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

Tennessee Valley Authority
February 1983

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

EXECUTIVE SUMMARY

This report supplements previous Section 316(a) submittals to constitute a complete evaluation of the thermal effects of the Browns Ferry Nuclear Plant (BFNP). It supports the adoption of alternative thermal limitations of 90°F maximum temperature (T_{max}) and 10°F maximum temperature rise (ΔT_{max}) without any restrictions on TVA's operation of the plant cooling system and the balance of the TVA power system to meet these limitations. In addition, it supports the use of a 24-hour running average of the temperature at the 5-foot depth at the edge of the mixing zone to determine compliance with the limitations. The adoption of these limitations would provide for the protection of the aquatic biota in Wheeler Reservoir and still allow for cost effective operation of the plant. These proposed alternative thermal limitations are based upon the results of more than 10 years of actual operating experience, hydrothermal modeling studies, and the jointly sponsored TVA/EPA research on thermal criteria at the Browns Ferry Biothermal Research Station.

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Introduction

The purpose of thermal discharge limitations is for protection and propagation of balanced, indigenous population of aquatic organisms in receiving water bodies. According to established protocol, this is best accomplished by protecting temperature-sensitive fish species judged important, desirable, or both. In this 316(a) evaluation for alternative thermal discharge limits of 90°F T_{max} and 10°F ΔT_{max} (90/10) for Browns Ferry Nuclear Plant (BFNP), emphasis is on sauger, smallmouth bass, and walleye, the three species identified in the Alabama Water Quality Criteria as the key temperature-sensitive species in the Alabama portion of the Tennessee River basin. This report supplements a previous 316(a) demonstration (TVA 1980) which supported establishment of a 90°F T_{max}, but which did not address the ΔT_{max} limit.

Survival of key fish species and maintenance of a balanced aquatic community were emphasized in the previous demonstration. Principal conclusions were: (1) a 90°F T_{max} limit would not result in lethal conditions for sauger, smallmouth bass, or walleye, (2) fish, plankton and macroinvertebrate communities were not adversely affected when BFNP was operated under a 90°F T_{max}, and (3) temperatures that approach or reach 90°F do not coincide with the reproductive season of smallmouth bass, sauger, walleye, or the majority of other fish species in Wheeler Reservoir.

The present evaluation is based on current U.S. Environmental Protection Agency (EPA) guidelines for applying water quality temperature criteria, and it addresses issues of specific concern identified by the Alabama Department of Conservation and Natural Resources, Alabama Water Improvement Commission (now Alabama Department of Environmental Management), and EPA, Region IV. This evaluation is based upon more than 10 years of actual operating experience, hydrothermal modeling studies, and the jointly sponsored TVA/EPA research on thermal criteria at the Browns Ferry Biothermal Research Station. Results are summarized in the body of the report and in the technical Appendices 1 through 6.

History

The BFNP is located on an 840-acre tract on the north shore of Wheeler Reservoir in Limestone County, Alabama, at Tennessee River mile (TRM) 294. The site is approximately 10 miles northwest of Decatur, Alabama, and 10 miles southwest of Athens, Alabama. The plant includes three nuclear-powered generator units having a total electrical generator nameplate rating of 3,456 megawatts. The plant was designed in 1966 with a once-through heat dissipation system to meet a 93°F T_{max} and a 10°F ΔT_{max} above ambient. With the application of more stringent thermal criteria in 1972 (86°F T_{max} and 5°F ΔT_{max}), six mechanical draft cooling towers were retrofitted to the plant. However, the cooling towers have failed to perform up to design specifications. As a result, there has been a continuing need to exceed the thermal criteria to allow continued operation of the plant during peak summer periods or extremely low river flows while alternatives to the heat dissipation system were evaluated. Technical details relating to the establishment of thermal criteria and modifications to the plant cooling system are discussed in Appendices 1 and 2, respectively.

Biological

The fish community in Wheeler Reservoir is dominated by warmwater species. With the exception of sauger and walleye, all important game and commercial species, including smallmouth bass, are in this category. Smallmouth bass were previously considered to be a coolwater species along with sauger and walleye; however, current research, including investigations at the Browns Ferry Biothermal Research Station, has shown that temperature requirements for this species are essentially the same as those for largemouth bass and other warmwater centrarchids. Although sauger and walleye generally have intermediate thermal requirements relative to coldwater and warmwater fishes, their tolerance of warmer temperatures is greater than initially indicated from observations of these species in northern waters.

Wheeler Reservoir, with a normal flow-through time of about one to two weeks, is typical of other Tennessee River mainstream reservoirs in that productivity and standing stocks of phytoplankton and zooplankton generally increase in downstream areas of the reservoir. Diverse populations of both phytoplankton and zooplankton occur. Abundant macroinvertebrates in the vicinity of BFNP are Asiatic clams, mayflies, midges, oligochaetes, and snails.

Based on EPA recommendations (published in 1976 and 1977), the current 5°F ΔT_{max} was originally included to indirectly set seasonal maximum limits for reproduction and winter survival, whereas, the 86°F or 90°F T_{max} apparently was applied as the maximum summer temperature for growth. However, the 86°F or 90°F T_{max} frequently has been assumed to be the upper limit for survival. There are no provisions for a short-term (24 hours) temperature maximum for survival in the present water quality thermal criteria for Alabama.

For this demonstration, the 90°F T_{max} was evaluated relative to summer temperature limits for growth of sauger, smallmouth bass, and walleye; and the 10°F ΔT_{max} was evaluated relative to seasonal temperature limits for reproduction and winter survival of these species. Short-term maximum limits for survival during summer were assessed. Also, because the ultimate effect of 90/10 limits is contingent on the distribution of target fish species relative to temperature conditions resulting from the BFNP thermal discharge, temporal or spatial fish distribution was a primary consideration in assessing growth, survival, and reproduction. Effects of these limits on invertebrate fish-food organisms also were addressed.

Although the maximum summer temperature limit is to maintain growth of aquatic organisms at rates necessary to sustain reproducing populations, this limit does not apply to the mixing zone and is not based on maximum growth rates per se. For fish, this limit is derived from the lethal temperature and the optimum growth temperature, and it is based on a Maximum Weekly Average Temperature (MWAT). From experiments with smallmouth bass, sauger, and walleye at the Browns Ferry Biothermal Research Station, summer temperature limits (MWAT) for growth were 90°F for smallmouth bass and 88°F for sauger and walleye.

Although summer water temperatures greater than 88°F throughout lower Wheeler Reservoir would generally be unsuitable for growth of sauger and walleye, operation of BFNP under a 90/10 limitation would not be expected to adversely affect growth of these species because temperatures above 88°F do not exist for extended periods and are normally confined to surface zones not generally occupied by sauger and walleye during summer. Occurrences of temperatures from 88°F to 90°F (5-foot depth at the edge of the mixing zone) would increase, but durations for these occurrences would seldom exceed 6 hours.

The confinement of warmer temperatures to surface strata was demonstrated under actual severe conditions in July 1980. During this period, temperatures greater than 90°F, which occurred both upstream and downstream of the BFNP thermal discharge at the 5-foot compliance depth, did not result in fishkills. On July 18 upstream temperatures reached 90.8°F and the average downstream temperature (edge of mixing zone) was 91°F. Under these extreme conditions, sauger, or walleye would be expected to avoid the entire zone of the reservoir immediately downstream of the mixing zone. However, during this period sauger were collected in gill nets at the edge of the mixing zone and adjacent to the diffusers where bottom temperatures were 2°F to 4°F cooler than those at the 5-foot depth.

Because smallmouth and largemouth bass are sympatric in Wheeler Reservoir, some level of interspecific competition between these two congeneric species would be expected, particularly because feeding habits are relatively similar. However, 90/10 thermal limitations would not adversely affect smallmouth bass via competitive exclusion by largemouth bass because these species have similar overall temperature requirements. Furthermore, differences in habitat selection and inherent behavioral responses generally segregate these species regardless of the thermal regime.

Although elevation of the ambient thermal regime of Wheeler Reservoir by up to 10°F could advance the spawning season for smallmouth bass, sauger, and walleye, this would not be expected to adversely impact populations of these species. Investigations at the Browns Ferry Biothermal Research Station have shown that, although spawning can be advanced in elevated thermal regimes, similar changes occur simultaneously in the rest of the biological community such that the supply of food organisms is not a limiting factor for survival of newly-hatched fry. Also, because major spawning areas for these species are outside the zone of thermal influence from BFNP, no significant proportion of the spawning populations of these species would experience temperatures that approached 10°F above ambient.

It is generally recognized that fish congregating in thermal discharges of power plants may suffer cold shock if suddenly exposed to ambient temperature water due to plant shutdown. However, current research has shown that a sudden temperature decline greater than 20°F is required before cold shock is a major problem. With a maximum river temperature rise at BFNP of 10°F, cold shock is not likely to occur. Further, BFNP is not likely to shut down all three units simultaneously. Even if this event occurred, "cold shutdown" of a nuclear unit is not instantaneous and cooling water is circulated for several days to cool the reactor core which precludes a rapid temperature decline in the heated discharge zone. Therefore, based on operational characteristics of the plant and tolerance levels of fish, operation of BFNP under a 10°F ΔT_{max} would not subject fish to cold shock should plant shutdown occur. Technical details relating to biological aspects of this demonstration are included in Appendix 3.

Hydrothermodynamics

The hydrothermal aspects of Wheeler Reservoir are governed primarily by geometry, riverflow, and meteorology (including solar inputs). BFNP is located in a region with a deep main channel and extensive overbanks. Upstream from Browns Ferry, riverine conditions are found while downstream, the reservoir becomes deep and wide starting near the confluence of the Elk River. Streamflow past Browns Ferry is regulated by Guntersville Dam upstream and Wheeler Dam downstream. Water travel time from BFNP to Wheeler Dam ranges from one-half to two weeks depending on riverflow. Important meteorological variables for the various heat transfer processes are air temperature, relative humidity, wind speed, and solar radiation. The major surface heat transfer processes include absorption of solar radiation, radiant exchange of heat between the water surface and the atmosphere (long wave radiation) and evaporation. Other heat transport mechanisms in the reservoir include advection (horizontal water movement) and convection (vertical water movement). Technical details on the hydrothermodynamic aspects of this demonstration are included in Appendix 4.

Natural water temperature changes in Wheeler Reservoir over the annual cycle are in the range of 45 to 55°F with monthly changes of 15 to 20°F. Meteorological changes can cause water temperatures throughout the reservoir to change 5°F in 10 days. Daily variations due to solar heating can cause 1 to 2°F changes during fully mixed conditions and up to 5°F changes in the surface layer down to 5 feet during periods of weak thermal stratification.

Temperature patterns upstream of BFNP are fully mixed during the fall, winter, and early spring with weak thermal stratification occurring for a few hours on some days during April through September. Temperatures in the overbanks near BFNP are similar to those in the main channel except that the overbank areas are more responsive to changing meteorological conditions. Spatial differences (i.e., between overbank and main channel) caused by wind and flow induced mixing can cause 1 to 3°F differences on an hourly basis. In the lower portion of Wheeler Reservoir thermal stratification can be up to 10°F in the spring, but is much less in the summer. Thermal stratification is usually weak because of the relatively short transit time and turbine intake withdrawal from the entire vertical depth of the reservoir. Cooling periods can also easily break down stratification.

The potential effects of alternative limitations were evaluated with regard to near and far field regions of Wheeler Reservoir. Measured temperature data from periods when BFNP operated under higher temporary thermal limits, and predictive modeling of maximum plant operation under constant alternative limitations were used to describe potential changes in the thermal characteristics of the reservoir.

From the standpoint of compliance, the maximum temperature rise (ΔT_{max}) limitation is the overriding limitation on plant operation during spring, fall, and winter. Monitoring data from these periods showed a thermal gradient in the near field with surface temperatures approaching the ΔT_{max} limitation and bottom temperatures significantly closer to ambient temperatures. Higher flows during the winter and spring can cause more mixing, contributing to uniform temperatures over the entire depth of the reservoir.

A diffuser performance model was used to predict plant-induced temperatures at the edge of the proposed mixing zone (about 2,200 feet downstream of the diffusers). The simulations were performed using an alternative ΔT_{max} limitation of 10°F with no cooling tower operation until the downstream river temperature rise (ΔT) reached 10°F. 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 in the months of January, March, and May 1981. The longest duration, 319 hours (13 days), occurred during the December-January period. For 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 maximum temperature (T_{max}) limitation is important in the months of June through September. The most apparent plant-induced effects on near field temperatures during this period are the production of a deeper surface heated layer as compared to the naturally occurring solar heated layer, and the persistence of this heated surface layer through the night. Bottom temperatures remain close to ambient upstream conditions.

Near field diffuser model simulations used an alternative T_{max} limitation of 90°F with no cooling tower usage until the downstream river temperature reached 90°F. Comparisons were made with ambient upstream river temperatures and with predictions under the present limitation of 90°F with cooling towers used after the downstream river temperature reached 86°F. Predicted June, July, and August results over the 12 years of record showed that the average summer occurrence of temperatures greater than 86°F under the alternative limitation was 41.1 percent, under the present limitation was 12.8 percent, and for ambient upstream conditions was 7.2 percent. The most severe conditions occurred during July 1980 when the maximum monthly occurrences 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.

Durations of predicted river temperatures greater than 86°F were mostly less than 6 hours in length. However, some longer durations were predicted including 75 days in the severe summer of 1980.

Plant operation under alternative limitations had no significant effect on the seasonal temperature pattern. Only slight changes of less than 5°F were predicted over the annual cycle of temperature variation.

A zone of passage evaluation showed there are normally areas near the diffuser discharge which remain at or near ambient temperatures, especially in the overbank and deep water channel regions. However, periods exist when the entire downstream cross section is fully mixed. These conditions normally occur during periods of cooling or high flows but have appeared during severe summer periods in 1977 and 1980.

Observed far field temperatures, between the plant discharge and the far field monitors, are affected by 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 weak 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 and subsequent far field cooling. When meteorological conditions cause a warming of inflow temperatures, this warmer water tends to enter the downstream portion of Wheeler Reservoir at mid-depth leaving 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 climatic conditions, far field surface temperatures can remain the same or increase downstream to Wheeler Dam.

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

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 downstream of BFNP to be cooler than would occur under fully mixed conditions. Major climatic cooling events can rapidly cool the heated discharge plume and allow near-ambient temperatures to flow into the bottom layers of Wheeler Reservoir.

A hydrothermal reservoir model was used to predict the far field effects of plant operation under alternative limitations. The worst case evaluations considered extreme environmental conditions (high ambient temperatures in 1980 and low flows in 1981) and full mixing of the diffuser discharge. The results are conservative during the April through September period since water near ambient temperatures may travel around the diffusers into the lower reservoir. The major predicted effects of plant operation under alternative limitations are advanced warming and delayed cooling throughout the 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 slightly warmer temperatures. Isotherms from alternative limitation simulations showed increases in reservoir temperatures downstream of BFNP 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 that solar heat on a sunny spring or summer day between the diffuser and the present water temperature compliance monitors 1.5 miles downstream is equal to the plant discharged heat during the 12 hours of solar heating.

Wheeler Reservoir exhibits only transient, weak thermal stratification interspersed among periods of complete mixing which, coupled with very short hydraulic residence time of the reservoir, prevents the occurrence of severe oxygen depletion. Operation of BFNP with the proposed thermal limitations will not alter the occurrence of stratified conditions and, therefore, would not have a significant impact on dissolved oxygen concentration within the reservoir.

Compliance Monitoring

Experience with compliance monitoring has shown that short-term, near-surface temperature fluctuations can have a significant effect on compliance efforts. Technical details of the current and proposed compliance monitoring methods are included in Appendix 5.

Thermal limitations based on a 24-hour running average of measured or computed temperatures (updated hourly) are proposed to obtain a better representation of plant-induced temperature effects in Wheeler Reservoir. This temperature averaging would also provide a method that is more consistent with current guidelines for protecting aquatic biota which normally consider durations of exposure of 24 hours or longer.

Use of 24-hour averaging would allow some instantaneous temperatures to exceed the proposed limitations. However, durations of temperatures greater than the limits would never be longer than 24 hours because the plant would adjust operation so that the 24-hour running average temperature would not exceed the thermal limitation. The use of a 24-hour averaging would also have no significant effect on seasonal reservoir temperature patterns.

Economics

Operation of cooling towers and reduction of plant load to meet thermal limitations during periods of low reservoir flow or high ambient water temperature results in an increased demand for power from the TVA system. This additional demand must be met by generation from more expensive sources because TVA first operates its least expensive sources of power to meet demand. Proposed changes in reservoir thermal limitations or the compliance method that would decrease the extent of cooling tower operation and load reduction would result in significant cost savings to TVA ratepayers while still providing environmental protection. With the present 2-hour, running average compliance method, and 90°F T_{max} and 10°F ΔT_{max} thermal limitations, an annual average savings of about $3.5 million could be realized. In an extreme year in which both high ambient conditions and low reservoir flows exist, an annual savings on the order of $10 million could be realized with these limitations. If a 24-hour, running average compliance method were used in conjunction with 90°F T_{max} and 10°F ΔT_{max} thermal limitations, annual average savings would be expected to increase to about $4 million and in an extreme year savings of about $14 million could be realized. Technical details of the economic aspects of the proposed limitations are included in Appendix 6.

Conclusion

The results of this report support the establishment of alternative thermal limitations of 90°F T_{max} and 10°F ΔT_{max} using a 24-hour running average monitoring method with TVA having complete flexibility regarding the operation of the plant cooling system and the balance of the TVA power system to meet these thermal limitations. These limitations would ensure protection of the aquatic biota of Wheeler Reservoir and allow more cost-effective operation of Browns Ferry Nuclear Plant as well as the remainder of the TVA power system. The economic savings to the TVA ratepayer that would be realized with these limitations would be about $4 million in an average year and could expand up to about $14 million in an extreme year. Such savings could be realized without jeopardizing the use and well being of the aquatic resources of Wheeler Reservoir. These are the requested alternative thermal limitations for Browns Ferry Nuclear Plant.

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APPENDIX 1

HISTORY OF THE DEVELOPMENT OF THERMAL CRITERIA FOR BROWNS FERRY NUCLEAR PLANT

Tennessee Valley Authority
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APPENDIX 1

HISTORY OF THE DEVELOPMENT OF THERMAL CRITERIA FOR BROWNS FEERY NUCLEAR PLANT

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APPENDIX 1 HISTORY OF THE DEVELOPMENT OF THERMAL CRITERIA FOR BROWNS FERRY NUCLEAR PLANT

1.0 Introduction

The planning for the Browns Ferry Nuclear Plant (BFNP) was begun in 1966 as part of TVA's program to meet projected load requirements. Construction of the plant began in May 1967 after the Atomic Energy Commission (AEC) issued provisional construction permits for units 1 and 2. Unit 3 was given a construction permit in July 1968. Commercial operation was achieved on units 1 and 2 on August 1, 1974, and March 1, 1975, respectively. Units 1 and 2 were shut down in March 1975 because of a cable fire. Following the fire outage, all 3 units were placed in service in September 1976. Unit 3 was placed in commercial operation on March 1, 1977.

A major consideration in the initial planning of the plant was the design of a heat dissipation system which would allow efficient plant operation and simultaneously protect the aquatic resources of Wheeler Reservoir. However, during the design and construction period, resolution of the issue of heat dissipation and aquatic resources protection was extremely difficult because of changing and uncertain bases for the development of thermal criteria to protect aquatic resources of Wheeler Reservoir. As a result, when numerical criteria were eventually established, substantial retrofits to the heat dissipation system were required. Simultaneously, basic research to evaluate the appropriateness of the numerical criteria was also initiated.

TVA's BFNP is located at approximately mile 294.0 of the Tennessee River on Wheeler Reservoir. On May 5, 1967, the Alabama Water Improvement Commission (AWIC) adopted use classifications for stream segments in the Tennessee River Basin. The segment of the Tennessee River extending upstream from the mouth of the Elk River to U.S. Highway 31 and which included BFNP was classified for swimming and fish and wildlife.

To protect the quality of its waters for these uses, Alabama has adopted various quality criteria, including thermal criteria. Those thermal criteria applicable to the BFNP site include a maximum temperature of 86°F (T_{max}) and a temperature rise of 5°F (ΔT_{max}) which is intended to protect smallmouth bass, sauger, and walleye. Waters not identified by the Alabama Department of Conservation and Natural Resources as supporting these species are governed by a 90°F T_{max} and 5°F ΔT_{max} thermal criteria. Applicable thermal criteria are shown in their entirety in Exhibit 1.

1.1 Development of Alabama's Thermal Criteria

Since the passage of the 1965 amendments to the Federal Water Quality Act, much effort has been devoted to the development of water quality criteria. Provisions of the 1965 Act required each State to adopt and submit to the Federal Water Pollution Control Administration (FWPCA) for approval water quality criteria for interstate waters. The history of Alabama's effort to develop criteria and gain FWPCA approval graphically displays the divergence of professional opinion on the subject of thermal impacts. The following discussion briefly summarizes the events leading to Alabama's adoption in 1972 of the thermal criteria currently in effect. Table 1.1 also presents this chronology in tabular form.

In 1966, the Alabama Water Improvement Commission (AWIC) initiated its effort to develop suitable water quality criteria. In

Table 1.1

Sequence of Events Leading to Adoption of Alabama's Temperature Criteria

1966 October 14	AWIC approved water quality criteria consideration in public hearings. Temperature criteria were 10°F ΔT_{max} and 95°F T_{max}
1966 December 12,13	AWIC conducted public hearings in Sheffield and Guntersville to receive comment on criteria and use classifications for Tennessee River Basin.
1967 May 5	AWIC adopted revised temperature criteria for Tennessee River, 10% °F ΔT_{max}, 90°F T_{max}, except that 93°F T_{max} is allowed for no more than 8 hours in 24.
1967 June 19	After AWIC meeting when TVA and Alabama Power stated opposition to the May 5 criteria, the commission made the following revisions--93°F T_{max} and 10°F ΔT_{max}
1967 June 26	AWIC transmitted adopted water quality criteria and classifications to Department of Interior.
1967 July 8	Secretary of Interior Udall replied, citing additional requirements.
1967 August 30	AWIC responded to FWPCA, resolving points raised in above letter.
1968 January 19	Secretary Udall responded to AWIC, citing temperature and dissolved oxygen problems and antidegradation provisions. This is first reference to any temperature and dissolved oxygen conflict.
1968 February 15	Secretary Udall approved AWIC standards with exceptions, which include temperature and dissolved oxygen criteria and the antidegradation provisions.
1971 April 5-7	EPA sponsored a conference in Montgomery to promulgate water quality standards in Alabama.
1972 March 11	EPA published proposed thermal criteria for Alabama in Federal Register. 86°F T_{max} and 5°F ΔT_{max}.
1972 June 19	AWIC held a public hearing in Montgomery on proposed EPA criteria.
1972 July 17	AWIC adopted EPA's final criteria for temperature.

October, AWIC proposed thermal criteria which included a 95°F T_{max} and 10°F ΔT_{max}. These criteria were presented for comment at public hearings held in Sheffield and Guntersville on December 12 and 13, respectively. On May 5, 1967, AWIC adopted temperature criteria which included a 90°F T_{max} and a ΔT_{max} of 10 percent T_{max}. The need for these more restrictive criteria was questioned by TVA and the Alabama Power Company at a June 19 AWIC meeting. Both organizations expressed the concern that these criteria were more stringent than necessary to protect aquatic life and that the costs of compliance would be excessive. The Commission adopted a 93° T_{max} and a 10°F ΔT_{max}. On June 26, 1967, AWIC officially transmitted its completed criteria and stream classifications to the Department of Interior.

The next phase of the process involved Federal review of Alabama's criteria. In January 1968 the Department of Interior questioned the adequacy of temperature and dissolved oxygen criteria and the antidegredation provision. Little progress was made on these issues for more than three years. During this period, environmental regulatory responsibilities were transferred from the Department of Interior to the newly established U.S. Environmental Protection Agency (EPA).

In February 1971, the EPA notified the State of Alabama of its intent to proceed with promulgation of standards for Alabama. To afford affected parties an opportunity to express their views, EPA sponsored a conference in Montgomery, Alabama, in April 1971. Following the conference EPA published its recommendations in a report titled "Water Quality Standards-Setting Conference for the Interstate Wastes of the State of Alabama." The recommendations included a T_{max} for each month of the year and a 5°F ΔT_{max}. These recommendations were modified prior to the March 11, 1972 publication of EPA's proposed criteria in the Federal Register. These published criteria did not include monthly temperature maximums. For the Tennessee Valley portion of Alabama, a single criterion of 86°F T_{max} was established and the 5°F ΔT_{max} was retained. The AWIC promptly held additional hearings on the EPA criteria and on July 17, 1972 adopted them. On September 19, 1972, EPA formally approved the Alabama criteria. No further changes to the temperature criteria have been made since that time.

1.2 Alabama Thermal Criteria: Issues and Alternatives

The April 1971 Water Quality Standards Setting Conference offered an opportunity for interested parties to present their points of view on Alabama's Water Quality Standards. The opinions expressed by participants clearly indicate a recognition of the potential impacts of the discharges of waste heat to surface waters. Numerous such impacts were cited, including mortality, reproductive impairment, increased toxicity of certain pollutants, reduced assimilative capacity, and the shift of phytoplankton populations toward undesirable species. Although all participants shared the viewpoint that thermal criteria were necessary for the protection of aquatic life, the degree of protection necessary was in dispute. Table 1.2 lists the major conference participants and the thermal criteria which each supported.

AWIC, the Alabama Power Company, and TVA each supported those criteria adopted by AWIC in 1967. Each of these agencies contended that natural stream temperatures frequently exceeded the proposed 86°F T_{max} with no observable impact. TVA cited experience with numerous heated

Table 1.2

Thermal Criteria Recommendations of Participants in the Water Quality Standards Setting Conference

April 5-7, 1971

	Maximum Temperature T_{max}	Maximum Temperature Rise ΔT_{max}
Alabama Water Improvement Commission	93°F	10°F
Alabama Power Company	93°F	10°F
Bureau of Sport Fisheries and Wildlife[1]	86°F	5°F
Environmental Protection Agency[1]	86°F	5°F
Tennessee Valley Authority	93°F	10°F

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[1] In addition to the 86°F T_{max} these agencies originally called for maximum temperatures for each month of the year. Final recommendations contained only the 86°F T_{max}.

discharges including two sites in northern Alabama. At these two sites both the 86°F T_{max} and the 5°F ΔT_{max} were exceeded with no adverse impact. In addition, these agencies cited the difficulties and high costs associated with compliance with the more stringent criteria. They strongly urged EPA to carefully consider and balance all the water uses in developing criteria.

At the same time, two States, Georgia and Florida, adjoining Alabama had EPA-approved temperature criteria less stringent than those proposed by Alabama and rejected by EPA. The remaining States adjoining Alabama had proposed temperature criteria comparable to Alabama's (see Table 1.3). Citing Federal guidelines on standards development which required that "State standards be reviewed in terms of their consistency and comparability for those affected waters of downstream or adjacent States," Alabama's Governor Wallace had requested in March 1971 that EPA call a conference of all States in the region. Subsequently, EPA withdrew its approval of Georgia's standards and required the adoption of more stringent thermal criteria.

TVA suggested that, in view of the many uncertainties regarding thermal impacts on aquatic life, the adoption of final thermal criteria should await the completion of research underway at TVA's Browns Ferry Biothermal Research Station. In the interim, it was suggested that the criteria originally proposed by AWIC be approved. The Brown's Ferry research had been proposed by TVA in 1967 as a means of obtaining an adequate data base for the development of thermal criteria. The EPA (and its predecessor agency, the Federal Water Pollution Control Administration) and TVA agreed to the need for such research, as evidenced by their active participation in project planning and beginning

Table 1.3

State Maximum Temperature (T_{max}) Criteria Applicable to the Surface Waters of Alabama and Adjoining States

September 1970

State	Maximum Permissible Temperature (T_{max})	Status
Alabama	93°F	Proposed
Florida	No numerical limit	Approved
Georgia	93.2°F	Approved
Mississippi	93°F	Proposed
Tennessee	93°F	Proposed

in 1970, their funding of a portion of the project costs. In 1971 EPA's participation was formalized with the signing of a Memorandum of Agreement wherein EPA and TVA agreed to conduct a cooperative research program to investigate the effects of heat on aquatic life. This agreement provided for EPA's full participation in the operation and management of the project. The project was to be directed by a 6-member joint TVA-EPA committee on which the Director of EPA's Division of Water Quality Research and the Director of TVA's Division of Environmental Research and Development served as co-chairmen. In addition, EPA was to provide funding up to $2,500,000 for the development of the Browns Ferry Biothermal Research Station.

The discussions above clearly illustrate the divergence of professional opinion on thermal criteria which existed during the development of Alabama's criteria. Today, ten years after the adoption of these criteria, unresolved issues remain. These issues include the determination of appropriate T_{max} and ΔT_{max} criteria actually necessary to protect aquatic life in Wheeler Reservoir and the proper methods of application of such criteria at the BFNP.

EXHIBIT 1

Thermal Water Quality Criteria for the Alabama Portion of the Tennessee River Basin
Excerpts from Alabama Water Quality Criteria

Section VI.D.3.b.

The maximum temperatures in streams, lakes, and reservoirs in the Tennessee and Cahaba River Basins and for that portion of the Tallapoosa River Basin from the tailrace of Thurlow Dam at Tallassee downstream to the junction of the Coosa and Tallapoosa Rivers which has been designated by the Alabama Department of Conservation and Natural Resources as supporting smallmouth bass, sauger, and walleye shall not exceed 86°F.

Section VI.D.3.c.

The maximum in-stream temperature rise above ambient water temperature due to the addition of artifical heat by a discharger shall not exceed 5°F in streams, lakes, and reservoirs in noncoastal and nonestuarine areas.

Section VI.D.3.e.

In lakes and reservoirs there shall be no withdrawals from nor discharge of heated waters to the hypolimnion unless it can be shown that such discharge will be beneficial to water quality.

Section VI.D.3.f.

In all waters the normal daily and seasonal temperature variations that were present before the addition of artificial heat shall be maintained, and there shall be no thermal block to the migration of aquatic organisms.

Section VI.D.3.g.

Thermal permit limitations in State discharge permits may be less stringent than those required by criteria a. -d hereof when a showing by the discharger has been made pursuant to Section 316 of the Federal Water Pollution Control Act (FWPCA), 33 U.S.C. 1251 et sec. or pursuant to a study of an equal or more stringent nature required by the State of Alabama authorized by Title 22, Section 22-22-9(c), Code of Alabama, 1975, that such limitations will assure the protection and propagation of a balanced, indigenous population of shellfish, fish and wildlife, in and on the body of water to which the discharge is made. Any such demonstration shall take into account the interaction of the thermal discharge component with other pollutants discharged.

Note: The numerical limitations expressed in these criteria are normally applied at the five-foot depth for waters ten feet or more in depth. This is not, however, a requirement of the criteria.

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

APPENDIX 2

BROWNS FERRY NUCLEAR PLANT HEAT DISSIPATION SYSTEM AND OPERATION

Tennessee Valley Authority
February 1983

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

APPENDIX 2

BROWNS FERRY NUCLEAR PLANT HEAT DISSIPATION SYSTEM AND OPERATION

CONTENTS

APPENDIX 2 BROWNS FERRY NUCLEAR PLANT HEAT DISSIPATION SYSTEM AND OPERATION

2.0 Introduction

The initial design and modification to the heat dissipation system for BFNP were discussed in detail in the Final Environmental Statement (issued on September 1, 1972). Certain aspects of the history are summarized in the following paragraphs to provide continuity with events subsequent to the release of the Final Environmental Statement.

2.1 Diffuser System

The heat dispersal system for the BFNP was originally designed and constructed to meet criteria permitting a maximum temperature of 93°F (T_{max}) and a temperature rise of 10°F (ΔT_{max}). These criteria were judged by TVA to be adequate to protect aquatic life, and the State of Alabama subsequently proposed identical standards in compliance with the Water Quality Act of 1965. However, in applying these criteria, it was recognized in the early stages of plant design that condenser circulating water should not be discharged directly into the surface strata of Wheeler Reservoir. Instead, it was decided that by means of a diffuser, the condenser circulating water should be mixed as quickly as possible with as much unheated reservoir water as possible. By this procedure, no excessively warm surface strata would exist and the mixing zone would be restricted to a relatively small area.

Based on extensive TVA studies and the experience of others at the time BFN was designed, it was concluded that these heat dispersal facilities would adequately protect the waters of Wheeler Reservoir for the following uses: public water supply, swimming and other whole body water-contact sports, shellfish harvesting, fish and wildlife, agricultural and industrial water supply, and navigation.

Following the establishment of more stringent thermal criteria (86°F T_{max} and 5°F ΔT_{max}) for the Alabama portion of the Tennessee River basin, TVA determined that the diffuser system alone was not adequate to ensure acceptable conformance with these criteria. The alternatives of mechanical draft cooling towers, natural draft cooling towers, spray canal system, and cooling lake for heat dissipation were reevaluated, and it was decided that mechanical draft cooling towers would provide the best long-term solution to meet the thermal criteria. The towers were designed to supplement the diffuser system by dissipating part or all of the heat directly to the atmosphere.

2.2 Cooling Towers

The heat dissipation system selected consists of six 16-cell rectangular, mechanical-draft cooling towers designed to operate in either helper- or closed-mode. Conditions requiring operation of the towers occur most commonly during spring and summer months. When cooling towers are not required to comply with thermal water quality standards, the cooling system of the plant is operated in open mode as originally designed.

In July 1974, TVA requested and received concurrence from the AWIC and EPA to operate BFNP with alternative limitations of 90°F T_{max} and 5°F ΔT_{max} until such time as cooling tower construction could be completed and during the warranty run for Unit 1.

The cooling towers were placed in operation in 1976, but failed to meet the design requirements. As a result, during some summer months it was necessary to significantly reduce generation at the plant or exceed the thermal criteria adopted for Wheeler Reservoir. In addition to the operating deficiency, one cooling tower failed structurally. Subsequent inspections revealed that all of the towers needed structural upgrading. The use of the cooling towers was restricted until structural repairs could be completed in early 1979.

On June 30, 1977, EPA issued an NPDES permit for BFNP which contained the thermal limitations of 86°F T_{max} and 5°F ΔT_{max}. On July 13, 1977, TVA requested an adjudicatory hearing on the thermal limitations contained in the permit. On July 15, 1977, EPA stayed the thermal limitation of the permit and granted interim relief requiring that TVA comply with a 90°F T_{max} and a 5°F ΔT_{max} at any time the ambient upstream temperature exceeded 81°F. EPA also asked TVA to present a strategy for long-term resolution of the thermal issues. The request for an adjudicatory hearing is still open.

2.3 Long-term Resolution

Since the summer of 1977, BFNP has generally been operated to meet a 90°F T_{max} and a 5°F ΔT_{max} while studies and investigations were being performed by TVA to determine a permanent solution to inadequacies in the cooling towers. However, because of extreme meteorological conditions during the summer of 1980 and the spring of 1981, TVA requested and EPA and AWIC granted further temporary relief from the 90°F T_{max} and a 5°F ΔT_{max} limitations. This relief provided for operating up to a 93°F T_{max} during the summer of 1980 and a 8.5°F ΔT_{max} during the spring of 1981.

On March 31, 1980, TVA submitted to EPA and AWIC a Section 316(a) demonstration concluding that a permanent alternate maximum temperature limitation of 90°F T_{max} would not result in significant adverse impacts to the aquatic environment. This March 1980 submittal concluded that modifications to the existing cooling tower system would be the most cost-effective approach to improve the performance of the BFNP heat dissipation system if the TVA petition for a 90°F T_{max} was granted. However, specific recommendations on the actual modifications could not be made pending the completion of additional testing. Details of the tests and modifications which TVA was pursuing were summarized in a January 27, 1981, letter to EPA. Results of these studies, transmitted to EPA on July 3, 1981, showed that fan related improvements would increase the capability of the cooling system by 10 percent to about an overall efficiency of 88 percent. TVA completed these fan modifications to the towers prior to the summer of 1982.

EPA issued a draft Finding Of Fact on TVA's Section 316(a) demonstration on April 21, 1981. This finding provided for the establish ment of alternative thermal limitation of 90°F T_{max} and 5°F ΔT_{max} thermal limitations provided the cooling towers were operated whenever the downstream temperature at the edge of the mixing zone approached or exceeded 86°F. However, EPA has not undertaken final action on TVA's Section 316(a) demonstration.

In TVA's January 27, 1981, letter to EPA, TVA also proposed a modification for the reservoir temperature compliance monitoring system. EPA concurred with TVA's proposed modification subject to demonstration and validation of the system. In July 1982 TVA implemented a one-year demonstration of the proposed monitoring system in parallel with the current system. Results of this demonstration will be provided to EPA for approval following completion of the demonstration period.

days, but durations of this length would not significantly affect annual growth even if sauger were confined at this location. Under "worst case" predictions in 1980, temperatures 88°F to 90°F occurred at depths below five feet as the predicted volume of the reservoir downstream from BFNP greater than 88°F exceeded 90 percent. However, this condition existed only about five days (Figure 4.2-20A).

As noted in the preceding discussion, lethal temperature limits for sauger or walleye (94°F to 95°F) and smallmouth bass (98°F) would not be exceeded by 90/10 limitations. In conjunction with the application of a seasonal maximum temperature limit for growth (based on MWAT), a maximum temperature limit for short-term exposure is used to prevent lethal conditions. It is well established that fish can withstand short exposure to temperatures higher than those acceptable for growth without significant adverse effects (Brungs and Jones 1977).

Based on empirical results from studies at Browns Ferry Biothermal Research Station the following maximum temperatures for short-term exposure (24 hours or less) for sauger and smallmouth bass were determined: 92°F to 93°F for sauger and 95°F for smallmouth bass. Smallmouth bass tolerated 95°F for nine days without adverse affects (Wrenn 1980), and sauger tolerated 92°F to 93°F for 60 hours. Because sauger is the most sensitive, 92°F to 93°F would protect both species.

Under actual severe conditions in July 1980, temperatures greater than 90°F, which occurred both upstream and downstream of BFNP at the 5-foot compliance depth, did not result in fishkills. On July 18 upstream temperatures reached 90.8°F and the average downstream temperature (over a 9-hour period) was 91°F at TRM 292.5, with a peak temperature of 92°F. Under these extreme conditions, sauger would be expected to avoid the entire zone of the reservoir immediately downstream of the mixing zone. However, during this period sauger were collected in gill nets at the edge of the mixing zone and adjacent to the diffusers (stations 1, 3, and 4; Figure 3.2-1) where bottom temperatures were 2°F to 4°F cooler than those at the 5-foot depth.

3.2.1.1 Smallmouth Bass - Largemouth Bass Competition

Because smallmouth and largemouth bass are sympatric in Wheeler Reservoir, some level of interspecific competition between these congeneric species would be expected, particularly because feeding habits are relatively similar. However, various reports indicate both species tolerate a wide range of environmental conditions (see Stroud and Clepper 1975) and that interspecific competition is minimal (Jenkins 1975; Miller 1975). Observations by Jenkins were made relative to reservoirs larger than 500 acres. Miller noted that the ability of centrarchid basses to cohabit streams, rivers, and lakes with little or no hybridization suggests ecological and behavioral mechanisms are highly effective in permitting them to utilize limited resources without competitive exclusion or hybridization. Preference for gravel or rocky substrates by smallmouth bass appears to be a major factor in segregating these species where they occur in the same water body. Also, Reynolds and Casterlin (1978) reported thermotemporal patterns (endogenously controlled) of these two species are distinctly complimentary, and suggested this is a mechanism for segregating these species in time and space.

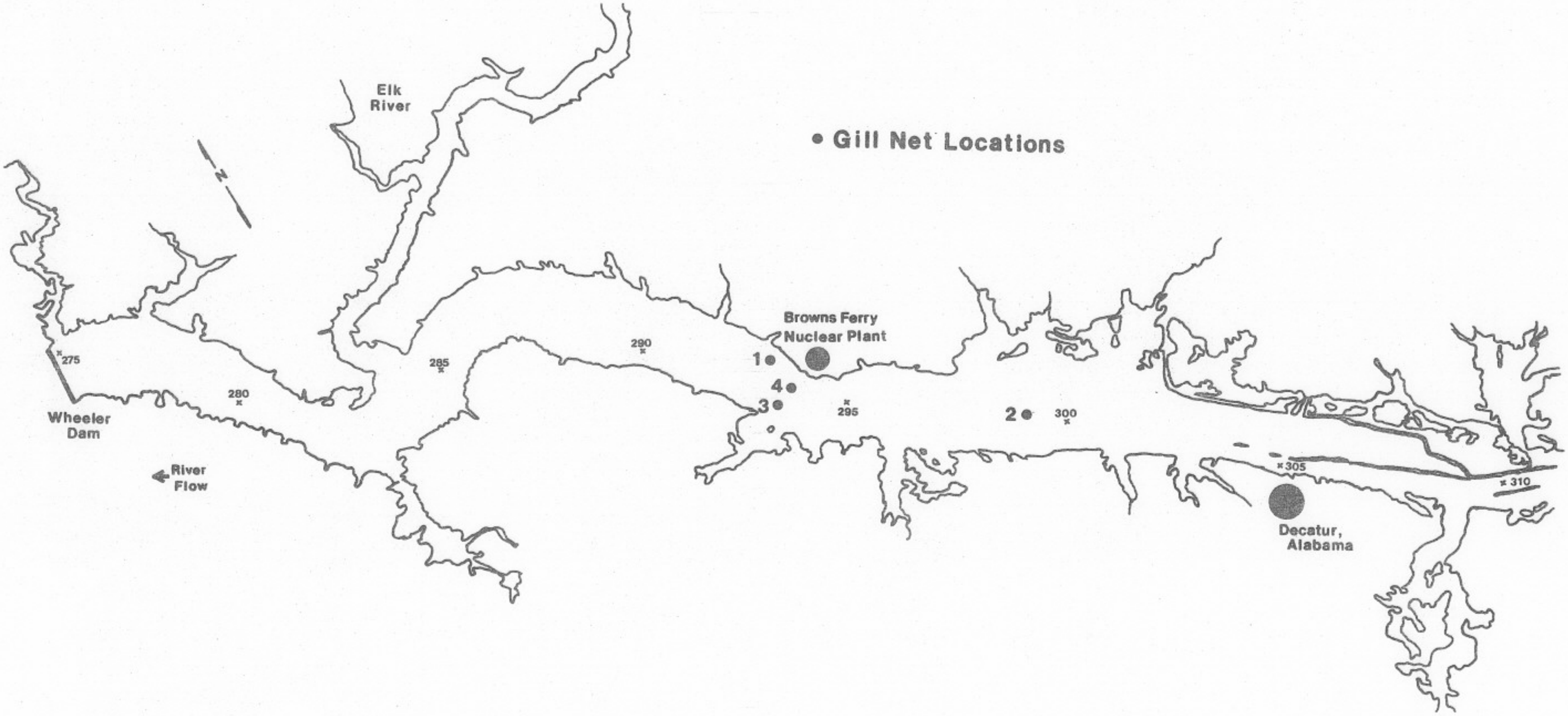

Figure 3.2-1. Location of gill net sample stations on Wheeler Reservoir near Browns Ferry Nuclear Plant.

Also, overall similarities in temperature requirements for smallmouth and largemouth bass further indicate elevated thermal regimes would not result in a competitive advantage for either species. Temperature limits for the following conditions are common to both smallmouth and largemouth bass: lethal 98°F (ORNL 1981; Wrenn 1980); optimum growth - 77°F to 84°F (Brungs and Jones 1977; Shuter et al. 1981); summer preference - 86°F to 89°F (ORNL 1981); avoidance at power plant sites - greater than 95°F (ORNL 1981).

Although effects of temperature on competition between these two species have not been reported in the literature, the preceding information indicates operation of BFNP under a 90/10 limitation would not adversely affect smallmouth bass via competitive exclusion by largemouth bass.

3.2.1.2 Zooplankton and Benthic Macroinvertebrates

Water temperatures expected to occur from operation of BFNP at 90/10 limits are not likely to result in significant long-term alterations of the zooplankton community. Generally, temperatures must exceed 93°F before impact occurs (Benda and Gulvas 1976; Carlson 1974; Wrenn *et al*., 1979). Adverse effects on selected species may occur during infrequent, low-flow periods. However, affected organisms would be replaced rapidly from upstream populations when more normal flows resume. During normal flow periods adverse effects, if they occur, should be minimal.

Potential effects on macroinvertebrates of operating BFNP at 90°F T_{max} and 5°F ΔT_{max} were evaluated and summarized in the previous 316(a) demonstration for a 90°F T_{max} (TVA 1980). Changes in thermal limitations proposed herein will slightly elevate bottom water temperatures over those evaluated in the previous report, although seasonality of bottom water temperatures will not be changed. Temperatures at the edge of the mixing zone usually will be 1 to 2°F higher than upstream bottom temperatures, although higher temperatures may occur during extraordinary low-flow periods (up to 5°F in winter and 3°F summer). Therefore, potential exists for summer bottom temperatures to reach 90°F in localized areas adjacent to the mixing zone during these rare periods.

Studies at Browns Ferry Biothermal Research Station have shown significant reductions in numbers (ca. 65 percent) of the entire macroinvertebrate community, excluding Mollusca, at temperatures between 87 and 93°F (Rodgers, 1980). However, in these studies it could not be determined if these reductions were due to direct thermal effects or due to increased predation by bluegill. In either case, reductions in the macroinvertebrate community were not manifested in lower standing stocks of fish.

Other researchers have shown reductions in population numbers of selected macroinvertebrate species at maximum temperatures that could occur downstream of BFNP. Therefore, some impact to the invertebrate community may occur as a result of operation of BFNP under 90/10 limits. However, the frequency of occurrence should be very low. Additionally, if they occur, recolonization by affected species should occur relatively rapidly because the duration of high temperatures will be short and ample populations of brood stocks exist upstream and in adjacent overbank areas. Therefore, these infrequent, short-term effects are not expected to substantially alter the benthic community of Wheeler Reservoir.

3.2.2 Reproduction of Sauger and Smallmouth Bass

Temperature is important in initiation and completion of spawning and the potential for adverse impacts resulting from power plant thermal discharges is generally recognized. Possible impacts could occur in relation to advanced spawning, or at the other extreme, temperatures could remain sufficiently high throughout the year such that spawning would be prevented entirely. In waters containing indigenous fish populations in which a seasonal temperature cycle is maintained, advanced spawning is more likely to occur than the latter. In relation to advanced spawning, primary concerns posed are that newly hatched fry may not survive because of an inadequate food supply or because they could be exposed to low or high temperature extremes.

Because operation of BFNP under 90/10 limitations would not disrupt the normal seasonal temperature cycle in Wheeler Reservoir (Figure 4.2-7), sustained high temperatures that could repress gonad development or inhibit spawning would not occur. Therefore, the possibility of advanced spawning and related potential impacts are emphasized in this assessment.

Evaluation of smallmouth bass reproduction at Browns Ferry Biothermal Research Station demonstrated that spawning can be advanced in elevated thermal regimes (Wrenn unpublished manuscript). Adult bass were held in outdoor channels (supplied with water from Wheeler Reservoir) under four thermal regimes: (1) ambient temperature of

Wheeler Reservoir, (2) ambient +3°C (5.6°F), (3) ambient +6°C (10.8°F), and (4) ambient +9°C (16.2°F). Peak spawning period was advanced 24 days in the +16.2°F regime and 16 days in the +10.8°F regime (Figure 3.2-2). Spawning in all treatments occurred within the normal temperature range reported for this species, 59°F to 79°F (Carlander 1977). Temperatures at peak spawning ranged from 64°F in the ambient regime to 72°F in the +9°C treatment (Table 3.2-1). The tendency for smallmouth bass to spawn at higher temperatures when water temperatures increase rapidly during the spawning season and at lower temperatures when the rise is more gradual was demonstrated in this study. Hatching rates (≧95 percent) were similar in all treatments. Zooplankton and macroinvertebrates (which colonize the channels from Wheeler Reservoir) were abundant in all treatments at the time of spawning and fry emergence. Mean total length of young-of-year smallmouth bass at 42 days ranged from 37 mm in the ambient regime to 48 mm in the +9°C (16.2°F) regime. Results of this experiment and previous studies (Wrenn 1980; Wrenn and Grannemann 1980) indicated that, although spawning can be advanced, similar changes occur simultaneously in the rest of the biological community (including spawning of other fish species) such that the supply of food organisms was not limiting for growth and survival of newly hatched fry or larvae.

Evaluation of zooplankton populations in the biothermal channels, conducted in conjunction with the fish experiments referenced above, showed the following: (1) advancement of the normal successional process in elevated temperature treatments, (2) equivalent or higher standing crop in elevated treatments (especially in the spring), (3) similar diversity in all treatments, and (4) the successional

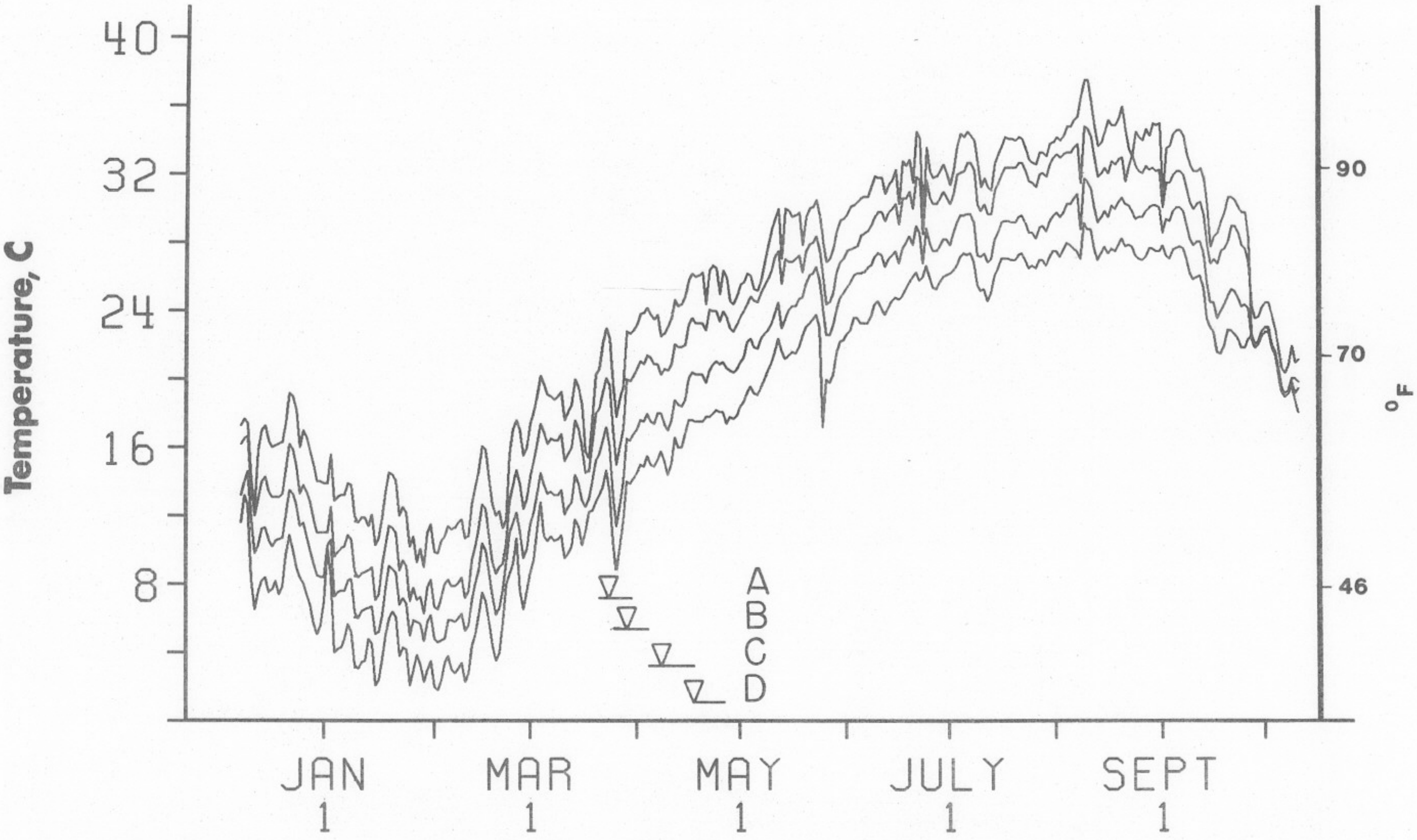

Figure 3.2-2. Spawning periods of smallmouth bass reared in outdoor channels under four thermal regimes, 1978-1979 (three channels per regime). Water temperatures in channels were ambient (Wheeler Reservoir) (D) or elevated about +3°C (5.4°F)(C), +6°C (10.6°F)(B) or +9°C (16.2°F) (A). Horizonal lines (A-D) - length of spawning period; wedge - date of peak spawning.

Table 3.2-1. Summary of smallmouth bass reproduction in four thermal regimes in outdoor channels. Temperatures were ambient (Tennessee River) or elevated +3°C, +6°C, and +9°C above amibient.

	TEMPERATURE TREATMENTS			
	AMBIENT	+3°C	+6°C	+9°C
Spawning Period				
Peak	16 Apr	7 Apr	30 Mar	22 Mar
Range	16 Apr- 26 Apr	5 Apr- 24 Apr	24 Mar- 6 Apr	20 Mar- 31 Mar
Temperature at peak, °C	17.6	18	20	22
Number of nests	17 (19)[a]	9 (19)	11 (14)	15
Mean incubation, days	5.1	5.2	3.8	3.7
Incubation temperature, °C (±1SD)	17.9 (0.2)	18.5 (1.6)	19.4 (1.0)	20.1 (0.9)
Mean time to rise, days	9.3	6.6	7.3	7.1
Development temperature, °C (±1SD)	18.4 (0.5)	19.9 (0.5)	20.3 (0.4)	21.3 (0.9)

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[a] Total number of spawns including those in which exact date of egg deposition unknown.

pattern of dominance was determined as much by predation as by temperature. Also, field monitoring results have shown that relative abundance of zooplankton increases downstream of BFNP (Taylor and Dycus 1980).

Site-specific observations on the effect of a 10°F ΔT_{max} on sauger reproduction are not available. Because both sauger and smallmouth bass are spring-spawners and require a rising temperature regime for successful reproduction, advanced spawning by sauger would be possible. Over the geographical range, spawning temperatures for sauger range from about 41°F to 59°F (Hokanson 1977). Based on the occurrence of larvae in ichthyoplankton samples, sauger in Wheeler Reservoir usually spawn from mid-March through the first week in April at temperatures ranging from about 52°F to 56°F. At these temperatures the incubation period is about 12 to 8 days (Smith and Koenst 1975).

Advanced spawning by sauger and smallmouth bass would be expected in a thermal regime 10°F higher than ambient; however, advanced spawning would occur only if the elevated regime is maintained in the spawning areas. Field observations indicate that the area of the reservoir downstream of BFNP, in which temperatures could be raised 10°F above ambient, is not a major spawning area for either sauger or smallmouth bass. Based on known concentrations of prespawning adult sauger in the tailwaters of Guntersville Dam and size distribution of sauger larvae collected in the vicinity of BFNP (Table 3.2-2), the major spawning area for sauger in Wheeler Reservoir is well upstream of BFNP. Total length (TL) of most sauger larvae collected in the immediate vicinity of BFNP was greater than 8 mm (larvae at this size are at least a week old). One- to two-day old larvae

Table 3.2-2. Mean total length (mm) of sauger larvae collected in the immediate vicinity of Browns Ferry Nuclear Plant.

	March	April				May	Total
Year	22-28	1-8	9-16	17-25	26-30	1-15	Number
1973	-	6.0	8.5	10.0	-	11.0	91
1974	8.2	8.0	8.3	9.1	-	14.1	107
1975	-	7.0	8.7	8.3	11.7	14.6	111
1976	10.0	10.0	10.5	14.5	-	22.0	13
1977	-	9.0	10.0	8.0	11.0	16.5	225
1978	-	-	8.0	-	-	14.0	2
1979	-	9.7	-	9.7	11.5	-	25
1980	-	8.0	8.9	9.6	10.4	11.0	76

(6 mm TL) are motile and apparently occur in the water column at this age. Occurrence of sauger larvae at BFNP appears to be directly related to discharge rates at Guntersville Dam. Major spawning areas for smallmouth bass are downstream of TRM 285 (near the mouth of Elk River) where the temperature regime, particularly during spring, is similar to upstream ambient conditions.

Because it is unlikely that a significant proportion of the sauger or smallmouth bass populations would spawn in areas that could be elevated 10°F, potential adverse effects relative to sudden temperature decline are greatly reduced. Also, based on laboratory tests and field observations, larvae of both species tolerate temperature changes of this magnitude. In the biothermal channels both eggs and larvae of smallmouth bass were not affected by a rapid decrease of 9 to 10°F. Smith and Koenst (1975) showed that 5 to 7 day old sauger and walleye tolerated sudden temperature changes (increase and decrease) well above 10°F.

Information obtained to date indicates that operation of BFNP under a 10°F ΔT_{max} limitation would not be expected to result in significant adverse impacts on the reproduction of sauger, smallmouth bass or other species even if the thermal regime was raised a full 10°F. Because ΔT's that reach 10°F would seldom occur (Table 4.2-1), the possibility of adverse impacts associated with advanced spawning is further reduced.

3.2.3 Winter Survival

Fish congregating in thermal discharges of power plants can acclimate to elevated temperatures and, if the temperature of the discharge declines rapidly, these fish could be suddenly exposed to ambient temperature water. Responses of fish to this situation depend on the duration of the reduction, magnitude of the reduction, and their physiological condition. In some circumstances, cold shock, a condition characterized by disorientation, loss of equilibrium, immobilization, or death can occur. Susceptibility to cold shock occurs only when the temperature decrease (-ΔT) is too rapid to allow acclimation to the lower temperatures and fish are confined such that other temperature gradients are not available for escape (e.g., in discharge channels that restrict movement). If cooling occurs slowly enough, fish can acclimate to lower temperatures. If -ΔT is small, even immediate cooling will not result in cold shock mortality unless lower lethal limits are exceeded.

Laboratory studies typically expose fish to reduced temperatures almost instantaneously, whereas nuclear power plants may continue to discharge heated water for hours or days following shutdown. Therefore, laboratory studies cannot be used to accurately predict occurrence of cold shock due to power plant shutdown; rather they should be viewed as "worst case" situations. Numerous laboratory studies have been conducted to establish the relationship between acclimation temperature and the lower temperature to which a fish can be exposed without cold shock. In general the ΔT should not exceed 18°F to 22.5°F during winter months (Brungs and Jones 1977). Horning and Pearson (1973) reported that smallmouth bass acclimated to 59°F tolerated a 23.4°F temperature reduction. Juvenile walleye mortality only occurred when fish acclimated to 77°F were exposed to 46.4°F (Smith and Koenst 1975).

No fish mortalities have been reported following shutdown of any TVA steam-electric generating plant. Because cold shock mortalities are not known to have occurred at TVA steam-electric plants, the data from a number of fishkills known to have occurred as a result of shutdowns of other thermal discharges have been reviewed. These data are summarized in Table 3.2-3 (from ANS-18.3, Committee Draft No. 7, July 1, 1974).

A review of these data indicates that freshwater fishkills occurred only when the -ΔT was high (29.9°F or greater). This suggests that the EPA nomograph (Brungs and Jones 1977) may be conservative when considering freshwater fish. One likely reason that cold shock mortalities have not been recorded when -ΔT's of less than 29.9°F have occurred is that the shutdown of a power plant exposes fish to temperature changes which are more gradual than the changes to which fish are exposed in the laboratory (the basis for the EPA nomograph). Fish exposed to gradually decreasing temperatures begin acclimating to colder temperatures, thereby reducing the lower lethal temperature.

With a maximum river temperature rise at BFNP of 10°F, cold shock should not occur. Further, BFNP is not likely to shut down all three units simultaneously. Even if this event occurred, "cold" shut down of a nuclear unit is not instantaneous and cooling water is circulated for several days in order to cool the reactor core, with a gradual decrease in discharge water temperatures until ambient conditions are reached. During this time, fish inhabiting the thermal plume would have sufficient time to acclimate to ambient conditions. Therefore,

Table 3.2-3. Recorded cold shock incidents at industrial locations that resulted in fishkills, 1967-1976.

Location	Date	Change in Water temp. ΔT °F(°C)	Number Killed	Species
Sandusky, Ohio	1/ 1/67	44(24)	300,000	Alewife, channel catfish, carp
Northport, Long Island	1/17/70	29(16)	10,000+	Bluefish
Yorkhaven, Pennsylvania	1/ 3/71	34(19)	15,000+	"Gamefish"
J. M. Stuart Power Plant	1/ 3/71	33(18)	7,500	Gizzard shad, catfish, drum, white bass, white crappie
Brunners Island Power Plant	2/ 4/71	44(24)	23,000+	Walleye, smallmouth bass, catfish, carp, suckers
Oyster Creek Nuclear Sta.	1/27/72	25(14)	200,000+	Menhaden (99%), bluefish, striped bass
Oyster Creek Nuclear Sta.	1/12/74	17(9)	20,000	Menhaden

based on operational characteristics of the plant and temperature tolerance of fish species of concern, BFNP operating under a 10°F ΔT_{max} limitation would not elevate water temperatures to a level which would subject fish to cold shock should plant shutdown occur.

3.2.4 Summary

1. Growth of smallmouth bass would not be adversely affected at 90°F.
2. Although 90°F throughout the lower Wheeler Reservoir, downstream of BFNP, would generally be unsuitable for growth of sauger or walleye, temperatures at this level would not prevail at depths normally occupied by these species.
3 Under the most severe conditions (e.g., in 1980 upstream ambient temperatures exceeded 90°F), distributional isolation of sauger from the immediate vicinity of the mixing zone did not occur.
4. Under 90/10 limitations, competitive exclusion of smallmouth bass by largemouth bass would not be expected because these species usually segregrate via differences in behavior and habitat selection and because both species have similar temperature requirements.
5. Although spawning by sauger and smallmouth bass could be advanced about two weeks in a thermal regime 10°F above ambient, significant adverse effects would not be expected because an adequate supply of food organisms would be available and larvae of both species tolerate sudden temperature changes of this magnitude if they should drift into cooler zones or if the plant went off-line.

6. Potential effects relative to advanced spawning would be further reduced because the zone in which temperatures could be elevated 10°F is not a major spawning area for either sauger or smallmouth bass.

7. A 10°F elevation of the ambient regime during winter would not be expected to cause significant mortalities due to cold shock because sauger, smallmouth bass, walleye, and other fish species readily tolerate sudden temperature changes of this magnitude. Also, during shutdown of a nuclear unit, temperature of the heated discharge usually declines gradually, allowing escapement and/or acclimation to cooler temperatures.

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

APPENDIX 3

OBSERVED AND PREDICTED EFFECTS OF ALTERNATIVE THERMAL LIMITS, 90°F T_{max} AND 10°F ΔT_{max} ON AQUATIC BIOTA IN WHEELER RESERVOIR

Tennessee Valley Authority
February 1983

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

APPENDIX 3

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APPENDIX 3

OBSERVED AND PREDICTED EFFECTS OF ALTERNATIVE THERMAL LIMITS, 90 ^{o}F T_{max} AND 10 ^{o}F ΔT_{max} ON AQUATIC BIOTA IN WHEELER RESERVOIR

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APPENDIX 3 OBSERVED AND PREDICTED EFFECTS OF ALTERNATIVE THERMAL LIMITS, 90°F T_{max} AND 10°F ΔT_{max}, ON AQUATIC BIOTA IN WHEELER RESERVOIR

3.0 Introduction

The purpose of thermal discharge limitations is protection and propagation of balanced, indigenous populations of aquatic organisms in the receiving water body. According to protocol established by EPA, this is best accomplished by protecting the most temperature sensitive fish species judged important, desirable or both. Based on this protocol, sauger, smallmouth bass, and walleye were initially classified as key temperature-sensitive species in the Tennessee River basin. Therefore, these species are emphasized in this evaluation of alternative thermal discharge limits of 90°F T_{max} and 10°F ΔT_{max} for TVA's BFNP.

This assessment is based on current guidelines (EPA 1976) for applying thermal water quality criteria and specific issues identified by the Environmental Protection Agency (Region IV), Alabama Water Improvement Commission, and Alabama Department of Conservation and Natural Resources. It follows a previous 316(a) demonstration (TVA 1980) which supported a 90°F T_{max}, but which did not address the temperature rise limit (ΔT). Temperature requirements for growth, survival, and reproduction of target fish species are emphasized. Effects of a 90°F T_{max} are further evaluated relative to summer temperature limits for growth, and effects of a 10°F ΔT_{max} were evaluated relative to temperature limits for winter survival and reproduction.

3.1 Biotic Community in Wheeler Reservoir

3.1.1 Fish Community

The fish community in Wheeler Reservoir is dominated by warmwater species (Table 3.1-1). With the exception of sauger and walleye, all important game and commercial species, including smallmouth bass, are in this category. Sauger and walleye are recognized by fisheries scientists as coolwater species (Hokanson 1977; Kendall 1978). Species in this category occur in conjunction with both warmwater and coldwater species. Definitive thermal-effects data for smallmouth bass, compiled since 1972, reveal that a "coolwater" classification for this species is not warranted. Recent studies show temperature requirements for smallmouth bass, particularly in relation to growth, survival, and preference, are essentially the same as those for largemouth bass and other warmwater centrarchids (Mathur *et al*. 1981; Stauffer *et al*. 1976; Reynolds and Casterlin 1976; Wrenn 1980).

Although temperature requirements for sauger and walleye are similar (Hokanson 1977), sauger is the dominant of the two species in Wheeler Reservoir. Both species exhibit negative phototropism, sauger more so than walleye. The dominance of sauger in lower mainstream reservoirs is attributed to the relative higher turbidity of these waters (Schlick 1978). Walleye is of marginal concern in Wheeler Reservoir, since: (1) the species is rare in the reservoir, and (2) there is no established walleye fishery. Adult sauger are neither common nor widely distributed in shallow overbank areas or embayments where substrates are primarily mud and/or silt. They prefer and select areas of moderate current over rock, gravel, and mixed rubble substrate in streams and tailraces or around reefs in deep water zones of lakes

Table 3.1-1. Common and scientific names* of fishes collected from Wheeler Reservoir during 1969 to 1979, preoperational and operational monitoring for Browns Ferry Nuclear Plant

Common Name	Scientific Name	Group**	Rotenone	Trap Nets	Gill Nets	Creel Census	Meter Netting
Paddlefish	Polyodon spathula	C		X	X		
Spotted gar	Lepisosteus oculatus	C	X	X	X		
Longnose gar	Lepisosteus osseus	C	X	X	X	X	X
Shortnose gar	Lepisosteus platostomus	C	X		X		
Skipjack herring	Alosa chrysochloris	C	X	X	X	X	X
Gizzard shad	Dorosoma cepedianum	P	X	X	X		X
Threadfin shad	Dorosoma petenense	P	X	X	X	X	X
Mooneye	Hiodon tergisus	C	X	X	X		X
Stoneroller	Campostoma anomalum	P	X				
Goldfish	Carassius auratus	C		X	X		
Carp	Cyprinus carpio	C	X	X	X	X	X
Bigeyed chub	Hybopsis amblops	P	X				
Silver chub	Hybopsis storeriana	P					X
Golden shiner	Notemigonus crysoleucas	P	X	X	X		
Emerald shiner	Notropis atherinoides	P	X				X
Spotfin shiner	Notropis spilopterus	P	X				X
Bluntnose minnow	Pimephales notatus	P	X				
Bullhead minnow	Pimephales vigilax	P					X
River carpsucker	Carpiodes carpio	C		X			
Creek chubsucker	Erimyzon oblongus	P	X				
Northern hogsucker	Hypentelium nigricans	C	X	X	X		
Smallmouth buffalo	Ictiobus bubalus	C	X	X	X		X***
Bigmouth buffalo	Ictiobus cyprinellus	C	X	X			
Black buffalo	Ictiobus niger	C				X	
Spotted sucker	Minytrema melanops	C	X	X	X	X	
Silver redhorse	Moxostoma anisurum	C			X		
River redhorse	Moxostoma carinatum	C	X	X	X		

Table 3.1-1. (Continued)

Common Name	Scientific Name	Group**	Rotenone	Trap Nets	Gill Nets	Creel Census	Meter Netting
Black redhorse	*Moxostoma duquesnei*	C	X		X		
Golden redhorse	*Moxostoma erythrurum*	C	X	X	X	X	
Shorthead redhorse	*Moxostoma macrolepidotum*	C	X		X		
Blue catfish	*Ictalurus furcatus*	C		X	X	X	X
Black bullhead	*Ictalurus melas*	C	X	X	X		
Yellow bullhead	*Ictalurus natalis*	C		X		X	
Brown bullhead	*Ictalurus nebulosus*	C		X	X		
Channel catfish	*Ictalurus punctatus*	C	X	X	X	X	X
Madtom	*Noturus* sp.	P	X				
Flathead catfish	*Pylodictis olivaris*	C	X	X	X	X	X
Blackstripe topminnow	*Fundulus notatus*	P	X				
Mosquitofish	*Gambusia affinis*	P	X				
Brook silverside	*Labidesthes sicculus*	P	X				X
White bass	*Morone chrysops*	G	X	X	X	X	X
Yellow bass	*Morone mississippiensis*	G	X	X	X	X	X
Rock bass	*Ambloplites rupestris*	G	X			X	
Green sunfish	*Lepomis cyanellus*	G	X			X	
Warmouth	*Lepomis gulosus*	G	X	X	X	X	
Orangespotted sunfish	*Lepomis humilis*	P	X				
Bluegill	*Lepomis macrochirus*	G	X	X	X		X
Longear sunfish	*Lepomis megalotis*	G	X	X	X		X
Redear sunfish	*Lepomis microlophus*	G	X	X	X		X
Smallmouth bass	*Micropterus dolomieui*	G	X	X	X	X	
Spotted bass	*Micropterus punctulatus*	G	X	X	X		X
Largemouth bass	*Micropterus salmoides*	G	X	X	X	X	X
White crappie	*Pomoxis annularis*	G	X	X	X	X	X
Black crappie	*Pomoxis nigromaculatus*	G	X	X	X	X	
Darter	*Etheostoma* sp.	P					X

Table 3.1-1. (Continued)

Common Name	Scientific Name	Group**	Rotenone	Trap Nets	Gill Nets	Creel Census	Meter Netting
Logperch	*Percina caprodes*	P	X				X
Sauger	*Stizostedion canadense*	G	X	X	X	X	
Yellow perch	*Perca flavescens*	G	X				
Walleye	*Stizostedion vitreum vitreum*	G		X	X	X	
Freshwater drum	*Aplodinotus grunniens*	C	X	X	X	X	X

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*Taken from *Common and Scientific Names of Fishes*, American Fisheries Society Special Publication No. 6, Third Edition, 1970.

**Indicates prey (P), commercial (C), or game (G).

****Ictiobus* sp. - larval fish; species not known.

and reservoirs. They may move between or among various habitat types and substrate zones but apparently spend little time in nonpreferred areas. To TVA's knowledge no reefs exist in the deep-pool water above Wheeler Dam (TRM 275-287), and sauger are seldom caught in this reach. In the Wheeler Reservoir transition zone between pool and river channel (TRM 287-308) sauger are captured by netting near heated water outfalls with the largest numbers occurring in fall and winter seasons. Nearly all efforts by sauger fishermen are expended in the reach of the Tennessee River upstream from BFNP between TRM 308 and Guntersville Dam at TRM 348.8.

Sauger, especially maturing individuals, may be spread throughout the reservoir. When sauger begin moving in early winter on annual spawning runs, they generally move in such a way that by November or early December they concentrate near dams and existing municipal, industrial, and steam plant thermal discharges. Because of this, sauger fishermen in the Tennessee River basin concentrate efforts below dams and in and about steam plant discharge basins beginning in November. Good sauger fishing often continues through April and even early May.

Smallmouth bass generally are not known to be migratory in reservoirs of the southeastern United States; rather they are considered resident in an area. Usually they move locally in a vertical plane along shoreline features and show a seasonal response (i.e., depth selection) to temperature. Smallmouth bass are distributed in two distinct, well separated zones of Wheeler Reservoir, neither of which should experience much effect from the BFNP's thermal effluent. The upstream population resides in the tailrace and river channel below Guntersville Dam (TRM 348.8-308.0). The downstream population is associated with limestone bluffs from TRM 288.0 to Wheeler Dam (TRM 274.9), and in the Elk River (the main Wheeler tributary), from its mouth (TRM 284.5) to its source. In its upper portions, the Elk River is principally a smallmouth bass-rock bass stream.

Fish monitoring investigations in Wheeler Reservoir, conducted quarterly since winter of 1968, have shown the following species important in the sport harvest: largemouth bass, smallmouth bass, spotted bass, white bass, white crappie, bluegill, and sauger. Important commerical fish are: bigmouth buffalo, smallmouth buffalo, channel catfish, flathead catfish, blue catfish, carp, freshwater drum, and paddlefish. Although striped bass occasionally appear in Wheeler Reservoir and its tailwaters, the species is not discussed here because it has neither established reproducing populations nor does it occur in significant numbers. The dominant prey species in Wheeler Reservoir are gizzard and threadfin shad.

3.1.2 Plankton Community

Wheeler Reservoir, with a normal flow-through time of about one to two weeks, is typical of other Tennessee River mainstream reservoirs in that productivity and standing stocks of phytoplankton and zooplankton generally increase in downstream areas of the reservoir. Similar increases in Chickamauga Reservoir, as well as general increases from upper to lower mainstream Tennessee River reservoirs, were summarized by Urban et al. (1979).

As in other Tennessee River mainstream reservoirs, the phytoplankton community in Wheeler Reservoir is usually dominated numerically by Chrysophyta in winter and early spring, Chlorophyta in spring and early summer, and Cyanophyta in summer and fall. The zooplankton community is frequently dominated by Rotifera, although Cladocera or Copepoda are occasionally most numerous. Distinct seasonal trends for zooplankton are not as apparent as for phytoplankton. Diverse populations of both phytoplankton and zooplankton occur (Tables 3.1-2, 3.1-3).

3.1.3 Benthic Macroinvertebrate Community

Abundant macroinvertebrates in the vicinity of BFNP are: Asiatic clams (*Corbicula* sp.), oligochaetes, *Hexagenia* sp., *Caenis* sp., Chironomidae (*Chaoborus* sp.), snails, sponges, byrozoans, and a few mussels and crayfish. With the exception of *Corbicula* sp., all of these organisms are widespread geographically, and are ubiquitous in reservoirs or slow-flowing rivers. The Asiatic clam is not indigenous to North America, but is very abundant in the Tennessee River basin and has spread north at least as far as Ohio.

Table 3.1-2. List of phytoplankton genera collected from Wheeler Reservoir in summer, 1972-1979

CHRYSOPHYTA

Actinella
Achnanthes
Asterionella
Attheya
Caloneis
Chaetoceros
Cocconeis
Cyclotella
Cymatopleura
Cymbella
Denticula
Diatoma
Dichotomoccus
Dinobryon
Eunotia
Fragilaria
Gomphonema
Gyrosigma
Mallomonas
Melosira
Meridion
Navicula
Nitzschia
Ophiocytium
Pinnularia
Rhizosolenia
Rhoicosphenia
Stauroneis
Stephanodiscus
Surirella
Synedra
Tabellaria

CHLOROPHYTA

Actinastrum
Ankistrodesmus
Arthrodesmus
Acanthosphaeria
Botryococcus
Bracteacoccus
Carteria
Characium
Chlamydomonas
Chlorella
Chlorogonium
Chodatella
Chlorococcum
Cloisteridium
Closteridium
Closteriopsis
Closterium
Coelastrum
Cosmarium
Crucigenia
Cryptomonas
Dactylococcus
Dictyosphaerium
Echinosphaerella
Elakathothrix
Euastrum
Eudorina
Franceia
Gloeoactinium
Gloeocystis
Gloenkinia
Gonium
Kirchneriella
Micractinium
Micrasterias
Mougeotia
Oedogonium
Oocystis
Pachycladon
Pandorina
Pediastrum
Planktosphaeria
Platydorina
Pleodorina
Polyedriopsis
Protococcus
Protoderma
Pteromonas
Pyramimonas
Pyrobotrys
Quadrigula
Scenedesmus
Selenastrum
Schroederia
Sphaerocystis
Spondylomorum
Staurastrum
Stigeoclonium
Tetradesmus
Tetraedron
Tetrallantos
Tetraspora
Tetrastrum
Treubaria
Trochiscia
Ulothrix

CYANOPHYTA

Anacystis
Anabaena
Anabaenopsis
Aphanocapsa
Aphanothece
Aphanizomenon
Arthrospira
Chroococcus
Coelosphaerium
Cylindrospermum
Dactylococcopsis
Eucapsis
Gloeothece
Gomphosphaeria
Lyngbya
Merismopedia
Myxosarcina
Nostoc
Oscillatoria
Phormidium
Raphidiopsis
Rhabdoderma
Spirulina

Table 3.1-3. Species of zooplankton collected from Wheeler Reservoir, Alabama, near Browns Ferry Nuclear Plant during summer, 1978 and 1979.

	Tennessee River Mile							
	278	284	289	292	294	296[a]	301[a]	308
Cladocera								
Alona costata						X		
Alonella sp.				X				X
Bosmina longirostris	X	X	X	X	X	X	X	X
Ceriodaphnia lacustris		X		X	X			X
Chydorus sp.							X	
Daphnia ambigua				X				
Daphnia parvula				X	X	X	X	X
Daphnia retrocurva	X		X	X	X	X	X	X
Diaphanosoma leuchtenbergianum	X	X	X	X	X	X	X	X
Holopedium gibberum	X	X	X	X	X	X	X	
Ilyocryptus spinifer	X		X	X	X	X	X	
Leptodora kindtii	X	X	X	X	X	X	X	X
Moina micrura	X	X	X	X				
Moina minuta	X	X	X	X	X			
Pleuroxus denticulatus				X				X
Pleuroxus hamulatis					X	X	X	
Scapholebris kingi		X						
Sida crystallina				X	X	X	X	
Ceriodaphnia	X				X			X
Copepoda								
Canthocamptus robertcokeri					X		X	X
Cyclops bicuspidatus thomasi					X			
Cyclops varicans rubellus			X					
Cyclops vernalis	X	X	X	X	X	X	X	X
Diaptomus dorsalis	X	X			X		X	
Diaptomus mississippiensis						X	X	X
Diaptomus pallidus	X	X	X	X	X	X	X	X
Diaptomus reighardi	X	X	X	X	X	X	X	X
Ergasilus sp.	X	X	X	X	X	X	X	X
Eucyclops agilis					X			
Mesocyclops edax	X	X	X	X	X	X	X	X
Tropocyclops prasinus	X	X	X		X			
Rotifera								
Asplanchna sp.			X	X	X	X	X	
Asplanchna herricki	X	X	X	X	X	X	X	
Branchionus angularis	X	X	X	X	X	X	X	X
Branchionus bidentata			X	X	X	X	X	
Branchionus budapestinensis	X	X	X	X	X	X	X	X
Branchionus calcyciflorus	X	X	X	X	X	X	X	
Branchionus caudatus	X	X	X	X	X	X	X	X
Branchionus havanensis		X	X					

Table 3.1-3. (Continued)

	Tennessee River Mile							
	278	284	289	292	294	296[a]	301[a]	308
Branchionus quadridentatus			X		X	X	X	
Cephalodella sp.						X		X
Collotheca sp.			X	X	X	X	X	
Conochiloides sp.	X	X	X	X	X	X	X	X
Conochilus hippocrepis	X	X	X	X	X	X	X	X
Conochilus unicornis	X	X	X	X	X		X	X
Epiphanes macroura	X	X	X	X	X	X		
Filinia sp.			X					
Filinia longiseta	X	X	X	X	X			X
Hexarthra sp.		X	X					
Kellicottia bostoniensis				X				
Keratella cochlearis	X	X	X	X	X	X	X	X
Keratella crassa	X			X		X		X
Keratella earlinae	X	X	X	X	X	X	X	X
Lecane sp.					X			
Monostyla sp.						X	X	X
Platyias patulus			X	X	X		X	X
Ploesoma sp.		X						
Ploesoma hudsoni	X	X			X			
Ploesoma truncata	X	X	X	X	X	X	X	X
Polyarthra sp.	X	X	X	X	X	X	X	X
Rotaria sp.				X	X	X	X	X
Rotaria neptunia						X		
Synchaeta stylata	X	X	X	X	X	X	X	X
Triochocera sp.	X	X	X	X	X	X	X	

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a. Control Stations

3.2 Application of Thermal Criteria

Previous assessments for permanent or temporary alternative thermal limits at BFNP have not addressed the maximum temperature (T_{max}) and rise (ΔT) simultaneously. However, it is important to recognize that functionally these components are not independent. Previously, an independent relationship between the ΔT_{max} and ΔT limitations has been inferred because: (1) from the standpoint of compliance, both limits have been exceeded or imposed plant operational restrictions at different periods of the year, and (2) guidelines for setting a ΔT_{max} limit were not clearly defined in EPA's preliminary recommendations in 1971.

Interaction between temperature maximum and rise was later identified in EPA's published recommendations for applying numerical temperature criteria for the protection of freshwater fish (EPA 1976; Brungs and Jones 1977). However, requirements for a ΔT_{max} limit, as currently applied, were not included. According to these recommendations, appropriate thermal discharge limits that protect important or desirable fish species should be established on the basis of: (1) seasonal maximum temperatures for growth, reproduction, and winter survival, and (2) survival of short-term exposure (24 hours) to temperatures higher than those suitable for growth or reproduction. Seasonal maximum limits are based on maximum weekly average temperature (MWAT). In this approach, which emphasizes the importance of exposure duration (time) and season as well as temperature, a temperature rise limit (ΔT) is not utilized. Because elevated temperatures resulting from a thermal discharge are obviously a function of the ΔT, seasonal temperatures could be controlled by a ΔT_{max} limit, particularly during winter and spring. The temperature rise also may control the maximum temperature limit during summer but in the case of BFNP, the summer maximum is usually limited by the summer ambient regime.

Based on current EPA recommendations, the 5°F ΔT_{max} limit was originally included to indirectly set seasonal maximum limits for reproduction and winter survival, whereas the 86°F or 90°F T_{max} limit apparently was applied as the summer temperature maximum for growth. However, the 86°F or 90°F T_{max} frequently has been interpreted as the upper limit for survival. There are no provisions for a short-term temperature maximum for survival in the present thermal criteria for Alabama.

In the present assessment of thermal discharge limits of 90°F T_{max} and 10°F ΔT_{max} (90/10), seasonal temperature limits for growth and reproduction as well as short-term limits for survival of key fish species are emphasized. Effects of a 10°F ΔT_{max} are evaluated relative to: (1) seasonal limits for reproduction and winter survival, and (2) short-term maximum temperatures during the reproductive season. The 90°F T_{max} is evaluated primarily on the basis of seasonal temperature requirements for growth. Short-term maximum limits for survival during summer are discussed in conjunction with the 90°F T_{max} limit. The effects of 90/10 limitations on invertebrate fish-food organisms are addressed in conjunction with seasonal and short-term limits for fish.

The ultimate effect of alternative limits is contingent on the distribution of target fish species relative to the effects of the thermal discharge in downstream portions of the reservoir. Therefore, in assessing growth, survival, and reproduction, seasonal fish distribution is a primary consideration.

The 316(a) demonstration (TVA 1980), which supported establishment of a permanent 90°F T_{max}, emphasized survival of key fish species (smallmouth bass, sauger, and walleye) and maintenance of a balanced aquatic community. Principal conclusions were: (1) 90°F T_{max} is not lethal to smallmouth bass, sauger, or walleye, (2) fish, plankton, and macroinvertebrate communities were not adversely affected when BFNP was operated under a 90°F T_{max} limit, and (3) temperatures that approach or reach 90°F do not coincide with the reproductive season of smallmouth bass, sauger, or the majority of fish species in Wheeler Reservoir.

From discussions with the Alabama Department of Conservation, the Alabama Water Improvement Commission, and the Environmental Protection Agency, Region IV, the following were identified as issues of specific concern in the present assessment for 90/10 limits: (1) ability of smallmouth bass to compete with largemouth bass at higher temperatures resulting from an increase in the ΔT_{max} limit, (2) effect of a higher ΔT_{max} limit on fish reproduction, particularly from the standpoint of early spawning, and (3) thermal stratification--dissolved oxygen depletion resulting from an increase in the duration of 90°F at a higher ΔT_{max} limit. Item number 3 is discussed in Appendix 4.0 (section 4.2.2.5).

3.2.1 Summer Temperature Limits for Growth and Survival of Smallmouth Bass, Sauger and Walleye

According to current recommendations for applying thermal criteria, the purpose of a MWAT limit in summer is to maintain growth of aquatic organisms at rates necessary to sustain reproducing populations (Brungs and Jones 1977). This limit does not apply to the mixing zone, and it should be applied with adequate understanding of the normal seasonal distribution of important species.

MWAT is based on the physiological optimum temperature (i.e., growth or final preferendum) plus a factor calculated as one-third of the difference between the ultimate incipient lethal temperature and the optimum temperature for important sensitive fish species. The ecological significance of the physiological optimum temperature is based primarily on its correlation to zoogeographical distribution (as observed in two salmonid species) and not on maximum growth rates per se (K.E.F. Hokanson, EPA, unpublished manuscript). Because limits of zoogeographical distribution correspond closely to temperatures for zero net biomass gain, the MWAT is essentially an estimated temperature limit necessary to maintain biomass of the population(s) because change in biomass is a function of both growth and survival.

Field monitoring results at BFNP generally are not appropriate for evaluating effects of temperature on growth. However, tests conducted at Browns Ferry Biothermal Research Station (Armitage 1980) were specifically designed to evaluate the effect of elevated thermal regimes on growth, survival, and population biomass of selected fish species under essentially natural conditions.

Based on results of experiments with smallmouth bass (Wrenn 1980), walleye (Wrenn and Forsythe 1978), and sauger (Heuer, unpublished data), the calculated MWATs that would sustain growth of these species are 90°F for smallmouth bass and 88°F for sauger and walleye. These levels were derived from the following temperatures for growth and lethal limits. Good to excellent growth of both smallmouth bass and walleye occurred at 84°F to 86°F, and lethal limits were 98°F and 94°F, respectively. Walleye growth declined at temperatures above 87°F; however, zero net growth did not occur during a 75-day period when the mean daily water temperature was 89°F-91°F. Also, these studies identified two important conditions that should be considered in applying a calculated temperature limit based on optimum growth temperature: (1) elevated thermal regimes that could result in decreased fish growth during summer provide favorable growing conditions during other periods and (2) growth occurs over a range of temperatures and is not limited to the summer season, particularly at southern latitudes. For example, in the thermal regime 16°F (9°C) above ambient, 45 percent of the annual growth (weight) of smallmouth bass occurred above 84°F and 25 percent below 70°F. In the ambient thermal regime (Wheeler Reservoir conditions), 44 percent of the annual growth occurred below 77°F (the reported lower limit for optimum growth). Total biomass of smallmouth bass populations in these treatments was not significantly different after 322 days.

Although summer water temperatures greater than 88°F throughout lower Wheeler Reservoir would generally be unsuitable for growth of sauger and walleye, operation of BFNP under a 90/10 limitation would not be expected to adversely affect growth of this species since temperatures above 88°F do not exist for extended periods and are normally confined to surface zones not occupied by sauger and walleye, particularly during summer. Occurrences of temperatures from 88°F to 90°F would increase under a 90/10 limit (Table 4.2-7), but durations for most of these occurrences would be less than 6 hours (Table 4.2-10). Under extreme conditions (Table 4.2-11), 88°F to 90°F temperatures (5-foot depth at the edge of mixing zone) would occur for 12 to 13

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

APPENDIX 4

HYDROTHERMAL ASPECTS OF WHEELER RESERVOIR

Tennessee Valley Authority
February 1983

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

APPENDIX 4

HYDROTHERMAL ASPECTS OF WHEELER RESERVOIR

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(Continued)

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

APPENDIX 4

HYDROTHERMAL ASPECTS OF WHEELER RESERVOIR

TABLES

TABLES

(Continued)

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

APPENDIX 4

HYDROTHERMAL ASPECTS OF WHEELER RESERVOIR

FIGURES

FIGURES

(Continued)

FIGURES

(Continued)

FIGURES

(Continued)

APPENDIX 4 HYDROTHERMAL ASPECTS OF WHEELER RESERVOIR

4.0 Introduction

In this appendix the hydrothermal conditions of Wheeler Reservoir are characterized. The physical state of the reservoir is considered to provide information on aquatic habitats. Natural conditions (without plant operation) are first presented to illustrate the background for any evaluation of the effects of alternative thermal limitations.

The potential effects of alternative limitations on plant operation are then described. Past temperature monitoring data during periods when the plant operated under temporary variances (severe environmental conditions) are considered to provide a basic understanding of the potential thermal effects on the reservoir. Simulation models are then used to describe potential changes to the physical conditions of the reservoir under alternative limitations.

4.1 Hydrothermodynamics of Wheeler Reservoir

The hydrothermal aspects of Wheeler Reservoir are discussed to provide a perspective for the near field and far field effects of thermal discharges from BFNP. This section includes a description of (1) reservoir geometry, (2) reservoir flow patterns, (3) heating and cooling processes, and (4) typical observed water temperature patterns.

4.1.1 Wheeler Reservoir Geometry

4.1.1.1 Longitudinal Geometry

Wheeler is a mainstem reservoir that extends 74 miles from Wheeler Dam (TRM 275) to Guntersville Dam (TRM 349). The BFNP intake is located at TRM 294 (right bank). The main channel depth profile shown in Figure 4.1-1 increases slowly between Guntersville Dam and BFNP, where the maximum channel depth is approximately 25 to 30 feet. The main channel depth increases another 25 feet to between 50 and 55 feet at Wheeler Dam.

Reservoir widths follow a similar increasing pattern, characterized by a narrow riverine segment with occasional embayments from Guntersville Dam to the vicinity of Decatur, Alabama (TRM 305). The reservoir width and cross sectional area increase substantially between Decatur and Wheeler Dam. Downstream of Decatur, the reservoir covers large shallow overbank areas with depths of 5 to 15 feet. BFNP is located within the segment of reservoir having both a deep main channel and extensive overbank regions. The downstream portion of Wheeler, from Wheeler Dam to a few miles above the Elk River embayment, is deep and wide.

The cross sectional area above Decatur ranges from 20,000 to 50,000 ft^2 while the segment with large overbanks from Decatur to BFNP has a cross sectional area of 100,000 to 150,000 ft^2. The deep portion between the Elk River and Wheeler Dam has a cross sectional area of 300,000 to 400,000 ft^2. These different cross sectional areas affect flow velocities at these reservoir locations. For example, at a riverflow of 40,000 cfs, the upstream portion of the reservoir will have velocities of 0.8 to 2.0 ft/sec. These high velocities provide a great deal of turbulence and usually result in fully mixed conditions upstream of Decatur. Characteristic velocities in the overbank region near BFNP at the same flow would be 0.25 to 0.4 ft/sec. Velocities in the downstream portion of Wheeler Reservoir would be 0.1 to 0.15 ft/sec. Turbulent mixing becomes less as velocity decreases.

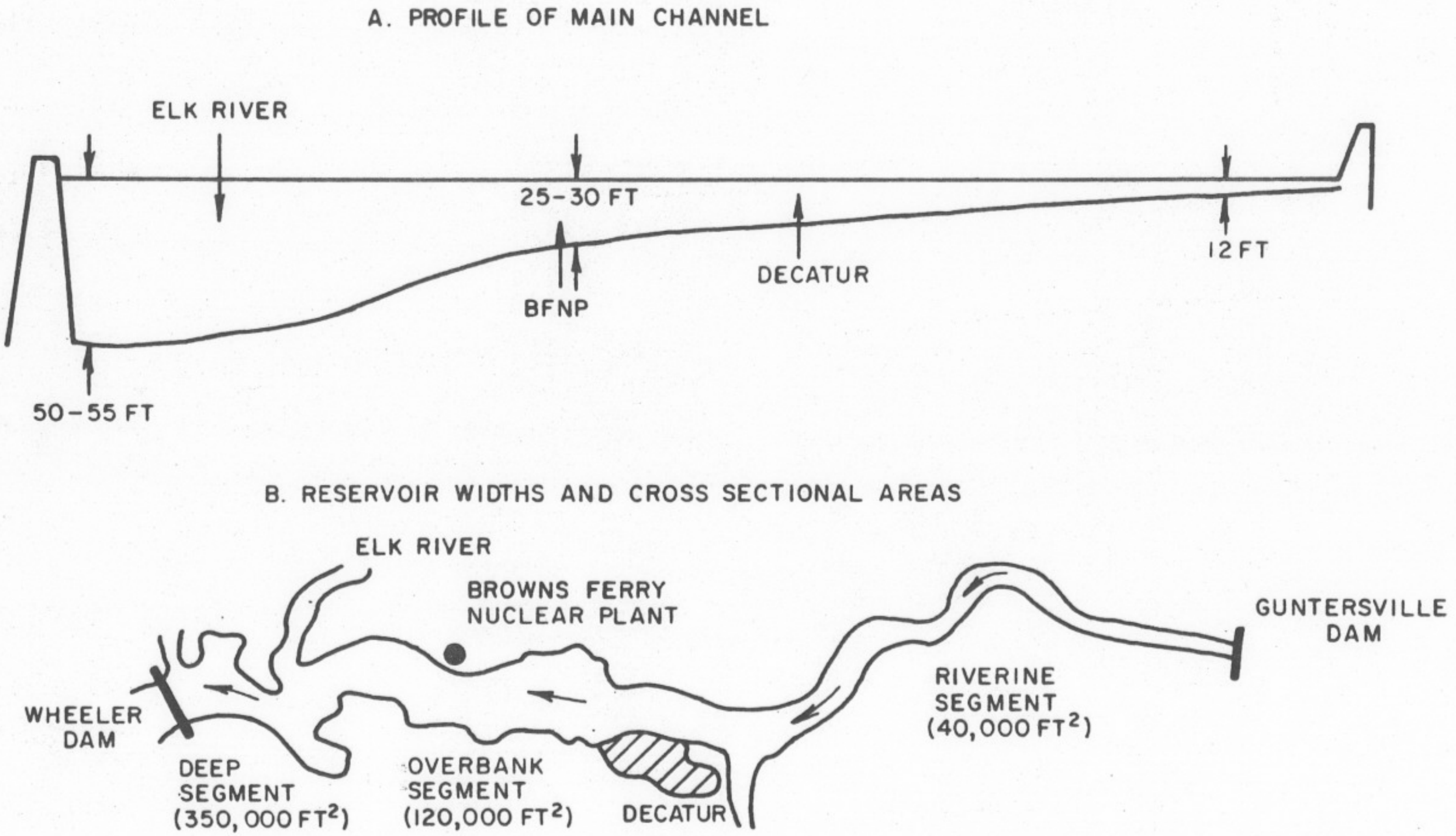

Figure 4.1-1. Geometry of Wheeler Reservoir.

4.1.1.2 Shallow Regions

The shallow portions of Wheeler Reservoir can be divided into three major types: (1) embayment areas that are partially isolated from the main reservoir; (2) overbank areas alongside the main channel; and (3) shallow portions near the main channel near the riverine reaches. Each of these areas has particular ecological importance so it is important to understand the temperature patterns that characterize these shallow areas.

The embayment areas are often quite shallow, with mean depths of 3 to 6 ft, and are isolated from the main channel flow. When fully mixed, embayments can cool rapidly in response to meteorological conditions because of their large surface area relative to their volume (low mean depth). The response to warming meteorological conditions is more complicated because the heating produces high temperature gradients near the surface, but the embayment areas are generally able to warm faster than the deeper main channel areas.

The shallow areas near the main channel in the riverine reaches are directly influenced by the main channel flows. When stratification occurs in the main reservoir during low flow and warm meteorological conditions, temperatures in the shallow areas correspond to the main channel temperatures at the same depth. (See Section 4.2.2.5 for a further discussion of the extent of thermal stratification in Wheeler Reservoir.)

Overbank areas, such as those between Decatur and the Elk River embayment (both upstream and downstream of BFNP) behave in a manner intermediate between embayments and main channel bank areas. Flow may be much lower in these overbank areas than in the main channel, allowing the temperature response to approach that of isolated embayments.

During solar heating, the reservoir becomes thermally stratified near the surface (approximately the upper five feet of the water column) unless flows produce full mixing from turbulence, or wind causes surface mixing. Flows in the embayments are always low so the only significant mixing process during solar heating is wind mixing. Velocities are usually lower in the overbank regions than in the main channel, so the overbanks may thermally stratify when the main channel does not. Assuming, however, that velocities are low enough throughout a portion of the reservoir to allow solar heating to thermally stratify the near surface water layers, the temperatures at all locations within this reservoir segment are very similar. This is because the turbidity of water in Wheeler Reservoir is usually high enough so that most solar radiation is absorbed within the top 5 feet. The total water depth does not influence the distribution of solar heat.

In summary, all three types of shallow areas in Wheeler Reservoir respond in a similar way to warming effects from solar heating. During low flow and calm wind conditions, mixing becomes minimal, and the temperature response of these shallow areas becomes very similar to each other and to the main channel areas. During fully mixed conditions the shallow areas will be similar in temperature to the main channel although the shallower areas may respond more quickly to changing meteorology.

4.1.2 River Flow and Travel Times

Instantaneous river flows in the vicinity of BFNP site are dependent upon discharges from Guntersville Dam (TRM 349), 55 miles upstream, and from Wheeler Dam (TRM 275), 19 miles downstream. River flow information is available from the streamflow gaging station at Whitesburg, Alabama, about 39 miles upstream of BFNP and through numerical flow routing model evaluations. The gaging station provides mean daily values which show an average streamflow of 42,500 cfs for 46 years of record. Since the plant-induced temperature rise is heavily dependent on river flow it was necessary to predict hourly values of flow at the site. An explicit one-dimensional unsteady numerical flow routing model (Ferrick and Waldrop, 1977) was used to determine hourly flows at BFNP. Hourly discharges from Guntersville and Wheeler Dams were used as boundary conditions with Elk River and local inflows as additional inputs. Wheeler headwater elevation was used on a weekly basis as a check for continued accuracy. This model is the one presently being used to schedule reservoir and hydroelectric operations for Wheeler Reservoir.

Table 4.1-1 presents an overall summary of flow conditions at the BFNP site. The percentage of time river flows were below the indicated flows are shown for mean daily flows (Whitesburg gage data) and for hourly flows (numerical model results) for several periods of record. Generally, the hourly data show a higher occurrence of flows less than 20,000 cfs. The mean daily flows tend to mask these low flow occurrences, normally only a few hours in duration. In the years 1969-1976 the dams were operated for peaking power to maximize hydroelectric efficiency, relatively independent of BFNP. Dam releases were often cut back during the morning hours when there was low power demand. This is evident in the higher occurrence of flows less than 20,000 cfs for the period 1969-1976 when compared to 1977-1981. After 1976, TVA's release schedules included the river flow needed for

Table 4.1-1. Percent of time when river flows near Browns Ferry Nuclear Plant are less than specified flows.

Tenn. River Flow Near Browns Ferry (cfs)	1959-1968 Mean Daily Flow Lower Than*	1969-1981 Hourly Flow Lower Than**	1969-1976 Hourly Flow Lower Than**	1977-1981 Hourly Flow Lower Than**	1980 Hourly Flow Lower Than**	1981 Hourly Flow Lower Than***
50000	76	57	52	65	72	88
40000	56	44	38	53	60	83
30000	27	32	29	37	38	72
20000	10	17	19	15	10	38
15000	6	10	13	5	2	17
10000	3	5	9	2	<1	5
5000	1	4	6	<1	<1	<1

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*Whitesburg Gage
**Flows Modeled at BFNP
***Flows Modeled at BFNP, 1/1/81-6/24/81

NOTE: All values are expressed as percent of time in given period.

operation of BFNP under existing thermal limitations, hence, the lower occurrence of low river flow during these periods.

The years 1980 and 1981 are also detailed in Table 4.1-1 since these were critical periods of plant operation considered in this report. Table 4.1-2 shows a breakdown of the flow occurrences by month to highlight conditions during the severe temperature periods in 1980 and the low flow period through May 1981. It is useful to compare these values with average monthly occurrence frequencies for the years 1977 through 1981 shown in Table 4.1-3. Flows during June through August 1980 were controlled to provide a minimum of 15,000 cfs past the plant to mitigate the high temperature problems. Starting in June 1980 and continuing through June 1981 flows were consistently lower than the historic average daily streamflow of 42,500 cfs because of the continuing drought conditions during this period.

The previous information was used to determine representative travel times in various segments of the reservoir. Segments of interest include: (1) Guntersville Dam to Decatur; (2) Decatur to BFNP intake; (3) BFNP diffusers to the downstream compliance monitors; (4) compliance monitors to the Elk River; and (5) Elk River to Wheeler Dam. Travel times, as shown in Table 4-1.4, govern the period for temperature responses and are needed to properly interpret longitudinal temperature gradients. This table indicates that travel times downstream of BFNP are significant during low flows. The present compliance monitors are more than 12 hours downstream and the far field thermal plume requires several days to reach Wheeler Dam. Natural heating, cooling, and mixing become significant as the thermal plume moves past the compliance monitors toward Wheeler Dam. In

Table 4.1-2. Percent of time when river flows near Browns Ferry Nuclear Plant are less than specified flows, 1980-1981.

Tenn. River Flow Near Browns Ferry (cfs)	1980							1981					
	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
50,000	90	95	99	98	100	97	100	100	60	95	93	99	81
40,000	79	81	93	86	98	89	97	100	48	90	89	98	70
30,000	30	27	49	60	94	75	88	98	30	79	75	96	50
20,000	<1	<1	2	24	39	20	31	29	4	42	42	83	23
15,000	0	0	<1	12	6	<1	<1	<1	<1	11	15	61	11
10,000	0	0	<1	3	2	<1	<1	0	0	0	2	24	4
5,000	0	0	0	<1	<1	0	0	0	0	0	0	<1	<1

NOTES: Hourly values of river flow determined from numerical model.
All values are expressed as percent of time in given month.

Table 4.1-3 Percent of time when river flows near Browns Ferry Nuclear Plant are less than specified flows, 1977-1981.

Tenn. River Flow Near Browns Ferry (cfs)	Month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
50,000	32	51	39	56	75	82	66	64	61	59	43	41
40,000	24	31	29	45	59	69	55	54	51	50	39	32
30,000	21	16	19	32	41	39	27	30	32	41	33	23
20,000	6	1	9	14	20	8	8	8	10	21	16	8
15,000	<1	<1	2	3	12	3	4	4	4	2	6	<1
10,000	<1	<1	<1	<1	5	<1	2	2	1	<1	1	<1
5,000	<1	0	0	0	<1	<1	1	<1	<1	<1	0	0

NOTES: Hourly values of river flow determined from numerical model.
All values are expressed as percent of time in given month.

Table 4.1-4 Travel times in days for selected segments of Wheeler Reservoir.

Segment (volume at elev. 556)	River Flow, 1000 cfs 10	 20	 30	 40	 50
1. Guntersville Dam to Decatur (TRM 349 to 305) (316,000 Ac-ft)	16	8	5.3	4	3.2
2. Decatur to Upstream Compliance Monitors (TRM 305 to 297) (130,000 Ac-ft)	6.6	3.3	2.2	1.6	1.3
3. Upstream Compliance Monitors to BFNP Intake (TRM 297 to 294) (38,500 Ac-ft)	1.9	1.0	.6 (14 hrs)	.5 (12 hrs)	.4 (10 hrs)
4. BFNP Diffuser to Present Downstream Compliance Monitors (TRM 294 to 292) (55,500 Ac-ft)	2.8	1.4	.9 (22 hrs)	.7 (17 hrs)	.6 (14 hrs)
5. Downstream Compliance Monitors to Elk River (TRM 292 to 286) (114,000 Ac-ft)	5.7	2.9	1.9	1.4	1.1
6. Elk River to Wheeler Dam (TRM 286 to 275) (193,000 Ac-ft)	9.7	4.9	3.2	2.4	1.9

NOTE: All values are expressed in days unless otherwise noted.

summary, flows through Wheeler Reservoir affect the mixing and travel time through various reservoir segments; therefore, flow conditions must be considered when evaluating temperature patterns in the vicinity of BFNP.

4.1.3 Heating and Cooling Processes

An understanding of the basic hydrothermal processes within Wheeler Reservoir will allow better evaluation of thermal discharge effects. The meteorological variables important for the various heat transfer processes are air temperature, relative humidity, windspeed, and solar radiation. The major surface heat transfer processes include absorption of solar radiation within the reservoir, long wave radiation, and evaporation. Besides radiation, other heat transport mechanisms in the reservoir include advection and convection.

4.1.3.1 Solar Heating

During sunny hours, the solar radiation absorption in near surface layers of the reservoir is the dominant heating process. Normally, the reservoir is moderately turbid so that most solar absorption occurs within the top 5 feet. Almost half the solar radiation is absorbed at the surface of the water because only the middle portion of the solar spectrum penetrates through water. As turbidity increases, the solar heating becomes concentrated closer to the surface. (See Section 4.2.2.3 for a comparison of the solar heating inputs with BFNP thermal inputs.)

4.1.3.2 Longwave Radiation

The radiant exchange of heat between the water surface and the atmosphere will produce warming when the air temperature is significantly warmer than the water, and will produce cooling as the air temperature drops below the water temperature. This can be a very important process during major weather pattern changes, but tends to stabilize the water temperatures during constant weather conditions. Under warming conditions, water temperatures will never become as warm as air temperatures because the ability of water to emit radiation is higher than that of air.

4.1.3.3 Evaporation

Evaporation produces a cooling of the water surface which increases with high windspeed and a large difference between water temperature and dewpoint temperature. Evaporation is quite important when considering the transient response of a thermal plume relative to the natural temperatures. Both evaporation and longwave radiation cooling change with an increased surface temperature, but the increased evaporative cooling is usually larger than the increased longwave radiation cooling. Windspeeds often increase during the afternoon along with the surface temperatures so that evaporative cooling has a definite diurnal variation.

4.1.3.4 Advection (Horizontal Movement)

Water temperatures in the reservoir (especially deeper areas) are significantly influenced by water inflows. This is particularly evident during spring heating and fall cooling when a large difference can exist between upstream inflows and reservoir conditions.

4.1.3.5 Convection (Vertical Movement)

Surface cooling may cause near surface mixing as the cooled parcels of water mix to depths of the same temperature. Late afternoon and evening mixing is very common following sunny days when thermal stratification has developed near the surface.

4.1.4 Observed Water Temperature Patterns

The temperature patterns observed in Wheeler Reservoir are constantly changing in response to varying flow and meteorological conditions. Examples of typical water temperature patterns are shown, using data from the BFNP thermal monitor network. A more systematic review of study periods during extreme conditions is then presented. Natural water temperature patterns upstream and far downstream of BFNP are emphasized here. Data illustrating the thermal discharge effects are shown in Section 4.2.

4.1.4.1 Time Scales and Magnitudes of Variation

An obvious water temperature fluctuation is the seasonal warming and cooling in response to seasonal meteorological variation. The time scale of this temperature dynamic is one year. This seasonal variation becomes relatively unimportant for a time scale of less than a few days when the reservoir may either warm or cool in response to transient weather patterns. The overall magnitude of this seasonal variation is remarkably constant, with winter temperatures dropping to between 35 and 40°F, and summer temperatures approaching 85 to 90°F. Thus water temperatures vary seasonally 45 to 55°F. Figure 4.1-2 shows the seasonal temperature pattern for 1977 at upstream Station 4 (TRM 297.8).

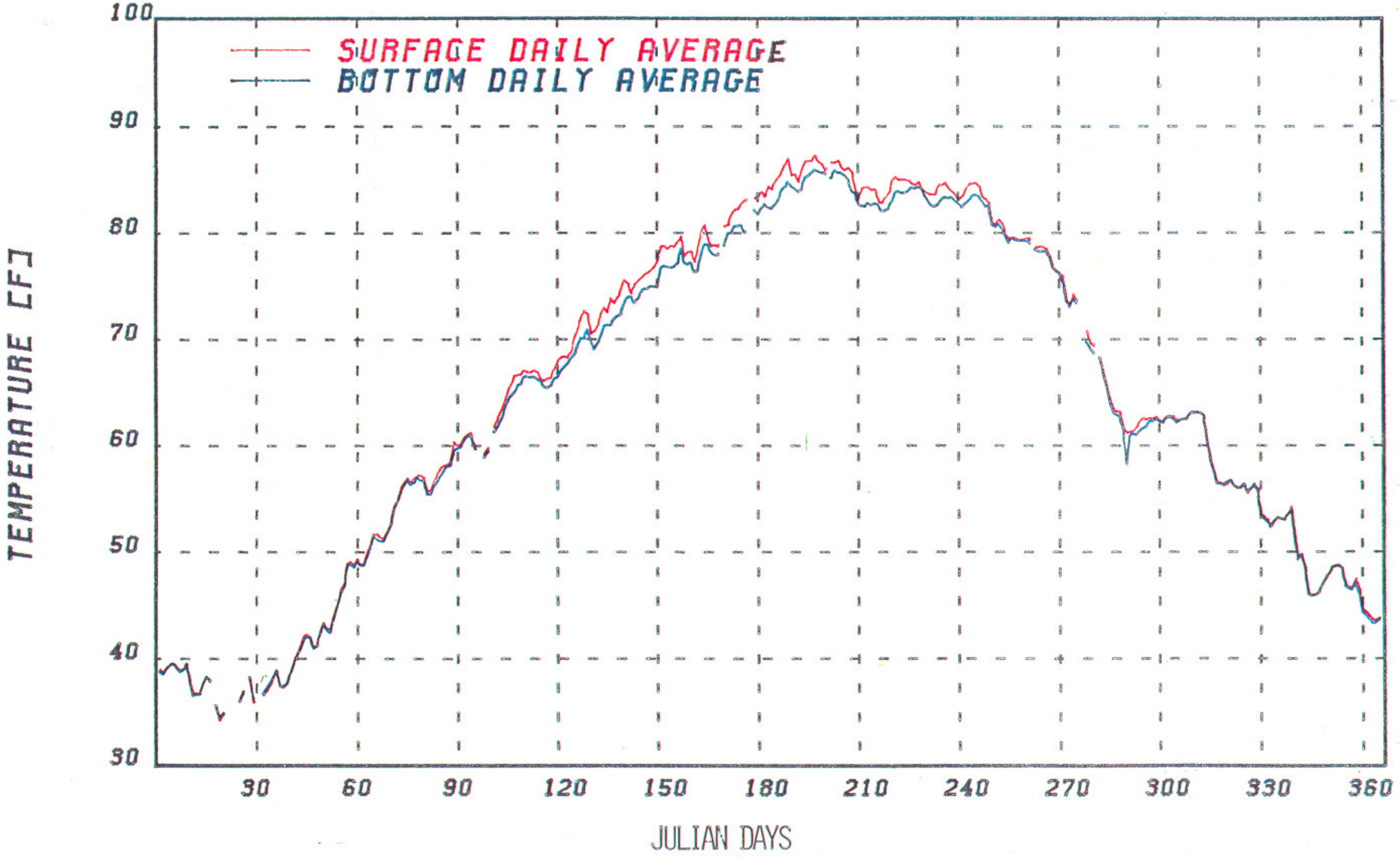

Figure 4.1-2. Daily average water temperatures at BFNP Station 4 (TRM 297.8) during 1977.

Upon closer examination, the seasonal pattern can be described as a sequence of warming and cooling periods caused by changing meteorological conditions. Water temperature fluctuations are not as large as the air temperature changes, but water temperatures in the entire reservoir commonly change by 5°F within 10 days. These transient fluctuations are generally larger in the spring, but the sequence of warming and cooling events is different each year. This means that water temperatures at any particular time of the year can only be predicted within a range of 10 to 15°F, while the predictable temperature range within a month is often 15 to 20°F.

4.1.4.2 Temperature Patterns in the Upstream Segment

Temperature data from several of the temperature monitors located in the vicinity of BFNP are used to illustrate the natural temperature patterns in Wheeler Reservoir. A map of the location of these monitor stations is shown as Figure 4.1-3. No station is located in the upstream segment above Decatur (Station 6 was removed during 1977) but those upstream temperature patterns can be deduced from Station 4 data, located in the main channel at TRM 298 (a few miles below Decatur).

The upstream main channel portion of Wheeler Reservoir is usually fully mixed during fall, winter, and early spring so that diurnal fluctuations are relatively small. Figure 4.1-4A shows temperatures at Station 4 during April 1977. Station 4 is located where overbank areas are already extensive. Fully mixed conditions continued for the first 10 days of April.

Daily fluctuations in surface temperatures become apparent in April and continue through September. During this half of the year

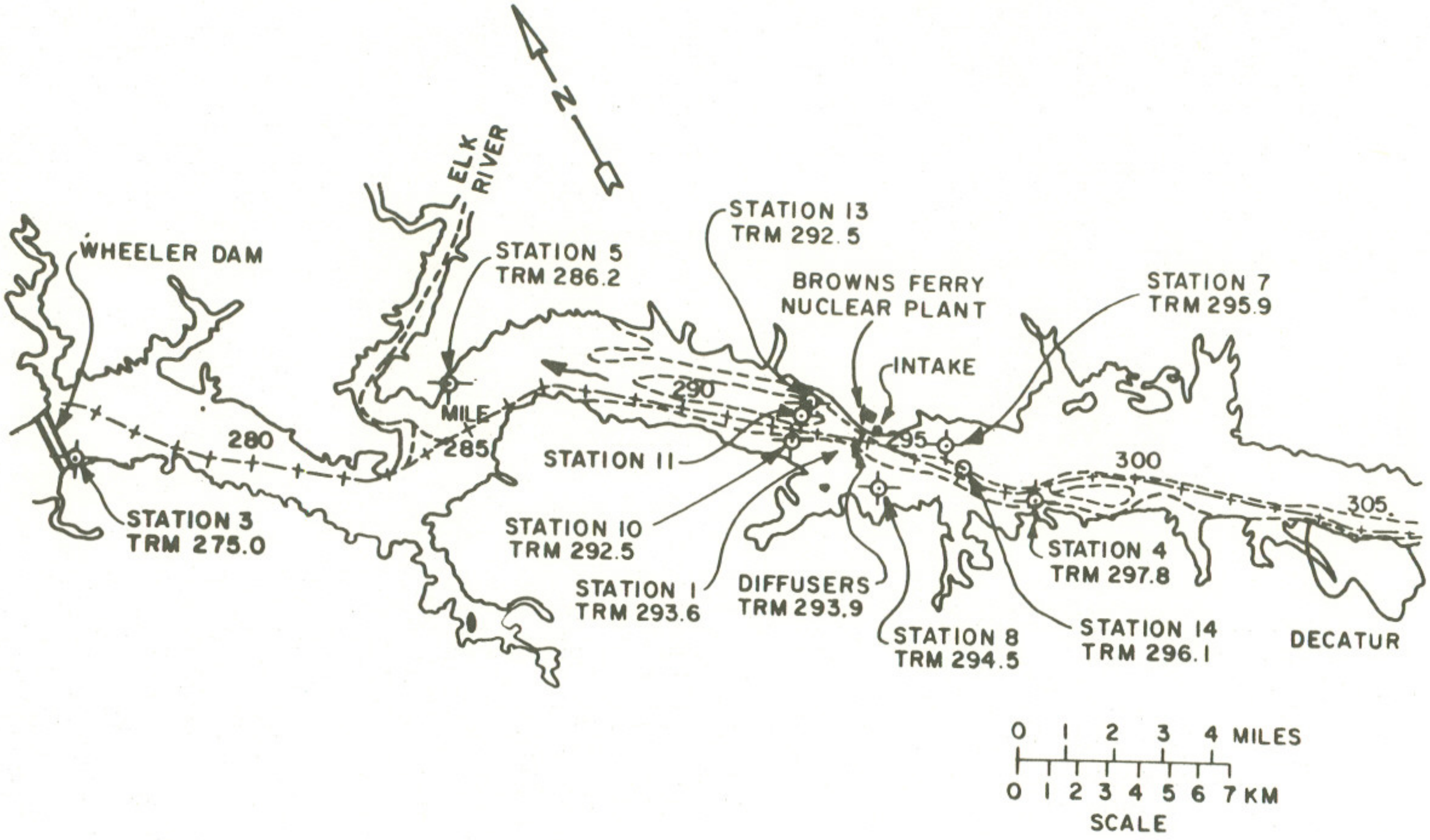

Figure 4.1-3. Map of Browns Ferry Nuclear Plant Site showing the location of the water temperature monitor stations in Wheeler Reservoir.

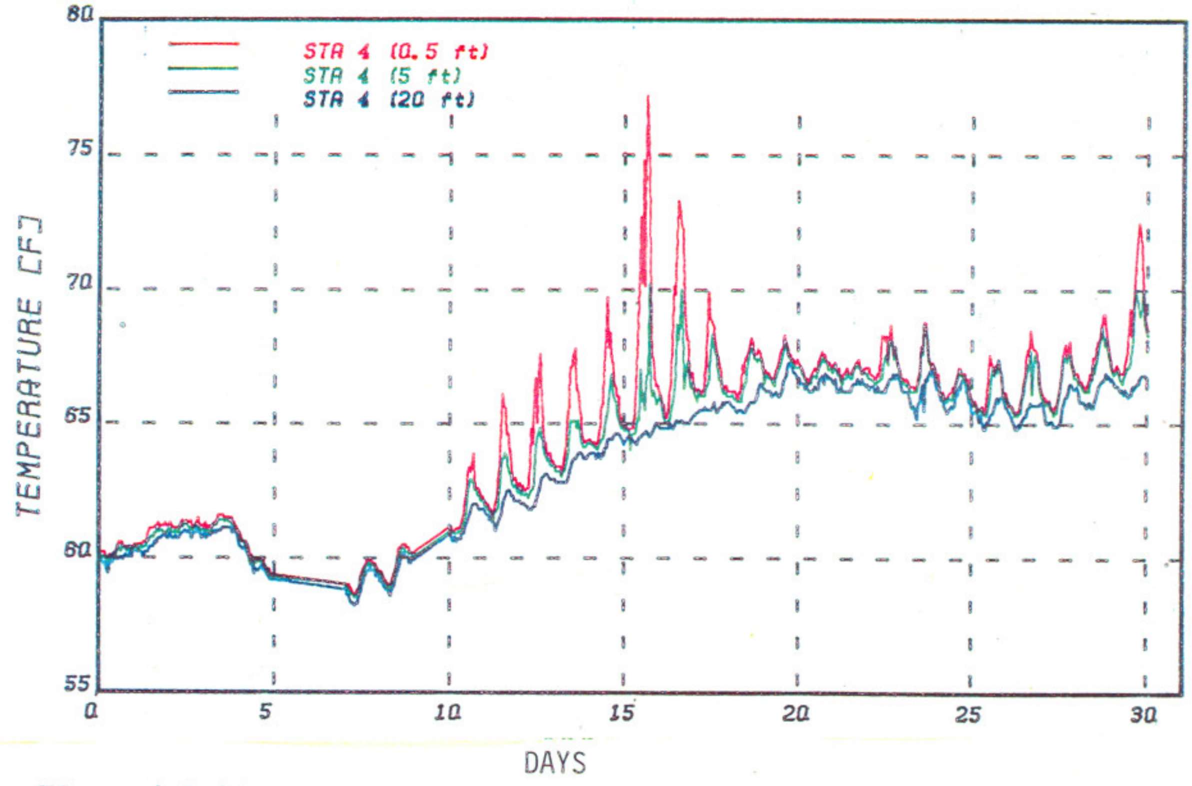

Figure 4.1-4A. Hourly water temperatures at BFNP Station 4 (TRM 297.8) during April 1977.

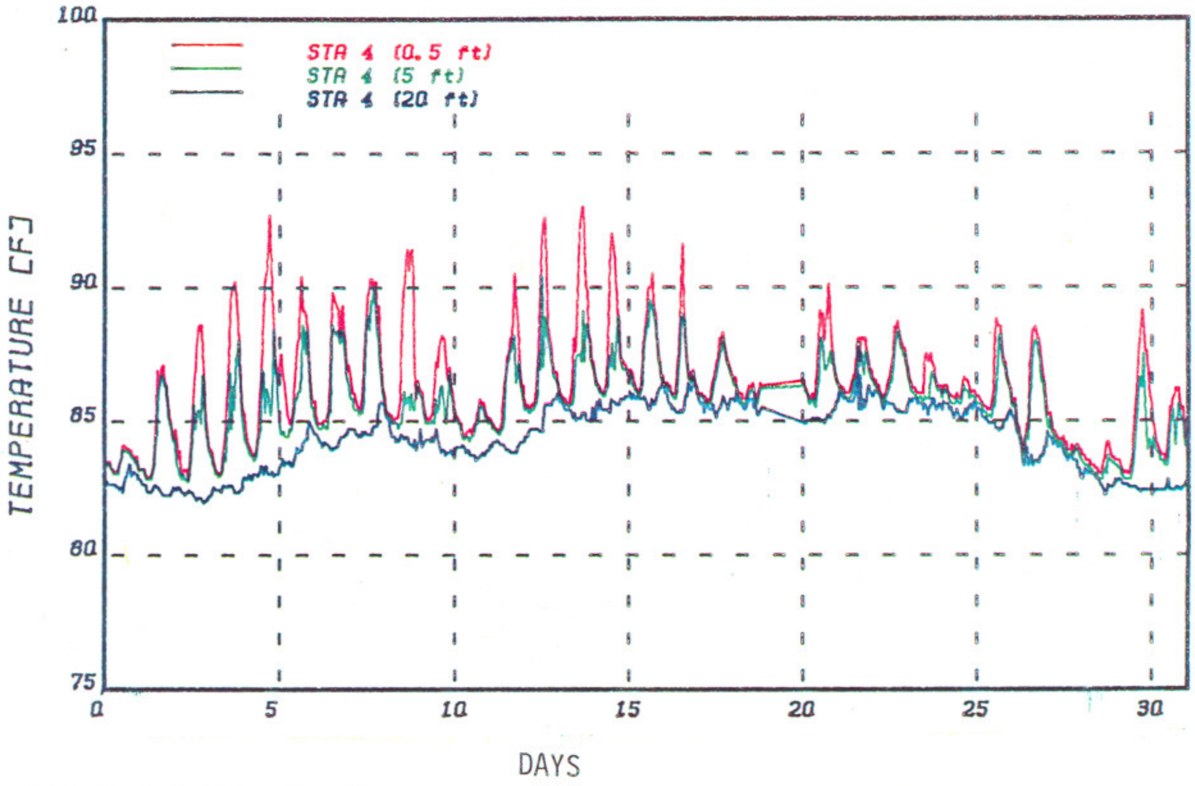

Figure 4.1-4B. Hourly water temperatures at BFNP Station 4 (TRM 297.8) during July 1977.

temperatures in the main channel are not always fully mixed. Figure 4.1-4A, April 1977, shows the start of dominant solar heating in the top 5 feet. Diurnal temperatures measured at .5 feet depth are often much higher than those at 5 feet. Diurnal fluctuations in surface temperatures can range up to 10°F while 5°F changes are not uncommon even at the 5-foot depth. Bottom temperatures are influenced by solar heating during the evening period as warmer surface water is mixed by convection currents throughout the water column. Station 4 temperatures during July 1977 are shown in Figure 4.1-4B. Bottom temperatures were stable between 82 and 86°F, whereas the surface temperatures (5-ft depth) fluctuated daily with the solar heating. During cloudy days and cooling events, the temperatures are more uniform.

The magnitude of the daily fluctuation in the surface temperatures (5-ft) is highly variable as solar, wind, and flow conditions change. Data from downstream monitor stations are similarly influenced by solar heat and mixing. The ambient condition of water flowing past the BFNP intake and diffuser is characterized by a diurnal stratification pattern.

4.1.4.3 Temperature Patterns in the Overbank Regions

Temperature patterns in the main channel and overbank areas upstream and downstream of BFNP are important for assessing thermal discharge effects relative to natural temperatures.

Station 7 is located 2,000 feet from the main channel in the overbank area upstream of BFNP. Water depth is 15 feet but several underwater ridges separate the main channel from Station 7. Station 14 is located in the main channel adjacent to Station 7 at TRM 296 in water 25 feet deep. Figure 4.1-5A shows temperatures from Stations 7 and 14 during July 1977. During warming, the overbank stratifies earlier and the bottom and surface temperatures separate more than those in the main channel; however, stratification usually does not persist from day to day at either location. Cooling is more rapid on the overbank, but temperatures slowly converge following a cooling event because the surface heat exchange in both main channel and overbank areas respond to common meteorological conditions. Overall, the temperature patterns are quite similar in the overbank and main channel areas, despite differences in depth and flow induced mixing. Surface temperatures respond to solar heating with similar diurnal fluctuations of 1 to 5°F although the hourly patterns can be separately influenced by wind and flow-induced mixing. Hour to hour differences of 1 to 3°F are common between the main channel and overbank stations.

Surface temperatures (0.5-ft and 5-ft) from four upstream stations are shown in Figure 4.1-5B for July 1977. The diurnal fluctuations dominate at both the main channel stations (4 and 14) and at the two overbank stations (7 and 8). Temperatures during the night, when the warmer surface water has been mixed throughout the water column, are almost always within 1°F of each other. Daytime heating is typically 3 to 5°F in the upper layer (5-foot depth) at all locations, although local mixing differences are evident.

In summary, although overbanks represent a different habitat zone than the main channel, the temperature patterns are surprisingly similar, with differences largely confined to the near surface layer and to periods of rapid warming or cooling.

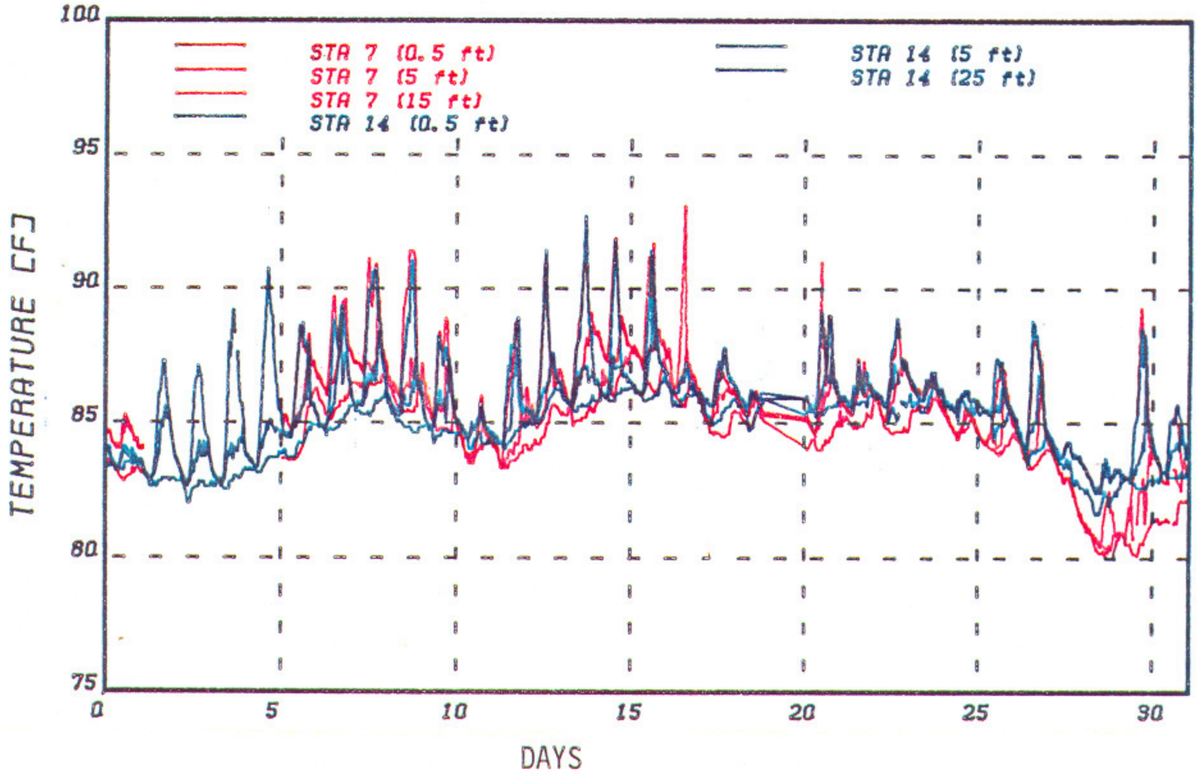

Figure 4.1-5A. Hourly water temperatures at BFNP Stations 7 (TRM 295.9) and 14 (TRM 296.1) during July 1977.

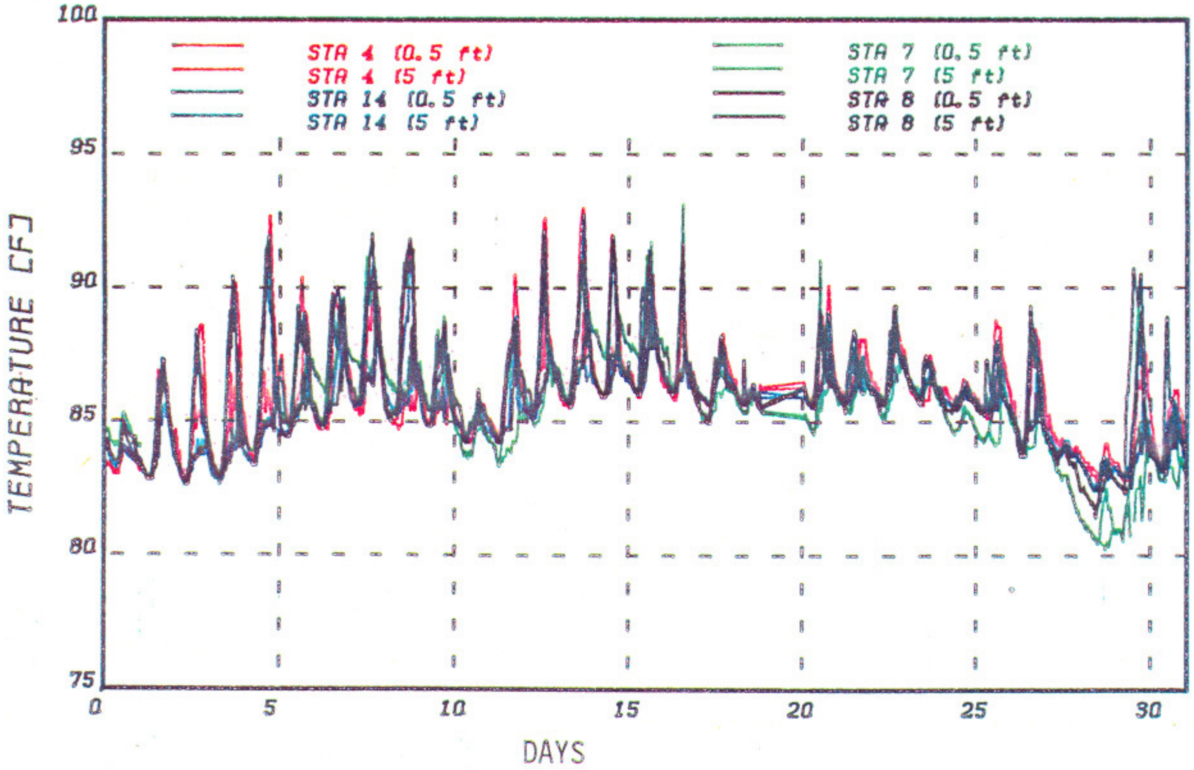

Figure 4.1-5B. Hourly water temperatures at BFNP upstream Stations 4 (TRM 297.8), 14 (TRM 296.1), 7 (TRM 295.9) and 8 (TRM 294.5) during July 1977.

4.1.4.4 Temperature Patterns in the Downstream Segment

Near Wheeler Dam, water depths approach 50 feet and the large cross sectional areas result in low velocities and limited turbulent mixing. Once stratification is initiated during warming meteorological conditions, weak stratification may persist for several days. Stratification can be reduced by a cooling event or when cool bottom water is released as part of the Wheeler Dam discharge and is replaced by warmer water flowing from upstream. The seasonal temperature pattern from Station 3 near Wheeler Dam is shown in Figure 4.1-6. The separation of the surface and bottom temperatures, although intermittent, is greater than at upstream station 4 (Figure 4.1-2). Complete mixing occurs many times throughout the year. Examination of monthly plots of Station 3 (Wheeler Dam) temperatures compared to Station 13 (TRM 292.5) temperatures shows that bottom temperatures at Wheeler Dam are governed by the upstream temperatures flowing into the deeper downstream segment of the reservoir. Figure 4.1-7A indicates that during spring, when temperatures are increasing, a temperature gradient of 10°F may develop at Station 3, but by summer (Figure 4.1-7B), when the upstream temperatures are constant at about 82 to 86°F, stratification at Station 3 exists only when the inflowing upstream temperatures fluctuate. Surface temperatures at Wheeler Dam are strongly influenced by solar heating and are very similar to surface temperatures upstream of BFNP, although hour to hour correspondence does not exist because of the differences in mixing between these locations.

4.1.5 Natural Hydrothermodynamics Summary

BFNP is located on Wheeler Reservoir in a region of expanding cross section. Upstream riverine conditions change to a deep channel

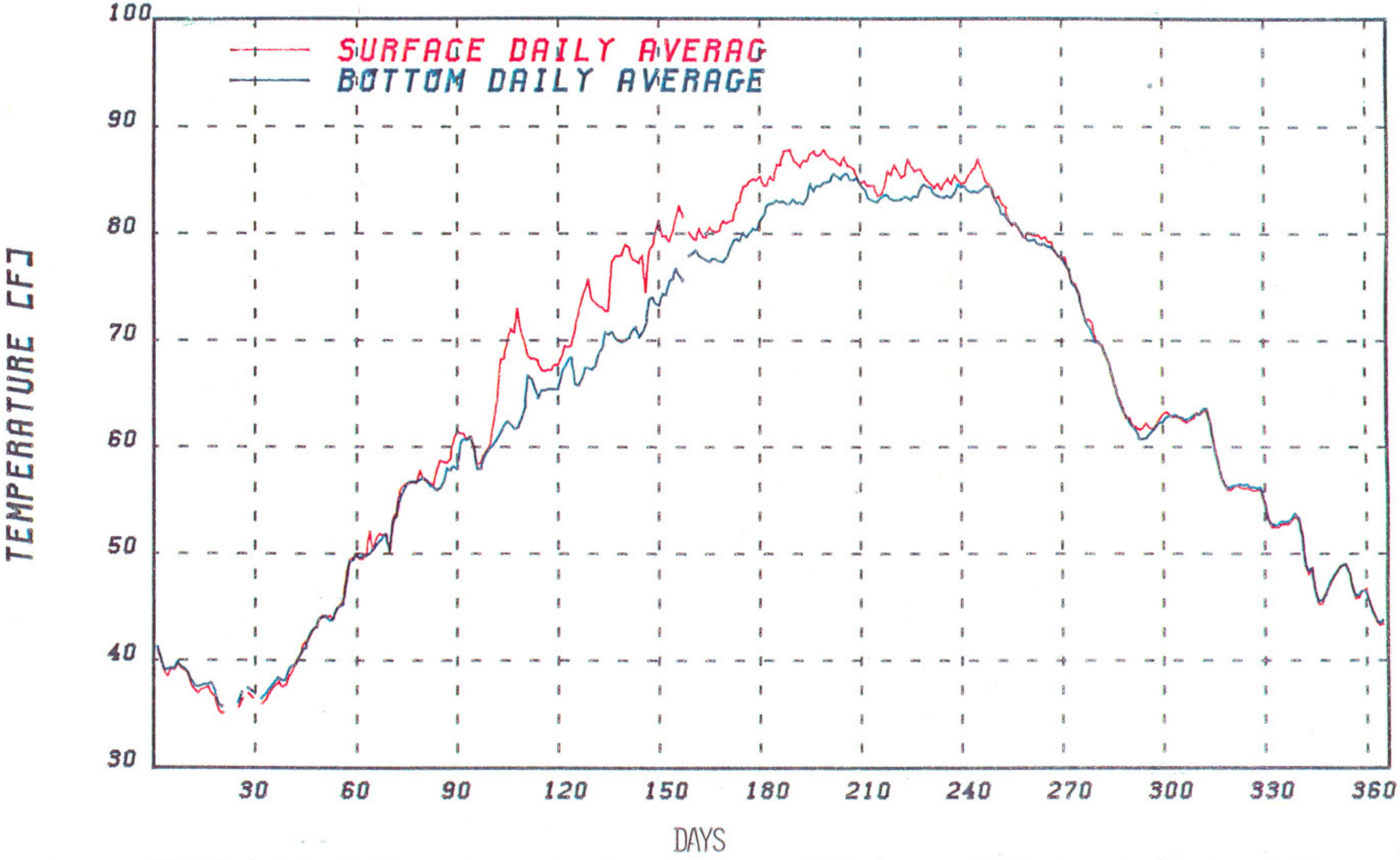

Figure 4.1-6. Daily average water temperatures at BFNP Station 3 (Wheeler Dam) during 1977.

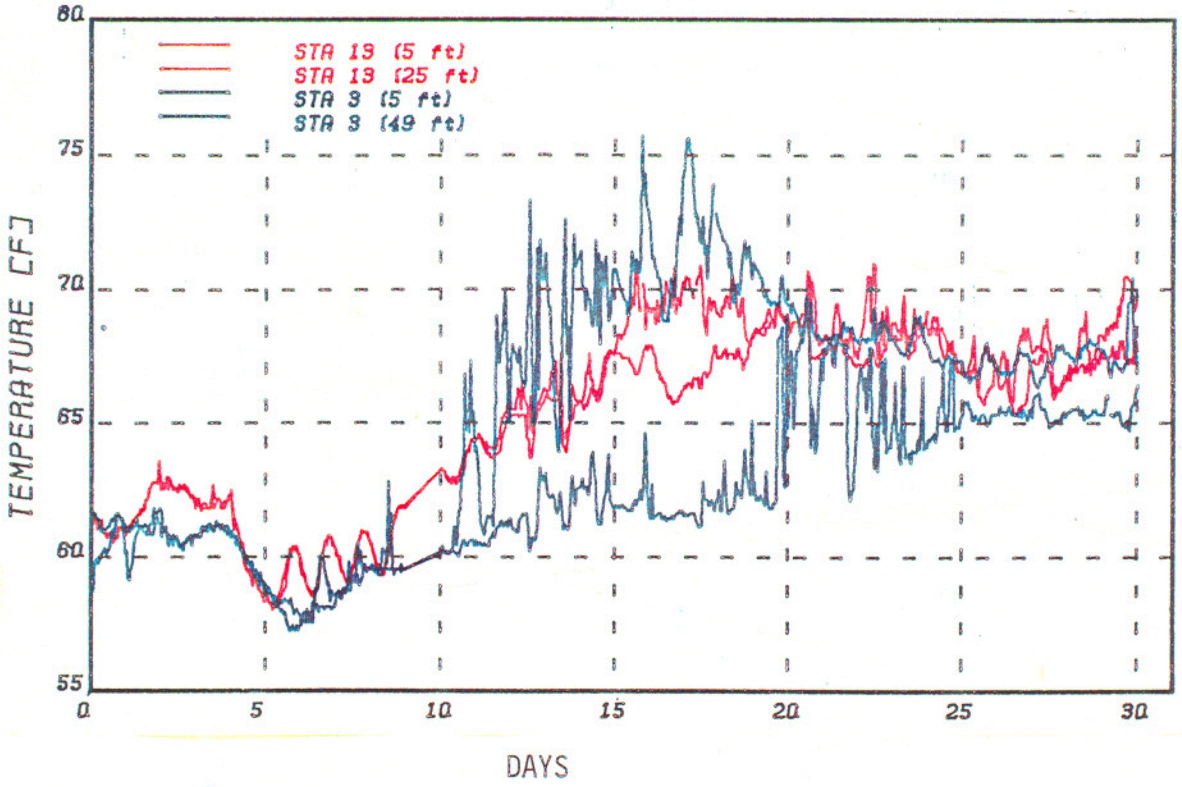

Figure 4.1-7A. Hourly water temperatures at BFNP Stations 13 (TRM 292.5) and 3 (TRM 275.0) during April 1977.

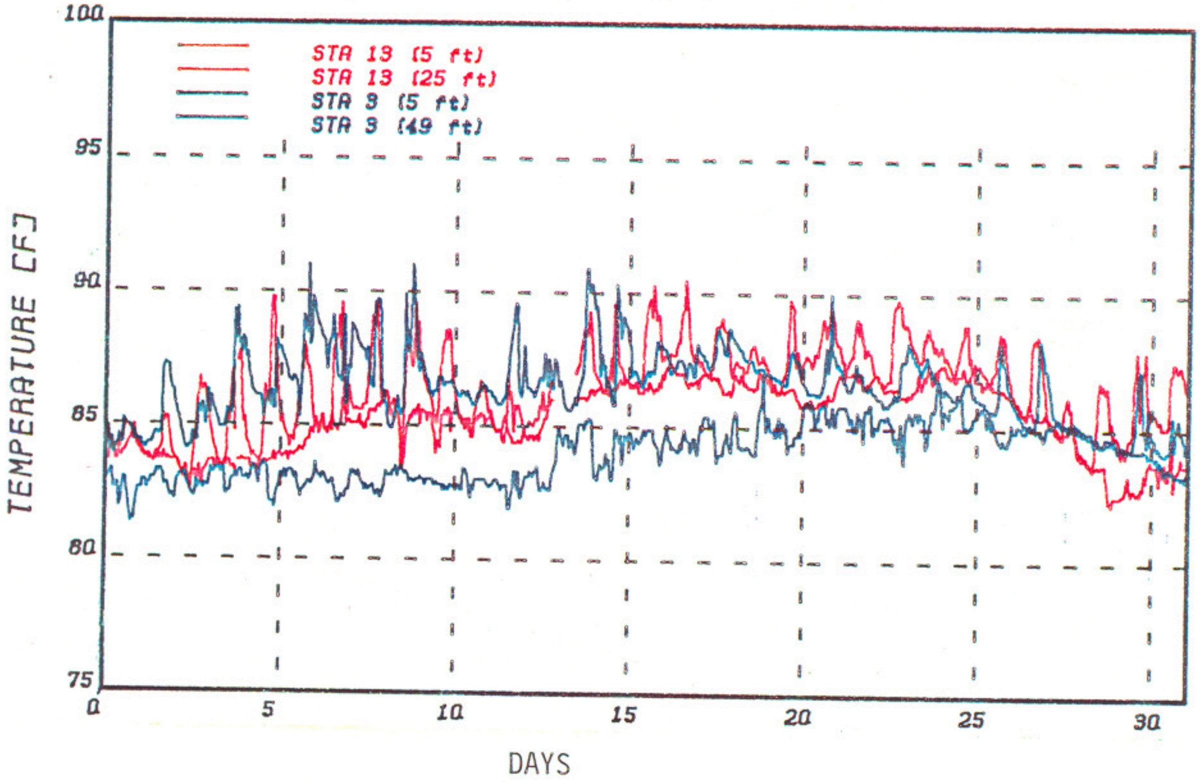

Figure 4.1-7B. Hourly water temperatures at BFNP Stations 13 (TRM 292.5) and 3 (TRM 275.0) during July 1977.

and extensive overbank regions just upstream of BFNP. Downstream, starting near the entrance of the Elk River, the reservoir is deep and wide.

River flow at BFNP is dependent upon discharges from upstream Guntersville Dam and downstream Wheeler Dam. Prior to 1977 the dams were operated for peaking power, cutting back releases during the early morning hours when there was low power demand. After 1976, TVA's release schedule included the flow needed for operation of BFNP under existing thermal limitations. Travel times from BFNP to Wheeler Dam range from one-half to two weeks depending on river flows.

Natural water temperature changes occur over various time scales and magnitudes of variation. Temperature changes over the annual cycle are in the range 45 to 55°F with monthly changes from 15 to 20°F. Meteorological changes can cause water temperatures throughout the reservoir to change 5°F in 10 days. Daily variations due to solar heating can cause 1 to 2°F changes during fully mixed conditions and up to 3 to 5°F changes in the surface layer down to 5 feet.

Temperature patterns upstream of BFNP are fully mixed during the fall, winter, and early spring with weak thermal stratification developing daily during April through September. Temperatures in the overbanks near BFNP are similar to those in the main channel except that the overbank areas are more responsive to changing meteorological conditions. Spatial differences, overbank to main channel, caused by wind and flow induced mixing can cause 1 to 3°F differences on an hourly basis. In the lower portion of Wheeler Reservoir thermal stratification can be up to 10°F in the spring, but much less in the summer when upstream temperatures are fairly constant. Thermal stratification is usually weak because of the relatively short transit time and turbine intake withdrawal from the entire vertical depth of the reservoir. Cooling periods can also easily break down stratification.

4.2 Hydrothermodynamics of Wheeler Reservoir Under Alternate Limitations

Effects of alternative limitations on the heated discharge into Wheeler Reservoir were studied for both near field and far field regions. In the near field, reduction of discharge temperatures results primarily from the diffuser induced mixing of the discharge with the receiving water. The present thermal limitations are imposed at the edge of a mixing zone after this initial dilution has occurred. The far field is considered as that region downstream of the mixing zone where the natural processes of flow, wind induced mixing, and surface heat exchange affects the water temperature.

Each region was studied in two ways. First, there have been several extended periods recently where BFNP operated with alternative limitations. Evaluations of these periods of high plant induced temperature rise and high maximum temperature conditions were used to identify potentially significant effects associated with alternative limitations. Second, predictive models were used to characterize the effects of maximum plant operation using historical flows, meteorology, and upstream temperatures as input. Predictions for the near field were used to compare the effect of alternative limitations by evaluating 12½ years of record. Far field modeling compared ambient conditions with the effects of maximum plant operation during the most severe conditions experienced at BFNP to date.