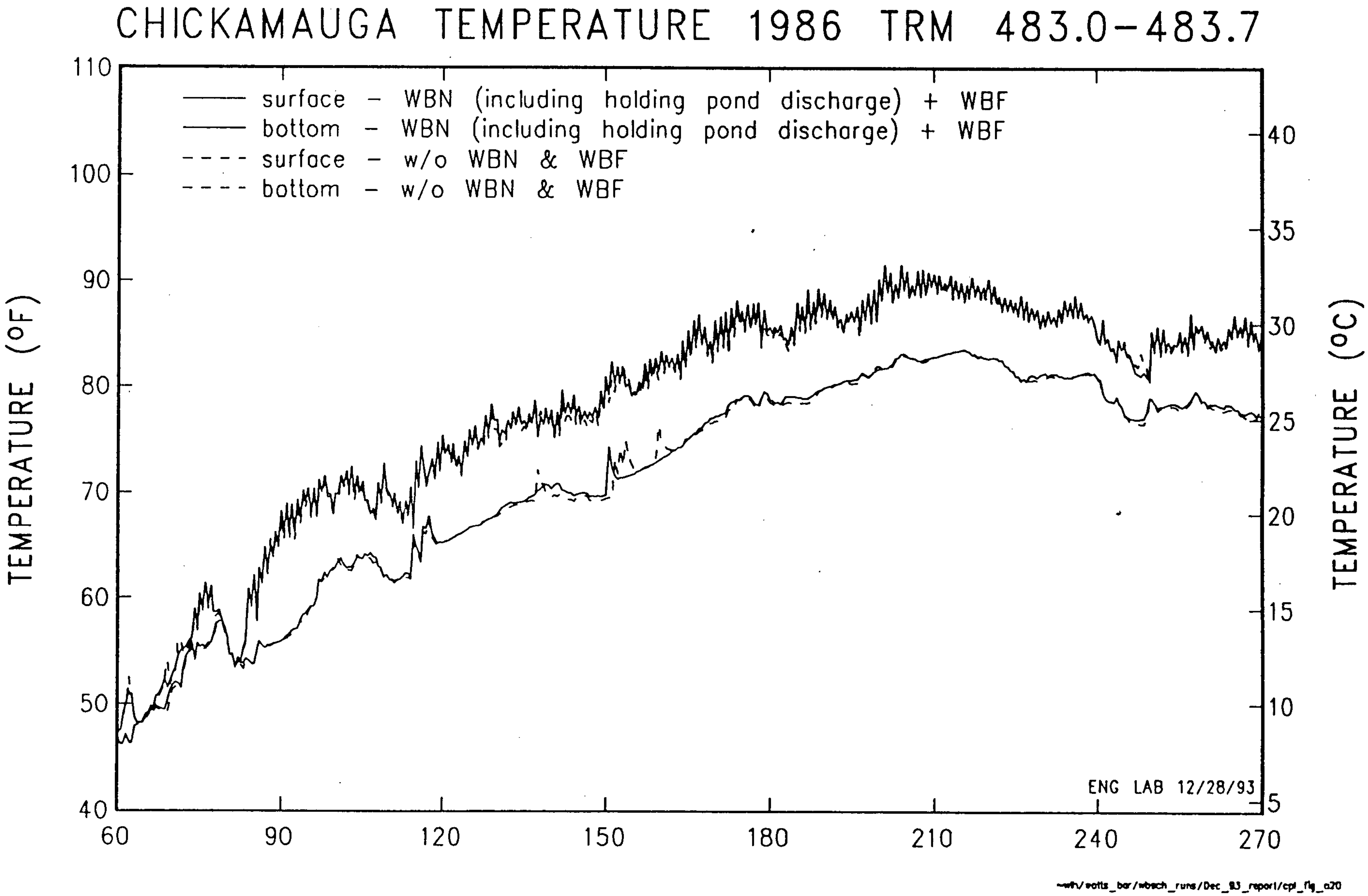


Figure A.20 Effects of WBN & WBF Thermal Discharges on Water Temperature Below the SQN Diffusers - 1986

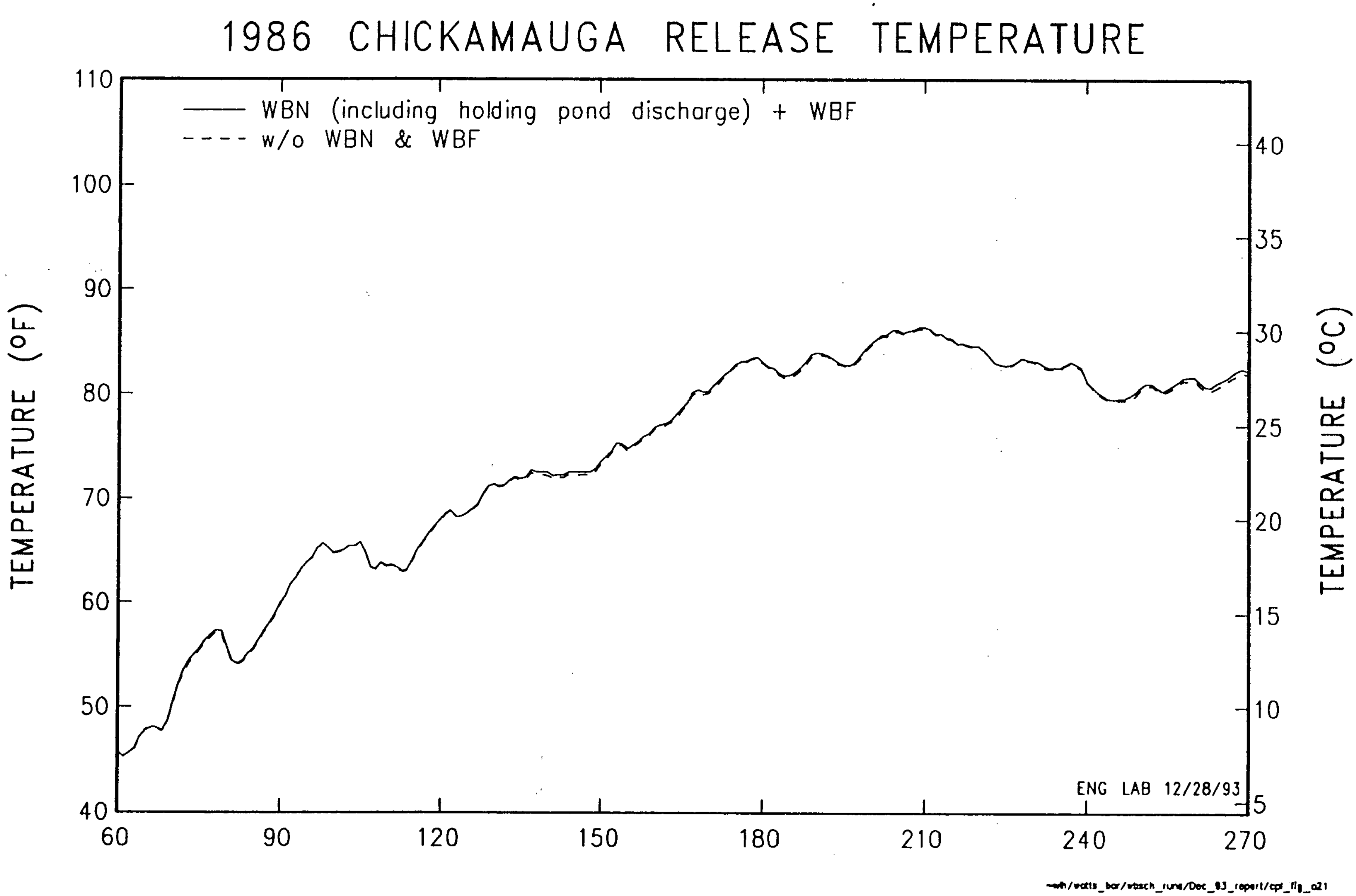


Figure A.21 Effects of WBN & WBF Thermal Discharges on Chickamauga Release Temperature - 1986

WATTS BAR 10 MILE

10 MILE EPZ QUADRANTS

EVACUATION SECTORS

25×20.5 MINUTE MAP SHOWING

- *Highways, roads and other manmade structures*
- *Water features*
- *Woodland areas*
- *Geographic names*

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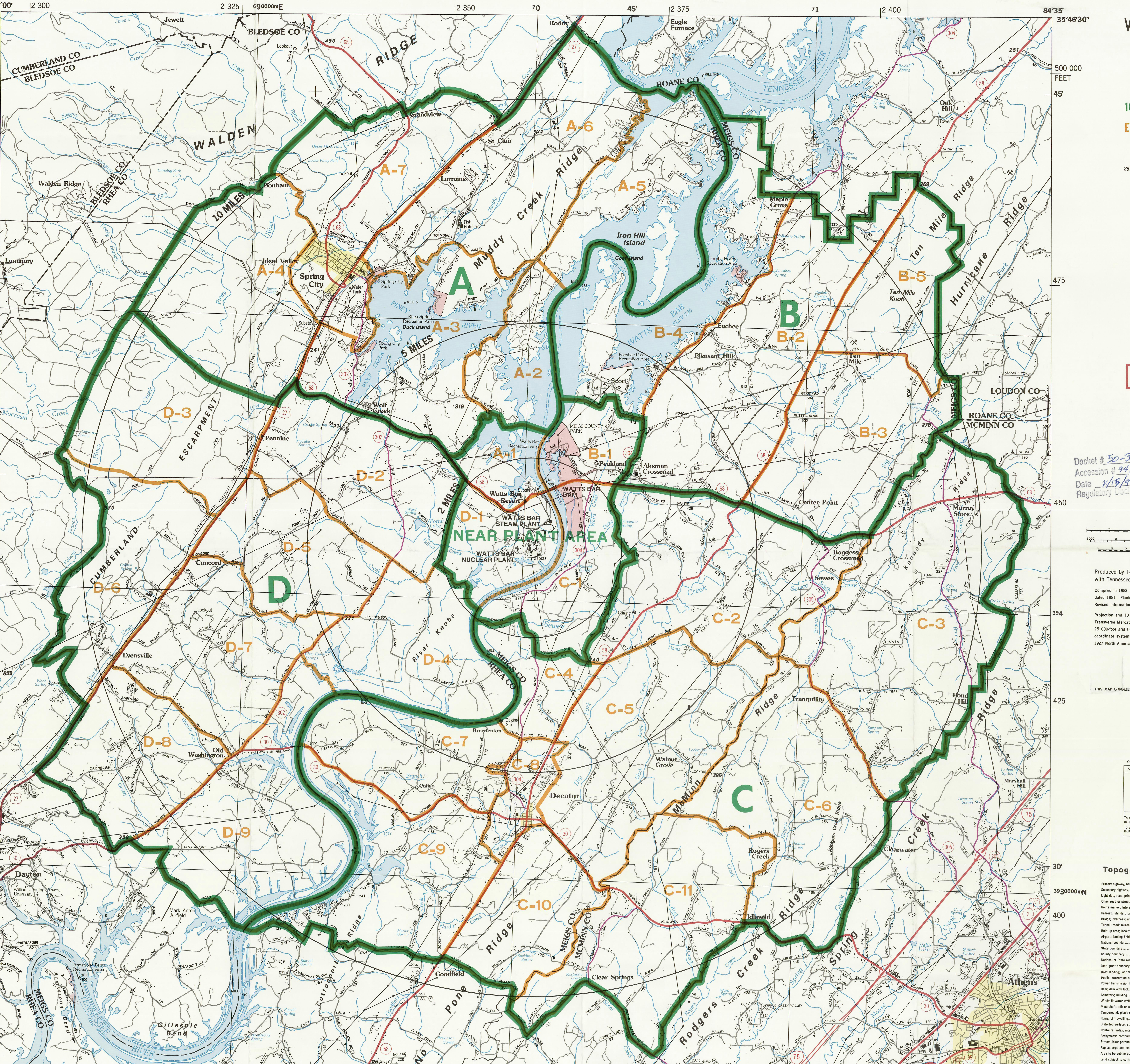

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Regulatory Docket File

SCALE 1:64,000

Produced by Tennessee Valley Authority in cooperation with Tennessee Emergency Management Agency

Compiled in 1982 from USGS-TVA 1:100,000 scale topographic maps dated 1981. Planimetry revised from best available source materials Revised information not field checked

Projection and 10 000-meter grid, zone 16: Universal Transverse Mercator
25 000-foot grid ticks based on Tennessee rectangular coordinate system
1927 North American Datum

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS

Topographic Map Symbols

BASE INFORMATION REVISION 2 OCTOBER 1992

QUADRANT AND SECTOR INFORMATION RELIABLE AS OF OCTOBER 1, 1992

9412010249-01